UWB, SP3 • HPEM/NEM • UXO

AMEREM '96

THE WORLD OF ELECTROMAGNETICS

ALBUQUERQUE, NEW MEXICO
MAY 27-31, 1996

ABSTRACTS

AMEREM 96 Conference Schedule

Time	Sunday May 26	Monday May 27	Tuesday May 28	Wednesday May 29	Thursday May 30	Friday May 31
		Registration Daily, 8 AM - 5 PM				
8:30 AM		HPEM-1 & UWB, SP-12: Propagation *(Cimarron)* HPEM-2: EM Interaction I *(Galisteo)* UWB, SP-1 & HPEM-29: Antennas I *(Brazos)* UWB, SP-2: (Invited) Polarimetric UWB Radar/SAR Sensing & Imaging *(Aztec)*	HPEM-6 & UWB, SP-5: High Power Impulse Antennas *(Brazos)* HPEM-7: Lightning *(Cimarron)* HPEM-8: Simulation Chambers *(Galisteo)* HPEM-9: Signal Process. II *(Cimarron)* HPEM-10: HPM Simulation & Effects *(Galisteo)* UXO-1: UXO Overview *(Aztec)* UXO-2: Soil Characterization *(Aztec)*	**Plenary Session** *Ballroom C*	HPEM-18: International EMC Stds. *(Galisteo)* HPEM-19: Sensors & Diagnostics *(Dona Ana)* UWB, SP-9: Propagation *(Cimarron)* UWB, SP-10 & HPEM-30: Pulser Technology *(Brazos)* UXO-6: Detection & Ident. I *(Aztec)*	HPEM-23: Protection Technology *(Cimarron)* HPEM-24: Bounded Wave Simulators *(Aztec)* HPEM-25: Transmission Line Modeling *(Galisteo)* HPEM-26: Misc. Simulators *(Aztec)* UXO-8: Detection & Ident. III *(Brazos)*
12:00			*Permanent UWB, SP Committee Luncheon*	*Chairman's Lunch (Ballroom A)*	*Permanent HPEM Committee Luncheon (LaCienega)*	*Permanent UXO Committee Luncheon*
1:30 PM	**Registration & Reception** *Convention Center* *4-8 PM*	HPEM-3: Component Effects *(Cimarron)* HPEM-4 & UWB, SP-13: Signal Process. I *(Aztec)* HPEM-5: EM Interaction II *(Galisteo)* UWB, SP-3: Antennas II *(Brazos)* UWB, SP-4: Topics in UWB *(Cimarron)*	HPEM-11 & UWB, SP-7: HPM Sources, Photonics & Techniques *(Aztec)* HPEM-12: Antenna Topics *(Brazos)* HPEM-13: Combined EM Effects Protection *(Cimarron)* HPEM-14: Statistical EM *(Dona Ana)* UWB, SP-6: Target Detection & Discrimination I *(Galisteo)*	HPEM-15: HPM Sources, Plasmas & Pulse Shortening *(Brazos)* HPEM-16: Optimization of HPM Effects *(Cimarron)* HPEM-17: HM/HS *(Dona Ana)* UWB, SP-8: Target Detection & Discrimination II *(Galisteo)* UXO-3: Signal Process. *(Aztec)* UXO-4: EOD Tools *(Dona Ana)* UXO-5: Containment *(Aztec)*	HPEM-20: Environments *(Dona Ana)* HPEM-21: Geomagnetic Induced Currents *(Cimarron)* HPEM-22: Exptl. Tech. for Coupling, Assessments & Maint. *(Brazos)* UWB, SP-11 & HPEM-31: Signal Process. *(Galisteo)* UXO-7: Detection & Ident. II *(Aztec)*	HPEM-27: System Testing *(Galisteo)* HPEM-28: Shielding Test Methods *(Cimarron)* UXO-9: Detection & Ident. IV *(Aztec)* UXO-10: Case Studies & Applications *(Brazos)*
	Albuquerque Convention Center *On 3rd Street, Between Marquette & Tijeras* Albuquerque, NM	**Exhibitors Reception** *Exhibit Hall* *5-8 PM*	**Southwestern Night** North Valley 7-10 PM	**Panel Sessions** San Miguel HPM Sources - 6:30 PM EM Interaction - 8 PM Messila UXO - 6:30 PM UWB, SP - 8 PM	**Reception** - 6 PM **Banquet** - 7 PM *Ballroom C*	

AMEREM '96

ALBUQUERQUE, NEW MEXICO
27-31 MAY, 1996

ABSTRACTS

HIGH POWER ELECTROMAGNETICS

NUCLEAR ELECTROMAGNETICS

ULTRA-WIDEBAND, SHORT-PULSE ELECTROMAGNETICS 3

UNEXPLODED ORDNANCE DETECTION & RANGE REMEDIATION

AMEREM '96

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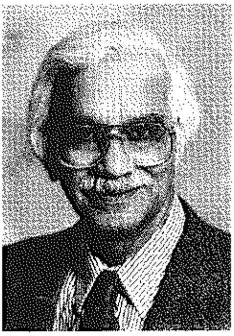

On behalf of the Permanent HPEM Committee, I would like to welcome you to the AMEREM '96 International Conference on "The World of Electromagnetics". This conference is actually a joint venture of three symposia addressed to: (i) High Power Electromagnetics (including Nuclear EM pulses); (ii) Ultrawide Band, Short Pulse EM; and (iii) Unexploded Ordnance Detection & Range Remediation. The scope indeed fits the title, "The World of Electromagnetics".

The technical program consists of over 325 papers arranged in 48 sessions. The Plenary Session, including a welcome by New Mexico's Governor Gary Johnson, is set for Wednesday morning. During the Wednesday evening Panel Sessions, a dozen experts will present their contemporary research topics. The Awards Banquet with entertainment will take place on Thursday.

The World of Electromagnetics keeps evolving at an ever faster pace. Contemporary research presented in this book of abstracts sprouted from the articles of Karzas and Latter in 1962. These articles made detection of EMP due to nuclear atmospheric bursts common knowledge. That fact alone, it is believed by some, led to the atmospheric test ban treaty signed during the President Kennedy, Chairman Khrushchev and Prime Minister Wilson era. The evolution of electromagnetics progressed to higher frequencies (>300MHz) and power levels viz. high power microwaves/ultrawide band/short pulses and that is the second component of this conference. Civil wars and political conflicts such as Desert Storm, estimates the United Nations, have resulted in about 100 million active mines in 62 countries - causing about 26,000 deaths and injuries. This formidable challenge is being tackled by the multitalented research of electromagnetics and that is the third component of AMEREM 1996.

The next conference, EUROEM 98, will take place in Tel Aviv, Israel under the able hands of Professor Joseph Shiloh. I expect to see you there with more exciting progress in the field of electromagnetics.

I wish to take this opportunity to thank the very hardworking steering committee without whose labors this first AMEREM conference would not have become a success. It is, however, the untiring efforts of Technical Program Committee Chairman Chris Jones and the professional touches of Dan McGrath that this book of abstracts has achieved a respectable stature.

Until EUROEM 98 in Tel Aviv,

With warm regards

Shyam H. Gurbaxani, Conference Chairman

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Transportation	Michael G. Harrison

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Monday, May 27, 8:30 AM **Room: Cimarron**

HPEM-1 & UWB, SP-12 Propagation

CoChairs: J.G. Gaudet, Phillips Laboratory, Kirtland AFB, NM
S.A. Blocher, Phillips Laboratory, Kirtland AFB, NM

8:30 AM **INTRODUCTION & ANNOUNCEMENTS**

8:35 AM **APPLICATION OF A SIMPLE MODEL TO TRANSIENT PROPAGATION THROUGH CONCRETE**, *S.A. BLOCHER and R.L. GARDNER, Phillips Laboratory, Kirtland AFB, NM* 2

8:55 AM **A SIMPLE METHOD FOR FITTING TIME DOMAIN DIFFUSION GREEN'S FUNCTIONS FOR LAYERED MEDIA**, *J.L. GILBERT, Metatech Corporation, Goleta, CA* 3

9:15 AM **TRANSIENT MICROWAVE PROPAGATION IN BIOLOGICAL MEDIA**, *D.C. STOUDT and F.E. PETERKIN, Dahlgren Division, Naval Surface Warfare Center Pulsed Power Systems & Technology Group, Dahlgren, VA* 4

9:35 AM **WIDEBAND TIME DOMAIN MEASUREMENT OF MATERIAL PERMITTIVITY AND PERMEABILITY**, *C. COURTNEY, Voss Scientific, Albuquerque, NM; K. BURR, formerly with Fiore Industries, Albuquerque, NM; and T. BOWEN, Phillips Laboratory, Kirtland AFB, NM* 5

9:55 AM **VECTOR WAVE PROPAGATION IN INHOMOGENEOUS ANOSOTROPIC MEDIA**, *N.I. PETROV, All-Russian Electrotechnical Institute, Moscow, Russia* 6

10:15 AM **BREAK**

10:40 AM **TUNNEL INTERFERENCE OF CIRCULARLY POLARIZED COUNTER-RUNNING WAVES IN GYROTROPIC MEDIA**, *D.I. SEMENTSOV and S.A. AFANASYEV, Branch of Moscow State University, Ulyanovsk, Russia* 7

11:00 AM **THE SCATTERING OF VLF AND LF RADIO WAVES FROM A LARGE-SCALE THREE-DIMENSIONAL CONVEX IRREGULARITY OF THE EARTH-IONOSPHERE WAVEGUIDE**, *O.V. SOLOVIEV and V.V. AGAPOV, University of St. Petersburg, St. Petersburg, Russia* 8

11:20 AM **APPLICATION OF THE LEAST TIME – MAXIMUM PROBABILITY PRINCIPLE TO THE THEORY OF LIGHTNING PROPAGATION**, *R. BRIET, LT-MP Applications, Citrus Court, CA* 9

APPLICATION OF A SIMPLE MODEL TO TRANSIENT PROPAGATION THROUGH CONCRETE

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Propagation of electromagnetic fields within buildings is of interest to practitioners of most components of high power electromagnetics. Concrete walls form one useful part of buildings. Phillips Lab personnel have made a number of transient measurements of an example concrete wall (T. Bowen, Private Communication). Those measurements show a consistent trend of increasing attenuation at high frequency, which is characteristic of attenuation due to bulk conductivity in concrete. There is no point of sudden increase that would be characteristic of the effects of rebar on the attenuation. We concluded that a simple one-dimensional model of the concrete could be sufficient to describe the wall attenuation.

The model we use is a simple three layer formulation (J. R. Wait, SOMETHING) which uses constant conductivity and permittivity. Spatial variation in the conductivity can be included by means of additional layers. Frequency dependent variation can be applied directly, since this model is in the frequency domain. Transients are computed using convolution and an inverse Fourier transform.

Data for the wall (T. Bowen, Private Communication) was taken to minimize three-dimensional effects so that the wall attenuation was isolated from the effects of windows and other apertures. All of these characteristics support the choice of the 1-D model. The comparison was, indeed, successful with minor deviations from the model using derived material properties. Later applications will include the use of measured conductivity and permittivity.

A SIMPLE METHOD FOR FITTING TIME DOMAIN DIFFUSION GREEN'S FUNCTIONS FOR LAYERED MEDIA

Jim Gilbert
Metatech Corporation
Goleta, California

In studies of the effect of magnetic storms on long conductors, it is useful to derive the Green's function for obtaining the horizontal electric field from the surface magnetic field (or equivalently, from the horizontal electric field that would be generated by that magnetic field over a uniformly conducting medium.) For submarine cables, we also wish to know the fields at depth in the upper layer, and, for cables running over continental shelf areas, the finite depth of the ocean has a noticeable effect on the horizontal electric fields. The Green's function can be calculated in the frequency domain and the result transformed to the time domain, but unless great care is taken for observers at depth, this can lead to acausal results and the spurious generation of high frequencies. In this paper we will describe a method of fitting the Fourier domain results with functions that may be analytically transformed into the time domain and convolved with the disturbed magnetic field.

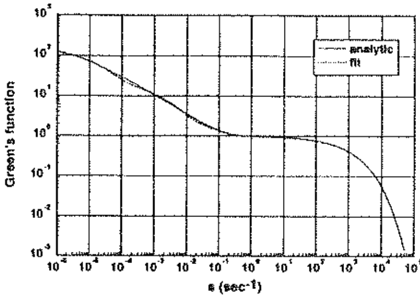

Figure 1. Fit for horizontal electric field for 1 km of seawater over poorly conducting earth. Observer depth is 10 meters.

For the simplest case where the first medium extends to a depth z_0 the Green's function to obtain the electric field at depth z becomes

$$G(s) = \frac{sinh(kz_0 - kz) + S\,cosh(kz_0 - kz)}{cosh(kz_0) + S\,sinh(kz_0)}$$

where $k = \sqrt{\mu_0 \sigma s}$ is the wavenumber in the upper medium and $S = \sqrt{\sigma_1 / \sigma_2}$ where the subscript denotes the layer of the media. From the form of the solution, the dependence on z may be made explicit and the dependence on S and z_0 fitted in the form

$$G(s) = e^{-kz} + cosh(kz) \sum_i B_i\, e^{-A_i k z_0}$$

where the B_i are independent of k. When the Green's function is fit in this manner, the inverse Laplace transform may be taken explicitly. Figure 1 shows a comparison between the exact solution and using three B_i terms. The paper will discuss the derivation of the fit formulae and the extension to multiple layers.

TRANSIENT MICROWAVE PROPAGATION IN BIOLOGICAL MEDIA

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We examine short-pulse propagation in a dispersive Debye medium. Transient fields that result when square-wave modulated radio frequency (RF) pulses propagate in water, characterized by the Debye model, have been examined both numerically and experimentally. Water was selected as the medium to be studied since it is the major constituent in most biological tissues, and in several respects the dielectric properties of tissues are governed by the water that they contain. The strong frequency dependence of the attenuation coefficient of pure water, over the frequency range being investigated (0-3 GHz), leads to a nonuniform attenuation of the frequency components contained in the RF pulse. Our numerical results show that the amplitude and temporal character of the propagating transient fields are the result of the low-frequency harmonic components in the initial RF pulse. This result was obtained by using a frequency-domain filtering technique where each frequency component of the initial RF waveform was attenuated exponentially by its associated attenuation coefficient for a particular propagation distance in water. The effects of group-velocity dispersion, when added, appear to have little effect on the solution. This arises from the fact that the index of refraction of water in the frequency range being investigated is nearly constant. However, in the same frequency range, the attenuation coefficient of water increases roughly with the square of the frequency. The transient fields, sometimes referred to as Brillouin precursors, can propagate much farther than would be expected if only the carrier frequency of the RF pulse is considered.

We first describe how a plane wave propagates in a lossy dielectric half-space, comprised of water, through the use of Maxwell's equations. Next, using frequency-domain filtering, we demonstrate how pulse distortion occurs when a square-wave modulated pulse propagates in water. Trapezoidal pulse modulation is also examined to illustrate the effect of a finite RF-pulse rise and fall time. Finally, we describe experiments performed with 16 MΩ-cm deionized water in a 50-Ω coaxial test cell, fitted with appropriate high-speed diagnostics. The amplitude of the transient fields generated by a 1-GHz square-wave modulated pulse was measured as a function of propagation distance in the test cell. The measured transients are compared with those generated numerically and are found to be in very good agreement.

WIDEBAND TIME DOMAIN MEASUREMENT OF MATERIAL PERMITTIVITY AND PERMEABILITY

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Accurate knowledge of material complex relative permittivity ($\varepsilon_r = \varepsilon_r' - j\varepsilon_r''$) and permeability ($\mu_r = \mu_r' - j\mu_r''$) is required for just about any analysis or design effort that considers the effect of the electromagnetic properties of materials. Applications include the design of radar absorbing material (RAM) and RAM geometry, design of transmission line circuits on microwave substrates, and simulation and analysis of the propagation of electromagnetic waves in and through complex media. The measurement of ε_r and μ_r can be accomplished in a number of ways. In the late 60's and early 70's, before the advent of the automatic network analyzer, time domain methods were popular. These techniques utilized the spectral content of a fast rise time pulse to determine the frequency dependence of the complex ε_r and μ_r of materials. However, these methods relied on approximations which may not be valid for some cases of interest. The measurement procedure discussed in this paper is unique in two ways. First, though the time domain scheme employed here is based on previously described methods, the data reduction techniques used eliminate some of the approximations and sources of potential error of the earlier work. Secondly, the sample chamber is large enough to accommodate large samples (to 2.75 inch outer diameter). This permits determination of average material properties of inhomogeneous materials such as concrete and biological samples. This paper presents the theory of the time domain measurement technique employed, a description of the measurement hardware, limitations of the approach, and a sample measurement example.

VECTOR WAVE PROPAGATION IN INHOMOGENEOUS ANISOTROPIC MEDIA

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The quantum-theoretical methods and the coherent states formalism are used for investigation of the paraxial vector wave beam propagation in 3D inhomogeneous anisotropic media. In the paraxial approximation Maxwell equations can be reduced to the parabolic equation of Schrodinger type for vector wave function. The algebraic perturbation theory is developed to investigate of evolution of the beam parameters. The effect of influence of polarization on the trajectory of beam is investigated. It is shown that in the case of circular polarization the plane of the meridional ray propagation is rotated. Depolarization of linearly and circularly polarized radiation in graded-index medium is studied. It is shown that depolarization takes place even in an isotropic medium due to the diffraction of beam. Particularly, degree of polarization of both linear and circular polarized radiation decreases by the quadratic law with distance due the diffractional mechanism. Depolarization of sagittal rays is stronger than the depolarization of meridional rays. Depolarization is enhanced at the increase of wavelength of radiation and axis displacement of an incident beam. Depolarization has a wave nature and may be interpreted as a result of interaction between polarization (spin) and trajectory (orbital moment).

TUNNEL INTERFERENCE OF CIRCULARLY POLARIZED COUNTER – RUNNING WAVES IN GYROTROPIC MEDIA

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The propagation of counter–running waves in the media with complex material constants is accompanied by the formation of undamped interference flux of energy. First of all, the interference of this type, that is called 'tunnel interference', is characteristic of absorbing media (Sementsov D.I. & Efimov V.V., J. Phys. D: Appl. Phys. 28, 1225–31, 1995). Besides of that, the tunnel interference may be observed in non–absorbing media in the case of pure imaginary wave vectors, for example, in the region of negative values of dielectric constant ε or magnetic permeability μ. With the aid of interference flux the radiant energy may be transferred through the layers of materials, where the energy flux of a single wave is absent or is strongly damped. Both magnitude and direction of the interference flux may be easily controlled by variation of the phase difference of counter–running waves.

In the paper, the tunnel interference of counter–running waves is investigated in the media, that become gyrotropic in the presence of external permanent magnetic field. Here the additional possibilities are revealed of interference flux control with the aid of applied magnetic field using the field dependencies of the components of tensor ε or μ (Sementsov D.I. et. al., Pis'ma Zhurn. Tehn. Phys. 19, N 11, 6–11, 1993). Two coherent circularly polarized waves are considered normally incident from the opposite sides on the plane–parallel longitudinally magnetized layer. The numerical analysis is performed of the dependencies of full and interference energy fluxes on the value of external field, the wave frequency, the phase difference and the layer parameters. The cases of right and left polarization are discussed. The following kinds of gyrotropic media are studied.

1) Magnetogyrotropic media such as microwave spinel and garnet ferrites. The ferrite is assumed to possess both electric and magnetic losses. The effect of enhance of layer transmittance as well as the influence of a counter–running wave on Faraday effect are investigated in microwave frequency band.

2) A non–magnetic metal and a semiconductor in a strong magnetic field. The formation of spiral plasma waves (helicons) in the plasma of solids is discussed in the situation of two counter–running radio frequency waves penetrating the layer.

The Scattering of VLF and LF Radio Waves From a Large-Scale Three-Dimensional Convex Irregularity of the Earth-Ionosphere Waveguide

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This paper presents a mathematical model, an asymptotic theory and an appropriate numerical algorithm to study the influence of the large-scale three-dimensional ionospheric perturbation on the VLF and LF radio wave propagation in the Earth-ionosphere waveguide (EIWG).

We consider again, as in our previous studies (V.V.Agapov and O.V.Soloviev, *Proc. of the EUROEM-94*, Bordeaux, France, 1994), parallel-plane model of the EIWG. However now we assume the strong ionospheric perturbation to cause a convex irregularity of the guide. Thus we consider the three-dimensional domain $\mathcal{D}$ bounded by two impedance surfaces S_e and S_i one of which is non-uniform. The surface S_e is defined as $z = 0$ and the surface S_i is formed by the plane $z = h$ and by the truncated cylinder of the height h_p standing on this plane and protruding inside the cavity of the guide. The lateral surface of cylinder S_l and its base S_p are characterized by the impedance values δ_l and δ_p, respectively.

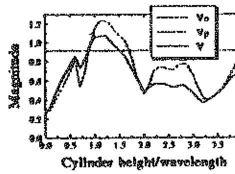
The harmonic ($e^{-i\omega t}$) point source which excites the waveguide cavity $\mathcal{D}$ is assumed to be a vertical electric dipole. Therefore, in the scalar approximation the electromagnetic field may be characterized by the vertical component of Hertz's vector $\Pi(x, y, z)$. The unknown function $\Pi(x, y, z)$ obeys Helmholtz's equation and the following impedance boundary conditions:

$$\frac{1}{\Pi}\frac{\partial \Pi}{\partial n} = ik\delta(M)|_{M \in S_e, S_i}$$

where: $k = \omega\sqrt{\epsilon_0\mu_0}$, $\delta(M) = \delta_e$ if $M \in S_e$, $\delta(M) = \delta_i$ if $M \in S_i \backslash (S_p \cup S_l)$, $\delta(M) = \delta_p$ if $M \in S_p$, and $\delta(M) = \delta_l$ if $M \in S_l$. We point out here that in practice for such field polarization: $|\delta_{e,i,p}| < 1$ and $|\delta_l| \gg 1$.

Using the second Green's formula we may obtain the integral equation that may be handled with the aid of the modified asymptotic three-dimensional procedure (O.V.Soloviev and V.V.Agapov, *Proc. of the URSI Int. Symp. on Electromagnetic Theory*, St. Petersburg, 1995). The proposed technique can be used to study the influence of irregularity of various lateral extent (small, large, or comparable with wavelength).

The presented figure illustrates the behavior of the field magnitude as the function of the height h_p of the cylinder protruding from an impedance plane S_e in the absence of the second surface. The elliptic cross section of the cylinder $[(x - x_p)/a]^2 + [y/b]^2 \leq 1$ is characterized by the values $a = 5\lambda$, $b = 4\lambda$, $x_p = 30\lambda$, where $\lambda = 2\pi/k$.



The following parameters of the model were accepted: $\delta_e = (1.4436 - 1.4436i)10^{-3}$, $\delta_p = 0.2319 - 0.1468i$, $\delta_l = (1.0000 - 1.0000i)10^2$, transmitter point $(0, 0, 5\lambda)$, observation point $(45\lambda, 0, 4\lambda)$. The curve marked as V_0 corresponds to the attenuation function of the unperturbed waveguide and the curve V_p corresponds to the case when we discard the influence of the lateral surface S_l.

APPLICATION of the LEAST TIME - MAXIMUM PROBABILITY PRINCIPLE to the THEORY of LIGHTNING PROPAGATION

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ABSTRACT

In the last few hundred years, the principle of least time/least action had produced significant advances in classical, and modern physics, including the derivation of Snell's Law in optics by Fermat, the derivations of geodesic equations in Hamiltonian mechanics, the derivations of generalized force equations from the LaGrange equation, etc. This paper introduces the Least Time - Maximum Probability Principle as a natural marriage of the proven Principle of Least Time, and classical probability theory.

Recent studies of commonalties in classical, and modern physics concepts, lead us to summarize our findings in the following hypothesis:

In a large number of observations/measurements (of a phenomenon), *the proportionate number of similar outcomes* (of the observations/measurements of the phenomenon) *is inversely proportional to the time it takes to complete the process that produced the observable/measurable phenomenon.*

In classical statistics, the proportionate number of similar outcomes is a measure of the probability of an event. The inverse of the processing time measures the frequency of occurrence of the event/phenomenon: the shorter the time to complete the process, the more often the phenomenon can be observed. Thus, the minimum time corresponds to the maximum probability. This is the origin of the Least Time-Maximum Probability (LT-MP) Hypothesis.

In lightning the process is the transport of a large number of charged particles from a source region to a drain region. Applied specifically to this phenomenon the principle teaches:

Lightning follows the path of Least Time,
because it is the path of Maximum Probability.

This paper shows that the LT-MP Principle is a selection rule for choosing the most probable lightning channel. It exposes the existence of lightning zones, including the zone of protection, and it reveals that our concept of lightning protection systems design needs revision. The LT-MP Principle explains many lightning observations. With the introduction of the LT-MP Principle, the author hopes to bring Lightning Phenomenology within the sphere of mainstream science.

Monday, May 27, 8:30 AM **Room: Galisteo**

HPEM-2 **Electromagnetic Interaction I**

CoChairs: M. Harrison, Phillips Laboratory, Kirtland AFB, NM
M. Ianoz, Swiss Federal Institute of Technology, Lausanne, Switzerland

8:30 AM **INTRODUCTION & ANNOUNCEMENTS**

8:35 AM **NONLINEAR DIFFUSION OF PULSED MAGNETIC FIELDS IN THIN-WALLED FERROMAGNETIC CYLINDERS**, *W.J. CROISANT, C.A. FEICKERT and M.K. MCINERNEY, U.S. Army Construction Engineering Research Laboratories, Champaign, IL* 12

8:55 AM **F.D.T.D. METHOD APPLIED TO THE GENERATION AND PROPAGATION OF SHORT PULSE**, *F. TRISTANT, F. TORRES and B. JECKO, IRCOM Faculte des Sciences, Limoges, France* 13

9:15 AM **DERIVATION OF THE SKIN DEPTH FOR SHORT ELECTROMAGNETIC PULSES**, *D.W. SCHOLFIELD and D. LIN, Phillips Laboratory, Kirtland AFB, NM* 14

9:35 AM **PREDICTION OF HIGH POWER AND WIDEBAND TRANSMISSIVITY OF PERIODIC STRUCTURES**, *D.T. MCGRATH, Phillips Laboratory, Kirtland AFB, NM* 15

9:55 AM **INVESTIGATION OF THE SHORT PULSE PROPAGATION IN RECTANGULAR CAVITIES BY USING A REFLECTION METHOD**, *S.V. TKATCHENKO and G.V. VODOPJANOV, Radio Research & Development Institute, Moscow, Russia; and L.M. MARTYNOV, Ministry of Posts and Telecommunication, Moscow, Russia* 16

10:15 AM **BREAK**

10:40 AM **THE SCATTERING OF ELECTROMAGNETIC WAVES, POLARIZED IN THE INCIDENCE PLANE IN THE OVERCRITICAL REGION OF ISOTROPIC PLASMA**, *V.G. LAPIN, Radiophysical Research Institute, Novgorod, Russia* 17

NONLINEAR DIFFUSION OF PULSED MAGNETIC FIELDS IN THIN-WALLED FERROMAGNETIC CYLINDERS

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Electrically conductive ferromagnetic shields with field dependent magnetic permeabilities exhibit nonlinear behavior when subjected to intense, pulsed magnetic fields such as those associated with electromagnetic pulse (EMP), electrostatic discharge (ESD), or lightning. This paper considers the magnetic fields arising in the walls of hollow, thin-walled cylinders due to short-duration, axially-directed current pulses along the outer surface.

A planar approximation to the cylindrical problem involves the solution of a nonlinear partial differential equation for the magnetic field strength, $H(x,t)$

$$\frac{\partial^2 H}{\partial x^2} = \sigma \mu_{rd}(H) \frac{\partial H}{\partial t} \tag{1}$$

subject to the initial condition

$$H(x,0) = 0\,, \tag{2}$$

a pulsed magnetic field condition at the outer surface (x=0)

$$H(0,t) = A\left[\exp\left[-\frac{t}{t_r}\right] - \exp\left[-\frac{t}{t_f}\right]\right]\,, \tag{3}$$

and a vanishing field condition at the inner surface (x=d)

$$H(d,t) = 0\,. \tag{4}$$

The relative differential permeability, $\mu_{rd}(H)$, is defined as

$$\mu_{rd} \equiv \frac{1}{\mu_o}\frac{dB}{dH}\,, \tag{5}$$

where $B(H)$ is the magnetization curve. Representations of the form

$$\mu_{rd}(H) = 1 + A_1 \exp\left[-\frac{H}{H_1}\right] - A_2 \exp\left[-\frac{H}{H_2}\right] \tag{6}$$

are used to model the relative differential permeability.

In this study, the problem is solved numerically using an implicit finite difference formulation with backward time differencing, and the calculated spatial distribution of $H(x,t)$ is observed at various times. The calculations have been performed for a number of cases involving intense, short-duration pulses. The salient features of $H(x,t)$ have been examined including: the profiles during the applied pulse, the progression of the maximum magnetic field, the position and rate of diffusion of the saturation front, and the characteristics of the late time magnetic field profiles. The use of the limiting nonlinear theory (for a step magnetization curve) to predict the extent of saturation has been investigated.

F.D.T.D. METHOD APPLIED TO THE GENERATION AND PROPAGATION OF SHORT PULSE

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The Finite Difference Time Domain method (F.D.T.D.) is used to simulate a High Power Microwave (H.P.M.) radiating device (figure 1), including P.M.L. (BERENGER : Journal of Computational Physics) to simulate free space.

We simulate both the guide and the horn ; the guide is excited by the spatial distribution of electric field on its fundamental mode.

A sinusoid modulated by a gaussian is the time excitation. This allows us to study phenomena on a wide band width. We can so get the radiation pattern, the reflection coefficient S_{11} and the radiated field at different frequencies. Thus we can get, in only one computer run, the radiation of the different H.P.M. sources.

If the excitation is too powerful, breakdown phenomenon will occur in the horn. To solve this problem, we close the aperture with a TEFLON plate to create a vacuum inside the horn.

Then we can notice an important desadaptation of the horn (figure 2) due to three parameters : guide - horn transition, horn aperture and TEFLON plate.

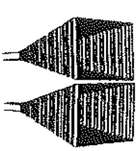

figure 1 : simulated device

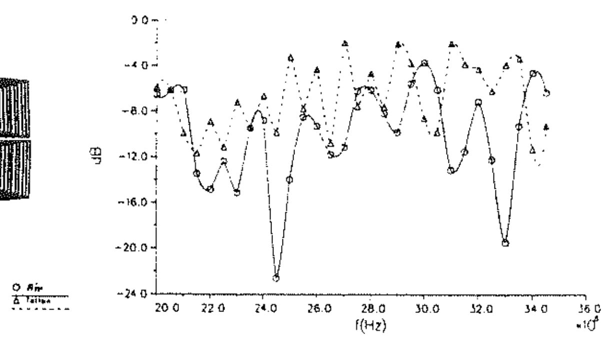

figure 2 : S_{11} of the horn

The radiation of the H.P.M. device is computed inside both near-field and far-field areas and allows us to see at the same time the directivity of the device and the homogeneity of the field in the test zone.

We have made an other run with two neighbouring horns in order to increase radiated power and to enlarge the test area.

CONCLUSION

Radiating devices with one or more horns can now be simulated with our F.D.T.D. algorithm. This survey enables us to know the behaviour of each microwave device, in a wide frequency band, and in one calculation.

DERIVATION OF THE SKIN DEPTH FOR SHORT ELECTROMAGNETIC PULSES

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As the time duration of an electromagnetic pulse becomes shorter the bandwidth of the pulse increases. This presents a problem in the selection of a frequency for the calculation of the electric permittivity and associated parameters such as: the attenuation constant, the skin depth, phase velocity, and index of refraction. For a short electromagnetic pulse one could easily argue for the election of the fundamental harmonic since this frequency contains a plurality of the power, the median harmonic since this frequency would bisect the frequencies of the pulse spectrum, or that frequency which bisects the total power of the pulse spectrum. spectrum exactly. This paper presents a technique for calculation of the above parameters based on the fourier transform of a double exponential pulse into the frequency domain. Each frequency component of the frequency domain signal is then treated separately as a continuous wave signal with the electric permittivity considered to be a transfer function of some material. The resulting spectrum in the frequency domain is than inverse fourier transform back into the time domain. The resulting waveform is compared with the original double exponential pulse.

PREDICTION OF HIGH POWER AND WIDEBAND TRANSMISSIVITY OF PERIODIC STRUCTURES

Daniel T. McGrath
USAF Phillips Laboratory

A new calculation method based on the frequency-domain finite element method with periodic boundary conditions allows accurate and efficient predictions of electromagnetic reflection from, and transmission through, general periodic structures. It has been used successfully for calculating properties of several structures interesting to high power and wideband applications.

The method solves for the time-harmonic electric field within a unit cell of the assumed infinite periodic array. It imposes radiation boundary conditions at surfaces on each side of the planar structure using sums of higher order Floquet modes. This allows the radiation boundary to be as close as possible to the material object, not requiring an excessive number of grid cells in free space. A second periodicity condition wraps opposing unit cell side walls onto each other mathematically, with a phase shift appropriate to the incident wave angle. Finally, reflectivity and transmissivity are computed from the resulting electric field solution at the outer boundaries. Since it solves directly for the electric field, the method is useful for locating field concentrations, and thereby assessing the breakdown strength of periodically inhomogenous materials. Post-processing with model-based parameter estimation provides a means of estimating wideband pulse propagation through those materials.

This paper will review the theoretical and mathematical formulation of the periodic hybrid finite element method and some of the details of its implementation in a general-purpose computer code. It will present results of example cases that illustrate its effectiveness and versatility: crossed conducting bars representative of reinforced concrete, showing differences in oblique-angle transmissivity between connected or unconnected bars; artificial dielectric constructed from spherical conductors, showing estimates of dispersion and field breakdown; and pyramidal cones of carbon-loaded urethane absorber, demonstrating efficient calculation of absorption performance.

INVESTIGATION OF THE SHORT PULSE PROPAGATION IN RECTANGULAR CAVITIES BY USING A REFLECTION METHOD

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A need to study the propagation of short electromagnetic pulses ($\tau \leq L/C$, where τ-a pulse duration, L - a typical cavity size, C - the light velocity) in rectangular metallic resonators arises in relation to a number of electromagnetic compatibility problems such as an evaluation of strong electromagnetic pulse field effects on facilities inside racks and enclosures with slots and apertures, an evaluation of mutual coupling between interior units or printed circuits operating in the pulse mode, etc.

The paper suggests an easy computation technique based on an exact analytical expression for the resonator Green function in the time - domain (assuming that the cavity conductivity is perfect). The Green function is derived by a reflection method which is well known in electrodynamics and is applied to primary electric or magnetic currents inside a rectangular cavity (S.Tkatchenko, G.Vodopjanov, L.Martynov, Proceedings of EMC Zurich'95, p.513.). The primary current vector potential producing electromagnetic fields which meet the boundary conditions on the cavity walls is obtained by examining signal re-reflections from the cavity walls, i.e. by summing up image vector-potentials of the primary current taking into account any changes of a primary current image direction due to reflection. For the primary current pulse time function at any finite time t the number of reflections under consideration is limited and can be approximately defined by the following equation $N_\Sigma(t) \approx Int\left(4\pi/3 \cdot (c\,t)^3 \cdot V^{-1}\right)$ (where V - the resonator volume). Consequently, when the characteristic pulse rise time is such that the ct/L value is in the order of several units, the rectangular resonator Green function is calculated quite easily even at PC-type computers.

The above technique is also used to resolve the problems of a short front pulse penetration into a rectangular cavity with a small aperture. The well-known Bethe method whereby the hole is replaced by equivalent electrical and magnetic dipoles is applied. The currents induced in an internal wiring of a simple geometric shape are evaluated. The mutual coupling for such wiring structures is also estimated.

In conclusion possible reflection method applications for studies of the short pulse propagation in cavities of different geometric shapes (convex polyhedrons) are discussed. Possible applications of the above method for certain geometric symmetries are presented.

THE SCATTERING OF ELECTROMAGNETIC WAVES, POLARIZED IN THE INCIDENCE PLANE IN THE OVERCRITICAL REGION OF ISOTROPIC PLASMA

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Over-critical plasma region, where electromagnetic wave field has not oscillating character as a rule is not important in the forming of the reflected field pattern. At the same time the electric field strength of the wave, polarized in the incidence plane, has the singularity at the plasma resonance level (N.G. Denisov, Sov. Phys. JETP 4, p. 544, 1957 ; V.L. Ginzburg, ***Propag. of Electromagn. Wave in Plasmas,*** Pergamon, New York, 1970). In the presence of incident wave energy losses because of dissipation or plasma wave excitation processes (D.E. Hinkel-Lipsker, Phys. Fluids, B 4, p.559, 1992), the maximum field value becomes a finite, but still can be the maximal one in the plasma volume. When the low scale inhomogeneities are present in the plasma, this big field value region may define the whole scattering wave field. Previously, in the papers (N.G. Denisov, Izvestiya Vuzov Radiofizika, **3**, p. 208, 1960; M.L.V. Pitteway, Proc. Roy. Soc., **A254**, p. 86, 1960), the effective scattering has been marked in the vicinity of reflection level in the case of normally incident wave. Nevertheless, the case of obliquely incident TM - polarized wave under discussion, not yet was analyzed as far as to-day, in spite of the field value can be sufficiently bigger in the plasma resonance region in this case.

If the plane monochromatic electromagnetic wave falls under the angle θ_0 to the semi - infinite isotropic plasma ($z \geq -L$) with dielectric constant $\varepsilon_0(z) = -z/L + i\nu_{eff}/\omega$ and small inhomogeneities $\varepsilon_1(\vec{r})$: $|\varepsilon_1| \ll |\varepsilon_0|$. In the case of semi - infinite , smoothly inhomogeneous plasma ($\rho \equiv \frac{\omega}{c}L \gg 1$) it may be concluded:

- For the big incidence angles ($k_0 L \sin^3\theta_0 \gg 1$) the field, scattered in the plasma resonance region, basically go out of the plasma in the direction normal to plasma boundary (the spectral width is $\delta æ/k_0 \sim (k_0L)^{-1/3} \ll \sin\theta_0$. Intensity of this part of radiation encreases when dissipation ν decreases and when incident angle θ_0 tends to it optimal value $\theta_{0,max} \sim (k_0L)^{-1} \ll 1$.
- The field, scattered in the subcritical plasma region in the case of elongated in the plasma gradient direction inhomogeneities ($\partial\varepsilon_1/\partial z = 0$), has wave vectors constituent the angle θ_0 with respect to the plasma density gradient: $(æ/k_0 - \theta_0) \sim (k_0L)^{-1} \ll \theta_0$, ($\rho\sin^3\theta_0 \gg 1$)
- When the dissipation is small enough, the plasma resonance region can contribute the main part to the scattered field amplitude.

Monday, May 27, 8:30 AM **Room: Brazos**

UWB, SP-1 & HPEM-29 Antennas I

CoChairs: J. Aurand, Sandia National Laboratories, Albuquerque, NM
K. Min, Wright Laboratory, Eglin AFB, FL

8:30 AM **INTRODUCTION & ANNOUNCEMENTS**

8:35 AM **OPTICALLY-EXCITED PHOTOCONDUCTING ANTENNAS FOR GENERATING ULTRA-WIDEBAND PULSES**, *D.W. LIU and P.H. CARR, Rome Laboratory, Hanscom AFB, MA* 20

8:55 AM **ARTIFICIAL DIELECTRICS FOR ULTRA-WIDEBAND APPLICATION**, *J.S.H. SCHOENBERG and C.J. BUCHENAUER, Phillips Laboratory, Kirtland AFB, NM* 21

9:15 AM **A TEM-HORN ANTENNA WITH DIELECTRIC LENS FOR FAST IMPULSE RESPONSE**, *J.F. AURAND, Sandia National Laboratories, Albuquerque, NM* 22

9:35 AM **COPLANAR CONICAL PLATES IN A UNIFORM DIELECTRIC LENS WITH MATCHING CONICAL PLATES FOR FEEDING A PARABOLOIDAL REFLECTOR**, *C.E. BAUM and J.J. SADLER, Phillips Laboratory, Kirtland AFB, NM; and A.P. STONE, University of New Mexico, Albuquerque, NM* 23

9:55 AM **RADIATED WAVEFORMS AND SPECTRA IMPULSE RADIATING ANTENNAS (IRAS)**, *D.V. GIRI, Pro-Tech, Lafayette, CA* 24

10:15 AM **BREAK**

10:40 AM **ELECTROMAGNETIC ANALYSIS OF EXPONENTIALLY TAPERED COPLANAR STRIPLINE ANTENNAS USED IN COHERENT MICROWAVE TRANSIENT SPECTROSCOPY TECHNIQUE**, *V. BERTRAND, M. LALANDE and B. JECKO, Institut de Recherche en Communications Optiques et Microondes, Limoges, France* 25

11:00 AM **SIMULATION OF REFLECTOR ANTENNA WITH TEM HORN FEED**, *V. VEREMEY, Institute of Radiophysics and Electronics, Kharkov, Ukraine; and S. LATINSKY and Y. TKACH, Institute of Electromagnetic Research, Kharkov, Ukraine* 26

11:20 AM **NUMERICAL SIMULATION OF UWB-PULSE EMISSION FROM COAXIAL TEM-HORN**, *V.P. GUBANOV, S.D. KOROVIN and I.V. PEGEL, High Current Electronics Institute, Tomsk, Russia; and V.P. TARAKANOV, Institute of High Temperatures, Moscow, Russia* 27

11:40 AM **(INVITED) DESIGN OF TEM HORNS: FREQUENCY AND TIME DOMAINS**, *J.G. MALONEY and G.S. SMITH, Georgia Tech Research Institute, Atlanta, GA* 28

OPTICALLY-EXCITED PHOTOCONDUCTING ANTENNAS FOR GENERATING ULTRA-WIDEBAND PULSES

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ABSTRACT

Photoconducting antennas excited by 80 picosecond laser pulses are ultra-wideband sources of short-pulse electromagnetic radiation. In this work, 80 picosecond pulses from a frequency-doubled, mode-locked, Q-switched YLF laser generate photoelectrons in dc-biased high-resistivity semiconductor wafers (D. W. Liu, J. B. Thaxter, and D.F. Bliss, OPTICS LETTERS, vol. 20, 1544-1546, 1995). We have investigated InP:Fe, GaAs, and Low-Temperature grown GaAs for this application. The microwave radiation due to the dc-driven photocurrent is detected at the near field with an inductive loop and at the far field by an impulse antenna. These signals are observed in real time with a Tektronix 11802 sampling oscilloscope. We have studied nonlinearities in the microwave radiation for optical fluences as high as 300 $\mu J/cm^2$. This nonlinearity was analyzed and found to be consistent with a surface mobility of 1250 cm^2/v-sec. This mobility is below the steady-state value of 4600 cm^2/v-sec, but almost a factor of four higher than the corresponding value for photoconducting antennas at terahertz frequencies. We have also observed voltage nonlinearities at dc-bias fields as low as 12 KV/cm.

Multi-element phased arrays can be implemented with multiple laser beams and the size of the radiating antenna can be varied by changing the diameter of the optical beam. Reconfiguration is implemented by moving the optical beams. Fiber optic feeds for individual elements make novel 2-D and 3-D phased array antennas possible. Spectrum shaping of the radiated waveform is being investigated for high-resolution-tracking-radars and noncooperative IFF systems.

ARTIFICIAL DIELECTRICS FOR ULTRA-WIDEBAND APPLICATION

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Kirtland AFB, NM 87117-5776

Artificial dielectrics have been proposed for use in ultra-wideband (UWB) antenna and source applications such as lenses, where considerable weight savings may be realized over heavier natural dielectrics. Artificial dielectrics are synthetic media that may be composed of conductive elements imbedded in a natural dielectric medium, or binder. The elements may be metallic disks or spheres, arranged in a periodic lattice, with each element much smaller than the shortest wavelength supported by the UWB source. The effective dielectric constant of artificial dielectrics can be designed to be much greater than natural dielectrics of comparable weight. However, artificial dielectrics cause fields propagating through them to become concentrated between conducting elements, which may cause dielectric breakdown at lower field levels.

It has been demonstrated that a periodic lattice of elements imbedded in a uniform dielectric slab of finite thickness is accurately modelled using the Hybrid Finite Element Method (D.T. McGrath, PL-TR-95-1103, 1995). Since the analysis considers medium of finite thickness, the code may be used to synthesize artificial dielectrics with elements that change in size or spacing as a function of propagation depth. This may allow for graded permittivity and may reduce coherent Bragg scattering in the artificial dielectric. This numerical method will be used to determine the permittivity and electromagnetic field distribution in candidate artificial dielectrics. Suitable artificial dielectrics will be evaluated for their permittivity, index of refraction and field breakdown subjected to high power microwave (HPM) short pulse excitation.

A TEM-HORN ANTENNA WITH DIELECTRIC LENS FOR FAST IMPULSE RESPONSE

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We recently designed and built a TEM-horn antenna with a dielectric aperture lens in order to achieve faster transient pulse response. The antenna consists of a conventional TEM-horn configuration (two flat, long triangularly-shaped conducting plates with a constant separation angle), and an additional solid Teflon™ lens placed at the aperture end of the plates.

TEM horns are commonly used for wideband time-domain work because they offer minimum dispersion as a traveling-wave endfire structure (which can be made fairly nonresonant). However, even carefully designed TEM horns have an inherent pulse smearing effect due to spherical wavefront propagation within the structure. A dielectric planar-spherical aperture lens is used to compensate for this plane-wave to spherical-wave conversion. The idea is simply to collimate the wavefront between the plates in order to improve the impulse response.

A 91-cm-long antenna was designed and built. Two different schemes were employed for the plate configuration: the first version utilizes single-sided etched copper traces on low-loss printed-wiring boards (PWB), and the other version utilizes solid copper plates. The PWB configuration is designed with stepped resistive loading at the aperture end of the traces in order to minimize ringing antenna currents, and a custom transition from the parallel-plate antenna structure to coaxial feedpoint. The solid-plate configuration was then developed because the impulse response of the PWB topology wasn't good enough. The resulting step-equivalent risetime (10-90%) of the solid-plate version is 24 ps, the fastest TEM-horn we have designed and built. In both configurations, expanded polystyrene is employed as a solid structural material between the plates, and the dielectric planar-convex lens is located at the aperture end of the plates.

This paper describes our antenna design for both plate configurations, and measurements of the resulting performance for two nominally-identical antennas. This type of antenna offers very good short-pulse operation, and is highly recommended for wideband time-domain antenna work.

COPLANAR CONICAL PLATES IN A UNIFORM DIELECTRIC LENS WITH MATCHING CONICAL PLATES FOR FEEDING A PARABOLOIDAL REFLECTOR

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PL/WSR, KAFB
Albuquerque, NM 87117
Alexander P. Stone*
Department of Mathematics and Statistics
University of New Mexico
Albuquerque, NM 87131

One form of an impulse radiating antenna (IRA) consists of a paraboloidal reflector fed by conical transmission lines that propagate a spherical TEM wave, which originates from the focal point of the reflector. The design considerations of a uniform dielectric lens useful in launching a spherical TEM wave onto such a paraboloidal reflector have been investigated in earlier work and the geometrical parameters for the lens design determined. The lens design in essence consists of specifying the cylindrical radius of the outermost ray which intercepts the reflector, a dielectric medium for the lens, the angle from the apex of the conical transmission line (focal point) to the edge of the reflector, and the angle made by the line inside the lens with respect to the directions of launch.

There are several reasons for employing dielectric lenses in such an application, and these include the fact that a dielectric medium can be used to ensure a spherical TEM wave launch inside the lens. All rays emanating from the switch center should exit the lens boundary and end up on a spherical wavefront centered on the focal point at the same instant. The "equal transit-time" condition, which provides the basis for the lens design, generates an optimal spherical wave launch onto the reflector. The frequency dependence of the dielectric constant of the lens medium is also an important consideration in the choice of the material. The dielectric constant chosen is approximately 2.26, which is that of materials such as transformer oil or polyethylene and is approximately frequency independent over the frequency range of interest. In this paper impedance characteristics of coplanar conical plate geometries which pass through a lens boundary are investigated. The lens impedance as a function of the half-angle of the interior conical plates, as well as the impedance outside of the lens is calculated. Numerical results are presented as a function of the reflector geometry, so that one can trade off the various performance characteristics.

RADIATED WAVEFORMS AND SPECTRA IMPULSE RADIATING ANTENNAS (IRAs)

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ABSTRACT

Paraboloidal reflector antennas, illuminated by spherical TEM waves, have now been established to possess wide-band and non-dispersive properties. Past analyses (C.E.Baum and E.G.Farr, Ultra-Wideband Short Pulse Electromagnetics, edited by H.L.Bertoni et al., pp139-147, Plenum Press, NY 1993) have focused on the prepulse and the impulse, assuming a step-function excitation. The analysis has now been extended to include the diffracted fields from the launcher plates and the circular rim of the reflector. The leading terms of diffracted signal from the launcher plates have been determined, while the total diffraction from the circular rim of the reflector can be obtained in closed form. As may be expected, these two components of diffraction are small and of opposite signs and immmediately follow the impulse portion of the radiated waveform.

Even if one ignores the diffracted signals, the radiated waveform consisting of the feed step and the impulse has been known to possess a net zero area (or no dc component). This important portion of the radiated waveform has been analytically Fourier transformed for an ideal step-function, and a practical double- exponential pulse excitations. Typical radiated waveforms at a distance of 304 m from a prototype IRA are shown in figures 1 and 2.

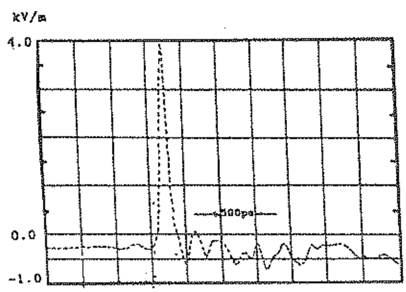

Figure 1. Measured electric field at a distance of 304 m (Prototype IRA)

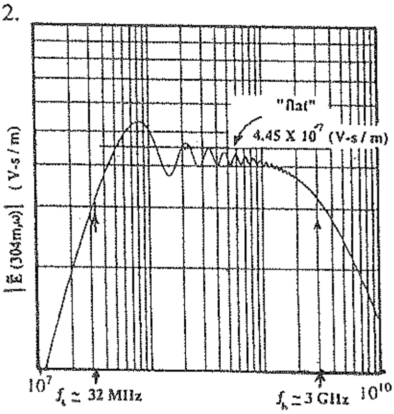

Figure 2. Computed spectral magnitude

The extremely high bandwidth of such antennas is clearly observable in Figure 2. In this presentation, we will describe the analysis (time and frequency domains) and some typical measurement data.

ELECTROMAGNETIC ANALYSIS OF EXPONENTIALLY TAPERED COPLANAR STRIPLINE ANTENNAS USED IN COHERENT MICROWAVE TRANSIENT SPECTROSCOPY TECHNIQUE

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With the advent of reliable sources of ultrashort optical pulses, photoconductive switches, photoconductive sampling have turned into usual methods that allow to generate and to detect ultra-fast electric pulses. Recent experiments have shown that commuting devices of optoelectronic pulses associated with appropriate antennas can be used to generate, control and detect picosecond bursts of electromagnetic radiation. It leads to various applications as the transient radiation properties of antennas or as the characterization of material by coherent microwave transient spectroscopy technique.

The experimental configuration is shown schematicaly in Fig. 1. The transmitter is biased with a DC voltage, while the receiver is connected to low-frequency signal-averaging electronics. The optical beam is focussed on the feedline of the transmitter, where an ultra-fast electric pulse is generated. All or part of the spectrum contained in this pulse is radiated, depending on the characteristics of the transmitting antenna. The field incident on the receiver induces a transient voltage across its feedline which is photoconductively sampled as a function of time by the variably delayed probe beam. Generally, exponentially tapered coplanar stripline (ETCS) antennas are employed in this experiment because of their broad bandwidth, directivity and transmission-line natures.

This paper deals with an electromagnetic analysis of these ETCS antennas. In particular, the purpose of this electromagnetic study is to understand the radiation mechanism of this antenna type and to optimize it. For this analysis and for the considered frequency bands, the Finite Difference Time Domain (FDTD) method is a suitable method because it takes all the propagation and radiation modes into account. The time evolution of the electric field is calculated in free space at different points in the propagation direction (Fig. 2) for different antenna geometries. For example, the effect of substrate thickness on radiation properties of ETCS antennas is shown in Fig. 3. So, the computation of radiation patterns is realized by using Huygen's principle to transform the near field obtained by FDTD method to the far field.

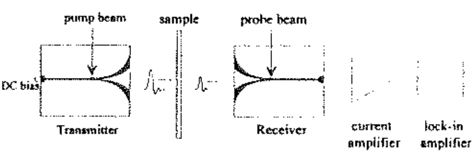
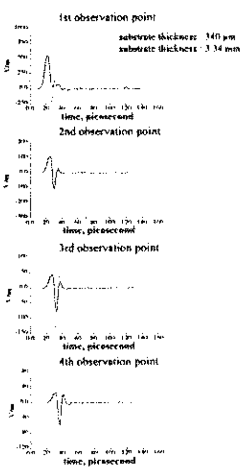


figure 1 : schematic of the coherent microwave transient spectroscopy experiment



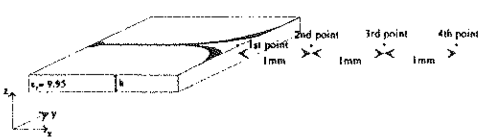


figure 2 : observation points

figure 3 : time evolution of y field component

SIMULATION OF REFLECTOR ANTENNA WITH TEM HORN FEED

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Development of techniques for wide-band pulse signals radiation is in a focus of modern antenna engineering. Known antenna constructions for pulse radiation do not completely satisfy requirements of initial signals shapes preservation and focusing radiated fields. In the present paper characteristics of pulse radiation of an antenna with a cylindrical reflector and a TEM-horn irradiator have been studied. A possibility antenna parameters improvement by using coatings of antenna reflecting elements with non-linear characteristics have been analyzed.

Antennas formed by sections of transmission lines with two or more conductors supporting the TEM mode have been studied by many authors. The wide band characteristics of such antennas makes them attractive for pulse signals radiation. The development of new theoretical methods which allow to study antenna characteristics both in the longwave region and in the resonance wave region with high accuracy and reliability is necessary for design and analysis of the such antennas. Rigorous numerical methods which make possible to calculate radiating systems characteristics with a predetermined accuracy and with taking into account antenna resonance properties play a particular role in an analysis of wide band antennas. The Generalized Reimann-Hilbert Problem approach, which reduces the corresponding boundary value problem to a well-conditioned system of linear algebraic equations, has been used for numerical solving the corresponding diffraction wave problem.

In the present paper a two dimensional antenna for pulse radiation, formed by a cylindrical main reflector and two cylindrical screens located symmetrically in the focal region is analyzed. The considered irradiator is a simplified two-dimensional model of TEM horn antenna. An application of the rigorous numerical approach allows us to take into account an influence of scattering from screens edges and of the re-reflection between the irradiator elements and the antenna reflector on radiated signal characteristics. The properties of the considered antenna under simple harmonic of pulse excitation have been investigated. Pulse characteristics of the antenna have been calculated by means of the method of Fourier transforms on the base of data obtained in the frequency domain. It has been shown that the re-reflection from edges of screens, which forms the horn irradiator, effects on the radiated pulse characteristics. An influence of high modes excited in the TEM-horn irradiator on the radiated field has been studied.

The steepness of the radiated pulse fronts and a possibility of concentration of the pulse radiation are very important in some applications. It is shown in the paper that using the main reflector properties allows to radiate pulse signals in a given direction. The peaking of a pulse signal can be achieved by means of electromagnetic properties of the reflector antenna.

A possibility of application of reflecting antenna coatings elements in order to improve radiated signals characteristics has been considered. The particular attention has been paid to the coating with non-linear properties. It is shown that pulse antenna characteristics can be efficiently controlled by varying non-linear characteristics of the coatings.

NUMERICAL SIMULATION OF UWB-PULSE EMISSION FROM COAXIAL TEM-HORN

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Tarakanov V.P.
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Results of time-dependent computer simulation of ultrawide band pulse emission from a coaxial TEM-horn are presented. The axisymmetric version of fully electromagnetic finite-difference PIC-code KARAT was applied. The simulated volume of sufficient size was closed in terms of boundary conditions. To suppress possible reflections of the signal, the walls of the chamber were considered as covered with absorber. Uniform rectangular grid was used in RZ-plane.

A real experimental configuration of antenna has been considered, with partial dielectric filling (transformer oil). At the antenna input, a trapezoidal TEM-pulse was simulated, few nanoseconds in duration.

The shape of emitted pulse appeared in agreement with the experiment and may be characterized generally as bipolar, with significant dependence on the feeding pulse duration. The latter should not much exceed some value for efficient operation of antenna of given size, in particular, in terms of power reflections back to the feeder.

Formation of spatial structure of emitted pulse is presented visually. The radiation pattern is a wide ring with zero on the axis.

A part of emitted power forms a potential (TEM) wave running back along the outer surface of outer antenna conductor. The corresponding part of energy increases with the duration of the feeding pulse. Further, under real conditions, this wave may turn partially into a wave propagating with decay along the ground surface on which the antenna is placed.

Design of TEM Horns: Frequency and Time Domains

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A TEM horn antenna is often viewed as a transmission line structure designed to radiate at its open end. The assumed TEM form for the waves on the structure imply low dispersion and reasonable bandwidth. Thus, the TEM horn is often used for broadband and short-pulse applications.

Although this antenna has been used for many years in a variety of configurations (resistively loaded, shaped, etc.), there is little parametric information that can be systematically used to design an antenna to meet specifications for a particular application. In this paper, we will examine the TEM horn in its most basic form - two metallic sheets, each an isosceles triangle with the angle at the apex α and the side length s. The planes of these triangles are separated by the angle β. This antenna will be analyzed using the finite-difference time-domain (FDTD) method.

In the frequency domain, the parameters α, β, and s/λ_0 completely describe the antenna. Important properties of the antenna, such as its impedance, directivity, etc. will be presented as a function of these parameters. In addition, we will show how these parameters affect the performance when the antenna is used to radiate a short pulse.

Monday, May 27, 8:30 AM **Room: Aztec**

UWB, SP-2 (Invited) Polarimetric UWB Radar/SAR Sensing & Imaging

CoChairs: W.-M. Boerner, University of Illinois at Chicago, Chicago, IL
S.R. Cloude, Applied Electromagnetics, St. Andrews, Scotland

8:30 AM **INTRODUCTION & ANNOUNCEMENTS**

8:35 AM **POLARIMETRY IN ULTRAWIDEBAND INTERFEROMETRIC SENSING AND IMAGING**, *W.-M. BOERNER, University of Illinois at Chicago, Chicago, IL; and J.S. VERDI, Naval Air Warfare Center, Warminster, PA* 30

8:55 AM **POLARIZATION PROCESSING IN UWB RADAR**, *S.R. CLOUDE, P.D. SMITH and A. MILNE, Applied Electromagnetics, Scotland, U.K.* 31

9:15 AM **IMPORTANCE OF POLARIZATION FOR OPTIMIZING INFORMATION CONTENT IN UWB RADAR**, *E. KROGAGER, Danish Defence Research Establishment, Copenhagen; and W.-M. BOERNER, University of Illinois, Chicago, IL* 32

9:35 AM **POLARIZATION STRUCTURE OF ULTRA-WIDE-BAND RADAR SIGNALS**, *V.A. SARYTCHEV and G.B. KATCHALOVA, Holding Company "Leninez", St. Petersburg, Russia* 33

9:55 AM **IMPLEMENTATION OF THE OPTIMAL POLARIZATION CONTRAST ENHANCEMENT CONCEPT IN ULTRAWIDEBAND (MULTI-SPECTRAL) POL-SAR IMAGE ANALYSIS**, *H. MOTT, University of Alabama at Tuscaloosa, Tuscaloosa, AL; and W.-M. BOERNER, University of Illinois at Chicago, Chicago, IL* 34

10:15 AM **BREAK**

10:40 AM **PROPAGATION AND CLUTTER ANALYSIS OF MEASURED POLARIMETRIC UWB-FOPEN-SAR IMAGERY**, *J.S. GWYNNE and J.D. YOUNG, The Ohio State University, Columbus, OH* 35

11:00 AM **THE P-3 ULTRA-WIDEBAND SAR: TWO-PASS INTERFEROMETRY**, *N.O. VANDENBERG and D.R. SHEEN, Environmental Research Institute of Michigan, Ann Arbor, MI* 36

11:20 AM **POLARIZATION EFFECTS OBSERVED WITH ULTRAWIDEBAND RADAR**, *R.S. VICKERS, A. SCHMIDT and K. DREYER, Stanford Research Institute, Advanced Sensors Division, Palo Alto, CA* 37

11:40 AM **CALIBRATION OF AN UWB, SHORT PULSE, POLARIMETRIC SAR SYSTEM**, *D.J. BLEJER and C.F. LEE, Massachusetts Institute of Technology, Lexington, MA; and J. McCORKLE, M. RESSLER and M. BENNETT, U.S. Army Research Laboratory, Adelphi, MD* 38

12:00 PM **MULTISPECTRAL AND WIDEBAND BISTATIC VECTOR INVERSE SCATTERING: UWB TREATMENT OF CANONICAL SURFACE SECTIONS**, *W.-M. BOERNER, University of Illinois at Chicago, Chicago, IL; and F.A. MOLINET, Societe Mothesim, France* 39

POLARIMETRY IN ULTRAWIDEBAND INTERFEROMETRIC SENSING AND IMAGING

Wolfgang-Martin Boerner* and James Salvatore Verdi,

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Abstract: 'WISIP: Wideband (μHz - PHz) Interferometric Sensing and Imaging Polarimetry' has become an important, indispensable tool in wide area military surveillance and global enivronmental monitoring of the terrestrial and planetary covers. It enables dynamic, real-time optimal feature extraction of significant characteristics of desirable targets and/or target sections with simultaneous suppression of undesirable background clutter and propagation path speckle at hitherto unknown clarity and never before achieved quality. 'WISIP' may be adopted to the Detection, Recognition and Identification (DRI) of any stationary, moving or vibrating target or distributed scatterer segments versus arbitrary stationary, dynamically changing and/or moving geo-physical/ecological enivronments, provided the instantaneous 2x2 phasor (Jones/Sinclair) and 4x4 power density (Mueller/ Kennaugh) matrices for forward-propagation/backward-scattering, respectively, can be measured with sufficient accuracy. For example, the DRI of stealthy, dynamically moving and/or camouflaged stationary objects occluded deeply into heterogeneous stationary and/or dynamically moving inhomogeneous volumetric scatter environments such as precipitation scatter, the ocean sea/lake surface boundary layers, the littoral coastal surf zones, pack-ice and snow or vegetative canopies, dry sands and soils, etc., can now be successfully realized. A comprehensive overview is presented on how these modern high resolution/precision, complete polarimetric coregistered signature sensing and imaging techniques, complemented by full integration of novel navigational electronic tools, such as DGPS, will advance electromagnetic vector wave sensing and imaging towards the limits of physical realizability. Various examples utilizing most recent image data take sets of the NAWC/ERIM-P3-UWB-TOPIF'E-CATI/LTBL-POLSAR and NASA-JPL-AIRSAR airborne, the NASA/DARA/DASI-SIR-C/X-SAR shuttle, and the ESA ERS-1/2 satellite imaging systems will be presented for demonstrating the utility of WISIP.

PRESENTATION: 20 Minutes
AMEREM'96 May 27-31, UWB-SP-EM-3, Albuquerque Convention Center
Session: Polarimetric UWB Radar/SAR Sensing and Imaging, PU-1

POLARIZATION PROCESSING IN UWB RADAR

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Abstract

In this paper we consider a new method for the characterisation of wave polarization effects in ultra wide band (UWB) radar scattering. Polarization techniques are now well established for narrow band SAR imaging applications but are relatively underdeveloped for the case of the very wide band signals employed in UWB systems. Here the narrow band geometric invariance of the polarization ellipse no longer applies and a more general approach must be made to the concept of geometric invariants.

Despite the theoretical and experimental complications caused by employing UWB polarized signals, wave polarization effects are expected to be of significant use in the application of UWB Radar for the detection and identification of man made and natural targets. It is this objective which motivates this study.

We begin by considering the polarization dependence of UWB target signatures in the 250MHz to 2.5GHz band. These signatures are generated using a combination of 3-D time domain finite difference codes and a 3-D time domain integral equation solver. The signatures are generated for a range of canonical targets such as rectangular plates and dihedral structures.

The signatures are first interpreted in the time domain in terms of fundamental current wave propagation and scattering mechanisms and their functional dependence on wave polarization is then examined.

We review the different methods currently employed for wide band polarimetry and then outline a geometric theory of wide band polarimetry which may be used for the processing of invariant features of polarimetric signatures of UWB Radar targets.

We conclude by applying these methods to the target signatures generated using the numerical codes and conclude about the potential of polarization processing techniques in UWB signal processing.

Importance of Polarization for Optimizing Information Content in UWB Radar

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The scattering properties of a radar target can only be fully characterized in terms of a complex scattering matrix in which the elements represent the four combinations of transmit and receive polarization. The amount of information gathered by a single polarization radar may therefore be even very limited, for example when the single polarization response is near zero while the cross polarized return is at a maximum. Although this has been known from the early days of radar it is only in recent years that the practical utilization of polarization has gained significant interest.

Over the last decade or so the interest for polarimetric radar has been strongly increasing, and significant technological improvements have taken place. In addition to this, methods for accurate calibration of polarimetric radars have been developed, so that a good polarization purity and channel balance can be obtained which is of decisive importance to fully utilize polarimetric data.

In conjunction with the ongoing efforts to extend the capabilities of radar by applying ultra-wideband techniques in a variety of fields, it is important to keep in mind the fact that the full amount of potentially available information still can only be accessed by a polarimetric radar. By combining the potentials of ultra-wideband techniques and polarimetric techniques, radar will be capable of acquiring useful types of target characteristic information, which has not been utilized in the past. This should significantly enhance the possibilities for successful identification and classification of radar targets, a subject of increasing importance in military as well as civilian applications.

The paper deals with some of the underlying theory of polarimetric radar, in particular so as to emphasize the relations between actual physical target characteristics and target characteristic parameters that can be extracted from fully polarimetric, ultra-wideband radar data.

POLARIZATION STRUCTURE OF ULTRA-WIDE-BAND RADAR SIGNALS.

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The paper deals with the polarization structure of signals with arbitrary temporal structure E(t), even for compound signals. The basis for study of the signals system polarization structure without restrictions on number and spectral structure of system's components is analyticity of components relations, determined by Hilbert transformation. The mentioned relations permits to uniquely determine envelope, phase and instant frequency of a signals system and to find out the analogy with theory of analytical signals. It is found that the structure of elliptically polarized waves can be transferred on the signals system with arbitrary components number and its spectral structure. Any signal, even with components unmatched on temporary structure, admits the decomposition on two orthogonally polarized components, but with various temporary structures. It is shown, that any signal can be presented as sum of two orthogonally polarized components with desirable polarization state and that this presentation is general and adequate to any signal, including Walsh signals, noise, pulse signals and so on. Also it is shown that there is the analogy between the traditional polarymetry and ultra-wide-band polarimetry. In ultra-wide-band polarymetry the scattering matrix is complex, moreover the imaginary unit is adequate to turning in space on an angle, but not in time.

IMPLEMENTATION OF THE OPTIMAL POLARIZATION CONTRAST ENHANCEMENT CONCEPT IN ULTRAWIDEBAND (MULTISPECTRAL) POL-SAR IMAGE ANALYSIS

Harold Mott[1] and Wolfgang-M. Boerner[2]

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In polarimetry strict distinction must be made between optical polarimetry, defined for the forward propagation case in terms of the Jones/Mueller matrix calculus, versus radar polarimetry, defined for the (back)scattering case in terms of the Sinclair/Kennaugh matrix formulations. In this analysis, the optimal polarimetric contrast between a desirable (target) and undesirable (clutter) scattering feature is determined for radar polarimetry for which it is often desirable to select radar antenna polarization that maximize the contrast in received powers from such two distinct classes of scatterers. For example, a terrain-mapping POL-SAR imager may use polarization state manipulations to maximize the contrast between forested areas and farmland, whereas in a combined TOP-POL-SAR ← → POL-MTI imager, the polarization states may be chosen to optimize the "stealthy" aircraft target return relative to heterogeneous dense, dynamically changing background clutter. The fixed antenna polarization of such systems chosen for contrast optimization for either purpose may result in a target return that is small compared to external noise or internal receiver noise, clutter and speckle; and it may therefore be more appropriate to determine in a real-time image data take post-processing mode the polarization(s) that maximize(s) the signal-to-noise and its ratio with respect to speckle and clutter. A complete analysis of methods for the Sinclair [S], the Graves [G] and the Kennaugh [K] matrices is provided for all of the scattering scenarios discussed here. Also, it is shown why such a procedure applied to the covariance matrices $[\Sigma^{3,4}]$ for either the three(3)-dimensional reciprocal symmetric or the four (4)-dimensional bistatic (non-reciprocal) case in not useful; and that a group-theoretic expansion in terms of the "canonical eigenvalues" of the covariance matrix will instead provide the closely associated Polarimetric Entropy Coefficients (PEC H/A/α) of Cloude. Specifically, it is demonstrated that with the prior implementation of Cloude's PEC (Polarimetric entropy H, polarimetric anisotropy A, derived from the eigenvalues of $[\Sigma]$, and the polarimetric canonical target phase α derived from the associated eigenvectors), it is possible to specify which class of OPCE coefficients is the most effective one for truly optimal contrast enhancement. Various examples utilizing most recent image data take sets of the NAWC/ERIM-P3-UWB-TOPIF'E-POLSAR and the NASA-JPL-AIRSAR, as well as the NASA/DARA/DASI-SIR-C/X-SAR shuttle imaging systems will be presented for demonstrating the utility of the PEC and OPCE concepts in POL-SAR image anlaysis.

PRESENTATION: 20 Minutes
AMEREM'96 May 27-31, UWB-SP-EM-3, Albuquerque Convention Center
Session: Polarimetric UWB Radar/SAR Sensing and Imaging, PU-5

Propagation and Clutter Analysis of Measured Polarimetric UWB FOPEN SAR Imagery

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The ultra wide bandwidth aspect of a foliage penetration (FOPEN) radar system poses many new challenges. Much of the past work pertaining to foliage propagation and clutter analysis must be re-evaluated for the UWB case as phase coherency and high resolutions can change basic underlying assumptions. Measured results show that some of the previously assumed components of clutter coherently focus in a UWB image altering the statistics. This presentation primarily focuses on the analysis of data gathered from the following measurement systems.

An HP8753 based stepped frequency radar and a Tek DSA-602A based impulse radar were used to collect UWB foliage measurements in the 200-2000 MHz frequency range. By using the tilting reflector of the Ohio State University Big Ear Telescope as a rail system, these radars were able to collect aperture sizes of approximately 300 feet from a vantage point of 100 feet above the ground. This rail system provided fixed repeatable positioning that overlooked a woodlot typical of the forested areas found throughout the central and northeastern United States. Polarimetric calibration was made possible by the inclusion of a small 2 foot dihedral in the foreground spatially isolated from the earliest foliage returns. This, in conjunction with antenna pattern measurements, permitted calibrated RCS measurements of down range targets concealed in the forest. Numerous dihedrals and trihedrals ranging in sizes from 4 to 8 feet on edge placed on the forest floor provided the means to probe the effects of the foliage canopy and to extract propagation and scattering statistics.

The presented data will described the polarimetric propagation loss and phase dispersion of the overhead canopy. Interactions between concealed targets and nearby trees will be identified. Additionally, clutter statistics characterizing the scattering coefficient per unit area (σ°) and clutter coherency will be presented. Coherent "clutter" components such as tree trunks will be identified. Measured data will be presented in the frequency, time, and image domains.

THE P-3 ULTRA-WIDEBAND SAR: TWO-PASS INTERFEROMETRY

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Under the Advanced Research Projects Agency (ARPA)/ASTO and Air Force Wright Laboratory sponsorship, the Environmental Research Institute of Michigan (ERIM) has developed and Ultra-WideBand (UWB) Very High Frequency (VHF)/UltraHigh Frequency (UHF) fully polarimetric airborne synthetic aperture radar (SAR) for studying the detection of foliage-obscured objects. This paper describes the radar and presents some examples of its capabilities including polarimetric imagery.

The radar is installed in the Naval Air Warfare Center (NAWC) P-3 testbed aircraft and takes advantage of existing ERIM-built multimode, fully-polarimetric X/L/C-band SAR hardware. The UWB system began operation in December 1994 and is operated jointly by NAWC and ERIM with NAWC responsible for flight operation and ERIM responsible for radar operation. The radar operates with a bandwidth of 515 MHz in the 200-900 MHz VHF/UHF band and has a peak transmitter power of 1,000 W.

An interesting application of the sensor is two-pass interferometry where the underlying terrain topology is mapped. This is in contrast to higher frequency InterFerometric SAR (IFSAR) which maps the tops of the tree canopy. A comparison of UHF and X-Band IFSAR imagery will be presented. The polarimetric properties of the foliage will also be shown along with image examples of objects beneath the foliage.

Polarization Effects Observed with Ultrawideband Radar

Roger S Vickers
Arlen Schmidt
Kenneth Dreyer

ABSTRACT

An ultrawideband radar operating from 200 - 400 Mhz has been flown over a series of concealed targets, some buried and some under foliage. The radar collected data in VV , HH and HV polarizations. Initial analysis of the data indicates strong polarization -dependence on some foliage returns. and shows that dramatic improvements in target detection are possible through multi-polarization processing Examples of imagery showing the variation of target and foliage characteristics with polarization will be included in the paper. For buried targets, HH polarization includes stronger returns from surface targets than VV, due to Brewster Angle effects. Thus the two images, (HH and VV) can be used to some extent to reduce the returns from surface ground clutter in a detection strategy. Examples of mine detection using multi-polarization data will be given.

Calibration of an UWB, Short Pulse, Polarimetric SAR*

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The Army Research Laboratory (ARL) has been developing and operating impulse radars since 1988. These radars were developed for studying foliage and ground penetration phenomenology and concealed target detection. The first radar was used on the ARL rooftop in "rail SAR mode" where the radar was moved along a linear rail to form a synthetic aperture. This system was upgraded to have higher transmit power, higher PRF, faster A/D converters, and faster data-transfer rates. This new system, after initial testing in the rooftop test bed configuration, was mounted on a 150 foot, self-propelled boom lift, and used at the Aberdeen Proving Grounds (APG) and the Yuma Proving Grounds (YPG) for synthetic aperture radar imaging in the field. A foliage penetration test was performed at APG and a ground penetration test was performed at YPG.

The "Boom" SAR is a fully polarimetric system that uses two TEM horn antennas for transmit and two for receive. The polarization basis for the Boom SAR is a standard linear basis, so the radar polarizations are HH, VV, HV, and VH. Since the system uses four antennas, the radar is quasi-monostatic; this implies that the scattering matrix for the system is nonreciprocal. Polarimetric calibration for nonreciprocal systems requires complicated processing.

The polarimetric properties of the Boom SAR system will be characterized in both the time and frequency domains. The characterization will be achieved by: (1) measuring the principal plane antenna patterns at discrete frequencies over the radar bandwidth, and (2) measuring the responses of several calibration targets in all four polarimetric channels. The calibration targets treated as scattering vectors must span polarization space. This will be achieved by using a combination of trihedral and dihedral scatterers for frequencies above 100

* This work was sponsored by the U.S. Army Research Laboratory as the executing agency for the DIA/Central MASINT Office Ground Penetration Radar Program under Air Force Contract #F19628-95-C-0002. Opinions, interpretations, conclusions, and recommendations are those of the author and are not necessarily endorsed by the United States Air Force.

MULTISPECTRAL AND WIDEBAND BISTATIC VECTOR INVERSE SCATTERING: UWB TREATMENT OF CANONICAL SURFACE SECTIONS

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In order to correlate high resolution/precision interferometric POL-SAR images with the underlying ground truth, it is essential to develop the RCS matrix expressions for simple, canonical shapes in closed analytic form and to provide numerical algorithm verification analyses. This is achieved by extending the common geometrical optics (GO) and physical optics (PO) scalar RCS closed form solutions via the Geometrical Theory of Diffraction (GTD) of J.B. Keller and the Physical Theory of Diffraction (PTD) of P. Ya. Ufimtsev to the full polarimetric, slightly bistatic cases as required for proper implementation in modern wideband (multispectral and impulse) POL-SAR Systems Calibration and Image Normalization procedures.

First, the PO current approximation, corrected by the second order term of the Lüneburg-Kline expansion of specular reflections from an arbitrary convex three-dimensional, perfectly conducting surface, is transformed in the time domain and injected in the time-domain Kirchhoff formula. Employing Kennaugh's bistatic correction approach of the transient ramp response formula, the expressions for the first-order and second-order corrections to the scattered far-field vector (polarization) wave interrogation are obtained for both the monostatic and the bistatic cases. The resulting expressions force the scattering matrix to become asymmetrical due to the local curvature difference as expressed in terms of the derivatives of the Kennaugh-Cosgriff silhouette area function. In a next step, canonical closed form solutions for the truncated cylinder, the wedge, the truncated cone and the cone-tip are found by employing GTD for the respective scattering matrices. Also, the polarimetric bistatic creeping wave solutions for the sphere, the prolate and oblate as well as for the generalized ellipsoidal prefectly conducting scatterers are provided by implementation Fock's theory of vector diffraction and Ufimtsev's Physical Theory of Diffraction. This grief analytical review analysis is them concluded, with a preliminary analysis of Huynen's doubly skewed asymmetric curved phylotaxic surfaces which requires the future extension of the vector PTD methods currently advanced by Pathak, Ufimtsev, Molinet, et al.

Some computer-numerical and experimental data results are provided for comparison using recent measurement-model corroborative results of Molinet who implemented the excellent UWB multispectral POL-RAD data sets collected at CELAR, Bruz in France.

PRESENTATION: 20 Minutes
AMEREM'96 May 27-31, UWB-SP-EM-3, Albuquerque Convention Center
Session: Polarimetric UWB Radar/SAR Sensing and Imaging, PU-10

Monday, May 27, 1:30 PM **Room: Aztec**

HPEM-4 & UWB, SP-13 Signal Processing I

CoChairs: S.J. Frazier, Naval Air Warfare Center, Patuxent River, MD
D. McLemore, Kaman Sciences Corp., Albuquerque, NM

1:30 PM **INTRODUCTION & ANNOUNCEMENTS**

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NEAR-FIELD PHASE RECONSTRUCTION USING PLANE-TO-PLANE ITERATIVE FOURIER PROCESSING AND INFRARED THERMOGRAMS OF ELECTROMAGNETIC FIELDS

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ABSTRACT

There continues to be significant interest in the development of new near-field measurement techniques for the purpose of determining the far-field radiation patterns of antennas. The current practice today is to carefully position a hard-wired field probe at several well known locations about a surface around the antenna under test while recording the magnitude and relative phase of each measurement. Many different techniques have been developed for accurate probe positioning and minimization of the number of probe location measurements required; however, all these techniques are time intensive due to the large number of probe measurement locations required.

Thermographic measurements of microwave fields have been developed for the purpose of mapping radiating field intensity patterns and mapping of surface currents induced in conductors by radiating fields. A resistive sheet positioned in a radiating field will absorb energy and heat in proportion to the strength of the radiating field. A thermal 'picture' is then taken of the heat pattern on the resistive sheet. Each pixel of this thermal picture then represents a measurement of the intensity (magnitude) of the field at the pixel location on the resistive sheet. A single thermal image, therefore, provides a rapid measurement of the field magnitude over a surface; with the effective number of probe locations limited only by the pixel resolution of the imaging camera.

The problem with current thermographic measurement techniques is that only the magnitude of the field is measured. In order to obtain a far-field pattern from near-field antenna measurements, relative phase information is also required.

Microwave holography techniques appear well suited to the determination of the complete, complex, field data from thermographic measurements. This paper discusses the progress made to date using a plane-to-plane iterative Fourier processing technique to determine both magnitude and relative phase information from infrared imaging data; thus, enabling near-field measurements of antenna patterns using the thermal imaging technique.

TIME DOMAIN ANALYSIS USING MAGNITUDE ONLY FREQUENCY DOMAIN DATA

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Time domain signals are usually recovered from frequency domain measurements with a Fourier transform using both magnitude and phase components of the measured data. However there are many cases where phase data are not available or the accuracy of the phase data is questionable. In this situation, one can still obtain time domain results using the Hilbert transform (see F.M. Tesche, "On the Use of the Hilbert Transform for Processing Measured CW Data", *IEEE Trans. on Electromagnetic Compatibility*, Vol. 34, No. 3, August 1992, pp. 259-268) or the "cepstrum" method (T.F. Quatieri and J.M. Tribolet, "Computation of the Real Cepstrum and Minimum Phase Representation" *Programs for Digital Signal Processing*, IEEE Press, 1979). The former method involves the computation of a convolution integral which is relatively time consuming. The latter method can use any available Fourier transform, and if a FFT is used, the computation can be performed relatively quick. However either method involves the assumption that the measured magnitude data correspond to a minimum phase process. Thus the recovered time domain results are not unique. This presentation examines the consequence of this non-uniqueness in terms of errors in time domain norms such as the peak amplitude and the peak derivative. There is no error in the total energy. If the uncertainty or error in the time domain waveform norms is acceptable, then use of results based on a minimum phase assumption is justified.

The presentation begins with a review of the derivation of the cepstrun method. The cepstrum is defined as the logarithm of the frequency domain data. If these data are expressed in terms of a magnitude and phase, $Me^{j\phi}$, then the cepstrum becomes $\ln M + j\phi$. If phase is not available, one can obtain a minimum phase approximation of the phase, ϕ^*, under the assumptions that the corresponding time domain signal to the cepstrum must be both real and causal. This is done in three steps: compute the inverse Fourier transform of lnM, force the resulting time domain signal to be causal, and compute the Fourier transform of the adjusted time domain signal. The imaginary part of this Fourier transform is ϕ^*. The time domain analysis is done using the measured magnitude data, M, and the derived phase, ϕ^*.

We compare the results of the minimum phase Fourier transform (MPFT) to those from a conventional Fourier transform (FT) using the proper phase. Several analytic signals are analyzed. The MPFT reproduces the FT results for simple waveforms. When one computes the inverse transform of the sum of two analytic spectra where one component has a linear phase shift corresponding to a time delay in the time domain, the results show the sum of the two time domain components with the time delay removed. The final analytic example shows that the MPFT of a mis-matched transmission line with multiple time delayed components compares closely to that from a FT. We present explanations for the behavior of the MPFT and FT in these examples based on analytic waveforms. Finally we compare MPFT and FT results obtained from measured data. Differences are measured in terms of peak and peak derivative norms. We use results from comparisons of both analytic data and measured data to reach conclusions of the uncertainty in time domain data due to the minimum phase approximation. Results show that the uncertainties may be small enough for many applications. In these cases, one may choose to streamline the measurement process by recording magnitude data only.

ERROR CORRECTION IN TRANSIENT ELECTROMAGNETIC FIELD MEASUREMENTS USING DECONVOLUTION TECHNIQUES

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It is difficult to make accurate transient electromagnetic field measurements in the pico-second domain because of the limitations and defects of measurement components. In this paper, we present a two-step deconvolution routine to compensate for the measurement distortion in our ultra-wide-band biological exposure facility, which mainly consists of a plasma switch and a symmetric septum GTEM cell. The measurement system includes a Tek SCD 5000 transient digitizer and two EG&G D-dot sensors: model ACD-1D(A), which was mounted on the top ground wall of the cell and utilized for real time monitoring during exposures, and model ACD-1D(R), which was used to map the field on the bottom ground wall of the cell where the specimens are placed. The transfer function of cable-scope system was evaluated using a reference impulse generated with a PSPL 4050B step generator with a 5210 IFN and characterized with a Tek CSA 803 signal analyzer with a SD 30 sampling head. The reference impulse was injected into the cable at the D-dot sensor end and measured with the SCD 5000 (Bao *et al.*, Proc. SPIE 2557:237-248, 1995). Due to its right angle structure, the ACD-1D(R) gives a different response from that of the ACD-1D(A), especially to the fast leading edge. The right angle bend in ACD-1D(R) causes a reduction of the initial spike and reflections in dD/dt signals. To correct the error due to reflections, we proposed an impulse response for ACD-1D(R): $h(t) = a_o\delta(t) + \sum_{k=1}^{N} a_k\delta(t - \tau_k)$, and compensated the waveform with deconvolution: $f_c = F^{-1}(F_m/H)$, where F_m and H are the Fourier transforms of measured dD/dt with ACD-1D(R) and $h(t)$, respectively, and F^{-1} stands for inverse Fourier transform. The parameters in $h(t)$ were determined with a least squares technique: $S = \sum_i \mid f_r - f_c \mid^2$, where f_r is the reference dD/dt measured with ACD-1D(A) that was located symmetrically to ACD-1D(R), and S is minimized using the Levenberg-Marguardt algorithm.

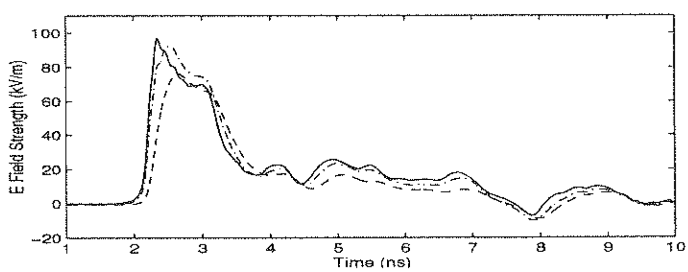

Figure: Comparison of measured field (dashed line) using an EG&G ACD-1D(R) D-dot sensor, field after cable-scope compensation (dash-dot line), and field after cable-scope and D-dot sensor compensation (solid line).

WAVEFORM COMBINATION, BOUNDING AND MODELING OF PULSED AND CW EMP DATA

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Abstract

The use of modern signal processing techniques and algorithms applied to the Electromagnetic Pulse (EMP) waveform has created new opportunities to use all data gathered during aircraft system level EMP evaluations. Research into combining, compressing, and storing transient and continuous wave (CW) waveforms is being conducted by the Naval Air Warfare Center Aircraft Division (NAVAIRWARCENACDIV) at Patuxent River, Maryland. This paper will present advanced waveform bounding algorithms that were not yet developed or presented in the paper for EUROEM in 1994.

During current aircraft EMP evaluations, different simulator polarization's and aircraft configurations are tested to ultimately quantify system survivability. Measurements acquired at the Horizontally Polarized Dipole (HPD), Vertically Polarized Dipole (VPD), and Low Level Continuous Wave (LLCW) simulators provide the stress data for use in direct drive strength testing.

Present research is focused on Tree-Structured Quadrature Mirror Filter Banks used in combining low level continuous wave (LLCW) test measurements with HPD/VPD measurements to develop stress envelopes that encompass the frequency range from 100 kHz to 1 Ghz. The HPD/VPD simulators providing a high level pulsed environment with an upper frequency bound of approximately 150 MHz and the stepped frequency CW simulator with an upper bandwidth limit of 1 GHz. By merging the two overlapping signals, pulsed and CW, into a single waveform that, greater confidence in system survivability can be determined.

DERIVING EMP DIRECT DRIVE PARAMETERS FROM LLCW DATA

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Abstract

The Electromagnetic Transients branch of the Naval Air Warfare Center Aircraft Division located in Patuxent River Maryland has been pursuing new test tools for determining systems survivability to high frequency threats, such as DOD-STD-2169A/B.

Recently, a new approach for the generation of high frequency direct drive signals based on a Gaussian white noise sources has been developed. A prototype generator had been built using a filter to shape the frequency content at the noise source. A mulitchannel noise source has been acquired to better approximate the amplitude in subbands since then.

Techniques have been developed to extract the operating parameters for a high-frequency (100 MHz to 1 GHz) multichannel noise source direct drive generator from low level CW coupling data. The required parameters are the attenuator settings for the noise source channels, the pulse envelope of the high frequency waveform, and the relative timing of the low and high frequency portions of the transient response. The channel settings are obtained from the frequency-domain cumulative action integral, and the pulse envelope is extracted from the inverse Fourier transform of the high frequency portion of the CW spectrum. The relative timing can, in principle, be determined from comparison of the inverse transforms of the low and high frequency portions of the spectrum. However, comparison with high level pulse measurements suggests a systematic error. These techniques were applied to bulk current measurements from a fighter aircraft and to "worst-case" combinations of individual measurements.

The bulk current measurements were acquired in two E-Field polarization's for each of two simulators. The Horizontally Polarized Dipole (HPD) 5 MegaVolt Electromagnetic Pulse (EMP) simulatorand the Low Level Continuos Wave (LLCW) center-fed semi-ellipse antenna with geometry and dimensions similar to those of the HPD were used.

1. "High Frequency Direct Drive Generation Using White Noise Sources", S.Frazier et. al., 12th annual HEART CONF., Feb 14-17, Naval Postgraduate School, Monterey, CA.

STATISTICAL TREATMENT OF IMPULSIVE NOISE

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The impulsive noise is one man-made electromagnetic disturbance, which has become a problem of great concern in the electromagnetic compatibility EMC, this noise can be conduced and radiated.

It is evident, that electrical, electromechanical and electronic systems generate impulsive noise, which can be conduced by the ac power-distribution network through the equipment power cord. The regulation control of power line conduced noise originated in commercial equipments is organized by both industrial and international standards commissions. However, there is discrepancy in some aspects, i.e., in US, the conducted emission limit extends from 450 KHz to 30 MHz and Germany extends from 10 KHz to 30 MHz. Nowadays, these problems are complex because the number of systems that use electric energy is growing and the electronic equipment is sophisticated, such as digital processing equipment, which are recognized as being particularly vulnerable and whose malfunctioning can produce serious consequences, besides the frequency range has increased.

As well, it is clear that electromagnetic spectrum becomes more and more congested due to the need for communicating the vast amount information used nowadays, besides an added pollution in the radio spectrum is given by man-made impulsive noise. Such noise affects telecommunications systems, particularly in the face of limited available band width resources and will become more and more so, a major limiting factor in the successful functioning of such systems.

This impulsive noise is a random process, which can not be adequate described in terms of Gaussian model and their study is a complicate science due mainly to the near infinite of noise-generating sources. The impulsive noises are of short-time duration and can be found in many situations, like accidental hit telephone, lightning in atmosphere, switching transients in the power lines and spark ignition motor car systems. Since the interferences are a sequence of impulses and obey a heavily tailed distribution, it is desirable to choose a proper model for predict the impulsive noise that affects the electronic systems.

In this paper we propose a novel model with Gamma-distribution for the evaluation of the envelope and time parameter of the impulsive noise. As an example, the model is used to predict: a). impulsive interferences level in radio systems for the range frequency VHF/UHF and in cellular communications systems about of a zone of México city; b). impulsive noise on single-phase 120 Vrms mains in residential environment.

ON THE USE OF A REGRESSIVE RATIONAL FUNCTION MODEL TO INTERPOLATE NOISY SPECTRAL DATA

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Generally, discrete-time or discrete-frequency data are obtained via uniform sampling. In some cases, this may not be practical. For instance, logarithmic spacing is often used to limit the samples to a practical number in frequency domain data, collected for frequencies over several decades. Moreover, for high frequency measurements, gaps in the frequency domain data occur as a result of skipping certain communication frequency bands. Accordingly, interpolation is used to characterize the frequency domain response.

Interpolation techniques require a data model to restore the unknown data samples. Often, the model is quite simple. Consequently, interpolation is related to function approximation. In general, interpolation schemes presume some degree of smoothness for the function to be interpolated. However, this may not be valid for noisy data. Moreover, if the interpolating function is fitted to the known data points with additive noise, significant interpolation error may occur.

Various interpolation schemes have been used to restore unknown data samples. However, most of them have been performed on time-series data. Techniques for interpolating complex frequency data have received little attention. Traditional techniques, such as linear, cubic spline, and Lagrange interpolation, have been shown to be data dependent and are generally not satisfactory. They become highly unstable for data corrupted with noise.

A regressive rational function interpolation for noisy complex frequency domain data is presented. This technique incorporates the use of the singular value decomposition method and a statistical measure of goodness-of-fit to obtain the best estimate of the model coefficients. Additional features include a self-tuning ability to obtain an optimum model order and noise reduction. Compared to traditional interpolation techniques, this method is shown to be more robust. Results are obtained for noisy data with low signal-to-noise ratios to ascertain the validity of the technique.

A SLIDING ITERATIVE PROJECTION ALGORITHM FOR ADAPTIVE FILTERING AND SPATIAL PROCESSING

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Gradient least mean squares (LMS) algorithm is widely used in adaptive applications due to its ease of implementation. But slow convergence of the LMS algorithm leads to unsatisfactory performance and poor trackability in the nonstationary conditions. This paper presents an iterative projection (IP) algorithms with sliding windowing (SIP) for adaptive filters and spatial processing systems. They improve the convergence performance in comparison with the LMS algorithm and provide better output signal - to - (interference + noise) ratio (SINR) in adaptive spatial processing. Computer simulations demonstrate the good properties of these algorithms.

Consider a least squares problem $\mathbf{A}\mathbf{w} \cong \mathbf{d}$ where $\mathbf{A}$ is the data matrix, $\mathbf{w}$ is the weight vector to be estimated, $\mathbf{d}$ is the desired (reference) signal vector. It is necessary to minimize the Euclidian norm of the residual vector $\mathbf{r} = \mathbf{d} - \mathbf{A}\mathbf{w}$. Optimal weights provide the residual vector $\mathbf{r}$ to be orthogonal to the linear space spanned by the columns of the data matrix $\mathbf{A}$. One way to satisfy this condition is to iteratively subtract from $\mathbf{r}$ its projection onto each column of $\mathbf{A}$. Corresponding iterations are described as follows: $\mathbf{r}^{i+1} = \mathbf{r}^i - \mu\mathbf{A}\mathbf{U}\mathbf{A}^H\mathbf{r}^i \quad \mu < 1 \quad i = 1, 2, \ldots, I$ where $\mathbf{U} = \mathrm{diag}\left(\frac{1}{\|\mathbf{a}^1\|^2}, \frac{1}{\|\mathbf{a}^2\|^2}, \ldots, \frac{1}{\|\mathbf{a}^N\|^2}\right)$, $\mathbf{r}^1 = \mathbf{d}$, the superscript H corresponds to the conjugate transpose operation, and $\|\mathbf{a}^n\|$ denotes the Euclidian norm of the vector $\mathbf{a}^n$. In the case of sliding windowing with overlapping the initial vector is equal to the previous block solution. The window is rectangular, i.e. one newest sample is added and one oldest sample is rejected, forming a new data block. Only fixed number of iterations I are performed with this block, and so the algorithm is expected to converge only after appending and processing a lot of new observations. The convergence of the weights to their optimum values for each block is not required. Numerical experiments show that the SIP algorithm provides faster convergence and better SINR in comparison with normalised LMS. Moreover, output SINR for normalised LMS are very unstable even for large data volume.

The paper has presented two sliding iterative projection algorithms which may be used in real time signal processing and provide faster convergence and better performance in comparison with the LMS algorithm. By selecting an appropriate iteration number I one may rich the compromise between the convergence speed and implementation complexity. In this sense these algorithms are more flexible than the general optimum block adaptive algorithm, besides, they not require matrix inversion.

NONLINEAR SPATIAL SEPARATION OF COMMUNICATION SIGNALS WITH ADAPTIVE LINEAR ARRAYS

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The problem of blind signal separation arises in many applications, including communications, sonar signal processing with adaptive arrays, interference canceling, and so on. In this paper a nonlinear sliding iterative algorithm (NSIA) is used for blind spatial separation of independent non-Gaussian communication signals received with a uniformly spaced linear array. This algorithm is very useful for recovering the desired signal in communication systems in the presence of man-made signal-like interference. Desired and undesired signals may be of a very similar structure, for example, frequency manipulated with the same baud rates and carrier frequencies, which case presents difficulties for the signal separation with many other methods.

NSIA is constructed with using the criterion of mutual statistical independence of all signals at the outputs of the adaptive system. The main merit of this approach is its universality - the possibility of processing arbitrary types of signals without any a priori information about them. In this case the least mean squares criterion is replaced by the criterion of mutual statistical independence of all output signals. Both numerical simulations and results of processing real radio-communications signals show the possibility of successful separation of signals. Sliding windowing with overlapping is used. The initial weights for the current block are equal to the previous block solutions. The window is rectangular, i.e. one newest sample is added and one oldest sample is rejected, forming a new data block. Only fixed number of iterations I are performed with each block, and so the algorithm is expected to converge only after appending and processing a lot of new observations. The convergence of the weights to their optimum values for each block is not required. The algorithm proposed demonstrates fast convergence. Corresponding output signal - to - (interference + noise) ratio (SINR) is quite satisfactory for its practical application in adaptive spatial processing.

Several numerical experiments were performed for the linear array consisting of four identical omnidirectional sensors which are equally spaced with the half-wavelength distance. For example, in the case of three signals with the signal-to- (thermal noise) ratios = [30, 30, 30] dB and the directions of arrival = [-20, 0, 20] degrees, respectively, NSIA recovers each signal separately in some output channel with the output SINRs 21, 19 and 24 dB. Good results may be provided no longer than after processing 50 independent samples from the sensors.

The paper concerns the problem of recovering N unknown statistically independent non-Gaussian communication signals impinging on the linear array. NSIA method proposed improves the convergence performance in comparison with the algorithms derived by applying the neural networks approach. By selecting an appropriate iteration number one may rich the compromise between the convergence speed and implementation complexity.

SWORD — General Standards For Storing and Processing Waveform Data

* Dr. P. Parhami, J.T. Robinson, SARA, Inc.
Dr. Stu Kelley, Gene Stokes, Defense Nuclear Agency (DNA)

The DNA, as with most DoD and DOE related agencies, have been precluded from effectively utilizing their valuable historical nuclear effects test data. In recognition of this fact, DNA's Data Archival and Retrieval Enhancement (DARE) activity was tasked to collect and make available all historical nuclear-effects data on one data base management system server (with multi-media capability) — accessible through DNA's Wide Area Network.

To assist DARE, SARA has adapted the Scientific Workstation for Operations, Research, and Development (SWORD) architecture for storing nuclear effects waveform data on DARE. SARA's platform independent SWORD architecture is designed to ensure preservation of both measured data and its associated descriptive data, as well as enabling efficient data exchange and analysis. With SWORD, DNA can both preserve, exchange, and acquire data at significantly lower cost.

The SWORD architecture includes **computer platform independent** standards for storing and manipulating waveform data generated by any effects simulator. These standards ensure that all raw, intermediate, and final data products are stored in a single standardized Waveform Interchange File Format (WIFF). In the SWORD architecture, waveform data are stored directly in a database management system (DBMS). Each DBMS record consists of the measured data in compressed form, along with appropriate descriptive labels. All data are stored as a text or large binary data type in the DBMS. Records are imported to and exported from the DBMS as WIFF files. Data are preserved through inclusion of the descriptive labels with the measured data in the WIFF files. **The measured data and its descriptive labels are, therefore, never separated.** Data acquisition, exchange, and analysis efficiencies are achieved through utilization of standardized WIFF files — which, by design, are platform independent. WIFF files can be exchanged transparently between PC, Mac, and UNIX platforms thereby providing for flexibility in choice of database and analysis tools.

SWORD has been selected as a candidate data type for DARE. The standard will be fully implemented in DARE under a Phase II SBIR program and published for general use. The same SWORD standard is currently in use by UK's DRA (see related paper at this conference), B-2 HM/HS program, and DNA's ARES program. As a part of the DARE SBIR program, we will be publishing the SWORD standard and related tools free of charge as a public domain standard on the World Wide Web. SARA has received commitments from a number of DoD organizations for adoption of this standard in their simulator operations.

Monday, May 27, 1:30 PM **Room: Galisteo**

HPEM-5 Electromagnetic Interaction II

Chair: D.T. McGrath, Phillips Laboratory, Kirtland AFB, NM

1:30 PM **INTRODUCTION & ANNOUNCEMENTS**

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1:55 PM **APPLICATION OF NORM CONCEPTS TO EVALUATION OF ELECTROMAGNETIC COUPLING,** *N. SOVEIKO, University of Ottawa, Ontario, Canada; and S.L. PRIMKA, Ben-Gurion University of the Negev, Beer Sheva, Israel* 55

2:15 PM **USING A TEST WIRING AS A FIELD SENSOR IN ELECTROMAGNETIC TOPOLOGY,** *J.P. PARMANTIER, ONERA, Meudon, France* 56

2:35 PM **THE PROCEDURE FOR CALCULATING THE ELECTRODYNAMIC CHARACTERISTICS OF THE WIRE COMPLEX CONFIGURATION ANTENNAS AND THEIR RESPONSE TO THE IMPACT OF PULSED AND HARMONIC ELECTROMAGNETIC FIELDS,** *Y.V. PARFENOV and O.A. TARASOV, Russian Federation Ministry of Defense, Moscow, Russia* 57

2:55 PM **RIGOROUS ANALYSIS METHOD FOR MUTUAL COUPLING BETWEEN COMPLEX ANTENNAS IN FAR OR NEAR FIELDS,** *L. PAGE, M. JOUVET and B. JECKO, Institut de Recherche en Communications Optiques et Microondes, Limoges, France* 58

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3:40 PM **ON THE INCORRECTNESS OF TELEGRAPH EQUATION APPLICATION FOR CALCULATING HEMP-INDUCED CURRENTS ON AERIAL TRANSMISSION LINES,** *V.M. KUVSHINNIKOV and Y.V. PARFENOV, Russian Federation Ministry of Defense, Moscow, Russia* 59

4:00 PM **THE MODELING OF A BOEING 757 AIRCRAFT SUBJECTED TO HIGH INTENSITY RADIATED FIELDS,** *G.J. RIGDEN, Electro Magnetic Applications, Inc., Lakewood, CO* 60

NUMERICAL CALCULATION OF FIELDS AT DISTANT POINTS FROM EQUIVALENT SURFACE SOURCES IN THE PRESENCE OF A LOSSY GROUND

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The time-domain finite difference (TDFD) method has proven to be valuable a valuable tool in many computational electromagnetic problems over the last twenty years. As computer resources have grown, the range of problems addressable by TDFD has correspondingly grown. One of the more current applications is the calculation of the electromagnetic fields generated by an object, as seen at some distant point. These calculations have applications in antenna pattern, radar cross-section, self-generated electromagnetic signature and similar areas. By constructing a detailed numerical model, many specific features of an object's EM characteristics can be examined at a level of detail which is impossible to achieve if one is limited to a more generic model which is analytically soluble.

In the TDFD method, a standard procedure for obtaining EM fields at distant points uses a set of sources on a surface which encloses the object of interest. In this case the finite-difference algorithm is used to calculate the fields emanating from the object and propagating to the equivalent source surface which is inside the calculational volume. The presence of a lossy ground, however, requires the additional calculation of ground reflected fields at the distant points. Because the ground reflections for a finitely conducting ground depend not only on polarization and angle of incidence but also on frequency/time, the additional computer resources required are often prohibitive.

An approximate approach to calculate the reflected fields using the Fresnel reflection coefficients has been developed with only a moderate increase in computer resources. Some features of the implementation are:

- accuracy selectable according to needs of problem and resources available
  - typical error < 5% of reflected field
- frequency range adaptable to problem
  - 1 KHz - ∞
- angular range and granularity adaptable to problem
  - typically 1-89° angle of incidence, interpolation on 5° grid
- Fresnel coefficients calculated in frequency domain
- Fresnel coefficients Fourier transformed to time domain
- Time domain Fresnel response functions approximated by a sum of exponential relaxation functions
- Effective time domain convolution with one backstorage location for each of the exponential functions

Sample results are obtained for a set of lossy ground parameters. Verifying comparisons are made with results obtained using conventional solutions. The range of validity and the computational cost of the approach are discussed.

Application of Norm Concepts to Evaluation of Electromagnetic Coupling

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This paper describes an application of the norm concepts to the evaluation of electromagnetic coupling. Recent developments in this field concentrate on bounding of levels for the solutions of multiconductor transmission line equations [A.Agrawal and C.Baum, Bounding Of Signal Levels At Terminations Of A Multiconductor Transmission-Line Networks, Electromagnetics, vol.8, pp. 375-422, Hemisphere Publishing, 1988] and State Space ODEs [Kontorovich V.Ya., Solution of EMC Problems by System Dynamics Theory, EMC'89 Intl. Symp., Zurich, 1989, p.51-54]. Here we apply an approach which is similar to those in these references to the solution of linear operator equations.

Electromagnetic coupling phenomena are described by linear operatorial equations in Hilbert spaces [D.G.Dudley, Mathematical Foundations for the Electromagnetic Theory, IEEE Press, 1994]. Numerical solutions of such equations involve approximation of linear operator by matrices and the solution of resulting linear matrix equation. The dimension N of these matrix equations tend to be large, with the computational cost of their solution proportional to N^3. Fortunately, in problems regarding EM coupling, the solution will be integrated (summed) to produce the final result, in which case an exact solution of the matrix equation need not be found. Rather it is sufficient simply to estimate an appropriate norm of the solution to the matrix equation. This may be done by obtaining the associated norms of the matrix blocks and solving the resulting linear matrix equation which has a much smaller dimension. The most computationally expensive part of the procedure -- obtaining matrix norms -- has a cost proportional to N^2 in the worst case, where N is the dimension of the original equation.

Numerical experiments showed that computational time can be reduced by several orders of magnitude, preserving reasonable accuracy of estimation. We provide an example for evaluation of microstrip MTL parameters (capacitance matrix) in inhomogeneous media, explain the procedure and compare accuracy and computational cost to the traditional numerical technique (Method of Moments).

Using a test wiring as a field sensor in Electromagnetic Topology

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In the past few years, many studies have demonstrated that Electromagnetic Topology (EMT) could be used to help for the ***EM design*** of systems. As an example, ONERA developed a numerical code, named CRIPTE, based on EMT concepts. Since 1991, in the frequency range from DC up to 1 GHz, the code, mainly based on the multiconductor transmission line formalism, has been particularly helpful to simulate EM coupling on ***complex wiring***. It has been validated on several models and, recently, on the EMPTAC aircraft (collaboration between ONERA, CEG and Philipps Laboratory). Nowadays, under the name "WINCRIPTE" (because of a graphical adaptation), several French companies begin to use it in their programs. Furthermore, in the context of experiments, CRIPTE code also proved that it could be a convenient tool to help to the understanding of EM coupling on real systems. Indeed, engineers can use all the capability of the code to model cable harness networks and to breakdown their problems in subnetworks, according to EMT concepts.

In the EMT theory, ***source terms*** are modelled with per unit length series voltage and parallel current generators, distributed all along the cable topological models (tubes). These source models are very well adapted to describe any kind of EM excitations and particularly, EM field illuminations. In this case, several models derive these generators from the ***incident fields*** applied on the cable (Agrawal, Taylor, Rachidi). The important point to remember is that "incident fields" means "the fields in the absence of the wiring". Consequently, provided that the fields are determined on the running way of the wiring, these fields can be used, whatever the number of elementary wires and terminal loads are in the wiring. ***Agrawal's model*** is especially attractive because the source terms description is limited to voltage generators, which are equal to the incident tangential fields on the wiring location. Nevertheless, one of the main problems of topological simulations remains to introduce the good values of source terms into the models because these ones, coming from the scattering inside the whole structure, may generally appear very complex.. A numerical solution is to calculate these terms with ***3D codes*** (as an example, CRIPTE code is linked to ONERA's ALICE FDTD code). But during an experiment, such 3D codes are not available because they require high performance computers which cannot run in real time whereas a cable network code does.

Consequently, we propose an ***experimental method***, based on the use of a ***test wiring***, to determine the equivalent source distribution along the running way of the cable network. As source terms do not depend on the wiring, the simplest wiring must be chosen as a test wiring. Generally, this one will be made of only one wire. The most precise procedure is to remove the actual wiring and replace it, at the same place inside the structure, by the test wiring. But, under certain conditions, other simpler procedures may still give good results. For example, the test wiring can be installed onto the existing wiring or can be chosen inside the existing wiring. The numerical treatment deals in a first step, to perform current measurements all along the test wiring and, in a second step, to calculate the response of the test wiring to localised voltage generators. The "in situ" voltage generator distribution, according to Agrawal's model, is then derived from the resolution of an ***inverse problem***, producing the same currents as the ones measured.

The talk will present the formalism of the test wiring method, the numerical and experimental validations which have been performed with CRIPTE code, its limitations and the perspectives of the study.

THE PROCEDURE FOR THE CALCULATING THE ELECTRODYNAMIC CHARACTERISTICS OF THE WIRE COMPLEX CONFIGURATION ANTENNAS AND THEIR RESPONSE TO THE IMPACT OF PULSED AND HARMONIC ELECTROMAGNETIC FIELDS

V.V. Parfenov, O.A. Tarasov*
Russian Federation Ministry of Defense

The calculational procedure "Impulse-A" has been developed, based on the correct solution of the Fredholm equation of the first kind in a space - frequency representation by a regularization method which gurantees obtaining a stable solution in contradistinction to the techniques using approximate kernel of a integral equation. In Table 1 we present computed results for real and imaginary current components on input of the symmetric half-wave vibrator of length = 1m and the radius of a conductor = 0.014m in exciting it by delta-generator. These results demonstrate errors in determining imaginary component of current in using approximate kernel. The procedure "Impulse-A" also allows one to calculate the antenna electrodynamic characteristics, responses to pulsed field effects and to calculate fields radiated by antennas. Figures illustrate examples of calculation of current amplitude-time characteristics for 50-ohm load of asymmetric cylinder helical antenna with the radius of a turn = 0.035m, the pitch of a turn =0.05m, the radius of a conductor = 0.001m, the number of turns = 3 at axial (fig.1) and side (fig.2) incidence of pulsed electromagnetic field (fig.3). In addition, figures show amplitude-time characteristics of a generator exciting helical antenna with abovementioned parameters (fig.4) and of electromagnetic field components Ex (fig.5) and Ey (fig.6) radiated by antenna in axial direction.

Table 1

Number of vibrator partition points	Procedure using approximate kernel	Procedure "Impulse-A"
21	(0.00858,-0.00318)	(0.00883,-0.00338)
61	(0.00804,-0.00168)	(0.00855,-0.00309)
141	(0.00766, 0.01783)	(0.00846,-0.00292)
341	(0.00743, 0.15133)	(0.00843,-0.00282)

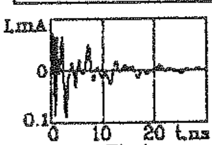

Fig.1

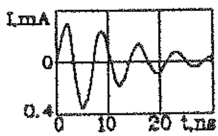

Fig.2

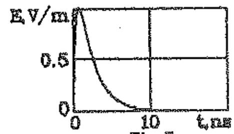

Fig.3

Fig.4

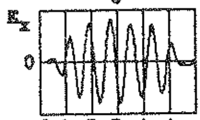

Fig.5

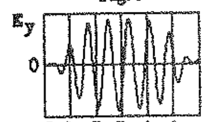

Fig.6

RIGOROUS ANALYSIS METHOD FOR MUTUAL COUPLING BETWEEN COMPLEX ANTENNAS IN FAR OR NEAR FIELDS

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In many applications, it is necessary to know the mutual coupling between antennas. On the structure of interest, (a radioaltimeter) the transmitting and receiving antennas are not located on the same dielectric substrate. They lie on a conducting plane, distant from each other by one or several wavelengths. The F.D.T.D. method is very useful to model real printed antennas, particularly the limited dielectric substrate, but in this case the region near the antennas is too large to be studied by this method.

The main principle of the ***Hybrid Method*** used for this analysis is to associate two techniques to compute the electromagnetic fields in two separate regions:

- near the transmitting and receiving antenna for the F.D.T.D. method,
- in the region between these antennas for the time-domain electromagnetic field integral form computating.

The Hybrid Method is composed of three distinct steps:

- Fig. 1.(a) shows the electric and magnetic equivalent surface current densities $(\vec{J}_T, \vec{M}_T)$ located on a closed area Σ_1 surrounding the transmitting antenna (in this example, a dipole antenna). These sources are deduced from the electric and magnetic fields computed by the F.D.T.D. method near the antenna.
- In Fig. 1.(b), the electric and magnetic fields radiated by each surface current $(\vec{J}_T, \vec{M}_T)$ are computed at several points of an imaginary area Σ_2 located near the receiving dipole antenna. These fields are obtained by Time Domain Integral form computing. Electric and magnetic surface current densities created on the Σ_2 area are easily deduced $(\vec{J}_R = \vec{n} \wedge \vec{H}_R \text{ et } \vec{M}_R = -\vec{n} \wedge \vec{E}_R)$.
- In Fig. 1.(c), $(\vec{J}_R, \vec{M}_R)$ equivalent densities illuminate the receiving antenna .

The current induced in the adapted load of the receiving antenna $i_2(t)$ and the feed current of the transmitting antenna $i_1(t)$ are computed by Fourier Transform $(I_1(f), I_2(f))$.

The transmission coefficient between these two antennas is deduced: $S_{21} = I_2(f)/I_1(f)$

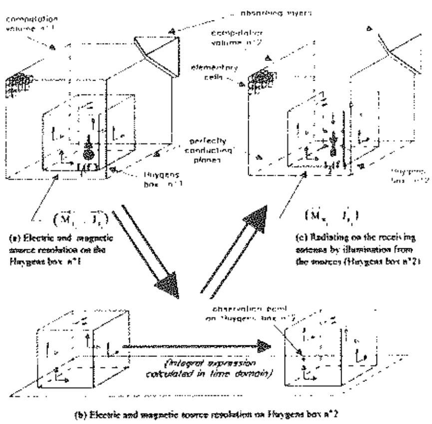

Figure 1: The Hybrid Method principle

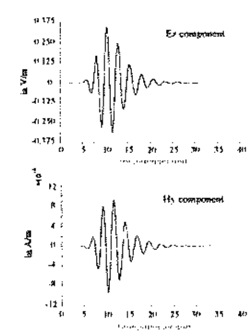

Figure 2: Comparison of the main components of the electric and magnetic fields at the observation point on Huygens box n°2 (ex: Ez and Hy components), between: the F.D.T.D method; the Hybrid Method; the Integral equations method.

The Hybrid Method gives good results compared to other methods (Figure 2) for the electromagnetic field calculation. The advantages of this technique are that we don't model the whole computation volume and that it could be applied to microstrip patch antennas.

ON THE INCORRECTNESS OF TELEGRAPH EQUATION APPLICATION FOR CALCULATING HEMP-INDUCED CURRENTS ON AERIAL TRANSMISSION LINES

V.M.KUVSHINNIKOV*, Yu.V.PARFENOV
Russian Federation Ministry of Defense

It is known that high-altitude nuclear explosions induce currents and voltages of the largest magnitude on lines disposed approximately in the incident EMP plane at large distances from the burst point.

Based on the problem solution analysis on interaction between the vertically polarized EMP and the infinite long wire elevated at height (h) above the ground with finite conductivity (σ) and permittivity (ϵ), it is shown in this paper that all calculations of the induced current amplitudes on lines performed, by solving telegraph equations for indicated situations at real soil conductivities turn out to be underestimated by about 2 times and more (Fig.1). As the elevation angle (ϑ) decreases the discrepancy between results increases and is estimated to be of the order $(\sin\vartheta)^{-1/2}$ times.

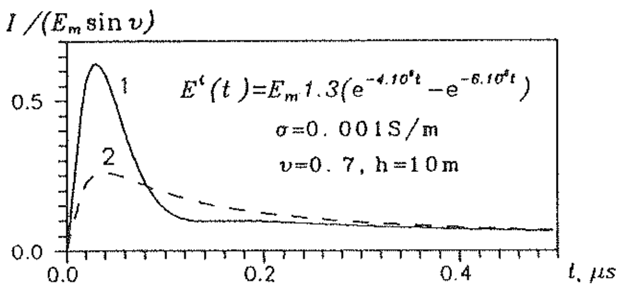

Fig.1. Current impulse in a wire (I):
1—exact solution, 2—telegraph equations

In the domain of the current-induced amlitude formation the wire impedance (Z) is determined from the soil resistance

$$Z \sim \frac{(\sin\vartheta)^{1/2}}{\sin\vartheta + (\epsilon' - 1)^{1/2}} . \qquad (1)$$

In this domain longitudinal gradients of scattered fields are significantly larger than transverse ones and telegraph equations become incorrect since their formulation assumes inverse relation of gradients. However the telegraph equations may be used in this domain if one takes into account the relation (1) in the wire impedance calculations.

Resposibility for publishing work authenticity rests entirely with the autors.

THE MODELING OF A BOEING 757 AIRCRAFT SUBJECTED TO HIGH INTENSITY RADIATED FIELDS

by
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This effort is a product of the NASA Fly-by-light/Power-by-wire (FBL/PBW) program which was initiated to develop technology for a future generation of commercial transport aircraft. A major objective of this program is to develop tools and techniques for assessing the survivability of modern aircraft using FBL/PBW equipment in high intensity radiated environments (HIRF). These tools and techniques involve numerical methods which must be experimentally validated. This effort thus involved numerical modeling of a Boeing 757 commercial aircraft subjected to HIRF where the results were compared with experimental data obtained during on-ground and fly-by tests. The fly-by tests were done by flying near on-the-ground transmitting sources in the HF, VHF, and UHF frequency bands. Experimental data consisted of interior aircraft current and voltages on wires and cables along with exterior and interior electric fields. The numerical model involved the obtainment of structural aircraft information from CAD files in the IGES format. The model was created, meshed, numerically subjected to various HIRF environments and the results analyzed via a post-processor within the framework of EMA's commercially available finite difference software package titled, 'EMA3D'. The Boeing 757 finite difference model was grided to a cell dimension of five inches to accurately resolve internal structures. A five inch resolution is capable of resolving HIRF frequencies to an upper limit of 300 MHz. This enabled the calculation of numerical results directly comparable to the experimental results associated with transmitting sources in the HF and VHF frequency bands.

Monday, May 27, 1:30 PM **Room: Brazos**

UWB, SP-3 Antennas II

CoChairs: E.L. Mokole, Naval Research Laboratory, Washington, D.C.
E. Farr, Farr Research, Albuquerque, NM

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2:15 PM **A UNIFIED ANTENNA PARAMETRIZATION IN THE TIME AND FREQUENCY DOMAINS,** *A. SHLIVINSKI, E. HEYMAN and R. KASTNER, Tel-Aviv University, Tel-Aviv, Israel* 64

2:35 PM **TRANSIENT FIELDS OF PARABOLIC REFLECTOR ANTENNAS,** *S.P. SKULKIN and V.I. TURCHIN, Radiophysical Research Institute, Novgorod, Russia* 65

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3:40 PM **TRANSIENT ARRAYS,** *C.E. BAUM, Phillips Laboratory, Kirtland AFB, NM* 67

4:00 PM **PROPERTIES OF ULTRAWIDEBAND ARRAYS,** *J.L. SCHWARTZ and B.D. STEINBERG, University of Pennsylvania, Philadelphia, PA* 68

4:20 PM **ASYMPTOTIC APPROXIMATIONS FOR OPTIMAL CONFORMAL ANTENNAS,** *T.S. ANGELL and R.E. KLEINMAN, Center for the Mathematics of Waves, Dept. of Math Sciences, University of Delaware, Newark, DE; and B. VAINBERG, Dept. of Mathematical Sciences, University of North Carolina, Charlotte, NC* 69

SOME BASIC PROPERTIES OF ANTENNAS ASSOCIATED WITH ULTRAWIDEBAND RADIATION

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WASHINGTON, DC 20375-5336

Before selecting, designing, or analyzing ultrawideband (UWB) radiators, one must understand the how and why of broadbandedness of antenna elements that are thought to be UWB. The UWB behavior of a radiator is well defined by its short-pulse response. In an ideal situation, when excited by a short pulse, an UWB antenna should be capable of radiating a distortionless replica of that pulse. Alternatively, an ideal distortionless replica is obtained from a mathematical standpoint when the antenna's transfer function has linear phase and frequency-independent magnitude.

To achieve the aforementioned understanding of the fundamental characterictics of UWB radiation, a study of the behavior of the radiated and received pulses associated with thin half-wave dipoles under a zero-order approximation to the induced current is made. Although a thin dipole, a low-gain element, usually is not considered to be a broadband antenna, its distortion of a single-cycle is not too great and is certainly quantifiable. In particular, a closed-form expression for the field is derived, the duration of the input signal is increased by 50%, and the number of zero crossings increases from 3 to 5. It is found that the temporal distortion and stretching of the excitation is caused by radiation from the discontinuities at the dipole's endpoints and from a delayed radiation at its feed point induced by reflections from the endpoints. This study of a simple radiating structure shows the following:

(i) An infinitely long dipole can radiate the exciting input pulse without any distortion, since the distortion is caused by the radiations and reflections from the antenna's discontinuities, which are the nonexistent endpoints. Therefore, if by some artifice, the reflections and radiations from the endpoints of a finite antenna could be prevented, the exciting input pulse would be radiated without distortion. In other words, a relatively narrowband dipole would perform as an UWB radiator.

(ii) Frequency-domain analysis of the dipole, as well as other narrowband antennas, suggests that the primary reason for narrowband behavior of an antenna is the rapid variation of its input impedance with frequency. Thus one infers that the cause of such variations is mainly due to the reflection of the exciting signal from the radiator's discontinuities.

The preceding observations suggest: if either by some artificial means (such as loading) or by suitable shaping of an antenna the reflections from its discontinuities can be eliminated or at least minimized, the antenna becomes UWB. Since radiation and reflection take place at a radiator's discontinuities, one may infer that if both the current and voltage along a given antenna can be represented by continuous functions within an open region on the antenna surface, neither radiation nor reflection will occur from such a region. In other words, since all antennas are finite and have discontinuities, the exciting pulse cannot be radiated without distortion.

In addition to the study of the radiating and receiving mechanisms of thin half-wave dipoles, similar investigations are made for wide-angle bicones having unequal cone angles when subjected to short-pulse excitations. Furthermore, the possibility of radiating and receiving circularly polarized sinusoidal pulses involving a pair of orthogonal dipoles are examined.

Generation of Wideband Antenna Performance by [Z] and [Y] Matrix Interpolation in Method of Moments

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Designing antennas for radar and communications applications often requires the evaluation of the antenna's wide band operation capabilities. Identifying the appropriate electromagnetic modeling tools of these antennas can be quite challenging, since such antennas come in diverse configurations that range from thin-wire type antennas to complex surface structures such as spiral and bow-tie antennas. The triangular surface patch Method of Moments (MoM) formulation is one popular modeling approach. The surface patches allow curved and flared boundaries to be modeled by a linear approximation of the boundary and detailed features to be modeled with a locally dense mesh. Since the elements of the MoM impedance matrix, or [Z], must be recomputed for each new frequency point, the computation of antenna performance over a wide frequency range can become computationally very time consuming

This paper discusses the efficient computation of the performance of wideband antennas using the methodologies based on the frequency interpolation of the [Z] (*E. H. Newman, IEEE Trans. AP-36, pp. 1820-1822, 1988*) and [Y] matrices. There are distinct differences between the [Z] and [Y] matrix interpolation techniques. The elements of [Z] vary slowly with frequency while the elements of [Y] fluctuate rapidly and are sensitive to the location of the antenna resonant frequencies (*K. L. Virga and Y. Rahmat-Samii, 1995 IEEE APS Symposium Digest, pp. 1262-1265*). The elements of [Z] can be interpolated by simple interpolation functions, such as a quadratic, while the interpolation of the elements of [Y] require complex functions. The use of rational functions to represent the elements of the [Y] matrix has been considered. The rational function representing [Y] can be written as a ratio of two polynomials of higher orders (*Burke et. al, IEEE Trans. Magn., pp. 2807-2809, 1989*). The coefficients of these polynomials can typically be determined by several frequency samples or by the higher order derivatives of the function at one frequency.

Both the [Z] and [Y] matrix interpolation are used with the method of moments in order to significantly reduce the computation time required to evaluate the computation of the antenna performance over a wide bandwidth. A comparison of the simulation run times will be given. The methods will be used to analyze the performance of various representative wideband antennas. One particular application addresses the analysis of antenna characteristics for short pulse radiation. The time domain response is determined by performing an inverse Fourier transform on the frequency domain data.

Unified Antenna Parametrization in the Time and Frequency Domains

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Tel Aviv University, Tel Aviv 69978, Israel

Recently (A. Shlivinski, E. Heyman and R. Kastner, 1995 URSI Meeting), a full set of antenna parameters in the time domain (TD) has been presented in the context of a complete transmit-receive system representation. The theory has been derived entirely in the TD field equations. In this work, a more refined version of the parameters is presented, with the transmitting and receiving effective heights being defined with respect to incident or reflected currents and voltages at the antenna terminals, as opposed to terminal currents or open circuit voltages. Modification of the frequency domain (FD) definitions provides a unified system representation. Central to this TD development is the evaluation of the transmitting effective height $\mathbf{h}^t(\hat{\mathbf{r}},t)$ by the Slant Stack Transform (SST) of the time dependent current distribution, in the manner equivalent to the FD Fourier transform evaluation of the far field. TD reciprocity then leads to the interrelation of the receiving and the transmitting effective heights by a temporal integration. The vector autocorrelation of the transmitting effective height, denoted $\mathcal{R}_{h^t}(\hat{\mathbf{r}},\xi)$, is then used to define the time dependent gain operator under impulsive source excitation as $\mathbf{g}^t(\hat{\mathbf{r}},\xi)=\frac{1}{4\pi c^2}\frac{\eta}{Z_0}\mathcal{R}_{h^t}(\hat{\mathbf{r}},\xi)$, where Z_0 is the line impedance at the antenna port and $\eta=\sqrt{\mu/\varepsilon}$. $\mathbf{g}^t$ is incorporated in the following TD Friis-like operator

$$f(\xi)=-(c/2r)^2\,\mathbf{g}_T^t(\hat{\mathbf{r}}_{TR},\xi)*\mathbf{g}_R^t(\hat{\mathbf{r}}_{RT},\xi)\partial_t^{-2}, \tag{1}$$

such that the ratio between the energy transmitted to the receiver load, $\mathcal{E}_L$, to $\mathcal{E}_R$, the maximum energy available at the source, is $\mathcal{E}_L/\mathcal{E}_R=f(\xi)*\bar{\mathcal{R}}_{v_g}(\xi)\big|_{\xi=0}$. Here, $\bar{\mathcal{R}}_{v_g}(\xi)$ is the autocorrelation of the source pulse, normalized to a unit energy. Upon Fourier transforming (1), we reconstruct an FD (Friis) multiplicative operator

$$F(\omega)=-(c/2r)^2\,\mathbf{G}_T^t(\hat{\mathbf{r}},\omega)\cdot\mathbf{G}_R^t(\hat{\mathbf{r}},\omega)(-i\omega)^{-2} \tag{2}$$

which is seen to operate on the power spectrum of the source. Integration of (2) over ω then yields the total energy ratio. In this way, the TD and FD representations have been unified. The aforementioned succession of concepts will be demonstrated for the example of a short antenna.

Transient fields of parabolic reflector antennas

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Institute of Applied Physics, Nizhny Novgorod, Russia

Introduction

A number of applications require to calculate radiation of a short pulses at different distances before the reflector. The basic theory of an impulse radiating antenna (IRA) was given by Carl E. Baum and others (*C. E. Baum, in book U-WB, SP Electromagnetics, Plenum Press, pp. 139-147, 1993; D.V. Giri and C. E. Baum, Sensor and Simulation note 365, February 2 1994.*). IRA, usually considered in those papers, consists of a conical TEM feed that attaches to a reflector antenna. Another technique to calculate transient fields from circular plane aperture was described in (*S. P. Skulkin, V. I. Turchin, Proc. EUROEM '94 Symposium, France, pp. 1498-1504, 1994*). But some applications require to have more accurate space-time distributions of near-field. For instance, it is necessary for near-field measurements of antennas (*S. P. Skulkin, V. I. Turchin, et al., Radiophysics and quantum electronics, 32, no. 1, pp. 61-70, 1989*) and scattering of objects . In these cases, it is important to describe the transient fields from parabolic reflector antennas taking into account the polarization effects and the shape of the antenna.

The method

The paper based on the method of transient field calculation [5]. Here we use the assumption that short pulse is radiated by a small feed (electrical dipole) that attaches to a reflector antenna. We also assume that antenna diameter is much more than maximal wavelength respective to the minimal frequency of the pulse spectrum. In this case the reflector surface current can be calculated only by the use of the feed magnetic field. The strict formulas were obtained for field in the half-space before the antenna. We compare calculation results for parabolic reflector, circular plane aperture and results of measurements of transient fields from 7 meters parabolic reflector antenna. We also discuss the influence of feeder operation frequency band to the space-time field distribution.

Results and Conclusions

We illustrate that the structure of the spatial-temporal field distribution is quit complex, especially in the near-field region. We show that in this region there is a big difference between transient fields of parabolic antennas and plane aperture and we discuss the nature of this effect.

The method described is also useful for the monochromatic field calculation, first off all, in the cases when plane wave spectrum (PWS) approach, used usually, is of some uncertainty due to evanescent PWS in the near zone and in the Fresnel zone, and due to the domains of the integrand high oscillations in the neighbourhood of aperture axis.

Transient Fields of Rectangular Aperture Antennas

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Introduction

Transient field properties of impulse radiating antennas (IRA) were described predominantly for reflector antennas with circular aperture (C. E. Baum, in book U-WB, SP Electromagnetics, Plenum Press, pp. 139-147, 1993). However, the shape of aperture changes completely the spatial-temporal field distribution. The goals of the paper are to describe the transient fields of rectangular aperture and to compare these results with results obtained for circular aperture (S. P. Skulkin, V. I. Turchin, Proc. EUROEM '94 Symposium, France, pp. 1498-1504, 1994).

The method

When we derive the explicit formulas of transient field of a rectangular planar aperture, we use the assumption that the δ-pulse is radiated by each point of the aperture. We write the integral up to terms decreasing as $1/r$ (here r is the distance between the antenna and observation points) and we take into account the inphase of radiating surface and the reflector dimensions being much more than the wavelength. The use of δ-function in the integrand makes it possible to come from a two dimensional integral to one-dimensional one over a line of cross-section of the radiating surface and a sphere. Results are presented in elementary functions. We analyse PRC in near and far zones. The theoretical and experimental results are compared. We compare the spatial-temporal field distributions for rectangular and circular apertures.

Conclusions

We show that a rectangular aperture response in near-field region consists of several pulses, whereas for circular aperture antennas this number of pulses is limited by 2. For the both aperture shapes the initial pulse is shortest and has the maximal magnitude.

The method proposed is also useful for the monochromatic field calculation, because for field computation we use a one dimensional Fourier - transformation of the strict formulas expressed in elementary functions that allows one to simplify the estimation of the temporal sampling and provides any precision required.

TRANSIENT ARRAYS

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Arrays for radiating large fast electromagnetic pulses are an outgrowth of nuclear EMP simulation technology. Here the question was how launch TEM waves (planar or spherical) over large apertures (meters) with high voltages (megavolts) and fast risetimes (nanoseconds). In this case the aperture source distributions were made to match the appropriate TEM modal distributions (in general nonuniform) corresponding to cylindrical or conical transmission lines. Note that while the highest frequencies in the pulse restrict the size of individual elements of the array, it was recognized ab initio that the elements had to be connected together in a manner to pass low-frequency currents through the array and thereby produce the low-frequency portions of the pulse.

Large transient arrays were also considered in the same time frame for radiating unguided waves with otherwise similar parameters. Using unit cells based on interconnected conical transmission lines (TEM horns) various symmetries can be imposed on the array based on the two-dimensional space groups. Among the possibilities are unit cells based on squares, regular hexagons, and equilateral triangles.

In a more modern context transient arrays are being considered for applications in which subnanosecond-risetime pulses are to be applied to the array elements to make an impulse radiating antenna (IRA) with performance similar to reflector IRAs and lens IRAs. The benefit to be gained (say for radar applications) is the ability to electronically steer the beam. However, this benefit is gained at the cost of greater complexity due to the large number of array elements and the requirement for accurate rapidly adjustable times for triggering the individual elements (sources). There is a significant trade off between the scan angle for the beam and the element size, risetime and angle between the TEM-horn conductors. In addition, as in the cases of other types of IRAs, an array IRA can be designed with auxiliary conductors and resistors to match the low frequency electric- and magnetic-dipole moments so as to give some desirable low-frequency directivity to the beam.

PROPERTIES OF ULTRAWIDEBAND ARRAYS

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Highly thinned or sparsely filled arrays can reduce the quantity of electronics supporting the array and the data-handling requirements of an imaging system for a fixed number of array channels, greatly enlarge the aperture, and correspondingly improve its resolving power. It is well-known that the cost is a dramatic decrease in dynamic range, or contrast. Aperture thinning generally leaves the shapes of the main lobe and near-in sidelobes intact, but the loss in absolute gain implies that main lobe energy has been redistributed into the side radiation region. In conventional narrowband arrays, periodic thinning produces grating lobes of similar shape and strength to the main lobe. Aperiodic thinning destroys the coherent sidelobe buildup in the grating lobes but not the grating lobe energy, which becomes distributed throughout the visible region in a manner determined by the particular thinning procedure. It is common knowledge that sidelobe statistics are similar for a wide variety of thinning procedures, both deterministic and random, with a few notable exceptions [1]. Thus many proposed designs for high resolution two-dimensional arrays are based upon a random distribution of elements [2].

Current technology in ultrasound and electromagetics is now able to construct radiating array elements that can transmit a high energy pulse which has only two or three cycles. The corresponding arrays are called ultrawideband (UWB) arrays. In a highly thinned UWB array, the distribution of side energy is very different from conventional narrowband (NB) arrays. Due to the UWB nature of the pulse, the radiated waveform from these arrays at any point in space varies in time. As a result, the waveform has an extra dimension with respect to NB across which undesired side energy can be distributed. UWB arrays can be highly thinned and achieve a much lower side energy level than NB arrays. A method for characterizing ultrasparse, ultrawideband one- and two-dimensional arrays will be presented. Contrary to conventional wisdom, this analysis shows that in a highly thinned UWB array, a periodic array gives a lower side energy level than the random array.

[1] B.D. Steinberg, <u>Principles of Aperture and Array System Design: Including Random and Adaptive Arrays</u>, John Wiley and Sons, Inc., New York, 1976.
[2] D.H. Turnbull, P.K.Lum, A.T.Kerr, F.S. Foster,"Simulation of B-Scan Images from Two-Dimensional Transducer Arrays:Part1: Methods and Quantitative Contrast Measurements,"Ultrasonic Imaging, 14, 1992.

ASYMPTOTIC APPROXIMATIONS FOR OPTIMAL CONFORMAL ANTENNAS

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In earlier work, we have given constructive methods to compute the surface currents on a conformal antenna which is required to radiate a maximal amount of energy into a predetermined sector of the far field. The resulting optimization problem was considered as a constrained optimization problem with constraints on the set of input currents which reflected certain physical limitations.

Recently, the authors have used asymptotic methods to compute approximate optimal surface currents in the time harmonic two-dimensional electromagnetic case (the Helmholtz equation with impedance boundary condition), for the case of high frequency. The analysis is complicated by the fact that we are dealing simultaneously with two large parameters, both the wave number k and the position $\mathbf{x}$. Moreover the radiation pattern is related to the current distribution through either the Dirichlet–to–Neumann or Neumann–to–Dirichlet map (depending on the polarization) on the antenna surface. In general these maps are not known explicitly. However our work effectively constructs these maps at high frequencies for convex surfaces.

The analysis involves defining a related time dependent problem which approaches the original problem for large time in a way very different from the Fourier transform of the frequency domain problem. The distinguishing feature of this new formulation is that the large time behavior corresponds to the high frequency behavior of the time harmonic problem rather than the low frequency behavior as is the case in the usual time dependent formulation. By applying the principle of limiting amplitude, we succeed in obtaining the high frequency characterization of the Green's function for the problem and then an explicit form for an approximation to the optimal current.

In the present work, we extend these asymptotic results to the full three–dimensional time–harmonic electromagnetic case. We obtain a representation of the suboptimal current which explicitly shows the dependence on the total curvature of the radiating structure at each point, $\kappa(\mathbf{x})$. Specific computations are carried out for some canonical shapes.

Monday, May 27, 1:30 PM **Room: Cimarron**

UWB, SP-4 **Topics in UWB**

CoChairs: L. Felsen, Boston University, Boston, MA
E. Heyman, Tel-Aviv University, Tel-Aviv, Israel

1:30 PM **INTRODUCTION & ANNOUNCEMENTS**

1:35 PM **REGULATORY HURDLES FOR ULTRA-WIDEBAND TECHNOLOGY,** *A.W. CLEGG, Naval Research Laboratory, Washington, D.C.* 72

1:55 PM **SHORT-PULSE RADAR VIA ELECTROMAGNETIC WAVELETS,** *G. KAISER, University of Massachusetts-Lowell, Lowell, MA* 73

2:15 PM **TIME-DOMAIN FAR FIELDS,** *A.D. YAGHJIAN, Rome Laboratory, Hanscom AFB, MA* 74

2:35 PM **CONSERVATION OF POWER IN THE GALERKIN APPROXIMATION OF THE ELECTRIC FIELD INTEGRAL EQUATION,** *S.M. BOOKER, New Jersey Institute of Technology, Newark, NJ* 75

2:55 PM **INVERSE PROBLEMS FOR A PERTURBED DISSIPATIVE HALF-SPACE,** *M. CHENEY and D. ISAACSON, Rensselaer Polytechnic Institute, Troy, NY* 76

REGULATORY HURDLES FOR ULTRA-WIDEBAND TECHNOLOGY

Andrew W. Clegg, Naval Research Laboratory

By definition, ultra-wideband signals require enormous spectrum space; however, the radio spectrum is a precious and limited natural resource. Recent events such as the multi-billion dollar FCC license auctions, the loss of hundreds of megahertz of exclusive government spectrum, and the downsizing and possible elimination of the Federal government spectrum management authority, have underscored the value and vulnerability of radio spectrum space for Government R&D. Because the radio spectrum is allocated in relatively small blocks to a variety of radio services, UWB systems currently have no regulatory basis for routine operation in the national and international spectrum management process.

In the United States, Federal government use of the radio spectrum is regulated by the National Telecommunications and Information Administration (NTIA), part of the Commerce Department. The NTIA has established a working group to investigate UWB systems and how to integrate them into the current regulatory environment. Several basic questions are being addressed, including:

- What is the definition of a UWB signal? One proposal calls for defining UWB as any signal that cannot be transmitted solely within a single spectrum allocation block.
- What is the level of interference from UWB signals to existing communications systems? Although the power spectral flux density is typically low (due to the wide bandwidth), informal tests have shown that UWB systems can produce noticeable levels of interference to common devices such as television sets.
- What is the level of use expected of UWB systems? Coordinating spectrum sharing requirements for use of a UWB system on an infrequent basis is fairly simple. However, UWB systems are very useful for a variety of Government and industrial applications such as remote sensing, target detection, and underground probing, so their use may become widespread.

The purpose of this presentation is to raise awareness of spectrum management hurdles facing UWB development--hurdles that are as real and challenging as any technical difficulties encountered in UWB research and development.

SHORT-PULSE RADAR VIA ELECTROMAGNETIC WAVELETS

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ABSTRACT

The new theory of electromagnetic wavelets makes it possible to perform radar analysis directly in the space-time domain, based on the fundamental principles underlying the emission, reflection and reception of electromagnetic waves. (See G. Kaiser, *A Friendly Guide to Wavelets*, Birkhäuser, 1994, and *IEEE Antennas and Propagation Magazine*, February, 1996). Being independent of the Fourier transform and even of the usual (affine) wavelet transform, this formalism is therefore equally valid for ultrawideband or short-pulse radar as for narrowband or continuous-wave radar. However, Fourier analysis does have a natural place in this theory and can be used as usual to analyze resonances in the return.

A transmitting antenna following an arbitrary (possibly accelerating or nonlinear) trajectory $\alpha(t)$ emits an electromagnetic wavelet which is propagated in space by the appropriate causal Green function. This defines an *emission operator* E_α which, acting on any time signal $\psi(t)$, gives the emitted space-time wave $(E_\alpha\psi)(\mathbf{r}, t)$. The *reception operator* is the dual of E_α, measuring a given space-time wave $F(\mathbf{r}, t)$ along the given antenna trajectory $\alpha(t)$ to give the received time signal $(R_\alpha F)(t)$. Reflection is modeled as reception followed by re-emission, i.e., by the operator $E_\alpha R_\alpha$ transforming space-time waves to space-time waves. Let the receiving antenna follow another arbitrary trajectory $\gamma(t)$ (possibly different from the trajectory $\alpha(t)$ of the transmitter), let the target follow a third (arbitrary and unknown) trajectory $\beta_0(t)$, and let the transmitted and received signals be $\psi(t)$ and $\chi(t)$, respectively. The objective is to estimate the target trajectory $\beta_0(t)$ from a knowledge of $\alpha(t), \gamma(t), \psi(t)$ and $\chi(t)$. This is achieved by maximizing the *ambiguity functional* $\tilde{\chi}[\beta]$, obtained by matching the actual return $\chi(t)$ with the *computed* return due to a *trial trajectory* $\beta(t)$. When the radar is monostatic and the target is assumed to move uniformly in the line of sight, then $\tilde{\chi}[\beta]$ reduces to the usual *wideband ambiguity function*, which is just the ordinary wavelet transform of $\chi(t)$ with respect to the wavelet family obtained by applying translations and dilations to $\psi(t)$. In the narrowband approximation, it reduces further to the usual time-frequency ambiguity function, which is a windowed Fourier transform of the video signal of the return.

Time-Domain Far Fields

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The far-field characteristics of classical electromagnetic fields satisfying Maxwell's equations have been investigated quite thoroughly for sources radiating at a single frequency, that is, for frequency-domain or time-harmonic fields. For example, frequency-domain far fields radiated by finite sources in a volume of finite extent decay as $1/r$ or faster as the distance r to the far field approaches infinity. In addition, these far fields are analytic functions of their angular variables θ and ϕ. Using a plane-wave decomposition, frequency-domain near fields can be expressed as an integral over the far-field pattern and its analytic continuation to complex angles of observation.

The characteristics of time-domain far fields, that is, the far fields of electromagnetic sources that turn on and off in a finite time interval, have not been investigated nearly as thoroughly as those of frequency-domain far fields. Thus, the purpose of this paper is to derive some of the characteristics of time-domain far fields and to concentrate on those characteristics that are unique to the time domain.

Sufficient conditions are given on the source current that ensure the time-domain far fields will decay as $1/r$ or faster as $r \to \infty$. When these conditions are not satisfied, slower than $1/r$ far-field decay can occur and, in particular, the necessary conditions are derived in for the existence of "electromagnetic missiles," far-field pulses with energy decay slower than $1/r^2$.

Like the frequency-domain fields, the time-domain near fields can be expressed as an integral of the time-domain far-field pattern over real and complex angles of observation. However, after all sources are turned off, the time-domain fields throughout all space can be written as an integral of the far-field pattern over real angles of observation only.

It is also shown that under very general conditions, satisfied by all physically realizable fields, the time-domain far-field pattern, like the frequency-domain far-field pattern, is an analytic function of its angular variables θ and ϕ. Moreover, it is shown that time-domain far fields with zero sidelobes cannot be excited by finite sources in a finite region of space.

Finally, it is proven that there are also restrictions on the time dependence of electromagnetic far fields. Namely, the integral over all time of the far electric and magnetic fields must be zero for sources that turn on and off in a finite time interval.

CONSERVATION OF POWER IN THE GALERKIN APPROXIMATION OF THE ELECTRIC FIELD INTEGRAL EQUATION

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The problem of transient scattering from an arbitrary surface may be solved using a time-marching algorithm based on the electric field integral equation (EFIE). Such approaches are derived from a Galerkin approximation of the EFIE; see for example (S. M. Rao & D. R. Wilton, IEEE Trans. AP-39, 56-61, 1991). In the case of a perfectly conducting surface the EFIE is a first kind integral equation and the computed solution is prone to numerical instabilities, which rapidly obscure the desired transient response. The suppression of such instabilities is a significant problem in the design of numerical methods based on the time-domain EFIE. It has been shown (B. P. Rynne & P. D. Smith, J.E.W.A. 4, 1181-1205, 1990) that temporal averaging of the computed surface currents can help to suppress such instabilities. It has also been shown that, for surfaces of finite conductivity, it is possible to pose the EFIE as a second kind integral equation (Booker et al, Proc. URSI International Symposium on EM Theory, 480-482, 1995), a formulation which is less prone to numerical instability.

In this paper the design of novel numerical algorithms based on a Galerkin approximation of the time-domain EFIE is considered. These algorithms are applicable to the problem of transient scattering from surfaces of arbitrary conductivity. In particular, attention is given to the role played by conservation of power in the discretised scheme. It is shown that the time-domain formulation of the EFIE satisfies a power conservation law which is generally not preserved by a full discretisation of the problem. However, this power conservation law is necessarily preserved by a semi-discrete Galerkin approximation (where the spatial part of the problem is approximated using Galerkin's method, with expansion coefficients which are continuous functions of time). It is also shown that this power conservation law *is* preserved by a full discretisation of the EFIE, subject to certain constraints on the time-discretisation of the problem. These constraints include the use of an averaging method for the calculation of the surface current density. In addition it is shown that, for surfaces of finite conductivity, the time-discretisation required to ensure the conservation of power *necessarily* gives rise to a second kind integral equation. The implications of these results for the design of numerical algorithms to solve transient scattering problems are considered.

INVERSE PROBLEMS FOR A PERTURBED DISSIPATIVE HALF-SPACE

Margaret Cheney* and David Isaacson
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Troy, NY 12180

This talk addresses the scattering of electromagnetic (and acoustic) waves from a perturbed dissipative half-space. For the electromagnetic case, we restrict our attention to a two-dimensional medium and the Transverse Electric polarization to obtain a simple scalar model. This model retains the most important physical effects, namely variable wave speed and dissipation. This model is also appropriate for acoustics, in either two or three dimensions.

For this model we discuss three inverse problems: two inverse scattering problems and one boundary value problem. These three problems are related in a simple way. In particular, the inverse scattering problems can be transformed into the inverse boundary value problem.

Finally, a possible approach for solving this inverse boundary value problem is suggested. This approach is based on the idea of layer-stripping: one uses the first return pulse to obtain the medium parameters on the top surface, then mathematically strips away this known top layer. This process is repeated, and the medium parameters are found as layer after layer is mathematically removed.

We show how this process could be applied to bistatic data from a stepped-frequency radar. Unfortunately, the algorithm is unstable, and a new idea is needed to make it useful in practice.

Details appear in Inverse Problems, vol. 11 (1995), pp. 865–888.

Monday, May 27, 3:40 PM **Room: Cimarron**

HPEM-3 **Component HPM Effects**

CoChairs: J. Hausner, Logicon RDA, Albuquerque, NM
P.J. Vail, Phillips Laboratory, Kirtland AFB, NM

3:40 PM **ELECTRONIC COMPONENT SUSCEPTIBILITY MEASUREMENTS FOR STUDY OF HPM RADIATION EFFECTS**, *G. GORANSSON, National Defence Research Establishment, Linköping, Sweden* 78

4:00 PM **(INVITED) STUDIES ON ELECTROMAGNETIC RADIATION OF ULTRASHORT DURATION PULSE INTERFERENCE ON UHF ELECTRONIC DEVICES**, *N.P. GADETSKI, K.A. KRAVTSOV, I.I. MAGDA, Y.V. PROKOPENKO and V.I. CHUMAKOV, National Science Center Khar'kov Institute of Physics & Technology, Khar'kov, Ukraine; and V.E. NOVIKOV and Y.V. TKACH, Institute of Electromagnetic Reserches, Khar'kov, Ukraine* 79

4:20 PM **JOINT EFFECTS OF IONIZING RADIATIONS AND ELECTROMAGNETIC FACTORS ON ELECTRONIC CIRCUITS**, *V.N. BLOKHIN, V.P. DANILOV, L.N. ZDOUKHOV, Y.V. PARFENOV and E.A. FESIK, Russian Federation Ministry of Defence, Moscow, Russia* 80

4:40 PM **POWERFUL ULTRA-HIGH-FREQUENCY ELECTROMAGNETIC RADIATION INTERACTION WITH MULTILAYER HETEROGENEOUS MATERIALS**, *V.V. KISELEV and S.V. PANTELEEV, Russian Federation Ministry of Defense, Moscow, Russia* 81

5:00 PM **FORMATION OF THE DEFECT STRUCTURE IN COPPER AT HIGH POWER PULSED MICROWAVES INFLUENCE**, *A.N. DIDENKO, Moscow Phys. Eng. Inst., Moscow; E.V. KOZLOV, Y.P. SHARKEEV, N.V. GIRSOVA, Tomsk St. Acad. of Architect. & Bldg., Tomsk; A.S. SULAKSHIN, Microwve Ctr. of Inst. of Nucl. Physics, Tomsk; Y.V MEDVEDEV, Siberian Phys. Tech. Inst., Tomsk, Russia* 82

ELECTRONIC COMPONENT SUSCEPTIBILITY MEASUREMENTS FOR STUDY OF HPM RADIATION EFFECTS

Gunnar Göransson
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Besides investigating field penetration, shielding and coupling to cables knowledge of the susceptibility of electronic components to microwaves is an important factor both in design and analysis of systems with respect to microwave interference, degradation and damage.

The susceptibility of a component depends on various parameters, for example frequency, pulse width and pulse repetition rate but also on type of component and technology. It is also important to investigate the susceptibility variations between different samples of the same type and the same manufacturer and between different manufacturers. Other important activities in the studies of HPM effects on electronic components are to find and evaluate test methods (including instrumentation, test set-up and test fixtures). An important task is to develop a test fixture that gives a good coupling between the microwave source and the DUT.

Measurements have been performed using direct injection into the components. Up to now the investigated components have been IC-circuits like NAND-gates, line-drivers, latches etc. We have also investigated linear circuits (operational amplifiers). The digital circuits have been in TTL logic and CMOS. The investigations show that, for digital components, logic levels can shift and supply current can drastically increase. In some cases it has been found that upset/disturbance of the components may occur at relatively low microwave power. For linear circuits the susceptibility levels can be lower than mW. Furthermore, it has been shown that the sensitivity is very dependent on frequency. An example of microwave effects in an operational amplifier is shown in the figure below.

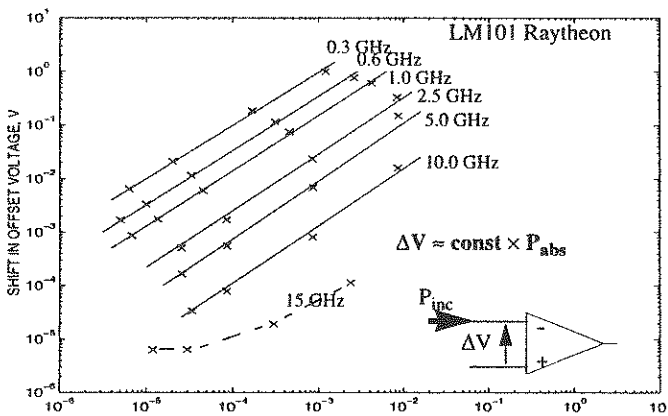

Figure. Shift in offset voltage versus absorbed microwave power at different frequencies for an operational amplifier.

STUDIES ON ELECTROMAGNETIC RADIATION OF ULTRASHORT DURATION PULSE INTERFERENCE ON UHF ELECTRONIC DEVICES

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A series of experimental researches has been directed on generation, metrology and radioelectronic equipment interference problem for the electromagnetic radiation of ultrashort-duration pulse (USDP), 0.1 - 100.0 ns. Of interest are the interaction processes of the USDP emission sources both relatively narrow and ultra-high spectrum with complex microwave electronic structures, in particular, processes of a nondegrading character.

The USDP emission pulse power and, accordingly, its spectral density are usually of rather high magnitudes. The high interference efficiency of the factor is stipulated for its far-distance action, for shock nature of the USDP process and for broad spectrum. On the example of studies on microwaves electronic systems (the receivers of various technology and elemental base) reaction, it has been shown the extremely high destructive action of the factor on system functioning, even at the power levels considerably lower (of hundred times) then the levels of degrading effects in object microstructures.

The peculiarity of the affecting electromagnetic USDP factor is the system nonlinear dynamic response formation, that can, under some circumstances, exceed a condition of chaos preventing normal functioning of device. The danger of chaos excited in system by the external signal, is displayed on its futher dynamics that is determined by processes inside. Then the system dissipates an energy of power supply for a characteristic relaxation time that is much more than the external USDP signal duration.

The work is directed on development of the electronic devices protection technologies from the effects of electromagnetic USDP radiation. These approaches include:

- quantitative avaluation of nonlinear reaction, based on results of an electronics testing
- avaluation of system functioning adequacy;
- development of numerical methods of testing for optimizations of electronics architecture, accounting its functional application.

JOINT EFFECTS OF IONIZING RADIATIONS AND ELECTROMAGNETIC FACTORS ON ELECTRONIC CIRCUITS

V.N.Blokhin*, V.P.Danilov, L.N.Zdoukhov,
V.V.Parfenov, E.A.Fesik
Russian Federation Ministry of Defence

As is known, the pulsed ionizing radiations influence on electronic systems is usually accompanied by generation of electromagnetic fields and induced potentials in circuits. The joint effects due to the almost simultaneous ionizing radiations and electromagnetic factors effects is interesting because of a possible change of the effects quantitative characteristics as compared to separate effects. Therefore the studies were performed to estimate this effects danger and to investigate its peculiarities. The results of calculations and experiments can be illustrated by some practically important examples of effects on simple circuits.

The energy W dissipating in reverse biased diode due to the simultaneous influence of ionizing radiation and induced voltage may be considerably greater then the one due to induced voltage influence without ionization. The dependence of W (and of p-n-junctions failure probability) on dose rate can have a maximum, the location of which depends on the diode properties, pulse characteristics and loop impedance. The phenomena is explained by changes of energy dissipation process dynamics with simultaneous ionization of semiconductor and by redistribution of dissipated - energy among a circuits components.

Moreover, the simultaneous induced voltages and - ionizing radiations influence on digital devices is capable to change the threshold failure dose rate. Under the certain impact factors parameters the threshold failure levels of logical IMS (for example, of D-trigger) can be ten times less as compared to threshold level of ionizing radiation only. This effect depends on the time shape and consistency of ionizing radiations and induced voltages pulses as well as effect considered above.

Thus, the joint influence of ionizing radiation and induced voltages can essentially differ from their separate influence, can be more dangerous and can decrease the accuracy of experimental studies of dose rate effects. The effectiveness of some protective measures (from electromagnetic effects) can be found unsufficient.

POWERFUL ULTRAHIGHFREQUENCY ELECTROMAGNETIC RADIATION INTERACTION WITH MULTILAYER HETEROGENEOUS MATERIALS

V.V.Kiselev, S.V.Panteleev
Russian Federation Ministry of Defense

Powerful ultrahighfrequency electromagnetic fields (UHF EMF) cause a number of thermophysical effects in multilayer heterogeneous materials. To study them a complex of techniques for solving the problems of electro- and thermodynamis has been developed. Multiple re-reflection of electromagnetic radiation on inter-layer boundaries is taken into consideration as well as change in their electrodynamic and thermophysical properties, possibility of the materials sublimation and catching fire. The techniques have been tested in special experimental studies. Calculated thermal fields distribution was compared to experimental data. Developed experimental methods have allowed to avoid strong electromagnetic disturbances that are generated in UHF EMF as well as distortions of UHF fields on electric heterogeneities-welded contacts of thermocouples.

Temperature measurements dubbing was conducted using thermovision apparatus. In the course of experimental studies, visual monitoring of the samples being irradiated was conducted by means of film-, photo- and telerecording.

Physico-mathematical model of UHF plasma gapping by complex heterogeneous dielectrics has been developed. The model is based on the assumption that the field on dielectric heterogeneties is stronger. Calculative estimates were conducted of gap initiation levels decrease by heterogeneous materials having various dielectric characteristics and heterogeneity dimensions. The model can be used to estimate atmospheric gap thresholds near the surface of heterogeneous structures given environment pressures are diverse. The method estimationhas been tested in specially undertaken experimental studies.

Theoretical and experimental investigations have shown the possibility of ignition and burning of multilayer heterogeneous materials combustible components in UHF EMF at standard atmospheric conditions. It is determined that nonstationary burning is accompanied by significant changes in the materials electrophysical and strength properties. The features of these processes depending on atmospheric pressure near the samples surface have been investigated. Quantitative characteristics of principal physical effects accompanying interaction of powerful UHF EMFs with multilayer heterogeneous materials have been obtained.

FORMATION OF THE DEFECT STRUCTURE IN COPPER AT HIGH POWER PULSED MICROWAVES INFLUENCE

Andrei N.Didenko*, Edward V.Kozlov**, Yurii P. Sharkeev**,
Alexander S. Sulakshin***, Nataliya V. Girsova**, Yurii V. Medvedev****

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**Tomsk State Academy of Architecture and Building, Tomsk, Russia
***Microwave Center of Institute of Nuclear Physics, Tomsk, Russia
**** Siberian Physical Technical Institute, Tomsk, Russia

Recently a new phenomenon was described in periodicals. It was established, that the high power pulsed microwaves (HPPM) leads to a change in a defect structure of the polycrystal copper near surface layer. An maximum change was observed in the skin-layer where the dislocation density increased by an order of magnitude with that of the initial state.

In the present work the systematic experimental results of the defect structures formed in the near surface layers of well annealed copper under the influence of HPPM whose parameters varied within wide ranges are suggested. The samples were exposed to single pulses every 30-40 seconds when the total pulse number was 2,50 and 100. The HPPM wave length was equal to 2.85 and 10 cm and the pulse duration was varied from 50 to 350 ns. The density of the HPPM-radiation was varied from 2 to 400 kW/sqcm. The defect structure of the irradiated samples were investigated using the transmission electron diffraction microscopy. In addition, the measurement of the electric conductivity of the irradiated near surface layers was carried out using noncontact method. The conductivity measurement technique is based on the registration of losses introduced into the HPPM magnetic field of a resonator by the investigated sample.

It was established that the HPPM resulted in the formation in the near surface copper layers of the dislocation structure whose density is by an order of magnitude and more higher than that in the initial state. The near surface layer thickness with the changed dislocation structure is equal to from one to three calculated thicknesses of the skin-layer. The pointed effect turned to be stable. The dislocation density increases with the distance from the irradiated surface reaching its maximum value on the boundary of the skin-layer and then it slowly decreases. The HPPM energy absorbed by a sample at irradiation is compared with the energy which is necessary for the formation of the observed dislocation structure.

The possible mechanisms responsible for the formation of the observed defect structure at the HPPM influence on metals are discussed. One of the probable reasons of the dislocation generation are the stresses caused by the crystal lattice distortions under the influence of the electric component of the HPPM irradiation.

Tuesday, May 28, 8:30 AM **Room: Brazos**

HPEM-6 & UWB, SP-5 High Power Impulse Antennas

CoChairs: P.D. Smith, University of Dundee, Dundee, Scotland
V.P. Efremov, High Energy Density Research Center, Russia

8:30 AM **INTRODUCTION & ANNOUNCEMENTS**

8:35 AM **ULTRAWIDEBAND SOURCES AND ANTENNAS – THE STATE OF THE ART**, *W.D. PRATHER, Phillips Laboratory, Kirtland AFB, NM* 84

8:55 AM **IMPULSE RADIATING ANTENNAS, PART III**, *E.G. FARR, Farr Research, Albuquerque, NM; and C.E. BAUM, Phillips Laboratory, Kirtland AFB, NM* 85

9:15 AM **DESIGN AND PREDICTIONS OF TWO TYPES OF IMPULSE RADIATING ANTENNA**, *E.G. FARR, Farr Research, Albuquerque, NM; and C.A. FROST, Pulse Power Physics, Albuquerque, NM* 86

9:35 AM **A DEVICE FOR RADIATING HIGH POWER RF FIELDS FROM COAXIAL STRUCTURES**, *J. WELLS, G. WATT and H. WIGGLESWORTH, Fiore Industries, Albuquerque, NM; T. BOWEN, Phillips Laboratory, Kirtland AFB, NM; and D. VOSS, D. ECKHARDT, N. KEATOR and C. COURTNEY, Voss Scientific, Albuquerque, NM* 87

9:55 AM **HIGH VOLTAGE UWB HORN ANTENNAS**, *P.D. SMITH, Applied Electromagnetics, St. Andrews, Fife, Scotland; and C.J. BROOKER, Defence Research Agency, Sevenoaks, Kent, England* 88

10:15 AM **BREAK**

10:40 AM **BREWSTER-ANGLE INTERFACE BETWEEN FLAT-PLATE CONICAL TRANSMISSION LINES**, *C.E. BAUM, Phillips Laboratory, Kirtland AFB, NM* 89

11:00 AM **DESIGN OF THE LOW-FREQUENCY COMPENSATION OF AN EXTREME-BANDWIDTH TEM HORN AND LENS IRA**, *M.H. VOGEL, Phillips Laboratory, Kirtland AFB, NM, on assignment from TNO Physics and Electronics Laboratory, The Hague, Netherlands* 90

11:20 AM **AN EFFICIENT RADIATING STRUCTURE INCORPORATING AN EXTENDED GROUND PLANE AND A BREWSTER ANGLE WINDOW** , *C. BAUM and W. PRATHER, Phillips Laboratory, Kirtland AFB, NM; and J. WELLS, Fiore Industries, Albuquerque, NM* 91

11:40 AM **OPTIMIZED TEM HORN IMPULSE RECEIVING ANTENNA**, *M.A. MORGAN and R.C. ROBERTSON, Naval Postgraduate School, Monterey, CA* 92

ABSTRACT

Ultrawide Band Sources and Antennas
The State of the Art

William D. Prather

USAF Phillips Laboratory
Kirtland AFB, NM

Ultrawide Band (UWB) sources and antennas are of interest for a variety of potential applications that range from transient radar systems to high power jammers and communications systems. This technology is of current interest to the USAF Phillips Laboratory where research efforts have been underway for a number of years.

The development of new sources and antennas for the production of high power UWB energy has proceeded along several distinct lines in the past 6 to 8 years and is now beginning to branch out into other lines of technology. The research into UWB transient antennas has also contributed significantly to the development and improvement of wideband continuous wave antenna designs and has brought new knowledge about gas switching and insulation, materials breakdown, propagation and optics.

The approaches have included three main thrusts: very powerful, high pressure hydrogen spark gap pulsers; compact hydrogen gas switches in conjunction with high gain ultrawide band antennas; and solid state switched arrays. Recent developments in high voltage insulating oil and significant increases in solid state switching technology have made significant contributions to the constantly evolving technology of UWB sources and radiators. Also, developments in stacked Blumlein technology are opening up new possibilities for compact UWB devices. As UWB technology progresses, of course, it is also making possible experiments which are teaching us a great deal about the propagation of wideband transient signals and the use of scattered return signals for locating and identifying a variety of objects from small shell casings and mines to full sized aircraft.

This paper reviews the progress to date along these lines and describes these exciting new areas of research into UWB technology and sytems development.

IMPULSE RADIATING ANTENNAS, PART III

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†Phillips Laboratory, 3550 Aberdeen Ave., Kirtland AFB, NM 87117

In this paper we continue our general discussion of Impulse Radiating Antennas (IRAs), which has been carried on during the first two UWB,SP EM conferences. IRAs are a class of antenna that in general consist of a TEM feed section, and either a lens or reflector to generate a planar aperture field. In this presentation we summarize much of the more recent information, including new antenna designs, new calculation methods, and an optimization of the impedance of the Lens IRA.

First, we consider the optimal feed impedance for infinitely long TEM horns (an approximation for finite-length horns) and TEM horns with lenses, or lens IRAs. We consider both TEM horns whose plates are flat, and whose plates are confined to a circular arc. We also consider configurations in which the fields in the entire aperture are allowed to radiate, and configurations in which only the fields between the plates are allowed to radiate. The optimal impedance is determined as the impedance that provides the highest radiated field for a given input power.

Next, we consider a new feed-point lens design for half IRAs. The half IRA antenna has recently been proposed for radiating a high-voltage, single-ended source. However, the feed point may need to be electrically large, because of dielectric breakdown considerations. We propose here a lens that can guide a transient waveform from a coaxial feed onto the conical arms of a reflector IRA with $F/D = 0.25$. The lens is a prolate spheroid on one end, and a quartic surface on the other end. Example designs will be shown.

We also consider methods of calculating the radiated field from a four-wire aperture, both on- and off-boresight. This is an approximation to the field in the aperture of a four-armed reflector IRA. Results for but a full aperture, and for a half aperture will be presented.

Finally, we explore a wide variety of new IRA designs. First, we consider a low-frequency compensated TEM horn, which provides the correct $\vec{p} \times \vec{m}$ cardioid pattern at low-frequencies. We also look at various configurations of IRAs that allow the beam to be steered. Finally, we consider designs that include two reflecting or refracting surfaces. This flexibility allows very compact designs, and also allows flexibility in the choice of input impedance.

DESIGN AND PREDICTIONS OF TWO TYPES OF IMPULSE RADIATING ANTENNA

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In this presentation we summarize the design and predictions for two types of Impulse Radiating Antenna (IRA). IRAs are a class of antenna that in general consist of a TEM feed section, and either a lens or reflector to generate a planar aperture field. The two designs considered here include a 23 cm diameter reflector IRA, with an *F/D* of 0.38, and a solid dielectric lens IRA (TEM horn plus lens), with the same diameter, and with a prolate spheroidal lens to focus the aperture.

The reflector IRA consists of a paraboloidal reflector, fed by a conical 4-arm feed, whose combined input impedance is 200 Ω. The lens IRA was constructed from a solid block of polyethylene, conical in shape, and capped by a prolate spheroid. It can be short, because of the prolate spheroidal lens, and it will provide a better match to 50 Ω, when compared to a lens-horn antenna with an air-filled horn. Since there are fewer dielectric interfaces, there will be fewer reflections.

The technique for calculating the step response antenna pattern involves calculation of the line integrals of the quasistatic potential over the aperture. The resulting step responses are then convolved with the derivative of the driving voltage to obtain the overall waveshape. The reflector configuration was calculated using a 4-wire approximation to the aperture. The lens IRA was calculated under the assumption that the aperture was that of a TEM horn built with circular plates.

Antenna pattern measurements will be obtained by using two identical antennas. First, the boresight response of the antenna will be determined by placing both antennas in an orientation facing each other. Afterward, one of the antennas will be scanned in the H- and E planes. Signal processing includes techniques for extracting the single-antenna response from the 2-antenna measurement.

A Device for Radiating High Power RF Fields From Coaxial Structures

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ABSTRACT

A device, called a point geometry converter (PGC), which abruptly converts from a coaxial to planar geometry has been developed and tested for radiating short pulse, high power broadband electric fields from coaxial sources. Highly filtered transformer oil provides the necessary insulation to allow coaxial diameter to be tapered to and outer conductor dimension of about one inch. The device incorporates an exponentially tapered impedance transformer and the transition to the parallel plate structure is accomplished much more easily at this reduced diameter. The impedance taper has shown insulation to 2.5 MV/cm at a 350 picosecond pulse width. This structure fitted with a TEM horn antenna has been shown capable of propagating broadband pulses with rise times of less than 200 picoseconds. Data will be presented from both the H3 and H2 HPM sources fitted with this structure. Radiated electric field strengths of greater than 150 KV/m at 5 meters have been accomplished using this device. Preliminary data will also be presented on a new concept for applying the PGC at lower source out put impedances. This device separates the coaxial transmission line into four or more parallel plate lines in parallel. Since the effective impedance of each parallel plate line is four or more times that of the coaxial line, this may be done at lower coaxial impedance and thus less field stress. The parallel plate lines must be twisted such that the fields add from one plate to another and the electrical lengths are the same. This design may prove vital to future HPM sources having greater output power.

HIGH VOLTAGE UWB HORN ANTENNAS

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The pressurised gas spark gap is widely used in high power switching operations. There is recent interest in developing these switches for use in very fast (below 200 ps risetime), high pulse repetition rate (above 1 kHz) and high voltage generators (see C.A. Frost, T.H. Martin et al., *Proc. 9th IEEE Pulsed Power Conf.*, 491-494, 1993, and W.R. Cravey, E.K. Freytag et al. *ibid.*, 483-486). High pressure spark gaps are versatile, lightweight, inexpensive and robust. This paper describes a low inductance gas sharpening gap for fast risetimes, a high pulse repetition frequency modulator and a matched antenna to radiate the transient pulses.

In order to minimise losses and preserve the fast risetime it is desirable that the spark gap should be integral with the antenna for optimal performance. A stripline arrangement was therefore used for the spark gap so that transition to a TEM horn antenna is relatively straightforward. The sharpening gap was incorporated into 50Ω stripline separated by Perspex dielectric. This section was operated at 1 kHz pulse repetition frequency and 25 kV output. Good performance was obtained using nitrogen at up to 300 psig without gas flow.

The TEM horn antenna was designed to fit directly onto the output of the spark gap with minimal discontinuity in impedance. It was intended for free space operation from a balanced 50Ω stripline to permit radiation of transient pulses with risetimes less than 150 ps. This antenna was designed using Brewster angle matching techniques described by C.E. Baum and A.P. Stone (*Transient Lens Synthesis*, Hemisphere Pub. Corp., 1991) to ensure a constant 50Ω transition across the solid dielectric/air interface.

The impedance of the stripline-horn section was determined by time domain reflectometry to differ minimally from the 50Ω specification. Measurements of the pulsed waveform generated in the stripline section, in the dielectric filled section of the antenna and in the air filled section recorded fall times below 150 ps. Measurements of the radiated farfield confirm that the radiated waveform is very nearly proportional to the derivative of the spark gap output, as expected.

The results confirm that the antenna represents a constant impedance transition from source to radiating aperture that is able to withstand operation at 25 kV voltage with 1 kHz pulse repetition frequency. The antenna preserves the fast risetime of the source and directively radiates a transient which is proportional to the derivative of the applied voltage. Modifications and extensions to the basic design will be discussed.

BREWSTER-ANGLE INTERFACE BETWEEN FLAT-PLATE CONICAL TRANSMISSION LINES

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One kind of impulse radiating antenna (IRA) is a lens IRA consisting of a conical transmission line (TEM horn) with a lens near the horn aperture to focus the wave at infinity. Whether or not one includes the final lens there is still the problem of launching a fast high-amplitude TEM wave on the conical transmission line from some high voltage pulser. Going back from the horn aperture toward the apex, the spacing of the plates (conductors) decreases until at some position one needs to be concerned about voltage breakdown. One can increase the dielectric strength by using gases such as SF_6, or a medium such as transformer oil. In the latter case, one has a relative dielectric constant greater than air, giving a mismatch at the boundary of this medium.

This paper considers an approach to optimizing the launch of the spherical TEM wave on the conical transmission line in air (or other gas) from another conical transmission line in a dielectric medium with relative permittivity greater than one. The dielectric boundary S_B between these two is designed to utilize the Brewster-angle phenomenon, but there are limitations due to more than one component (polarization) of the electric field in the TEM wave. The TEM waves, being spherical on the conical transmission lines, when matched on the dielectric surface also require some curvature of this surface for optimal matching. In general, there are two different curvatures of S_B in the E and H planes to avoid astigmatism and make the apex of the final conical transmission line coincide with the virtual focus. There is also the lens to be added near the horn aperture to focus the fields at infinity. Furthermore, there is the resistive termination for the low-frequency load to be seen by the high-voltage pulser, and for the optimization of the low-frequency radiation by optimal combination of electric and magnetic dipole moments. There is still the design of the pulser and its matching to the conical transmission line on the incident side of S_B to consider.

DESIGN OF THE LOW-FREQUENCY COMPENSATION OF AN EXTREME-BANDWIDTH TEM HORN AND LENS IRA

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on assignment from
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The TEM horn is an antenna which can be used for radiating (or receiving) short electromagnetic pulses of extreme bandwidths. When a lens is placed at the horn aperture, it is called a lens IRA (Impulse Radiating Antenna). These antennas present, for the low-frequency part of the pulse, an open circuit to the source, which can be a problem. A large part of the energy will be reflected back into the source and may cause damage to the source. Therefore, a resistive termination has to be connected to the two conductors of the horn. Preferably, the resistance of this termination is matched to the impedance of the horn for low frequencies. The physical shape of this resistive termination, i.e. the placement of the path of the current and the distribution of the resistors along this path, is important as it significantly affects the low-frequency performance. By routing the currents behind the horn, the associated magnetic dipole moment can be oriented to combine with the electric dipole moment to enhance low-frequency radiation in the forward direction (same direction as the high-frequency radiation) and reduce it in the backward direction.

We will discuss the considerations and restraints that have to be taken into account in order to achieve the optimum design: complete cancellation of backward radiation and maximization of forward radiation for the lowest frequencies, in order to give the TEM horn the widest possible bandwidth.We will present the optimum design, which has been achieved with a combination of analytical and numerical methods. In the analytical approach, the antenna has been modeled as a very long structure, so that effectively a two-dimensional problem had to be solved. In the numerical approach, the method of moments has been used.

In both approaches, first the path of the current and the placement of the resistors was chosen. Then, knowing the voltages everywhere, the charge distribution was calculated in the limit of the frequency going to zero. The shape of the loop and the magnitude of the current determine the magnetic dipole moment, while the distribution of the charge determines the electric dipole moment. Then, the shape of the loop and the distribution of the resistors was modified, within practical constraints, until the optimum was reached. This optimum design will be presented as well.

AN EFFICIENT RADIATING STRUCTURE INCORPORATING AN EXTENDED GROUND PLANE AND A BREWSTER ANGLE WINDOW

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ABSTRACT

A TEM radiating structure has been designed and tested incorporating the PGC (Point Geometry Converter) concept with an extended ground plane and a Brewster angle window for better energy transfer and greater risetime capability. This structure is mated to the output of the H3 high power microwave source and has been shown capable of propagating field strengths in excess of 100 KV per meter at 5 meters with rise times of about 100 picoseconds. The structure was designed to optimize the launch of a fast high-amplitude spherical TEM wave from the flat plate conical transmission line. It uses a singly curved Brewster window curved only in the **E** plane with the **H** plane radius of curvature set to infinity. The device transitions from the H3 output impedance of 20 ohms to 60 ohms at the highest field stress section of the PGC and then increases to 120 ohms at the Brewster window output. The structure is fitted with fast self integrating electric field sensors with sufficient band width for measuring the fast risetime along the length of the structure. The device incorporates transformer oil as the coaxial taper and initial flat plate conical transmission line media. The transformer oil has been shown to be capable of supporting extremely high electric field stress for very narrow pulses such as these. Data from these tests along with future plans will be presented as well as a concept for resistively terminating the antenna.

OPTIMIZED TEM HORN IMPULSE RECEIVING ANTENNA

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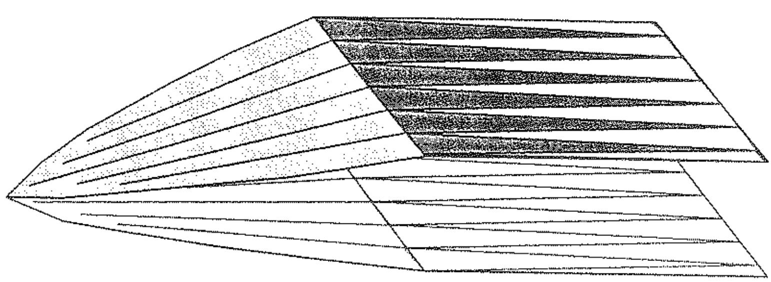
The design process for loaded TEM horn impulse receiving antennas is applied to produce a highly-optimized ultra-wideband structure, as illustrated below. This antenna employs a tapered impedance flare section terminated by a smoothly increasing resistive section to achieve the following design goals:

(1) Design to fit within a 18 cm x 23 cm x 76 cm cubical volume;
(2) Achieve a passband of 10 MHz to 10 GHz for $Z_{in}=50$ Ohms;
(3) Provide high-fidelity reception of $t_d < 100$ps impulsive waveforms;
(4) Optimize directivity and sensitivity given the size limitation in (1).

A Method-of-Moments numerical model was developed as an aid to the design process. This numerical model was employed extensively to search for optimum geometrical dimensions and resistive tapers to achieve the challenging 10MHz operation criterion, given the antenna size constraint.

Several prototype TEM horns were fabricated and performance evaluations were conducted using two procedures. Preliminary tests were performed in an anechoic chamber, using identical transmitting and receiving antennas, with a low-power dc-50GHz step-waveform source and a 50 GHz bandwidth sampling oscilloscope receiver. Open region tests were then conducted in a desert environment using a higher power impulse source radiating from a 10 foot diameter reflector with a conical TEM feed.



Loaded TEM Horn Antenna

Tuesday, May 28, 8:30 AM **Room: Cimarron**

HPEM-7 **Lightning**

CoChairs: J. Kappenman, Minnesota Power, Duluth, MN
Y. Das, Defence Research Establishment, Alberta, Canada

8:30 AM **INTRODUCTION & ANNOUNCEMENTS**

8:35 AM **HIGH VOLTAGE PULSES GENERATION BY MAGNETIC FLUX COMPRESSORS,** *E.V. CHERNYKH, E.V. NESTEROV and I.O. ZOLOTICH, Russian Academy of Sciences, Moscow, Russia* 94

8:55 AM **LONG ARC LIGHTNING GENERATOR,** *M. WHITAKER and S.J. FRAZIER, Naval Air Warfare Center, Patuxent River, MD* 95

9:15 AM **LIGHTNING-INDUCED ELECTROMAGNETIC PULSE (LEMP) – REFORMULATION OF FINITE DIPOLE ANTENNA MODEL,** *T.J. LIE and R. BRIET, The Aerospace Corporation, El Segundo, CA* 96

9:35 AM **DAPS FOR LARGE SCALE SYSTEM LEVEL INDIRECT EFFECTS LIGHTNING TESTS,** *M. WHITAKER, E.M. PARIMUHA and S.J. FRAZIER, Naval Air Warfare Center, Patuxent River, MD; and B. MCCLURE and P.L. LUMSDEN United International Engineering, Inc., Alexandria, VA* 97

9:55 AM **INTELLIGENT METHODS TO ANALYZE AND MITIGATE LIGHTNING CAUSED ELECTRIC POWER SYSTEM DISTURBANCES,** *J.G. KAPPENMAN and D.L. VAN HOUSE, Minnesota Power, Duluth, MN* 98

10:15 AM **BREAK**

10:40 AM **ELECTROMAGNETIC SITUATION IMPROVING IN BUILDING DUE TO OPTIMISATION OF DIRECT LIGHTNING STROKE PROTECTION,** *E.M. BAZELYAN, V.M. KOUPRIENKO and A.V. KHLAPOV, Science Research Center, St. Petersburg, Russia* 99

HIGH VOLTAGE PULSES GENERATION BY MAGNETIC FLUX COMPRESSORS

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The magnetic flux compressors (MFC) are known as a promising high power sources of the electromagnetic energy. An effective operation of the MFC directly connected with the definite relationship between the load parameters and the MFC ones.

In the present paper, the most emphasis is focused on the possibilities of using MFC for high voltage pulses generation on the non usual high impedance loads. We considered the matching problem between MFC and the load with help of the pulse or dynamic transformers and the electroexploding opening switches (EOS).

The simulation method was based on the two-stage dynamic EOS model and the finite-element model for helical MFC. The numerical simulations was realized for two types of the high impedance loads: 1) high inductive one (main stage of lightning discharge process) and 2) high resistive load (vacuum diode). It was obtained the power optimized areas of all system initial parameters for both types of loads. The scheme with dynamic transformer and thin wires EOS in nitrogen is optimizing one for the vacuum diode; the scheme with pulse transformer and thick wires EOS in condensed insulation - for lighting modeling. Some of the theoretical conclusions was confirmed by experiments.

LONG ARC LIGHTNING GENERATOR

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Abstract

The Naval Air Warfare Center Aircraft Division (NAWCAD), Patuxent River, MD is a U. S. Department of Defense Major Range and Test Facility Base and E Cube Center of Excellence. The NAWCAD Naval Lightning Laboratory has fielded a Long Arc Lightning Simulator designed to support large scale lightning tests.

The Naval Lightning Laboratory designs and develops custom built lightning simulators for direct and indirect effects testing as required to support test programs. The Long Arc Lightning Simulator was developed to meet some of the direct effects test requirements of MIL-STD-1757. The simulator was built to provide Voltage Waveforms A, B, and D. These waveforms are used to determine lightning attachments points and to identify lightning strike zones on aircraft models and build-ups of different sections of the aircraft, e.g. wing sections. This simulator is also used to provide the environment for nearby lightning.

The Long Arc Lightning Simulator's construction will be discussed. Details will be provided on the layout of components and considerations given to the types of components chosen. Efforts made to minimize flashover problems will also be discussed. Details of the triggering system will be presented. Also, details of the power supply used for charging the simulator will be discussed.

The operational checkout of the new simulator was performed without any problems. The simulator demonstrated that its design was fully functional and that it exceeded the performance requirements of MIL-STD-1757. The rate of rise of the output waveform is sufficiently fast to allow the use of waveshaping components external to the high voltage stack, simplifying the amount of effort required to convert the simulator output between the different parameters of waveforms A, B, and D.

LIGHTNING-INDUCED ELECTROMAGNETIC PULSE (LEMP)
-- Reformulation of Finite Dipole Antenna Model --

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The objective of this paper is to present a reformulated version of the conventional formalism of lightning-induced electromagnetic pulse (LEMP) based on the finite dipole antenna model. A lightning stroke in this work refers to a vertical upward current pulse along a channel of finite height from a perfectly conducting ground.

The conventional LEMP model per dipole antenna is represented by the work of Uman, McLain and Krider (1975) with its extension, by Master et al (1981), to include the case of an exponentially decaying current pulse. This conventional model is shown to be a sum of two parts: a quasi-electrostatic part and an EMP part. The quasi-electrostatic part, which is due to the point charges accumulated both along the lightning channel and at the channel end-points, increases monotonically in time and reaches a stationary non-zero electrostatic limit. This is the characteristic feature of the conventional model in the near region, where the EMP part tends to be overshadowed in the time domain by the quasi-electrostatic part.

The EMP part, like the conventional model, satisfies the Maxwell equations. It relates solely to the finite electromagnetic energy packet released from the lightning current stroke; it starts out in time at an electric field level of zero and ends up back to zero after the event. This feature contrasts with that of the quasi-electrostatic part. In the frequency domain, the EMP part differs from the conventional model only in the low frequency region below 500 Hz. Thus, in electronics applications, one is to deal with the EMP part.

The EMP of the electromagnetic field is shown to be a sum of two terms: the Coulomb term and the radiation term. For the case when the current pulse velocity is equal to the speed of light, the mathematical formalism leads to a closed form corresponding to that of Le Vine and Meneghini (1978). For other cases, the paper presents the results of numerical computations with a lightning current pulse of a double exponential form. Approximate expressions are applicable in the near and far regions.

DAPS FOR LARGE SCALE SYSTEM LEVEL INDIRECT EFFECTS LIGHTNING TESTS

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Abstract

The Naval Air Warfare Center Aircraft Division (NAWCAD), Patuxent River, MD is a U.S. Department of Defense Major Range and Test Facility Base, and E^3 Center of Excellence. The NAWCAD has fielded a highly automated Data Acquisition and Processing System specifically designed to support large scale lightning and electrostatic tests.* The system can collect data from 16 channels simultaneously, each channel controls a fiber optic link with 8 inputs, allowing the measurement of a maximum of 128 test points without reinstrumenting.

The system is driven by two µVAX II computers with CSP array processors accessing large data storage provided by RAM, Hard-drive, TK50 tape cartridge, and TS05 reel-to-reel tape drives, allowing flexible data handling and real time processing. To increase flexibility and eliminate single point failures, the system is divided into two modules, 8 channels each. Each channel can have a LeCroy 8828 (64k samples at programmable intervals of 5 to 320 nsec intervals) and/or a LeCroy 6880 (10k sample at 742 psec intervals). Each test point input can be automatically verified prior to data acquisition.

Test planning, conduct, reporting and analysis are highly automated and user oriented. They system is pre-test planning intensive to reduce test time and ensure test success. The ability of LDAPS to acquire significant amounts of data reduces test time and stress placed on the systems under test, thereby, reducing test costs. Immediately upon test completion, the test data can be stored on a standard IBM PC-CD ROM for post test analysis and archiving.

INTELLIGENT METHODS TO ANALYZE AND MITIGATE LIGHTNING CAUSED ELECTRIC POWER SYSTEM DISTURBANCES

John G. Kappenman & David L Van House
Minnesota Power, Duluth, MN

ABSTRACT

Lightning is the leading cause of electric power system disturbances, typically causing more than 60% of all transmission disturbances. Further, the potential impact of these disturbances is increasing as more voltage sensitive end-users develop on the network. As a result electri utilities have been searching for a method to gain a better understanding of the causal relationship between lightning and utility system performance, as well as methods to more effectively deploy lightning mitigation..

In response to the needs, Global Atmospherics and EPRI upgraded the National Lightning Detection Network (NLDN) in 1994 to increase the lightning detection performance required for utility analysis applications. Additionally, Minnesota Power participated in a collaborative effort with EPRI member utilities to research and develop a practical lightning analysis tool called FALLS(Fault Analysis and Lightning Locating System). FALLS provides a very comprehensive method of assessing transmission line lightning exposure and an improved method of analysing transmission line performance improvements for lightning caused performance problems.

This analysis tool offers utilities better insights and options on mitigation strategies with the limited capital available to yield the greatest performance improvements. For example, power system disturbance timing using GPS-based time stamping and GPS mapping of line locations when combined with the GIS-based analysis will allow utilities to locate lightning caused disturbances virtually to the transmission structure. Analysis of fault associated events can allow a utility to determine situations in which faults are occurring in unusual concentrations in certain sections of transmission lines. Further, once a set of high-incidence structure locations have been pinpointed, transmission line arresters or other mitigation options can be rapidly, accurately, and economically deployed on those affected sections, rather than upgrading the entire line to improve performance. This "Location-Centered" methodology may allow utilities to deploy mitigation more effectively and at a much lower cost to gain the equivalent performance improvements as compared to conventionally blanketing mitigation across an entire affected line.

ELECTROMAGNETIC SITUATION IMPROVING IN BUILDING DUE TO OPTIMISATION OF DIRECT LIGHTNING STROKE PROTECTION

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The creation of flavourable electromagnetic situation in building with great amount of microelectronic equipment forces to refuse the traditional methodes for lightning protection design, as such methodes allows to protect only from lightning direct strokes. The lightning protection system may and must solve the problem to make circuit for lightning currents spreading symmetrical, that guarantees minimum possible fields inside the building. This can be achieved by fixing possible lightning stroke point to air terminal provided with system of lightning conductors, designed specialy for that building on minimum EMF conditions in the main premises.

Lightning conductor moving away from the protected object also must meet the demands for electromagnetic situation. In spite of all this looped rope lightning conductors, enveloped the protected object along the perimeter are the most prospective. High efficiency of looped ropes was confirmed by calculations based on statistical methode and large-scale experiments on test bench SRC 26 CSRI . Such ropes provide the negative protection angles and allows to achive neccessary reliability with less hieght of lightning rods, then traditional air terminals.

In addition to traditional measurements for lightning direct strokes protection the organisation of protection from lightning currents bypassing to the object ground terminal by channels of spark discharge, creeping from lightning stroke point along the ground surface was considered. Experimental investigation [1] of creeping discharges as well as computer modelling prepared the science base to designing the effective means for protection from this dangerous lightning effect.

References:

1. E.M.Bazelyan,A.V.Khlapov,A.V.Shkilev, Development of a surge discharge over water and earth surfaces, Electrical Technology N3, pp 137-147,1992

Tuesday, May 28, 8:30 AM **Room: Galisteo**

HPEM-8 Simulation Chambers

Chair: Y.-G. Chen, Maxwell Laboratory, San Diego, CA

8:30 AM **INTRODUCTION & ANNOUNCEMENTS**

8:35 AM **MAJOR E3 UPGRADES TO SUPPORT DOD RDT&E REQUIREMENTS**, *S.J. FRAZIER and J. DAWSON, Naval Air Warfare Center, Patuxent River, MD; and A. IACONO, Naval Air Systems Command Headquarters, Washington, DC* 102

8:55 AM **OVERLAYING LLCW AND MODE-STIRRED DATA FOR AIRCRAFT E3 EVALUATION**, *C.E. GOLDBLUM, R&B Enterprises, West Conshohocken, PA; and S.J. FRAZIER, Naval Air Warfare Center, Patuxent River, MD* 103

9:15 AM **SYSTEM EXCITATION VIA CAVITY PUMPING AND COMPARISON WITH EXTERNAL FREE-FIELD EXCITATION**, *G. HOFFER, G. DEMUTH, D. BYRNE and D. MCLEMORE, Kaman Sciences Corporation, Albuquerque, NM; and H. DEL AGUILA, Phillips Laboratory, Kirtland AFB, NM* 104

9:35 AM **ELECTROMAGNETIC INTERFERENCE (EMI) INVESTIGATIONS OF A COMMERCIAL GPS RECEIVER -- A COMPARISON OF FREE-FIELD AND MODE-STIRRED CHAMBER TEST METHODOLOGIES**, *J. LAWRANCE and D.P. BYRNE Kaman Sciences Corporation, Albuquerque, NM; and H. DEL AGUILA, Phillips Laboratory, Kirtland AFB, NM* 105

9:55 AM **NOVEL ABSORBER FOR ANECHOIC CHAMBER**, *A. ENDERS and G. NIMTZ, University of Cologne, Koln, Germany; and W. OPITZ and R. SCHALLER, Frankonia, Heideck, Germany* 106

MAJOR E^3 UPGRADES TO SUPPORT DoD RDT&E REQUIREMENTS

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Abstract

The DOD and Naval Air Systems Team are planning several large scale E^3 developments at the Naval Air Warfare Center Aircraft Division (NAWCAD), Patuxent River, MD. The NAWCAD is a DOD Major Range Test Facility Base and serves as a Center of Excellence in E^3 RDT&E. The development provides a capability that is both comprehensive for S&T requirements & practical for the more pragmatic T&E customer needs. The cost of many RDT&E tools prohibit their proliferation but not the requirement to have and use them. Single siting these tools where they can be used by the various E^3, Electronic Warfare, mission systems, and communication systems engineers for both S&T and T&E use significantly reduces time, resources and funding requirements.

Topics include a brief discussion of overall NAWCAD installation capabilities. Range and E^3 capabilities such as the Shielded Hangar, Anechoic Chamber, and EMP Site are discussed. The technical aspects and roles of the following facility development efforts are covered:

ACETEF: Air Combat Environment Test and Evaluation Facility. This sophisticated man-in-the-loop simulation ground test facility allows the simulation of mission scenarios in a secure environment using operational aircraft, cockpit simulators and multiple laboratories. The role of the E^3 Laboratory within the ACETEF is discussed;

The Large Anechoic Chamber: Capable of holding either a large aircraft or several smaller tactical aircraft.

The Large Mode Stir Chamber: Both a small chamber within the existing shielded hangar and a large aircraft facility are being considered;

The E^3 Generating System: This is a DOD funded upgrade to expand the existing carrier deck EM environment simulation to a world-wide EM environment simulation;

EMTTEF: Electromagnetic Transient Test and Evaluation Facility, an upgrade of the EMP and lightning facilities to a single site temporal waveform RDT&E facility. It includes EMP, Lightning and electrostatics, and ultra-wideband simulation, instrumentation, analysis and modeling.

OVERLAYING LLCW AND MODE-STIRRED DATA FOR AIRCRAFT E3 EVALUATION

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Abstract

The Electromagnetic Transients Branch of the Naval Air Warfare Center Aircraft Division (NAVAIRWARCENACDIV) located in Patuxent River Maryland has been pursuing new test tools for determining system survivability to high frequency threats associated with E1 in DOD-STD-2169B, High Power Microwave (HPM)and Ultra Wide Band (UWB). Two of these tools are the existing Low Level Continuous Wave (LLCW) test system and the future aircraft size Mode Stirred Chamber.

The LLCW simulator determines the transfer function between a plane wave, low power, excitation field and the cabling on the platform under test. This transfer function yields the spectral profile of the cabling system from 100 kHz to 1 GHz. This spectral profile can then used to minimize the time and cost associated with mode stirred chamber testing.

In the mode stirred chamber, the platform under test is exposed to a high power, randomly polarized, random impedance excitation field as the platform's systems are simultaneously monitored. In the mode tuned test scenario, the test frequencies are stepped for each of the 201 tuner positions. The time (and cost) of testing is determined by the size of the steps which, in turn, are dictated by the bandwidth of the systems' responses. The spectral profile generated from the LLCW test would bound the bandwidth of the systems' responses and thereby optimize the mode stirred chamber testing.

We will present a risk/cost analysis for each of the correlation functions used to map the LLCW data into the mode stirred data. The optimal correlation function will be selected based on this analysis and a test plan will be prepared for a small test object (black box) where the susceptibility of the test sample will be determined independently via MIL-STD-461D testing.

SYSTEM EXCITATION VIA CAVITY PUMPING AND COMPARISON WITH EXTERNAL FREE-FIELD EXCITATION

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Testing of systems for the effects of electromagnetic environments has traditionally been done by immersing the entire system in the fields of the environment of interest or by applying direct drive techniques to subsystems that form the system. Isolated subsystems have also been tested by exposure to fields in an anechoic chamber, and a limited amount of subsystem testing has been attempted using the fields in a mode-stirred reverberation chamber. A logical extension of these developments is the testing of subsystems in a reverberation chamber formed by the internal cavities of the system itself.

This experiment involved measurements in a large (~ $120m^3$) internet aircraft bay to determine the feasibility of the cavity-pumping test technique. Various coupling measurements were made with the exterior of the aircraft illuminated by a free field environment field. Both stepped monochromatic and stepped bandwidth-limited noise-modulated sources were used to drive the radiating antenna. The coupling measurements were repeated with pumping of the cavity with a bandwidth-limited noise-modulated source. The primary objective of the experiment was to determine whether cavity pumping produces coupling responses in cables and electronic equipment similar to those resulting from external illumination. Secondary objectives included measurement of the cavity Q and field uniformity, determination of the cavity field amplitudes obtainable with available sources, and verification of pumping and measurement techniques.

At frequencies high enough that a cavity can support many modes, the cavity field structure is complicated and exhibits rapid spatial variations. At single observation point the field amplitude and direction show rapid variations with frequency. Averaging the field values over spatial coordinates gives the average cavity field. A similar value can be obtained from field values at a single location by averaging over a frequency bandwidth. Cables in the cavity experience different drive field patterns as the frequency is changed, and exhibit rapid frequency variations similar to those of the cavity. Superimposed on these frequency variations are the oscillations caused by reflections from mismatched cable loads. Both of types of cable response variation can be removed by averaging over frequency. Since transient environments of interest generally have bandwidths greater than the period of these variations, it is the average cable response that is relevant to producing effects in electronics.

If the Q of the cavity is large enough, then at high frequencies (i.e. high enough that the cavity supports may modes) the field in the cavity becomes uniform in a statistical sense (i.e., averages over frequency), and all memory about how energy was introduced into the cavity is lost. Under these conditions it makes no difference to internal coupling responses whether the field was produced by exterior fields leaking through apertures or by an internal source pumping the cavity. Thus, necessary conditions for satisfactory replication of external-illumination coupling responses by cavity pumping is sufficiently number of modes and a high Q.

A model of losses in the cavity was developed to calculate the cavity Q, the number of independent modes, and the field uniformity as a function of frequency. The Q of the cavity was measured from 0.5 to 4 GHz by the injection-loss and the fall-time methods. The field uniformity was determined from analysis of free-field magnetic field measurements at various locations inside the cavity. The measured Q and the field uniformity were in good agreement with the model predictions. Coupling measurements employing external illumination and internal cavity pumping were also performed. Agreement in the field data under the two excitation methods was good.

This Paper will present the theoretical Qs, the number of independent modes and the field uniformity. In addition, we compare the experimental results versus the theoretical predictions.

ELECTROMAGNETIC INTERFERENCE (EMI) INVESTIGATIONS OF A COMMERCIAL GPS RECEIVER--A COMPARISON OF FREE-FIELD AND MODE-STIRRED CHAMBER TEST METHODOLOGIES

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The GPS constellation satellites transmit carrier waves at about 1-GHz frequency that are limited in radiated power to several tens of watts. Because the carrier power density that reaches the earth's surface from these satellites is well-below the level of thermal noise, GPS receivers require sophisticated signal processing circuits and extremely high sensitivity. They are therefore vulnerable to unintentional EMI from localized radio/television transmitters that transmit in their operational bands, and to intentional jamming, as well.

For the past year, we have been studying the EMI susceptibility of a commercial GPS receiver: the Garmin Model 150 Avionics Receiver. These investigations have involved determining power thresholds for external EMI as a function of frequency, and also the development of mitigation or countermeasure techniques for EMI. In particular, we have used the Garmin GPS unit as a test-bed for comparing the utility of two common EMI test methodologies.

A comparison of the response of the Garmin GPS unit to both free field illumination in an anechoic chamber and to electromagnetic excitation in an electronic mode stir chamber (EMSC) was used to determine the effectiveness of the EMSC susceptibility test technique for EMI testing of GPS receivers. Electromagnetic immunity testing of an asset by free field illumination in an anechoic chamber is a widely accepted method that lends itself easily to analysis, but it is relatively slow and expensive compared to the electronic mode stir technique.

In the EMSC technique, a narrow-band white Gaussian noise (NBWGN) signal is injected into a reverberation chamber to create statistical field uniformity in the chamber and to eliminate the need to illuminate the test object at a variety of aspect angles. This method has the advantage over more conventional susceptibility test methods of more simplified data acquisition and shorter test times. Under most circumstances, there is considerable theoretical justification for the applicability of the EMSC technique for EMI testing; this paper presents additional empirical justification by favorably comparing interference thresholds determined by both techniques. It also describes the effectiveness of some simple measures that were developed and implemented for backdoor hardening.

NOVEL ABSORBER FOR ANECHOIC CHAMBERS

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W.Opitz, and R.Schaller, FRANKONIA, D-91180 Heideck

1 The Novel Material

1.1 Systems having linear extensions between 1 nm and 100 nm are called mesoscopic. Such systems have recently found much interest in basic research and for applications. For instance the dc- and ac-film resistance of mesoscopic metal layers is much larger than extrapolated from the bulk value. For instance a 10 nm thick metal layer, i.e. a 2-dimensional conductor, has a film resistance of about 377 $\Omega_{\square}$, a value which corresponds to the characteristic impedance of the vacuum. The theoretical extrapolation from a bulk metal results in a resistance of only 10 $\Omega_{\square}$, such a layer rather reflects like a mirror than absorbs electromagnetic waves.

1.2 For the novel absorber design, such mesoscopic metal layers with a thickness of the order of 10 nm and a film resistance near 377 $\Omega_{\square}$ are deposited on or are brought into an isolating substrate. For instance Titan has been deposited on an organic film of polyethylen by a PVD process.

2. The Absorber:

The mechanical realization of the absorber shape is independent of the absorbing function since the latter is realized by the ultra-low volume of the mesoscopic metal film in a very thin polymer film. So all advantages of an appropriately chosen material for the realization of the absorber shape and cover material also hold for the complete absorber: lightweight, non combustible, weatherproof and otherwise suited. If hollow pyramidal shapes are realized, transportation volume will be low by stacking the absorbers.

3. The Performance:

Absorbers have been already installed in several anechoic chambers for the frequency range 10 MHz to 1 GHz. Compared with the classical carbon loaded foam and ferrite absorbers the field homogeneity of anechoic chambers has reached performance levels never seen before. Even hardest tests like ANSI C63.4 compliance in 10 m semi-anechoic chambers with test volume diameters of up to 8 m have been successfully demonstrated, while test volume diameters of 4 m show values which are only dominated by residual calibration errors of antennas in the range of $\pm$ 2 dB.

Tuesday, May 28, 8:30 AM **Room: Aztec**

UXO-1 **UXO Overview**

Chair: *M. Kolodny, Army Research Laboratory, Adelphi, MD*

8:30 AM **INTRODUCTION & ANNOUNCEMENTS**

8:35 AM **OLD AND NEW UNEXPLODED ORDNANCE LOCATION TECHNOLOGIES**, *S.J. HOOPER, SR., Human Factors Applications, Inc., Holicong, PA* 108

8:55 AM **USATCES AND IT'S ROLE IN UXO/OE REMEDIATION**, *J. GALLAGHER, U.S. Army Technical Center for Explosives Safety, Savanna, IL* 109

9:15 AM **PRESENT SITUATION ON THE FIELD OF UXO IN HUNGARY**, *U.L. LUKACS, Military Academy, Budapest; and I.O. MUELLER, Hungarian Forensic Technical Expert Inst., Budapest , Hungary*....110

9:35 AM **A NEW-GENERATION MAGNETIC SEARCH SYSTEM FOR RAPID ACCURATE UXO LOCALIZATION AND CHARACTERIZATION**, *C.P. FRAHM, Rockwell Defense Electronics, Autonetics and Missile Systems Division, Anaheim, CA* 111

9:55 AM **PROBABILISTIC RISK ASSESSMENT OF EXPOSURE TO UXO AT FORT MEADE, MD**, *J.N. SKIBINSKI, F. ZAFRAN, A. UNGER, M. LUSTIK, L. CAIN and S. SAUNDERS, Science Applications International Corporation, McLean VA; and S. HILL, U.S. Army Environmental Center, Aberdeen Proving Ground, MD* 112

OLD AND NEW UNEXPLODED ORDNANCE LOCATION TECHNOLOGIES

Samuel J. Hooper Sr., Director of Operations, Human Factors Applications, Inc., Ordnance and Explosive Services

At the present time, both old and new technologies are being used to locate buried unexploded ordnance (UXO). The old technologies primarily employ hand held magnetometers and metal detectors to search and mark all subsurface anomalies in a given search area. All of the designated subsurface anomalies are then hand excavated to verify that they are UXO or metallic debris. In reality, the new UXO location technologies are for the most part a combination of the old detection technologies which have been married up with other existing technologies such as land navigation systems and computer software that is supposed to enhance the search equipment performance. With the new technologies, the search data is fed into a computer for analysis and based on this analysis, a map with designated subsurface anomalies is generated. The general location of the designated items must then be reacquired and then each of the designated anomalies must be pinpointed by a UXO technician using a hand held magnetometer or metal detector.

With both the old and new UXO search technologies, there are a number of inherent problems that hinder search operations. The paper being prepared for presentation at the AMEREM 1996 Conference will deal these problems. In addition to these issues, without identifying specific systems or companies, some of the claims related to performance of the new UXO search systems will also be addressed.

As shown by the UXO search system technology demonstrations at Jefferson Proving Ground, the actual performance of the systems currently on the market for the most part, differs greatly from their claimed capabilities. This is a very critical issue at a time when funding versus product delivery must be evaluated to determine the best value that the Government can obtain related to the site UXO survey, sampling, or remediation. With much of this property being turned over to the states and/or eventual private citizen ownership, the Government must have a reasonable confidence that the site has been thoroughly searched using the best UXO location technologies and is reasonably safe to be released.

The type of UXO service the client needs is also a critical issue. The UXO services may be a UXO survey without excavation of anomalies, a UXO survey with random sampling of the anomalies, or a UXO remediation of the entire site to a given depth. The desired UXO services must be taken into consideration during the planning for the project as to what UXO location technologies or combination of technologies are best suited for the project.

USATCES AND ITS ROLE IN UXO/OE REMEDIATION

Ms. Jean Gallagher, U.S. Army Technical Center for Explosives Safety (USATCES)

The USATCES serves as the technical advisor to the Army for explosives and chemical agent safety. Since 1992, the USATCES has greatly expanded its explosives safety support of programs and projects for the removal of ordnance and explosives (OE) from real property.

The Director of the Army Staff (DAS) approved an Explosives Safety Management Plan in February 1988, which established both the USATCES and the Department of the Army Explosives Safety Council (DAESC). The DAESC was established to formulate Army explosives safety policy; USATCES serves as technical advisor in these matters.

In 1992, USATCES began assisting the U.S. Army Corps of Engineers (USACE) in the Formerly Used Defense Sites (FUDS) Program by preparing Archives Search Reports (ASRs). In 1994, USATCES assisted Forces Command (FORSCOM) in preparing the Army's first Base Realignment and Closure (BRAC) safety submission for cleaning up real property containing OE. The OE mission has continued to evolve; currently the Logistics Explosives Safety Division has three teams assigned to ordnance cleanup operations.

OE mission-related responsibilities of USATCES include the following:

- Drafting DA policies that address explosives and/or chemical agent safety controls to be exercised during removal of munitions, explosives or toxic chemical agents from real property.
- Reviewing and providing Army approval of explosives and/or chemical safety submissions for the cleanup of real property containing unexploded ordnance (UXO) and/or explosives as a result of Army activities.
- Providing Army technical review of safety submissions for removal of OE from real property at FUDS.
- Providing technical assistance in the safety management aspects of OE removals and assisting major Army commands (MACOMs) and installations in the preparation of explosives and/or chemical safety submissions for OE removals and subsequent land disposals.
- Briefing will describe the purpose of a BRAC OE explosives safety submission and provide tips on expediting safety submissions.

PRESENT SITUATION ON THE FIELD OF UXO IN HUNGARY.

Dr.Univ.László LUKÁCS,Major,Ph.D. Military Academy Zrinyi Miklós,Budapest. Dr.Ing.Othmar MUELLER,Ph.D. ret.director Hungarian Forensic Technical Expert Inst. Budapest.

In present time there are thousands of UXO-discoveries each year in Hungary, since over 50 years of World War II. was ended here. The sort of the found UXO is very various and broad. In Hungary was a real war in 1944-1945 with hungarian, russian, german and other participiants and also the Allied Forces had heavy bombings also. After ten years here was a revolution 1956 with hard battles between the hungarian revolutionary peoples and the occupying russian /soviet/ army forces. The soviet occupying /-cca.45 years/ and the leaving caused also a great number of hidden and forgotten UXO. Now, at the southern boundary-lines of Hungary, partially some meters inside are layed land-mines of serbian origin.

In Hungary are working two organisations in connection with explosive devices. The Hungarian Army has an UXO-Battaillon for the military-types of UXO. The Hungarian Police has also a Bomb Disposal Unit to eliminate terrorist IEDs /Improvised Explosive Devices/. Sometimes the terrorists are applicating military EODs. /Explosive Ordnance Devices, for example hidden or thrown hand-grenades, rockets,etc./ The mentioned organisations have a very good contact and they are in a close co-working at some special findings.

Hungary is a land-mine cleared land published in some competent informations. The greatest problem is now the danger of unknown / this is a "grey-number and zone"/ UXO of several types /air-bombs,river and land mines, hand-grenades, shooted and not exploded mines, etc./. Such UXO are appareing suddendly on building working sites, fishing actions, or on training fields of the armies.

The lecture will show the statistical situation, the main types of UXO, the experiences of the hungarian disposal units and the possible methods of disposal.

A NEW-GENERATION MAGNETIC SEARCH SYSTEM FOR RAPID ACCURATE UXO LOCALIZATION AND CHARACTERIZATION

Charles P. Frahm, Ph.D., Senior Scientist
Rockwell Defense Electronics
Autonetics and Missile Systems Division
Anaheim, CA

ABSTRACT

There is a large domestic and world-wide need for technologies to remediate areas contaminated by substantial amounts of unexploded ordnance (UXO). It is generally recognized that passive magnetic sensors are currently the preferred instruments for detecting UXO with ferrous content. In fact, the results of recent demonstrations indicate that existing magnetic systems consistently outperform other technologies. Despite their higher performance levels, the existing magnetic systems fail to adequately meet the demanding requirements for cost-effective remediation of UXO-contaminated sites (i.e., high probability of detection, low false alarm rate, accurate 3-D localization, and rapid survey speed). This has spurred an interest in fused search systems employing two or more distinct technologies. Although future search systems are likely to be fused, they will almost certainly continue to employ magnetic sensors as the primary detection, localization, and characterization component. Thus, in any case, there is a real need for innovative improvements in passive magnetic search technology.

To meet the demanding requirements for UXO searches, Rockwell's Autonetics and Missile Systems Division is developing a new high-performance passive magnetic search system. The system will integrate an array of state-of-the-art, low noise, high sensitivity three-axis fluxgate magnetometers with a high precision positioning system and sophisticated signal processing. Against UXO targets this system is expected to have a survey swath width which is several times wider than the size of the array itself. As a consequence, significant survey cost savings will accrue because the system will be able to survey areas much more rapidly and with substantially less pre-survey site preparation. Furthermore, data can be collected along paths of opportunity, reducing the need for establishing survey lanes and markers. It will also have a significant stand-off range for targets in otherwise inaccessible areas, such as under trees, amongst rubble, or in ravines.

The initial system is being designed as a man-portable survey device, so that it can be used in all terrains without the limiting aspects of a towed system. However, the system could be readily adapted for towing on land, in the air, or underwater. With additional software, the system will be able to function not only in a survey mode, but in an "approach mode" as well. In the approach mode the system can locate in three-dimensions and characterize an isolated dipole-like source from a single measurement at one spatial location. 3-D localization accuracy against most UXO objects in both modes is expected to be substantially better than 1 ft. The superior performance characteristics of the system result from a special configuration of the sense elements and a novel compensation mechanism for dealing with the well-known imbalance problem associated with component sensors. System characteristics and performance estimates will be presented in this paper.

PROBABILISTIC RISK ASSESSMENT OF EXPOSURE TO UXO AT FORT MEADE, MD.

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As part of a Base Realignment and Closure (BRAC) study, SAIC is conducting an assessment of unexploded ordnance (UXO) at Fort George G. Meade in Anne Arundel County, Maryland. Fort Meade has been an operating U.S. Army installation since 1917 and encompassed 13,760 acres. In 1988, 9,000 acres of the facility were designated as a BRAC parcel as defined under the Base Realignment and Closure Act of 1988. The 9,000 acre BRAC parcel has historically been used as an ordnance range and training area and includes one active sanitary landfill, four inactive sanitary landfills, and ordnance demolition area, ammunition supply points, and the Tipton Army Airfield. SAIC is evaluating the effectiveness of the UXO surveys previously conducted at Fort Meade through a series of analyses: (1) collection of additional confirmatory UXO survey data, (2) conducting a statistical analysis of the UXO survey data, and (3) conducting a probabilistic risk assessment with exposure to UXO as the endpoint of concern. The probabilistic risk assessment focuses on risks of contact with UXO under a series of land use and exposure scenarios. Exposure scenarios include unrestricted use of Fort Meade as a wildlife refuge and recreational area (hunting, hiking, fishing, jogging), restricted use of the wildlife area (education and research activities), and continued use of Tipton Army Airfield by military personnel. This unique study at Fort Meade will provide the Army with a field-tested method for evaluating the significance of UXO contamination at DOD facilities. SAIC is implementing a statistically-based sampling program for UXO in the BRAC parcel. A computer-based exposure and risk model developed for this project provides both deterministic and probabilistic risk estimates. Results of analysis will be used as a decision-making tool in examining reuse options for the Fort Meade BRAC parcel.

Keywords: risk assessment, exposure, UXO, uncertainty, Monte Carlo, BRAC, DOD.

Tuesday, May 28, 10:40 AM **Room: Cimarron**

HPEM-9 **Signal Processing II**

CoChairs: P. Parhami, SARA
R. Lewis, US Army Corps of Engineers, Vicksburg, MS

11:00 AM **STOCHASTIC ANALYZER – A NEW GENERATION OF EM RECORDING INSTRUMENTATION**, *P. PARHAMI, M. MARINO, C. BERTHOLD and J.T. ROBINSON, SARA, Inc., Huntington Beach, CA; and D. LAWRY, Phillips Laboratory, Kirtland AFB, NM* 114

11:20 AM **DREAM – A MULTIMEDIA WORKSTATION FOR STORING & PROCESSING ELECTROMAGNETIC TEST DATA**, *J.T. ROBINSON and P. PARHAMI, SARA, Inc., Huntington Beach, CA; and N. CARTER and R. MARSON, Defence Research Agency, U.K.* 115

11:40 AM **CASSPER STOCHASTIC ANALYZER – APPLICATIONS**, *P. PARHAMI and M. MARINO, SARA, Inc., Huntington Beach, CA; and D. LAWRY, Phillips Laboratory, Kirtland AFB, NM* 116

12:00 PM **INVARIANCE AS A PRINCIPLE OF SYSTEM DESIGNING**, *O.V. STUKACH and V.N. ILYUSHENKO, Tomsk State Academy of Control Systems and Radioelectronics, Tomsk, Russia* 117

Stochastic Analyzer
A New Generation of EM Recording Instrumentation

*Dr. P. Parhami, M. Marino, C. Berthold, J.T. Robinson: SARA, Inc.
Dean Lawry: Air Force Phillips Laboratory

This paper introduces a new class of instrumentation system, "Stochastic Analyzers" for measuring transfer functions. In contrast with Network Analyzers, which employ a series of narrow band excitations over the bandwidth of interest, Stochastic Analyzers utilize a single wide-band stochastic (random) excitation signal. Signal Identification techniques are employed to reject random noise signal components and to derive complex transfer functions over the entire excitation bandwidth.

The Stochastic Analyzer offers the following key advantages over Network analyzer-based systems for measuring electromagnetic transfer functions:

- using low power wide band excitation signals minimizes/eliminates undesired interference with nearby communication channels — a critical consideration for testing at commercial airports,
- the ability to reject measurement system noise and to quantify confidence in the measured transfer function allows for the development of a fully automated test technique — resulting in significant labor savings during test setup, execution, and data analysis.

SARA has designed and developed CASSPER (Configurable Automated System for Sensing Electromagnetic Radiation) Stochastic Analyzer with the following key features:

- The system consists of a network of spatially distributed and frequency synchronized transmitters and receivers which are interconnected via fiber optics. Up to 63 transmitters and receivers can be daisy chained.
- The excitation signal is a 1 MHz wide programmable stochastic signal which can be transmitted at center frequencies ranging from 100KHz to 1GHz.
- The system has CW (narrow band), and stochastic (wide band) modes of operation. The stochastic mode can use local ambient transmitters as the excitation source — necessary for the development of a hardness surveillance system capable of continuous monitoring.
- Finally, the entire system is controlled and data are processed by a single personal computer. Customized software is being developed for automating CASSPER for a number of EM applications (see our related paper presented at this conference)

The brassboard CASSPER system has been operational since January 1996. The prototype system is currently under development and will be completed by October 1996. CASSPER is expected to be commercially available in the first quarter of 1997. Please visit our booth for a demonstration of CASSPER brassboard system.

DREAM — A Multimedia Workstation for Storing & Processing Electromagnetic Test Data

*J.T. Robinson, Dr. P. Parhami, SARA, Inc.
Dr. Nigel Carter, Roger Marson, Defence Research Agency, UK

During the past four years, the Defense Research Agency (DRA) and SARA have successfully developed and implemented DREAM: a signal processing workstation for storing and analyzing electromagnetic trial data. The program has been an unquestioned success with DREAM being used routinely on various DRA trial types such as Low Level CW, Low Level and High Level Transient, as well as Direct Drive susceptibility. The DREAM architecture lends itself to automation of routine analysis tasks as well as the ability to perform unique and state-of-the-art operations on the recorded data.

DREAM consists of a database and an analysis application for archiving and processing electromagnetic test data recorded by the DRA. The DREAM Data Interchange (DDI) and DREAM MATLAB Matrix (DMM) formats were defined under the original effort, and SARA developed a robust compression scheme to accommodate unevenly-spaced frequency domain data. These low level components have simplified the interchange and archiving of DRA legacy data — currently all DREAM archives are stored in the DDI format. DREAM is now up to version 5.1, and incorporates both traditional EMP time domain analysis, as well as modern HIRF testing algorithms. DREAM also incorporates a full GUI for the analysis performed in MATLAB, AppleEvent communication between the database manager and MATLAB, as well as an extensive on line manual.

Prior to its use of DREAM, DRA estimated that 6 weeks were spent in data analysis and reporting. With DREAM, DRA produces the preliminary report in the field immediately upon completion of the trial. DREAM is flexible enough to meet new test requirements, while the underlying software is constantly updated to incorporate the latest hardware and software performance improvements.

DREAM's DDI file format is 100% compatible with SARA's SWORD workstation standard also presented at this conference. Therefore, DREAM can seamlessly interchange data with all organizations which have adopted the SWORD standard — without any translation software and regardless of the computer platforms employed.

CASSPER Stochastic Analyzer — Applications

*Dr. P. Parhami, M. Marino, SARA, Inc.
Mr. Dean Lawry, Air Force Phillips Laboratory

In a sister paper we describe the Stochastic Analyzer as a new class of instrumentation system with certain key advantages over more traditional Network Analyzers. In this paper we describe applications of Stochastic Analyzer instrumentation technology to several current needs involving evaluation of electromagnetic emissions, coupling, and hardening.

CASSPER is the first implementation of a Stochastic Analyzer being developed under a Phase II SBIR program sponsored by the Air Force Phillips Laboratory. CASSPER is expected to become commercially available during the first quarter 1997. SARA is demonstrating a brassboard CASSPER system at this conference.

The following table outlines a sample of key application areas targeted by CASSPER which will be described in this paper:

Application	CASSPER Advantages
EMP Hardness Surveillance Programs	• Radiated signals will not interfere with nearby RF communication equipment. • Significantly lower cost than a comparably equipped Network Analyzer based low level CW measurement system. • Significantly reduces operator labor via increased automation. • Allows for the development of an in-situ continuous hardness surveillance system using local ambient RF sources.
EMI Field Characterization of Large Manufacturing Facilities	• Will not interfere with facility operations. • System can be quickly deployed and setup in problem areas. • Ambient free field and conducted transient levels of the facility can be fully characterized and cataloged (using multiple distributed receivers). • Ambient field and conducted transient levels of the facility can be reproduced in controlled laboratory environment (using multiple distributed transmitters).
Evaluate EMI from Consumer Electronics to Sensitive Aircraft Electronics.	• Using spatially distributed transmitters in the passenger cabin, any coupling path to the aircraft avionics can be identified and characterized. • The transmitters can be programmed to simulate RF radiation from most popular consumer electronics. • The system can be used to evaluate an aircraft during flight to account for changes in coupling path due to flight dynamics.
FCC Certification in Noisy Urban Environment	• Multiple receivers, surrounding the system under test, can be used to reject external (ambient) RF sources. • Eliminates the need for costly anechoic chambers or the need for testing at remote locations.

INVARIANCE AS A PRINCIPLE OF SYSTEM DESIGNING

O.V. Stukach, V.N. Ilyushenko (TACSR)

The system designing is connected to development of synthesis methods. The modern theory of synthesis is under construction on the optimum principle. Alongside with optimum principle the admissible principle is used. Other, more general is the principle of system invariance.

The problem of invariance was delivered in the theory of automatic control because increase of system work accuracy is required. Invariance is understand as a property of system to resist of hindrances. However the invariance can be considered as a immunity of the system response from any signal parameters. It turned out that the parametrical invariance is more significant, than invariance in a classical sense, and for systems of the most various purpose. It is explained by the response of any systems should not depend on any parameter of effect or system parameters.

It is known, that linear systems has the property of absolute parametrical invariance. The nonlinear system response depends on parameters of effect. And as far as linear systems are unsuitable for practical use, one can try to make the nonlinear system linear. It will cause improvement of the system characteristics, because the system which remaining nonlinear, acquires other not less important property of parametrical invariance. Thus, the invariance can take as a basis of a various system designing principle.

The realization of invariance condition at the system designing is considered on the nonlinear distortions minimization problem in impulse or strongly nonlinear systems. In case of impulse signals, as well as in strongly nonlinear systems the traditional methods are not applicable. For the substantation of other approach we shall notice, that nonlinear distortions are minimum, if the system response does not practically depend on source amplitude or nonlinear elements parameters. The requirement of system response immunity from source amplitude or its parameters and effect parameters meant invariance. Therefore the solution of a considered problem is reduced to synthesis of a invariant system. Nonlinear distortions are minimized by approximation of the nonlinear system response separate parameters to the some linear system response. Thus, for minimization of nonlinear distortions the invariancy defect of the system response form or separate parameters to source signal amplitude are used. Numerical-analytical minimization method of parameter system response dependence from amplitudes of impulses was offered. In case of a known system differential equation the analytical solution is possible.

The realization of invariant systems are considered on example of amplifier and controllable attenuator. An attenuator controlled the power level within 1,5...40 dB and adds a phase shift of about several degrees at working frequencies of 0,1MHz...3 GHz. The picosecond nonlinear impulse amplifier has small dependence of a response from amplitude source sine wave signal by impulse forming.

Tuesday, May 28, 10:40 AM **Room: Galisteo**

HPEM-10 **(Invited) HPM Simulation & Effects**

Chair: *D.V. Giri, Pro-Tech, Lafayette, CA*

10:40 AM **(INVITED) LOW-POWER MICROWAVE (LPM) RADIATING SYSTEMS AND EFFECTS,** *A.W. KAELIN and B. REUSSER, Defence Procurement Agency, Spiez, Switzerland; and D.V. GIRI, Pro-Tech, Lafayette, CA* 120

11:00 AM **(INVITED) A SWEDISH SURVEY OF HPM EFFECTS. THE THREAT, COUPLING PHYSICS AND TESTING.,** *K.G. LOVSTRAND, Defence Materiel Administration, Linköping, Sweden* 121

11:20 AM **(INVITED) HPM-SIMULATION ACTIVITIES IN GERMANY – METHODOLOGY AND ORGANISATION IN THE GERMAN FORCES,** *K. RUFFING, Wehrtechnische Dienststelle fur Fernmeldewesen und Elektronik, Greding, Germany* 122

11:40 AM **(INVITED) HPM AND THE INTERACTION TO THE ELECTRONICS OF SMART AMMUNITION - A NUMERICAL APPROACH WITH EXPERIMENTAL VALIDATION,** *J. BOHL, DIEHL GmbH & Co., Rothenbach, Germany* 123

LOW-POWER MICROWAVE (LPM) RADIATING SYSTEM AND EFFECTS

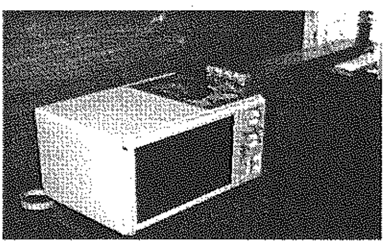
Dr. A. W. Kaelin* and Mr. B. Reusser
Defence Procurement Agency, NEMP-Laboratory, AC Zentrum, CH-3700 Spiez, Switzerland

and

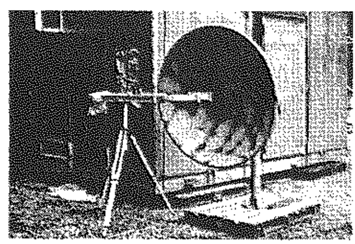
Dr. D. V. Giri
Pro-Tech, 3708 Mt. Diabolo Boulevard, Suite 215, Lafayette, CA 94549-3610, U.S.A.

ABSTRACT

The objective of this study was to design, fabricate and test a low-cost, low-power microwave (LPM) radiating system and also perform some preliminary coupling tests. Pulsed high-power microwaves (>100 MW) operating in a single shot or with tens or hundreds of Hz repetition rates are being developed in various countries and could pose a potential threat. Such systems are reaching power levels in the GW range, and are also frequency agile and intended to create intense electromagnetic signals in the range of 500 MHz to 3 GHz, to cause electronic damage to many military and civilian systems. While several nations may not be interested in developing or deploying HPM weapon systems, they will be compelled to understand the coupling and protect their military and civilian assets. LPM studies are a beginning in this direction at the NEMP Laboratory in Switzerland.



Commercial 800 W microwave oven with WR 340 attached



Parabola antenna fed by WR 340

Since a CW magnetron source at a fixed frequency of 2.45 GHz is readily available from a microwave oven, it was decided to design and fabricate an LPM radiating system capable of producing 100's of V/m electric field at several meters from the source and begin to look at coupling into readily available electronic components. Radiation from three different antennas, namely, i) open-ended WR 340 waveguide, ii) a standard pyramidal horn and iii) an existing reflector antenna fed by an open-ended WR 340 waveguide were calculated. This included both near and far field calculations. The required waveguide components were fabricated and the electric field measurements were performed, for all three radiators. Once the incident field levels were established, several test objects such as, fluorescent lamps, calculators, watches, radios, absorbing materials, explosives were exposed to the CW microwave environment. This presentation will describe the antenna calculations, measurements and coupling effects.

A SWEDISH SURVEY OF HPM EFFECTS. THE THREAT, COUPLING PHYSICS AND TESTING.

K G Lövstrand
Defence Materiel Administration, P.O. Box 13400, S-58013 Linköping, Sweden

The HPM vulnerablility of military electronics is investigated at a Swedish HPM effects survey. The vulnerability of a system is generally determined by several factors such as the HPM threat, coupling phenomena, resonance effects, non-linearities, component physics and many more factors. These factors are investigated in several parallell studies supporting the general systems vulnerability study.

The assumption is made at the study that an HPM weapon is designed according to a set of general systems vulnerablility features. Relevant threat and test features are thus deduced from the character of the hardness. The dominant threat parameters are studied in a test metodology study for objects of different character including testing of real systems, equipment and microelectronic components as well as generic test objects. HPM frequency, intensity, pulse energy, duration and repetition rate as well as duration of a pulse burst have been found to be of importance. The coupling of HPM into an object often shows a pronounced directivity.

Testing may be performed as low level coupling tests at system and equipment level supported by testing of critical microelectronic components. Testing of front end coupling to sensors and receiving systems may in many cases be adequate for determination of the dominant vulnerability of a system. Such testing may sometimes be achieved by microwave injection into a receiver signal input. In other cases testing of a complete live system is necessary in order to establish the vulnerability. Systems testing should normally be supported by additional analysis and component studies. In all cases it is important to have a good knowledge of the governing HPM stress factors for an efficient and reliable HPM system test.

At present a main HPM test system is about to be defined. The complete set of HPM stress factors should be considered at the definition of an optimized test system. Testing may be divided into damaging or permanent upset effects on one hand and disturbing effects causing mission abort on the other. The first type generally requires very intense and energetic pulses having a character that will couple hard to the target and its sensitive electronics. The other type should have a character that will couple to the target and above all have a pulse repetition and duration pattern that will cause upset of the signal processing and function of the test object. The intensity of such pulses could often be much lower than that of the first type. An optimal test system should thus be able to generate HPM of variable frequency content and both energetic monopulses or pulses with low repetition rate and pulse trains with a variable repetition rate of at least 0.1-1 kHz. The test system should be able to illuminate an area of the test object at least as large as the part of an object that accumulates HPM power in a cooperating resonance volume. The system requirements may be limited by the use of a combination of low-level testing, equipment testing and threat level system testing. At the definition of the test system optimisation possibilities were found by exclusion of a few test objects having some extreme properties e.g. susceptibility to high pulse repetition rate or having large receiving antennas. Such objects could be treated by analysis or component testing.

HPM-simulation-activities in Germany
Methodology and Organisation in the German Forces

Klaus Ruffing, Baudirektor
Section Leader Fachgebiet EMV
Wehrtechnische Dienststelle
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Kalvarienberg
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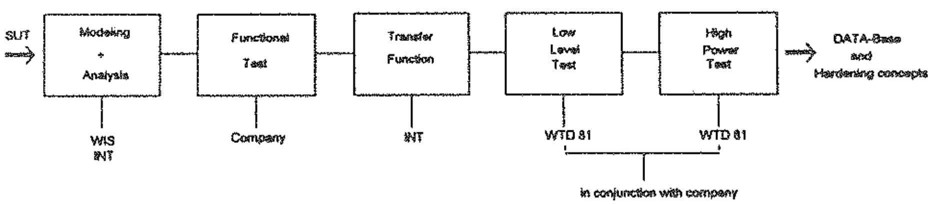
The German DoD-HPM research program uses an assessment process by the various organizations involved. The responsibility of all EM Effects (includes HPM) is defined in Fachgebiet EMV at WTD 81 (Technical domain on Electro-Magnetic-Effects.)
Within this section there are three different locations with several main fields. Today, we use mostly resonance tests to predict the parameters leading to some kind of systems disturbance. This will be supplemented by low power (low level) coupling tests to investigate the specific path and components underlying the overall system effect. Up to now this method will not directly indicate the specific component effect, it will, however, markedly limit the possibilities.

The methodology depicted in Figure 1 is a carefully structured combination of analysis - pre tests and assessment, low level tests, further assessements, high power test and final assessment which allows the highest degree of flexibility depending upon the resources available.



Lead function: Fachgebiet EMV

The modeling/analysis are made to find out resonant frequencies of the System Under Test (SUT).
The calculations are made for front/backdoor coupling (resonances), associated with hardy resonance effects.

The power-off/on tests does provide informations on critical frequencies, polarization, and angles of incidence.

Low and high power test are carried out to get the HPM parameters of SUT.

HPM and the Interaction to the Electronics of Smart Ammunition

> A Numerical Approach with Experimental Validation <

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Smart ammunition and missile systems are characterized by the use of highly complex electronics, computers and sensors. On one side, these systems provide excellent performance regarding the mission they are designed and built for. On the other side, these systems are due to their design requirements especially vulnerable against electromagnetic fields radiated from HPM- and similar sources. This vulnerability and susceptibility must be seen as a threat and as a chance as well. The friendly systems have to be hardened against this threat whereas the unfriendly smart ammunitions and missiles should be combated using HPM- and similar sources.

The consideration of this problem leads to a structured advance by bounds with the proposed splitting into the ***interaction of the free-field-condition to the missile's structure*** with the surface-currents and -charges, the cavity resonances and the induced currents on the wirings of the system. Secondly, into the ***susceptibility possibilities of the incorporated electronics and sensors*** caused by the induced currents on the wirings directly or indirectly via the induced cavitiy-resonances (figure 1).

Investigations are conducted under analytical, numerical and experimental aspects, whereas the systems or subsystems are powered and held in a defined flight-condition during the experiments. The investigations are based on available tactical hardware. The measured and simulated responses of the electronic-circuits due to the induced interferences are used as input-data for 6-DOF flightpath-simulations.

The interaction of the free-field-condition to the missile`s structure is determined using a program based on the FDTD-Method (Finite Difference in Time Domain). For the determination of the interferences of the electronics a CAE-Program is used for high-frequency response simulations of the electronic circuits depending on the measured and simulated induced interferences.

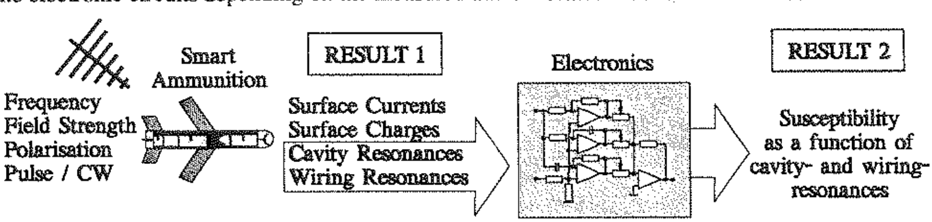

Figure 1: Structured procedure for the HPM susceptibility assessment of smart defense systems

Tuesday, May 28, 10:40 AM **Room: Aztec**

UXO-2 **Soil Characteriztion**

Chair: *G. Olhoeft, Colorado School of Mines, Golden, CO*

10:40 AM **COMPLEX PERMITTIVITY OF SOILS MEASUREMENTS IN THE S-BAND**, *C. STEUKERS, Royal Military Academy Brussels, Brussels, Belgium; and I. HUYNEN, Universite Catholique de Louvain, Lovain, Belgium* 126

11:00 AM **EFFECT OF SOIL CHARACTERISTICS ON MINE DETECTION: A CASE HISTORY OF CANADIAN EXPERIENCE IN FORMER YUGOSLAVIA**, *T.J. KATSUBE and G.M. LeCHEMINANT, Geological Survey of Canada, Ontario, Canada; and Y. DAS, Defence Research Establishment Suffield (DRES), Alterta, Canada* 127

11:20 AM **USING GEOLOGIC HETEROGENEITY TO DETECT BURIED OBJECTS**, *G.R. OLHOEFT, Colorado School of Mines, Golden, CO* 128

COMPLEX PERMITTIVITY OF SOILS MEASUREMENTS IN THE S-BAND

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Many of the advanced applications of electromagnetic waves like the detection of buried objects with Ground Penetrating Radar, the remote sensing of terrain with Ultra-Wide Band Synthetic Aperture Radar and the neutralization of Unexploded Ordnance by means of High Power Microwaves have one point in common : the study of the electrical properties of the soil. The better the knowledge of their dependency on the physical and mechanical properties (texture, porosity, plasticity, water content), the more cost effective the design of an appropriate system will be. A large amount of data have been collected in the past about the dielectric constant and the conductivity of minerals and rocks. Fewer measurements were carried out on runned soils which are of major concern in the abovementionned applications, especially for the neutralization of landmines which can only be buried in these types of soil. Therefore, a global measurement campaign has been started at the Royal Military Academy Brussels to determine the electrical properties of various types of soils between 0,4 and 4 GHz.

This paper reports recent measurements of the complex permittivity of soils in the S-band (2 - 4 GHz), carried out in the frame of a study concerning the neutralization of buried landmines by High Power Microwaves. Because of the surface roughness and the lack of rigidity of the most soil samples, the coaxial probe method was unpractical. Hence other methods have been applied.

The first one is the classical slotted line method : a waveguide section is partially filled with the material under test and the value of its complex permittivity, which determines the surface impedance of the air - dielectric interface in the guide, is deduced from VSWR and length measurements.

A second method, developped at the UCL Microwaves Lab, considers two identical waveguides with a different length. The transmission parameter $\exp(-\gamma L)$ of a waveguide of length L filled with the soil is obtained by measuring on a vector network analyser (VNA) two complex quantities on two waveguides of the same cross-section (i.e. four scattering parameters), filled by the substrate but differing by a length L. Because the unknown quadripoles, characterising the transition from the coaxial acces of the VNA to the reference planes of the section L are reciprocal and physically identical, it is possible to measure the transmission parameter the filled waveguide with only two elements, from which the soil permittivity can be deduced.

EFFECT OF SOIL CHARACTERISTICS ON MINE DETECTION: A CASE HISTORY OF CANADIAN EXPERIENCE IN FORMER YUGOSLAVIA

Katsube, .T.J.*(1), Das, Y.(2) and LeCheminant, G.M.(1)
(1): Geological Survey of Canada, 601 Booth St.,
Ottawa, Ontario, Canada K1A 0E8.
(2): Defence Research Establishment Suffield (DRES), P.O. Box 4000,
Medicine Hat, Alberta, Canada T1A 8K6

ABSTRACT

Canadian military engineers encountered interference in mine-detection when operating over certain types of soils common in former Yugoslavia (Croatia). Samples of the soil were transported to Canada for investigation. Geology of the problematic area is known for its karst formations and its abundance of Terra Rossa soil, suggesting the soil and underlying crust (metallic mineral grains cemented together) might be the source of interference because of the possibility of their high electrical conductivity and magnetic susceptibility. A comprehensive study consisting of physical (electrical and magnetic), mineralogical and chemical analysis were performed on the samples.

Results indicate the samples consist of granular material (fragments of limestone and cultural material such as reddish brick/tile) imbedded in a matrix of Brown Forest soil of high carbonate content and organic material. Surprisingly, the soil (matrix material) showed no signs of high electrical conductivity. However, some limestone-like fragments showed very strong electromagnetic and magnetic responses, and other granular and some parts of the soil showed moderate to weak responses. Results of microscope, scanning electron microscope and x-ray diffraction analysis indicated that these limestone-like fragments were small man-made iron particles coated with carbonate and silicate grains cemented by iron oxide (rust), a result of iron fragments being buried in soil for long periods of time. These fragments were hardly distinguishable from natural limestone. These analyses also indicated that the moderate to weak responses were a result of fine grained iron oxide (e.g., hematite) in the brick/tile, and of other cultural material (man-made iron particles <5 mm) and fine-grained natural magnetite in the soil.

Using Geologic Heterogeneity to Detect Buried Objects

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The processes of geology that emplace soils and sediments leave behind patterns of heterogeneity that are very distinctive. Such patterns are studied and described by earth scientists because they give clues to the processes that created the materials. The patterns also give indications of how the materials will react when manipulated (such as flowing a fluid through or ripping with a bulldozer). The operations of digging or trenching disturb these patterns.

The high resolution of ground penetrating radar allows rapid characterization and quantitative statistical description of these patterns of heterogeneity over distances of hundreds of meters with centimeter scale resolution. It also allows automatic mapping of disruptions in the patterns. Some changes in geologic heterogeneity are caused by natural processes such as stream channels that become buried after a landslide or the transition from an aeolian to a fluvial environment where wind blown sand dunes are washed away by a river. Quantitative description of geologic heterogeneity provides a background to describe the normal environment.

Objects with no physical properties contrast (such as plastic) have been found by mapping the change in the background geologic heterogeneity caused by the burial process. This is most obvious in the location of sites where plastic pipe has been buried in trenches, but is also visible in the burial of plastic land mines and in the location of repeated travel patterns. It has also sometimes been used to identify or discriminate objects with similar physical properties contrast and size when one is out-of-place in the context of the normal geologic heterogeneity.

Tuesday, May 28, 1:30 PM **Room: Aztec**

HPEM-11 & UWB, SP-7 HPM Sources, Photonics & Techniques

CoChairs: M. Arman, Phillips Laboratory, Kirtland AFB, NM
A. N. Sandalov, Moscow State University, Moscow, Russia

1:30 PM **INTRODUCTION & ANNOUNCEMENTS**

1:35 PM **MICROWAVE PULSE ENERGY COMPRESSION**, *A.N. DIDENKO, Russian Academy of Science, Moscow, Russia; and YR.G. YUSHKOV, Tomsk Polytechnical University, Tomsk, Russia* 130

1:55 PM **EXPERIMENTAL STUDIES OF A GENERATION DELAY TIME IN REFLEX TRIODE WITH INDUCTIVE STORAGE**, *A.N. DIDENKO, V.E. FORTOV, K.V. GORBACHEV, E.V. NESTEROV, S.A. ROSCHUPKIN, V.P. SHUMILIN and V.A. STROGANOV, Russian Academy of Sciences, Moscow, Russia* 131

2:15 PM **(INVITED) TESTING MICROWAVES FACILITIES OF HIGH-POWER PULSE RADIATION SOURCES BASED ON VIRTODE**, *N.P. GADETSKII, K.A. KRAVTSOV, I.I. MAGDA and YU.V. PROKOPENKO, Khar'kov Institute of Physics & Technology, Khar'kov, Ukraine* 132

2:35 PM **PHASE-LOCKING CONDITIONS OF VIRTUAL CATHODE OSCILLATOR**, *P. XIANGYANG and L. CHUAN-LU, National University of Defense Technology, Changsha, Hunan, China* 133

2:55 PM **PHOTONIC CRYSTALS FOR HIGH POWER MICROWAVES**, *K. AGI, M. MOJAHEDIE, K.J. MALLOY, L.D. MORELAND and E. SCHAMILOGLU, University of New Mexico, Albuquerque, NM; and J. SADLER and H. POHLE, Phillips Laboratory, Kirtland AFB, NM* 134

3:15 PM **BREAK**

3:40 PM **THE TIME EVOLUTION OF PHOTONIC CRYSTAL BANDGAPS**, *K. AGI, M. MOJAHEDIE and K.J. MALLOY, University of New Mexico, Albuquerque, NM* 135

MICROWAIVE PULSE ENERGY COMPRESSION

A.N.Didenko*, Yr.G.Yushkov**

*Russian Academy of Science, 117334, Moscow, Russia
**Scientific Research Institute of Nuclear Physics
of Tomsk Polytechnical University, Tomsk, Russia

High strength of electromagnetic waves and thermal and deformation processes that creates by high power microwaves can have sufficient interest for various technological purposes.

It was shown before that optimal duration of pulse varied from one to several tens nanoseconds and when density of high power microwave is equal to several Megawattes per sqcm, the pulse duration is equal to several tens nanoseconds.

Such a high power microwave can obtain not only by the methods of relativistic electronic but also on the base of usual radar microwave generators using method of microwave pulse energy compression. The basis of an operation of these devices is an microwave energy storing in a cavity and a following rapid extraction of a stored energy. The method requires of an application of waveguide resonant lines having input and output elements for transmitting of microwave energy.

Laboratory specimens of the devices in 3-cm, 10-cm and 300cm wavelength bands are created and they allow to get the microwave pulse power from 1 MW to 100 MW with minimum pulse width 1-2 ns. These devices amplify the input power of an exiting generator with coefficients equal to 50, 100 and 200 correspondently to the three wavebands mentioned above.

The compression of microsecond pulses of 1.3 MW pulse power of the industry issued magnetron of 10-cm wavelength band was carried out in the series compression system having three units. Output pulses at the output port of the last one had pulse power of 600 MW and pulse width of 0.5-0.7 ns that corresponded to 1-2 oscillations of a microwave field.

Microwave pulse obtained through the compression method can be used in high distance resolution radiolocation; in the studying of the simulation on biological objects and on radio-electronic elements and in the pumping of gaseous discharge lasers.

EXPERIMENTAL STUDIES OF A GENERATION DELAY TIME IN REFLEX TRIODE WITH INDUCTIVE STORAGE

Andrew N.Didenko, Vladimir E. Fortov, Kirill V. Gorbachev, Eugene V. Nesterov, Serge A. Roschupkin, Vladimir P. Shumilin*, Vadim A. Stroganov

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Virtual cathode devices are highly promising microwave oscillators. The capability to operate without external magnetic field is the most advantageous distinguishing feature of such devices. If the problem is to design the compact pulse microwave generator, this feature is very important.

It has been found recently that the process of high power microwave oscillation in reflex triode with inductive storage distinguished considerably from that in conventional schedules, when as the source of a voltage, the high current accelerators with forming lines were used. This is because of the delay time between the beginnings of the oscillations and current pulse in diode. The generation was began, as a rule, in a phase when the current decreased, and the power efficiency in this case was rather low. The causes of this generation delay time has been not understood yet. The fact that the generation delay time was proportional to the current rise-time gave some hopes to increase the efficiency by shortening the current rise-time. In our experiments we tried to check this supposition. We produced the current pulses in reflex diode with the peak values and front-times being close to those, received with the help of conventional forming lines.

We have found experimentally that the decrease of the current pulse rise-time brought about the shortening of the generation delay time, but the power efficiency was not increased. As a result of the increase of the beam maximum current the generation starts at the current pulse forward front.

TESTING MICROWAVES FACILITIES OF HIGH-POWER PULSE RADIATION SOURCES BASED ON VIRTODE

N.P. Gadetski, K.A. Kravtsov, I.I. Magda, Yu.V. Prokopenko
National Science Center "Khar'kov Institute of Physics & Technology"
Akademicheskaya, 1, Khar'kov, 310108 Ukraine

Testing microwave facilities of the NSC "KhIPT" with the large pulse power levels have used a variety of vircator with the output power and frequency control - Virtode. A high-current relativistic device of that type represents the radiation source of high level convenient for experiments on electromagnetic compatibility and resistance of electronic equipment to effects of the ultrashort duration pulse microwaves (N.P. Gadetski, I.I. Magda, S.I. Neisteter, Yu.V. Prokopenko, V.I. Chumakov, Plasma Phys. Rep. 1993, v. 19 (4), p. 273; and S.P. Bludov, N.P. Gadetski, K.A. Kravtsov, Yu.V. Lonin, I.I. Magda, et al., Plasma Phys. Rep. 1994, v. 20 (8), p. 643.). The output power control within the limits of 50 - 500 ÌW at an efficiency of 20% is obtained due to microwave feedback signal phase variation. The radiation in frequency range of 2,5 - 10 GHz is provided depending upon the coupling efficiency and working frequency of a compound system virtode - BWT, that uses the relativistic beam-current modulation in the area of beam collector. The absence of resonators in the working area of the virtode electrodynamic structure and the broadband input matching of the control signal at traveling wave regime are the peculiarities of the device providing generation and amplification of the ultrashort duration pulse microwaves.

Phase-Locking Conditions of Virtual Cathode Oscillator

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Department of Applied Physics, National University of Defense Technology
Changsha, Hunan, 410073, P.R. CHINA

ABSTRACT

Experiments have demonstrated that virtual cathode oscillator(VCO) can be locked by the injected signal from,for example,relativistic magnetron.This can be described by Van der Pol Equation,with a forced oscillation term on its right side:

$$d^2E/dt^2 - 2\gamma\,(1 - E_0^2/E_{nl}^2)\,dE/dt + \omega_0^2E = -(2\omega_i^2/Q)\,E_i\mathrm{Sin}(\omega_i t)$$

Phase locking conditions for driven vircator have been widely studied.Usually,these conditions include some unknown quantities,such as the amplitude (E_0) of the vircator after phase locking.In this paper,a sufficient and necessary condition(under first approximation) is derived,completely expressed by the original coefficient of Van der Pol equation($\gamma, E_{nl}, \omega_0, \omega_i, E_i$).It may be called as direct condition,for one can judge whether phase locking occurs only by the coeffient of the equation.

Another way of phase locking is mutual phase locking or peer-to-peer phase locking.An important condition of this way is that the length of the conecting bridge should be $n\lambda/2$, λ is the wavelength of microwave.It can be obtained from the coupled Van der Pol equations.In this paper,the bridge is considered as a resonant cavity with a small aperture in each end. The most efficient coupling between VCOs occurs only when the bridge is resonant with microwave.From this point of view,the same condition is derived.Because no special equations are used,this condition may be universal.

PHOTONIC CRYSTALS FOR HIGH POWER MICROWAVES

K. Agi[1], M. Mojahedie[1*], L.D. Moreland[2], E. Schamiloglu[2], K.J. Malloy[1], J. Sadler[3], and H. Pohle[3]

[1]*Center for High Technology Materials*
University of New Mexico

[2]*Pulsed Power and Plasma Science Laboratory*
University of New Mexico

[3]*Phillips Laboratory*
Kirtland Air Force Base

Photonic crystals (PCs) are three- or lower-dimensional periodic dielectric structures that exhibit ranges of frequencies (stop bands) where propagation of electromagnetic radiation is forbidden. If the stop bands are omnidirectional, the PC dispersion relation exhibits a full forbidden region or bandgap, and these structures are therefore known as photonic bandgap structures. We have recently begun the first investigations of high power microwave (HPM) applications of photonic crystals. Here we present results from experiments where a PC is used as a quasi-optical component for high-power microwaves. We find that the frequency selectivity of the photonic crystal can be utilized to control the radiation emanating from the HPM source.

The Sinus-6 electron-beam accelerator-driven backward wave oscillator (BWO) was used as the source. A mode converter was placed between the BWO and the conical horn antenna to convert the output TM_{01} mode from the BWO into a TE_{11} mode. The RF frequency and the peak power densities measured 1.16 m downstream from the horn antenna are 9.7 GHz and 325 kW cm^{-2}, respectively. All the results reported here were obtained by averaging over many shots from the Sinus-6. For contrast, two photonic crystals with stop band centered about 9.5 GHz (in-gap) and 19.5 GHz (out-of-gap), are used for the measurements.

Traditionally, metallic reflectors are used to guide the electromagnetic radiation. In the experiments presented here, the frequency selective characteristics of the photonic crystal is utilized to emulate a quasi-optical reflector; the in-gap crystal exhibiting strong reflection and the out-of-gap crystal exhibiting small reflection. Results show that even under high power excitation, the photonic crystal exhibits a linear response. In addition, in contrast to a finite, planar-metallic reflector, the crystal response shows no edge diffraction. Furthermore, the edge currents that can play a role in air breakdown are eliminated with the dielectric structures.

In HPM, heating effects due to ohmic and dielectric losses are important. Infra-red thermal pattern imaging was used to characterize heating effects in the PC as well as the relative strength and intensity of the scattered fields. The response of the photonic crystal to various CW microwave excitation frequencies and power levels were studied. Preliminary results show only minimal heating takes place within the crystal. This technique is useful for further characterization of photonic crystals.

THE TIME EVOLUTION OF PHOTONIC CRYSTAL BANDGAPS

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The study of Photonic Crystals (PCs), which are three or lower dimensional periodic structures, has predominantly focused on steady state bulk properties such as bandgaps, band edges, and density of states. However, the time evolution of the bands has not yet received similar attention . In this paper the time evolution of PC bands are investigated in two parts. First, joint-time-frequency analysis (JTFA) algorithms are used to study the evolution of stop bands in a one-dimensional PC. Secondly, using the insights obtained from the one-dimensional case, the stop band evolution of a three-dimensional PC are discussed.

The three-dimensional PC studied here is a face-centered-cubic (fcc) arrangement of cylindrical air atoms in a dielectric host. The host material used is a low-loss Stycast plate with a dielectric constant of 10. The thickness of the plate was chosen to scale the stop-band near the peak of the short-pulse excitation (22 GHz). Three periods are used to study the bandgap evolution such that the center period is in a symmetric scattering environment.

The experimental set-up consists of photoconductively switching planar antennas to generate and detect short pulse radiation. The optical source is a mode-locked titanium-sapphire laser that generates 6 ps pulses at 76 MHz repetition rate and a (tunable) wavelength of 740 nm. The antennas are printed, using standard lithographic techniques, on low-temperature-grown (LTG) GaAs with a recombination time of 0.8 ps. The fast recombination time results in the bandwidth of the electrical pulse and hence the radiated pulse, being limited by the antenna and not the material. Typically, the usable frequency content of the radiated waveform is from 5 to 70 GHz.

The system response is de-embedded from the photonic crystal response to obtain the transfer function (frequency-domain) of the photonic crystal. These results are compared to CW measurements that are performed on the crystal using a network analyzer for verification. By taking the inverse Fourier transform of the transfer function, one obtains the impulse response (time-domain) which is then used, in conjunction with JTFA algorithms, to map out the stop-bands as a function of both time and frequency.

Results on time evolution of stop-band for the one- and three-dimensional PCs will be presented. Furthermore, the analogies between quantum mechanical tunneling of electrons through a potential barrier and tunneling of optical pulses through photonic band gaps are used to discuss the time evolution of the stop-bands.

Tuesday, May 28, 1:30 PM **Room: Brazos**

HPEM-12 **Antenna Topics**

CoChairs: M. Litz, Army Research Laboratory, Adelphi, MD
P. Barré, Phillips Laboratory, Kirtland AFB, NM

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AIRFRAMES AS ANTENNAS

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Aircraft have long been used as platforms for various kinds of antennas for various applications (radio, radar., direction finding, etc.). Many of these antennas are small compared to the major aircraft dimensions such as fuselage length and diameter, wing length, etc. These antennas can be electrically large and/or small depending on frequency or pulse characteristics, whether or not they use a metal aircraft skin as a ground plane. This paper considers large antennas (including arrays) which use a large portion or all of the external airframe. These antennas are for operating in the HF or VHF bands, including pulses dominated by these frequencies.

The current discussion concerns the use of such antennas as radars with frequencies considerably below those in common use. By moving the frequency down to the resonant region of airborne targets (aircraft, missiles), one can, in some cases, increase the scattering length (and cross section), thereby allowing one to detect the target at larger ranges. In addition, the target natural frequencies can be used as identifier via the SEM (singularity expansion method) representation of the scattering. The large dimensions of the target are of the order of a half wavelength in size at the lowest order resonances, thereby indicating the important frequencies. In order to effectively radiate such frequencies, one needs antennas of similar dimensions (or larger), thereby indicating the use of major portions of the airframe of the airborne antenna platform.

In order to achieve cross-range resolution and suppress ground clutter, one can use SAR (synthetic aperture radar) techniques. The SAR portion is not for identification, but location. Note that we are not looking for resolution sufficient to resolve small geometric features of the target sufficient to produce an identifiable image. We are looking for enough resolution to pinpoint the target location (average), especially in cross range. The SAR technique allows one to achieve this resolution, even with these relatively long wavelengths. Note that SAR is not the only way, in principle, to achieve this resolution. With two radar aircraft one can also use bistatic techniques.

SHIP PLATFORM FOR HF/VHF ARRAYS

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In order to transmit and receive electromagnetic waves as a surface wave over the ocean and scan the beam in azimuth as a radar one can design arrays of antennas on a ship. The frequencies of interest for such surface waves and for some targets of interest near the ocean surface lie in the HF and VHF bands. The distance out to which such a wave can effectively propagate is strongly affected by the sea state(wind speed).

In order to transmit and/or receive such a surface wave there are various places one might mount antennas on a metal ship surface. Since one will, in general, wish to steer the radar beam so as to locate the target in range and azimuth, one can have one or more arrays of antennas mounted on the ship. While one can use arrays for both transmit and receive, one can also use an array for one function and a more azimuthally omnidirectional antenna for the other function, and still obtain target bearing. Such arrays can be extended along either or both sides of the ship to steer the beam fore and aft on the desired side. Note that as a surface-wave radar, it is targets near the sea surface (ships, low-flying aircraft and missiles, periscopes, etc.) that are of interest.

Assuming a typical ship with an approximate vertical symmetry plane, then port and starboard arrays can be placed symmetrically with respect to this plane. There are various locations on the hull, deck, and gunwale. Mounting antennas outside the hull involves various considerations. One may wish the elements to be near the water line (say within a quarter wavelength, or about 7.5 m at 10 MHz or 2.5 m at 30 MHz). However, antenna efficiency is not the only factor since one must allow for the spray and splash from the sea under various conditions. Mounting antennas on the deck has other problems, including closer proximity to other electromagnetic radiators and scatterers. However, one can combine the electric- and magnetic-dipole properties to give some low-frequency directionality. The antenna design is also influenced by the various frequencies one may wish to use. This could take the form of operating one frequency at a time, or some spectrum of frequencies simultaneously, or even some kind of pulse, the two-sided Laplace (or Fourier) transform of which has some special spectrum for use in target identification.

COMPUTATIONAL AND EXPERIMENTAL INVESTIGATIONS OF SHAPED END RADIATORS

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The experimental and computational results of the near and radiation fields from two types of Shaped End Radiators (SER) is presented. These two radiators receive at their input the circular symmetric TM_{01} mode of a circular waveguide and radiate this energy into a highly directive beam of microwave energy. The diameter of the input waveguide is approximately 1.25λ. The first radiator is a basic SER which is simply a circular waveguide with a bevel cut end. SERs with bevel angles of 20° and 30° radiate an approximately elliptical beam. A SER prototype with a 30° bevel has a measured directivity of 13 dB and compares to the 13 dB gain calculated from a Finite Difference Time Domain (FDTD) code run (J. H. Beggs, R. J. Luebbers and B. G. Ruth, IEEE Transactions on Antennas and Propagation, Vol. 41, No. 9, Sept. 1993) on a model of the prototype. The SER is an efficient and very inexpensive radiator for the TM_{01} mode but, due to a geometrical limitation, has a low effective aperture for large aperture areas and hence a practical upper limit on the maximum gain. This problem is eliminated by a prescribed smooth circular to elliptical waveguide transition with a bevel cut end. This together with a waveguide axis offset function that acts to increase and shape the aperture area of the SER and radiused aperture edges has led to a radiator with a circular beam having much higher gain and very low back lobe radiation. The final geometry can only be adequately described as spoon shaped and hence it has been coined the Spoon Shaped End Radiator (SSER). A laboratory prototype has a measured directivity of 19.1 dB and a -40 dB back lobe.

Quantitative spherical power pattern measurements were taken of the prototypes at 18 GHz. Qualitative infrared measurements were also taken. These were performed by placing a lossy carbon-loaded medium mounted on a rigid non-conducting material at various planes of interest. The resultant two dimensional pattern of the joule heating due to the tangential electric field at the surface was then imaged using an infrared camera. Photographs of the electric field intensity pattern at various positions within the waveguide and antenna aperture were obtained. Near-field radiated patterns in the longitudinal (vertical) plane were also photographed. Quantitative Finite Difference Time Domain (FDTD) code calculations were performed on approximate cubic cell structure models of the SER and SSER that provide near fields in the same planes as the infrared measurements and farfield radiated power patterns at the same angles as the spherical power pattern measurements.

COAXIAL BEAM ROTATING ANTENNA (COBRA) CONCEPTS TO PRODUCE CIRCULARLY POLARIZED FIELD WITH A BORESIGHT PEAK

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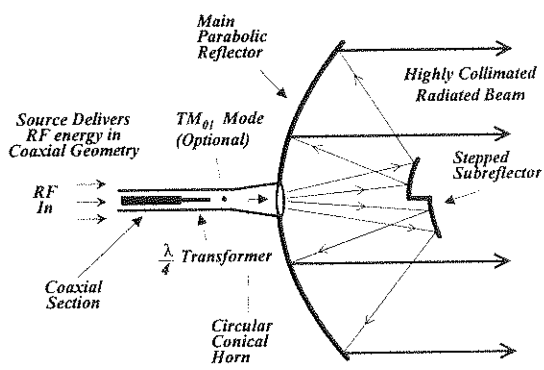
Many high power microwave (HPM) sources utilize the TM_{01} (E_{01}) circular waveguide, or the coaxial TEM mode as the output mode. If radiated directly, these modes generate a doughnut-shaped pattern with a boresight null. To avoid this, one often resorts to mode conversion techniques to convert the azimuthally symmetric mode to a more useful circular TE_{11} or rectangular TE_{01} mode. Unfortunately, mode conversion is not perfect (efficiencies are typically 50% to 75%), and the addition of the mode converter adds weight and length to the source. Antenna designs that avoid mode conversion have been considered, but they tend to be low gain, do not radiate a boresight peak (along the axis of the source), and consequently the nature in which the HPM source is pointed becomes an issue. This paper describes a concept for a novel class of reflector antennas. Designated the Coaxial Beam-Rotating Antenna (COBRA), these antennas accept directly the guided mode of the source and radiate a high gain, circularly polarized, pencil beam boresight peak. The fundamental idea is to use a stepped reflector to transform the azimuthally symmetric mode of the source. Various configurations of the COBRA concept will be presented including: single, stepped parabolic reflector; dual reflector with stepped subreflector; and configurations with coaxial feeds that drive directly the reflector / subreflector. An analysis of the radiated field dependence on the number of steps in the reflector, and calculations to show its circularly polarized nature will also be presented.



COBRA Antenna Concept (Cassegrain Option)

Investigation of Corona Losses on High Voltage Pulsed Dipole Antennas

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Advances in pulsed power technology have recently resulted in pulsed RF and impulse sources operating at or above the megavolt level. It is to be expected that, at some point, atmospheric breakdown and corona losses will limit radiated field strength. A point of diminishing returns could ultimately be reached where more antenna voltage does not increase radiated fields proportionately. For the past year, Sandia Labs has explored the practical limits of voltage which may be applied to a simple antenna and measured the associated losses.

The test set-up comprises a 50 MHz pulsed RF source, parallel plate transmission line, and half wavelength dipole antennas. The source is a mismatched bipolar Blumlein with 100 ohm impedance and maximum operating voltage of 1.4 MV (20 GW peak power). The dipole is mounted horizontally, one quarter wavelength above the ground plane. Antenna element diameter affects electric field strength at the surface of the conductor so that corona losses would be greater on small diameter structures. Therefore, radiated field strength measurements were made with three dipoles of varying diameter (2 mm, 1.6 cm, and 25 cm). Radiated field strength measurements were made overhead in the far field by a D-dot monitor.

Data were collected for the three antennas operating up to 1.4 MV source voltage. The testing was done both with the dipoles in air and in SF6 insulating gas enclosures. Three dimensional curve fitting software was used to generate an empirical equation describing the overall performance. The data fit the simple expression $z = a + bx^c y^d$ where x is dipole diameter in cm, y is source voltage in kV, and z is normalized radiated electric field in kV/m. For the air data, the value of a was small, and b was nearly 1, so radiated fields varied essentially as voltage to the 2/3 rds and diameter to the 1/5 th (the c and d coefficients). This curve fit described the entire system performance including losses in the source, transmission line, antenna match and bandwidth, and high voltage corona losses. Especially for the smaller antennas, the source voltage versus radiated field strength curves went nearly flat at high voltage indicating that the corona losses were very severe.

USE OF RECIPROCITY AND FDTD TECHNIQUES IN NEAR-FIELD ANTENNA CALIBRATION

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The sensitivity of an axisymmetric restively loaded antenna in the near field may be determined using a two dimensional finite difference time domain Maxwell solver. In this paper, the response of a discone antenna to near field excitation by an electric dipole source is derived by using the finite difference method for a step function current injected at the antenna feed point to determine the electric field away from the antenna. The field in the time domain is then fit to a series of exponentials for times before possible reflections from the calculational boundaries. A typical fit is shown in Figure 1, where we have not fit the high frequency oscillations known to result from dispersion in the finite difference approach. For an electric dipole source oriented parallel to the axis of the discone, the reciprocity relation becomes

$$P'E = IV$$

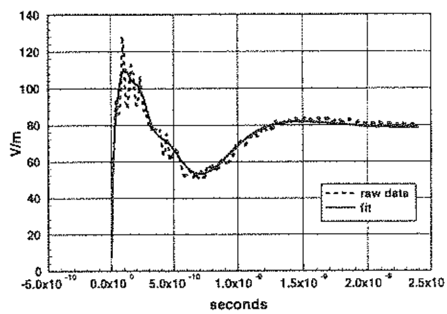

Figure 1. Complex exponential fit to FDTD solution.

where I is the step function current injected at the antenna feed in the FDTD simulation, P' is the dipole moment time derivative, E is the electric field at the observer in the FDTD solution and V is the voltage at the antenna feed.

Taking the Fourier transform of E/I gives the antenna calibration in ohms/m as a function of frequency useful for narrow band frequency domain work, but one may also develop an operator which, when convolved with the measured antenna voltage, gives the dipole moment of the source. This is found by noting that, in the Laplace domain, the $E(s)/I(s)$ may be expressed as a ratio of polynomials of the same order in s. Then we may find the roots of the inverse, and, upon finding the roots d_i of the numerator, the time derivative of the dipole moment may be expressed in terms of the measured antenna voltage $V(t)$ as

$$\frac{d\xi_i}{dt} - d_i\xi_i = \frac{dV}{dt} \qquad P'(t) = c_0 V(t) + \sum_i c_i \xi_i$$

The paper will discuss the antenna loading and consider the effect of the asymptotic behavior at large s on this technique.

RADIOHOLOGRAPHIC MEASUREMENTS ON LARGE RUSSIAN MIRROR ANTENNAS

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The use of the existing large mirror antennas and creation of new ones presumes the necessity to measure their reflecting surface for defining of the shortest operating wavelength and adjusting of mirror shields positions for greater performance of these antennas.

Nowadays such measurements are effectively done by the radioholographic method. During a number of years, the Radiophysical Research Institute has been carried out measurements of the antenna characteristics with dimensions from 7 to 70 meters in the frequency range from 500 MHz to 11 GHz with discrete radio sources, Sun and geostationary satellites.

The report presents peculiarities of measurement methods using natural radio sources and satellites. The realized variants of facilities for holographic measurements are considered as well as characteristics of the equipment used and developed anew. The experimental results obtained by the authors in different antennas are given.

In particular, the report presents the equipment and algorithms for radioholographic measurements of the two 64-meter radiotelescopes the same type TNA-1500, placed near Moscow, one at Medvezhy Ozera and other at Kalyazin. The technique and results of measurements, realized in 1995-96, may be discussed.

This research was supported in part by USA Astronomy Society.

EMPIRICAL OPTIMIZATION OF THE X ANTENNA

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Abstract

The real dimensions of this television antenna being very big, we have realized a laboratory prototype for the experimental optimization and microwave measurements. According to the similarity principle, the laboratory model can be realized with a reduction by a factor scale (quotient of the real and laboratory functioning frequencies) of the real antenna dimensions. The measurement conditions in the laboratory must correspond exactly to the space functioning of the real antenna.

The X antenna is based on the Yagi antenna principle. It is constituted from an active element with a reflector and three drivers. The main difference between these two antennas is the geometrical form of their elements. The real working frequency of this antenna is about 200 MHz. According to the similarity principle (equation 1), its reduction factor is about 45, if we work at a frequency of 9 GHz.

$$A_1/A_2 = f_2/f_1 \qquad (1)$$

A_1/A_2 is the reduction factor (ratio of the real and simulated antenna dimensions) and f_2/f_1 is the frequency ration (laboratory to real frequency ratio).

We have used a microwave bench working in the X band (8GHz-12GHz) to measure the main parameters of the antenna. These parameters are : The input impedance Z_e, the Gain G, the functioning frequency band B, the radiation pattern and the half-power beam-width θ_d. We have used the measurement line method for Z_e and the comparison method for G (the reference antenna was a horn antenna with G = 16 dB). The functioning frequency band is obtained by plotting the maximum gain G_m versus frequency. For the adaptation of the antenna to the coaxial cable, we have used a small parasitic element between the dipole and the first driver. The results obtained for a frequency of 9 GHz are very interesting.

We find that the gain of this antenna (13.5 dB) is greater than that of Yagi antenna, for the same number of elements. The functioning frequency band (B = 1GHz or B ≈ 20 MHz in the real space) shows the relative selectivity of this antenna. The value of the half-power beam-width (θ_d =18°) proves the great directivity of the antenna. All these parameter values show this interesting structure as a television antenna. We have obtained another relevant result by establishing an empirical expression for the radiation pattern that is very difficult to obtain theoretically for irregular shape antennas.

THE SYNTHETIC APPROACH OF WIDEBAND MICROSTRIP ANTENNA DESIGN

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Abstract-Wideband microstrip antennas have enjoyed increasing support for use in radar and communications systems where weight, size and conformability are critical factors. In this paper, a synthetic method of designing broadband microstrip antenna is presented, and the dual-patch configuration fed by coaxial probe is investigated by adopting new feed technique and impedance matching network to obtain broad bandwidth. The two factors restricting the bandwidth of microstrip antenna, the inductive reactance introduced by coaxial feed probe and the frequency dependence of the input impedance are mainly studied. A two-sided structure has been employed in the configuration design. The improved dual-patch structure is fabricated on one side of the ground plane, and the loseless impedance matching network is on the other side. The coupling between the dual-patch structure and the loseless matching network is accomplished by a probe through the ground plane.

The coaxial probe introduces a series inductive reactance which becomes quite significant with respect to the radiation resistance. In order to widen the bandwidth, the conventional feed technique is improved, and a small square capacitive patch fed by the coaxial probe is introduced into the dual-patch structure and used to counteract the inductive reactance caused by the feed probe. To broaden the bandwidth further, the lossless impedance matching network is introduced, which is applied to compensate the frequency dependence of the input impedance, thus to lower the input VSWR and broaden the input impedance bandwidth. The impedance matching network is designed by the real frequency technique, and low-pass circuit is employed to realize the impedance matching network.

The experimental results demonstrated that the bandwidth of microstrip antenna can be broadened significantly by adopting dual-patch configuration, developed feed technique and impedance matching network. The achieved input impedance bandwidth is more than 24% for VSWR less than 1.5

Tuesday, May 28, 1:30 PM **Room: Cimarron**

HPEM-13 (Invited) Combined Electromagnetic Effects Protection

CoChairs: G.H. Baker, Jr., Defense Nuclear Agency, Alexandria, VA
J.P. Castillo, Logicon/RDA, Albuquerque, NM

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1:55 PM **(INVITED) AN APPROACH TO DEVELOPING UNIFIED SHIELDING EFFECTIVENESS PERFORMANCE REQUIREMENTS,** *J.I. LUBELL and A.M. CHODOROW, Mission Research Corporation, Colorado Springs, CO* 149

2:15 PM **(INVITED) AN APPROACH TO DEVELOPING UNIFIED PENETRATION PROTECTIVE DEVICE PERFORMANCE REQUIREMENTS,** *J.I. LUBELL, Mission Research Corporation, Colorado Springs, CO; and R.E. THOMAS, TCS, Scottsdale, AZ* 150

2:35 PM **(INVITED) COMPARISONS OF COUPLED EXTERNAL EM ENVIRONMENTS TO LONG AND SHORT LINE CONDUCTORS,** *W.A. RADASKY and K.S. SMITH, Metatech Corporation, Goleta, CA* 151

2:55 PM **(INVITED) A SIMPLE REPRESENTATION OF ANTENNA RESPONSES TO EM FIELDS COVERING A WIDE FREQUENCY RANGE,** *W.J. STARK, Mission Research Corporation, Colorado Springs, CO* 152

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3:40 PM **(INVITED) COMBINED BATTLEFIELD ENVIRONMENTAL EFFECTS MATRIX,** *R.F. GRAY and J.I. LUBELL, Mission Research Corporation, Colorado Springs, CO* 153

4:00 PM **(INVITED) MANY FACES OF HIGH-POWER ELECTROMAGNETICS AND ASSOCIATED PROBLEMS IN STANDARDIZATION,** *D.V. GIRI, Pro-Tech, Lafayett, CA; and A.W. KAELIN, Defence Procurement Agency, Spiez, Switzerland* 154

AN APPROACH FOR UNIFIED ELECTROMAGNETIC PROTECTION

OVERVIEW

Walter J. Scott*
Defense Nuclear Agency
Jerry I. Lubell
Mission Research Corporation

Twenty first century battlefield systems will be comprised of complex electronics subsystems, many of which will be interconnected. These systems must operate in increasingly complex battlefield electromagnetic environments. At the same time the system complexity, operability requirements, and environment complexity are increasing, there is renewed emphasis on using commercial electronic components, and on minimizing the use of military standards and practices. Therefore, there is a greater possibility for electronic subsystem malfunction during and after exposure to battlefield electromagnetic environments; and the consequences of electronic malfunction on the battlefield mission performance increase in geometric proportion to system complexity and interconnectivity requirements.

The purpose of this paper is to provide an overview of a DNA program to develop an approach for unified protection and testing of battlefield systems against both hostile and natural electromagnetic environments. In addition to addressing unified protection and testing, the program is developing an approach to facilitate the application of commercial electronics in military systems and to reducing the number of military standards that have to be applied during the system development process.

The paper will be presented in several parts. First the battlefield environments addressed by the program will be discussed. The environments are organized according to hostile, natural, and operational electromagnetic environments. Characteristics of the environments will be discussed including radiated and conducted and transient and narrow-band features.

Next, the unified protection concept and the corresponding allocation concept will be described. The allocation concept is formulated to allow the user to conduct engineering trade studies to optimize protection to match the anticipated battlefield environments and risk of system malfunction.

Application of the allocation concept requires use of existing military and civilian standards. The coverage provided by civilian and military standards for each step in the allocation process will be discussed.

AN APPROACH TO DEVELOPING UNIFIED SHIELDING EFFECTIVENESS PERFORMANCE REQUIREMENTS

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Alan M. Chodorow
Mission Research Corporation

The unified electromagnetic environment protection concept and corresponding allocation approach developed by DNA are based on using an electromagnetic barrier to reduce natural, hostile, and operational electromagnetic environments generated outside a system to acceptable levels inside the system. The barrier is comprised of an electromagnetic shield and penetration protective devices for conducted penetrations through the shield. The purpose of this paper is to describe an approach for developing unified shield performance requirements that can be used to specify the shield performance. The shielding effectiveness performance requirements can be used to cover the full range of battlefield electromagnetic environments that may be specified for battlefield systems.

While an electromagnetic barrier concept is used, there is no implication that this approach is the "low-risk" approach as described in MIL-STD-188-125. In contrast to the low risk approach, the DNA unified approach allows protection allocation to be assigned to the enclosed electronic subsystems, thereby reducing shielding effectiveness requirements. Moreover, there is no implication that the shield must be a single integral shield surrounding the entire system. Rather, the shield design should be customized match the particular system design constraints and risk requirements.

The approach to developing the shield performance requirements is divided into two pieces, one for transient environments, and the other for narrow-band environments. In both cases, the approach consists of a comparison of parameters describing the environments to corresponding parameters describing the immunities. The shield performance requirements are then described in terms of insertion loss as a function of frequency. This approach to determining shielding effectiveness is compatible with existing commercial and military standards such as IEE-STD-299 and MIL-STD-188-125.

The unification process can occur at several levels. Unification of some of the radiated transient environments and independently, among some of the narrow-band environments is practical and is included in the methodology. However, unification among the transient environments and the narrow-band environments is not practical.

At the shield performance level, a single unified shield performance specification can be used to cover multiple environments.

AN APPROACH TO DEVELOPING UNIFIED PENETRATION PROTECTIVE DEVICE PERFORMANCE REQUIREMENTS

Jerry I. Lubell*
Mission Research Corporation
Roland E. Thomas
TCS

The purpose of this paper is to describe an approach for developing unified penetration protective device performance requirements that can be used to specify protection device performance for the full range of battlefield environments that may be applicable to battlefield systems.

The penetration protective device performance requirements are based on the difference between conducted stresses and conducted immunities. The conducted stresses are determined using approaches described by Radasky and Stark in companion papers. The conducted immunities are derived from commercial and military standards.

Thevenin source terms are developed for each of the externally generated, coupled environments. These source terms are generated for both RF and transmission line penetrations, and for both transient and narrow-band conducted environments. The Thevenin source terms are driven into immunity test ports. These ports are classified as AC power ports, DC power ports, antenna ports, signal/control ports, and an enclosure port.

Penetration protective device performance requirements are then derived based on comparisons of norms from transient conducted stress to immunity norms, frequency domain comparisons of transient conducted stresses and immunities (insertion loss), and narrow band stress/immunity comparisons as a function of frequency (insertion loss).

Emphasis is placed on using both commercial and military immunity standards. This facilitates the use of commercial electronics and allows the user to customize the immunity levels to his specific application. Because the different immunity standards use different specification and test methods, and because the conducted environments are formulated as Thevenin sources, a method was developed to allow comparison of these different quantities on a common basis. The approach is to compare the sources and immunities on the basis of current delivered to standard test loads.

Examples of unified protective device performance requirements will be presented. It will be shown that no single immunity standard provides reasonable coverage of all environments, no single conducted environment appears to dominate, and that in the aggregate, about 60 dB of attenuation protects equipment with IEC-1000-4,-5,-6 immunities against HEMP (E1), nearby lightning, and HIRF environments.

COMPARISONS OF COUPLED EXTERNAL EM ENVIRONMENTS TO LONG AND SHORT LINE CONDUCTORS

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Metatech Corporation
Goleta, California USA
Phone: 1-805-683-5681, FAX: 1-805-683-3023

To save money in an era of tight system budgets and to still produce systems which can survive the variety of expected electromagnetic threats presents a difficult challenge. One approach that shows promise is to try to combine the electromagnetic threats in a way to minimize the system hardening and testing costs. To that end, it is believed that by treating threats in generic EMC categories such as radiated and conducted environments and by further grouping these environments into pulse and continuous wave (CW) categories, significant consolidation can be achieved.

This paper begins with a typical list of EM radiated environments of interest to a modern electronic military system. These include lightning, high intensity RF (HIRF), unclassified HEMP and simple theoretical examples which describe wideband and narrowband EM threats. Each of these radiated environments is then examined with regard to its frequency content and expected spatial variation. Using this information, simple coupling geometries are defined to allow the computation of coupled currents.

The coupled currents (the conducted environments) are derived using different methods. For nearby lightning computed results in published papers are scaled for the conditions of interest. For HEMP the values published in MIL-STD-188-125 are used directly to describe the coupled long line currents due to early, intermediate and late-time HEMP. For other pulsed EM threats, analyses are performed using a transmission line coupling code. Finally for CW EM threats, analytic and transmission line calculations are performed that depend only on the frequency of oscillation and the conductor length.

After the coupling calculations have been completed, the conducted environments are grouped into categories to demonstrate how consolidation can be accomplished for the sample environments considered here. We believe this approach can be extended to deal with any specific set of EM threats, although the amount of cost savings achieved will clearly depend on the details of the system threats considered.

A SIMPLE REPRESENTATION OF ANTENNA RESPONSES TO EM FIELDS COVERING A WIDE FREQUENCY RANGE

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Colorado Springs, Colorado
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A number of military and commercial standards prescribe performance requirements for electronic equipment to ensure that the equipment operates properly when it is subjected to a variety of electromagnetic stresses. These stresses could be due to natural causes such as lightning and electrostatic discharge (ESD), due to electromagnetic interference from other operational electronics (EMC, EMI and HIRF), and due to various man-made environments such as electromagnetic pulse (EMP), high power microwaves (HPM) and ultra wide-band (UWB) fields.

The performance requirements typically include a set of required tests to evaluate the performance. At present, there are different test requirements for each of the EM environments, and these tests add to the cost of developing, operating and maintaining electronic systems. There is a need to unify and simplify the tests required. Ideally, one single consolidated test would be performed to cover all of the EM environments. One approach for addressing this problem is to develop requirements for a set of categories of stresses to electronic equipment. Examples of such categories are identified MIL-STD-188-125. They include electrical power, audio and data lines, electrical control and signal lines, RF communications antenna lines, and shielded conduits. In this paper we examine how the test requirements can be simplified for RF communications antenna lines.

Our technical approach is to represent the antenna stress in terms of simplified Thévenin or Norton equivalent circuits. We take advantage of the fact that most antennas are connected to the electronics via coaxial cables having a constant characteristic impedance. In the case of a Norton equivalent circuit, this allows us to approximate the equivalent circuit source impedance by the constant characteristic impedance of the coaxial cable, and the source current by twice the current as seen at the base of the antenna when it is terminated by the characteristic impedance of the coaxial cable. Our paper describes equivalent circuits that can be established for two groups of EM environments. We also discusses the range of validity of our approximation for the equivalent circuit.

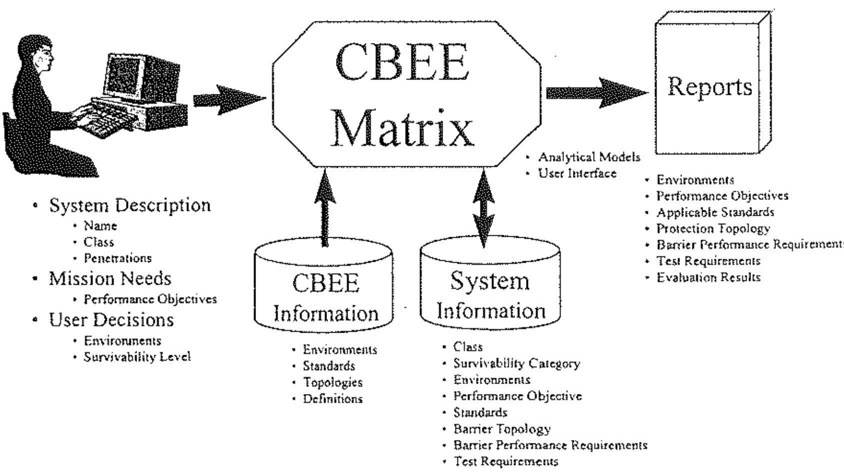
COMBINED BATTLEFIELD ENVIRONMENTAL EFFECTS MATRIX

Robert F. Gray
Jerry I. Lubell*
Mission Research Corporation

The unified protection and allocation concept described in the previous papers is being assembled into a personal-computer based computer program called the "Combined Battlefield Environmental Effects Matrix". The purpose of this paper is to describe the computer program.

The purpose of the program is to capture the environments, standards, and allocations algorithms that are needed to codify the methodology for developing, producing, and fielding systems that can function during and after exposure to battlefield electromagnetic environments.

The environmental effects matrix software components include the information data base, the system information data base, report processing, the user interface, and various coupling, allocations, standards, and electromagnetic topology algorithms. The program architecture concept is shown in the figure below.



The user defines the system, mission operational needs, and supplies some data on the anticipated electromagnetic environments and the survivability level. The matrix, interactively with the user, develops the barrier topology and the performance requirements for the shield and the penetration protective devices. By iterating on the environments, performance requirements, and survivability level, the user can optimize the topology and corresponding performance requirements to match specific constraints imposed by the system under development.

MANY FACES OF HIGH-POWER ELECTROMAGNETICS AND ASSOCIATED PROBLEMS IN STANDARDIZATION

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ABSTRACT

The acronym HPEM (High-Power Electromagnetics) has now been established to include NEMP, lightning, HPM, UWB and perhaps other electromagnetic environments will be added to this list, in future. Various standards have evolved over the last three decades in the areas of NEMP and lightning both in the classified and unclassified domains. Some examples of NEMP unclassified standards are: 1) BELL curve, 2) Baum in Proceedings of the IEEE, June 1992, 3) NATO-Unclassified, 4) IEC 77C (Sec) 20, 5) Leuthauser (1994), 6) VG-95371-10 (Nov.1995) etc.

In the emerging technologies of HPM and UWB, Mark N Phasers [C.D.Taylor and D.V.Giri, High-Power Microwave Systems and Effects, Published by Taylor and Francis, 1994] and Impulse Radiating Antennas (IRAs) [D.V.Giri and others, A Reflector Antenna for Radiating Impulse-Like Waveforms, Sensor and Simulation Note 382, 4 July 1995] can be viewed as state-of-the art systems for effects testing and other applications.

In this presentation, we gather most of the specifications dealing with NEMP and lightning that are readily available in open and unclassified literature, in the U.S. and in Europe. In addition, we also present and discuss some interesting HPM and UWB environments from the two references cited above. Wherever applicable, time and spectral magnitude plots will be presented along with the salient features such as risetimes, peak amplitudes, decay times, repetetion rates etc. While the information presented here is not new, it is considered imporatnt and useful to bring all of the high-power electromagnetic environments under one umbrella, and point out certain difficulties in their standardization.

Tuesday, May 28, 1:30 PM **Room: Dona Ana**

HPEM-14 **Statistical Electromagnetics**

CoChairs: T. Lehman, Consultant, Albuquerque, NM
A. Ciccolella, European Space Agency, Noordwijk aan Zee, The Netherlands

1:30 PM **INTRODUCTION & ANNOUNCEMENTS**

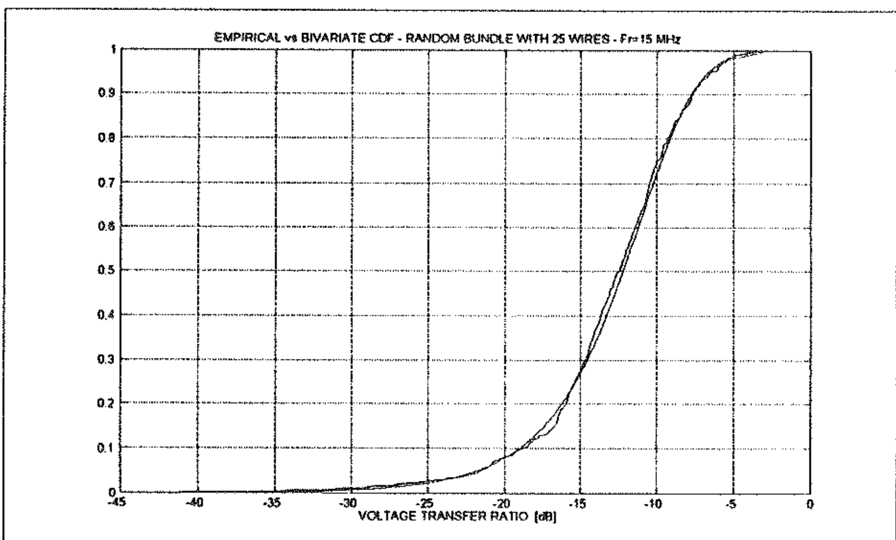
1:35 PM **CDF OF CROSSTALK INTENSITY IN RANDOM CABLES**, *A. CICCOLELLA, European Space Agency, The Netherlands; and F.G. CANAVERO, Politecnico di Torino, Italty* 156

1:55 PM **COUPLING OF STATISTICAL EM FIELDS TO CABLES IN AN OVERMODED CAVITY**, *R. HOLLAND, Shield Rite, Inc., Albuquerque, NM; and R. ST. JOHN, Mission Research Corporation, Albuquerque, NM* 157

CDF OF CROSSTALK INTENSITY IN RANDOM CABLES

A. CICCOLELLA* (ESA-ESTEC, NL) F.G. CANAVERO (Politecnico di Torino, I)

This paper defines the Cumulative Distribution Function of the crosstalk intensity occuring in random cables with arbitrary terminal loads' topology. It is well known that in random cables the sensitivity of the crosstalk intensity with respect to the relative wire positions can be extraordinary large. The unpredictable mutual positions of the wires in a random cable prevent any rigorous deterministic solution for the coupling problem and demonstrate the need of statistical methods. A model based on non uniform Multiconductor Transmission Lines, leading to a Boundary Value Problem, has been already established and validated. This model was applied in the past to several bundle geometries, referred to same cable, to create a significant set of samples for the subsequent statistical analysis. Although the results matched very well the experiments, the above simulation required heavy computational effort to achieve a significant amount of data for the statistical analysis when a cable of 25 wires was considered. Furthermore, the resulting crosstalk's CDF was fitted with the Pearson's system of curve without relying on any physical background. To avoid these drawbacks, we focused our investigation to the general solution of the Boundary Value Problem resulting from the MTL equations. We deduced that the PDF of the real and imaginary part of the voltages (or currents) at the line teminations is a Multivariate Gaussian function. With further simplifications and assumptions, we specialised the above to the termination of interest and we found that the PDF can be approximated by a Bivariate Gaussian. By performing a polar transformation of the random variables and integrating on the new domain, we found that the CDF of the crosstalk intensity can be obtained in a rather complicated integral form but easy to handle. So, only a reduced set of data is now required to estimate the distribution's parameter. An example is given here below. This technique could be applied to the BLT equations if we consider the strict analogy of these with the MTL equations.



COUPLING OF STATISTICAL EM FIELDS TO CABLES IN AN OVERMODED CAVITY

Richard Holland*, Shield Rite, Inc., Box 8250, Albuquerque, NM 87198, 505-842-6018
Richard St. John, Mission Research Corp., 1720 Randolph Rd., Albuquerque, NM 87106, 505-768-7655

The current response of cables in a complicated, highly overmoded chamber is not a problem which is tractable by deterministic solution of Maxwell's equations.

Our approach, which is probably the only feasible one, is first to characterize the statistical distribution of electromagnetic fields or power flux in the chamber. This distribution, in general, may have frequency or position as the independent variable. Depending on the nature of the enclosure (frequency-dependent Q, degree of homogeneity, etc.) the electromagnetic fields have a zero-bias normal distribution, a bipolar log-normal distribution, some mix of the two, or some, as yet unevaluated, distribution with the property that the associated power-flux distribution $f(z)$ looks like a modified Bessel function of the second kind

$$f(z) = \Lambda^2 z\, K_2(2\sqrt{\Lambda z}) \qquad \Lambda = 3/\,\mathrm{mean}[z] = 3/\mu$$

A normal field distribution leads to a chi square (with two degrees of freedom) power-flux distribution. A bipolar log-normal field distribution leads, at least approximately, to a monopolar log-normal power-flux distribution. (This is a novel and unpublished statement.) Formulas relating the field distribution parameters to the power flux distribution parameters prove to be quite simple for the normal, log-normal, and mixed distributions. This may also prove to be true for the modified Bessel distribution, although we have not yet been clever enough to work through the requisite modified Bessel function algebra.

The Bessel distribution comes from a model in which the power externally incident on the chamber apertures looks chi square with six degrees of freedom and the chamber's response to an internal source would be chi square with two degrees of freedom. Consequently, in this model, the chamber's internal response to external excitation has a two-variable distribution which is the product of one-variable chi square distributions with two and six degrees of freedom (T. Lehman, personal communication). Eliminating one of the two variables by integration over all possible values leads to a modified Bessel function.

Our goal, then, becomes one of modeling the cavity field or power flux distribution from measured samples. These fields are then applied as drivers to a model of the chamber cables. Lastly, the resulting cable currents on the model are compared in statistical distribution to measured cable currents. When the driven cable model yields currents with a distribution in good agreement with the measured cable current distribution, we consider the simulation to be performing well. In general, our modeled cable current distributions match observed results within a factor of two, which is commensurate with the experimental uncertainty.

Tuesday, May 28, 1:30 PM **Room: Galisteo**
UWB, SP-6 **Target Detection & Discrimination I**
Chair: *L. Carin, Duke University, Durham, NC*

1:30 PM **INTRODUCTION & ANNOUNCEMENTS**

1:35 PM **DIHEDRAL REFLECTOR CALIBRATION FOR UWB RADAR SYSTEMS**, *P.D. SMITH and A.P. LAMBERT, University of Dundee, Dundee, Scotland* 160

1:55 PM **SHORT-PULSE SCATTERING FROM SURFACE ANTI-PERSONNEL AND BURIED ANTI-TANK MINES**, *S. VITEBSKIY and L. CARIN, Duke University, Durham, NC* 161

2:15 PM **ON OPERATION OF UWB RADAR DISCRIMINATION SCHEMES IN A NOISE BACKGROUND**, *S. PRIMAK, University of Negev, Beer-Sheva, Israel; N. SOVEIKO, University of Ottawa, Ontario, Canada; and M. HORENIAN, Library of Russian Academy of Science, St. Petersburg, Russia* 162

2:35 PM **DENSE MEDIA PENETRATING RADAR**, *K. MIN and M. WILLIS, Wright Laboratory, Eglin AFB, FL* 163

2:55 PM **ARL UWB BOOM-SAR**, *J. McCORKLE, J. SICHINA, K. KAPPA, M. RESSLER, L. HAPP and K. STURGESS, U.S. Army Research Laboratory, Adelphi, MD* 164

3:15 PM **BREAK**

3:40 PM **EARLY RESULTS FROM THE FIRST FOPEN AND GPEN EXPERIMENTS USING THE ARL BOOM-SAR**, *J. McCORKLE, J. SICHINA, K. KAPPA, M. RESSLER, L. HAPP and K. STURGESS, U.S. Army Research Laboratory, Adelphi, MD; and S. VITEBSKI and L. CARIN, Duke University, Durham, NC* 165

4:00 PM **SCATTERING OF SHORT RADAR PULSES FROM MULTIPLE WIRES AND FROM A CHAFF CLOUD**, *H. UBERALL, University of America, Washington, D.C.; and Y. GUO, Johns Hopkins Applied Physics Laboratory, Laurel, MD* 166

4:20 PM **CHARGE AND CURRENT INDUCED ON A BENT SQUARE PLATE**, *L.F. LIBELO, M. LITZ and E. MENDOZ, U.S. Army Research Laboratory, Adelphi, MD; F.S. LIBELO, L&L Associates, Bethesda MD; and C.L. ANDREWS, SUNY, Albany, NY and University of Maine, Orono, ME* 167

DIHEDRAL REFLECTOR CALIBRATION FOR UWB RADAR SYSTEMS

P.D. Smith* and A.P. Lambert
Department of Mathematics and Computer Science,
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Dihedral reflectors are widely used to calibrate radar systems, particularly for polarimetric measurements. In transient measurement systems their response must be calibrated across the bandwidth of operation, which generally includes wavelengths both short and long compared to reflector dimensions. As a result, accurate wide bandwidth methods for the prediction of their UWB signature are highly desirable. This paper considers the response of such reflectors, comparing theoretical/numerical predictions with experimental measurements, and demonstrates a successful, fully polarimetric calibration which is important for ultrawideband systems. Both calculations and measurements are performed directly in the time domain.

Although high frequency (ray) techniques provide good approximations to the behaviour of large scatterers in the frequency domain (see A.C. Polycarpou, C.A. Balanis and P.A. Tirkas, *Electromagnetics*, **15**(5), 457-484, 1995), the time domain electric field integral equation (EFIE), (see, e.g. B.P. Rynne, *IMA J. Appl. Math.*, **35**, 297-310, 1985), is ideally suited to the direct calculation of the wideband response of small to intermediate size targets. This approach has already been used to optimize the radiated field of TEM horns (A.P. Lambert, S.M. Booker, and P.D. Smith, *AGARD Conf. Proc.* **564**, *High Power Microwaves(HPM)*, chap. 8, Ottawa, Canada, May 1994) and to calculate their characteristic impedance (S.M. Booker, A.P. Lambert, and P.D. Smith, *J. Electromagnetic Waves & Applications* 8(12), 1669-1693, 1994).

In this paper, the time domain EFIE has been used to calculate the transient response of several dihedral structures. Taking the incident field to be a Gaussian pulse, responses of reflectors with dimensions of the order of $1-4$ pulsewidths have been calculated. The experimental verification was carried out using a TEM horn with step input to produce an essentially Gaussian incident pulse. The scattered field from the dihedrals, in both horizontal and vertical polarizations, was then measured using a D-dot sensor. This paper discusses the methods used in detail and clearly demonstrates that accurate calibration of canonical structures, such as the dihedral, can be achieved in the time domain.

Short-Pulse Scattering from Surface Anti-Personnel and Buried Anti-Tank Mines

Stanislav Vitebskiy and Lawrence Carin*
Department of Electrical and Computer Engineering
Duke University
Durham, NC 27708-0291

The method of moments is used to analyze short-pulse plane-wave scattering from perfectly conducting bodies of revolution on the surface of and buried within a lossy, dispersive half space. The analysis is performed in the frequency domain, with the time-domain fields synthesized via Fourier transform. To make this analysis efficient, the method of complex images is used to compute the frequency-dependent components of the half-space dyadic Green's function. Results are presented for short-pulse scattering from perfectly conducting model anti-personnel and anti-tank mines, after calibration with various canonical targets (spheres and cylinders). The electrical parameters of the model-soil halfspace are measured from several soil types.

Ground penetrating radar (GPR) has been a topic of intense research for several decades. As part of these studies, significant attention has been directed toward understanding electromagnetic propagation in the earth, as well as on the study of scattering from buried targets. The insight gained from such phenomenological studies can be applied to the development of new signal processing and imaging schemes, as well as to the design of new GPR systems.

Most previous investigations of GPR phenomenology have examined narrowband operating conditions. Recently, however, there has been an interest in ultra-wideband short-pulse radar for ground penetrating applications. Such systems generate short pulse waveforms with large instantaneous bandwidth, giving rise to time-domain phenomenology which is fundamentally different than that of narrowband systems. As a first step toward understanding the wave physics associated with short-pulse scattering from buried targets, we consider here short-pulse plane-wave scattering from surface and buried perfectly conducting mines (modeled as a body of revolution, or BOR). To make such a study tractable, the soil is modeled as a lossy, dispersive halfspace, and the axis of revolution of the buried target is assumed normal to the air-ground interface; this assumption restricts the target orientation but allows one to view the target-halfspace composite as a single BOR. Anti-personnel mines are often found on the air-ground surface, while anti-tank mines are usually buried. Thus, in this study the mines will be so modeled.

ON OPERATION OF UWB RADAR DISCRIMINATION SCHEMES IN A NOISE BACKGROUND

Sergey Primak*, Nick Soveiko, Margarita Horenian*****

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** Department of Electrical Engineering, University of Ottawa
161, Louis Pasteur, Ottawa, Ontario, K1N 6N5, Canada
***Department of the New Receipt
Library of Russian Academy of Science, St. Petersburg, Russia

Ultrawide-band (UWB) Radar target discrimination schemes have been of great interest during last two decades and main of them are reviewed in (C.E. Baum, E.J. Rothwell, K.-M. Chen, D.P. Nyquist, Proc. IEEE, 79, 10, 1481-1492, 1991). Most of the researches assumed that the returning signal is corrupted by White Gaussian Noise (WGN). In real life the background is neither uncorrelated nor Gaussian. In this research we investigated the degradation of the discrimination schemes developed to operate in WNG in the presence of correlated non-Gaussian Noise.

As the mathematical model of noise we use the solution of a Stochastic Differential Equation (SDE) in the form

$$\dot{x} = f(x) + g(x)\xi(t) \tag{1}$$

where f(x) and g(x) are properly chosen non-linear functions and $\xi(t)$ is WNG. The detailed procedure for the determination of these functions can be found in (V. Kontorovich & V. Lyandres, IEEE Tran. Sig. Proc., 10, 1995, to appear).

We use the measured frequency response of an open-ended rectangular cavity and its inverse Fourier transform as a model of backscattered response. We use *801* samples in range *2-18* GHz with step *0.02* GHz for each aspect angle of the target.

The time-domain response is mixed with noise and processed by a corresponding discrimination scheme. Using a great number of noise realizations, we estimate the probability of errors for each scheme as a function of SNR. We investigate the dependence of the degradation in the ability to correctly discriminate targets for each scheme with respect to noise statistics and SNR.

Dense Media Penetrating Radar

Kwang Min and Marcelious Willis
Armament Directorate Wright Laboratory
Eglin AFB FL 32542

Dense media penetrating radar utilizing an impulse single pulse is under development at the Armament Directorate of Wright Laboratory, Eglin AFB. A series of experiments has been conducted to study the performance of the devices. These radar utilize extremely short electromagnetic pulses on the order of 150 ps or less in pulse width and use a few select antennas most suitable to transmit and receive impulse signals. Several configurations with a variety of component combinations and geometry are utilized and the results compared. Eglin has a large sand box, a permanent structure of rooms with concrete walls (some filled with sand), and an array of bomb bays separated by concrete walls to facilitate suitable tests.

Media of interest include sand, soil, and concrete. Sources utilized include two Pulse Power Physics sources developed under the Air Force SBIR program; Power Spectra BASS-02X and Picosecond Pulse Laboratory PSPL4015B. Antennas used include TEM horns, E-Systems array antenna developed under an Air Force PRDA program, and Farr Research 18" reflector IRA(Impulse Radiating Antenna) developed under the Air Force SBIR program. Tektronix CSA803 and SCD 5000 were used to collect data.

Analysis of data and algorithm development are conducted in-house. Very clear results locating a variety of targets behind one concrete wall and two concrete walls spaced by 10 feet of air were obtained. Similar results were obtained when layers of sand were included. Results of algorithm development leading to identification of target kind, size and material characteristics will be presented. Desirable signal processing relevant to this area will be discussed.

ARL UWB Boom-SAR

John McCorkle, Jeff Sichina, Karl Kappa, Mark Ressler,
Lynn Happ, and Keith Sturgess
Army Research Laboratory
Adelphi, MD

Low frequency ultra wide bandwidth (UWB) synthetic aperture radar (SAR) has been proposed as a technique to survey large regions and detect objects obscured by foliage or buried underground. Many signal processing techniques have been proposed to capitalize on a host of signatures (early-time, late-time, anisotropic, polarimetric etc.). However, little high quality data - high SNR data spanning the entire 50MHz to 1050 MHz region of interest, and spanning the full polarimetric set, and spanning both vertical and horizontal apertures needed for 3D and interferometric studies -- is available for evaluating such techniques on real data. This paper will describe the Army Research Lab UWB Boom-SAR which was built to fill that void. It is a synthetic aperture radar built on a 150 ft high boom-lift that can be driven down a road while fully extended. . The Boom-SAR covers a frequency range of 50 MHz to 1050 MHz and has a programmable swath width. The Army Research Lab (ARL) has used the Boom-SAR to collect data on targets in foliage and underground targets. The foliage penetration (FOPEN) collections were done at the Aberdeen proving ground (APG) in Aberdeen Maryland. The ground penetration (GPEN) collections were done at Yuma Proving Ground (YPG) in Arizona. The radar antennas are loaded TEM horns. The transmitter consists of a Power Spectra BASS (bulk avalanche semiconductor switch) pulse generator. The receiver is a set of Tektronix 2 Gs/s digitizers that connect to a Mercury Raceway digital signal processing (DSP) compute system. This DSP system does real-time equivalent-time-mode interleaving and presumming to produce the equivalent of data sampled at 8 Gs/sec which is stored to a hard disk array. Embedded with the radar data is northing, easting, and height data which is derived from an optical motion measurement system. UWB SAR images are formed using a backprojection algorithm that runs on Mercury Raceway processors, Sun workstations, or IBM-PC's. This paper will address each of these areas and some of the hardware that was developed to obtain the 80 dB dynamic range, 6 by 12 inch imaging performance demonstrated.

Early Results From The First FOPEN and GPEN Experiments Using The ARL Boom-SAR

John McCorkle, Jeff Sichina, Karl Kappa, Mark Ressler,
Lynn Happ, and Keith Sturgess
Army Research Laboratory
Adelphi, MD

Stan Vitebski and Lawrence Carin
Duke University
Department of Electrical Engineering
Durham, NC

Low frequency ultra wide bandwidth (UWB) synthetic aperture radar (SAR) has been proposed as a technique to survey large regions and detect objects obscured by foliage or buried underground. Many signal processing techniques have been proposed to capitalize on a host of signatures (early-time, late-time, anisotropic, polarimetric, 3D etc.). However, little high quality data - data with high SNR, spanning the entire 50MHz to 1050 MHz region of interest, spanning the full polarimetric set, and spanning both vertical and horizontal apertures needed for 3D and interferometric studies -- is available for evaluating such techniques. The Army Research Lab Boom-SAR was built to fill that void and has recently been used to collect data on GPEN (ground penetration) targets and FOPEN (foliage penetration) targets. The foliage penetration (FOPEN) collections were done at the Aberdeen proving ground (APG) in Aberdeen Maryland. The ground penetration (GPEN) collections were done at Yuma Proving Ground (YPG) in Arizona. These data sets have produced images with over 80 dB dynamic range. This paper will describe the results of these data collections and compare some of the results to MOM (method of moments) model results. Images showing vehicles behind trees and buried mine will be presented.

SCATTERING OF SHORT RADAR PULSES FROM MULTIPLE WIRES AND FROM A CHAFF CLOUD

Herbert Überall*
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Washington, DC 20064

Yanping Guo
Johns Hopkins Applied Physics Laboratory
Laurel, MD 20723

The present calculation of the transient, short-pulse response of one or several perfectly conducting wires, and its extension to chaff clouds consisting of multiple, randomly distributed and oriented wires (modeled by up to 1000 wires of equal length) is based on the analytic wire cross section formulas of Einarsson (Acta Polytech. Scan., Electr. Eng. Series, No. 23, 1967). These have been programmed using computer-generated random-number sets of position and orientation parameters, in order to obtain responses characteristic for the size of the chaff cloud, and its wire distribution in location and orientation.

The scattering of short pulses by a single wire is governed by the radiation of pulses of "traveling waves" that re-radiate from the wire ends as the traveling waves get reflected from these (Y. Guo and H. Überall, J. Electrom. Waves Applic. 8, 355, 1994). Rescattering also takes place from neighboring wires, creating interaction effects when the wire spacings are closer than 1-2 wavelengths (R. G. Wickliff and P. C. Garbacz, IEEE Trans. Antennas Propagat. AP-22, 503, 1974). These effects must be taken into account, if necessary, for a proper interpretation of the chaff scattering results. It is found that for ultra-wideband scattering where many wire resonances contribute, the traveling wave effects are synthesized from combinations of individual wire resonances.

The pulses returned from chaff clouds have also been analyzed as to their dependence on the polarization states of incident and observed signals, such as linear to linear, linear to circular and circular to circular polarizations. These effects add to the possible determination of cloud size and its wire distribution from the received echo form. We finally observe a decreasing (non-linear) dependence of the echo amplitude on the number of wires in the cloud, which again can contribute to the remote-sensing approaches for a chaff cloud.

* Expected Presenter

CHARGE AND CURRENT INDUCED ON A BENT SQUARE PLATE

L. F. Libelo*, M. Litz, E. Mendoza, ARL, Adelphi MD, F. S. Libelo, L&L Associates,Bethesda MD and C.L. Andrews, SUNY**, Albany NY and University of Maine, Orono ME

Induced surface charge and surface current distributions were measured over the illuminated and shadow sides of a bent, square, thin metal plate. At any point on the plate the surface charge density σ is proportional to the normal component of the E-field. At that same point the components of surface current density K_x and K_y are respectively given by the tangential components of the magnetic field H_y and H_x. Miniature electric and magnetic dipole sensors with high impedance leads were utilized to obtain scans of normal electric and tangential magnetic field components just off the surface of the plate on both sides. A brief description of these sensors will be given.

Experimental results shall be shown for monochromatic CW illumination of a λ x λ plate of thickness λ/100, with a 2π/3 dihedral bend parallel to an edge at 1/3 of the edge length. Only the case of incidence normal to the larger section of a face and polarizations both parallel and orthogonal to the bend will be presented. The effects of the corners, the edges, the bend and polarization relative to the bend are readily observed. Comparison of the measured charge and surface current distributions on the illuminated and the shadow sides will be discussed.

Analytical/ numerical studies of this type of structure conventionally calculate at each point on the "thin" plate the sum of each physical quantity on the two sides. Nevertheless, comparison will be made, where it is meaningful, of the measured results with results of known existing analytic studies.

***Physics Professor Emeritus*

Wednesday, May 29, 8:30 AM **Room: Ballroom C**

Plenary Session

CoChairs: D. Serafin, Centre d'Etudes de Gramat, Gramat, France
J. Shiloh, Rafael, Haifa, Israel

8:30 AM **WELCOME & ANNOUNCEMENTS**

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9:30 AM **HIGH-POWER MICROWAVES: AN OVERVIEW WITH A FOCUS ON CERENKOV DEVICES,** *J.A. SWEGLE, Lawrence Livermore National Laboratory, Livermore, CA* 171

10:00 AM **THE CONTINUING HUNT FOR THE YELLOW ELEPHANT,** *G. YONAS, Sandia National Laboratories, Albuquerque, NM* 172

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11:00 AM **HIGH EXPLOSIVE PULSED POWER COLLABORATIONS BETWEEN THE LOS ALAMOS NATIONAL LABORATORY AND THE RUSSIAN FEDERAL NUCLEAR CENTER AT ARZAMAS-16,** *I.R. LINDEMUTH, R. REINOVSKY, C. M. FOWLER, C.A. EKDAHL, and S.M. YOUNGER, Los Alamos National Laboratory, Los Alamos, NM* 173

11:30 AM **UNEXPLODED ORDNANCE CONTAMINATION: BETTER SOLUTIONS REQUIRE MORE THAN BETTER SENSORS,** *R.E. DUGAN, Institute for Defense Analyses, Alexandria, VA* 174

12:00 PM **AN OVERVIEW OF CRIPTE CODE: A TOOL TO HELP IN THE PREDICTION AND UNDERSTANDING OF EM PROBLEMS ON COMPLEX SYSTEMS,** *J.P. PARAMANTIER, ONERA, Meudon, France* 175

Future Directions for Ultra-Wideband Radar

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Arlington, VA 22203-1714

The status and future directions of ultra-wideband (UWB) radar are reviewed, from the perspective of the Advanced Research Projects Administration (ARPA). Particular emphasis is placed on UWB radar systems, for which a detailed discussion is given on the research directions most needed from the academic, government lab, and industrial communities. Additionally, we examine the missions for which UWB radar is expected to yield the highest payoff, in comparison to conventional radar systems.

HIGH-POWER MICROWAVES: AN OVERVIEW WITH A FOCUS ON CERENKOV DEVICES

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As the field of high-power microwaves (HPM) passes the two-decade mark, we see a growing understanding of detailed device physics; a sharpening vision of the factors underlying current device limitations; an increasing interest in the practicalities of system design with regard to size, weight, and complexity; and a developing market for commercially-produced sources and systems. This talk will consist of two parts, the first of which will be a summary of the state of the art of the field. The performance of the major device types will be reviewed. Common factors affecting the performance of HPM sources in general will be laid out. The growing interest in systems issues will be addressed, and the major commercial producers will be noted.

In the second part, the focus will be on Cerenkov devices such as relativistic backward wave oscillators and traveling wave tubes as well as multiwave Cerenkov generators and multiwave diffraction generators. Research on this class of devices has been particularly successful in producing high power and efficiency and high values of the energy per pulse. The three approaches to maximizing device performance-- axial variations in the slow wave structure, plasma filling, and multiwave operation with two-section structures -- will be discussed and compared.

The Continuing Hunt for the Yellow Elephant

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From the point of view of an aggressor, the lesson of the 1991 Gulf War is that American or allied forces must be convincingly deterred from intervention. Weapons of mass destruction are attractive because they greatly increase the risk to the United States or its allies if they choose to intervene. The capability of U.S. theater missile defense systems has significantly improved since the Gulf War, but these improvements do not defeat the deterrent value of WMD that could threaten our armed forces. We may, thus, soon find ourselves in the unfortunate position of being deterred by others rather than having the deterrent capability we relied on throughout the Cold War. Consequently, the U.S. must also develop the capability for excising a rogue state's WMD production storage and delivery capability through military means should that become necessary. We would hope never to have to exercise a military counterproliferation option, but effective deterrence against rogue leaders who hold even the lives of their own citizens in low regard must make deterrence a very personal reality for those leaders.

Military capabilities for excising WMD assets would be equally useful for delivering destruction directly to the leaders who are preparing for a WMD attack. But we do not currently have the right arsenal of weapons, and an optimum integrated battle management/command, control, communications, and intelligence system for precision deterrence. However, with a comprehensive program and sufficient investment, the United States could develop such capability within a period as short as five years. The effort would require substantial improvements in intelligence, reconnaissance, surveillance, target acquisition, fast precision strike, and target kill assessment capabilities. System elements would include new families of sensors, advanced communications and signal processing, high-performance computing, and new precision strike weapons, including penetrators. Many of these system elements exist at various stages of research or development. Most require advanced development to incorporate enhanced capabilities and design robust, deployable hardware.

The world will be entering a perilous chapter of history if weapons of mass destruction successfully proliferate to rogue regimes. The United States urgently needs to respond to this emerging threat by planning and investing now. If we fail to enhance our military capabilities to address the threat of weapons of mass destruction, we may not have sufficient deterrent credibility to discourage the threatened or actual use of WMD. The more credible our military capability to respond to such challenges, the greater the deterrent against both development and use of WMD by rogue states. The speed, precision, and reduced level of violence of information technology-based weapon systems will overcome the reluctance of authorities to respond militarily to threats of WMD at a time when public opinion is inclined to disapprove of placing lives in jeopardy in foreign ventures. Such convincing demonstrations of capability will drive nations who desire WMD to seek other paths of influence.

High Explosive Pulsed Power Collaborations between the Los Alamos National Laboratory and the Russian Federal Nuclear Center at Arzamas-16

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Abstract

In June, 1992 the Los Alamos National Laboratory began a series of historic collaboration with the Russian nuclear weapons design institute at Arzamas-16 in the area of high explosive pulsed power, plasma physics, and other areas of high energy density physics. The first joint experiment conducted by Russian and American nuclear weapons laboratories occurred on September 22, 1993 and consisted of a unique Russian high current pulsed generator and Los Alamos diagnsotics. Subsequent experiments measured the critical fields of the YBCO high temperature superconductor using generators capable of producing magnetic fields of over 10 megagauss. An extensive series of measurements of the properties of magnetized deuterium-tritium plasmas has been made to investigate the potential for Magnetized Target Fusion, an alternate approach to fusion that utilizes pulsed power as the driving energy source. The first observation of the transition of argon from an insulator to a conductor at many megabar pressure was made using a magnetically compressed sample. A preliminary experiment was performed to investigate a novel scheme for the implosion of a plasma bubble as a means to generate soft x-rays. Additional experiments are planned for this year both at Los Alamos and Arzamas-16.

UNEXPLODED ORDNANCE CONTAMINATION: BETTER SOLUTIONS REQUIRE MORE THAN BETTER SENSORS

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It is inevitable that some ordnance does not explode as intended. This unexploded ordnance (UXO) remains as the legacy of past testing, training, and wartime activities. Unexploded ordnance contamination and the resulting humanitarian and economic impacts have intensified the need for systems to detect, identify, and remediate unexploded ordnance worldwide.

The scope of the UXO-contamination problem worldwide is staggering. Millions of acres land are contaminated with unexploded ordnance. In some cases the ordnance is over 100 years old, and in other cases it is sophisticated modern ordnance. Within the United States, greater than 11 million acres of government lands are potentially contaminated. UXO contamination within the United States is predominantly the result of testing and training activities to prepare for war; however, in some rare cases, ordnance greater than 100 years old remains from the Civil War and earlier military activities.

Unexploded ordnance contamination is also a worldwide humanitarian concern. In many countries, there is a significant fatality rate caused by unexploded ordnance that remains after military conflicts. In 1991 in France, 36 farmers were killed while tilling their land. There is one casualty per day in Khe Sanh, Vietnam, and more than 14,000 Poles died in the 36 years immediately following World War II. In the United States, on the other hand, UXO contamination is typically limited to well-defined areas on test ranges and training bases, and as a result, rarely poses a danger to the public. Nevertheless, accidents do occur. In Tierrasante, CA, two young boys were killed and several others were injured when an old 37-mm round exploded. This accident and others incidents, such as the discovery of UXO from a World War I munitions facility in a residential neighborhood of Washington DC, have raised consciousness within the United States regarding the potential danger of unexploded ordnance on land that is in the public sector.

UXO contamination strains economies. In many countries, unexploded ordnance limits access to major economic installations since key installations, such as power plants and water treatment plants, are often vigorously attacked and defended during war. Many years after a war or conflict, unexploded ordnance may inhibit development. As an example, during the construction of a rail bed in France, deminers were on constant duty to remove ordnance; 5 tons of bombs were removed on a typical day. In addition, four front end loaders and several earth movers were destroyed over the course of the project. On government lands in the United States, UXO contamination inhibits the transfer of land from the custody of the government to the private sector during consolidation efforts and base closure and realignment. In the United States alone, cost estimates for the surface and subsurface remediation of UXO-contaminated land vary, but most are in the tens or hundreds of billions of dollars.

As a result of this contamination, there is great incentive to develop systems to identify, detect, and remediate unexploded ordnance. To date, the focus has been on detection systems. As might be expected, a great deal of controversy ensued regarding the capabilities of sensor systems used for the detection of surface and subsurface UXO. However, perhaps more significant than the controversy over detection system capabilities is the lack of a fully integrated "systems-level" approach to the problem of UXO contamination. While the development of improved detection and identification systems is important, detection is but one part of UXO clearance. Other elements of UXO clearance are intensely hazardous, costly, and time consuming. Better tools, including better analytical tools used in framing policy decisions, are needed if significant progress is to be made toward a solution for this pernicious worldwide problem.

An overview of CRIPTE code: a tool to help to the prediction and the understanding of EM coupling on complex systems

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CRIPTE* code is a tool used in EMC to model and solve any kind of EM coupling on ***networks***, described in terms of ***EM Topology*** elements [1]. In this formalism, a network is made of ***junctions***, linked to each other thanks to ***tubes***. From a general point of view, junctions represent any kind of topological volume and are characterised with ***S-parameters*** (or their equivalent Z or Y-parameters). Specially, these junction S-parameters may themselves come from the concatenation of ***sub-networks***. External or internal sources can be applied on tubes: generally, internal sources represent the equivalent ***Thevenin generators*** associated to a junction, whereas external sources represent EM ***field to line*** coupling.

CRIPTE code main domain of application is ***cable network***, for which it enables to treat very complex wiring topologies [2]. In this case, tubes are described as ***multiconductor transmission lines***, what gives the opportunity to take into account mutual coupling between wires. In this domain, the frequency range of interest is from DC to an average of 500 MHz, but, nowadays, an extension of its application to 1 GHz is under study on the EMPTAC aircraft.

ONERA** has undertaken to apply EM Topology since 1989. Very quickly, the requirement of a numerical code to solve the well-known ***BLT****** equation led ONERA to develop a first version of CRIPTE code. This original version, entirely written in FORTRAN language, was specially used to validate the topological rules that ONERA developed [3]. Since 1993, "CRIPTE" code has been translated in a "X-Window" interface, what makes its use more convivial and secure. It is now called "***WINCRIPTE***". The scientific computations (in frequency domain) are written in FORTRAN. The graphical routines are written in C-language, calling "Motif" resource. For this, it is easy to install WINCRIPTE on any kind of workstations (HP, SUN, IBM, DEC, Silicon Graphics) supporting "Unix" system.

The talk will underline and illustrate all the capabilities of the code to deal with complex EMC problems on large systems. Specially, it will be shown how the code may be used to help on the ***analysis*** of EM coupling on complex systems: for this, some results obtained on the EMPTAC aircraft in recent studies will be presented [4]. It will be also underlined how the code may be used as a ***predictive*** tool in EMC. For this, processes dealing with the computation of sources with a 3D code, the calculation of tube characteristics with a 2D code and finally, the calculation of the network response with CRIPTE code will be demonstrated.

Future developments would be undertaken in 1996, to overcome some of nowadays limitations of the code. Soon, the ***field radiation*** of lines and the ***non-linearity*** of junctions would be taken into account.

Wednesday, May 29, 1:30 PM **Room: Brazos**

HPEM-15 **HPM Sources, Plasmas & Pulse Shortening**

CoChairs: F.J. Agee, Phillips Laboratory, Kirtland AFB, NM
D. Parkes, Defence Research (ARA), Malvern, UK

1:30 PM **INTRODUCTION & ANNOUNCEMENTS**

1:35 PM **ELECTROMAGNETIC PROPERTIES OF CORRUGATED AND SMOOTH WAVEGUIDES FILLED WITH RADIALLY INHOMOGENEOUS PLASMA**, *A. SHKVARUNETS, S. KOBAYASHI, J. WEAVER, Y. CARMEL, J. RODGERS, T. ANTONSEN, JR., V.L. GRANATSTEIN and W.W. DESTLER, University of Maryland, College Park, MD* 178

1:55 PM **PHASE-LOCKED RADIAL KLYSTRON OSCILLATORS**, *M.J. ARMAN, Phillips Laboratory, Kirtland AFB, NM* 179

2:15 PM **PHYSICS OF CONVENTIONAL AND RELATIVISTIC KLYSTRON AMPLIFIERS**, *A.N. SANDALOV, V.M. PIKUNOV and V.E. RODYAKIN, Moscow State University, Moscow, Russia* 180

2:35 PM **A LONG PULSE (>1 MSEC) FIELD EMISSION ELECTRON GUN WITH STABLE CROSS SECTION FOR HPM SOURCES**, *Y. CARMEL J. RODGERS, F. SKILFF, T. ANTONSEN JR. and V.L. GRANATSTEIN, University of Maryland, College Park, MD; and A. SHKVARUNETS and P. STRELKOV, General Physics Institute, Moscow, Russia* 181

2:55 PM **PULSE SHORTENING IN THE RELATIVISTIC KLYSTRON OSCILLATOR**, *F.J. AGEE, K.J. HENDRICKS, M. HAWORTH, D.J. SCHIFFLER, JR., M.J. ARMAN, K.E. HACKETT and T. ENGLERT, Phillips Laboratory, Kirtland AFB, NM; D. COLEMAN, Sandia National Labs, Albuquerque, NM; and M. SENA and D. RALPH, Maxwell Labs, Albuquerque, NM* 182

3:15 PM **BREAK**

3:40 PM **PULSE SHORTENING STUDIES AND PLASMA DIAGNOSTICS ON THE UNM LONG-PULSE BWO EXPERIMENT**, *C. GRABOWSKI, J.M. GAHL, and E. SCHAMILOGLU, University of New Mexico, Albuquerque, NM; and D. YOUNG and O. ISHIHARA, Texas Tech University, Lubbock, TX* 183

4:00 PM **REPETITIVE 100MW RELATIVISTIC MAGNETRON**, *I. SCHNITZER, A. ROSENBERG, C. LEIBOVITCH, M. BOTTON, J. LEOPOLD, I. COHEN and J. SHILOH, Rafael, Haifa, Israel* 184

4:20 PM **FREQUENCY-AGILE RELATIVISTIC MAGNETRONS FOR HPM VULNERABILITY ASSESSMENT TESTING**, *J. BENFORD, B.D. HARTENECK, J.S. LEVINE and H.D. PRICE, Physics International Company, San Leandro, CA* 185

ELECTROMAGNETIC PROPERTIES OF CORRUGATED AND SMOOTH WAVEGUIDES FILLED WITH RADIALLY INHOMOGENEOUS PLASMA

A. Shkvarunets, S. Kobayashi, J. Weaver, Y. Carmel*, J. Rodgers, T. Antonsen Jr., V.L. Granatstein and W.W. Destler, University of Maryland, College Park, MD. 20742.

The creation and diagnosis of plasmas in high power microwave devices remains one of the primary challenges of plasma microwave electronics. In the present work we deal with (a) diagnostics techniques for characterization of radially nonuniform plasma columns suitable for use in high power microwave sources and (b) the effects of such plasmas on the electromagnetic properties of finite length, spatially periodic slow wave structures. Experimental studies were performed both for a strong and a weak guiding magnetic field. A single Langmuir probe technique cannot be used alone for precise characterization of magnetized plasma columns, especially for measurements of the electron plasma density. However, using a combination of a novel cylindrical resonant cavity technique supported by accurate numerical calculations of the plasma influence on cavity resonances of a long, thin plasma column we were able to characterize pulsed plasma columns. The peak density (higher than $10^{12}cm^{-3}$) and the spatial distribution(transverse and axial) of the plasma was measured as a function of the applied magnetic filed(2 to 10kG) and the plasma gun operating conditions.

By applying a combined probe-microwave resonator (X band) technique to plasma-filled, open, corrugated cavities we were able to measure in situ, for the first time, the complete dispersion curve of the TM_{01n} modes of a plasma-loaded, finite length, corrugated cavities immersed in guiding magnetic field. The frequency shifts of the TM_{01n} modes in this open slow wave structure were measured as a function of the background plasma density and the magnetic field intensity. The dispersion diagrams were reconstructed up to peak plasma density of 10^{12} cm^{-3}. Frequency upshifts and "flattening" of the dispersion curves were observed for both strong and weak guiding magnetic fields. A discrepancy between the dispersion calculation and the measured data was identified for background plasma above $10^{12}cm^{-3}$.

PHASE-LOCKED RADIAL KLYSTRON OSCILLATORS

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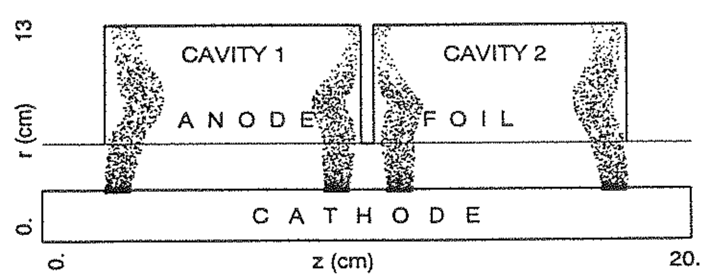
ABSTRACT

The advantages of the radial klystron over the conventional klystron, and in particular, the radial klystron *oscillator* over the radial klystron amplifier has been reported. (1. M. Joseph Arman etal, *Proceedings of the Seventh National Conference on HPM Technology*, Nov. 1995, Monterey, CA, 2. M. Joseph Arman, *Proceedings of SPIE's Int. Symposium on Optical Science, Engineering, and Instr., Intense Microwave Pulses III*, July 1995, San Diego, CA). Briefly, the radial structure of this design allows for much smaller impedances and thus higher powers, the beam-cavity coupling is stronger because the beam travels *inside* the cavity; and the source is much more compact because there is no need for external magnetic fields. The radial klystron oscillator is particularly interesting because it is more compact, and being a transit-time oscillator, it is more stable and more efficient.

The amount of power extracted from a single source, however, is limited in many ways, the most important being the low efficiencies associated with high power single sources. Overall high efficiency is crucial for sustained (longer than 100 ns) operation. *Phase-locking* of several low power but highly efficient sources has been suggested as an alternative means of achieving higher powers for longer durations. Phase-locking however, although relatively successful for amplifiers, has proven difficult for oscillators. Here I report on the phase-locking of two radial klystron oscillators and present the results of the numerical simulations, carried out using the PIC codes MAGIC and SOS. The two phase-locked radial klystron oscillators presented here, share the same dc input pulse and the same diode. An RF extraction manifold may be used to extract the power. The method devised here can be easily extended to many identical sources of this kind, making coherent radiation of RF energy in the tens of kilojoules, a possibility. A computer simulated model of the two-source device is shown below.



A phase-locked two-source model shown with the beam after saturation

Physics of Conventional and Relativistic Klystron Amplifiers

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A high accelerating voltage usage in RKA leads to significant changes of nonlinear bunching process in electron beam. An important relativistic effect connected with relativistic velocity of electrons movement, is an excitation of rotation wake fields of electron bunches [1]. There is nonsymmetrical velocity modulation for accelerating and decelerating bunch particles [2]. The voltage increasing intensifies the influence of 2D bunch effects.

The most complicated problem in RKA is energy beam extraction. The single-gap output cavity causes a shortening of radiation pulse duration, which is connected with RF breakdown due to large energy concentration in output section. The overcoming of this difficulties can be made by distributed output energy [3]. The extended output circuit must be as multi-gap cavity or couple-gap cavity. For X band the periodical super dimensional waveguide with distributed RF extraction system may be used.

The RKA high efficiency is possible only under careful analysis of nonlinear interaction phenomena in all parts of klystron: electron gun, linear and non linear bunchers, output system and collector. For this purposes the computer codes "Klystron MSU" [4], "Arsenal MSU" [5], "Multiwaves MSU" [6] were worked out at MSU. "Klystron MSU" is 1-1.5D disk-ring code of electron beam and is used as the first step of klystron calculation. The 2.5D PIC code "Arsenal MSU" allows to analyzed klystrons, containing thermionic and field-emission electron guns, linear and nonlinear bunchers, distributed output structures, conventional and depressed collectors. This code is based on the self-consistent analysis of charged particles dynamics in electromagnetic fields, representation of electron beam by large particles and modified Galerkin's method for Maxwell equations solution. The computer code "Multiwaves MSU" helps for investigation of dispersion characteristics of electromagnetic and electronic waves, electromagnetic fields structures, problems connected with RF breakdown and self-excitation of parasitic oscillations in output structure based on diaphragm waveguides. All of these techniques were used for design of the different types of klystrons.

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A LONG PULSE (>1 μsec) FIELD EMISSION ELECTRON GUN WITH STABLE CROSS SECTION FOR HPM SOURCES

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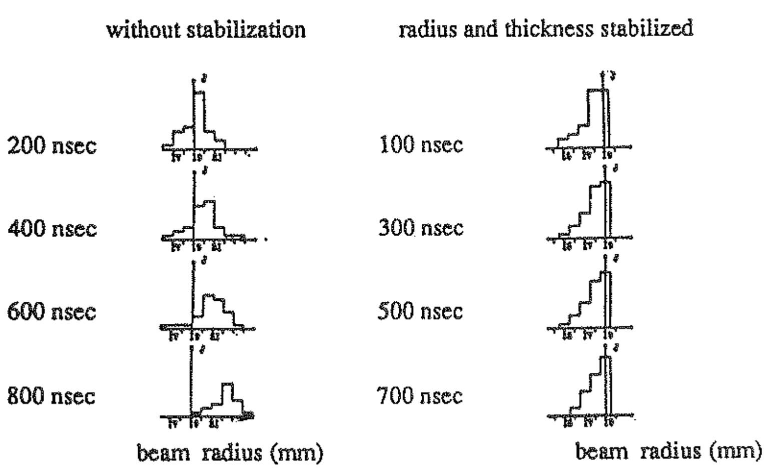
Field emission guns, such as those used in many HPM devices, are greatly affected by the plasma which is generated on both the cathode and anode. The gun impedance is time dependent due to the closure of the anode-cathode gap by the rapidly moving cathode and anode plasma. Even more important, the transverse dimensions of the electron beam are changing during the pulse. This is because the cathode plasma, which is the source for the beam electrons, tends to expand radially at a high velocity (>2mm/μsec). The change in the transverse beam dimensions reduces the beam-wave interaction efficiency since the beam is no longer at the correct position for optimum rf interaction. The plasma which is generated due to the beam interception leads to early termination of the microwave pulse. The creation of intense, relativistic, long pulse electron guns with minimal temporal variation of its cross section during the pulse is therefore a major issue for long pulse HPM sources. Design considerations for a special, foil-less field emission gun capable of generating a high quality, long pulse (1μsec and over), relativistic electron beam with a stable beam cross section will be reported. The gun is immersed in a strong magnetic field of unique geometry which suppresses cathode stalk emission. Comparison between the measured radial distribution of the electron beam current density J(r) of a gun with a stabilized radius and thickness and a gun without stabilization is shown in the figure (hollow beam, V=500 kV, I=3 kA).



PULSE SHORTENING IN THE RELATIVISTIC KLYSTRON OSCILLATOR

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Relativistic klystrons have been studied in a number of laboratories and constitute one of the most powerful microwave tubes , achieving output power in excess of 1 GW for those driven by very powerful electron beams. Conventional klystrons are also quite powerful and find use in many commercial applications. Work in our laboratory has focused upon two forms of the relativistic klystron, an amplifier and an oscillator. The latter has been studied by us analytically and experimentally and has achieved very high power. However, the relativistic klystron oscillator has exhibited the problem of pulse shortening, in which the high power performance of the tube cannot be sustained for the duration of the applied electrical pulse. This phenomenon, called variously pulse shortening or pulse tearing is also observed in tubes designed for lower power. The process of conditioning commercial tubes is a costly part of the production of high power tubes for applications including those used as drivers for linear accelerators. For high power microwave tubes operating in excess of 100 MW, it presents a limitation on the energy that can be extracted from these tubes. The subject of pulse shortening is one of current interest in a number of laboratories worldwide. The roles of the cathode emission , influence on impedance stability, and the corresponding performance of the tube is discussed. The paper describes new diagnostic techniques used in recent work. Data from several cathodes are presented and techniques that can improve RKO performance are discussed. The results are compared with earlier work on the relativistic klystron amplifier.

PULSE SHORTENING STUDIES AND PLASMA DIAGNOSTICS ON THE UNM LONG-PULSE BWO EXPERIMENT

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Pulse shortening in high power microwave (HPM) devices is common among all long-pulse, electron beam-driven sources from backward wave oscillators (BWO's) to gyrotrons. Although the electron beam may continue to propagate through the interaction region for several microseconds or more, the duration of the emitted microwave pulse is typically no more than ~ 100 ns. The specific reasons for pulse shortening may vary among various devices, but all explanations of the phenomenon put forth involve either the introduction of plasma in the interaction region and/or the degradation of the beam quality. Plasmas may be formed in the interaction region when beam electrons strike residual gas particles or when the intense microwave fields cause breakdown. Plasmas may also be formed as the beam strikes the beam dump or, through expansion, hits other surfaces. Degradation of beam quality may be caused by one of these various plasma sources or simply by the intense microwave fields found within the devices.

To gain a better understanding of pulse shortening, an investigation of pulse shortening in high power BWO's is being conducted at the University of New Mexico (UNM) on the UNM Long-Pulse BWO Experiment. Driving the experiment is a modified Physics International Pulserad 110A electron beam accelerator, which can produce intense relativistic beams with energies ranging from 200 ~ 500 kV at currents of 1.5 ~ 4.0 kA and having pulse durations of 400 ~ 500 ns (FWHM). Microwave radiation is generated in the X band with maximum peak powers of at least 200 MW, but with pulse widths of only 10's of ns (FWHM). Longer pulse widths approaching 100 ns FWHM can be obtained but at lower powers.

Because of the long pulse widths available from the experiment and the good repeatability of the beam pulse characteristics from shot to shot, the UNM Long-Pulse BWO Experiment is an excellent test facility for studying pulse shortening and incorporating new diagnostics needed to further such a study. Recent experiments have involved using a collector with a small aperture at varying radii (S. D. Korovin and I. V. Pegel, Sov. Phys. Tech. Phys. **37**, 434-8, 1992) to monitor the beam current profile at different radii as a function of time. These results are being correlated with the initiation and cessation of the microwave pulses in separate experiments. PIC simulations are being performed to further investigate the behavior of the beam profile in the experiment over time. Recently, a pulsed laser system has been proposed which could monitor axial velocity spread in the beam and plasma formation close to the walls of the slow-wave structure. Details of the results to date and plans for the proposed beam and plasma diagnostics will be presented at this conference.

REPETITIVE 100MW RELATIVISTIC MAGNETRON

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Since the first landmark by Bekefi et al. [*Phys. Rev. Lett.* 37, 379 (1976)], announcing a 900MW relativistic magnetron, substantial improvements accomplished peak power levels of several gigawatts. However, pragmatic considerations emphasized repetitive mode of operation and longer pulse duration (i.e., higher average power) at the expense of peak power. Repetition rate of about 200pps with peak power levels around 600-300MW and pulse lengths 30-70ns (~20J/pulse) were achieved by Physics International, USA, and by the Institute of Nuclear Physics, Tomsk, Russia [review: J. Benford and J. Swegle, High-Power Microwaves, Artech house, 1992]. It seems that pulse duration, at these power density levels, is restrained by fundamental, not fully appreciated, mechanism(s).

At Rafael, we initiated a relativistic magnetron research program aiming for rep-rated generation of 150 - 200ns long pulses with peak power of about 100MW. Our magnetron design *(Patent pending)* is **fundamentally different** from those that led to the achievements mentioned above. The cathode is grounded and the positive H.V. pulse is injected to the anode block (essentially, an A6 resonator) through an external cavity, that serves as a buffer cavity between the anode-cathode interaction region and the output waveguide. In this grounded cathode geometry the axial current is eliminated (improving efficiency). Moreover, the H.V. line is connected perpendicularly to the magnetic field axis, allowing the use of a CW, U-shaped, low current, electromagnet. For the cathode, we conceived a special scheme of alternating metal/dielectric disks, employing the principle of triple point plasma initiation [G. Mesyats, *Beams '94*, 93-99].

At present, the magnetron is driven by a rep-rated (≤20pps), 120Ω, Marx-PFN generator. Pulse trains of **50MW** peak power and **150ns** duration at 10Hz were measured with Vgenerator=300kV, Vdiode=180kV, Idiode=1kA, and η=28%. At higher charging voltage, improved vacuum conditions, and lower rep-rate, **100MW** pulses have been measured with Vgenerator=360kV, Vdiode=180kV, Idiode=1.5kA, and η=37%. However, these pulses tend to be shorter, about **70ns** long. We present detailed studies of the emitted pulse shape, the temporal evolution of its spectral power density and diode impedance, which suggest some physical insight to the relativistic magnetron's operation. We also show some preliminary 2-D computer simulations that support this picture. It is concluded that Rafael's novel relativistic magnetron may be further improved to generate more powerful pulses of over 150ns duration. In principle, this magnetron may be tunable through the buffer cavity in a way similar to coaxial magnetrons.

FREQUENCY-AGILE RELATIVISTIC MAGNETRONS FOR HPM VULNERABILITY ASSESSMENT TESTING

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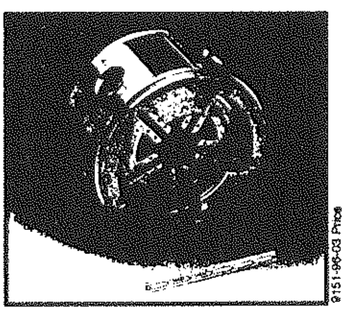
We are developing a family of frequency-agile relativistic magnetrons. We have proven operation with a suite of four magnetrons over the frequency range from 1 to 3 GHz, and we are currently designing new resonators to extend operation to both lower and higher frequencies. We have achieved tuning ranges of >30% [defined as $(f_U - f_L)/f_L$, where f_U and f_L are the upper and lower frequencies of the tuning range] in each of the individual L- and S-band resonators. The magnetrons are designed for repetitively pulsed applications and have been operated at rates up to 100 pps.

Power is extracted from two vanes, and is in the range of 400 to 500 MW. Power varies by less than a factor of two across the tuning bandwidth. Pulse durations are crudely 100 ns at this output level. We are using a network of phase shifters and 3-dB hybrids to combine the power into a single arm and to provide a continuously adjustable attenuator. We have demonstrated the frequency and phase stability that this requires. All tuning controls can be either manually or remotely actuated.

We are currently exploring means to extend the average power capability of the tube by simultaneously increasing both the output pulse duration and the repetition rate. These considerations as well as the pulsed power driver designs suitable for burst operation at these parameters will all be discussed.



Frequency-Agile S-band Relativistic Magnetron Resonator

Wednesday, May 29, 1:30 PM **Room: Cimarron**

HPEM-16 **(Invited) Optimization of HPM Effects**

Chair: *R.L. Gardner, Phillips Laboratory, Kirtland AFB, NM*

1:30 PM **INTRODUCTION & ANNOUNCEMENTS**

1:35 PM **(INVITED) SYSTEM LETHALITY FOR HIGH POWER ELECTROMAGNETICS**, *R.L. GARDNER, Phillips Laboratory, Kirtland AFB, NM* 188

1:55 PM **(INVITED) HOW TO THINK ABOUT SYSTEM RF EFFECTS**, *K.S.H. LEE, Kaman Sciences Corporation, Santa Monica, CA* 189

2:15 PM **(INVITED) OPTIMIZING ELECTROMAGNETIC EFFECTS**, *D.P. MCLEMORE, Kaman Sciences Corporation, Albuquerque, NM; and S. KOKOROWSKI, Kaman Sciences Corporation, Santa Monica, CA* 190

2:35 PM **(INVITED) ON THE DESIGN AND APPLICATION OF PULSE RADIATING ANTENNAS TO HIGH POWER MICROWAVE WEAPONRY**, *F.M. TESCHE, EM Consultant, Dallas, TX* 191

2:55 PM **(INVITED) HPM LETHALITY LIKELIHOOD**, *V. van LINT, VvL Inc., La Jolla, CA* 192

3:15 PM **BREAK**

3:40 PM **(INVITED) ESTIMATES FOR BACKDOOR COUPLING OF HPM INTO SPACECRAFT**, *W.J. KARZAS, Consultant, Los Angeles, CA* 193

4:00 PM **GENERALIZED PROBABILITY OF EFFECT ANALYSIS**, *T.W. LARKIN, Metatech Corporation, Albuquerque, NM* 194

4:20 PM **(INVITED) DETERMINATION OF PROBABILITY OF EFFECTS FOR HPM AND HPRF: METHODS AND DATA-NEED**, *T.C. MO, Logicon RDA, Los Angeles, CA; and G.H. BAKER, Defense Nuclear Agency, Alexandria, VA* 195

4:40 PM **STATISTICAL MODELING OF RF ENGAGEMENTS**, *A.J. ALEXANDER and G.E. FAUSS, Mission Research Corporation, Albuquerque, NM; and T.G. FROMM, Phillips Laboratory, Kirtland AFB, NM* 196

5:00 PM **(INVITED) DIRECTED RADIO FREQUENCY ENERGY ASSESSMENT MODEL (DREAM)**, *K.M. McLAUGHLIN and R.E. O'CONNOR, SPARTA, Inc., Huntsville, AL; and J.T. TATUM, U.S. Army Research Laboratory, Adelphi, MD* 197

SYSTEM LETHALITY FOR HIGH POWER ELECTROMAGNETICS

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System lethality and its reciprocal problem of establishing hardness play a large role in virtually any electromagnetic discipline. The purpose of this paper is to cite some of the basic issues of electromagnetic lethality as a way of introducing the other papers of this session. While most of the issues are generic, we will focus on high power microwave (HPM) applications.

Conditions for the lethality of an HPM weapons system against a class of targets must be established. The difficulty in establishing those condition lies in the granularity of the data. Granularity is a measure of the density of experimental points in a phase space describing the waveform, its propagation and the system under attack. This phase space has many dimensions and its granularity must be compared to the impact of changes in the system design on the lethality condition.

A waveform used in an HPM weapon should be chosen for its lethality. The lethal characteristics of a waveform may be its power, energy, rate of rise, repetition rate, characteristic frequency, or some combination of those parameters and perhaps others. A designer must choose the optimum point in this six or so dimensional space that will cause the system to not complete its mission. The challenge for the source designer is to not only build the source, but build it in such a way that it is effective against a class of problems.

There are, unfortunately, many examples that show differences in lethality for small changes in system topology. The insertion of a single filter can change lethality by many orders of magnitude. Since coupling calculations and measurements are so complicated the answer is difficult to find through the source, propagation, coupling approach. Another approach is through the examination of the electronic functions that are being performed by the target. It may be that there is no need for some of these types of measurements.

How to Think About System RF Effects

K. S. H. Lee
Kaman Sciences Corporation
Santa Monica, California

In the current thinking of the RF effects assessment community, system effects are expressed in terms of probability of effect (PE) versus threat level with uncertainty as a parameter. This paper first examines the question if it is appropriate at all to characterize system effects in probabilistic language. Pros and cons on this question are discussed in detail. Next, the paper will discuss the kinds of data and analysis needed for arriving at such a result. Particular emphasis will be placed on pointing out the assumptions involved in each step of the derivation and which assumption is supported by existing data and first-principle calculations. Examples are given to illustrate how to derive important parameters from data bases for inputs to PE calculations. Simple first-principle formulas in terms of effective absorption area for stress calculations are also given. Finally, a method is discussed for updating PE when more data become available.

Optimizing Electromagnetic Effects

Donald P. McLemore
Stan Kokorowski

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Albuquerque, NM and Santa Monica, CA

In the course of investigating an electromagnetic effect on a system or subsystem valuable insights would be achieved if one were able to determine how well the electromagnetic source causing the effect was optimized. That is, could the source produce the same effect with less amplitude and a broader frequency content of the incident effect-generating electromagnetic field; or, per chance, would the electromagnetic effect be more easily generated with higher field amplitudes and more high frequency content? Questions such as these are often pivotal to source developers and warrant research effort.

A candidate normalized stress scalar is offered in this paper which yields a quantitative measure of how well an electromagnetic source maximizes the peak norm of the stress at a system critical interface. Consider an electromagnetic field, E(t), incident upon some system causing a voltage or current, S(t) at a critical circuit node.

It is certainly true, assuming linearity, that

$$\tilde{S}(\omega) = \int_{-\infty}^{\infty} \tilde{E}(\omega)\tilde{T}(\omega)e^{j\omega t}dt,$$

where $\tilde{T}(\omega)$ is the frequency domain transfer function describing the voltage or current at the critical node per unit incident electric field. Defining a time domain impulse transfer function as:

$$\tau(t) = \frac{1}{2\pi}\int_{-\infty}^{\infty} \tilde{T}(\omega)e^{j\omega t}d\omega,$$

our proposed "measure of merit," r(t) becomes $r(t) = \frac{s(t)}{E_o T_o} = \frac{1}{2\pi E_o T_o}\int_{-\infty}^{\infty} \tilde{T}(\omega)\tilde{E}(\omega)e^{j\omega t}d\omega$

where

$$E_o = \left[\int_{-\infty}^{\infty} E(t)^2 dt\right]^{1/2} = \left[\frac{1}{2\pi}\int_{-\infty}^{\infty} \tilde{E}(\omega)\tilde{E}^*(\omega)d\omega\right]^{1/2}, \quad T_o = \left[\int_{-\infty}^{\infty} \tau(t)^2 dt\right]^{1/2} = \left[\frac{1}{2\pi}\int_{-\infty}^{\infty} \tilde{T}(\omega)\tilde{T}^*(\omega)d\omega\right]^{1/2}$$

One could equally well define this constant in the time domain, or $r(t) = \frac{1}{I_o T_o}\int_{-\infty}^{\infty} \tau(t')E(t-t')dt'$

One can show that this "measure of merit," r(t), will be maximized when

$$E(t_m - t') = \frac{I_o}{T_o}\tau(t') = E_{\max}(-t'),$$

setting t_m to zero, since the time reference is arbitrary and can be arbitrary without any loss of generality. Thus, the waveshape for the incident E-field which produces the maximum peak current or voltage is a time-inverted impulse response and for this case r(t) will have a maximum value of 1 because of the normalizations.

ON THE DESIGN AND APPLICATION OF PULSE RADIATING ANTENNAS TO HIGH POWER MICROWAVE WEAPONRY

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Considerable effort has been spent in attempting to utilize emerging fast-pulse technologies in the development of a viable, high-power microwave (HPM) weapon. Key elements in doing this include the production of a suitable energy pulse by a localized excitation source, transmitting energy from this source to a suitably designed radiating element, and coupling the transient pulse into the target system.

Elements of such an antenna system are shown in Figure 1, where a hypothetical antenna is excited by a pulsed source through a feed line. This configuration is general and can is applicable to virtually every type of pulse-radiating structure. Key in understanding the behavior of this antenna are the following:

- how the source impedance Z_s and the input impedance of the antenna, Z_{in}, interact through the transmission line, thereby limiting the amount of available power to the antenna,
- a knowledge of the pulse "radiation" pattern of the antenna,
- evaluation of the radiating efficiency of the antenna at selected frequencies, and
- other practical issues, such as source power requirements, the possibility of high-voltage arcing, and mechanical design issues.

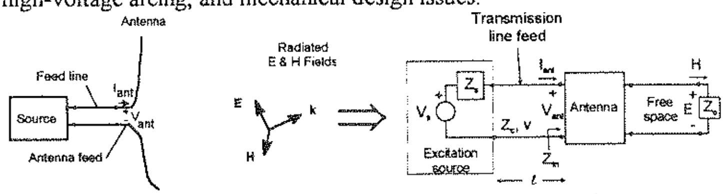

Figure 1. Antenna source and feed model for a pulse-radiating antenna.

In this paper, the above model will be examined in detail, with the effects of source mismatch, transmission line length, and the non-ideal antenna behavior due to antenna resonances being illustrated. It is important to realize, however, that the design and development of such a system *cannot* be made without additional knowledge of how the pulsed radiation field interacts with the intended target and how an effective kill can be obtained. Such considerations involve a knowledge of the electromagnetic characteristics of the target, as well as the details of the behavior of the internal electronics with respect to burn-out or logic upset levels. This knowledge should also be used in the design of the pulse radiating system, and these issues are addressed in the paper.

HPM Lethality Likelihood

Victor van Lint, VvL,inc.

High-power microwave (HPM) usefulness as an electronic countermeasure depends on having reasonable confidence in effectiveness, i.e., in denying function, with reasonably high probability, to adversary electronic equipments under typical engagement scenarios. The HPM engineer must face the challenge of choosing the correct combination of HPM parameters (e.g., frequency, pulse width, pulse repetition rate, other modulations) for which the effectiveness is maximized at minimum penalty (e.g., source power, technology risk). The sensitivity is demonstrated by coupling data that show large variations in electromagnetic coupling ($\geq$40 dB) over relatively small frequency variations (typical a few tens of MHz). For some types of electronics large variations in sensitivity are observed for HPM modulation frequencies changes around internal electronic operation frequencies. This raises the question whether it is possible to learn enough about equipments for which access is limited (perhaps a few units that may have a different history than deployed units) to select optimum HPM operating parameters, or whether we must use a large (usually prohibitive) margin to overwhelm the uncertainties.

A promising approach combines topological decomposition (i.e., factoring the target response analysis into separable steps) with critical feature identification (i.e., establishing what target parameters determine the response and how they are determined by the target's inherent characteristics. The overall HPM response can usefully be factored into source/radiator characteristics, electromagnetic propagation, electromagnetic coupling to produce electrical excitation on target wiring, rectification to produce HPM-envelope-like signals, and response of the target electronics to those signals. Each of these steps can be treated separately, because there is relatively little effect from other steps (i.e., minimal cross talk between links in the interaction chain). The sensitivity to HPM frequency is principally due to electromagnetic coupling; the sensitivity to modulation parameters is principally due to electronics response. Critical coupling frequencies may be determined by inherent parameters (e.g., diameter of an optical port) or less determinate variations (e.g., tightening of fasteners). Ranges of critical modulation parameters are usually determined by function (e.g., spin rate of optical seekers), but the exact value may be uncertain due to equipment variations or in-flight variables (e.g., slowing down of a coasting spinner). Once these dependencies are understood quantitatively, tradeoffs can be made between HPM power, frequency agility, duty cycle, and acquiring target feedback information.

ESTIMATES FOR BACKDOOR COUPLING OF HPM INTO SPACECRAFT

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For several purposes it is desirable to estimate the coupling of microwave energy into the interior electronic systems of a spacecraft illuminated by HPM.

In addition to the energy entering via deliberate penetrations (e.g, antennas, sensors), microwaves can enter through "backdoor" routes: out-of-band antenna coupling or openings in the exterior spacecraft surface, either due to non-integral shielding construction or due to non-deliberate electromagnetic points of entry in an otherwise shielding surface.

In this paper we describe the chain of physical processes which lead via the "backdoor" from an exterior RF (microwave) illuminating flux to the power induced in spacecraft interior cabling (and thus conducted into subsystems). (For these estimates to be valid, the spacecraft must have a quasi-Faraday-cage configuration whereby an interior and exterior can be defined.)

We first show a sequence of physically derived computational algorithms for penetration through apertures, based on the work of Yang and Lee; these calculations give the amount of RF energy "inside" a spacecraft cavity. For conditions appropriate to randomizing this RF energy in overmoded spacecraft cavities (roughly, that interior dimensions are much greater than RF wavelengths) Lehman's statistical description is appropriate. We base our analysis for the coupling onto spacecraft cabling on this statistical description and find that a simple result ensues. Little knowledge of the cabling geometry is needed for this estimates; the detailed cable layout is not required, only simple geometric parameters (length, radius, etc.)

For convenience, the final result is expressed in terms of an effective cable coupling cross section by which the exterior flux is multiplied to get power induced in a cable.

Generalized Probability of Effect Analysis

T.W. Larkin
Metatech Corporation

Electronic devices have a stress threshold, say *T*, at which an electromagnetic stress, say *S*, causes failure. Inherent variabilities cast *S* and *T* as random variables; the probabilistic analysis of the inequality $T \leq S$ is termed the probability of effect, P_E. The expense of testing complex electronic components invariably results in sparse data sets on which to base P_E analyses, hence some reliance on expert opinion is inevitable. A P_E analysis method is described in this paper which incorporates expert opinion and test data in a central way through a Bayesian approach; a rigorous derivation of the distribution of a random variable P_E is the result. The analysis is general in that distributional choices have no intrinsic affect upon resulting computational techniques. Also, the analysis can be based on any mixture of reliability data, i.e. binary, interval censored or exact, or can be based on expert opinion alone.

Determination of Probability of Effects for HPM and HPRF: Methods and Data-Need

Charles T. C. Mo, Logicon RDA, USA
George H. Baker III, The Defense Nuclear Agency, USA

Abstract

To quantify the many uncontrolled physical variations and information uncertainties in the HPM and HPRF electromagnetic (EM) coupling and electronics system effect responses, a probabilistic formulation becomes necessary. The formulation maps, or translates, the probability distributions of the input EM and system response parameters into output probability of effect (PE) and its distribution. Two categories of probabilistic distributions prevail. One distribution originates in the statistical inferences from tested samples (at component or subsystem or system levels) to untested population, a procedure which carries with it the frequency meaning of probability only when the samples are randomly drawn from the population. The other probability distribution results from propagating the "uncertainty error" of specific physical parameters and serves only to index, without a rigorous frequency interpretation, overall uncertainty and book-keep relative worthiness of the accuracy of these parameters.

In this paper, after delineating the why, the elements, the logic flow, and the use of PE quantification, we present a practical approach that organizes the test results and analysis estimates according to an data hierarchy, from the simplest and most direct one to the lesser ones. The data hierarchy is to: 1) sample system units and do function response test; 2) do separate tests on stress S and strength T at some same interface level; 3) do modeling and analysis on S and T; 4) combine of the above, emphasizing system level testing if we have many units and component level testing if we have only one unit. Mathematical formulation and *hypothetical generic* illustrations of PE determination will be given. These illustrations include a binomial confidence bound, a raw- or structured- data bootstrap estimate, and a last-resort Bayesian prior-weight normalized likelihood.

STATISTICAL MODELING OF RF ENGAGEMENTS

* Dr. ALBERT J. ALEXANDER
GARY E. FAUSS
MISSION RESEARCH CORPORATION

CAPTAIN TIMOTHY G. FROMM
USAF PHILLIPS LABORATORY/WSTS

A statistical-based end-to-end engagement simulation has been developed to perform RF susceptibility and lethality assessments. The simulation is a data-driven computer model which predicts stress as a function of target geometry from a specific source. The model predicts stress transfer through RF receiver components using test based transfer functions. The model predicts component level damage or receiver upset based on stress-strength comparisons.

Physics-based algorithms have been used in the model to calculate the RF stresses in a victim's receiver. Where there are known or statistical variablities, or incomplete knowledge of the relevant inputs, a probabilistic description is used and propagated through these algorithms. The estimated effect and associated uncertainty bounds are then provided. These probabilistic descriptions can be in the form of a wide variety of standard probability distribution functions or frequency distributions obtained by other methods. Statistical results are obtained either by Monte Carlo sampling techniques, method of moments or other analytic means.

Since the model is data driven, a companion test program is evaluating RF effects on different receiver designs including spread spectrum. These and other results will be used to validate certain asspects of the model. The model has been used to perform some preliminary assessments of communication type satellites to RF interference.

A windows based user interface has been developed to guide the user through a problem definition. The simulation will run on workstations or personal computers under UNIX/LINUX

The modeling approach lends itself to the analysis of a variety of problems where uncertainty analysis is required. Examples include detonation of unexploded ordinance, risk assessments, and environmental assessments.

DIRECTED RADIO FREQUENCY ENERGY ASSESSMENT MODEL (DREAM)

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John T. Tatum*
US Army Research Laboratory
Weapons Technology Directorate
Adelphi, Maryland 20783-1197

ABSTRACT

The Directed Radio Frequency Energy Assessment Model (DREAM) is a one-on-one engagement model that provides survivability analysts a tool to determine the probability of survivability of systems against Radio Frequency Directed Energy Weapons (RF DEWs). The model is being developed for the Joint Technical Coordinating Group on Aircraft Survivability by the U.S. Army Research Laboratory (ARL), the U.S. Air Force Phillips Laboratory (AF PL) and their respective support contractors SPARTA, Inc. and Ball Aerospace Engineering Division.

DREAM is a Microsoft Windows application that runs of an IBM compatible personal computer and provides a graphical user interface to facilitate the input of parameters describing the RF DEW, the environment/propagation conditions, the target flight path, and a target description, in the form of a fault tree representation. DREAM contains both a target engagement module or "susceptibility module" and a target interaction or "vulnerability" module that permits modeling of all aspects of an RF DEW engaging a target system. Based on the input parameters DREAM computes the probability of failure of a system's electronics as a function of the incident RF DEW power density and the range to the target. Though DREAM was designed primarily for determining the probability of survivability of aeronautical systems, it can also be used for computing the probability of failure of other types of targets that have trajectories similar to the flight paths that are built-in. This paper will describe DREAM, with emphasis on the target interaction module, and will also provide an example of how DREAM can be used to estimate the failure probability of a hypothetical system.

Wednesday, May 29, 1:30 PM **Room: Dona Ana**

HPEM-17 Hardness Maintenance/Hardness Surveillance

Chair: D. Lawry, Phillips Laboratory, Kirtland AFB, NM

1:30 PM **INTRODUCTION & ANNOUNCEMENTS**

1:35 PM **HM/HS TOOLS**, *J.D. HAINES, S.J. FRAZIER and M. CLELLAND, Naval Air Warfare Center, Patuxent River, MD; and W. DEPASQUALE and B.S. LUBOSCH, DUAL Incorporated, Lexington Park, MD* 200

1:55 PM **E-6A HM/HS PROGRAM**, *J.D. HAINES, S.J. FRAZIER and M.R. CLELLAND, Naval Air Warfare Center, Patuxent River, MD; and W. DEPASQUALE and B.S. LUBOSCH, DUAL Incorporated, Lexington Park, MD* 201

2:15 PM **VH HELICOPTER HMHS PROGRAM**, *M.E. MALLORY and S.J. FRAZIER, Naval Air Warfare Center, Patuxent River, MD* 202

2:35 PM **EXPERIMENTATIONS ON COMPONENTS OF NEMP PROTECTIONS TO DETERMINE THE PERIODICITY OF THE MAINTENANCE**, *C. GIRARD and Y. BOURDET, Alcatel Cable, Bezons, France* 203

HM/HS TOOLS

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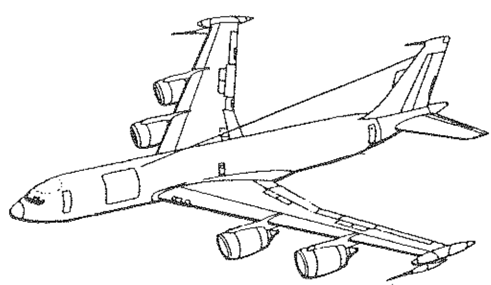
Abstract

The E-6 Hardness Assurance, Maintenance, and Surveillance Program was developed to meet the needs of the TACAMO Fleet and serves as a model for the United States Department of Defense. The program includes various techniques to monitor aircraft hardness integrity and maintenance procedures to direct the hardness critical process. A database was also developed which integrates all test and maintenance data to aid aircraft hardness surveillance efforts.



The E-6 Hardness Assurance, Maintenance and Surveillance Program identified a requirement for support equipment to verify proper operation of hardness protection devices installed on the aircraft. This paper describes the Test Bench for Nuclear Hardness (TBNH-6) which was developed to evaluate the Terminal Protection Modules installed on the E-6. The TBNH-6F is a self contained, environmentally controlled, test station that measures filter attenuation from 2 kHz to 150 MHz, the value of discrete components, leakage current of capacitors and the firing voltage of non-linear components. Test measurement results are stored in the TBNH-6 computer processor for life cycle analysis. The TBNH-6 has proven to be an invaluable tool for monitoring the EMP hardness integrity of the E-6A.

E-6A HM/HS PROGRAM

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Abstract

The challenge facing the E-6 Program Manager and Fleet is to ensure that the electromagnetic hardness design is maintained throughout the E-6 aircraft life cycle. The electromagnetic pulse community has worked closely with the Program Manager and Boeing Aircraft Co. to properly integrate the logistics elements necessary to accomplish this effort. This dynamic process began early in the acquisition phase and is evolving as changes in life cycle mission requirements occur.

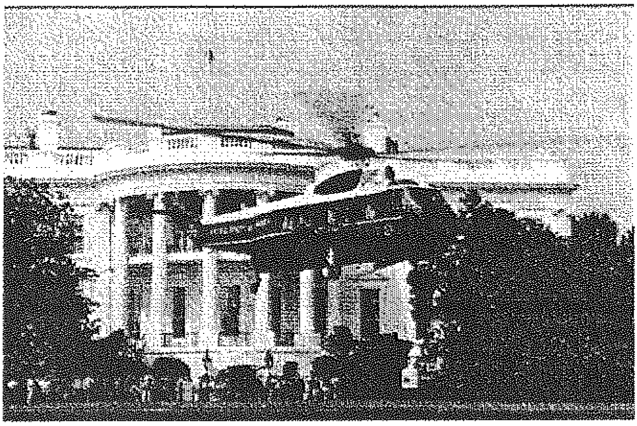
This paper identifies the U. S. Navy E-6 Hardness Assurance, Maintenance, and Surveillance Program. The program includes various techniques and data management techniques to monitor aircraft hardness integrity and maintenance procedures to direct the hardness critical process.

The E-6A design specification required that aircraft EMP hardening features provide a substantial margin of protection above upset for all flight critical and mission essential equipment. A layered hardening approach was selected to accomplish this requirement. Hull hardening is the primary hardening feature of the E-6A. This feature includes the use of conductive door seals and embedded etched screen windows to make the hull like a solid metal enclosure. Arrestors, filters, dielectric isolation devices, and conductive pulleys protect from aperture penetrations such as antennas and control cables. Shielded interior wiring, as well as, RF tight consoles and cabinets were integrated to increase shielding effectiveness.

Hardness Assurance tests were conducted on each aircraft to verify specification compliance. Hardness Maintenance procedures were also developed to ensure that Fleet operations, logistic support, and/or maintenance do not degrade the designed hardness. Finally, Hardness Surveillance tests and inspections are performed periodically to monitor aircraft hardness integrity.

The E-6 Hardness Assurance, Maintenance, and Surveillance Program was developed to meet the needs of the TACAMO Fleet and serves as a model for the U. S. Department of Defense.

VH HELICOPTER HM/HS PROGRAM



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Abstract

This paper describes the VH Electromagnetic Pulse (EMP) hardness surveillance program that has been established for the VH-60N/VH-3D Presidential Executive Transport Helicopters. The helicopters are specifically hardened for nuclear EMP with a 30 dB margin of survivability design goal. The program consists of a thorough EMP baseline test followed by a series of EMP Hardness Assessment Tests (HAT's) at the Naval Air Warfare Center Aircraft Division (NAVAIRWARCENACDIV), Patuxent River, Maryland. Baseline EMP tests and EMP HAT's on selected aircraft have been completed and are currently scheduled before and after the Special Progressive Aircraft Rework (SPAR). Additionally, hardness surveillance equipment have been procured to support annual field surveillance test at HMX-1 Quantico, VA. Any major modifications or EMP equipment changes to the airframe are assessed to determine the overall impact on the EMP hardening. Results of the system level and field surveillance tests are analyzed and entered into the HM/S database, which is used to support fleet life cycle EMP hardness of the VH Helicopter.

EXPERIMENTATIONS ON COMPONENTS OF NEMP PROTECTIONS TO DETERMINE THE PERIODICITY OF THE MAINTENANCE

C.GIRARD * , Y.BOURDET
ALCATEL CABLE
DEPARTEMENT TELECOMMUNICATION
UNITE ELECTRONIQUE ET ELECTROMAGNETISME
FRANCE

In the field of protection used to suppress the induced surges on power, coaxial and telecontrol lines due to the NEMP pulse, we have to know in all cases the performances of products which work on military sites well .

To be sure that a protection stays operational at any time in the event of the NEMP pulse , we have to specify a periodicity for the maintenance, to choose several specific tests to check the conditions of evolution and degradation on components .

you can't precise the operations for maintenance if you don't answer the following questions :

-which parameters modify the reliability of my protection along the year?
-what are the several types of degradation for the components inside the protection ?
-where are the limits of evolution in the characteristics for each component ?
-how many over volts (or current) are acceptable at the output of the protection for my equipment to be protected ?

We have made a special study on this subject for our customer , CENTRE D' ETUDES DE GRAMAT (C E G) with the following purpose :

- Looking for the different parameters on power, coaxial or telecontrol lines which decrease the reliability such as lightning,
- Experimental tests with surge waves on main components for a protection ; like power line arresters , capacitors for filters , diodes , varistors , ...
- Implementation of results in a data base
- Reliability calculation for protections and periodicity determination for maintenance .

We suggest a presentation of the main technical results we obtain on different components for protection .

The reliability calculations are presented by the French contractor company : CORIS .

Vednesday, May 29, 1:30 PM **Room: Galisteo**

JWB, SP-8 Target Detection & Discrimination II

CoChairs: K. Chen, Michigan State University, East Lansing, MI
L. Page, Institut de Recherche en Communications, Limoges, France

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1:55 PM **EARLY TIME SIGNATURE ANALYSIS OF DIELECTRIC TARGETS USING UWB RADAR,** *S.R. CLOUDE and A. MILNE, Applied Electromagnetics, Scotland, U.K.; and G. CRISP, DRA Malvern, England, U.K.* 207

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2:55 PM **CLASSIFICATION OF BURIED TARGETS USING TIME-FREQUENCY SIGNATURES EXTRACTED BY A GROUND PENETRATING RADAR,** *H.C. STRIFORS, National Defence Research Establishment, Stockholm, Sweden; A. GUSTAFSSON and ABRAHAMSON, National Defence Research Establishment, Linköping, Sweden; and G.C. GAUNAURD, Naval Surface Warfare Center, Silver Spring, MD* 210

3:15 PM **BREAK**

3:40 PM **THE E-PULSE TECHNIQUE FOR DISPERSIVE SCATTERERS,** *S. PRIMAK, Ben-Gurion University of the Negev, Beer-Sheva, Israel; J. LoVETRI and Z. DAMJANSCHITZ, The University of Western Ontario, Ontario, Canada; and S. KASHYAP, Defence Research Establishment Ottawa, Ontario, Canada* 211

4:00 PM **USING THE E-PULSE TECHNIQUE AND HYPOTHESIS TESTING TO PERFORM RADAR TARGET IDENTIFICATION,** *J.E. MOONEY, L.S. RIGGS and C.R. SMITH, Auburn University, AL* 212

4:20 PM **TARGET DETECTION AND IMAGING USING A STEPPED-FREQUENCY ULTRA-WIDEBAND RADAR,** *E.J. ROTHWELL, K.M. CHEN, D.P. NYQUIST, A. NORMAN, G. WALLINGA and Y. DAI, Michigan State University, East Lansing, MI* 213

4:40 PM **SHORT PULSE SCATTERING MEASUREMENTS ON CONDUCTING CYLINDRICAL CAVITIES,** *M. PIETTE, Royal Military Academy Brussels, Brussels, Belgium; and M. PERROT, Ecole Militaire de Saint-Cyr, Guer, France* 214

5:00 PM **RCS DETERMINATION FROM LOCALIZED SHORT-PULSE SCATTERING MEASUREMENTS: THEORY AND EXPERIMENT,** *M.P. KESLER, J.G. MALONEY, E.J. KUSTER, P.G. FRIEDERICH, AND B.L. SHIRLEY, Georgia Tech Research Institute, Atlanta, GA* 215

COMPUTER SIMULATION AND MODELING OF DETECTION OF BURIED OBJECTS USING GPR: INITIAL WORK

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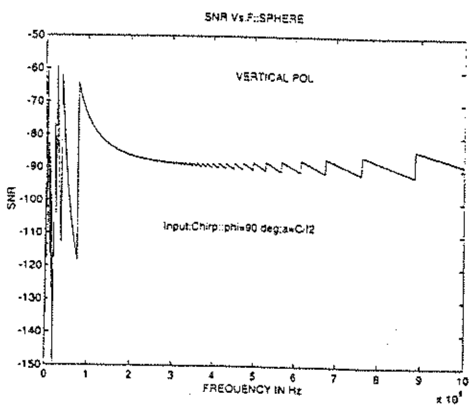
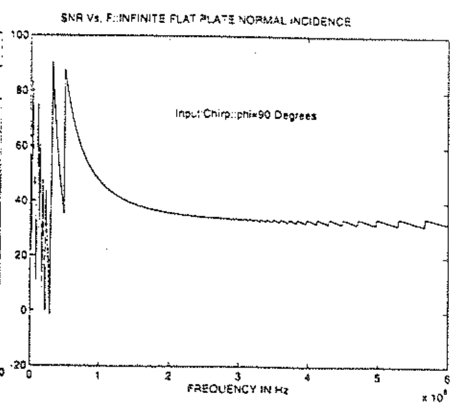
This presentation addresses the problem of detection of buried objects of various shapes and sizes using a ground penetrating radar(GPR). This is a summary of the initial work done at the Energy Technology Division of the Argonne National Laboratory while the author was a faculty research participant under the Argonne Educational Programs. The earth's crust has been modeled initially as a multilayer in a generic form and different targets have been modeled using appropriate low and high frequency techniques. The targets include perfectly electrically conducting(PEC) spheres,a PEC and imperfectly conducting infinite anf finite flat plates, a large curved surface(simulates the surface of large cylinder), and a finite PEC cylinder. A parametric study has been performed to set guidelines for the design of the hardware. Results are presented for the signal to noise ratio(SNR) of specular, monostatic and quasi-monostatic cases for various combinations of the radar, object and ground parameters initially in a frequency range of 100 to 1000 MHz. The potential of the use of chirp pulse in the buried object detection is also investigated. The figures show the SNR vs. frequency for typical cases. It is found that a conventional matched filter is not going to be of much use to deal with the complexity of wide bandwidth. The initial work on the design of an adaptive filter to improve the SNR for given scenarios will also be presented.





Variation of monostatic SNR in dB with frequency for

PEC sphere. a = $\lambda_2/4$

PEC flat plate

EARLY TIME SIGNATURE ANALYSIS OF DIELECTRIC TARGETS USING UWB RADAR

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Abstract

There is considerable topical interest in the use of Ultra Wide Band (UWB) Radar for the detection and classification of dielectric cylindrical targets.

In wide band problems, interest has centred mainly on analysis of the late time signal through an autoregressive signal model and associated pole locations in the complex plane. The main attraction of this method is that the poles are aspect independent and characteristic of target size and shape. However, the early time portion of the signal also contains important information about the scatterer. In this paper we present an analysis of the early time response for dielectric i.e. penetrable targets with cylindrical or spherical geometry.

We present a combined analytical, numerical and experimental study of the UWB backscatter signature of homogeneous and inhomogeneous dielectric cylindrical targets, showing in particular that the early time response of the target is dominated over a range of incidence angles by the glory wave pheonomenon.

The frequency range under consideration is from 250 MHz to 2.5 GHz, which matches that used by the time domain measurement facility located at DRA Malvern.

An analytical approach is used to first evaluate the impulse response of an infinite cylinder model and to establish important wave scattering mechanisms. This is then extended by using a 3-D finite difference time domain solver for evaluation of the exact backscatter response of finite cylinders for a range of incidence angles and polarizations. Finally, experimental measurements made at DRA Malvern are used to validate the predictions.

The implications for dielectric target detection and identification are examined. In particular, we examine the polarization dependence of the early time signature and use knowledge of the angular variation of the various backscatter mechanisms to speculate on the possibility of target detection using UWB SAR techniques.

SPECTRAL CORRELATION OF COMPLEX TARGET RESONANCES

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The U.S. Army Research Laboratory (ARL), working with the University of Maryland Department of Electrical Engineering, recently developed a novel method for efficient recognition of resonances in imagery from ARL's ultra-wideband (UWB) synthetic-aperture radar (SAR) instrumentation system, currently being used in foliage- and ground-penetration studies. The recognition technique uses linear transforms—Fourier, wavelets, etc.—to provide a basis for the design of spectrally-matched filters. Implementation of the technique is very straightforward: an expectation of the target ringdown is projected onto a transform basis set, yielding a set of spectral coefficients— the "spectral template." UWB SAR image data are projected onto the same basis set, yielding a second vector of coefficients— the "spectral image." A simple correlation coefficient is generated from the two vectors, providing a measure of co-linearity of the spectral template and the spectral image—higher correlation values indicate greater co-linearity. Exceeding a correlation threshold results in a target declaration. This target-recognition technique, known as the "spectral correlation method," is relatively fast and very easily implemented—a single 32-megabyte bipolar SAR image can be processed in less than five minutes.

Initial spectral-correlation efforts focused on canonical targets (dipoles), and the results have been widely reported. Current studies are focusing on tactical targets, such as CUCVs. Early results on CUCVs have shown that a single resonance-based template can be used effectively in the recognition of tactical targets. Ongoing studies have demonstrated a substantial reduction in the false-alarm rate over results reported previously, and have shown an improvement in foliage-penetration performance. Also, the target set has been expanded to include other tactical vehicles. These results, as well as improvements in the recognitions-processing stage, are reported in this paper.

FEATURE EXTRACTION FROM ELECTROMAGNETIC BACKSCATTERED DATA USING JOINT TIME-FREQUENCY ISAR

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Inverse synthetic aperture radar (ISAR) imaging has long been used by the microwave radar community for signature diagnostic and target identification applications. ISAR is a simple and very robust process for mapping the position and magnitude of the point scatterers on an object from multi-frequency, multi-aspect scattered field data. However, complex targets often contain other scattering phenomena such as resonances and dispersive mechanisms, which do not behave like point scatterers. For instance, aircraft signatures consist of not only scattering centers, but also resonances from sub-skinline features such as inlet ducts, cockpits and antenna windows. These scattering mechanisms appear in an ISAR image as blurred clouds which extend down-range and often do not correspond to the spatial features on the target. On the other hand, these mechanisms do provide very useful information which, if properly extracted and interpreted, can become important features in the target classification process.

A number of researchers have reported that joint time-frequency analysis is an ideal tool for analyzing electromagnetic backscattered signals that are composed of scattering centers, resonances and dispersive phenomena. In the joint time-frequency plane the behaviors of these mechanisms are well known and easily identifiable. However, the application of joint time-frequency techniques thus far dealt only with single aspect information. In this paper, we present a new processing technique, the joint time-frequency ISAR, that combines the joint time-frequency representation with the standard ISAR imaging. The basic idea is to apply joint time-frequency processing to the range (or time) axis of the ISAR image to extract the time-frequency behavior of the scattering mechanisms. The joint time-frequency processing algorithm chosen in our implementation is the adaptive Gaussian representation (AGR) recently introduced by Qian and Chen (*Signal Processing*, 36, 1-11, 1994). In this procedure we expand the signal as a summation of Gaussian basis functions that are chosen adaptively to best represent the signal. This algorithm is robust and does not result in any loss in resolution. More importantly, since the data are parameterized in terms of Gaussian bases, the point scattering mechanisms and the resonance phenomena can be readily separated based on the width of the basis functions in the time-frequency plane.

By applying this procedure we can decompose the original ISAR image into two new images: an enhanced ISAR image containing only scattering centers and a frequency-aspect plot to display only resonance features. This new algorithm is tested using data generated by the moment method simulation of simple structures and the chamber measurement data from a scaled model airplane. The results show that non-point scattering mechanisms can be completely removed from the original ISAR image, leading to a cleaned image containing only physically meaningful point scatterers. The non-point scattering mechanisms, when displayed in the frequency-aspect plane, can be used to identify target resonances and cut-off phenomena.

CLASSIFICATION OF BURIED TARGETS USING TIME-FREQUENCY SIGNATURES EXTRACTED BY A GROUND PENETRATING RADAR

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ABSTRACT

We study the scattering interaction of electromagnetic pulses of short duration with selected targets. The targets are metal objects buried at different depths in dry sand. The backscattered echoes are extracted by an impulse radar system playing the role of a ground penetrating radar (GPR). These echoes are studied by means of a time-frequency distribution of the Wigner-type, which, in particular, makes it possible to analyze how each one of each target's signature features evolves in time. We demonstrate this capability by computing and displaying time-frequency distributions of echoes returned from each target when they are buried in dry sand to a selected depth. These distributions, viewed as target signatures, are then used as templates for target classification. To be useful for target identification purposes, a signature representation should display a "sufficient" amount of distinguishing features, and still be robust enough to suppress the interference of noise contained in the received signals. Multiple scattering between a target and the surface of the ground is another obstacle for successful target recognition that time-frequency distributions could counteract by unveiling the time progression of the returned target information. We then use a classification algorithm based on a fuzzy cluster estimation technique to reduce the number and kind of features in the templates. The classification algorithm is put to a test against validation data taken from an additional set of returned echoes. The same targets are used but they are buried at different depths, illuminated with the GPR antennas at slightly different positions, or both. Class membership of a target is then decided using a simple metric. The results of our investigation serve to assess the possibility of classifying subsurface targets using a GPR.

THE E-PULSE TECHNIQUE FOR DISPERSIVE SCATTERERS

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The E-pulse radar target discrimination scheme employed in the frequency domain to extract aspect dependent information about a target was presented in 1993 (E. Rothwell, *et al.*, Ultra-Wideband, Short-Pulse Electromagnetics, 1993, pp. 475-482). It was assumed there that the resonant-free frequency response of the target can be modeled as a sum of complex exponentials where complex time parameters τ_m are associated with the scattering centers. Once the τ_m are obtained, the corresponding E-pulse can be determined using standard techniques. It was found that the expansion coefficients, B_m, can be frequency dependent (J. Moore, H. Ling, AP-43, No. 6, pp. 623-626) with complicated scatterers having coefficients which depend on powers of the frequency: ω^n, $n \geq 1$. The traditional procedure fails to construct E-pulses for such scatterers. Here we extend the E-pulse technique to take into account the dispersive properties of scatterers modeled by a frequency response

$$R_E(\omega) = \sum_{m=1}^{M} B_m e^{\tau_m \omega}, B_m = \sum_{i=0}^{I_m} b_{mi}\omega^i. \tag{1}$$

It can be easily verified that the differential operator $L_{\tau,p} = \left(\frac{d}{d\omega} - \tau\right)^{p+1}$ annihilates the function $\omega^i e^{\tau\omega}$, $0 \leq i \leq p$. In turn, the operator

$$L = \prod_{m=1}^{M} L_{\tau_m, I_m} = \prod_{m=1}^{M} \left(\frac{d}{d\omega} - \tau\right)^{I_m + 1} \tag{2}$$

annihilates the frequency response $R_E(\omega)$. Instead of using the continuous differential operators of equation (2) the discrete domain approximation can be used. Let Z denote the shift operator in frequency $\Delta\omega$: $Zx(\omega) = x(\omega - \Delta\omega)$. It can be shown that the discrete operator $L^{\Delta\omega}_{\tau,p} = (e^{\Delta\omega\tau}Z - 1)^{p+1}$ annihilates the frequency series

$$x(n) = (n\Delta\omega)^i e^{\tau n\Delta\omega}, 0 \leq i \leq p$$

and the operator

$$L^{\Delta\omega} = \prod_{m=1}^{M} L^{\Delta\omega}_{\tau_m, I_m} \tag{3}$$

annihilates the series obtained from (1) after discretization using the frequency step $\Delta\omega$.

This technique has been applied to the estimation of the unknown aspect angle of cylindrical waveguide cavities. The frequency response of these targets was measured in the laboratory and then processed using Prony's method to extract the poles τ_m and the parameters b_{im}. The E-pulse corresponding to each aspect angle of observation was then constructed and the results of using these E-pulses in a discrimination scheme will be presented.

Using the E-pulse Technique and Hypothesis Testing to Perform Radar Target Identification

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In this paper, the Extinction pulse (E-pulse) technique is combined with hypothesis testing to perform target identification. The E-pulse technique is essentially based upon the natural resonances of a conducting body. Each target has its own set of unique natural frequencies. An extinction waveform is synthesized to annihilate the natural modal content of the scattered field from a specific target. Convolving the E-pulse with the impulse response from the correct target results in a zero late-time (the time after the excitation has passed) response. Convolving the same E-pulse with the impulse response from a dissimilar target yields a "large" response. Thus, the E-pulse scheme reduces the identification process to discriminating between no response and a "large" response. Furthermore, this approach has the beneficial property of being aspect independent.

However, in a real environment where noise will inevitably corrupt the radar signature, the robustness of the E-pulse technique is diminished. Convolving the E-pulse with the signature from its intended target in the presence of noise will not produce a null late-time response. The result will be some convoluted form of the noise. Repeating the same filtering process on the dissimilar target will result in some "signal plus noise." Thus, the identification process now involves distinguishing between "noise" and "signal plus noise." In the late time, where the energy content of the signature is already low, this identification process is not so simple. Moreover, the E-pulse approach is **no longer** aspect independent because it involves comparing "noise" to "signal plus noise" where the latter happens to be highly aspect **dependent**.

Although the E-pulse scheme definitely has merit, it alone cannot completely resolve the target ID problem, especially under the influence of such nuisance parameters as noise and aspect angle. One possible method of overcoming these parameters while retaining the E-pulse approach is to conduct a binary hypothesis test at the output of the E-pulse filter. Such a test will yield a measure of belief (a probability) as to whether the output is either "noise" (correct target) or "signal plus noise" (wrong target).

This paper will expound on the rationale of using the E-pulse technique and binary hypothesis testing to perform target identification. Furthermore, performance results as a function of signal-to-noise ratio will be presented and analyzed for several different thin wire targets.

TARGET DETECTION AND IMAGING USING A STEPPED-FREQUENCY ULTRA-WIDEBAND RADAR

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A. Norman, G. Wallinga and Y. Dai
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An ultra-wideband radar system currently under development at the Naval Command, Control and Ocean Systems Center will radiate several hundred discrete frequencies within a 1 GHz bandwidth centered in either C- or X-band. This data can be used to synthesize an equivalent band-limited, time-domain scattered field response for use in target detection or identification schemes. An important application involves the detection of a target above a disturbed sea surface. When the sea clutter signal is large in comparison with the target return, detection using conventional narrow-band radar becomes quite difficult. By observing the sea in the time domain, it is possible to separate the individual scattering events from sea crests and use the periodic nature of the sea swells to reduce the clutter signal.

This paper will investigate the transient, band-limited scattered field response of realistic sea surfaces using both experimental and theoretical methods. Scale model ocean waves will be constructed using conductors, fresh water, and salt water, and the stepped-frequency response of each will be measured in an anechoic chamber scattering range. A realistic Donelan-Pierson surface relief model will be examined as well as a simpler sinusoidal model. Comparisons will be made between the measured responses and those obtained from a theoretical, integral-equation-based analysis. Measurements will also be made of scale-model targets in the presence of the artificial sea surfaces, and clutter cancellation of the sea clutter signals will be demonstrated using E-pulse techniques.

Another interesting application of the stepped-frequency system is in the area of target imaging. A bistatic, time-domain imaging algorithm has been developed at Michigan State University which uses convenient band-limited interrogation waveforms. Measurements of scale-model aircraft targets will be used to obtain target images directly in the time domain for a variety of observation angle apertures. Image quality will be investigated as a function of bandwidth, aperture angle, and bistatic arrangement.

SHORT PULSE SCATTERING MEASUREMENTS ON CONDUCTING CYLINDRICAL CAVITIES

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The Royal Military Academy Brussels has developed a Time-Domain Scattering Range for measuring *directly in the time-domain* the monostatic and bistatic short pulse scattering of complex targets. The system consists at the transmitting side of a long monocone antenna on ground plane coaxially fed by a fast step function generator and, at the receiging side, of a broadband e-sensor connected to a 20 GHz digitizing oscilloscope. The target under test is put on the ground plane and illuminated with the TEM wave radiated by the antenna. After calibration with conducting and dielectric canonical targets (M. Piette, E. Schweicher, A. Vander Vorst, IEEE AP-S/URSI Conference 1995, URSI-A p. 268), the TD-Scattering Range is now used to measure and analyse the short pulse scattering on bodies which are not strictly canonical but are relevant as main contributors to the RCS of a complex target. This is the case of reentrant cavities like the jet inlets and the cockpit.

The present paper reports recent measurements of short pulse scattering on cylindrical cavities which can be seen as a simple model for the jet inlet. Both monostatic and bistatic impulse responses of a conducting cylinder open at one end and shorted at the other end are measured with a gaussian plane wave excitation pulse having a duration from 90 to 300 ps. The length of the cylinders ranges from 2 to 8 times the pulse length and the diameter of the cavity ranges from 0,5 to 2 times the pulse length. The analysis of the waveform obtained in the monostatic case for end-on incidence shows clearly (because they are time separated) the relative contributions of the different scattering mechanisms to the total RCS : diffraction on the cavity aperture, backscattering of the creeping wave travelling along the outer surface of the cylinder and backscattering due to the reflection on the bottom of the cylinder of the energy coupled into the cavity. The measurements carried out with other angles of incidence (monostatic) and also in the bistatic configuration show the dynamic range of the amplitude of each of these contributions. Because the cavity is a quite difficult body with regard to the exact calculation of the scattered field, the measurements reported here and that will be detailed in the oral presentation can help to have a better understanding of the physical mechanisms contributing to the RCS of a cavity.

RCS Determination from Localized Short-Pulse Scattering Measurements: Theory and Experiment

Morris P. Kesler, James G. Maloney, Eric J. Kuster,
Paul G. Friederich and Brian L. Shirley

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Ve report results of a new method for measuring the RCS of a target using a series of localized cattering measurements. A localized scattering measurement is one in which the transmitting ınd receiving antennas are located in close proximity to the target, typically on the order of the arget diameter or less, much closer than the traditional far-field distance. Thus, the fields incilent on the target are generally non-planar, and the scattered fields are more complex than in the 'ar-field. In the previous meeting, we presented results of localized scattering measurements vith detailed comparisons to numerical models (MoM and FDTD). Excellent agreement was ;enerally obtained for complex, laboratory-scale targets (dielectric and magnetic coated finite :ylinders, etc.).

n this paper, we will present the application of localized measurements to the determination of 'ar-field RCS. The technique involves performing a series of individual scattering measurenents, and then combining the results in an optimized fashion to extract the monostatic or ›istatic RCS. This approach is similar to the near-field scanning technique for RCS measurenent, however, by optimizing the way in which the individual data are combined, the number of neasurements needed can be significantly reduced. For example, the scan-plane size can be educed to as small as twice the size of the target (a factor of 5 times smaller than a typical nearfield scan).

The optimization technique is derived from a plane-wave synthesis technique. The weighting coefficients are determined by minimizing the least-square error between the generated field and the desired plane wave over a volume enclosing the target. Using this approach, a planar field can be generated over the target region by using an "effective" array only twice the dimension of the target. A similar approach can be used to select the desired plane wave component of the scattered field. We will present the details of the theory behind this new RCS measurement technique, as well as comparisons of measured results to model predictions.

Wednesday, May 29, 1:30 PM **Room: Aztec**

JXO-3 **Signal Processing**

Chair: *M. Wynn, Naval Surface Warfare Center, Panama City, FL*

1:30 PM **INTRODUCTION & ANNOUNCEMENTS**

1:35 PM **MAGNETIC GRADIENT TENSOR SIGNAL PROCESSING FOR UXO LOCALIZATION AND CLASSIFICATION,** *M. WYNN and G. ALLEN, Naval Surface Warfare Center, Panama City, FL* 218

1:55 PM **APPLICATION OF FREQUENCY DISPERSIVE SIGNAL PROCESSING METHODS TO DETECTION OF UNDERGROUND OBJECTS,** *L. ZHANG, Mandex, Inc., Fairfax, VA; and I. KOHLBERG, Kohlberg Associates, Inc., Alexandria, VA* 219

2:15 PM **ON DATA PROCESSING OF MULTIPATH EFFECT,** *ZengLin and JingShuHua, The 54th Research Institute of Ministry of Electronic Industry, ShiJiaZhuang, China* 220

2:35 PM **LASER NEUTRALIZATION OF SURFACE UNEXPLODED ORDNANCE,** *O.C. HOFER, Sparta, Inc., Huntsville, AL* 221

MAGNETIC GRADIENT TENSOR SIGNAL PROCESSING FOR UXO LOCALIZATION AND CLASSIFICATION

M. Wynn and G. Allen

Naval Surface Warfare Center
Dahlgren Division
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Panama City, Florida

ABSTRACT

A major portion of the UXO burden consists of ferromagnetic objects that are detectable because they create small changes in the earth's magnetic field. Common methods of detecting these changes with sensors in motion employ total field sensors, which provide a single channel of information that can be difficult to interpret, and interpretation typically requires large data samples over a grid. A more powerful method of detection and interpretation would be available if three-axis vector magnetometers could be used in motion, but the uncontrollable rotations of such a sensor in the large earth's field will produce random variations that greatly exceed the small anomalous fields associated with UXO targets. Thus, to produce multi-channel magnetic measurements in motion, methods must be developed to deal with the background earth's magnetic field.

The U. S. Navy has been developing alternative sensors for magnetic detection in motion for over twenty years. They are tensor gradiometers, which can measure the three spatial derivatives of the three components of the magnetic field at each point in space. The primary thrust has been to develop gradiometers based on superconducting technology, but there have been recent efforts to develop fluxgate technology for short-range, man-portable applications.

The matrix representing the magnetic gradient tensor is symmetric and traceless because of the vanishing curl and divergence of the static magnetic field in air, so each measurement produces five independent quantities. This presentation describes signal processing algorithms that include monitoring the gradient tensor magnitude for proximity of sources, interactive direction finding to a source on a point by-point-basis, and standoff position (including depth of burial) and magnetic moment vector determination with data determined both at separate points, and essentially at a single point. The algorithms use the gradient tensor values, as well as estimates of the gradient tensor rate of change with either time or position.

The algorithms are based on the inversion of the gradient tensor equations for a magnetic dipole, and the inversion of the gradient rate tensor equations for a magnetic dipole, with these procedures used both individually and jointly. The procedures individually provide point-by-point values for the bearing vector to the source, the direction of the moment vector, and the ratio of the moment vector magnitude to a power of the range-to-source. The individual procedures have multiple solutions which can be sorted by a variety of techniques that generally involve measurements at more than one point. When the procedures are used jointly, they produce a unique solution for the full position vector and magnetic moment vector of the source on essentially a point-by-point basis.

We describe experimental results obtained with a prototype five-axis gradiometer in motion against real UXO targets, and describe the requirements for a practical, self-contained system.

APPLICATION OF FREQUENCY DISPERSIVE SIGNAL PROCESSING METHODS TO DETECTION OF UNDERGROUND OBJECTS

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Kohlberg Associates, Inc., Alexandria, VA, (703)751-5637

This investigation deals with novel signal processing techniques for increasing the Signal-to-Clutter Ratio (SCR) for an airborne radar platform when the ground is dispersive. A dispersive propagation condition may arise for deeply buried objects with modest conductivity or for shallow buried objects in highly conductive soil (e.g., rain, snow). ***Figure 1*** is a sketch of the comparison between the surface clutter response, $S_C(t)$, and buried object response, $S_B(t)$, for a hypothetical impulse-like transmitted waveform $S_T(t)$. Under typical conditions $|S_C(t)| >> |S_B(t)|$ so that robust signal processing techniques must be used to increase the SCR for detection.

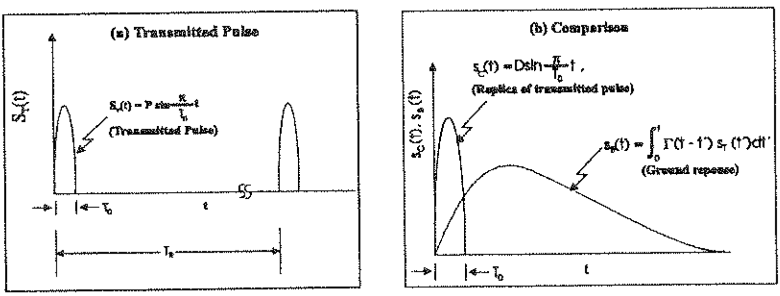

Figure 1. Response of surface clutter and buried object in the dispersive regime

The time-spreading feature of the buried target return shown in ***Figure 1(b)*** can be used to differentiate between the target and surface clutter. This is discussed in the "Correlation Coincidence Detection" (Mandex patent pending) algorithm that can greatly increase the SCR. The range of applicability of the algorithm is discussed in terms of Ground Penetrating Radar (GPR) type, frequency, target type and depth, and ground characteristics. In addition, we present a modification of the traditional matched filter theory that optimize the SCR in the presence of dispersion and scattering in the ground. The transfer function of the resulting filter, H(f), is of the form:

$$H(f) = \frac{kG^*(f)S_T^*(f)}{N_0/2+|\Psi(f)S_T(f)|}e^{-j2\pi f t_d}$$

where G(f) is the transfer function of the ground which depends on: reflection from ground surface, penetration down and back from buried target, and response of buried target. Ψ(f) depends on: multiple scattering from ground irregularities, surface roughness (a multiple scattering problem), and discrete surface objects. How these factors affect the detection of buried objects is addressed in the study.

On Data Processing of Multipath Effect

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Multipath effect has been an important problem to puzzle the designers and researchers in radar and sonar system. It directly influences the possibility of the continuous target measurement and the measurement accuracy. This paper tries to filter the multipath interference and make the tracking measurement possible and improve the measurement accuracy so as to obtain the better trajectory adaptively from the different viewpoint to the traditional ones.

This paper analysis the producing mechanism of the sea multipath effect, sets up the sea multipath interference, and also, on this basis, proposes the method to use the extended kalman filter(EKF) to filter the multipath interference on the step of data processing for the low-flying targets above the sea. In this paper, the defuse scatter and specular reflection models are distinguished and that the specular reflection is the key factor to influence the measurement accuracy is pointed out. The computer simulation result proves that this method can effectively overcome the sea multipath effect and increase the elevation measurement accuracy. Although only the sea target example is given here, the proposed method will be of great value for reference in the general sonar and radar systems.

Key Words: multipath effect, kalman filter, radar, sonar

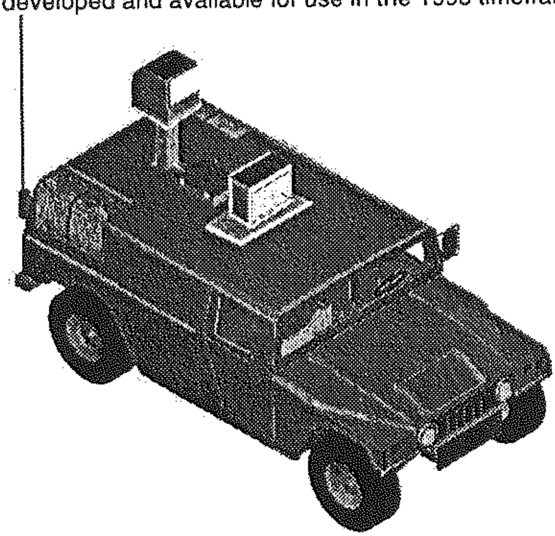
LASER NEUTRALIZATION OF SURFACE UNEXPLODED ORDNANCE

Dr. Owen C. Hofer, SPARTA, Inc., Huntsville, AL 35805

The use of lasers for neutralization of surface laid UneXploded Ordnance (UXO) has been demonstrated in extensive live field demonstration tests in 1994 at Redstone Arsenal, AL. The testing was conducted with an arc lamp-pumped Nd:YAG laser. The system was readily integrated onto an M113A2 armored personnel carrier. The tests showed that the system was very effective in neutralizing greater than 95% of the UXO tested. The concept is effective against landmines (PROM-1, BLU-91, BLU-97, TMA-3, TMA-4, RG-42, Type 69), rifle grenades (MDL-57), artillery rounds (105 mm, 155 mm, CTG-4.2), and general purpose bombs (MK-81, MK-82, OFAB-100/120).

The use of laser UXO neutralization is fast and safe because the propagating laser beam remotely heats the UXO until deflagration or detonation occurs. The neutralization process usually causes a low order explosion; this prevents collateral damage. The neutralization process does not depend on the UXO case material (plastic or metal) or fusing scheme (electronic, mechanical, magnetic). The laser radiation heats the case until the interior temperature of the munition case exceeds the explosive material's combustion temperature, causing neutralization.

The recent development of diode-pumped lasers, which are more efficient electrically and have higher laser beam quality, will permit the integration of the system onto smaller platforms such as the U.S. Army's HMMWV. A recent system analysis and packaging study by SPARTA, Inc. has shown that the system can be easily packaged on a HMMWV as shown below. It is anticipated that the system will be developed and available for use in the 1998 timeframe.



Vednesday, May 29, 3:40 PM **Room: Dona Ana**

IXO-4 **EOD Tools**

CoChairs: R. Way, Marine Corps Det., Indian Head, MD
J. Lorentz, Yuma Proving Ground, AZ

3:40 PM **ORDNANCE AND EXPLOSIVE PROGRAM KNOWLEDGE BASE (OE-KB)**, *L. HELMS, Army Corps of Engineers, Huntsville Division, Huntsville, AL* 224

4:00 PM **DEVELOPING A CENTER OF EXPERTISE**, *R. NORE, Army Corps of Engineers, Huntsville Division, Huntsville, AL* 225

4:20 PM **SITESTATS/GRIDSTATS: A STATISTICAL CHARACTERIZATION OF DISPERSED ORDNANCE AND EXPLOSIVES CONTAMINATION**, *A. FANNING, Army Corps of Engineers, Huntsville Division, Huntsville, AL* 226

4:40 PM **OECERT (ORDNANCE AND EXPLOSIVES COST ESTIMATING AND RISK TOOL)**, *A. FANNING, Army Corps of Engineers, Huntsville Division, Huntsville, AL* 227

ORDNANCE AND EXPLOSIVE PROGRAM KNOWLEDGE BASE (OE-KB)

author: Lynn Helms, Geotechnical Engineer
CEHNC-ED-CS-G

Background: The U.S. Army Engineering and Support Center, Huntsville (CEHNC) is the Mandatory Center of Expertise (MCX) for Ordnance and Explosives. An OE-GIS standard was created for CEHNC and has been applied to several projects. The GIS assembles all the data required to associate the non-intrusive geophysical data to it's correct geographical location, the relational database, mapping and remote sensing data. The purpose is to use the GIS tools to manage the efficient and seamless transition, from data assembly, data fusion, project administration, resource tracking, project brief preparation and to discriminate OE from background anomalies. The discrimination is being done by a program that uses a subset of the GIS data called the OE-KB. The KB's purpose is to collect and analyze investigative information for Ordnance from multiple Ordnance GIS systems and compile it to establish a knowledge base of characteristics of investigated ordnance.

Problem: The OE project sites are geographically dispersed, have differing environmental characteristics and widely varying types of ordnance and dispersion patterns. In addition they may utilize various investigative instruments and techniques for subsurface investigations. These techniques can identify but not discriminate geophysical anomalies. A profile or fingerprint of a specific ordnance item should be established to assist in anomaly evaluations that could then be applied to future projects. This is the primary purpose of the KB technique.

Solution: KB-1. The KB-1 product was created and tested using both digital and analog methods to measure the shape characteristics and perform database manipulations to assist in ordnance discrimination. The GIS system provided the mechanism for input, queries and output of mapping , modeling, and related project data. The KB-1 objectives are to document and archive the occurrence of OE and related site specific conditions for each project and to enable a quantitative analysis of characteristics, such as mass and depth, from non-intrusive geophysical surveys. Instrument data from the Geonics EM-61 conductivity meter, and the TM-4 magnetometer provided the basic input for analyses. The specific type of data manipulation applied depends upon the geophysical instrument or other sensor employed. These included statistical filters, algebraic, numeric, Fourier, matrices and Intergraph GIS image manipulating software routines. Anomaly characteristics are compared to known UXO electronic, processed numerical, and interpreted image signatures to further enhance the OE investigation.

KB-2. The KB concept has been enhanced. In the KB-2 evolution, the computer now uses Artificial Intelligence and shape recognition routines to assist in anomaly identification. The KB-2 is a multipurpose program that accepts geophysical data in a generic format, prepares the data for submission to an analytical engine, submits the data to the engine, and prepares the results for presentation to the user. The current analytical engine in KB 2 is a complex domain neural network. The architecture is a multiple-layer feed-forward network. It is designed to easily accept other analytical engines as the need arises. Different geophysical techniques as well as different environmental terrains will each require unique approaches to produce the best possible results.

KB-2 is currently optimized to provide mass and depth estimates for targets identified by the Geonics EM-61. Work is under way to provide for analysis of total field magnetometer and gradiometer data.

KB Summary: The KB is part of a comprehensive decision support system. The intent is to provide the tools to enable well informed decisions on OE investigations and enhanced project management. The KB is a building block to begin the ordnance discrimination process, ultimately resulting in large execution (removed) lost savings. These tools are intended to be used with a data visualization methodology that facilitates fusion of the analytic results of the KB modules with more qualitative analysis. During use it will incorporate geophysics and project data from multiple sites in a process of continuous development and enhancement. Enhancement will include additional technologies, incorporation of data fusion from multiple geophysical instruments, and a statistical analysis of previous and current project OE field and geophysics data.

DEVELOPING A CENTER OF EXPERTISE

Mr. Robert Nore
Group Leader
Ordnance and Explosives Center of Expertise

Address: U.S. Army Engineering and Support Center, Huntsville
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Huntsville, AL 35807-4301

In 1990 Huntsville was designated the Mandatory Center of Expertise (MCX) and Design Center for Corps of Engineers activities involving Ordnance and Explosives. The program started with a budget of less than $2 million and very limited personnel resources, and by 1995 had grown to $90 million. The program was at first expected to be fairly limited in scope. There was a considerable vacuum in policy, procedures, and guidelines on how to properly execute ordnance projects, on the personnel qualifications required to ensure safe and efficient execution, how to contract for the work, on how environmental regulations as they applied to ordnance, and many other considerations. A training program had to be developed to ensure that Huntsville personnel and other affected Corps of Engineers personnel were informed on the emerging policies, procedures and guidelines. Agreements were needed with supporting or parallel agencies such as 52nd Group (EOD), Army Environmental Center, and others in order to delineate roles and responsibilities. Applications of the latest technologies to the ordnance program needed investigation.

The MCX tasks of policy, training, and technology development were coupled with Design Center requirements to execute a program of investigations and cleanup actions that grew almost exponentially. At first, MCX development took a back seat to project execution, since personnel resources were not available to execute both programs concurrently. After several attempts at reorganization, we finally found a satisfactory structure that separated MCX resources from Design Center resources. At that point the MCX was able to focus on developing the documentation needed to define the future of the ordnance program.

This paper will examine briefly the functions of the MCX and its evolution. Accomplishments of the MCX will be reviewed in the areas of policy and procedures, training, technology applications, technical oversight of ordnance projects, and lessons learned. Plans for the future of the ordnance program will also be discussed.

Title: SiteStats/Gridstats: A Statistical Characterization of Dispersed Ordnance and Explosives Contamination

Author: Arkie Fanning, PE

SiteStats/GridStats is a statistical sampling decision support tool that statistically characterizes the density of ordnance at FUD sites. SiteStats/GridStats was jointly developed by the Huntsville Division Corps of Engineers and QuantiTech Inc. This tool is designed to minimize the sampling requirements necessary to characterize Ordnance and Explosives (OE) contamination for a specified level of statistical confidence. The characterization includes a confidence interval and point estimate of contamination density using the hypergeometric probability distribution and the sequential probability ratio test. SiteStats is used to determine the ordnance density for the FUD site. GridStats (a submodule of SiteStats and a stand alone program) is used to determine the ordnance density for an individual grid. GridStats has significantly reduced the number of anomalies that must be investigated in a grid to determine the density of that grid. Under the current GridStats configuration, no more than 40% of anomalies have to be investigated to achieve statistical confidence of the density of the grid. Normally much less than 40% of the anomalies have to be investigated (on average 20-25%). SiteStats/GridStats uses sophisticated statistical techniques such as a sequential probability ratio test and clustering algorithms to both increase the statistical confidence and to decrease the data required to be investigated. SiteStats/GridStats is designed to be resident on a laptop computer, is used in the field by non-technical people and to be extremely user friendly. SiteStats/GridStats has been used at numerous FUD sites and has saved the Government significant amounts of money in the investigation stage of the Engineering Evaluation and Cost Analysis phase and has led to the development of much more accurate ordnance density estimates for the sites (the ordnance density is required to determine the public risk inherent at the site). Future anticipated enhancements to SiteStats/GridStats include developing a Bayseian version based on historical usage, use of a proportion test in GridStats rather than a discrete test, and the development of a binomial module that would eliminate the need for flagging individual anomalies.

Title: OECert (Ordnance and Explosives Cost Estimating and Risk Tool)

Author: Arkie Fanning, PE

OECert is a risk based decision model for use in characterizing and prioritizing Formerly Used Defense Sites (FUDS) remediation work. OECert has been jointly developed by the Huntsville Division Corps of Engineers and QuantiTech Inc. The model uses several factors at a site (density of ordnance, type of ordnance, terrain features, population density, and many others) to determine the risk to public safety at the site. The model uses many of these same factors, as well as other factors, to develop rough order of magnitude life cycle costs for the site. The model is being used to determine the public risk represented by the various remediation alternatives that are generated during the Engineering Evaluation and Cost Analysis phase at a FUD site. The model allows the Government to determine the risk reduction for dollar spent for the remediation alternatives under consideration. The model is also currently being used to prioritize work areas at a site (which area of a site should be cleaned first) and may in the future be used to develop a prioritized list of sites for remediation. OECert is more discriminating than are Risk Assessment Codes and can be used to compare the potential public risk at varying sites plus it can compare the potential public risk both before and after remediation at any given site. It can also be used to determine when it becomes economically unfeasible to further remediate a site. The mathematics and engineering required to ensure the accuracy of the model has been developed and gone through peer review. The peer review found the model theoretically correct and operationally usable. A menu driven computer program has being written that will allow non-technical personnel to update and run the model.

Vednesday, May 29, 3:40 PM **Room: Aztec**

JXO-5 **Containment**

Chair: *F. Dunfrund, Yuma Proving Ground, Yuma, AZ*

3:40 PM **AN ON-SITE DEMOLITION CONTAINER FOR UNEXPLODED ORDNANCE,** *J.M. SERENA III, Army Corps of Engineers, Huntsville Division, Huntsville, AL* 230

4:00 PM **VAPOR CONTAINMENT STRUCTURE DEVELOPMENT AND USE,** *J.P. MANTHEY, Army Corps of Engineers, Huntsville Division, Huntsville, AL* 231

4:20 PM **AN ORDNANCE REMEDIATION BARRICADE GUIDE,** *J.P. MANTHEY, Army Corps of Engineers, Huntsville Division, Huntsville, AL* 232

AN ON-SITE DEMOLITION CONTAINER FOR UNEXPLODED ORDNANCE

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The U.S. Army Engineering and Support Center, Huntsville (USAESCH), is the Army's Mandatory Center of Expertise for ordnance and explosive remediation. We are actively involved in the removal is unexploded ordnance from active military installations, installations slated for closure, and formerly used defense sites (FUDS). The removal of ordnance presents hazards from the effects of an explosion, including blast overpressures and fragment projectiles. Both people and their property must be protected from these effects. Currently, all munitions must be buried before on-site detonation, or transported to a remote site for demolition.

USAESCH has developed a containment structure for use in on-site demolition of unexploded ordnance. In operational use, ordnance to be destroyed will be placed inside the container and detonated. This vessel is designed to contain the effects of the explosions and limit the evacuation zone to a very small work area. The container uses innovative materials for the capture of fragments and reduction of blast pressures. The container will permit on-site detonation of the ordnance and permit on-site detonation of recovered ordnance much more safely and efficiently.

This paper presents the work involved in developing, fabricating, and proof testing the first in a planned series of ordnance demolition containers. Analysis and design techniques are presented. Testing of innovative blast and fragment mitigating materials, and the effectiveness of these materials, is discussed. The proof testing and certification of the container is outlined. The details of the completed container, and recommendations and limitations for its use, are presented.

VAPOR CONTAINMENT STRUCTURE DEVELOPMENT AND USE

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The U.S. Army Engineering and Support Center, Huntsville, (USAESCH) is actively involved in the location and removal of buried unexploded munitions at numerous sites. In many cases, the munitions include liquid filled rounds which may contain hazardous chemical agents. A critical parameter for safety siting is the downwind hazard in the event of an accidental detonation of a chemical munition. An extensive test program has been conducted to determine the effectiveness of a typical environmental vapor containment structure (VCS) in controlling the downwind hazards resulting from the accidental detonation of a chemical filled munition. This decrease in downwind hazards allows significant reductions in the required evacuation distance. Tests were conducted using replica scale models of the "Livens" and 4.7-inch munitions, filled with an inert agent simulant and detonated inside of a full scale typical steel arch confinement structure. These tests were required for deployment at Wesley Seminary in Washington, DC, in the community of Spring Valley. The internal shock and quasi-static pressures, external overpressures, and the interior and exterior simulant dosages were measured. Prior to conducting the confinement tests, limited arena tests were performed to determine the fragmentation hazards for each munition. As part of the arena tests, measurements were made of the side-on overpressures. A description of the confinement structure, structural features pertaining to blast and chemical agent containment, the model munitions, as well as an overview of the tests conducted and a summary of the test results, are presented in this paper. Additional development includes a partial capture annex to the VCS, which uses open suction hoods near the release point with high suction flow rates to capture a non-explosive release of chemical agent. The partial capture system (PCS) is to be used in removal operations where the possible chemical release is non-explosive and a total containment system such as the VCS cannot be used. Another planned refinement of the VCS is to clearly define its limits and use for a generic chemical ordnance item. A discussion of the additional refinements included in this paper.

AN ORDNANCE REMEDIATION BARRICADE GUIDE

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Barricades are widely used for mitigating the effects of fragmentation from an accidental explosion during the removal process. These barricades are designed for each site as required for the site specific requirements. The criteria and design parameters for barricades have not been clearly defined and thus the designs and use of barricades vary widely. Barricade designs presently require significant efforts by engineering personnel, and due to the urgencies of many ordnance removal operations, little time is available. The U.S. Army Engineering and Support Center, Huntsville, is developing a guide for the design, construction, and use of barricades for explosive ordnance removal operations. The guide will initially include use and construction of an aluminum framed portable barricade with three or four fragment mitigating surface types. The guide will allow field personnel to easily specify and construct a barricade for use, including the thickness of the fragment mitigating material used. The only parameters required from the field personnel will be the approximate fragment mass and velocity resulting from an accidental detonation. This will result in a commonality in barricades and reduce the engineering requirement in removal operations. This paper will cover the initial barricade guide development along with the future development plans, including Graphical Information System (GIS) computer program development; other barricade types including modular, equipment mounted, trailer mounted, and acceptor barricades; and potential new fragment mitigating material development. This effort is being conducted for the Innovative Technologies Development Program in support of Huntsville Division's Ordnance and Explosives Army Mandatory Center of Expertise.

PANEL SESSIONS

:ey Issues in High Power Microwave Sources 234

'ate: Wednesday, 29 May 1996
ime: 6:30 p.m. - 7:45 p.m.
ocation: San Miguel Room
loderator: James Benford, Physics International

anel Members: Gregory Denisov, Nizhny Novgorod, Russia
Kirk Hackett, Phillips Laboratory, Kirtland AFB, NM
Dave Parkes, Defence Research Agency, UK
John Swegle, Lawrence Livermore National Laboratory, Livermore, CA

Inexploded Ordnance - A Multi-dimensional Challenge 235

late: Wednesay, 29 May 1996
ime: 6:30 p.m. - 7:45 p.m.
ocation: Mesilla Room
loderator: Andy Hooper, Yuma Proving Ground

'anel Members: Carl Baum, Phillips Laboratory
Randy Cerar, Army Environmental Center
Regina Dugan, Defense Advanced Research Projects Agency
Harry Hambric, Night Vision and Electronic Sensors Directorate, Ft. Belvoir, VA
Ralph Way, Marine Corps Detachment, Indian Head, MD

:lectromagnetic Interaction 236

)ate: Wednesday, 29 May 1996
'ime: 8:00 p.m. - 9:15 p.m.
.ocation: San Miguel Room
/loderator: Robert L. Gardner, Phillips Laboratory

'anel Members: Carl Baum, Phillips Laboratory
Robert Hutchins, BDM Federal
Donald McLemore, Kaman Sciences
J.P. Parmantier, ONERA, FR
Victor van Lint, Consultant

'uture Directions and Applications for
Iltrawideband/Short Pulse Electromagnetics 237

)ate: Wednesday, 29 May 1996
'ime: 8:00 p.m. - 9:15 p.m.
.ocation: Mesilla Room
/loderator: Lawrence Carin, Duke University

'anel Members: Serpil Ayasli, Lincoln Laboratory
Carl Baum, Phillips Laboratory
Mark Davis, Advanced Research Projects Administration
John McCorkle, Army Research Laboratory
Arje Nachman, Air Force Office of Scientific Research

Key Issues in High Power Microwave Sources

Date: Wednesday, 29 May 1996
Time: 6:30 p.m. - 7:45 p.m.
Location: San Miguel Room
Moderator: James Benford, Physics International

Panel Members: Gregory Denisov, Nizhny Novgorod, Russia
Kirk Hackett, Phillips Laboratory, Kirtland AFB, NM
Dave Parkes, Defence Research Agency, UK
John Swegle, Lawrence Livermore National Laboratory, Livermore, CA

Abstract: This session will consist of a discussion of current burning issues such as how to improve source efficiency, extraction of radiation and the universal phenomena of pulse shortening. The international makeup of the panel will reflect a wide range of opinion.

Unexploded Ordnance - A Multi-dimensional Challenge

Date: Wednesay, 29 May 1996
Time: 6:30 p.m. - 7:45 p.m.
Location: Mesilla Room
Moderator: Andy Hooper, Yuma Proving Ground

Panel Members: Carl Baum, Phillips Laboratory
Randy Cerar, Army Environmental Center
Regina Dugan, Defense Advanced Research Projects Agency
Harry Hambric, Night Vision and Electronic Sensors Directorate, Ft. Belvoir, VA
Ralph Way, Marine Corps Detachment, Indian Head, MD

Abstract: It is hard to overstate the difficulty of the problem of unexploded ordinance (UXO) remediation. The task is dangerous, technically difficult, and expensive. This alone should be enough of a challenge but when you consider the sheer magnitude of the UXO contamination and the fact that it exists worldwide, it would appear to be an impossible problem. The development of systems that will allow us to quickly and easily detect and locate UXO will take decades of engineering efforts. This type of development will be expensive but the reward in land returned to the public, lives saved, and technology spin-offs will more than make up the cost. Sensor technologies to identify UXO generally exist. However, the area of target identification remains one of the most difficult, as yet unsolved, problems facing us to date. Simply put, the funds do not exist to dig up every contact unless we have a priori knowledge that the contact is, in fact, UXO. Typically, in a test range environment or a battle field, a variety of metallic objects will have been driven into the ground making detection and identification of UXO a formidable task. Finally, we have limited experience in the area of integrating technologies for detection and identification. We do know, however, that no single sensor system will solve the problem. Multiple sensors, providing multi-spectral data, will have to be combined in order to increase the probability of detection and indentification. Considering the enormity of the UXO problem, we must be careful when deciding where to begin. We already know how to deal with UXO once it has been found. We don't know where it is located and how much is present. At least, we're beginning to ask the right questions. Now where do we go from here?

Electromagnetic Interaction

Date: Wednesday, 29 May 1996
Time: 8:00 p.m. - 9:15 p.m.
Location: San Miguel Room
Moderator: Robert L. Gardner, Phillips Laboratory

Panel Members: Carl Baum, Phillips Laboratory
Robert Hutchins, BDM Federal
Donald McLemore, Kaman Sciences
J.P. Parmantier, ONERA, FR
Victor van Lint, Consultant

Abstract: This session will concentrate on the fundamentals of electromagnetic lethality as applied to high power electromagnetics. An international team of experts will first deliver papers in two preceding sessions and then bring all of the important points together in this panel session. Prediction of the failure of a complex system due to electromagnetic stimulus is difficult and requires careful thought. This group represents several centuries of experience in the subtleties of electromagnetic lethality and hardening covering the disciplines of HPM, lightening, EMC, EMI, and several varieties of EMP.

Future Directions and Applications for Ultrawideband/Short Pulse Electromagnetics

Date: Wednesday, 29 May 1996
Time: 8:00 p.m. - 9:15 p.m.
Location: Mesilla Room
Moderator: Lawrence Carin, Duke University

Panel Members: Serpil Ayasli, Lincoln Laboratory
Carl Baum, Phillips Laboratory
Mark Davis, Advanced Research Projects Administration
John McCorkle, Army Research Laboratory
Arje Nachman, Air Force Office of Scientific Research

Abstract: Over the last several years, ultrawideband (UWB) short-pulse (SP) electromagnetics has received renewed interest for military and civilian applications. An UWB / SP waveform typically has bandwidth greater than 25%, with the center frequency determined by the desired application. Recent applications which have seen considerable activity include foliage penetrating radar, ground penetrating radar, directed-energy weapons, and material characterization. As this technology continues to mature, the research and systems communities must coalesce on which applications are most likely to be most fruitful and what technical challenges still must be overcome. In this panel session, leaders in the UWB / SP community will address these issues, with each panel member delivering a short formal presentation of their views on these issues, followed by an open discussion involving panel and audience members.

hursday, May 30, 8:30 AM **Room: Galisteo**

PEM-18 **(Invited) International EMC Standards**

CoChairs: M.W. Wik, Defense Materiel Administration, Stockholm, Sweden
W.A. Radasky, Metatech Corp., Goleta, CA

8:30 AM **INTRODUCTION & ANNOUNCEMENTS**

8:35 AM **(INVITED) STATE OF THE ART OF EMC STANDARDIZATION**, *J. DELABALLE, Schneider Electric, Grenoble , France* 240

8:55 AM **(INVITED) IEC STANDARDIZATION OF IMMUNITY TO HIGH ALTITUDE EMP (HEMP)**, *M.W. WIK, Defense Materiel Administration, Stockholm, Sweden; and W.A. RADASKY, Metatech Corporation, Goleta, CA* 241

9:15 AM **(INVITED) DEVELOPMENT OF THE IEC HEMP CONDUCTED ENVIRONMENT STANDARD**, *W.A. RADASKY, Metatech Corporation, Goleta, CA* 242

9:35 AM **(INVITED) PROTECTION CONCEPTS AGAINST THE EFFECTS OF A HIGH ALTITUDE EMP FOR THE CIVIL STANDARD OF THE IEC SC77C**, *M. IANOZ, Swiss Federal Institute of Technology, Lausanne, Switzerland; and W. BUECHLER, Boise, ID* 243

9:55 AM **(INVITED) ACTIVITY IN ESTABLISHING OF STANDARDS IN THE FIELD OF ELECTROMAGNETIC PULSE OF DIFFERENT RESULTS IN RUSSIA**, *V. LOBOREV, Y. PARFENOV, P. SIDORJUK, L. IVANOV, A. ANISIMOV and A. CHIKUROV, Central Institute of Physics and Technology, Moscow, Russia* 244

10:15 AM **BREAK**

10:40 AM **(INVITED) DEVELOPMENT OF HEMP SPECIFICATIONS AND STANDARDS FOR CIVILIAN USE: TEST METHODS FOR SHIELDING ENCLOSURES**, *F.M. TESCHE, EM Consultant, Dallas, TX* 245

11:00 AM **SHIELDING CRITERIA OF SHIELDED ENCLOSURES THAT ARE EXPOSED TO EXO-NEMP PERTAINING TO AEP4 ED 3, ED 4 AND THE AMENDMENT TO ED4**, *A.P.M. ZWAMBORN and W. PONT, TNO-Physics and Electronics Laboratory, The Hague, The Netherlands; and G.J.J. REMKES, Fokker Special Products, Hoogeveen, The Netherlands* 246

11:20 AM **FEASIBILITY STUDY OF USING COMMERCIAL EMC-STANDARDS ON BOARD ROYAL NETHERLANDS NAVY SHIPS**, *A.B. WOLTERING and A.P.M. ZWAMBORN, TNO-Physics and Electronics Laboratory, The Hague, The Netherlands; and J.A.M. VERNOOY and H. KLOK, Royal Netherlands Navy, The Hague, The Netherlands* 247

STATE OF THE ART OF EMC STANDARDIZATION

Jacques DELABALLE
Secretary IEC SC 77B
SCHNEIDER ELECTRIC, FRANCE

The goal of this paper is to give information on EMC standardization work within IEC, especially within TC 77 for basic, generic and product family standards, as it stands in 1996. It indicates also what is the situation regarding product standards.

The beginning of the paper is dedicated to the organization of TC 77, CISPR and ACEC (Advisory Committee on Electromagnetic Compatibility).

The second clause presents the different families of EMC publications of the IEC 1000 series (IEC 1000-2 series for environment, IEC 1000-3 series for limits, IEC 1000-4 for testing and measurement techniques, IEC 1000-5 for installation and mitigation guidelines).

Then the different types of EMC standards are explained.

Basic EMC standards : They specify the general conditions and rules for the achievement of EMC to all products.

Generic EMC standards : They are pecular to the EMC field. They are related to a given environment and are applicable to all equipment installed in that environment when there is no specific product standard to the equipment.

Product standards - Product family standards : EMC product standards specify the requirements and tests specific to the products considered. EMC product family standards relate to a group of similar products for which the same features apply.

The third part of the paper gives an overview on the major emission standards. A list is given with the specified emission limits. It concerns IEC 1000-3 series.

The fourth part is dedicated to immunity standards regarding testing and measurement techniques. The most important figures of the standards are given.

The fifth part presents some EMC product standards completed or under consideration in the IEC. It is shown how the different phenomena, therefore the corresponding basic EMC standards, are taken into consideration by the different product committees.

As a conclusion corresponding tables between IEC and CENELEC standards are presented.

IEC STANDARDIZATION OF IMMUNITY TO HIGH ALTITUDE EMP (HEMP)

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This paper begins with a review of the organization of the International Electrotechnical Commission (IEC) and the technical subcommittee 77C; SC77C has been formed to develop high-altitude EMP standards and technical reports for the protection and testing of civil electronic equipment and installations. It is working very closely with the IEC EMC subcommittees SC77A and SC77B to combine protection requirements and tests when possible. The Secretariat of subcommittee SC77C is held by Sweden with Manuel Wik holding the position of Secretary and Tomas Wedin serving as the Assistant Secretary. William Radasky of the USA is the subcommittee Chairman.

The bulk of the paper will deal with the nine standards and reports that are under current development, with technical overviews given for each project. Of particular interest is the fact that three of the standards have been approved by the national committee members and should be published before May 1996. These are listed below.

- 1000-2-9 Description of the HEMP Environment: Radiated Disturbance. Project Leader – Guy Champiot, France

- 1000-5-4 Specification of Protective Devices: Radiated Disturbance. Project Leader – Jacques Delaballe, France

- 1000-5-5 Specification of Protective Devices: Conducted Disturbance. Project Leader – Walter Büchler, Switzerland

In addition, two other standards are expected to be completed during 1996:

- 1000-4-24 Test Methods for Protective Devices: Conducted Disturbance. Project Leader – Walter Büchler, Switzerland

- 1000-2-10 Description of HEMP Environment: Conducted Disturbance. Project Leader – William Radasky, USA

The paper will conclude with a discussion of potential new work items with a goal to obtain new ideas and contributions from the EMP and EMC communities.

DEVELOPMENT OF THE IEC HEMP CONDUCTED ENVIRONMENT STANDARD

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This paper describes the technical background and status of the IEC HEMP Standard for Conducted Environments. The present draft document provides the external HEMP currents and voltages coupled to external long lines and antennas. These HEMP stresses are required to enable a civil system designer to determine the amount of protection required at a building point-of-entry (PoE) or for an exposed power transformer or telephone repeater.

One of the most important features of this document that is different from other published HEMP standards is the presentation of conducted stresses in a probabilistic manner. This is accomplished for the early-time HEMP and its interactions with elevated long lines and simple antennas (both vertical monopoles and horizontal dipoles). The workers on this project feel this approach is consistent with the application of the HEMP standards to civil rather than military equipment. For the early-time HEMP coupling to buried cables and for the coupling of the intermediate-time and late-time HEMP fields, the results were found to vary less with observer location. This resulted in conducted environments which varied in a prescribed manner with ground conductivity and cable length as the major parameters.

While this draft standard identifies the external long line and antenna stresses, and to a lesser extent the internal cable stresses, the actual test requirements for internal (to a building) electronic equipment will be determined through a process which considers other factors including external power transformers, PoE protection, and the objective to combine EMC and HEMP equipment tests. These issues will be summarized in the conclusion of the paper.

Protection Concepts against the Effects of a High Altitude EMP for the Civil Standard of the IEC SC77C

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The International Electrotechnical Commission (IEC) has created the Technical Subcommittee 77C to elaborate civil standards for the protection against HEMP.

In protected areas (buildings, installations, systems or equipment), the effect of a HEMP can occur from the radiated electromagnetic field or through conducted penetration of voltage and current surges (conducted disturbance). The aim of this paper is to present a report on the status of the work on the future document IEC 1000-5-3, " HEMP Protection Concepts".

Radiated and conducted environments produced by lightning and HEMP are similar to some extend. Protection concepts for civil applications should therefore take advantage of already installed lightning protection. The designer of the HEMP protection should estimate if, by admitting a certain risk, the lightning protection can be considered as sufficient also against HEMP.

After discussing the concept of zoning, the general methods suited for the protection against radiated and conducted disturbances as well as wiring concepts, the paper discusses the relation between HEMP and lightning protection principles. For HEMP a unique curve of the variation of the early-time electric field vs. time has been defined in IEC 1000-2-9. For lightning, the field shape and intensity depend on the distance to the striking point but it is reasonable to consider only distances not exceeding about 1 km, which makes possible to select only a single shape of lightning electric and magnetic field vs. time. The lightning current parameters as defined by IEC 1312-1 will discussed.

The HEMP conducted environment has been defined in IEC 1000-2-10 using an approach in which a combined horizontal and vertical polarization as a function of the dip angle of the observation point and the probability of occurrence of the elevation and azimuthal angles have been considered. Concerning lightning IEC 1312-1 defines two lightning current curves one for the first return stroke the second for the subsequent strokes but it is much more difficult to determine typical lightning induced currents and voltages. These differences will have consequences on the protection concepts against lightning and against HEMP.

Building and shielded enclosures protection concepts shown in the following tables, proposed for the HEMP standard are presented and discussed.

Building Protection			
		Conducted protection	
Radiated attenuation (dB) 100 kHz 30 MHz		Not protected	Protected
	0	B_{00}	B_{01}
	> 20	B_{10}	B_{11}

Shielded Enclosure Protection		
		Conducted protection
Radiated attenuation (dB) 100 kHz 200 MHz		Protected
	≥ 20	S_1
	≥ 40	S_2
	≥ 60	S_3
	≥ 80	Special

In conclusion the stresses represented by typical HEMP-induced and lightning voltages and currents on protection components are discussed and compared.

ACTIVITY IN ESTABLISHING OF STANDARDS IN THE FIELD OF ELECTROMAGNETIC PULSE OF DIFFERENT RESULTS IN RUSSIA

Central Institute of Physics and Technology (CIPT)
V.Loborev, Ju.Parfenov, P.Sidorjuk, L.Ivanov, A.Anisimov, A.Chikurov

There is Technical Committee of standards in the field of technical means electromagnetic compatibility (TC EMC) of State standard in Russia, that deals with development of state standards and with establishing of international standards in the field of electromagnetic pulse of different results. The TC EMC consists of 12 subcommittees (PK).

Participation of Russia in International standards development in subject "Immunity to HEMP" of IEC subcommittee 77C is realized by subcommittee PK11 of the Technical Committee EMC of Russia presented by leading organization - CIPT . Russian National standards in immunity to HEMP will be developed after acceptance of appropriate International standards with taking into account peculiarities and needs of national economy. However, development of national standards will be complicated by the fact, that a number of principal, to our opinion, remarks did not taken into account by development of IEC standards 1000-2-9, 1000-2-10 and 1000-5-5.

Carrying out technical means certification on immunity to HEMP after putting into practice complex of standards, developed by the 77C subcommittee, will be complicated also by absence of standard on methods and means of pulsed field parameters measuring by the tests of objects on HEMP-simulators. In this connection, we think, that it is advisable to include in the list of prospective works of the 77C subcommittee development of these international standards. Besides, for facilitation of certification equipment choosing, it is advisable to work out International catalogue on HEMP-simulators, measuring means and means of metrological providing of objects tests on the HEMP effect, that may be enclosure to standards mentioned above.

At present, there are great number of branch national standards on tests of equipment and objects on immunity to lightning. However, some of them take into account need of protection of separate devices and not of object as a whole. Other standards do not reflect up-to-date conception about lightning discharge parameters. Therefore, to establish common requirements to certification of technical means, and, in the first place, of aviation technics, it is needed to develop International standards on parameters of lightning fields and currents, and on methods of objects tests on immunity to lightning as well.

In the same connection, development of common International standards on parameters of static electric discharges, forming in natural and artificial radiation zones of the Earth, and on methods of check-up of space apparatus devices immunity to such discharges is needed too.

DEVELOPMENT OF HEMP SPECIFICATIONS AND STANDARDS FOR CIVILIAN USE: TEST METHODS FOR SHIELDING ENCLOSURES

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Electromagnetic pulse technologies have matured to the point where various specifications and standards for the protection of civilian systems against this war-time threat are being developed. One such activity is being conducted by the International Electrotechnical Commission (IEC) within the Technical Committee No. 77 on Electromagnetic Compatibility. Although this is primarily an European standard, investigators from the U.S. are participating in this effort through the auspices U.S. National Academy of Sciences.

The overall specification document, when it is completed, will encompass a wide variety of areas, including a description of the HEMP field environments, coupled surges on above-ground and buried lines, attenuation of fields and currents due to protective structures, test methods, and mitigation methods. One element of this standard document will be the specification of test methods for shielding enclosures.

On a system-level basis, such tests of shielded enclosures can be conducted either using pulsed or continuous wave (CW) fields illuminating the entire enclosure, or the testing can involve a partial illumination, similar to the PARTES concept suggested by Baum. Facilities for such testing can range from full-scale EMP simulators, such as ARES, down to small TEM or GTEM cells for small enclosure (black-box) tests.

In addition to tests of the shielding of the entire enclosure, there is the possibility of using current injection test methods for certain types of protective enclosures, such a shielded cables, for which the shielding is characterized by a transfer impedance and admittance. Moreover, similar tests for individual penetration points in a shield, such as gaskets, seams or other apertures, are possible.

In this paper, the various test methods being suggested for the IEC document are reviewed and a brief overview of the resulting specification document is provided.

SHIELDING CRITERIA OF SHIELDED ENCLOSURES THAT ARE EXPOSED TO EXO-NEMP PERTAINING TO AEP4 ED 3, ED 4 AND THE AMENDMENT TO ED4.

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①Left Fokker 1-12-1995

At the present time projects involving hardening against exo-NEMP are involved in either EMP-model specifications of AEP 4 Ed.3, Ed. 4 or possibly in the near future the amendment of Ed.4. Note that since last last november 1990, new projects should be EMP hardened in accordance to Ed.4 specifications. In order to gain insight into the shielding characteristics of enclosures pertaining to these pulse models, we have caried out a study to define appropriate shielding characteristics.
Exo-NEMP shielding requirements for shielding enclosures as such are not unique. A number of different sets of shielding requirements can be constructed, which all lead to a residual electric and/or magnetic field inside the enclosure that must be sufficiently small. Hence, a certain degree of freedom in choosing appropriate shielding requirements is present. From an economic point of view, it is desirable to select that shielding requirement that leads to minimisation of manufacturing cost of the shielded enclosure.
Formulating the shielding requirements it is obvious to use the laws of physics that dictate a natural behavior of the attenuation function. Note that these trends of attenuation curves are general, and applicable for any shielded enclosure. As a consequence, these natural trends should be included in the requirements to be examined.

In order to develop a set of attenuation functions, a computer program has been written that computes a function by using an minimum-phase reconstruction in an iterative manner. In this presentation, this computer program has been used to develop a set of shielding functions to meet the 5 V/m and 13 mA/m requirements for the electric field and magnetic field, respectively. However, not for all pulse parts this requirement could be achieved. This will be discussed. The formulated shielding functions are presented, discussed and compared. During this comparison, the internal fields inside the shielded enclosures under the different external NEMP-pulse excitations will be discussed in more detail.

FEASIBILITY STUDY OF USING COMMERCIAL EMC-STANDARDS ON BOARD ROYAL NETHERLANDS NAVY SHIPS

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Nowadays, several navies are investigating the applicability of using commercial EMC-standards as a reference to buy equipment and systems to be used on board naval ships. Since the commercially available equipment have to meet the European EMC-directive 89/336/EC, it is expected that in those cases where equipment needs to comply to these EMC-requirements only a consideral amount of money will be saved.

In this paper, the encountered differences between the MIL-STD-461C and D together with the civil EMC-requirements will be discussed. It is noted that this comparison involves limiting-values as well as the pertaining measuring methods. Subsequently, we have determined the electromagnetic environments that will be encountered on board Royal Netherlands Navy ships. Within these established EM-environments, the necessary EMC-requirements that must be put on the equipment are defined. A few of the assumptions made in the theoretical approach of the comparison are verified by using measurement data taken from commercially available equipment. This provides some insight into the practical value of the comparison. It is noted that in case the necessary EMC-requirements could not be met with civil EMC-standards, it is examined whether additional installation rules, or other additional constraints, would lead to an EM-environment in which commercial equipments could be used.

In the presentation, the comparison between the EMC/EMI-standards will be discussed. Special attention will be given to the comparison of the measurement methods. The determined EM-environments will be elucidated in more detail as well as the pertaining EMC/EMI-standards to minimize incompatibility problems. Special attention will be given to the relation between present EM-fields and induced currents on long cables. The latter influences the conducted immunity requirements. Finally, the conclusions will be elucidated more detail.

hursday, May 30, 8:30 AM **Room: Dona Ana**

IPEM-19 Sensors & Diagnostics

CoChairs: T. Bowen, Phillips Laboratory, Kirtland AFB, NM
C. Courtney, Voss Scientific, Albuquerque, NM

8:30 AM **INTRODUCTION & ANNOUNCEMENTS**

8:35 AM **BREAKOUT BOX FOR DIRECT INJECTION EXPERIMENTS OF AIRCRAFT ELECTROMAGNETIC SUSCEPTIBILITY**, *C. COURTNEY, Voss Scientific, Albuquerque, NM; G. DEMUTH, Kaman Sciences Corporation, Albuquerque, NM; V. MARTINEZ, Phillips Laboratory, Kirtland AFB, NM; and J. LEHR, Fiore Industries, Inc., Albuquerque, NM* 250

8:55 AM **DEVELOPMENT OF A LOW LOSS LIQUID LOAD SOLUTION FOR TERMINATION OF HIGH POWER BROADBAND PULSES**, *J. WELLS, J. EGGERT and M. USHER, Fiore Industries, Albuquerque, NM; and R. COPELAND, Phillips Laboratory, Kirtland AFB, NM* 251

9:15 AM **RESISTIVE SENSOR FOR SHORT HIGH POWER MICROWAVE PULSE MEASUREMENT**, *M. DAGYS, Z. KANCLERIS, V. ORSEVSKIJ and R. SIMNISKIS, Semiconductor Physics Institute, Vilnius, Lithuania* 252

9:35 AM **HIGH POWER MICROWAVE FIELD MEASUREMENTS USING STARK BROADCASTING**, *T. ENGLERT, K. HENDRICKS and D. SHIFFLER, Phillips Laboratory, Kirtland AFB, NM* 253

9:55 AM **LASER SPECTROSCOPIC MEASUREMENT OF STRONG ELECTRIC FIELDS IN HPM DEVICES**, *F. SKIFF, Y. CARMEL, J. RODGERS, T. ANTONSEN, JR. and V.L. GRANATSTEIN, University of Maryland, College Park, MD* 254

10:15 AM **BREAK**

10:40 AM **EXAMPLES OF IR FIELD MAPPING OF MICROWAVE POWER DENSITIES**, *H. POHLE, W. PRATHER and J. SADLER, Phillips Laboratory, Kirtland AFB, NM* .... *(Not Available)*

11:00 AM **ISOTROPIC PHOTONIC ELECTRIC FIELD SENSOR FOR SUBNANOSECOND PULSE MEASUREMENTS**, *F. GASSMAN and M. MAILAND, EMC BADEN Ltd., ABB Research Center, Switzerland* 255

BREAKOUT BOX FOR DIRECT INJECTION EXPERIMENTS OF AIRCRAFT ELECTROMAGNETIC SUSCEPTIBILITY

Clifton Courtney
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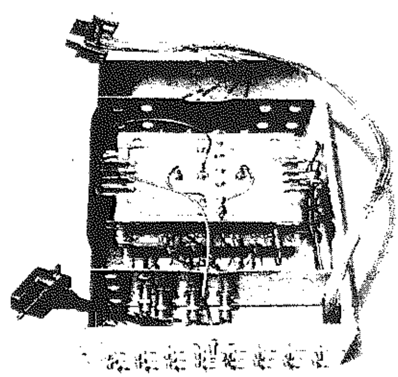
Often the determination of the electromagnetic susceptibility of an aircraft's electronics includes direct injection experiments. An interfering signal, CW or transient in nature, is applied directly to the data bus and signal lines of the aircraft system under test. The purpose is to determine the parameter space (frequency, peak magnitude, total waveform energy, repetition rate, waveform rise time, etc.) of the interfering waveform for which the system(s) are susceptible, and the resulting impact on a system's mission or function. In the past, the frequency or spectrum of the injected signal was typically in the VHF regime and lower (< 150 MHz). Recently, susceptibility of aircraft components to signals with spectrums to 1 GHz and higher have been of interest. Application and measurement of signals in these frequency regimes must be made with greater care since physical cable and component lengths can become significant fractions of a wavelength. Without properly designed and transit-time matched transmission lines, the waveform induced in the wires and circuits of the system under test could be quite different from the assumed interfering waveform. Consequently, the characterization of the upsetting waveform is incomplete (the induced waveform is not the drive waveform), and the determination of upset thresholds is inadequate or in error. This paper describes a breakout box designed for narrow and wideband high-voltage direct injection experiments of aircraft 1553 bus systems to 1 GHz and higher. A description is given of the breakout box, and the design and analysis of the direct injection circuit, the voltage and current sensors, and the high-voltage power divider. Frequency domain characterizations of the circuits are presented, and an example of wideband transient pulse injection and the associated measurements is given.



Breakout Box with top removed to show internal components.

DEVELOPMENT OF A LOW LOSS LIQUID LOAD SOLUTION FOR TERMINATION OF HIGH POWER BROADBAND PULSES

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This paper presents data from the effort to develop a liquid load solution for the oil breakdown experiment. The load was required to have high power handling capability and low dielectric constant and loss tangent. Solutions with high dielectric constant short the higher frequency components of the pulse. The solution developed was composed of copper bromide dissolved in ethyl acetate solution with 10% acetone. We were able to achieve resistivities as low as 200 ohm-centimeters using these components. This will allow for a wide range of resistance values to be achieved in any given geometry. Lower resistivities typically were able to achieve faster rise times. Data will be presented showing that the solution was capable of rise times of 250 picoseconds for the required volume. Calibration of the solution was performed on the mini-tinman calibration fixture with components modified to hold the solution, for this reduced volume we were able to effectively terminate pulses with risetimes of 150 picoseconds. The solution was also calibrated in a parallel plate fixture using an HP 8510 network analyzer for measuring transmission and reflection from the load solution. This data is presented also.

This solution may have applications in other areas requiring termination or monitoring of signals with risetimes in this range. The solution is flammable and an irritant to sensitive tissue. A fume hood, respirator and gloves are required for working with the solution.

RESISTIVE SENSOR FOR SHORT HIGH POWER MICROWAVE PULSE MEASUREMENT

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At the present day high power microwave (HPM) sources generate short (≤ 100 ns) microwave pulses, peak power of which ranges up a few tens of GW. The microwave signal from the output of HPM generator will be strongly attenuated if the peak power of the microwave pulse is measured with the help of a standard microwave diode. On the one hand, this results in the decrease of the measurement accuracy. On the other hand, the strong stray pick up and electromagnetic field interference is typical to the environment nearby high power microwave generators, even though the special measures for measuring system shielding are sometimes insufficient to provide high power microwave pulse measurement with desirable accuracy. Therefore, the problem of great importance is to develop the sensors that can perform measurement of the high power pulses at such conditions.

One of the most favourable devices for HPM pulse measurement is a resistive sensor (RS), the performance of which is based on electron heating effect in semiconductors. A few years ago we have developed the RS for measurement of the HPM pulses with duration 0,5-300 μs (M.Dagys et al, IEEE MTT, vol. 43, 1379-1380, 1995). In this paper the modified RS made from low resistivity n-Si for HPM pulse measurement in a nanosecond range (5- 200 ns) is presented.

Power heads on a basis of this type of RS are constructed and manufactured for different frequency band waveguides. The heads were calibrated up to 180, 60, 80 and 30 kW in S, C, X and Ku-bands, respectively. DC pulse supply is used for RS feeding, so the output signal of the order of a few tens of volts is obtained without any amplification. The head connected to a horn antenna is used for microwave pulse power density measurement in free space. Pulse power densities up to a few MW/m^2 are detected. Switching off DC supply parasitic signal induced in the measurement circuit by the external electric field is determined. It is less than 2% of the useful one. It seems that designed power heads can be used at a higher power level that are practically limited by the waveguide's breakdown. Our investigation confirmed the proposition that RS are one of the most perspective semiconductor devices for HPM pulse measurement in different transmission lines without using directional couplers or attenuators. They produce high output signal, are reliable and overload resistant.

High Power Microwave Field Measurments Using Stark Broadening

Thad Englert, Kyle Hendricks, and Don Shiffler*
Air Force Phillips Laboratory

High power microwave sources driven by intense relativistic electron beams have been a subject of much research over the last decade. In the course of research upon the issues of rf breakdown, we have developed a diagnostic capable of measuring high rf power levels in high electric field regions. This diagnostic is the rf Stark effect. To investigate the effect, a hydrogen-filled glass tube is placed in a region of high rf power. When an rf pulse impinges on the tube, the gas in the tube is ionized. By spectroscopicly observing the H_α and H_β lines, the Stark splitting of the atomic states can be observed. This splitting is proportional to both the rf electric field and frequency. In this paper we present results from a series of experiments performed at the Phillips Laboratory on a relativistic klystron. The spectroscopic measurements were performed in the near field of the radiating antenna using an optical multi-channel analyzer with a quarter meter and a half meter spectrometer. These experiments demonstrate that Stark broadening can be a useful diagnostic in high field environments.

LASER SPECTROSCOPIC MEASUREMENT OF STRONG ELECTRIC FIELDS IN HPM DEVICES

F. Skiff*, Y. Carmel, J. Rodgers, T. Antonsen Jr., V.L. Granatstein, University of Maryland, College park, MD 20742

Uncontrolled amounts of plasma in an undesirable location within HPM sources adversely affect the microwave generation and transmission, leading to pulse shortening. For example, microwave absorption in the vicinity of the collector/window can occur at the lower hybrid frequency, when the following condition is satisfied

$$\omega^2_r = \omega^2_c + \omega^2_p$$

where ω_r, ω_c, and ω_p are the radiation, cyclotron and plasma frequencies respectively. Backstreaming of electrons from the collector to the rf interaction region, often at velocities of up to 100 cm/μsec, can create plasma at the walls even when the density of the energy deposition is less than 2 J/cm^2. Often, even secondary, low energy electrons (100eV), backscattered from the collector with a low current density of 1A/cm^2 are enough to generate plasma. The plasma can then "explode" under the influence of strong, local electromagnetic fields and expand at an extremely high velocity, disrupting the interaction. Understanding the plasma "explosion" under the influence of strong, local, electromagnetic fields is critical to an understanding of pulse shortening effects. We propose to measure strong electromagnetic fields inside HPM sources by laser spectroscopy. The primary principle behind spectroscopic measurements of electric fields is the change in the energy levels of an ion or atom which is produced by the presence of electric fields. These changes result not only in shifts in the spectra, but may also introduce new lines, and may have dramatic effects on the radiative coupling between lines (line strengths). This technique may allow one to measure four quantities; field magnitude (in space and time), field polarization, and field spectral composition.

Isotropic Photonic Electric Field Sensor for Sub-Nanosecond Pulse Measurements

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Recently the demand for pulsed electromagnetic field measurements has been increased. The techniques of high power microwaves, pulse scattering, EMP, ESD and transient radar still lack reliable EM field monitors. One of the main obstacles to develop such field sensors are the enormous difficulties to miniaturize the sensor head providing simultaneously sufficient sensitivity, dynamic range and electrical isolation.

This paper will present a recent prototype development of a fully triaxial photonic field probe for transient and continuous wave electric field measurements. The probe head incorporates three parallel electrooptic Lithium Niobate modulators packaged in purely dielectric material. The modulators cover a frequency range from dc to 3.5 GHz, where in the range dc to 1 GHz an amplitude flatness of ± 0.5 dB can be specified. The modulator input impedance has been optimized to provide maximum electric field sensitivity in conjunction with a broad band dipole antenna. The sensor system including an external 100 mW low noise, single frequency laser and 18 GHz bandwidth GaInP photo detectors reaches a pulse sensitivity of about 4 V/m. For narrow band measurements a sensitivity limit of 500 µV/m/√Hz can be shown. The 1 dB compression point has been set to 12 kV/m peak to peak and could be increased to about 50 kV/m loosing sensitivity correspondingly.

Since the electrooptic modulator works fully passive long term surveys are possible. Further the modulators show good stability within -10 to +50 °C. A forced aging test switching temperatures between -10 and 250°C during 300 hours showed only a neglectable drift of the modulator bias point.

Test measurements were carried out in a small TEM cell with 7.5 cm septum height yielding a ±2dB flat frequency response up to 1 GHz. The cell frequency response was calibrated by a reference monopole. Figure 1 shows a comparison of TEM cell input pulse and sensor response. The rise time is in the range of 300 ps. Figure 2 shows a frequency response measurement in the range of 0.1 to 1 GHz.

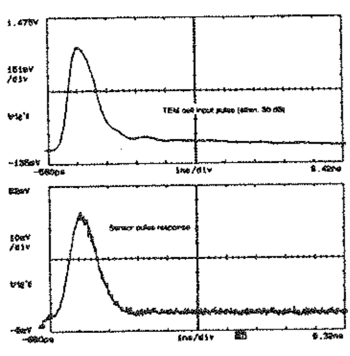

Fig. 1: Comparison of TEM cell input pulse (upper) and sensor pulse response (1ns/div, rise time ≈ 300 ps).

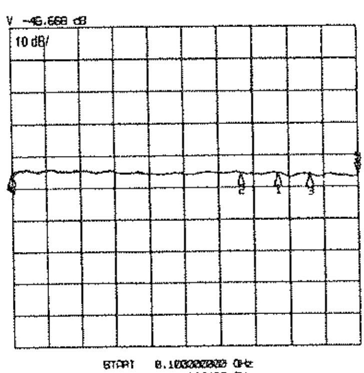

Fig. 2: Sensor frequency response in TEM cell (range shown 0.1 to 1 GHz).

Thursday, May 30, 8:30 AM **Room: Cimarron**

JWB, SP-9 Propagation

CoChairs: S.L. Dvorak, University of Arizona, Tucson, AZ
H. del Aguila, Phillips Laboratory, Kirtland AFB, NM

8:30 AM **INTRODUCTION & ANNOUNCEMENTS**

8:35 AM **ELECTROMAGNETIC PULSE PROPAGATION ACROSS A PLANAR INTERFACE SEPARATING TWO LOSSY, DISPERSIVE DIELECTRICS**, *J.A. MAROZAS and K.E. OUGHSTUN, University of Vermont, Burlington, VT* 258

8:55 AM **ANALYTIC TECHNIQUES FOR MODELING UWB PROPAGATION IN LOSSY, LAYERED SOIL MODELS**, *L.B. FELSEN, Boston University, Boston, MA* 259

9:15 AM **ULTRA-WIDEBAND IMPULSE PROPAGATION**, *R.C. ROBERTSON, R. JANASWAMY and M.A. MORGAN, Naval Postgraduate School, Monterey, CA; and R. SKORUPA and J.A. CUMMINGS, CECOM RDEX IEWD, Warrenton, VA* 260

9:35 AM **MEASUREMENTS OF SHORT-PULSE PROPAGATION THROUGH CONCRETE WALLS**, *J.F. AURAND, Sandia National Laboratories, Albuquerque, NM* 261

9:55 AM **PROPAGATION OF ULTRA-WIDEBAND ELECTROMAGNETIC PULSES THROUGH A LOSSY IONOSPHERE**, *S.L. DVORAK, D.G. DUDLEY and R.W. ZIOLKOWSKI, University of Arizona, Tucson, AZ* 262

10:15 AM **BREAK**

10:40 AM **TRANSIENT DIELECTRIC COEFFICIENT AND CONDUCTANCE IN DIELECTRIC MEDIA IN NONSTATIONARY FIELD**, *A. GUTMAN, Voronezh State Forestry Engineering Academy, Russia* 263

11:00 AM **THE SHORT PULSE PROPAGATION IN THE DIELECTRIC MEDIA**, *A. GUTMAN, Voronezh State Forestry Engineering Academy, Russia* 264

ELECTROMAGNETIC PULSE PROPAGATION ACROSS A PLANAR INTERFACE SEPARATING TWO LOSSY, DISPERSIVE DIELECTRICS

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ABSTRACT

The asymptotic description of both the reflected and transmitted fields due to a freely-propagating pulsed electromagnetic field that is incident upon a planar interface separating two different lossy, dispersive media is presented. The analysis is based on the angular spectrum representation of the reflected and transmitted fields in the reflected half-space $z < 0$ and the transmitted half-space $z > 0$, respectively, where the interface separating the two media is situated at the plane $z = 0$. The frequency dispersion of the complex permittivity of each medium is described by the double resonance Lorentz model which provides a causal description of resonant dispersion phenomena in lossy dielectrics. The analysis emphasizes the asymptotic description of the space-time evolution of the reflected and transmitted electromagnetic field vectors.

Analytic Techniques for Modeling UWB Propagation in Lossy, Layered Soil Models

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An analytic study is reported on the propagation of frequency- and time-domain waveforms in model soil environments. Frequency- and time-domain propagation through a lossy, dispersive, inhomogeneous environment such as soil poses a problem of great complexity, one for which there is a need for studies of basic electromagnetic phenomenology. These studies are likely to lead to new phenomenological understandings which will ultimately affect inversion schemes. Further, such insights will likely affect numerical forward solvers as well, resulting in greater efficiency and robustness.

We address beam propagation in a lossy, dispersive, layered medium. The formal frequency and time domain machinery for expanding aperture fields (either primary as produced by a source of radiation, or secondary as represented by scattering data from an environment) in terms of a continuum of beam-type basis fields is well established, as are the first-order asymptotic techniques to extract the wave physics from these formal representations. These basis beam propagators can be allowed to interact with various environments. In this endeavor, use is made of the huge reservoir of beam tracking algorithms that have been developed in various disciplines because beams as such simulate well the fields excited by arrays, transducers and other practical source configurations. These studies have been made using various types of approximations (paraxial, quasi-plane-wave, etc.) for the beam models. Basic beam algorithms, in particular the rigorous complex source technique, are discussed. The power of the complex source technique resides in the fact that it rigorously converts frequency and time domain Green's functions generated by elementary spatial and space-time sources, respectively, at real locations into steady state and pulsed beam excitations in the same environment when these source locations are made complex. The conversion applies to exact as well as asymptotic representations.

After individual phase space beams have been tracked through an environment, they need to be combined for synthesis of the field. Because these beams, which are generated by an extended aperture, arrive from different directions and have therefore sampled different portions of the environment, the asymptotically approximated individual beams may not be adequate and uniform methods may be needed. Models are selected so as to highlight the influence of specific environmental parameters without undue interference from other parameters.

ULTRA-WIDEBAND IMPULSE PROPAGATION

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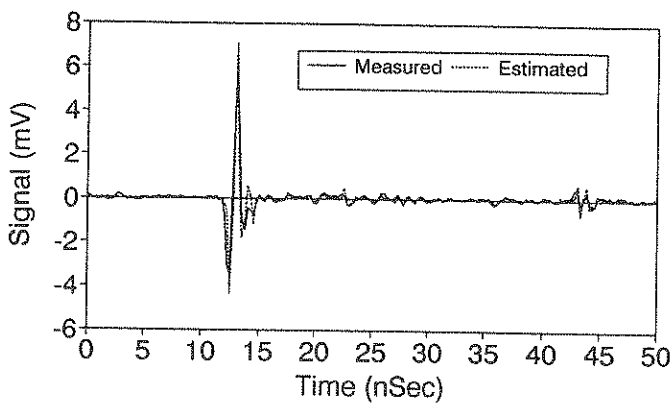
A procedure is developed for estimating the dispersive propagation behavior of ultra-wideband, impulsive electromagnetic signals for line-of-sight paths over rough surface terrain. The ground is assumed to be a homogeneous lossy dielectric half-space with a random surface boundary. Using this model for the ground, we develop the frequency-domain transfer functions relating electromagnetic field waveforms at two specified locations for the cases of horizontally and vertically polarized fields.

The time-domain signal waveform at a specified point is then estimated by inverse transforming the product of the transfer function and the discrete Fourier transform of the measured impulsive signal at another known location. The transmitting antenna is assumed to be a circular reflector with a specified azimuthally symmetric aperture distribution

The estimation procedure was first validated using a synthetic transmitted impulse signal. Measurements were then conducted in a desert environment at various ranges from a vertically polarized impulsive source. An example of the comparison of predicted and measured waveforms at a distance of 1.8 miles from the source is shown below. The prediction is based upon a measurement made at a range of only 0.1 miles.



Comparing Measured and Estimated Signals at 1.8 Miles

MEASUREMENTS OF SHORT-PULSE PROPAGATION THROUGH CONCRETE WALLS

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We recently performed a series of experimental measurements of short-duration electromagnetic propagation through two different concrete walls. Several different pulse shapes were used for the incident radiation, with frequency content from VHF to 20 GHz. Both walls were 30 cm thick, with 3 layers of reinforcing steel bars inside. For this set of data, the incident wave polarization was vertical linear only. Corroborating swept-frequency measurements were made with a vector analyzer.

The transmitter portion of the wideband time-domain measurement system consisted of a very fast low-voltage commercial pulse generator and a wideband TEM-horn antenna with dielectric aperture lens. The receiver consisted of an identical TEM-horn antenna and a wideband sampling oscilloscope. In terms of characterizing the propagation through a wall or other lossy dielectric layer, the most straightforward configuration is a free-space transmission measurement, in which a radiated EM wave is launched by a transmitting antenna, propagates through a material layer of some thickness, and is captured by a receiving system. The material layer under test is modeled as a two-port device, with an overall transfer function which relates the output pulse to the input excitation pulse. This transfer function can then be used to unfold or determine the dielectric constant and loss tangent of the material layer.

Two different transmission measurements are made in order to form the layer transfer function. One is a free-space reference measurement, representing the measurement system response. The other is the through measurement, in which the pulse is actually measured through the layer of interest. The transfer function is then given by the frequency-domain ratio of the processed received waveforms.

This paper describes the propagation measurements through the two different walls, and examines the transfer function, dielectric constant, loss tangent, attenuation constant, and time-domain impulse response of these walls. The attenuation increases steadily with frequency, and is a strong function of moisture content (as expected) within the concrete.

Propagation of Ultra-Wideband Electromagnetic Pulses through a Lossy Ionosphere

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An efficient computational method for the analysis of an ultra-wideband electromagnetic pulse propagating through the ionosphere is indispensable in applications involving high-power, ultra-wideband radar systems. In the simplest model for the ionosphere, the plasma is assumed to be homogeneous and the earth's magnetic field is ignored. In this plasma, the wave number can be written as (M. A. Messier, *EMP Theoretical Notes*, 117, 1971) $k = (\omega^2 - \omega_p^2 - j\nu\omega_p^2/\omega)^{1/2}/c$, where ω_p is the plasma frequency and ν is the electron collision frequency. As numerous authors have demonstrated, the impulse response for a cold, lossless plasma ($\nu = 0$) can be written in closed form in terms of Bessel functions of the first kind.

In a recent paper (S. L. Dvorak and D. G. Dudley, *IEEE Trans. EM Compat.*, 37, pp. 192–20 0, 1995), an exact, closed-form expression was obtained for a more complex signal (i.e., a double exponential pulse) propagating through a homogeneous, lossless plasma. It was demonstrated that the inverse Fourier transform representation for the field satisfies a second-order, non-homogeneous, ordinary differential equation. This differential equation was solved, thereby yielding an expression involving incomplete Lipschitz-Hankel integrals. Since the incomplete Lipschitz-Hankel integrals can be efficiently computed using known convergent and asymptotic series expansions, the expression provides an efficient method for modeling propagation of ultra-wideband pulses through a cold, homogeneous plasma.

The usefulness of the closed-form expression was demonstrated by comparing its results with those produced with the fast Fourier transform technique (FFT). Because of the long tails associated with these UWB pulses, a large number of points are required in the FFT to avoid aliasing errors. In contrast, the closed-form expression provides accurate and efficient numerical results regardless of the number of points computed.

Addition of losses to the model significantly complicates the problem since it is no longer possible to obtain closed-form solutions for the impulse response, much less for a double-exponential source. However, since the high-frequency behaviors for the lossy and lossless cases are identical, we can use the closed-form lossless expressions in an asymptotic extraction technique. This allows the high-frequency behavior to be subtracted off and handled analytically. The remaining signal is then handled numerically via a FFT. It is demonstrated that the asymptotic extraction technique significantly reduces the number of sample points required by the FFT.

Transient Dielectric Coefficient and Conductance in Dielectric Media in Nonstationary Field

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The super-short pulses propagation in the dielectric media may be investigated in the time domain directly, without frequency dispersion analysis, if the transient dielectric coefficient and conductance are known. Their calculation is the subject of the present paper.

According to the classic notions a molecule is simulated by one or several linear harmonic oscillators. Each of the oscillators corresponds to the normal electron oscillations in the molecule. The molecule dimensions are considerably less than electromagnetic wavelength in wide frequency range. Therefore one may suppose that the field acting on the elementary dipole is a homogeneous one. In this case the correlation between the field, the polarisation vector and the average macroscopic field is simple. For our purpose the average macroscopic field is assumed in two modes: 1) the function of a single step (Heviside function); 2) a linearly growing function of time. Then an integral equation for the polarization vector may be obtained from the harmonic oscillator motion equation. The integral equation has an analytical solution, which describes the polarization establishment process, attenuated periodically or aperiodically depending on the elementary oscillator parameters.

The transient dielectric coefficient formulae are obtained now from the well known correlations between dielectric coefficients, polarization vector and electrical field. The established value of the coefficient coincides exactly with the known one for the static field. The polarization function of time obtained allows us to calculate the polarization current and therefore the transient conductance.

The established value of the conductance equals zero for an ideal dielectric. However, the polarization energy losses cause the non-zero transient conductance.

Different types of interaction between the pulse and the media depending on correlation pulse and media time parameters are discussed in the paper.

The Short Pulses Propagation in the Dielectric Media

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The results obtained (see A.Gutman "Transient Dielectric Coefficient and Conductance ..." UWB, SPIII, 1996) are used in this paper to estimate the nonstationary absorption and dispersion of short electromagnetic pulses in dielectric media.

The transient conductance is an attenuated periodical or aperiodical function of time. Amplitude, period of oscillation, attenuation constant of the transient conductance are expressed by plasma frequency of the dielectric, the oscillation frequency of the elementary oscillator, which models a normal electron oscillation in the molecule, and the attenuation constant of this oscillator. All these parameters may be calculated if the following macroscopic characteristics of the dielectric are known: 1) the dielectric coefficient and conductance in a static field, 2) the stationary dielectric coefficient and conductance at the elementary oscillator frequency. Effective absorption by an arbitrary form of the pulse can be calculated, in the form of the convolution between the function of the pulse versus time and transient conductance. In the case of a rectangular pulse the transient conductance does not change the law of establishing during the pulse duration. Therefore the effective conductance for a rectangular pulse can be defined as an average one during the pulse duration.

The effective conductance and the stationary conductance ratio depends on the pulse and the establishment duration. The ratio is nearly unity if the pulse duration is much greater than the establishment one. The ratio may be considerably less than unity if the pulse duration is much shorter than the duration of the establishment of the stationary conductance. The calculation of this ratio is presented in the paper for the dielectric which has dielectric coefficient 6+i0,6 at frequency 10GHz and 2 in the static field. The calculation results are represented in the table, where the pulse duration is given in the first line in seconds, and the ratio is given in the second line.

Table 1.

10^{-10}	10^{-11}	10^{-12}	10^{-13}
~ 1	~ 0,5	~ 0,05	~ 0,005

The evolution of the wave equation for the linearly growing field wave falling on the flat boundary of dielectric was investigated for $t \geq \frac{z}{c}$ and for $t >> \frac{z}{c}$. The approximate solution obtained for the equation gives the dispersion estimation of the short pulse.

ıursday, May 30, 8:30 AM **Room: Brazos**

WB, SP-10 & HPEM-30 Pulser Technology

Chair: G. Loubriel, Sandia National Laboratories, Albuquerque, NM

8:30 AM **INTRODUCTION & ANNOUNCEMENTS**

8:35 AM **COMPACT SOLID-STATE ULTRA-FAST SOURCES FOR IMPULSE RADAR**, *C.A. FROST, Pulse Power Physics, Albuquerque, NM* 266

8:55 AM **HIGH GAIN GAAS PHOTOCONDUCTIVE SEMICONDUCTOR SWITCHES**, *G.M. LOUBRIEL and F.J. ZUTAVERN, Sandia National Laboratories, Albuquerque, NM* 267

9:15 AM **NUMERICAL SIMULATION OF THE AVALANCHE BREAKDOWN PROCESS IN PULSE SHARPENING DIODES**, *F.J. FOCIA, E. SCHAMILOGLU and C.B. FLEDDERMANN, The University of New Mexico, Albuquerque, NM* 268

9:35 AM **ULTRAWIDEBAND PULSER TECHNOLOGY**, *D.M. PARKES, DRA Malvern, Worcs U.K.* 269

9:55 AM **HIGH POWER, SUB-NANOSECOND RISING WAVEFORMS CREATED BY THE STACKED BLUMLEIN PULSERS**, *F. DAVANLOO, D.L. BOROVINA, J.L. KORIOTH, R.K. KRAUSE and C.B. COLLINS, University of Texas at Dallas, Richardson, TX; F.J. AGEE, Phillips Laboratory, Kirtland AFB, NM; and L.E. KINGSLEY, U.S. Army CECOM, Ft. Monmouth, NJ* 270

10:15 AM **BREAK**

10:40 AM **INVESTIGATION OF ANOMALOUS SUB-NANOSECOND PULSE BREAKDOWN STRENGTH FOR TRANSFORMER OIL**, *J. WELLS and J. LEHR, Fiore Industries, Albuquerque, NM; R. COPELAND and W. PRATHER, Phillips Laboratory, Kirtland AFB, NM; and D. VOSS, Voss Scientific, Albuquerque, NM* 271

11:00 AM **ULTRAFAST ELECTROMAGNETIC PHENOMENA IN ORDINARY ELECTROSTATIC DISCHARGES**, *C.J. BUCHENAUER, Phillips Laboratory, Kirtland AFB, NM and Los Alamos National Laboratory, Los Alamos, NM* 272

11:20 AM **HIGH VOLTAGE BREAKDOWN AT NANOSECOND PULSE WIDTHS**, *J. MANKOWSKI, M. KRISTIANSEN and L. HATFIELD, Texas Tech University, Lubbock, TX* 273

11:40 AM **ULTRAFAST HIGH-POWER OIL SPARK SWITCH PERFORMANCE DETERMINED FROM MEASUREMENTS OF ELECTROMAGNETIC RADIATION EMITTED DIRECTLY BY THE SWITCH**, *C.J. BUCHENAUER, Phillips Laboratory, Kirtland AFB, NM and Los Alamos National Laboratory, Los Alamos, NM* 274

12:00 PM **FIRST ACHIEVEMENT OF A PUMP AND PROBE EXPERIMENT INVOLVING AN OPTOELECTRONIC GIGA/TERAHERTZ ULTRASHORT PULSE GENERATOR FOR MEASUREMENTS OF TRANSIENT PROPERTIES IN MATERIALS**, *J-F ELOY, V. GERBE and J-H TROMBERT, CEA/DAM/CESTA, LeBarp, France* 275

COMPACT SOLID-STATE ULTRA-FAST SOURCES FOR IMPULSE RADAR

Charles A. Frost, Pulse Power Physics
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In this presentation we describe the design, performance characterization, and application of an ultra-miniature high power solid-state pulser providing 125 kW peak power with 0.1 ns risetime. Experimental data on both pulser performance and antenna coupling is presented. Ultra-fast pulsers have been available for decades, but recent advances in solid-state technology have allowed miniature pulsers to deliver peak powers exceeding 10^5 watts. The miniature pulsers, combined with advances in UWB antennas and digitizer technology, enable renewed consideration of miniature UWB impulse radars for short range target discrimination and material-penetrating applications. We have developed novel impulse sources for use in these radars. The sources are extremely compact with pulser volume < 1 cubic inch. They are affordable because they use only commercially available components.

We discuss the generation of ultra-fast risetime pulses using avalanche transistors, step-recovery diodes, and delayed breakdown devices. As a specific example, we describe the design and characterization of an ultra-miniature pulser using an array of breakdown devices to generate a 2.5 kV impulse with 0.1 ns risetime and 2 ns falltime from a pulser with a volume < 1 cubic inch. The relative merits of the various high power solid-state switching devices will be compared, and recommendations will be made for specific applications. The emphasis of this work is the development of inexpensive pulsers using commonly available components but providing parameters suitable for high power radar.

Computer circuit models have been developed which give good agreement with the measured pulser performance. As an example, the 2.5 kV multi-stage pulser circuit is analyzed in detail, and predictions are compared to experimentally measured waveforms. A 10 kV pulser design is also analyzed using the same method.

The ultra-fast pulsers have been mated to UWB antennas to form complete impulse sources. The interaction of antenna and pulser will be discussed, and specific impedance matching networks for use with the IRA antenna will be described. Experimental results on antenna matching will be presented.

HIGH GAIN GaAs PHOTOCONDUCTIVE SEMICONDUCTOR SWITCHES[1]

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The ability of high gain GaAs Photoconductive Semiconductor switches (PCSS) to deliver fast risetime pulses when triggered with small laser diode arrays makes them suitable for their use in ultra-wideband, impulse transmitters. This talk will summarize the state-of-the-art in high gain GaAs switches.

A high peak power impulse pulser that is controlled with high gain, optically triggered GaAs Photoconductive Semiconductor Switches (PCSS) has been constructed and tested. The system has a short 50 Ω line that is charged to 100 kV and discharged through the switch when the switch is triggered with as little as 90 nJ of laser energy. We have demonstrated that the GaAs switches can be used to produce either a monocycle or a monopulse with a period or total duration of about 3 ns. For the monopulse, the voltage switched was above 100 kV, producing a peak power of about 48 MW to the 30 Ω load at a burst repetition rate of 1 kHz. The laser that is used is a small laser diode array whose output is delivered through a fiber to the switch. The current in the system has rise times of 430 ps and a pulse width of 1.4 ns when two laser diode arrays are used to trigger the switch. The small trigger energy and switch jitter are due to a high gain switching mechanism in GaAs. This experiment also shows a relationship between the rise time of the voltage across the switch and the required trigger energy and switch jitter. Because the jitter is small, we can trigger two current filaments simultaneously. The time evolution of the current filaments in an optically triggered, high gain GaAs switch was studied by recording the infrared photoluminescence from the filaments. The filament velocity is measured to be as high as $5.9 \pm 1 \times 10^9$ cm/s. This speed is 600 times larger than the peak drift velocity of carriers in GaAs. This observation supports switching models that rely on carrier generation at the tip of the filament. The filaments speed up as they cross the switch: for one voltage range initial speeds were $0.7 \pm 1 \times 10^9$ cm/s and final speeds exceed $5.5 \pm 1 \times 10^9$ cm/s.

This work was supported by the United States Department of Energy under contract DE-AC04-94AL8500.

NUMERICAL SIMULATION OF THE AVALANCHE BREAKDOWN PROCESS IN PULSE SHARPENING DIODES

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ABSTRACT

Pulse sharpening diodes are used in numerous applications to reduce the rise time of pulses. A typical application involves capacitively coupling the diode to an existing pulse generator such that the diode will be reverse biased by the applied pulse. The diode is initially reverse-biased with a DC source and then the pulse generator is fired. The large reverse-bias voltage causes the device to avalanche breakdown and act as a fast closing switch. The principle of operation is that of fast, reversible, delayed avalanche breakdown. The breakdown process occurs very rapidly but is not instantaneous. This allows for reducing the rise time of the driving pulse. The rise time of a typical kilovolt level pulse can be improved from the nanosecond range to hundreds of picoseconds or less. Use of the pulse sharpening diode in this manner is not restricted to any particular means of pulse generation.

One pulse sharpening diode developed by the A.F. Ioffe Physico-Technical Institute, Russian Academy of Science, is called the Silicon Avalanche Shaper (SAS). For the past year and one half, research at The University of New Mexico has involved experimentally verifying the operating parameters of existing pulse generation and sharpening diodes provided by the Ioffe Institute. Numerical modeling of the SAS is now in progress with the goal of understanding the underlying physics of operation of the device. The ultimate goal is to optimize performance by computer simulation rather than empirical methods.

This paper describes a method for the dynamic simulation of the avalanche breakdown process in silicon-based pulse sharpening diodes. The simulation uses commercially available software that incorporates SPICE3 for the circuit-simulation and numerical models for the critical devices. The numerical modeling of the critical devices in the circuit can be one or two dimensional and is based on the solution of Poisson's equation and the current-continuity equations. The program allows user specification of device geometry, doping levels, doping profiles, and external circuit parameters. This work is being performed in order to establish an educated starting point for fabrication of pulse sharpening diodes at UNM facilities. Results of the numerical simulation are provided. A comparison of the numerical simulation to experimental data is made.

ULTRAWIDEBAND PULSER TECHNOLOGY

Professor David M. Parkes,
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Research has been conducted over the last decade into improving Ultrawideband or Impulse Pulser Technology. Several new areas have been investigated and some older known technologies have been dramatically improved by incorporating modern techniques.

A large majority of the research has been aimed at specific applications and pulsers have tended to have been manufactured to meet customers generated specifications and have only been produced in small quantities.

Switches such as spark gaps and Hydrogen Thyratrons have improved because of techniques such as optical, electromagnetic and semiconductor triggering. High pressure Hydrogen spark gaps and ferrite line pulse sharpeners are now used to produce the fast risetimes which were not previously obtainable from conventional gas discharge devices.

Novel switches which incorporate microwave triggering have been investigated with the aim of reducing jitter and providing the possibility of using multiple switches which can be triggered simultaneously.

The advances in material sciences have led to improved efficiency and higher voltages being attained in the semi-conductor switches, whilst semiconductor lasers have improved such that pulsers can now be made more compact.

Semiconductor switches have been shown to have advantages in very fast switching at moderate voltages which can then be stacked to give reliable high voltage outputs with significant repetition rates and still maintaining the very fast risetimes. Pulser arrays are now required where jitter and precise trigger control is essential.

Applications for these pulsers expand rapidly, ranging from short range medical to medium to long range radar uses. It is therefore important that the technology is available to meet the requirements.

As system designers now have a wide range of generators to choose from, it is essential that the correct pulser is identified for the appropriate application.

Application of UWB pulsers will be reviewed and the criteria for pulse generator selection discussed.

HIGH POWER, SUB-NANOSECOND RISING WAVEFORMS GENERATED BY THE STACKED BLUMLEIN PULSERS

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The opportunity to develop a light, portable source of High Power Microwaves (HPM) is very clear. Advances in stacked Blumlein technology for voltage multiplication, together with the availability of fast photoconductive switches for commutation, would seem to make it unnecessary to continue to rely upon specialized vacuum or plasma tubes for HPM devices in some applications. At the 100 MW level of power, broad-band sources operating at kilo-Hertz repetition rates can be conceived which simply match compact pulse power devices to the radiation impedance of free space.

The repetitive stacked Blumlein pulse power generators developed at the University of Texas at Dallas consist of several triaxial Blumleins stacked in series at one end. The lines are charged in parallel and synchronously commuted with a single switch at the other end. In this way, relatively low charging voltages are multiplied to give a high discharge voltage across an arbitrary load. The stacked Blumlein pulsers have produced high power waveformsms with risetimes and repetition rates in the range of 5-50 ns and 1-200 Hz, respectively, using a conventional thyratron or spark gap. To generate waveforms with sub-nanosecond risetimes at kilo-Hertz repetition rates, fast switching devices such as photoconductive switches offer significant advantages.

This paper describes the feasibility of an intense pulse power source for Ultra-Wideband HPM systems based upon stacked Blumlein technology by adapting the design for use with photoconductive switches. Significant progress in the development of the stacked Blumlein pulsers commuted with GaAs switches in the avalanche mode is reported. These pulsers currently produce high power nanosecond pulses with risetimes on the order of 200 psec.

INVESTIGATION OF ANOMALOUS SUB-NANOSECOND PULSE BREAKDOWN STRENGTH FOR TRANSFORMER OIL

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ABSTRACT

Data is presented from recent experiments indicating anomalous electric field strength for transformer oil breakdown under fast rise time, short pulse width conditions (less than 1.0 nanosecond duration). The data indicates that under single pulse conditions breakdown strength of up to four times those predicted by extrapolating other empirical data can be achieved. Under repetitive pulse conditions of up to 1.2 Khz, breakdown strengths are still well above those predicted using empirical data. This anomaly was first observed on the Phoenix high power broadband microwave source. The Phoenix source uses an oil peaking switch where it was noticed that electric field levels at breakdown were at least twice those expected.

The H3 series high power microwave source was used to conduct these experiments. A special liquid load solution was developed for effectively terminating the fast pulse from the source and dissipating the output power of eight joules per pulse. A reflection coefficient of less than 1.3 was achieved using this load which adequate to prevent damage to the source. It was required that the solution have low dielectric constant and also maintain a low loss tangent over the frequency range of interest. The load hardware was designed to maintain a 50 ohm geometry throughout the structure.

High band width self-integrating electric field sensors were used to accurately measure the field strengths across the breakdown gap. These sensors had been very accurately calibrated for the band width of interest and cable compensations included in the reduced data.

The results presented here have far reaching implications many areas of applied pulsed power and will be vitally important in future high power ultrawideband source development.

ULTRAFAST ELECTROMAGNETIC PHENOMENA IN ORDINARY ELECTROSTATIC DISCHARGES

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Small-scale electrostatic discharges redistribute charge buildup through highly resistive spark channels that dissipate the stored energy relatively slowly. However, such arcs are also known to emit UHF radiation, an effect that requires a rapidly changing current. Experiments have demonstrated that the high-frequency radiation is generated during the early formative phase before the arc is fully developed. (W.B. Maier et al, "Electrical Discharge Initiation and a Macroscopic Model for Formative Time Lags," *IEEE Trans. Plasma Science*, Vol. 21, No. 6, Dec., 1993) Measurements of local currents and radiated fields have been performed on spontaneously occurring arcs 3- to 25-mm long between a ground plane and 12– to 150-mm-diameter metal spheres charged to 10 to 35 kV. The observations suggest that resistive leader channels or corona structures advance across the gap at speeds of ~ 1 cm/ns and that the UHF radiation, in the form of an ultra-wideband pulse, is emitted when the space charge that has accumulated at the head of a *positive* leader or corona ball makes electrical contact with the negative electrode. At that time and location, over a few-mm-long path, the current rises to a peak value of 2 amperes in less than the measurement system risetime of 100 ps. This naturally occurring "peaking gap" appears to be the source of the rapidly changing current that gives rise to the UHF radiation pulse.

Improved diagnostic tools and methods have become available that may help resolve these ultrafast phenomena and directly verify the arc radiation model. These include ultrafast high-sensitivity replicating E-field sensors, low-loss high-frequency delay lines, ultra-wideband amplifiers, fast fiber-optic transmission systems, and numerical correction methods. Plans for new measurements using advanced experimental methods are described.

HIGH VOLTAGE BREAKDOWN AT NANOSECOND PULSE WIDTHS

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High voltage breakdown of liquids and gases at pulse widths of 100's of picoseconds is an important factor in the design of ultra-wideband radiation sources. Existing empirical data on liquid and gas high voltage breakdown at pulse widths of 100's of picoseconds to several nanseconds are limited. An empirical scaling relationship between electric field and breakdown time of gases has been found from a wide set of data by T.H. Martin. However, breakdown time of less than several nanoseconds is reported only by the Felsenthal and Proud data. These data were taken at relatively low gap voltages (4~30 kV) and low gas presures (1~760 mm-Hg).

Breakdown of liquids and gases with a breakdown time of up to 4 nanoseconds is being investigated. The pulsed voltage is supplied by the Russian-made SEF 303A current source. The SEF 303A is a Blumlein generator with Tesla transformer charging, capable of delivering a 250 kV, 4 nanosecond wide pulse with 1 nanosecond risetime into a 50 ohm load. The gap breakdown area consists of Rogowski profile electrodes. This coaxial geometry gap breakdown area is preceded and followed by coaxial lines from the pulser. These coaxial lines have transit times long enough so that all relevant data are collected by the time the reflected waves arrive back at the gap. This makes the requirement for a super-low inductive matched load a non-critical factor. The diagnostic setup consists of capacitve probes calibrated with a reed switch-coaxial line setup capable of 1 kV pulses with less than 400 picosecond risetimes. Liquids to be examined are hydrocarbon oils cleaned to a 1 micron particulate level, distilled water, and nondispersive, high dielectric strength fluids. Gases to be examined include H_2, N_2, O_2, SF_6, Ne, He, and Ar from 1 to 60 atm.

Submitted to UWB 96.

ULTRAFAST HIGH-POWER OIL SPARK SWITCH PERFORMANCE DETERMINED FROM MEASUREMENTS OF ELECTROMAGNETIC RADIATION EMITTED DIRECTLY BY THE SWITCH

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The search for simpler and improved impulse-radiating antenna designs has led to a return of the Hertzian generator in which some part of the antenna itself is charged to a high voltage and then subsequently shorted at the feed point by a spark switch. (C.J. Buchenauer, "Spark Gap Generated Electromagnetic Pulses for Time Domain Measurements," *Ultra-Wideband Radar: Proceedings of the First Los Alamos Symposium*, pp. 529-536, CRC Press, Boca Raton, Florida, 1991; D.V. Giri and C.E. Baum, "Reflector IRA Design and Boresight Temporal Waveforms," Sensor and Simulation Note 365, Feb., 1993; and C.J. Buchenauer and J.R. Marek, "Hybrid Antenna-Sources for Radiating High-Power Impulsive Fields," *Intense Microwave Pulses III*, H.E. Brandt Editor, Proc. SPIE 2557, pp. 209-213, 1995) Such hybrid antenna-sources, which require no feed lines or baluns, can virtually eliminate the performance degradation caused by transit-time dispersion, skin and dielectric losses, and electrical breakdown effects. The source region can maintain conical symmetry to within a few millimeters of the feed-point switch, thus providing conditions for launching near-ideal spherical TEM step waves for driving impulse-radiating, focused-aperture antennas. The ideal source symmetry allows the switch performance to be directly specified from measurements of the near and radiated fields. Such measurements have yielded sub-nanosecond pulse risetimes that are much faster than predictions from earlier spark-switch scaling laws and measurements made by other methods. Through careful attention to symmetry, optical principles, and precise measurement methods, risetimes as short as 60 ps have been measured. Future work to extend spark-switch scaling laws into the sub-nanosecond regime will be discussed. Examples of impulse-radiating antennas using these methods will be presented.

First Achievement of a Pump and Probe Experiment Involving An Optoelectronic Giga/terahertz Ultrashort Pulse Generator for Measurements of Transient Properties in Materials

by Jean-François ELOY*, Vincent GERBE, Jean-Hugues TROMBERT
CEA/DAM/CESTA, F33114 Le Barp, France

We have developed an ultrawide band time measurement method for etermining the transient electromagnetic properties of materials at microwave 'equencies.

The main principle of this time-domain spectroscopy consists of slab cattering of an ultrashort electromagnetic pulse in free space with picosecond pump-robe optoelectronic measurements [ELOY J-F. et al., Journées d'Etudes IEE/SEE Antennes imprimées" , Sept. 25-26th, Lille (France)]. The deconvolution of the 'ansmitted signal and incident pulse permits us to calculate the transient response of 1aterial from which we can deduce the spectral transfer function. In this way, we ıbtain the constitutive parameters of materials in the giga/terahertz range.

The experimental setup involves a repetitive microwave ultrashort pulse jenerator (switched by an ultrafast laser source $TiAl_2O_3$), a sampling detector, and a ıynchronous system for implementing a time-equivalent sampling technique. Our ›ulser and sampler microdevices are coplanar stripline antenna structures Exponentially Tapered Coplanar Striplines, ETCS) processed on a SoS substrate ELOY J-F. et al., Proc. Journées Maxwell'95, June 6-9th 1995, edt J-F ELOY, ;EA/DAM/CESTA, Le Barp, France (1995)].

The characteristics of repetitive ultrashort EM pulses delivered by this jenerator present after 5 cm (free space) propagation, a peak-to-peak amplitude of about 1 mV. The signal-to-noise ratio is close to 150 with a 5 ps rise-time and a 10-100 GHz spectral bandwidth.

The first attempts of standard dielectric sample measurements have been achieved with a 5 to 10 % accuracy in the 30 to 110 GHz frequency range. We present some examples of experimental data and results.

'hursday, May 30, 8:30 AM Room: Aztec

)XO-6 **Detection & Identification I**

Chair: *D. Sparrow, Institute for Defense Analyses, Alexandria, VA*

8:30 AM **INTRODUCTION & ANNOUNCEMENTS**

8:35 AM **THE PHENOMENOLOGY OF DETECTING BURIED UNEXPLODED ORDNANCE**, *D.A. SPARROW, T.W. ALTSHULER and A.M. ANDREWS, Institute for Defense Analyses, Alexandria, VA* 278

8:55 AM **MAGNETIC IDENTIFICATION OF MINES AND UNEXPLODED ORDINATES**, *J. ENDSLEY, EG&G MSI, Albuquerque, NM* 279

9:15 AM **A SHAPE DEPENDENT MAGNETIC MODEL FOR UNEXPLODED ORDNANCE**, *T.W. ALTSHULER, Institute for Defense Analyses, Alexandria, VA* 280

9:35 AM **DETERMINING UXO DETECTION LIMITS FOR MAGNETIC SURVEY METHODS**, *R. DiMARCO, B. BARROW and D. DePROSPO, Arete Engineering Technologies Corporation, Arlington, VA* 281

9:55 AM **COMPARISON OF FREQUENCY AND TIME DOMAIN ELECTROMAGNETIC INDUCTION SENSORS FOR THE DETECTION AND CHARACTERIZATION OF BURIED UXO**, *B. BARROW, R. DiMARCO and N. KHADR, Arete Engineering Technologies Corporation, Arlington, VA; and H.H. NELSON, Naval Research Laboratory, Washington, D.C.* 282

10:15 AM **BREAK**

10:40 AM **USE AND LIMITATIONS OF MAGNETIC DIPOLE MODELS IN UXO DETECTION AND CHARACTERIZATION**, *D. DePROSPO, B. BARROW and R. DiMARCO, Arete Engineering Technologies Corporation, Arlington, VA* 283

11:00 AM **HIDDEN/BURIED OBJECT IDENTIFICATION**, *G.D. SOWER, EG&G MSI, Albuquerque, NM* 284

11:20 AM **RESONANCES OF PERFECTLY CONDUCTING WIRES AND BODIES OF REVOLUTION BURIED IN A LOSSY, DISPERSIVE HALF SPACE**, *S. VITEBSKIY and L. CARIN, Duke University, Durham, NC* 285

11:40 AM **THE SEM REPRESENTATION OF ACOUSTIC AND ELASTODYNAMIC SCATTERING**, *C.E. BAUM, Phillips Laboratory, Kirtland AFB, NM* 286

THE PHENOMENOLOGY OF DETECTING BURIED UNEXPLODED ORDNANCE

*D. A. Sparrow**, *T. W. Altshuler*, *and A. M. Andrews*
Science and Technology Division, Institute for Defense Analyses, Alexandria, VA 22311

The need for and difficulties associated with clearing land contaminated with unexploded ordnance (UXO) is attracting increased attention as a result of the base closure process and as a result of recent high profile clearance activities in built-up areas. The importance of executing a complete clearance, with confidence on the part of both experts and the public that the clearance is complete, places a premium on effective detection of buried unexploded ordnance. This is equally true for clearance on formerly used defense site already in the public domain, such as Camp Elliot, CA and Camp Springs, DC, and for defense sites in the process of being released, such as Jefferson Proving Ground, IN and Fort Ord, CA.

The resulting increased emphasis on the detection of buried UXO has led to a number of initiatives based on sensing technologies used in other areas, such as environmental monitoring, geological research and prospecting, and military reconnaissance and surveillance. However, the targets, backgrounds and operating conditions in these traditional sensing areas are substantially different than in UXO clean-up. Thus we examined which aspects of targets, background and operating conditions limit the detection capability of current and proposed approaches to the detection of buried UXO.

The paper will cover target signatures, signal propagation from the target to the sensor, system sensitivity, and background discrimination. The effects of target size, depth and orientation, geological character of the ground, available system sensitivity and the sources of background signals will be discussed for magnetometers and ground penetrating radars. Magnetometers are passive sensors, with signal propagation essentially independent of the geology, and recent dramatic improvements in system sensitivity. Ground penetrating radars are active systems with signal propagation which depends on both the geology and the chosen radar frequencies, and recent innovations in signal processing aimed at improved background suppression. We also include brief discussions of the phenomenological issues for induction coils (electro-magnetic sensors) and laser, infra-red and thermal neutron systems aimed at surface and near surface detection.

MAGNETIC IDENTIFICATION OF MINES AND UNEXPLODED ORDINATES

John Endsley
EG&G MSI, Albuquerque

The detection of mines and unexploded ordinates with metal detectors has been around for over fifty years. Yet despite the maturity of the detection technology, the process of clearing a mine field is still a very time consuming and dangerous undertaking. Much of the time spent clearing a minefield is spent marking and investigating the area where a metal object has been detected. High false alarm rates can result in many man-hours of tedious, stressful work. Even when a detection is known to be a mine, the type of mine usually needs to be identified for recording and destruction. This process can entail a careful probing and excavation of the mine's location; the danger of this is increased when the orientation of the mine is unknown.

This presentation investigates methods to identify both the type of mine and its orientation based upon the return of a pulsed metal detector. Theoretical results have shown that the scattered magnetic fields from conductive targets can be represented as the summation of decaying exponentials. The decay coefficients are determined by the natural resonances of the target and thus can be used to identify different types of mines. They can also be used to discriminate mines from innocuous targets. Although the decay coefficients are aspect independent, the amplitudes of the exponentials are not. Thus, the detected signal will be a function of the orientation.

Experimental results based upon both the direct exponential expansion and other simpler feature extraction and waveform recognition techniques are compared. Results on both the identification and orientation problems are presented. The application of these results to walk-through security screening systems is also discussed.

A SHAPE DEPENDENT MAGNETIC MODEL FOR UNEXPLODED ORDNANCE

T. W. Altshuler, Institute for Defense Analyses, Alexandria, VA 22311

Magnetic detection of unexploded ordnance (UXO) relies on the presence of a magnetic signature associated with the ferrous UXO. Similarly, other ferromagnetic materials, both man-made and naturally occurring will cause magnetic anomalies similar to those of the UXO. In order to enhance detection capabilities using magnetometers as well as assist discrimination of UXO from magnetic clutter, it is valuable to have estimates of the expected magnetic signatures from different types of ordnance items.

Ferrous ordnance is often modeled using an equivalent solid spherical magnetic mass, which permits an analytic solution to the magnetic signature. The magnetic signature of the ordnance is assumed to be caused by only the induced magnetization of the UXO. The remanent magnetization is typically ignored in this model. The spherical model neglects the shape and orientation of the ordnance relative to the geomagnetic field. In addition, the ordnance is assumed to be a solid ferrous object, not hollow. To provide a more realistic estimate of the signature of buried, ferrous UXO, a model that accounts for the shape, size and orientation of ordnance is presented. The magnetic signature is shown to be strongly dependent on shape and orientation. In addition, it is shown that the induced magnetic signature for a hollow ferrous UXO is approximately that of a solid ferrous object, unless the wall thickness is small.

The ordnance shape is modeled as a prolate spheroid, to account for the shape of ordnance, while preserving an analytic solution. Contributions to the magnetic signature by the induced and remanent magnetization are investigated. The induced contribution to the magnetic signature of the prolate spheroidal model for UXO is shown to vary by as much as an order of magnitude depending on orientation. In addition, the direction of the induced magnetization of the UXO is shown to be misaligned with both the long axis of the prolate spheroid and the geomagnetic field for most UXO orientations. The large variation in signature as a function of orientation is a result of the demagnetization field and thus is strongly dependent on the ratio of the length to diameter of the prolate spheroid. The full magnetic signature of the ferrous prolate spheroid is dominated by the dipole field at a distance far from the center of volume of the spheroid.

The remanent magnetization of the UXO is highly dependent on the specific magnetic history of the UXO. The initial magnetization in the Rayleigh region of the hysteresis curve is used to investigate the effects of the shape and ordnance wall thickness on the remanent magnetization for both spherical and prolate spheroidal models. Contrary to the findings for the induced magnetization, the wall thickness strongly influences the remanent magnetization. It is demonstrated that the remanent magnetization is stronger for hollow objects than for solid objects of the same size. Thus the magnetic signature of UXO should not be scaled with the ferrous mass, but with ordnance size.

Determining UXO Detection Limits for Magnetic Survey Methods

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Passive magnetic sensors, including total field sensors, field component sensors and gradiometers are currently the preferred method for UXO surveys. To properly interpret the results of such surveys it is important to understand what UXO the survey may have missed as well as what was detected. There are three ways that UXO may be missed in a magnetic survey: the magnetic signal of the target may be too small to be detected in the local clutter, the magnetic signal may be large enough in places but may be missed due to finite spatial resolution of the survey, or the signal may be measured but passed over in post-survey analysis. In this paper we describe a method for quantifying the detection performance of surveys using passive magnetic sensors and demonstrate the method using data from three types of typical UXO surveys.

The dipole nature of the passive magnetic signature at the surface for most buried UXO allows physical modeling of the signal amplitude. Combining this signal model with a model for the instrument motion along the survey path and a model for the declaration of detections, allows for calculation of survey performance. Performance is specified by dividing the size and depth parameter space for UXO targets into three regions based on the likelihood that a target with those parameters will be detected (always, sometimes, never). For shallow targets the likelihood of detection is dominated by the probability that the sensor will pass nearby over the target. For deeper targets the surface signal is always encountered and the detection likelihood then depends on the relative amplitudes of the target signal and the detection noise (for example: environmental fluctuations, instrument noise, and noise introduced by the motion of the sensor). As is typical for geophysical methods there is a sharp transition between targets with amplitudes large enough that they are always detected, and slightly deeper and/or smaller targets which are never detected. This sharp transition results from the cubic dependance of the magnetic signal amplitude on target size, and the cubic (total field) or quartic (gradiometer) dependance on target depth.

Comparison of Frequency and Time Domain Electromagnetic Induction Sensors for the Detection and Characterization of Buried UXO

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Magnetometers measure the response of buried, ferrous ordnance to the earth's magnetic field. Electromagnetic (EM) sensors extend this capability in that they measure the response of UXO to a field transmitted by the sensor. The characteristics of the transmitted field can now be varied and the changes in the response from the UXO used to better characterize its nature. Typically, EM sensors either transmit a fixed frequency and measure the phase of the response, or they transmit a pulse and measure the time decaying response. In both cases, the nature of the response is sensitive to an object's size, conductivity, and magnetic permeability. At the May 1994 UXO conference we reported on results with a frequency domain, Geonics EM31. In a similar fashion with a time domain, Geonics EM61 modified to record the time response, we have measured a variety of objects, including simulated and inert ordnance. Analysis and modeling of these results has allowed us to compare these two electromagnetic techniques in terms of detecting and characterizing UXO. Limits of detection as a function of size and depth will be presented. The ability to discriminate between various ranges of size and ferrous versus non-ferrous materials will be compared. The phase and time decay responses from a collection of objects will be shown to reflect the properties of individual objects as opposed to the size of the entire group. The effect of orientation for cylindrical objects has been measured and modeled as well.

Based on all of this, we will consider possible design modifications aimed at improving the ability to detect and characterize UXO. Increased transmitter strength, the effect of different frequencies or pulse shapes, and alternate transmitter/receiver configurations are some of the options to be discussed.

Use and Limitations of Magnetic Dipole Models in UXO Detection and Characterization

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In this paper we present results of a magnetic dipole model for target parameter estimation and detection performance using both gradiometer and total field magnetometer data from seeded test sites. In addition we investigate the validity regime of this model and under what circumstances it may break down. The data reported on represent a broad class of UXO targets, ranging from 60mm shells to 2000 lb bombs, as well as non-UXO targets such as pipes and storage drums. The magnetic dipole model is parameterized by object location (x,y,z), dipole moment orientation (inclination and declination) and strength and assumes that the signal falloff is cubic for total field data and quartic for gradiometer data (the object is sufficiently far from the sensor that higher order moments do not contribute). Target parameter estimation for this study was done using a Maximum Likelihood Estimation algorithm to estimate the "best" dipole parameters for a given target. Overall, for both total field and gradiometer data, we find that the depth estimation accuracy is of order twenty percent. Target size is estimated from the dipole moment under the assumption that the anomaly is entirely induced and roughly spherical. The apparent size of the object is therefore the equivalent spherical radius. For both total field and gradiometer data, size estimation accuracy runs from fifteen percent for compact targets, such as drums, to thirty percent for less compact, higher aspect ratio targets such as UXO. We attribute this greater variability in size for UXO targets to the fact that the dipole moment of an elongated object varies substantially depending on the relative orientations of the long axis of the object and the direction of the earth's magnetic field. Even higher aspect ratio targets, such as shallow, long pipes (i.e., 5-10 feet) are outside the validity range of the dipole model and may be more appropriately modeled as a source-sink pair.

In addition to parameter estimation, we have embedded the dipole model in a detection performance model. This model calculates the probability of detection (pd) for a target size (equivalent sphere) at a particular depth. The transition from high to low pd is sharp and defines a "critical curve" in size-depth space. We find that the dipole-based performance model correctly estimates this critical curve for both total field and gradiometer data.

HIDDEN/BURIED OBJECT IDENTIFICATION

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The detection and identification of hidden and buried objects includes such items as unexploded ordnance (UXO), including land mines; airport passenger and baggage screening; screening at schools, courtrooms, prisons, and security facilities; and assessment of pavement composition and condition in highways, bridges, and runways. The solution to the problem can only be achieved by a systems engineering approach. This approach must start with the physics of the target and develop a measurement technique that utilizes certain of its natural properties. These determine the hardware required to make the measurements, the data processing algorithms for extracting the pertinent features from the data, pattern recognition processes to match the acquired features to libraries or classes of targets. Different physical properties of targets can be simultaneously measured and characterized, each physical property which results in a distinct determination of the target identity, perhaps with different properties being more easily measured under different environmental conditions. The results of the characterization of the different physical properties of the sought targets are correlated by a sensor fusion process which results in a decision as to the target identification, characterization, or "threat" versus "non-threat" criterion.

Some of the physical properties of both metal and dielectric target objects of interest include natural resonances such as electromagnetic, magnetic, and acoustic scattering. Other properties, either of the desired targets or the medium in which the targets are located, include the dielectric properties of soil, asphalt, and concrete layers. The electromagnetic resonances and the dielectric properties can be measured by impulse radar systems, specifically as ground-penetrating radars (GPR) utilizing impulse-radiating antennas (IRAs) as transponders, resulting in target identification by means of electromagnetic singularity identification (EMSI). Magnetic singularity identification (MSI) is determined by means of impulse metal detectors, while acoustic singularity identification (ASI) can be determined with impulse ground-penetrating sonar systems.

All of the measurement systems require proper transponders for transmitting and receiving energy with the appropriate wavelengths corresponding to the natural resonances of the targets, in a manner that maximizes energy transfer. The measured signals of the energy scattered from the target is digitized and processed using fast A/D and DSP devices. Signal processing techniques include removal of static system noise signals, random transients, and ambient radio frequency signals by appropriate time-domain or frequency-domain filtering. Deconvolution processes are used to remove the response of the measurement system from the data. Singularity extraction can be done by Proney's method, model based parameter estimation, E-pulse techniques, and/or the matrix pencil method.

Resonances of Perfectly Conducting Wires and Bodies of Revolution Buried in a Lossy, Dispersive Half Space

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The Method of Moments is utilized to compute the complex resonant frequencies and modal currents of perfectly conducting wires and bodies of revolution buried in a lossy, dispersive half space. To make such an analysis tractable computationally, the half-space Green's function is computed via the method of complex images, with appropriate modifications made to account for the complex frequencies characteristic of resonant modes. Results are presented for wires and bodies of revolution buried in lossy soil using frequency-dependent measured parameters for the complex permittivity, and we demonstrate that the resonant frequencies generally vary with target depth. In addition to presenting results, relevant issues are addressed concerning the numerical computation of buried-target resonant frequencies.

With recent developments in short-pulse sources and antennas, several researchers have been investigating transient radar techniques for the detection and identification of buried objects. For localized targets, an important identification tool is the well-known singularity expansion method (SEM), which exploits the fact that the late-time portion of the time-domain fields scattered from a target can be represented in terms of a sum of damped exponentials, each characterized by a complex frequency. The SEM is attractive for airborne targets because the resonant frequencies are aspect-independent (although their excitation strengths are generally aspect dependent), and therefore they provide a useful target signature. However, for objects buried in a half space (or other underground scenario), the *total* target is the object in the presence of its environment; i.e., when the object depth and orientation change, the characteristics of the *total* target will in general also change. Thus, in the context of SEM-based identification for GPR, it is important to determine the degree to which the resonant frequencies change as a function of target depth and orientation.

Although researchers have examined the SEM processing of GPR signatures, we are unaware of a rigorous analysis of the resonances of buried targets. Our algorithm computes the resonant frequencies of targets buried in a frequency-dependent, lossy half space, with rigorous account taken for the effects of the air-ground interface; particular results are presented here for the cases of buried perfectly conducting wires and bodies of revolution.

THE SEM REPRESENTATION OF ACOUSTIC AND ELASTODYNAMIC SCATTERING

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Recent papers have considered the SEM (singularity expansion method) representation of perfectly conducting and dielectric targets in lossy media (such as soil), in particular the behavior of the pole terms (natural frequencies, natural modes, and coupling vectors). As the incident field can be approximated as a plane wave in the vicinity of the target and wavelengths (in the external medium) are of the general order of the target dimensions, we can think of determination of the SEM parameters for identifying the target as EMSI (electromagnetic singularity identification). An alternate technique applies to metal targets noting that they are not perfectly conducting and have poles on the negative real axis of the s (complex frequency) plane, corresponding to simple decaying exponentials in time domain. The frequencies of interest are quite low, corresponding to diffusion through the target. As such, we can think of the determination of the SEM parameters of the targets (representing the magnetic polarizability dyadic) as MSI (magnetic singularity identification). The EMSI and MSI have various advantages and limitations, depending on the characteristics of the target and the surrounding medium.

Another technique with yet different advantages and limitations involves the scattering of sound waves from the target. This involves the acoustic and elastodynamic properties of the medium surrounding the target, these properties varying considerably from water to the various kinds of soils of potential interest. Since the sound waves satisfy a wave equation in such media (approximated as uniform, isotropic, linear, and reciprocal) there are similarities in the formal structure of the acoustic and elastodynamic scattering to the electromagnetic scattering.. It has been observed that there are resonances in the scattering of sound waves that can also be used to identify targets in a manner similar to that which has been observed in the electromagnetic case. Since there has been considerable development of the SEM formalism for electromagnetic scattering, it should be helpful to apply this to acoustic/elastodynamic scattering to aid in understanding the target-identification potential here. As is exhibited in this paper, the pole terms in the acoustic/elastodynamic scattering have a similar form involving natural frequencies, natural modes, and coupling terms which are scalar or vector depending on the types of waves (p and/or s) involved. Let us call this type of target identification ASI (acoustic singularity identification). The four elastodynamic scattering-coefficient residues conveniently can be expressed as products involving only two angular functions, one scalar and one vector. This simplifies the calculation of the SEM pole terms and the measurement of these parameters. Note the similarity to the electromagnetic case, except that there are now four residues for a given pole due to the combinations of p and s waves. The present results apply to the case of non-degenerate natural modes, but can be extended to cases of degenerate modes that occur with some target symmetries.

ursday, May 30, 1:30 PM Room: Dona Ana

'EM-20 **Environments**

Chair: *J.L. Gilbert, Metatech Corporation, Goleta, CA*

:30 PM **INTRODUCTION & ANNOUNCEMENTS**

:35 PM **THE MODERN RESEARCH PROBLEMS,** *V.M. LOBOREV, Y.V. PARFENOV and L.N. ZDOUKHOV, Russian Federation Ministry of Defense, Moscow, Russia* 288

|:55 PM **HEMP ENVIRONMENT AND TRANSMISSION LINE RESPONSE PROBABILITY FUNCTIONS,** *K.-D. LEUTHAUSER, Fraunhofer-Institut fur Naturwissenschaftlich-Technische Trendanalysen (INT), Euskirchen, Germany* 289

2:15 PM **EFFECT OF GAMMA-PULSE FORM ON PARAMETERS OF ELECTROMAGNETIC PULSE GENERATED BY HIGH ALTITUDE NUCLEAR BURST,** *N.V. GHARANIUSHKIN, A.G. KOZLOVSKY, V.M. KONDRATIEV and V.M. LOBOREV, Russian Federation Ministry of Defense, Moscow, Russia* 290

2:35 PM **THE COMPARISON OF ACTION X-RAYS AND PULSE ELECTRON BEAM OF THE COMPOSITE MATERIAL,** *V.P. EFREMOV, and V.E. FORTOV, Russia Academy, Russia; and A.B. DEMIDOV, Institute of Atomic Energy of I.V. Kurchatova, Russia* 291

THE MODERN RESEARCH PROBLEMS

Loborev V.M.*, Parfenov Y.V., Zdoukhov L.N.
Russian Federation Ministry of Defense

The first high-altitude nuclear tests demonstrated the NEMP danger to electronics and electrotechnical systems and primarily to those ones which have long wire and cable lines in their structures. In 1962 a high-altitude event was produced in Kazakhstan. In this test region there was an aerial communication line with length 550 km over distances 40...650 km from the burst point. As calculations show this line has been affected by the HEMP with following parameters: the pulse amplitude is ≈10 kV/m, the rise time is ≈10 ns, the pulse width at half maximum is ≈50ns. The surge voltages with amplitude of tens kilovolts occured in the line as the consequence of the HEMP impact. The following disruptions took place under the action of these voltages: operation of dischargers, blow-out of fuse links, de-energization. The further investigations showed that the observed disruptions were not random. The model experiments confirmed that high-altitude nuclear explosions will produce their effects on aerial communication and power lines and it will follow mass disturbances in the form of insulator arc-over, operation of protective devices, shorting between phased wires and so on. Thus the high-altitude nuclear explosion may cause global disruption of communication and electric power systems. Therefore until the smallest threat of nuclear burst is retained over any State territory this State should carry out investigations and provide with provective means for vulnerable systems both for military and civil ones.

Taking note of aforsaid we would like to mention useful activities of the International Electrotechnical Commission Subcommittee 77C in developing standards defining HEMP characteristics, the induced currents and voltages as well as the protective measures for electronics and electrotechnical systems. However we would like advise this Subcommittee to explore not only NEMP well studied in past ten years but also new threatening menaces which may arise from nuclear weapon improvement and from appearance of other high power electromagnetic sources such as magnetoexplosive generators, compact capacity accumulators. It must be recognized that these new sources can be effectively used as a weapon by terrorists and criminals. In this connection ones have to study these menaces and take timely protective action from them.

Electromagnetic fields interact not only with technical systems but they also affect a human being. For example, the workers operating EMP simulators are exposed during simulator pulsing operations. Both observations of many years on personnel health and experimental studies on animals showed that pulsed electromagnetic fields with nanoseconds width impact negatively on a man, particularly on his nervous system.

HEMP ENVIRONMENT AND TRANSMISSION LINE RESPONSE PROBABILITY FUNCTIONS

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The present paper deals with probabilistic aspects of the electromagnetic pulse environment generated by high-altitude nuclear bursts (HEMP). Because the location of Ground Zero is unpredictable, it is assumed that presumptive observer or transmission line positions are uniformly distributed within the total HEMP coverage area.

A complete set of HEMP threat parameters (including peak electric field, peak rate of rise, energy fluence, and polarization of the incident plane electromagnetic wave) is calculated for any observer position using the self-consistent EXEMP code developed by the author.

The first part of the paper presents cumulative probabilities of the various threat parameters. Also shown is the influence of a gamma yield variation. For lower yields, there is not only a reduction of the maximum peak electric field but also a more distinct decrease of the peak electric field strengths when approaching the horizon of the coverage area.

The second part deals with the "convolution" of the complete HEMP environment and the interaction with semi-infinite transmission lines over a perfectly conducting ground. Time domain transmission line theory is not only applied to the horizontal conductors but also to a variety of associated vertical elements. The positions of the transmission lines are considered to be uniformly distributed over the coverage area and their orientation angles (i.e. azimuths) are assumed to be random with respect to the propagation vector of the incident electromagnetic wave. Monte Carlo calculations were performed to investigate cumulative probabilities and mean values of induced currents and open-circuit peak voltages.

Particular attention will be paid to the question of occurrence of so-called positive spikes (F. M. Tesche & P. R. Barnes, Electromagnetics 8, 213-239, 1988) resulting from substracting the vertical line element contribution from the horizontal line response. As will be shown, these spikes appear only in a few cases. They can be pretended by inadequate approximations for the vertical riser response.

Effect of Gamma-Pulse Form on Parameters of Elecrtomagnetic Pulse Generated by High Altitude Nuclear Burst

N.V.Gharaniushkin, A.G.Kozlovsky, V.M.Kondratiev, V.M.Loborev

Russian Federation Ministry of Defense

An effect on various objects exerted by an early-time high altitud electromagnetic pulse (HEMP) is largely defined byits time and amplitud parameters which in their turn depend on the form of the gamma-ray radiatio pulse emerging from the explosion point. In this connection it is of practica interest to determine possible range of variations in EMP parameters when th form of gamma-pulse is varying.

This paper presents results of research of the influence of the gamma-pulse form (rise time, pulse duration, pulse structure) on parameters of HEMP. Calculation were carried out according to the special designed programme (V.M.Kondratiev A.G.Kozlovsky, V.M.Loborev. Electromagnetic fields generated by gamma and X-ray radiations of high altitude nuclear burst, EUROEM, Bordeaux, 1994, Book o Abstracts).

The nuclear burst was simulated by a monoenergetic gamma-radiation poin source placed on high altitude. Two simulating sources of gamma rays wer used. They generated a single pulse and two staggered in time ones. The duratior of the pulse front and the pulse width in the middle of the pulse peak were varied . Pulse spacing was varied in time too. It is shown that at the ground surface th duration of the pulse front at the level of 0.1 - 0.9 of its peak value cannot be less than 0.5 ns and its duration less than 4 ns that can be explained by finite time o Compton electrons life. In a number of cases for gamma-pulse with comple structure the amplitude of EMP from the second gamma-pulse was less than the amplitude of EMP from the first gamma-pulse. It's due to influence of air conductivity produced by the first gamma-pulse on generating EMP from the second gamma-pulse. For this reason the amplitude of the first EMP is greater than the amplitude of the second one at a short distance from the ground zero of the burst and only at a great distance away from the ground zero the ratio of EMP amplitudes changes inversely due to decreasing of the influence o air conductivity produced by the first gamma-pulse.

The authors bear the responsibility for authenticity of the published materials.

THE COMPARISON OF ACTION X-RAYS AND PULSE ELECTRON BEAM ON THE COMPOSITE MATERIAL

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DEMIDOV A.B.
Institute of Atomic Energy of I.V.Kurchatova

Analysis of pressure waves generated by the different kinds of energy fluxes in the composite material is considered for the case of small components sizes in comparison with the energy deposition zone.

Fast bulk energy deposition generates shock wave, which propagates inside of matter. Pressure arriving in the material is proportional Gruneisen coefficient of matter. Absorption of energy by composite material in the form x-rays and in the form electron beam pulse differs not only energy deposition zone profiles but distribution of the energy deposited between components.

The behavior of multi-component composite materials is non-equilibrium at the fast bulk energy deposition. Responses of components with different thermophysical and mechanical properties are various and, as a result, an equilibrium are established in the media after some thermal and acoustic relaxation.

Analytical model for estimation of the effective Gruneisen parameter for two- component composite material is offered in this paper. This model for two- component media shows, the pressure generated by the particle beam pulse and x-rays pulse in such media depends on the distribution of the energy deposited between components and concentrations of components. To verify the model, series of experiments with electrons accelerator (E_{max}=450kev, I_{max}= 70 kA) has been performed. The electron pulse had a duration at half maximum of approximately 45-75 nsec. The Perry method for the thick samples was used for measurement of the effective Gruneisen parameters. Measuring the total energy deposition in the target during the pulse, and the maximum of the rear surface displacement gives us effective Gruneisen coefficient. Comparison experimental data for two- component media gives good agreement with offered estimation. Availability of distributions of the energy deposited between components in case of x-rays pulse and in the case of electron beam pulse and experiments carried out with electrons accelerator gives us possibility to determine pressure profile in x-rays pulse energy deposition zone.

hursday, May 30, 1:30 PM Room: Cimarron

PEM-21 (Invited) Geomagnetic Induced Currents

CoChairs: W.A. Radasky, Metatech Corporation, Goleta, CA
R. Pirjola, Finnish Meteorological Institute, Helsinki, Finland

1:30 PM **INTRODUCTION & ANNOUNCEMENTS**

1:35 PM **(INVITED) IMPACTS OF GEOMAGNETIC DISTURBANCES ON ELECTRIC POWER SYSTEMS AND FORECAST IMPROVEMENTS NECESSARY FOR SECURE OPERATIONS**, *J. KAPPENMAN, Minnesota Power, Duluth, MN* 294

2:15 PM **(INVITED) GEOPHYSICIST'S VIEWPOINT IN STUDIES OF GEOMAGNETICALLY INDUCED CURRENTS**, *A. VILJANEN and R. PIRJOLA, Finnish Meteorological Institute, Helsinki, Finland* 295

2:35 PM **(INVITED) SIMULATION OF IONOSPHERIC CURRENTS DURING GEOMAGNETIC STORMS**, *J. CHEN, U.S. Naval Research Laboratory, Washington, D.C.* 296

2:55 PM **(INVITED) IONOSPHERIC CURRENTS FROM FREJA AND PREDICTED GEOMAGNETIC INDUCED CURRENTS**, *L. ZANETTI, The Johns Hopkins University Applied Physics Laboratory, Laurel, MD; J. KAPPENMAN, Minnesota Power, Duluth, MN; and W. FEERO, Electric Research and Management, Inc., State College, PA* 297

3:15 PM **BREAK**

3:40 PM **(INVITED) SUMMARY OF RESULTS FROM THE FINNISH GIC PROGRAM**, *A. VILJANEN and R. PIRJOLA, Finnish Meteorological Institute, Helsinki, Finland* 298

4:00 PM **(INVITED) THE ORNL GEOMAGNETIC FIELD MONITOR: AN UPDATE OF MEASUREMENT ACTIVITIES**, *F.M. TESCHE, EM Consultant, Dallas, TX; and P.R. BARNES, Oak Ridge National Laboratory, Inc., Oak Ridge, TN* 299

4:20 PM **(INVITED) DEVELOPMENT OF MODELS TO PREDICT GEOMAGNETIC INDUCED CURRENTS (GICS) IN LONG LINE SYSTEMS**, *W.A. RADASKY, K. SMITH and M.A. MESSIER, Metatech Corporation, Goleta, CA; and J.G. KAPPENMAN, B. PERRETT and R. PARENTEAU, Minnesota Power, Duluth, MN* 300

4:40 PM **(INVITED) SPACE WEATHER SERVICES AND GIC**, *J. JOSELYN, NOAA Space Environment Center, Boulder CO* 301

Impacts of Geomagnetic Disturbances on Electric Power Systems and Forecast Improvements Necessary for Secure Operations

John G. Kappenman, Minnesota Power, Duluth, MN

Geomagnetic Disturbances can induce near DC currents (Geomagnetically Induced Currents, GIC) to flow through the power system entering and exiting the many grounding points on a transmission network. Solar Cycle 22 has been especially important because of the unprecedented impacr that recent storms have had on electric power system operations and equipment. For example, a March 1989 storm created havoc on power systems across the entire North American continent. Since geomagnetic storm activities are at the highest levels in more than 30 years, the magnitudes of GIC in power lines and transformers have reached unprecedented levels. More importantly, power systems have grown more vulnerable because of the longer lines and larger and more efficient transformers being added to network over the past 3 decades. A summary of significant power system events and vulnerabilities will be provided along with the present status of continuing research and investigations that are underway.

Geophysicist's viewpoint in studies of geomagnetically induced currents

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Studies of geomagnetically induced currents (GICs) as seen from a geophysical viewpoint are discussed in this paper. The presentation has two parts: discussion of the (so far mainly unused) possibilities to apply GICs in basic research, and answers to some frequently asked questions.

GICs in a network are produced by the horizontal geoelectric field integrated along the conductors of the network. Thus GICs can yield information of ionospheric currents and the earth's conductivity, which determine the geoelectric field. There are two possibilities to use GICs for geophysical research:

1) The integrating nature of GICs reduces the effect of rapid spatial variations that are typical for the geoelectric field. So the large-scale conductivity structure of the earth can be investigated.

2) Recordings of GICs combined with magnetometer observations provide a ground-based tool to monitor large-scale ionospheric currents.

Single power lines or any other simular conductors would be ideal for these purposes.

Although GICs have been widely studied, there are still problems that do not have clear answers in the literature, or have been treated incompletely. We discuss here geophysical questions connected with geometrical issues, and with the relation between the geoelectric field and GICs. A special emphasis is focused on the problem of using standard load-flow programs when GICs are calculated applying models of the goelectric field.

SIMULATION OF IONOSPHERIC CURRENTS DURING GEOMAGNETIC STORMS

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The coupling of the magnetosphere and ionosphere during geomagnetic storms is investigated using a three-dimensional magnetohydrodynamic (MHD) simulation model. In the first simulation, the input solar wind condition is given by the magnetic field, particle density, and plasma flow calculated from a model magnetic cloud. In the second simulation, the solar wind data from an actual magnetic cloud (13-14 January 1988) is used. The cross-polar potential, joule heating and electron energy precipitation into the polar cap are computed. Synthetic magnetic indices Dst and AE are defined to serve as surrogates for the usual indices describing the disturbed magnetic field and auroral electrojet currents. The cross-polar potential simulated for the actual magnetic cloud event is compared with the convection electric field measured by the DMSP F8 satellite. The agreement is good, both qualitatively and quantitatively. The cross-polar potential and precipitating electron energy are obtained as a function of latitude and magnetic local time in relation to the input solar wind magnetic field.

Ionospheric Currents from Freja and Predicted Geomagnetic Induced Currents

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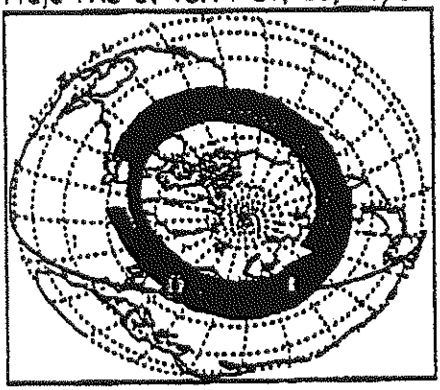
William Feero, Electric Research and Management, Inc., State College, Pa.

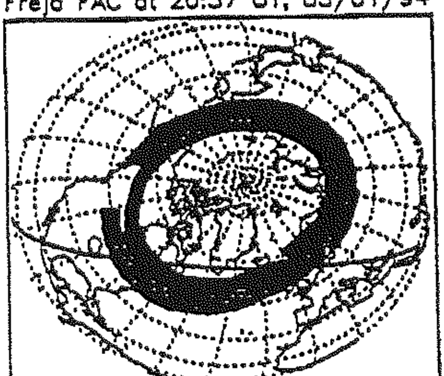
Abstract for Invited GIC Session of the AMEREM 1996 Conference
Albuquerque, N.M., May 27-31, 1996

Temporal and spatial fluctuations of large scale electric currents totaling millions of amperes in the ionosphere have long been known to induce current and voltage in the Earth's surface and on large manmade conductive structures. Magnetic field measurements from the Swedish Freja satellite together with the Region 1/Region 2 statistical patterns of field-aligned currents have been used in real-time to determine the location and evolution of the auroral zone. These patterns have been correlated for a number of cases with Geomagnetic Induced Currents (GICs) from the Sunburst monitoring equipment on the electric power system. Freja data from earlier local times, e.g. data monitored from European ground stations, have given precursor information of later North American sector geomagnetic activity. Details of the GIC and it's effects on the east coast power distribution system and the temporal evolution of the auroral zone currents monitored by this real-time system on May 1, 1994 will be presented; space observed ionospheric currents occurred at about 15 UT and GIC alerts were issued by Sunburst to subscribing utilities at about 20 UT. Records of these e-mail warnings as well as Freja maps of field-aligned currents are available on Internet (URL is *http://sd-www.jhuapl.edu/Freja*).

Freja FAC at 15:14 UT, 05/01/94



Freja FAC at 20:37 UT, 05/01/94



Summary of Results form the Finnish CIG program

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Geomagnetically induced currents (GICs) in the Finnish high-voltage power system have been studied for 20 years both experimentally and theoretically. GICs have been recorded at one or more power stations and in a transmission line too. Currents over 100 A have been observed several times (201 A at maximum), but no inconveniences have occurred. Theoretical studies of GICs are based on a dc model of the power system, taking especially into account that the geo-electric field driving GICs is generally not a gradient of a scalar potential. So the network model allows for assuming any kind of electric field.

Together with the Finnish power company Imatran Voima Oy, we performed a special GIC project in 1991-92. GICs were then measured at four transformers and in one transmission line. Using models of ionospheric currents and of the earth's conductivity, and observations of the geomagnetic field, we were able to derive statistics of the occurrence of GICs in the whole 220 and 400 kV power system. The free parameters of the geophysical models were fitted by using statistics of the recorded GICs. Results show that GICs larger than 100 A can still be expected during the most intense magnetic storms, but the growing number of earthing points generally reduces GICs.

THE ORNL GEOMAGNETIC FIELD MONITOR: AN UPDATE OF MEASUREMENT ACTIVITIES

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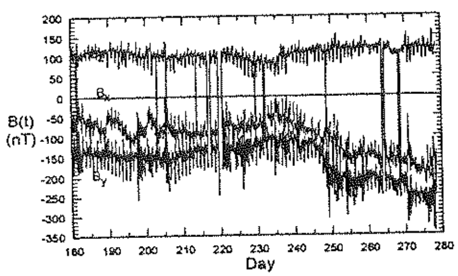
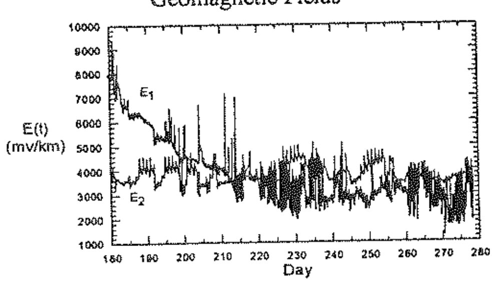
In the last EUROEM meeting, the development of an unattended monitor site for measuring geomagnetic fields was reported (Barnes, P. R., and F. M. Tesche, *Remote Geomagnetic Field Monitor for Measuring Solar Magnetic Storms*). Since then, this monitor has been operating in a more-or-less continuous manner, acquiring data of the three components of the geomagnetic field and two components of the earth-induced E-field.

As an example of the measured data, the two figures below illustrate the B-field and E-field records for days 180 through 280 in 1995. The sharp "spikes" in the data records occur at times when the monitor did not collect data, due to various operational problems.



Geomagnetic Fields



Earth-Induced E-fields

Data from the past year have been rather uninteresting, with no significant geomagnetic storm activity. Measurements with this system are continuing, however, with the hope that a storm data will be recorded and that a discernible correlation between the B and E fields can be observed.

This paper will review the goals of this geomagnetic storm monitoring program, provide an overview of the design and operation of the ORNL monitor, and illustrate in more detail the measurements made using this system for the past year.

DEVELOPMENT OF MODELS TO PREDICT GEOMAGNETIC INDUCED CURRENTS (GIC) IN LONG LINE SYSTEMS

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Over the past four years, Metatech Corporation, in cooperation with Minnesota Power, has fielded a comprehensive set of fast ($\Delta t = 2$ seconds) geomagnetic field, electric field and GIC measurements useful for the evaluation of the relationship among geomagnetic disturbances, induced electric fields in the earth, and the coupling of these fields to long power lines or other conductors. Our measurement setup includes a 3-vector fluxgate magnetometer at the Forbes 500 kV substation North of Duluth, Minnesota. In addition, we have measured the average induced electric field using two insulated long lines (55 and 76 km) oriented approximately North/South and East/West and terminating at Forbes. Finally, GIC measurements have been made on 500 kV and 230 kV power line neutrals grounded at Forbes. In addition to these measurements, we have developed time and frequency dependent EM codes to evaluate the generation of electric fields in deep layered earth media. These numerical models have been used to compare calculations with the measured data.

Our results presented at the EUROEM meeting in 1994 and more recent symposia clearly indicate that it is possible to compute the waveshapes of induced electric fields given some knowledge of the local geology and given the fluctuations of the geomagnetic field. This paper will describe our most recent code/data comparisons and will explore the relationship between the measured electric fields and GICs for several power transmission line neutrals in Minnesota.

The last portion of this paper will discuss our plans to develop efficient validated computational methods to predict GICs for different types of systems located throughout North America given a predicted geomagnetic field description. This capability will become more important in the future because of plans by NASA and others to measure characteristics of the solar wind in real time and to relate these measurements to ionospheric geomagnetic disturbances.

SPACE WEATHER SERVICES AND GIC

Jo Ann Joselyn; NOAA Space Environment Center
Research and Development Division, Geospace Branch

Warnings and predictions of the level of disturbance of Earth's space environment, recently described as "space weather," are advantageous to worldwide private and public endeavors such as communication and navigation systems, electric power networks, geophysical exploration, spacecraft control, and scientific research campaigns. Geomagnetically induced currents (GIC) are a case-in-point: the rapid fluctuations of Earth's magnetic field that occur during episodes of unusual space weather generate damaging currents in long conductors such as pipelines, powerlines, and train tracks. In March, 1989, a system-wide power blackout in Quebec, Canada has been attributed to effects caused by a severe geomagnetic storm. This same storm caused power distribution problems throughout the US and contributed to the total loss of a $3 million dollar transformer on the Eastern seaboard. A DOE study of the projected effects of a similar or larger storm showed that those effects could reach the proportions of national disaster because of our increasing societal dependence on electric power.

To address the global need for space weather observations and warnings, there are 10 international centers that supply space weather information to the relevant communities within their own geographical regions. In the US, space weather services are a joint operation of the USAF Space Command (the 50th Weather Squadron) and the Space Environment Center (SEC) of the National Oceanic and Atmospheric Administration (NOAA). The Space Weather Operations (SWO) team works around the clock to monitor more than 1400 separate data streams that sense solar, magnetospheric, and ionospheric parameters; they take immediate action to issue alerts when predetermined threshold levels are exceeded. SWO also predicts several parameters that describe space weather conditions several days in advance. In particular, daily geomagnetic indices and the probability of disturbed geomagnetic conditions are forecast. At this time, forecasts are primarily based on persistence, recurrence, and empirical/statistical models. In the near future, data from spacecraft positioned between the Sun and Earth will be used to sense storm fronts before they impact Earth, providing time for agencies to take steps toward mitigation of the worst effects.

ıursday, May 30, 1:30 PM Room: Brazos

PEM-22 (Invited) Experimental Techniques for Coupling, Vulnerability Assessments & Maintenance

CoChairs: D. Serafin, Centre d'Etudes de Gramat, Gramat, France
B. Miller, Titan, Albuquerque, NM

1:30 PM **INTRODUCTION & ANNOUNCEMENTS**

1:35 PM **(INVITED) EXPERIMENTAL TECHNIQUES FOR MICROWAVE COUPLING ASSESSMENT**, *J.C. BOLOMEY, JC Bolomey Consultant, Paris, France* 304

1:55 PM **(INVITED) MICROWAVE DEVICES FOR VULNERABILITY ASSESSMENT**, *B. MILLER, Titan Corporation, Albuquerque, NM* 305

2:15 PM **(INVITED) APPLICATION OF THE MODE STIRRED REVERBERATING CHAMBER FOR ELECTROMAGNETIC COUPLING MEASUREMENTS AND SUSCEPTIBILITY TESTS**, *N. LAMBLAIN, D. WARIN, B. DEMOULIN and P. DEGAUQUE, University of Lille, France* 306

2:35 PM **(INVITED) LOCAL ILLUMINATION VERSUS GLOBAL ILLUMINATION FOR MICROWAVE COUPLING ASSESSMENT**, *I. JUNQUA, Sigma Plus, Toulouse, France; and D. SERAFIN, Y. DAUDY, AND J.M. LAGARDE, Centre d'Etudes de Gramat, Gramat, France* 307

2:55 PM **(INVITED) ESTIMATION OF COUPLING OF HPM PULSES TO MISSILES BASED ON MEASURED TRANSFER FUNCTIONS**, *CH. BRAUN, W. OCHS and H.U. SCHMIDT, Fraunhofer-Institu fur Naturwissenschaftlich-Technische Trendanalysen (INT), Euskrichen, Germany* 308

3:15 PM **BREAK**

3:40 PM **(INVITED) HIGH POWER MICROWAVE ORIENTED PROCESSING OF COUPLING CROSS SECTION MEASUREMENTS**, *F. THEROND, Satimo, Gramat, France; D. SERAFIN, Centre d'Etudes de Gramat, Gramat, France, and J.C. BOLOMEY, Ecole Superieure d'Electricite, Gif sur Yvette, France* 309

4:00 PM **(INVITED) POWER AND SIGNAL NEMP PROTECTIONS AGING AND MAINTENANCE. A LARGE SET OF EXPERIMENTS COMBINED WITH STATISTICAL PROCESS**, *M. BOURZEIX and J.C. BIOTTEAU, Centre d'Etudes de Gramat, Gramat, France* 310

4:20 PM **(INVITED) POWER AND SIGNAL NEMP PROTECTIONS AGING AND MAINTENANCE. EXPERIMENTAL PROCESS**, *C. GIRARD, Alcatel Cable, Bezons, France* .... *(Not Available)*

4:40 PM **(INVITED) POWER AND SIGNAL NEMP PROTECTIONS AGING AND MAINTENANCE. STATISTICAL PROCESS**, *H. LAMY, CORIS, LePlessiss Robinson, France* 311

5:00 PM **(INVITED) SCALE MODEL TECHNIQUES FOR COUPLING ASSESSMENT AND CODE VERIFICATION**, *J.R. MILETA, U.S. Army Research Laboratory, Adelphi, MD* 312

Experimental Techniques for Microwave Coupling Assessment

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Investigations on microwave coupling mechanisms are increasingly required for both military and commercial applications. High Power Microwave (HPM), cellular telephones or wireless local area networks represent some examples of demanding areas for assessing the vulnerability of electronic systems. As compared to EMP situations, microwave coupling is more complicated to take into account, due to the complexity of the interaction mechanisms. The difficulty of out-of band numerical modeling makes experimental assessments particularly valuable for 1) validating computer codes for microwave coupling predictions, 2) for suggesting simplifying assumptions in the modeling process or 3) for preparing significant high power testing modalties.

All existing experimental techniques differ from some aspects. The most important of these aspects is probably the way used to model the microwave environmental in which the equipment under test is expected to be immersed. On the one hand, deterministic plane wave illumination can be obtained from long or compact ranges in anechoic environments. On the other hand, at the opposite, statistically non-polarized isotropic illumination is usually performed in shielded reverberating chambers with mechanical or frequency mode steering. Several papers have been devoted to the comparison between both kinds of techniques [e.g. "Field Measurements Made in an Enclosure", E.E. Donaldson et al., Proc. IEEE, Vol.66, 464-472, 1978, or "A Review of Electromagnetic Compatibility/Interference, Measurement Methodologies", M.T. Ma et al., Proc. IEEE, Vol. 73, 388-411, 1985]. However, less well known are the near-field techniques more conventional approaches. By the way, the near-field data allow to obtain the same results, just because near-field techniques allow to synthesize a large variety of electromagnetic environments. In addition, near-field techniques offer the possibility to consider the equipment under test in receiving or transmitting operating modes. Moreover, the use of modulated probe arrays have been shown to provide a significant reduction of the near-field measurement time, especially in the microwave frequency range.

In this paper a linear multipole model has been developed which includes near field as well as far-field "ports". Such a multipole model can be efficiently used for clarifying some recognized critical points in microwave coupling assessment, such as 1) "local" versus "global" illumination, or 2) "worst coupling" configurations, or 3) test port selection. More generally, this model is shown to allow for comparing the results obtained on the same equipment from different experimental protocoles and for predicting the effect of an improper experimental realization of a given expected illumination.

Microwave Devices for Vulnerability Assessment

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Integrated circuit technology is finding increased acceptance in military hardware. Notable examples are the so-called "smart weapons", such as sea-skimming and terrain-following cruise missiles, which rely on sophisticated electronics, computers and sensors for their essential mission functions.

Because of the difficulty of intercepting such threats using conventional means, a variety of defensive directed energy concepts have been proposed, including the use of powerful microwave pulses (HPM). However, it is not easy to calculate the potential effectiveness of such weapons. The microwave energy must first penetrate into the target through cracks or necessary apertures such as radomes, then couple to various internal circuitry components, before finally causing disruption in the integrated circuits themselves. The details of these interactions are highly dependent on the specific targets, including their size and shape, manner of construction, the functional performance of the circuit components, and the susceptibility of individual components.

Vulnerability/susceptibility testing is therefore essential for evaluating the feasibility of HPM weapon concepts against targets of interest, and to concurrently determine methods for hardening friendly systems against potential HPM threats. In this paper we discuss and suggest performance criteria involving various types of microwave hardware and systems for conducting such tests.

APPLICATION OF THE MODE STIRRED REVERBERATING CHAMBER FOR ELECTROMAGNETIC COUPLING MEASUREMENTS AND SUSCEPTIBILITY TESTS

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The mode stirred reverberating chamber (MSRC) may be considered today as a suitable EMC testing method covering the microwave domain .

This measurement method was initiated ten years ago by the National Institute of Standart and Technologies.

Basically the MSRC method deals with the behavior of oversized electromagnetic cavities requiring that the wavelength is much smaller than the size of the cavity.

In this case it appears that the radiation pattern of any radiating device put inside the cavity becomes isotropic. However to avoid the effects of the fluctuations of electromagnetic field amplitude, due to the generation of standing waves, it is important to modify the electromagnetic field distribution. This can be made by means of either a mechanical mode stirrer (paddle wheel) or an electronic mode stirring.

The main advantages of this method are to reduce the operating time of the test and to decrease the required power of the electromagnetic source in case of susceptibility tests.

In this paper we propose a brief review of two applications of the MSRC.

The first application concerns electromagnetic measurements performed on a rectangular waves guides short circuited at both ends, having a cut off frequency of 2.5 GHz. The electromagnetic coupling between the outside and the inside of the waves guide is due to a small hole on one side. The electromagnetic field penetration will be measured with a small electric monopole probe located inside the waves guide.

From these measurements we deduce the coupling factor which corresponds to the ratio between the electromagnetic power measured outside and inside the device.

The test being performed on a wide frequency range from 500 MHz up to 10 GHz we point out the effects due to the own resonances mechanism of the device and more specially when we compare the mechanical mode stirrer technic and the electronic mode stirring. These measurements will be also compared with a test carried out in anechoic chamber.

The second application deals with a susceptibility test performed on a digital integrated circuit supplied by an inner battery and located inside a small shielded box. The electromagnetic disturbance is induced by a small electric monopole connected to the input port of the component. The test consists in recording the state of the output port.

The susceptibility test performed with the MSRC will be compared to the measurements carried out on an anechoic chamber following the EMC standart.

To conclude the paper recommendations will be proposed on the operating methodology needs to perform such tests with the MSRC.

LOCAL ILLUMINATION VERSUS GLOBAL ILLUMINATION FOR MICROWAVE COUPLING ASSESSMENT

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Nowadays, while designing systems, one must take into account the high power microwave threat in a frequency range from hundreds of MegaHertz up to 20 GigaHertz. In this day of age, considering that numerical codes dealing with electromagnetism are not enough mature to model real scale system in high frequency, experimental procedures are more appropriate to qualify and sometimes quantify the coupling of an electromagnetic microwave threat with a structure and its inner equipments and cables networks.

Nevertheless, to submit a large scale system to a high frequency electromagnetic wave implies an unachievable distance between the transmitter and the target. That is the reason why a low power microwave experimentation was conducted on a generic structure with various apertures and equiped with a basic cable network. the objective was to compare:

- on the one hand, the induced perturbation on the inner cables, when the whole structure lies in a microwave environment,
- on the other hand, the induced perturbation on the inner cables when a reduced size microwave spot scans the structure.

The first step of this program consists in bathing the target in a microwave environment. Therefore, the distance between the transmitter and the target must be chosen so that, in the whole frequency range (200 MHz up to 6 GHz):

- the transmitter generates an electromagnetic field following far field condition in the test area,
- the variation of the incident power density on the illumination spot must not be greater than 1 or 3 dB, in magnitude, and $\pi/8$ or $\pi/4$, in phase. Therefore, the system is illuminated by an uniform electromagnetic wave.

Once the incident electromagnetic environment in the test area correctly characterized, one focused on the limits of application of superposition theorem or apertures uncoupling, following the frequency threat, the distance between apertures, and the cavity space factor. From the results, various phenomena can be shown following the frequency band over the system size and the apertures dimensions(Polarization influence and propagation along cables in "low frequency", localized phenomena in "high frequency").

As a second step, only a limited area of the system was illuminated by a microwave spot of varying size (local illumination), using two experimental procedures (absorbers screen or parabolic reflectors). Therefore, for frequencies over 500 MHz, one brought to the fore that the induced signals on the cable network depend mainly of the penetration of the microwave perturbation through the closest point of entry if this one and its neighbouhood of two or three wavelengths are fully illuminated.

One has shown that in high frequency, the illumination of the whole structure and the illumination with a reduced size spot are comparable if both incident electromagnetic waves are similar in terms of polarization, incident angles, and planeity.

As a conclusion, the equivalence between global illumination and local illuminailion was shown and will lighten the microwaves experimental procedures. Indeed, to scan a structure with a reduced size spot would enable to decrease the distance between the transmitter and the target, and therefore, to increase the incident power density in the interfered area during high power microwave tests.

ESTIMATION OF COUPLING OF HPM PULSES TO MISSILES BASED ON MEASURED TRANSFER FUNCTIONS

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The INT participates for many years in the investigation of HPEM effects on systems and components. To measure the transfer functions of fields or currents coupled to relevant points of a system under test, we use an open three-plate transmission line simulator with low-power CW excitation. A recent test series was devoted to three experimental missiles which have been thoroughly investigated by various methods. The transfer function measurements are described in (Ch. Braun et al., AGARD Conference Proceedings 564, paper 13, 1995); other tests on the same test objects are presented by J. Bohl in paper 14 of the same proceedings.

The present paper exploits these measured transfer functions to calculate various "stress quantifiers" of the signals which would be coupled to the test points if the test object were illuminated by an HPM pulse of PHASER type. In this computer simulation, the PHASER pulse can easily be varied as to carrier frequency, pulse length and peak power whereas polarization and angle of incidence of the simulated HPM illuminations are restricted to the actual transfer function measurements. The parametric analysis has two goals:
(1) The numerical values of the various stress quantifiers (such as total signal energy, time domain peak value or average power) at the different test points afford a good picture of the frequency dependent shielding level(s) provided by the structure of the object under test. They even allow preliminary susceptibility assessment of subsystems with known susceptibility thresholds.
(2) The evaluation of the frequency characteristics of the various shielding levels emerging from these results (together with similar results on other systems) permits one to assess the threat potential of PHASER-like HPM illumination and/or the power levels required to exceed certain susceptibility thresholds.

HIGH POWER MICROWAVE ORIENTED PROCESSING OF COUPLING CROSS SECTION MEASUREMENTS

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In the context of microwave coupling analysis, Coupling Cross Section (CCS) measurements have proved to be a very efficient tool. For a given Object Under Test (OUT) and a given point of interest (POI) the CCS σ, in cm^2, is defined as the ratio of the power dissipated at the POI W_r, in W, to the incoming power density P_{inc}, in W/cm^2. The CCS s is a variable depending on the frequency f, the incidence angle (θ,φ) in spherical coordinates

$$\sigma(f,\theta,\varphi) = W_r(f,\theta,\varphi) / P_{inc}(f,\theta,\varphi) \qquad (1)$$

Once known, the CCS gives the complete mapping of the POI microwave behavior. By definition, the CCS σ is a qualitative data. A suitable processing of the CCS data is shown to be a powerful tool to investigate the OUT sensitivity to an HPM attack. The CCS processing is turned into a HPM effects analysis scheme by introducing *a priori* information either on the threat level or the vulnerability threshold of the POI.

The basic item in this procedure is the Angular Probability of Aggression (APA). This variable is an angular reduced version of the CCS. For a single frequency and according to a prescribed CCS threshold, the number of angles for which the CCS is greater than the threshold is computed. This value is then normalized to the whole set of possible incidence angle. The APA thus defined is thus only a frequency dependent variable. On a given solid angle area the APA represents the probability of the CCS to be beyond the prescribed threshold. Varying the CCS threshold results in a set of data that can be nicely plotted as a 2D image where one axis is the frequency, the second axis the CCS between two bounds and the quantity visualized the APA. An illustration of such an image is given on figure 1.

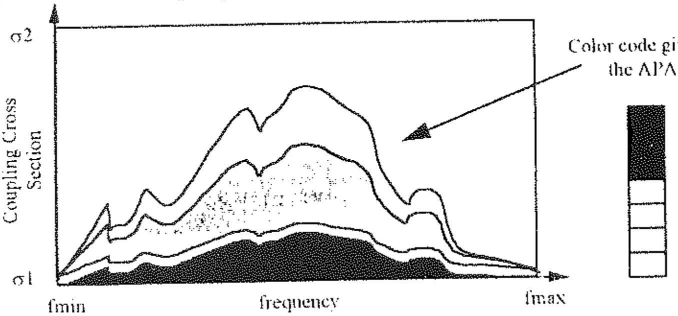

Figure 1 : Synthetic APA image versus frequency and CCS

Alternatively, one can use equation 1 to analyze the APA not only on the CCS but also on W_r or P_{inc}. Assuming the threat level P_{inc} is known, one can compute an image similar to that of figure 1 but where the bounds on the vertical axis are no more CCS but dissipated power W_r. Prior to real-scale HPM illuminations, such an image gives the angular chances that, with a given threat level, the dissipated power at the POI reach values between prescribed bounds. Similarly, such an image can be plotted versus frequency and incoming power density, assuming a threshold on Wr is known.

Images of APA obtained on complex objects tested in the Socrate facility (Centre d'Etudes de Gramat, France) will be shown and commented. These data are for about 1 m large objects in the frequency band 100 MHz - 4 GHz.

POWER AND SIGNAL NEMP PROTECTIONS AGING AND MAINTENANCE. A LARGE SET OF EXPERIMENTS COMBINED WITH STATISTICAL PROCESS

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Nowadays, a lot of NEMP hardened transmission fixed facilities are in use since at least a decade. On several sites, NEMP protection devices degradations have been observed despite the maintenance done. So the scope of the work presented here is to describe some ways chosen to optimize this maintenance. However, the following paper is limited to NEMP power and signal protections hardening maintenance. The main objective is to determine significant aging parameters and criteria.

NEMP protections are often designed also for other electromagnetic threat such as ligthning. Fortunatly, NEMP is not frequent, so the major causes of protection aging are nominal signals and overvoltages and currents collected by power or signal lines or antennas submitted to electromagnetic threat. Ligthning, wich is probably the most energetic of these threats is widely taken into account in this work.

Two main experimental ways are explored:

- on the one hand, a very large set of tests are done in laboratory, first on each separate components of protections and secondly on the complete protection. Most of the component characteristics are measured before and after repetitives overvoltages and current injections. On two power lines protections, nominal power and load fluctuations are simulated on a test bench and combined with climatic variations simulations and repetitives ligthning pulses injection.
- On the other hand, in situ interference pulse currents evaluations seen by power and antenna protections are done with specific lightning current maximum values and energy meters. Correlations with national ligthning mapping performed by METEORAGE company are in process.

Data and collected informations are implemented in a data base wich is used for statistical process. Failure mode and its criticity analysis PC software is developped and used to estimate the Mean Time Beetween Failure and the Mean Time To Repare of the protections.

The Centre d'Etudes de Gramat conducts this work with two french contractors companies: CORIS and ALCATEL-CABLE.

The paper only presents the outlines of the approaches. Technical results are presented by the two contractors in following papers.

POWER AND SIGNAL NEMP PROTECTIONS AGING AND MAINTENANCE STATISTICAL PROCESS

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CORIS - FRANCE

What reliability of the power and signal NEMP protections, according to their aging, can be expected regarding the NEMP occurrence?
What period of the protection check or replacement must be reserved to maintain in good condition the protection with a given probability?
The Statistical Process has the ambition to reply both questions.

The aim of this communication is to present the method used for the Statistical Process (results of a study funded by Centre d'Etudes de Gramat DGA/DRET/CEG-FRANCE).

First, a Failure Mode, Effect and Criticality Analysis was performed to identify component failures such as short-circuit, open-circuit, or characteristics drift.The effect of each failure mode was classified according to their influence on:

- protection against NEMP,
- operation cycle.

Secondly, a Boolean combination of failure modes (basic events) of the component was done prior to the life probability reckoning of the entire protection.
Thirdly, the main causes of the components failures were selected for the set of tests which are performed in laboratory (see ALCATEL-CABLE paper on the technical results of the experimentations).
Fourthly, the tests results were statistically analyzed to determine the parameters, and the confidence intervals, of the probability distribution of components lifetime.The following distributions were used:

- Exponential distribution, for random failures,
- Normal distribution, for aging,
- Log-Normal distribution, for lightning pulses,
- Binomial distribution, for pulse stress,
- Weibull distribution, for random failures and aging.

A specific PC software was developed to integrate life probability distributions of components and Boolean combinations of failure modes.This software allows us to compute the Mean Time Between Failure of a complete NEMP protection and its reliability time depending. A visual representation of the reliability curve indicates the best maintenance periodicity.

Scale Model Techniques for Coupling Assessment and Code Verification

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Scale modeling has been used effectively in predicting field interaction with metallic and non-metallic objects in a number of electromagnetic disciplines (e.g., radar crossection analysis, antenna design). It has been successfully used as a tool by itself, with numerical/analytic predictions, and with full scale experiments. This paper addresses its use in the prediction of electromagnetic pulse (EMP) propagation and interaction.

For more than twenty years the Army Research Laboratory has operated a small facility at the Ft. Belvior Engineering Proving Grounds devoted to the use of scale modeling to predict system response to the nuclear electromagnetic pulse (EMP). Systems modeled have ranged from small compact systems (e.g., tanks, shelter on a truck) to rather large distributed systems (e.g., communication facilities, interconnected missile systems, interconnected mobile communication systems). The facility has been used to design EMP simulators, evaluate the interaction between test object and simulator, plan large full scale tests, and formulate specifications for direct drive (current injection) experiments.

The facility and the testing conducted are fairly unique in that the experiments are predominantly conducted using scaled pulses, rather than cw, and that the systems modeled are land systems. In modeling land systems great care is taken to adequately replicate the scaled earth parameters. The test methodology employed will be described and results presented. As with all experimental (and for that matter analytical) techniques, the approach has some drawbacks and limitations. These will also be discussed.

The facility at Ft. Belvoir is scheduled for closure and relocation to the Adephi ARL site. Considerations that are going into the design of the new facility will be addressed. Further, with the reduction in funding and, consequently, reduced activity in EMP test and assessment, new applications for the facility are being planned.

While scale modeling has some drawbacks it remains a very useful tool in understanding the response of systems to the EMP and other electromagnetic environments. When used in conjunction with numerical/analytical models, full scale tests, and injection approaches it can substantially reduce the cost of traditional test efforts.

'hursday, May 30, 1:30 PM — Room: Galisteo

IWB, SP-11 & HPEM-31 Signal Processing

Chair: *L. Riggs, Auburn University, Auburn, AL*

1:30 PM **INTRODUCTION & ANNOUNCEMENTS**

1:35 PM **ANTENNAS AND ELECTRIC FIELD SENSORS FOR ULTRA-WIDEBAND TRANSIENT TIME-DOMAIN MEASUREMENTS: APPLICATIONS AND METHODS**, *C.J. BUCHENAUER, Phillips Laboratory, Kirtland AFB, NM and Los Alamos National Laboratory, Los Alamos, NM* 314

1:55 PM **ULTRA-WIDEBAND FREE-SPACE ELECTRO-OPTIC SENSORS**, *X.-C. ZHANG, Rensselaer Polytechnic Institute, Troy, NY* 315

2:15 PM **IMPULSE GPR FOR MINE DETECTION AND PAVEMENT ASSESSMENT**, *W.K. DAVIS and G.D. SOWER, EG&G MSI, Albuquerque, NM* 316

2:35 PM **COMPARATIVE ANALYSIS OF UWB UNDERGROUND DATA COLLECTED USING STEP-FREQUENCY, SHORT PULSE AND NOISE WAVEFORMS**, *E.K. WALTON, Ohio State University, Columbus, OH* 317

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3:15 PM **BREAK**

3:40 PM **MATCHED-PURSUITS TIME-FREQUENCY PROCESSING OF ELECTROMAGNETIC SCATTERING DATA**, *M. McCLURE and L. CARIN, Duke University, Durham, NC* 319

4:00 PM **ULTRA-WIDEBAND RADAR DETECTION IN WHITE NOISE**, *M. STEINER, K. GERLACH and F.C. LIN, Naval Research Laboratory, Washington, D.C.* 320

4:20 PM **NEW METHODS OF DESIGNING OPTIMUM BROAD-BAND RADAR SIGNALS**, *J-P OVARLEZ and J. DULOST, Office National d-Etudes et de Recherches Aerospatiales, Chatillon, France* 321

4:40 PM **USE OF THE SYNTHESIZED SHORT RADIO PULSE FOR NEAR-FIELD ANTENNA MEASUREMENTS** , *A.V. KALININ, Radiophysical Research Institute, Novgorod, Russia* 322

5:00 PM **THE PROBLEMS OF PICOSECOND ANALOG DEVICES MODELING AND CREATION**, *V.N. ILYUSHENKO and O.V. STUKACH, Tomsk State Academy of Control Systems and Radioelectronics, Tomsk, Russia* 323

ANTENNAS AND ELECTRIC FIELD SENSORS FOR ULTRA-WIDEBAND TRANSIENT TIME-DOMAIN MEASUREMENTS: APPLICATIONS AND METHODS

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Many time-domain electromagnetic measurements require sensors that can generate accurate signals proportional to the incident electric field for some finite clear time, after which the response may be of little interest, except for a possible frequency-domain requirement on the damping of resonances. Examples of such devices are given that combine more conventional antennas with open transmission lines. In designs that can have highly directional properties, antenna effective height h_{eff}, risetime t_r, and clear time t_c may be chosen independently. (C.J.Buchenauer and J.R.Marek, "Antennas and Electric Field Sensors for Time-Domain Measurements: An Experimental Investigation," *Ultra-Wideband Short-Pulse Electromagnetics 2*, Plenum Press, New York, 1995)

Examples of sensors and antennas are given that are useful in field strengths well below 1 V/m with effect heights of 10's of cm, to field strengths of 1 MV/m with effective heights less than 1 mm ($V = h_{eff}E$). Risetimes of 25 ps are achieved that are usually limited by even short signal cables. Clear times are equal to the round trip transit times for signals on the open transmission lines of length L, which can be folded to some extent ($t_c = 2L/c$). However, for special applications where $ct_r \gg h_{eff}$, it is possible to have $t_c \gg 2L/c$. Focusing optics are used in the more sensitive ultra-wideband sensor designs ($h_{eff} \geq 1$ cm, $t_r \leq 50$ ps).

Sensor designs may be adapted to meet specific requirements of the experimental measurement. Examples of free field and ground-plane-mounted designs are given that generate mV signals for sensitive sampling oscilloscopes and multivolt signals for scan converters. They may be optimized for either spherical or plane waves or made insensitive to either longitudinal or transverse field gradients. Design parameters that may be varied but not all chosen independently are physical size, field gradient sensitivity, directivity, risetime, clear time, and E-field sensitivity or effective height. Examples are presented of specialized sensor designs used in past and ongoing work in low-level signal measurements and pulsed power applications.

Ultra-wideband Free-Space Electro-Optic Sensors

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We developed a free-space electro-optic sensor for the coherent measurement of freely-propagating ultra-wideband pulsed electromagnetic waves (THz beams). Free-space electro-optic probe via the linear electro-optic effect (Pockels effect) offers a flat frequency response over an ultrawide bandwidth and the potential for a simple cross-correlation signal of the terahertz and optical pulses. Our preliminary research on ZnTe probes has demonstrated sub-wavelength spatial resolution, femtosecond temporal resolution (177 fs pulse duration), ultrawide bandwidth (1 kHz - 4 THz), and mV/cm field detectability. The simplicity of the detection geometry, capability of optical parallel processing, and excellent signal-to-noise ratio (S/N > 5000) make these sensors suitable for real-time 2-D subpicosecond far infrared imaging applications. Fig. 1 to Fig. 4 show the experimental setup and ultrawide bandwidth detection of 20 GHz, 500 GHz, and 1.25 THz signals, respectively.

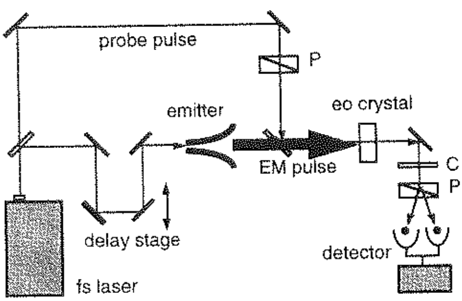

Fig. 1

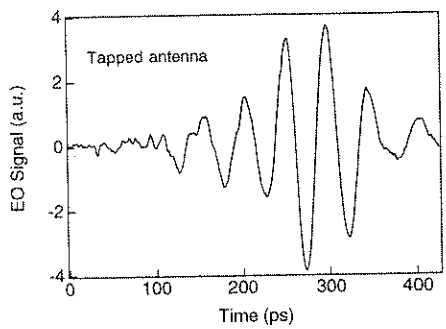

Fig. 2

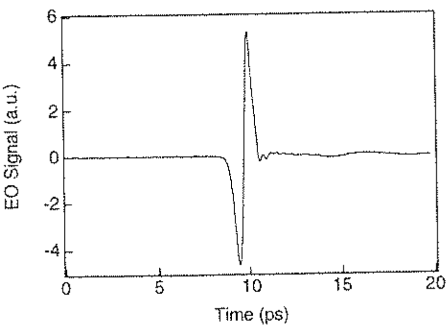

Fig. 3

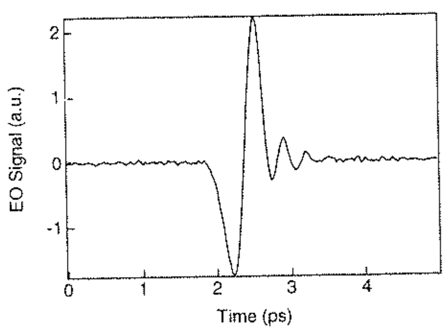

Fig. 4

IMPULSE GPR FOR MINE DETECTION AND PAVEMENT ASSESSMENT

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An impulse ground-penetrating radar (GPR) system is described which is used for both buried target (land mines) detection and identification, and also for determination of stratified pavement and soil properties. This system uses impulse radiating antennas (IRAs) as transponders to radiate and receive very short electromagnetic impulses from a short distance above the soil. Impulse widths from 75 picoseconds to 300 picoseconds are used, depending upon the specific application. A sampling system is used to down-convert the very fast real-time window (typically 20 nanoseconds) to a slower video time window (2 milliseconds) which can be digitized by a fast ADC. These digital waveforms are acquired every few milliseconds so that significant ground speed can be realized. Each waveform is processed in a digital signal processing (DSP) system. Signal pre-processing includes removal of static system signals and deconvolution of the system response, resulting in signals that are characteristics only of the target, at least up to some upper frequency limit. Features are then extracted from these signals which characterize the targets, the natural electromagnetic resonances of metal and dielectric mines via electromagnetic singularity identification (EMSI) techniques, or the dielectric constants and thicknesses of pavement and soil layers by downward deconvolution techniques.

Data are presented which show the natural resonances of a few metal and dielectric land mines in a particular soil, and the locations of the singularities (poles) of the dominant resonances. With a knowledge of the soil properties, which can be obtained with the GPR, these poles can be compared to those of known mines in a library and an identification or classification assessment made.

Data are also presented which show the results of some pavement assessments. The reflection and transmission coefficients at layer discontinuities are measured with the GPR. The dielectric properties of the layers determine the transmission and reflection coefficients, and so can be obtained. The thickness of each layer can then be determined from the measured boundary reflection times and the velocity of propagation in the measured dielectric.

COMPARATIVE ANALYSIS OF UWB UNDERGROUND DATA COLLECTED USING STEP-FREQUENCY, SHORT PULSE AND NOISE WAVEFORMS

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INTRODUCTION

Ground penetrating ultra-wideband radar systems often use a short pulse as the radiating signal. In order to obtain a wide bandwidth, the transmitter must put the energy into a pulse that is often less than 2 ns in extent. This means that the peak voltage must be very high, and the maximum power may be limited by various voltage breakdown mechanisms. The receiver is a high speed voltage sensor that must sample the waveform in increments of less than 1/10th ns. Such a system may suffer from timing jitter and speed limitations. In the crowded HF/VHF/UHF bands, it may be interfered with and may cause interference.

This paper discusses replacing the short pulse waveform with a continuous (in time) noise waveform. The receiver performs correlation with a delayed version of the transmitted waveform. Both the experimental and the signal processing consequences of this technique will be explored. Comparisons of the data and data processing between the classical systems and the noise system will be done.

EXPERIMENTAL SYSTEM

Three experimental systems will be used; a short pulse system, a step frequency system and the noise radar. The noise radar will transmit continuous in time random noise and a variable delay line will be used to provide the range delay. The received signal will be mixed with the signal from the delay line and low pass filtered. Thus the noise radar will provide correlation versus delay time and target position. Examples of underground probing and rotating target ISAR will be shown.

DATA ANALYSIS

It is possible to transform the correlation versus delay time obtained from the noise radar to the EM impulse response of the target. Thus it is possible to form ISAR and SAR images of the target. Methods of data calibration and computation of the target dispersive and/or resonance characteristics based on time frequency representations will be discussed. Comparisons with the step-frequency and the short pulse system will be given.

Local Spectrum Techniques for Time-domain Inverse Scattering

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With the trend toward increased bandwidth in radiating and detection systems, and the resulting gain in resolution, modeling algorithm *directly* in space-time can now be based on interrogation by well collimated short pulse wavepackets, also termed pulsed beams (PB) [1]. These solutions furnish not only a complete basis for representation of arbitrary space-time signals, but also provide individually highly resolved wavelets for local probing of targets or of the propagation environment. The spatial-temporal resolution achieved under the PB excitation conditions furnishes an unambiguous measure of where the "physical" signal resides, in contrast to frequency domain procedures that must rely on more intricate phase discrimination. It has been shown recently that the transient plane-wave spectrum of time-domain scattering data is directly related to the Radon transform of the scattering object. This relation has been termed *time-domain diffraction tomography* [4].

Here this relation is extended and used to form a PB-based scheme for local processing, backpropagation and imaging. The theory is applied first for data taken under interrogation by a (non-local) pulsed plane wave. For simplicity, the imaging is performed within the Born approximation. The analysis starts by processing the space-time scattering data using the local Slant Stack transform that localizes the spectral regions wherein the "physical" signal resides [2, 3]. The basis window elements in this local transform are PBs. This expresses the data as a local spectrum of PBs that can then be backpropagated and focused onto the image points. This *local processing* scheme is then generalized into a *local interrogation* scheme wherin the incident field is a PB that localizes the data a priori. Further localization can again be achieved by invoking the local Slant Stack processing. Numerical results for imaging of low contrast dielectric objects will be presented.

[1] E. Heyman, *IEEE Trans. Antennas Prop.*, **AP-42**, 311-319, 1994.
[2] B.Z. Steinberg, E. Heyman and L.B. Felsen, *J. Opt. Soc. Am. A*, **8**, 943-958, 1991.
[3] B.Z. Steinberg and E. Heyman, *SIAM J. Appl. Math.*, **53**, 381–400, 1993.
[4] T. Melamed, Y. Ehrlich and E. Heyman "Short Pulse Inversion of Inhomogeneous Media: A Transient Plane-wave Approach," *Inverse Problems*, (Submitted).

Matched-Pursuits Time-Frequency Processing of Electromagnetic Scattering Data

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Time-frequency processing has been investigated for several years, primarily in the form of windowed Fourier transforms and wavelet transforms; its success on real (measured) data has been mixed. In all such transforms, the data is projected onto a basis (a dictionary). However, in most cases the elements of the phase-space dictionary are not well matched to the underlying wave physics embodied in the scattered fields. This can be likened to processing a speech waveform, which is simply a time-dependent series of sounds. These time-dependent sounds can be projected onto any basis (Fourier, Gabor, wavelet, French, German, etc.), but it is preferable to project the speech onto a basis understood by the user (English, for example), which hopefully correlates to the language used in the original speech. For sonar and radar data, we know the "language" being spoken: wave scattering and propagation. Thus, it is natural that the basis (dictionary) onto which the data is optimally projected should *compactly* embody the underlying wave physics. While windowed Fourier transforms, wavelet transforms, and other time-frequency architectures are mathematically interesting and have important applications in data compression (for example), they are generally not well matched to the wave physics characteristic of sonar and radar signatures.

Fields scattered from a target can be parametrized in terms of 1) wavefronts, 2) resonances, and 3) chirped (cavity modes) waveforms. Thus, these are natural dictionary elements for implementation of the method of matched pursuits for scattered fields. The algorithm is summarized as follows. We define a dictionary as a family $D=(g_\gamma)_{\gamma\in\Gamma}$, where Γ is the set of indexes for the expansion functions $g_\gamma(t)$. The dictionary is composed of the wavefronts, resonances, and chirped waveforms discussed above. The algorithm is implemented with successive approximations of the scattered field f(t) with projections on elements of D. Let $g_{\gamma o}\in D$. After the first iteration, the scattered signal f(t) can be decomposed into

$$f=\langle f,\ g_{\gamma o}\rangle g_{\gamma o}+Rf\ , \qquad \langle f,\ g_{\gamma o}\rangle=\int_{-\infty}^{\infty} f(t)g_{\gamma o}^{*}(t)dt$$

where Rf is the residual vector after projecting f on $g_{\gamma o}$. Results will be presented for several radar scattering examples.

Ultra-Wideband Radar Detection in White Noise

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ABSTRACT

There has been several directions of research in Ultra-Wideband (UWB) signal processing; target identification and target detection are among the most fundamental. In terms of target detection in white noise, detector derivations must take into account the differences between conventional narrowband assumptions and those assumptions required for UWB short pulse signals. There have been several papers published previously in this area which examined such aspects of the detection problem. In (L. Cai, H. Wang, & C. Tsao, SPIE Vol. 1875, 1993) the authors developed a generalized likelihood ratio test (GLRT) which nearly optimally integrates the energy from different scatterers when the scatterer locations are known. In (A. Farina & F. A. Studer, Chinese J. of Systems Engineering and Electronics, vol. 3, pp. 32-34, 1992) the authors also developed a similar detector form although with slightly different assumptions.

An area which does not appear to be fully resolved in these and other papers is the issue of in-phase and quadrature (I/Q) sampling versus real sampling. That is, what are the theoretical underpinnings of the I/Q representation and what is the tradeoff in performance between I/Q and real processing. This issue is examined in depth in this paper. We will examine the assumptions made in the narrowband derivation and see that the I/Q detector does not necessarily result in the UWB area. We will show however, for a Gaussian modulated waveform, that the difference appears to be mainly a tradeoff of sampling rates and that by properly designing the match filters, nearly equivalent performance can be obtained when the real sampling rate is twice the I/Q rate, even as the waveform nears a single cycle. Several matched filter designs are discussed and there performances presented via simulation results.

We also compare the performance of the GLRT for cases when the target scatterers are known exactly versus when they are unknown. Additionally for the GLRT, an optimal bandwidth that should be used to optimize performance for a given mean scatterer separation is found similar to that found by Nitzberg (R. Nitzberg, IEEE AES-14, pp. 670-673, July 1978).

Another area of research which we examine is the design of detectors which take into account side information on the number of scatterers by specifying scatterer densities. We derive a GLRT for this problem and show its performance. Performance is compared with conventional algorithms such as the M out of N detector and the noncoherent integration detector.

NEW METHODS OF DESIGNING OPTIMUM BROAD-BAND RADAR SIGNALS

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In broad-band radar or sonar analysis, estimating the parameters such as the velocity and the position of a moving target is a delicate problem. In this case, the signal does not satisfy the Woodward's conditions and the problem of estimating a velocity parameter does not consist in estimating a Doppler shift but a true Doppler compression factor. Recent works have tried to resolve this problem ("*The Estimation of Time Delay and Doppler Stretch of Wideband Signals*", Qu Jin, Kon Max Wong and Zhi-Quan Luo, IEEE Trans. on ASSP, Vol.43, No 4, April 1995). More previous works have shown that the Mellin transform allows easily to compute, with a clear time-frequency interpretation, the Fisher Information Matrix elements built according to the Maximum Likelihood estimation theory and therefore, the variance lower bounds of velocity and delay estimates ("*Cramer Rao Bounds Computation for Velocity Estimation in the Broad-band Case Using the Mellin Transform*", J.P. Ovarlez, Proc. IEEE-ICASSP, Minneapolis, NM, 27-30 April 1993). An important result proves that the compression (or velocity) resolution depends only on the inverse of the signal spread in Mellin space (instead of the signal duration as in the narrowband case). The spread of a given signal in Mellin space has a direct interpretation in the time-frequency plane and can be perfectly characterized when duration, bandwidth and relative bandwidth are known. It is possible, for example, to found a broad-band signal with a given finite duration and no spread in Mellin space. Thereby, such a signal has no velocity resolution in broad-band sense.
After briefly recalling the main ideas and results of these works, we propose here to develop two new methods of designing optimum broad-band radar signals which minimize the Cramer-Rao lower bounds. The first method is based on the stationary phase principle, applied on frequency and Mellin spaces, which allows to construct signals with a given autocorrelation function in velocity and delay spaces i.e. the two main sections of the broad-band ambiguity function. The second method is the analogous construction (in frequency and Mellin spaces) of a signal using the classical narrow-band definition of the instantaneous frequency. The main idea is to propose a frequency phase law depending on the Mellin variable with the spreads in frequency and Mellin spaces related to the expected velocity and delay resolutions. Therefore, the signal is ensured to have good broad-band high resolutions properties.

USE OF THE SYNTHESIZED SHORT RADIO PULSE FOR NEAR-FIELD ANTENNA MEASUREMENTS

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The report considers the mirror parabolic antenna near-field, which is synthesized by the measurements at the discrete number of frequencies with the following Fourier transformation of data into time domain, where separation of the signal components with different propagation occurs. Identification of these components taking into account the geometry of the measurement facility and the inverse Fourier transformation of a part of them allows us to define more accurately the antenna near field, as well as to define the interference field. Using the pulse transient characteristic of antenna, time dependencies of the synthesized signals are determined as well as boundaries of time intervals, where there are components of the antenna and the interference.

These methodics can be used for increasing the accuracy of near-field antenna measurements either for determining the reflection level in facility. The efficiency of such measurements is defined first of all by the realized values of the band and the discrete of the frequency variation.

Feasibilities of the above methodics were investigated for planar near field measurement facility, which has been created in NIRFI as a model of the facility for ground tests of the transformed space antennas (A.V.Kalinin, Yu.I.Belov, V.I.Altunin, A preprint of the Space Research Institute, N.1244, USSR, Moscow, 1987, 26p., in Russian). During measurements the test antenna is directed to zenith. Scanning of the near field is carried out by slow azimuthal rotation of the antenna itself and fast rotation of the probe in the horizontal plane over the circular arc above the antenna axis. The advantage of this mechanical scheme is an absence of VHF-cable twists and due to this a high phase stability and a high accuracy of measurements.

The standard equipment was used, manufactured by the Russian industry for the near field antenna measurements: generator of the type G4-80 and receiver-ampliphasometer FK-2-24, which have a joint frequency range from 4 to 5.6 GHz. Components of the antenna near field were experimentally investigated in the time range up to 500 ns (in space - up to 150m) with the resolution about one ns (30 cm), that permits us to identify the paths and to determine levels of the signal being multireflected between the antenna and scanner elements. An effect of these reflection on the far-field antenna characteristics was estimated using the restored distribution of the signal components on the measurement plane.

THE PROBLEMS OF PICOSECOND ANALOG DEVICES MODELING AND CREATION

V.N. Ilyushenko, O.V. Stukach (TACSR)

In last years the works on development picosecond impulse range are intensity developed. The great successes in high-voltage picosecond impulse generation (up to hundreds kV), in formation of gigabyte sequence impulses etc. are achieved. However theoretical and applied bases of creation of amplifiers, devices of amplitude picosecond impulse controlling and other devices in working frequencies from a zero or 1 ...10 kHz up to 1 ...10 GHz are not enough developed. The complexity of their creation is stipulated extremely by high significance of a frequency range factor. In the majority of practical problems it resulted to necessary of the element characteristics realization, near to limiting (potential). As a result essentially difficulties of the analysis and synthesis of parameters are grown because the classical models in the basis of R,L,C- elements and operator function had the high order. The active and passive elements not always satisfied to the requirements on duration of processable signals because of reactive conductivity character changing in a frequency range or incompatibility of electrical or design-technical characteristics. Besides those element sizes become commensurable with of working range wave length, that causes dependence of impulse signal parameters (delay, amplitude, form) from the element geometry and their connections. Additional transfer parasitic channels, transformation and formation of impulses are created. A characteristic structural attribute of a system becomes multi-channeling. It resulted to necessary of research the signal transformation and formation processes at a structurally functional level and to necessary of the highspeed problem complex decisions, based on development of the system theory and circuitry.

In this connection the questions of search and development of new concepts and approaches to research are urgent. They are reflecting and generalizing laws of structural construction and being by a basis for understanding of the system characteristic formation processes and general principles of big systems and devices behaviour. Key and the most difficult in these questions are the problem of modeling. Is offered to decide it on the system approach basis, enabling to exclude circuitry aspects at a certain designing stage. Besides it gives possibility to investigate complex objects (systems) on the basis of ready and base functional units connected on determined rule with beforehand investigated or known characteristics. The system approach included following stages: the definition of the most complete describing objects system characteristics; designing of the operator (mathematical model), putting in conformity a class of source signals to class of target signals; construction of structure model or generalized structure of a system. The theory of microelectronic and other picosecond devices structural construction, satisfing to multi-channel and parametrical invariance principles is developed.

ırsday, May 30, 1:30 PM **Room: Aztec**

D-7 **Detection & Identification II**

Chair: *I. Kohlberg, Kohlberg Associates, Inc., Alexandria, VA*

30 PM **INTRODUCTION & ANNOUNCEMENTS**

:35 PM **APPLICATION OF SELF-SIMILARITY TO THE SCALING OF ELECTROMAGNETIC WAVES IN THE GROUND INCLUDING THE EFFECTS OF MULTIPLE SCATTERING,** *I. KOHLBERG, Kohlberg Associates, Inc., Alexandria, VA* 326

:55 PM **DETECTION OF SHALLOWLY BURIED OBJECTS USING AN IMPULSE RADAR,** *H. BRUNZELL, Chalmers University of Technology, Goteborg, Sweden; and A. GUSTAFSSON, National Defense Research Establishment, Linköping, Sweden* 327

:15 PM **GROUND PENETRATION RADAR TARGET CLASSIFICATION VIA COMPLEX NATURAL RESONANCES,** *C-C CHEN, F. PAYNTER, J.D. YOUNG and L. PETERS, JR., The Ohio State University, Columbus, OH* .... *(Not Available)*

:35 PM **TIME FOCUSING OF WIDE BAND GROUND PENETRATING RADAR IN LOSSY EARTH,** *M. GERSHENSON, Naval Surface Warfare Center, Panama City, FL* 328

:55 PM **MODELING OF ARL'S UWB RADAR GPEN FIELD TEST MEASUREMENTS,** *B.L. MERCHANT and F. LE, U.S. Army Research Laboratory, Adelphi, MD* 329

3:15 PM **BREAK**

3:40 PM **ULTRA WIDE BAND SCATTERING OF BURIED CYLINDRICAL TARGETS,** *M. JAUREGUY and P. BORDERIES, ONERA-CERT, Toulouse, France* 330

4:00 PM **MULTI-POLARIZATION SCATTERING AND SENSING FOR BURIED MINE DETECTION USING A GROUND-PENETRATING UWB RADAR,** *R. MEHTA, U.S. Army CECOM Night Vision Electronic Sensors Directorate, Fort Belvoir, VA; and D.P. BYRNE, Kaman Sciences Corporation, Albuquerque, NM* 331

4:20 PM **ELECTROMAGNETIC WAVE DETECTION AND IMAGING TECHNOLOGY FOR SHALLOW BURIED NONMETALLIC LAND MINES,** *L.G. STOLARCZYK and G.L. STOLARCZYK, Raton Technology Research, Inc., Raton, NM; and R. KELLY and J. MACK, Los Alamos National Laboratories, Los Alamos, NM* 332

APPLICATION OF SELF-SIMILARITY TO THE SCALING OF ELECTROMAGNETIC WAVES IN THE GROUND INCLUDING THE EFFECTS OF MULTIPLE SCATTERING

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The detection of buried objects using airborne radar includes the evaluation of returns from the buried object itself, discrete surface objects, ground backscatter clutter, and single & multiple volumetric scattering from ground irregularities (Kohlberg, O'Connor and Steger, UXO Conference, 1994). Analytical frequency domain solutions for these processes are available for simple ground models, but these may not be applicable for realistic conditions. Alternatively, scaled laboratory models executed in the time domain *that preserve the temporal shape of the incident field in a different time scale*, may provide a way to determine not only the fields, but also the probabilities of detection and false alarm.

The rigorously correct scaling relationship between the set of variables/parameters, $S=\{\varepsilon,\mu,E,t,..\}$, for the actual and laboratory ("~"), systems is obtained from Buckingham's Π-Theorem. By dimensionally expressing each member of S in the form: $M^a L^b T^c Q^d$ (where M, L,T,Q stand for mass,length, time, and charge respectively; and a,b,c,d are integers), the solution for the actual system is shown to determined from an equation of the functional form

$$f\left(\Pi_1(S),\Pi_2(S),....\Pi_{n-4}(S)\right)=0,$$

where the Π_k are dimensionless functions of S. The identical solution applies for a correctly scaled laboratory system with the relationship between S and $\tilde{S}$ determined from the set of equations $\Pi_k(S)=\Pi_k(\tilde{S})$ for k=1 to k=n-4. For example, in a single layer earth with E_o at the surface, we have:

$$\Pi_1 = E(x)/E_o, \Pi_2 = (\mu\varepsilon)^{1/2}x/t_c, \Pi_3 = \sigma t_c/\varepsilon$$
$$\Pi_4 = n_s t_c^3/(\mu\varepsilon)^{3/2}, \Pi_5 = \mu\varepsilon\Sigma_o/t_c^2,$$

where x is the depth, t_c is a characteristic time scale, n_s is the number of scatterers per unit volume with cross section Σ_o, and σ,μ,ε have their usual meaning.

This methodology is applied to the UXO problem, producing a variety of scaling relationship for different ground models including the effects of multiple scattering. An assessment is then made of the feasibility of this simulation approach.

Detection of shallowly buried objects using an impulse radar

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January 9, 1996

Abstract

The impulse radar has shown promising results for detecting buried objects, even non-metallic ones. One problem with the impulse radar is the strong backscattered signal from the ground surface. If the object is buried deeply below the surface this is no problem since the backscattered signal from the surface will arrive earlier than the target signal and we only have to gate the time signal. When the objects are shallowly buried gating is not possible since the backscattered signal from target and the surface will arrive almost simultaneously. The detection problem is thus to a large extent the problem of separating the target signal from the ground backscatter. In the present paper we introduce a signal model that exploits the different properties of the backscattered signals from target and ground surface. The signal model is of the form $\mathbf{w}_{x,y} = \mathbf{s}_{x,y} + \mathbf{b}_{x,y} + \mathbf{e}$, where $\mathbf{w}$ is the measured signal, $\mathbf{s}$ is the target signal, $\mathbf{b}$ is the background signal and $\mathbf{e}$ is an additive noise. The x, y subscripts denotes the position on the ground where the measurement is made. Under good conditions, when the background is homogeneous, $\mathbf{b}$ can be considered constant, independently of x, y. In this case we only have to align an estimate of the background signal to the measured signal and subtract it. We present algorithms for this simple case. In most cases, however, the background can be assumed to vary slowly as a function of x, y and must be estimated locally in a recursive manner. Different algorithms for this case are also presented in the paper. We also present different technologies for detection of shallowly buried objects, both metallic and non-metallic. One approach to detect objects with low signal power is to study adjacent measurements and look for concordant quick phase shifts in the signals.

TIME FOCUSING OF WIDE BAND GROUND PENETRATING RADAR IN LOSSY EARTH

Meir Gershenson, Naval Surface Warfare Center, Panama City FL. 32407.

Ground Penetrating Radar (GPR) is commonly used to image underground objects. When imaging through conductive soil, the quality of the image is deteriorated by attenuation and dispersion. While the attenuation can be addressed by using time dependent gain, no simple way exists to address dispersion, which blurs the image. In this paper I will address time focusing techniques that can eliminate the effect of the dispersion.

Using $\delta(t)$ for excitation of electromagnetic signal in conductive media, the equation describing the propagation in the Laplace domain is:

$$\nabla^2\vec{X}(s,r) - s\cdot\sigma\cdot\mu\cdot\vec{X}(s,r) - s^2\cdot\varepsilon\cdot\mu\cdot\vec{X}(s,r) = F(r).$$

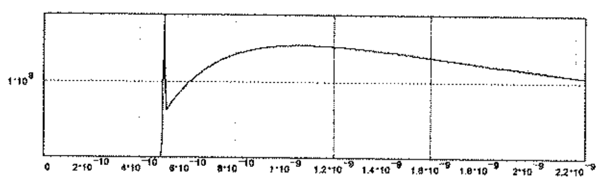
$X(s,r)$ is the magnetic or the electric field and $F(r)$ is the excitation. When $\sigma = 0$ we obtain the desired nondispersive propagation, while for $\sigma > 0$ the signal will disperse leading to reduced resolution. Using the above equation for the two cases, after certain algebraic manipulations, we find that in the Laplace domain the dispersive propagation is given in terms of the non dispersive as:

$$X_{\sigma>0}(s) = X_{\sigma=0}\left(\sqrt{s\cdot\left(s+\tfrac{\sigma}{\varepsilon}\right)}\right)$$

Using properties of the Laplace transform, it is possible to show that:

$$x_{\sigma>0}(t) = \frac{1}{2}\cdot\frac{\sigma}{\varepsilon}\cdot\left[\int_0^t x_{\sigma=0}(\tau)\frac{I_1\left(\frac{\sigma}{2\cdot\varepsilon}\sqrt{t^2-\tau^2}\right)}{\sqrt{t^2-\tau^2}}d\tau + x_{\sigma=0}(t)\right]\cdot\exp\left(-\frac{1}{2}\cdot\frac{\sigma}{\varepsilon}\cdot t\right).$$

$I_1(x)$ is the modified Bessel function of the first kind. The figure below shows a typical case of propagation through conductive media for $2\varepsilon/\sigma$=0.75n sec and $x_{s=0}(t)=\delta(t-t_o)$ t_o=0.5n sec.



Time

By moving the exponential decay to the left hand side, we obtain a Voltera equation of the second kind. Methods for solving $x_{\sigma=0}(t)$ in term of $x_{\sigma>0}(t)$ and in presence of noise are presented. Numerical examples demonstrating the techniques are also presented.

MODELING OF ARL'S UWB RADAR GPEN FIELD TEST MEASUREMENTS

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To detect and identify buried, semi-buried, and surface unexploded ordnance (UXO) the Army Research Laboratory is utilizing its Ultra Wideband (UWB) impulse radar in a ground penetrating (GPEN) mode. This UWB radar operates in the frequency band from 50 Mhz to 1150 Mhz. The radar is mounted on a mobile boom lift platform, enabling it to form Synthetic Aperture Radar (SAR) images as well as measuring range profiles. As an integral part of the UWB radar project, ARL is developing an in-house modeling capability.

Because target dimensions are no greater than several wavelengths at the highest frequency in the bandwidth of the ARL UWB radar, initial modeling capability is concentrating on Finite-Difference Time-Domain (FDTD) and Method of Moments (MOM) techniques, which are electromagnetic computational techniques for this range of wavelengths. MOM is a frequency-domain technique, directly producing results at a single frequency. Due to the radar's impulse nature, FDTD is especially well-suited because a time-domain solution (i.e., received field as a function of time) is directly produced. In FDTD two interleaved grids are constructed with the electric field on one grid and the magnetic field on the other. The electric and magnetic fields are also defined at alternate half time steps. The two curl Maxwell equations are discretized using central differences for both the spatial and temporal derivatives. An initial pulse is updated in time utilizing this leapfrog scheme.

We will present some modeling results of the recent GPEN field test measurements with the UWB radar. In these field tests targets such as trihedrals, cylinders with low height-to-radius ratio, dipoles, and 55 gallon drums were either buried, partially buried, or placed on the soil surface. Modeling results of selected targets will be expressed as received field as a function of time and will be compared with the UWB radar measurements.

ULTRA WIDE BAND SCATTERING OF BURIED CYLINDRICAL TARGETS

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Use of very short electromagnetic pulses is very useful for detecting buried objects. Indeed, the field scattered by a target illuminated by a ultra wide band pulse contains a lot of information very useful for identification purposes : high resolution imaging (location and strength of diffracting points), dispersive phenomena, resonances. The point is to be able to extract these discriminating features from the received scattered signals, overall in presence of clutter, and computations should be accurate enough to highlight these features without introducing numerical artefacts. We deal here with both electromagnetic modelling and processing of cylindrical objects diffraction when they are buried in a semi-infinite medium representative of soils which may be frequency dispersive and heterogeneous.

Modelling is performed in bidimensional geometry. Finite Difference Time Domain method (FDTD) is well suited for adressing such kinds of problems due to its generality and computational power. But its implementation in these geometries under the short pulse regime will make rise difficulties tied to numerical dispersion effects on total field calculations and computational space truncation in lossy or dispersive media mixed with usual free space absorbing boundary conditions. There is also a need of adapting mesh refinement to the local permittivity because this one may be very fluctuating and using an uniform grid over all computational space could be prohibitive. In the first part of the presentation, we will adress these points by describing the techniques we use for plane wave initialisation, space truncation and subgridding, and will show and analyze the levels of spurious, numerical reflections they introduce.

In the second part of the communication, we will present some results obtained for cylindrical scatterers of various constitution and shape embedded first in media of increasing losses, then in dispersive ones matching with soil properties over the incident pulse frequency band. Classification of the impulse responses is adressed through examination of the diffracting events and through resonances extraction.

MULTI-POLARIZATION SCATTERING AND SENSING FOR BURIED MINE DETECTION USING A GROUND-PENETRATING UWB RADAR

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Synthetic aperture radar (SAR) imaging at rf and microwave wavelengths is now being routinely used on space-based and airborne platforms for a variety of geoscience applications. Many of the SAR imaging systems that have been developed are capable of fully polarimetric operation (e.g. transmitter and receiver polarizations HH, HV, VH, and VV), and their images exhibit features that can be strongly polarization-sensitive, depending on the nature and composition of the objects being imaged.

Quad-polarization, multi-frequency SAR imaging has been used in at least one successful demonstration of surface and shallow-buried ordnance detection [G.G. Schaber, *et al.*, Proceedings of The Range Cleanup Workshop (UXO I), Naval Postgraduate School, Monterey, CA, March 1993]. These observations showed that contrast in the scattered signal images (i.e. between targets and clutter) can be strongly dependent on the polarization of the received radar signal, relative to the transmitted one.

Contrast enhancement is synonomous with increased signal-to-clutter ratio, which must be optimized for effective radar target detection and identification. Previous experimental and theoretical work [Knott and Senior, *IEEE Trans. Antenna Propagat.*, 20, 223-224, March 1972] suggests that one can expect stronger cross-polarized scattering (at certain scattering angles) from objects with rotational symmetry and severe topological "edges", than from relatively smooth, randomly-shaped objects with no evident symmetry. Apparently, the cross-pol scattered field from a body-of-revolution like a mine can dominate the scattering from similarly-sized, but randomly-shaped, clutter objects at specific scattering angles. This means that the scattered signal-to-background clutter ratio for a mine embedded in a collection of randomly-shaped objects (rocks, clumps, voids, soil particulates) should be enhanced in cross-polarization at certain scattering angles.

In this paper, we present results from an experimental and analytical investigation of the co- and cross-polarized scattering of UWB electromagnetic pulses from surrogate mine targets in a variety of buried environments. In the analytical program, a method-of-moments approach was used to calculate quad-pol, bi-static scattering of UWB radar pulses from model targets, with Fourier decomposition and reconstruction of the incident and scattered fields. In the experimental program, a bi-static UWB radar was used to validate the calculations and to investigate the co- and cross-pol behavior of target and clutter scattering in several different soils, and for both dielectric and metallic mine surrogates. Results from both programs will be presented for co- and cross-pol scattering as a function of bi-static radar and target configuration angles in three soil types. For each soil type, we also present experimental results for scattered target signal-to-clutter ratios at various configuration angles.

Electromagnetic Wave Detection and Imaging Technology for Shallow Buried Nonmetallic Land Mines

by

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Raton, New Mexico

and

Robert Kelly and Joseph Mack
of Los Alamos National Laboratories, Los Alamos New Mexico.

ABSTRACT

The principles of nonmetallic land mine detection are very different from those usec to detect conventional metallic land mines. In this paper, a resonant microstrip patch antenna (RMPA) sensor and associated microprocessor-controlled electronics are described. The RMPA sensor technology is based upon the measurement of the scattered EM wave from the buried land mine. In this sense, it is similar to radar. The difference lies in how the scattered wave is detected. The high Q of the RMPA sensor capitalizes on the measurable changes in resonant conditions such that a distinct advantage is obtained over nonresonant electromagnetic (EM) methods. The basic principle governing the detection process requires that the RMPA sensor be reasonably close to the mine (a few inches above the ground surface). The EM fields between the antenna and the buried target cannot be characterized solely by near-field, induction zone, and radiating field representations. All three contribute to the RMPA response, which specifically capitalizes on interaction phenomena in the reactive and radiating fields. The single high Q RMPA transmits primary EM fields and senses the reflected and scattered fields through alteration in resonant conditions of the RMPA. In particular, the RMPA transmits primary EM fields into the surrounding soil and senses the reflected field from the air-soil interface and the scattered field from the land mine. These fields alter the resonant conditions of the RMPA. These changes in the RMPA's resonant frequency and input impedance (resistance) are measured by the system's microprocessor-controlled electronics. This paper describes the theoretical modeling and controlled laboratory / field evaluation results. When the RMPA is swept over a nonmetallic (plastic) land mine buried in moist clay at a depth of two inches, the resonant frequency changes by less than 1% and the resonant resistance changes by 24%. Since the measurements have a 0.01% frequency and 1% conductance resolution, the probability of detection (PD) is higher than measurable with a nonresonant detector. Images of the buried land mines made by sweeping the RMPA sensor above the surface illustrate an outline of the buried object which increases the probability of detection and reduces the false alarm rate.

day, May 31, 8:30 AM **Room: Cimarron**

'EM-23 **Protection Technology**

Chair: *P.J. Miller, Metatech Corp., Albuquerque, NM*

:30 AM **INTRODUCTION & ANNOUNCEMENTS**

:35 AM **PROTECTING COMPUTER NETWORKS AGAINST INTERNAL AND EXTERNAL EMI/RFI**, *H.D. AGUILA and M.G. HARRISON, Phillips Laboratory, Kirtland AFB, NM; and D.P. BYRNE, Kaman Sciences Corporation, Albuquerque, NM* 334

:55 AM **ELECTRICALLY CONDUCTIVE METAL SILCIDES FOR EMI/RFI SHIELDING OF IR WINDOWS**, *E. SEVRUN, QUEST Integrated, Inc., South Kent, WA; H.D. AGUILA, Phillips Laboratory, Kirtland AFB, NM; and J. LEHR, Fiore Industries, Inc., Albuquerque, NM* 335

:15 AM **FIELD APPLICATION OF PROTECTIVE COATINGS FOR EMP GASKETS BY STYLUS ELECTROPLATING**, *L.D. STEPHENSON and L.H. DONOHO, U.S. Army Construction Engineering Research Laboratories, Champaign, IL* 336

9:35 AM **CAVITY FIELD REDUCTION TECHNIQUES**, *C.E. BAUM, Phillips Laboratory, Kirtland AFB, NM; and D.P. McLEMORE, Kaman Sciences Corporation, Albuquerque, NM* 337

9:55 AM **ANALYSIS OF NONLINEAR MULTISTAGE PROTECTION CIRCUITS AGAINST INTERFERING TRANSIENTS**, *J.L. ter HASEBORG and K. BORGEEST, Technical University Hamburg-Harburg, Hamburg, Germany* 338

10:15 AM **BREAK**

10:40 AM **SHIELDING EFFECTIVENESS OF A METALLIZED GLASS FIBER ENCLOSURE**, *W. COBURN, J. LATESS, C. REIFF and J. STEWART, U.S. Army Research Laboratory, Adelphi, MD; and L. ALBRIGHT, Booz-Allen, and Hamilton, Inc.* 339

11:00 AM **TYPICAL WIRING LOSSES ASSOCIATED WITH AIRCRAFT ELECTRONICS UNITS**, *R. HUTCHINS, BDM Federal, Albuquerque, NM; and G. DeMUTH and D. McLEMORE, Kaman Sciences Corporation, Albuquerque, NM* 340

PROTECTING COMPUTER NETWORKS AGAINST INTERNAL AND EXTERNAL EMI/RFI

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It is well-known that highly-integrated circuits are vulnerable to static discharge and to various kinds of electromagnetic interference (EMI). This is the reason that static sensitive handling procedures and MIL-specifications for electrical connections and enclosure shielding and grounding have been developed for systems employing these kinds of circuits. The information explosion of modern times has resulted in a growing reliance on computers and on networks in which a wide variety of computer systems and peripherals are electrically interconnected. Engineers now face more difficult challenges regarding the design of network equipment that is EMI resistant and yet still electromagnetically compatible (EMC) with other network devices than ever before. These challenges derive from both unintentional internal and external sources of interference, and from external sources that might be intentionally activated to cause degradations or disruptions in system performance. Both military and commercial computer systems and their interconnecting networks have become the principle targets in modern information warfare (IW).

This paper presents a variety of scenarios in which hostile sources of interference are placed in reasonable proximity to network equipment, and used to induce electrical signals within the target electronics that are comparable to or larger than the signals associated with normal internal message traffic. The approach is analytical, and employs conventional source emission, propagation, and coupling physics. In the calculations, we trade off source intensity, range, and attenuation between source and target (from enclosure and facility shielding), with target coupling and induced signal amplitude. The paper shows that for a significant fraction of the scenario parameter space, and for source technologies that have been widely developed and are readily available, induced signal amplitudes can easily exceed known thresholds for upset/interference in a variety of integrated circuit technologies.

Using technology developed by other EMI/RFI hardening programs at Phillips Laboratory, this paper identifies new and relatively low cost mitigation techniques that would be appropriate for reducing EMI/RFI in computer network equipment, describes their performance, as determined in these programs and suggest applications of these techniques for hardening computer networks systems.

ELECTRICALLY CONDUCTIVE METAL SILCIDES FOR EMI/RFI SHIELDING OF IR WINDOWS

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Current IR systems are extremely susceptible to electromagnetic and radio frequency interference (EMI/RFI) because they posses large apertures that present ideal front-door entry path for EM radiation. Significant amount of EM radiation can penetrate and couple to IR sensor and supporting electronics, which leads to a substantial degradation of system performance. Several technologies were investigated to eliminate these deleterious effects without degrading the IR system performance. It was determined that existing technologies offer adequate levels of EMI/RFI protection, but either degrade the system IR performance or are not strong enough to withstand the system's operational environment (i.e., military systems). Conductive metal mesh coatings on external surfaces of IR windows reduce the electromagnetic and radio frequency interface but are mechanically soft and easily damaged. Surface doped semiconductors, such as gallium arsenide, have optical absorption and emission problems, while semiconducting carbide coatings, such as germanium carbide, suffer performance loss at the low temperatures. Finally, electrically conductive metal silicides were investigated for erosion resistant EMI/RFI protective coating for IR windows and radomes. These silicides showed optimal EMI/RFI shielding and IR properties required for both military and commercial systems. Thin film based on tungsten, titanium and niobium silicides were sputtered on zinc sulfide substrates, their electrical properties were evaluated and their shielding effectiveness measured. A description of the deposition process, electrical performance, EMI/RFI and IR properties are presented in this paper.

FIELD APPLICATION OF PROTECTIVE COATINGS FOR EMP GASKETS BY STYLUS ELECTROPLATING

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In order to maintain reliable electromagnetic pulse (EMP) shielding for electronic equipment shelter interfaces, mating surfaces such as door gaskets and knife-edge contacts must provide low contact resistances. These interfaces must also be resistant to excessive amounts of corrosion and mechanical wear, which would tend to degrade their shielding integrity. The objective of this research was to establish the efficacy of stylus electroplating as a potentially viable field maintenance/repair technique for application of corrosion resistant, wear resistant coatings in order to help maintain the shielding integrity of those interfaces.

Aluminum alloy (6061-T6) knife-edge and channel test pieces were stylus electroplated with tin (Sn) or tin-lead (Sn-Pb) coatings over nickel (Ni) or copper (Cu) underlayers. For many of the sample substrate surfaces, a conventional baton-shaped stylus was utilized as the electroplating tool. For the complex geometry of a knife-edge substrate, however, a custom-designed electroplating tool appears to provide better control of the plating process, and circumvents problems of possible interference with previously deposited areas.

Electrodeposited coatings were compared in terms of physical appearance, thickness, microhardness, and adherence. Several sets of electroplated samples were subjected to the ASTM B-117-90 Salt Spray Test. The USACERL Gasket Cycler Testing System was employed to model the stochastic behavior of contact resistance versus number of open/close cycles for both pre- and post-salt spray tested coatings on knife-edge substrates.

This research has resulted in an optimized stylus electroplating procedure which enhances coating adherence, uniformity, and corrosion resistance, and mitigates common performance-limiting defects such as scarring, blisters, and ridges.

Cavity Field Reduction Techniques

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:cent high frequency coupling analyses have suggested that coupling to circuit nodes inside :ctrical boxes follows the average cavity fields inside an aircraft as a function of frequency with a nstant relationship between the power observed at the circuit node and the power which would coupled to an electrically long cable immersed in the cavity field. As a consequence, high :quency hardening strategies should include the reduction of these local fields.

nis paper examines the effectiveness of both traditional and non-traditional cavity field reduction chniques on a testbed aircraft. Experiments for this comparison were conducted during the onths of April and May 1994, at the Large Electromagnetic System Level Illuminator (LESLI) cility at Kirtland AFB.

ne effect of adding the traditional field reduction material, carbon embedded styrofoam, in the ivity was investigated in a cumulative fashion. Four separate sections of absorber sheets were lded to the cavity and the effectiveness of each was evaluated. Measurements of a transfer nction of the z-directed magnetic free field in the cavity and the skin current on the nose of the rcraft demonstrated that the field reduction capability of absorber material comes into play only hen the mode density in the cavity becomes appreciable at the higher frequencies (near 1 GHz). urther, cavity field reductions with two absorber sheets and 4 absorber sheets in the cavity were omparable.

number of other absorber-like concepts for hardening were also evaluated. One hardening :chnique was to line the walls of the cavity with ferrite loaded silicon tiles to reduce magnetic elds near the walls of the cavity and, in turn, to reduce cavity skin currents. All four x-y and y-z valls were covered (not the top and bottom of the cavity) with the tiles. Another idea was to load ne cavity with resistor lattices (rectangular boxes of resistors approximately 2 inches on a side all onnected together in a long parallelpiped) to reduce both the magnetic and electric fields. Two alues of resistors were used for these lattices: 50 and 680 ohms. All of these techniques show pproximately a 20 dB reduction in the field levels over most of the frequency band, which is omparable to the carbon-loaded foam reductions at high frequencies. This new hardening ardware, however, shows significant reduction of the fields at the lower frequencies, which was ot observed for the carbon loaded foam absorber. The effects of using the 50 ohm versus the 680 hm resistors in the resistor lattices seemed to make little difference.

ANALYSIS OF NONLINEAR MULTISTAGE PROTECTION CIRCUITS AGAINST INTERFERING TRANSIENTS

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Filters or protection circuits respectively are necessary in order to guarantee a faultless function (EMC) of electronic systems or to prevent a damage of electronic components caused by powerful transients respectively. If the signal spectrum overlaps with the spectrum of the transients and the peak values are much higher than the signal amplitudes nonlinear protection circuits are necessary. Nonlinear protection circuits are the subject of this contribution.
As already mentioned in other publications there exist essential differences between protection circuits for power lines and such for signal lines particularly RF-transmission lines. Extremely sensitive electronic components and inputs to be protected require two and more nonlinear stages in order to realize a sufficient reduction of the energy as well as of the remaining voltage peak of the interfering transient.
The paper represents protection circuits with two and three nonlinear stages containing gas arresters, varistors and suppressor diodes decoupled by ohmic resistances. The results of a computer based method will be shown. Besides this simulation procedure measurement results concerning the voltage drop at the individual stages i. e. the transient response of each stage in the time domain will be shown and discussed in order to assess the efficiency of the individual stages as well as the efficiency of the decoupling impedances between the stages.
Examples of nonlinear protection circuits developed for definite applications will be presented. Besides the transient response the influence of the transmission of the line signals by the nonlinear components in combination with the series impedances (decoupling impedances) will be considered. Protection circuits for RF-transmission lines require low decoupling impedances between the different stages. In such cases additional stages may be necessary in order to obtain the required transient response. Results will be presented which elucidate that intermodulation distortions depend on the nonlinear characteristics of the protective components as well as on the frequency, while the junction capacitance of suppressor diodes or the capacitance of varistors in combination with the series impedances serve as low-pass filter and determine the upper cut-off frequency or the insertion loss for the signals respectively. The lower the breakdown voltage of suppressor diodes - a low breakdown voltage is necessary for the protection of extremely sensitive components - the higher the junction capacitance and therefore the lower the upper cut-off frequency for the transmission of the signals. This results in the fact that the protection of sensitive devices on the one hand and the realization of a high upper cut-off frequency on the other hand requires opposite measures.

SHIELDING EFFECTIVENESS OF A METALLIZED GLASS FIBER ENCLOSURE

William Coburn*, John Latess, Chris Reiff, and Jack Stewart – Army Research Laboratory
and Linden Albright – Booze, Allen, and Hamilton, Inc.

Abstract–A shielding effectiveness (SE) test was conducted to evaluate the performance of metallized glass fiber (MGF) applied to an Army tactical shelter size enclosure. MGF is a glass fiber substrate with a metal coating which can be used to improve the electrical properties of reinforced composites. The material considered here (RoMHOglas™ – Metallized Glass Conductive Fibers produced by Lundy Technical Center, Pompano Beach, Florida) is an E-glass fiber metallized with Al and processed into a non-woven mat. When formed into a mat the MGF lead to an effective sample conductivity, σ_{eff}, which is the parameter of interest for electromagnetic shielding in the RF region. Previous results are discussed which show that σ_{eff} is dependent on the curing process and is optimized using vacuum bagging techniques.

We applied two layers of the MGF mat to the interior surfaces of a plywood full-scale model of an Army tactical shelter. Using overlapping seams, the MGF layers were secured to the plywood walls and sprayed with polyester resin. A vacuum bag was fitted to the interior and exterior of the shelter model. A vacuum was applied to compress the two layers of MGF mat and remove excess resin. Laboratory tests indicated that a minimum vacuum of 10 mm Hg would be required to achieve optimum performance; however, only about 5 mm Hg could be obtained due to leaks. A metal door with an eight cleat clamping arrangement and an EMI gasket was used to provide a continuously shielded enclosure. This shielded enclosure was then tested according to IEEE-STD-299-1991, with some modifications, at frequencies up to 900 MHz. The test data demonstrated that the seam treatments were effective in that seam leakage did not limit the enclosure SE. The results are presented as recommended by the test standard and indicate that compressed MGF mat can provide medium level SE at high frequencies but little or no magnetic field SE.

TYPICAL WIRING LOSSES ASSOCIATED WITH AIRCRAFT ELECTRONICS UNITS

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Electromagnetic fields coupled on wiring leading to aircraft electronics units result in induced voltages and currents that can disrupt or damage the electronics. To estimate the susceptibility of these aircraft electronics units to these threat fields, one compares the coupled signals less wiring losses inside the electronic unit to circuit or electronic component operating or damage levels. A key piece of information is the wiring losses associated with these aircraft electronics units. This presentation shows wiring loss data for several pieces of military aircraft electronics. The wiring losses act as a low pass filter that provides some protection against induced signals from electromagnetic field threats.

The measurements are basically network analyzer S21 data. We inject a known signal into the input pin of an aircraft electronics unit, and we record the response at selected points on circuit boards. The data frequency range is 1-1000 MHz. We obtain results for both signal and power line inputs. There are three types of response locations. One type is located on the same wire as the input source. Another type is found on nodes connected to a wire in the same bundle as the driven wire. The final type is at a node that is neither directly connected to the driven wire nor to any wire in the same bundle as the driven wire. We call these cases direct, indirect and buried respectively.

We present summarized data in two forms. One is a comparison of responses from power and signal pin inputs. Results show that the signal pin inputs are much larger. The cause of this difference is the low pass filtering usually done on power line inputs/outputs. Then we compare direct, indirect and buried responses. Although the results vary within the three types, the data averages within each class show consistent trends. The direct connection type has monotonically increasing loss that is negligible at 1 MHz and increases to about 20 dB at 1000 MHz. The indirect type has very large losses below 50 MHz. At about 100 MHz, the loss decreases to the 20-25 dB range. Above 800 MHz, the loss increases to the 25-30 dB range. The buried type also has large losses below 50 MHz. Above 100 MHz, the loss varies in the 40-50 dB range. We show the mean and the spread of this data and present our interpretation of the trends.

Room: Aztec

day, May 31, 8:30 AM
EM-24 **Bounded Wave Simulators**
Chair: *J.C. Giles, Los Alamos National Laboratory, Los Alamos, NM*

:30 AM **INTRODUCTION & ANNOUNCEMENTS**

:35 AM **EVALUATION OF THE GTEM SIMULATOR FOR PULSE IMMUNITY TESTING**, *W.A. RADASKY and K.S. SMITH, Metatech Corporation, Goleta, CA; and D. HANSEN, D. RISTAU and T. SPAETH, EURO EMC Service Dr. Hansen GmbH, Teltow, Germany* 342

:55 AM **ELECTRIC FIELD MEASUREMENTS WITHIN AND NEARBY A VERY LARGE TEM CELL WITH WIRE MESH CONDUCTING SURFACES**, *M.K. McINERNEY, U.S. Army Construction Engineering Research Laboratories, Champaign, IL* 343

:15 AM **STRIP-LINE ANTENNA SUPPLIED BY 800KV-1NS RISE TIME NEMP GENERATOR**, *F. PIRO and J.L. BRAUT, Alcatel Cable, Bezons, France; B. ARZUR and A. THOMAS, CNET, Lannion, France; and M. BLANCHET, MB et associes, Savigny Le Temple, France* 344

:35 AM **RADIATION EXPERIMENTS OF ELECTRIC FIELD ON A SMALL-SIZED EMP SIMULATOR**, *L. CHUAN-LU, National University of Defense Technology, Hunan, China* 345

EVALUATION OF THE GTEM SIMULATOR FOR PULSE IMMUNITY TESTING

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The Gigahertz TEM (GTEM) test cell is gaining in its world-wide acceptance for EMC testing for a variety of radiated emissions and immunity standards. It has the advantage of reasonable size (essentially a small shield room with an absorber lined termination on wheels) and cost with an external feed section. This feed section can be used to drive immunity waveforms (CW or pulse) into the simulator or to measure emissions (usually CW) from a tested product. The GTEM 1750, which is approximately 7.5 meters long and 3 meters tall and 4 meters wide at the termination end of the cell, is sufficient for testing electronics boxes which are on the order of 50 cm on a side.

This paper will examine the simulation fidelity characteristics of an empty and "full" test volume in a GTEM 1750 for a variety of EM pulses (different rise and fall characteristics) including those applicable to high-altitude EMP (HEMP). In particular, the impact of EM coupling in the GTEM cell to a test object and the importance of system cable orientation is discussed.

Comparisons will also be shown between measured and calculated EM fields to demonstrate the accuracy of the 3-D FDTD model and solution as provided by the META3D code. Measurements have been performed by EES using a variety of sensors including a high-frequency (30 - 1000 MHz) fiber optic system and a Holaday E field sensor system with digital readout. An evaluation of the TEM accuracy of the GTEM cell will also be examined as a function of observer location and frequency.

ELECTRIC FIELD MEASUREMENTS WITHIN AND NEARBY A VERY LARGE TEM CELL WITH WIRE MESH CONDUCTING SURFACES

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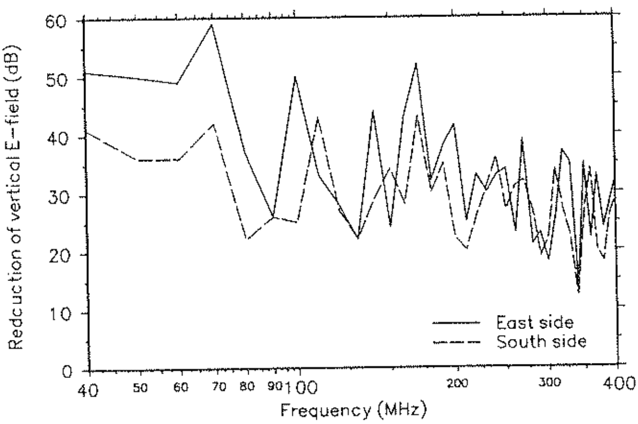
The U.S. Army Construction Engineering Research Laboratories' (USACERL) Electromagnetic Environment Simulator (EES) is fundamentally an asymmetric transverse electromagnetic (TEM) cell in which the inner conductor is vertically offset from the center. The design consists of three sections: the tapered wavelaunching section (south end), the central rectangular section, and the tapered output wave receptor section (north end). The major axis of the simulator is oriented north-south with the electromagnetic source and resistive termination located in small buildings at the south and north ends, respectively. A very large hinged door on the west side permits access to the test volume while a large bolted hatch on the east side allows access to the termination. The dimensions of the test volume (central rectangular section) are 7.0 m wide by 5.0 m high by 15.0 m long. The overall dimensions are 9.7 m wide by 6.7 m high by 92.1 m long. The conducting surfaces of the EES are steel wire mesh. The wire mesh on the top, sides and inner conductor has a 2 inch by 4 inch wire spacing while the bottom (ground plane) mesh has a 1 inch by 1 inch wire spacing.

Because the EES is located outside in a populated area, the ability of the wire mesh to reduce the radiated electromagnetic field is important. This paper will present E-field measurements from 30 kHz to 400 MHz taken at several directions and distances from the EES. An example of the reduction of the vertical E-field is shown in the accompanying figure. The E-field in the center of the test volume is compared to the E-field at distances of approximately 16.4 m to the east and 12.2 m to the south of the basic EES structure.



STRIP-LINE ANTENNA SUPPLIED BY 800kV-1ns RISE TIME NEMP GENERATOR

F. PIRO (1)*, J.L. BRAUT (1), B. ARZUR (2), A. THOMAS (2), M. BLANCHET (3)
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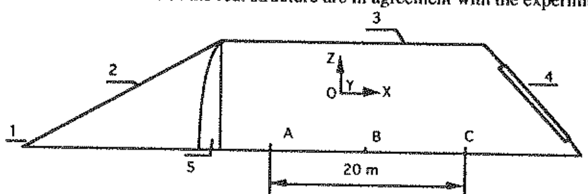
(2) CNET, 2 Route de Trégastel 22301 LANNION Cedex, FRANCE
(3) MB et associés, 35 Place de la Ronceraie 77176 SAVIGNY LE TEMPLE, FRANCE

Introduction

In collaboration with the Centre National d'Études des Télécommunications (CNET), Alcatel Cable have studied and realized a large strip-line simulator supplied by a very short rise time NEMP generator. This fast pulse circuit is driven by a 800kV Marx generator. The wave generated in the structure is the IEC 1000-2-9 standard (rise time = 2.5ns) which will probably replace the previous BELL waveform in the standards. This simulator, located at the CNET of LANNION (FRANCE), is destined to test large equipment with their cabling system.

Strip-line simulator

One solution to obtain a short rise time wave is to use a cone-shaped structure. This type of antenna has no geometric discontinuity and so better performances. But its main drawback is to have a non-homogeneous field in the long useful volume (20m x 2m x 2m). So we have decided to use an original dielectric lens. This lens is placed between the transition part and the flat part to limit the reflexion and diffraction phenomena generated by the geometric discontinuity (Patent ALCATEL CABLE (PIRO, BLANCHET) n°9413963 of 11/22/1994). The shape of the lens has been determined by experiments in a scaled reduced structure (1/10th). The results obtained in the real structure are in agreement with the experimentation.



where
1 is an impulse generator
2 and 3 are the line composed by steel wires
4 are the resistive wires adapted to the impedance of the transmission line
5 is a dielectric lens

Pulse circuit

The whole pulse circuit is contained in a non-metallic enclosure (4.5m x 1.9m x 1.2m) filled with SF_6 at the atmospheric pressure. It is composed by a strip-line capacitor, a fast switch pressurised at 15bars of SF_6, the launch transition of the strip-line, the capacitors to make the BELL waveform and a retractable transition connected to a N plug to make CW test.
So, this device has two special features. The first one is the possibility to simulate two bi-exponential waveforms (IEC and BELL). The change between these two waveforms is simply made by moving two rods of metal in a few second. The second characteristic is to be able to test equipment in CW up to 100 MHz.

Measurements

All the studies and measurements have been made at first at ALCATEL CABLE at Bezons (FRANCE) on a strip-line antenna especially realized for this project. We have reached an electric field strength of 150kV/m (ie three times the field of the IEC 1000-2-9 standard). The mesurements have displayed the followings caracteristics:

- electric field uniformity in the useful volume inferior at 2dB,
- rise time inferior at 1.6ns.

Radiation Experiments of Electric Field on a Small-Sized EMP Simulator

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ABSTRACT

In this paper,a small-sized EMP simulator,in which the maximum electric field strength and the pulse duration are $8.3x10^4$V/m and 600ns respectively,is described.The induction field experiments on naked and shielded cables in the simulator have shown that the induced voltage amplitudes are 1.7kV and 3.2kV,respectively,when the terminal load of simulator is a resistance of 180Ohm.

iday, May 31, 8:30 AM **Room: Galisteo**

ᵖEM-25 **Transmission Line Modeling**

CoChairs: J. Nitsch, Physikalisches Institut, Universitat zu Koln, Koln, Germany
F. Tesche, EM Consultant, Dallas, TX

8:30 AM **INTRODUCTION & ANNOUNCEMENTS**

8:35 AM **PULSE PROPAGATION ON LOSSY LINES**, *P.L.E. USLENGHI, University of Illinois at Chicago, Chicago, IL* 348

8:55 AM **TIME-DOMAIN NETWORK-ANALYSIS INCLUDING FIELD EXCITED LOSSY MULTICONDUCTOR TRANSMISSION LINES WITH NON-LINEAR TERMINATIONS**, *R.-M. VETTER and J.B. NITSCH, II. Physikalisches Institut, Universitat zu Koln, Koln, Germany* 349

9:15 AM **PERTURBATION SOLUTION FOR PERFECT NONUNIFORM MULTICONDUCTOR TRANSMISSION LINES IMMERSED IN A UNIFORM ISOTROPIC MEDIUM**, *J.B. NITSCH, C.E. BAUM and D.H. NITSCH, Wehrwissenschaftliches Institut fur Schutztechnologien - ABC-Schutz, Munster, Germany* 350

9:35 AM **VALIDATION OF A MULTICONDUCTOR, MULTIBRANCHED, AND MULTISHIELDED WIRING HARNESS MODEL**, *R.A. PERALA, P.H. Ng and T. RUDOLPH, Electro Magnetic Applications, Inc., Lakewood, CO* 351

9:55 AM **CALCULATION METHODE FOR CURRENTS, CREATED BY EMF IN BRANCHED CABLE COMMUNICATION NET**, *G. AKOMELKOV, A. ALTOUKHOV and V. KOUPRIENKO, Science Research Center, St. Petersburg, Russia* 352

PULSE PROPAGATION ON LOSSY LINES

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The analytical treatment of lossy transmission lines on which arbitrary pulses propagate usually involves a Laplace transform technique. The inverse transform, however, is difficult to obtain and requires cumbersome calculations. In this work, a direct time-domain approach is developed that is valid for lines with small losses. Obviously, the technique is also applicable to the problem of a planar pulse of arbitrary shape that is normally incident on a slab of penetrable material with small overall losses.

Consider a transmission line with series resistance R and inductance L per unit length, and shunt conductance G and capacitance C per unit length, on which an arbitrary pulse with voltage v(x,t) propagates. The telegrapher equation for the voltage may be written in the form

(1) $$\frac{\partial^2 v}{\partial \xi^2} - \frac{\partial^2 v}{\partial \eta^2} = \varepsilon_1 \varepsilon_2 v + (\varepsilon_1 + \varepsilon_2)\frac{\partial v}{\partial \eta},$$

where

(2) $$x = \xi \ell, \quad t = \eta \frac{\ell}{u}, \quad u = \frac{1}{\sqrt{LC}}, \quad R_c = \sqrt{\frac{L}{C}},$$
$$\varepsilon_1 = \frac{R}{R_c}\ell, \quad \varepsilon_2 = G R_c \ell,$$

and ℓ is the length of the line. If $R\ell \ll R_c$ and $G\ell \ll 1/R_c$, then

(3) $$\varepsilon_1 \varepsilon_2 \ll \varepsilon_1 + \varepsilon_2 = \varepsilon.$$

A first-order perturbation technique yields the result:

(4) $$v(x,t) = \left[1 - \frac{\alpha}{2}(x+ut)\right] v_o^{(+)}(x-ut) + \left[1 + \frac{\alpha}{2}(x-ut)\right] v_o^{(-)}(x+ut),$$

where $\alpha = \varepsilon/2$ is the attenuation constant on the line, and $v_o^{(\pm)}$ are the d'Alembert solutions for the lossless line.

Several examples are considered, and an extension to higher-order terms in the solution is discussed.

TIME DOMAIN NETWORK ANALYSIS INCLUDING FIELD-EXCITED LOSSY MULTICONDUCTOR TRANSMISSION LINES WITH NONLINEAR TERMINATIONS

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Introduction. This paper describes how lossy multiconductor transmission lines (MLTs), which are also excited by external fields, become included (as lumped sources and resistors) in a network analysis.

MTLs in a Network Simulation. The telegrapher equations for MTLs are solved in time domain with the aid of the Bergeron procedure. This procedure admits the termination of the lines with arbitrary nonlinear components and represents the conductors in an equivalent network as resistors and controlled current sources. The controlled current sources take into account the travelling times of the signals along the lines whereas the resistors simulate the characteristic impedances of the MTL.

On MTLs with losses there is no unique definition of the propagation time, due to the frequency dependency of the propagation speed. This leads to signal dispersion, in particular on MTLs with frequency-dependent losses, like, e.g., in the case of the skin effect. Therefore, for those cases, the Bergeron procedure has to be extended to MTLs having frequency dependent propagation constants. For this purpose the transfer functions of the MTL are calculated in the frequency domain and then are transformed into the time domain by convolution with the input signals. In order to facilitate the convolution procedure the time domain transfer functions are approximated by a sum of exponentials.

The calculations are performed in the modal space, i.e. the signals are represented in terms of eigenmodes. These modes propagate without crosstalk. At the ends of the MTL the real (physical) signal is reconstructed from the eigenmodes, and crosstalk is included via resistors in the terminations.

Coupling of external electromagnetic fields to the MTLs is taken into consideration by equivalent current sources at the ends of the lines. In the case of incident plane waves the additional computing time is very short.

Conclusion. The above methods enable us to deal with lossy MTLs in the time domain in a very efficient manner, in particular with regard to the time saving computation time. The effects of nonlinear termination elements as protection measures, e.g. against EMP, can be simulated, including reflections at the protected line ends as well as the generation of steep pulse slopes caused by protection elements.

It is possible to apply a modified Bergeron procedure also to nonuniform MTLs. This was done already with twisted cables. Currently we are working on the problem to include more general NMTLs and radiation effects in our network analysis.

PERTURBATION SOLUTION FOR PERFECT NONUNIFORM MULTICONDUCTOR TRANSMISSION LINES IMMERSED IN A UNIFORM ISOTROPIC MEDIUM

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Introduction

Although there are closed-form solutions for uniform and nonuniform multiconductor transmission lines (MTLs, NMTLs) with arbitrary sources, only a few examples exist which describe practical applications for NMTLs. In this paper we present a systematic approach to a perturbation solution of perfect NMTLs (plus reference) and apply our result to the one-dimensional exponential line to demonstrate its practical use and the fast convergence of the perturbation solutions to the exact one.

The Procedure

The telegrapher equations for NMTLs are combined to a first-order supervector/supermatrix differential equation regarding the voltage and the normalized (by the characteristic impedance matrix $\mathbf{Z}_c(z,s)$) current vectors as one 2N-dimensional supervector. The resulting equation can be solved with the aid of well-known mathematical techniques. The supermatrizant $\overline{\mathbf{M}}_{z_0}^{z}$ describing the solution on the interval $[z, z_0]$ can be represented as the product of three supermatrices

$$\overline{\mathbf{M}}_{z_0}^{z} = \begin{pmatrix} 1 & 0 \\ 0 & \mathbf{Z}_c(z;s)\cdot\mathbf{Z}_c^{-1}(z_0;s) \end{pmatrix} \odot \begin{pmatrix} \cosh(\mathbf{P}(s)(z-z_0)) & -\sinh(\mathbf{P}(s)(z-z_0)) \\ -\sinh(\mathbf{P}(s)(z-z_0)) & \cosh(\mathbf{P}(s)(z-z_0)) \end{pmatrix} \odot \overline{\mathbf{M}}_{z_0}^{z}(\Delta\overline{\mathbf{D}}) \quad (1)$$

Note that the propagation matrix $\mathbf{P}(s)$ does not depend (due to our assumption) on the local coordinate z. The second supermatrix in Eq. (1) corresponds to the solution of perfect MTLs. In the case that the third supermatrix in (1) (which itself is a supermatrizant for the perturbation term $\Delta\overline{\mathbf{D}}$) equals $\overline{\mathbf{1}}$ then the solution represents an approximation of an NMTL by a cascaded series of MTLs. This becomes easily obvious taking into account the product property of the supermatrizant

$$\overline{\mathbf{M}}_{z_0}^{z} = \overline{\mathbf{M}}_{z_{N-1}}^{z} \odot \cdots \odot \overline{\mathbf{M}}_{z_1}^{z_2} \odot \overline{\mathbf{M}}_{z_0}^{z_1} \quad (2)$$

and choosing for every subinterval $[z_{l+1}, z_l]$ the representation (1). The explicit form of the perturbation supermatrizant in Eq. (1) is more lengthy and mainly contains an approximation for the characteristic impedance matrix.

Conclusion

We have provided a powerful means for the approximation of NMTLs. It remains to work out many and more complicated applications.

VALIDATION OF A MULTICONDUCTOR, MULTIBRANCHED, AND MULTISHIELDED WIRING HARNESS MODEL

by
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Many electronic systems on vehicles such as aircraft are connected together by complex wiring harnesses. In general these harnesses have many branches, with varying numbers of conductors within each branch. In addition, a harness may have multiple shielding layers, such as an overall shield with several internal twisted shielded pairs (TSP) or coaxes. The harness plays a crucial role in the protection of the system to various environments, such as EMI, EMP, and HIRF. Validation of systems to the environment is usually done by testing (DO-160, MIL-STD-461, etc), but it is very useful and cost effective to be able to virtually prototype the harness with EM simulation software before hardware is built or tested.

The objective of this paper is to present an experimental validation of such simulation software. The software is based on the time domain finite difference solution of the multi-conductor TEM transmission line equations, with multiple shields and branches. The test article is a flight article aircraft wiring harness, which has several branches, an overall shield, and various numbers of TSPs within each branch. The test environment is MIL-STD-461 radiated susceptibility (RS) and conducted susceptibility (CS), and spans a frequency range from 10 KHz to 10 GHz. Comparisons of numerical with experimental results for voltages induced on the inner TSP conductors are made for a variety of test conditions. In particular, various harness bonding impedances are considered. Excellent agreement between numerical and experimental results is obtained.

CALCULATION METHODE FOR CURRENTS, CREATED BY EMF IN BRANCHED CABLE COMMUNICATION NET

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Radio-electronic equipment (REE) on working objects includes branched cable and w lines (electric supply, information interchange, etc). Interaction of EMF with cable net may cau the appearing of currents and voltages, dangerous for REE functioning. That is why one of t main problems is valuation of expected noise signal due to different EMF (artificial, natural technogenesic)

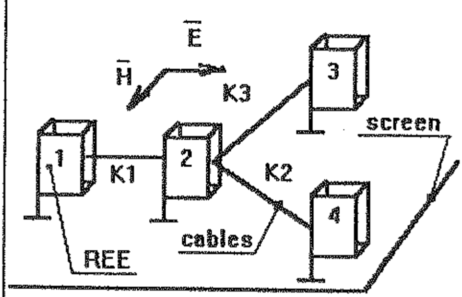

Fig. 1

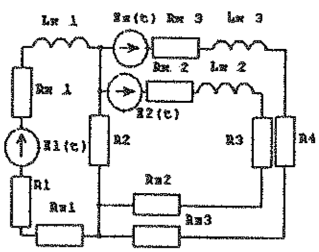

Fig. 2

The methode for current and voltag calculations, created by EMF in cable screer wire lines and REE housings is suggested this work. This methode allows to take in consideration the cable communication r complication and branching. The princip physical model of EMF interaction with cab net is shown on fig. 1.

The currents calculations in parts circuit K1-K3 is suggested to carry out with the quasi-static model. This way great simplifies the solution and increases resul accuracy of currents and voltages calculatio in electricaly-short cable lines.

The real circuit of cable lines and RE can be represented by the substitutional circu (fig. 2). The transient in substitutional circu during action of pulse electromotive force described by the system of equation composed on Kirghoff's laws. In general cas if the system consists of i-loops and every loc includes supply source Ek(t), resistance R inductance Lk, capacitance Ck, then tl system of equation can be written as :

$$1)\quad \left[\sum_{k=1}^{n}\left(Jk1(t)\cdot Rk1 + Lk1\cdot\frac{dJk1(t)}{dt} + \frac{1}{Ck1}\cdot\int Jk1(t)\,dt\right)\right] := \sum_{k=1}^{n} Ek1(t)$$

$$\cdots\cdots\cdots\cdots\cdots\cdots$$

$$i)\quad \left[\sum_{k=1}^{n}\left(Jki(t)\cdot Rki + Lki\cdot\frac{dJki(t)}{dt} + \frac{1}{Cki}\cdot\int Jki(t)\,dt\right)\right] := \sum_{k=1}^{n} Eki(t)$$

The solution of this system found by numerical methode allows to find the values of curren and voltages, appearing in circuit's branches during pulse emf action. This values correspond quantities of currents, flowing in cable screens and REE housings. This methode is realised application program.

day, May 31, 8:30 AM | Room: Brazos

:O-8 **Detection & Identification III**

Chair: *L. Carin, Duke University, Durham, NC*

:0 AM **INTRODUCTION & ANNOUNCEMENTS**

:5 AM **US AIR FORCE NEXT GENERATION BURIED UXO DETECTOR,** *K. BAKHTAR and E. SAGAL, Bakhtar Associates, Newport Beach, CA; and J. JENUS, JR., U.S. Air Force, Elgin AFB, FL* 354

:5 AM **AN ENHANCED BURIED OBJECT DETECTION SCHEME USING A TARGET CENTERED REVERSE TIME FINITE DIFFERENCE TIME DOMAIN APPROACH,** *K.S. KUNZ, The Pennsylvania State University, University Park, PA* 355

:5 AM **TIME DOMAIN ELECTROMAGNETIC METAL DETECTORS – HISTORY, CASE HISTORIES, FUTURE,** *P. HOEKSTRA, Blackhawk Geosciences, Golden, CO* 356

35 AM **THE VERY EARLY TIME ELECTROMAGNETIC (VETEM) INSTRUMENT: A TIME-DOMAIN NEAR-SURFACE PROFILING SYSTEM,** *D.L. WRIGHT, V.F. LABSON, M. DESZCZ-PAN and J.A. BRADLEY, U.S. Geological Survey, Denver, CO; T.P. GROVER, Colorado School of Mines; and L. PELLERIN, Lawrence Berkeley National Laboratory* 357

55 AM **IDENTIFICATION OF BURIED HIGHLY CONDUCTING OBJECTS USING LOW FREQUENCY MAGNETIC FIELDS,** *L.S. RIGGS and J.E. MOONEY, Auburn University, AL* 358

):15 AM **BREAK**

):40 AM **GEM-2: A NEW MULTI-FREQUENCY ELECTROMAGNETIC SENSOR FOR DETECTING BURIED UNEXPLODED ORDNANCE,** *I.J. WON, Geophex, Ltd., Raleigh, NC* 359

1:00 AM **REAL TIME MICROWAVE TOMOGRAPHIC INSPECTION TOOL FOR THE DETECTION OF BURIED OBJECTS: ASSESSMENT CAMPAIGN,** *P. GARREAU and G. COTTARD, SATIMO, Les Ulis, France; J.L. POLITANO, CREL DGPN, Le Chesnay, France; and J.C. BOLOMEY, SUPELEC, Gif sur Yvette, France* 360

1:20 AM **RADIO WAVE HOLOGRAPHIC IMAGING OF BURIED PROJECTILES AND LAND MINES,** *J.T. NILLES, G.P. TRICOLES and G.L. VANCE, GDE Systems, Inc., San Diego, CA* 361

1:40 AM **MEASURES OF PERFORMANCE FOR UXO DETECTION SYSTEMS AND IMPLICATIONS FOR UXO CLEANUP: THE JEFFERSON PROVING GROUND STORY,** *R.E. DUGAN, T.W. ALTSHULER, A.M. ANDREWS, V. GEORGE, M.P. MULQUEEN and D.A. SPARROW, Institute for Defense Analyses, Alexandria, VA* 362

US AIR FORCE NEXT GENERATION BURIED UXO DETECTOR

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Submitted to: **AMEREM 1996**
Technical Program Committee
P. O. Box 37378
Albuquerque, New Mexico 87176-7378 - U. S. A.

ABSTRACT

Under the US Department of Defense Small Business Innovative Research program (SBIR Department of The Air Force), a contract was awarded to Bakhtar Associates for development of the next generation Ground Penetrating Radar (GPR). Reflected electromagnetic waves are used for spatial location of buried unexploded ordnance in heterogeneous media. The approach being developed under this program is unique in terms of frequency range and electromagnetic power imparted to the ground. An HP8753D network analyzer is used for transmission and subsequent acquisition of the signals. The synthesized software controlled step frequencies of the transmitted signals are conditioned to compensate for variations of ground characteristics. A sophisticated software package is used to control acquisition of generated signals. A post-processing algorithm enables discrimination between potential targets and randomly originated "clutter". Output power is maintained at 0.1 watt. The basic detection unit consists of three network analyzers with associated signal conditioning software, amplifiers, and antennas. A series of three pairs of antennas are used to cover the range of operating frequencies from 30 kHz to 6 GHz. The combination of assembled hardware and developed software should enable Bakhtar Associates to meet the objectives of the proposed program for detection of buried unexploded ordnance. This paper provides a brief summary of the progress made and elaborates on the uniqueness of the approach.

AN ENHANCED BURIED OBJECT DETECTION SCHEME USING A TARGET CENTERED REVERSE TIME FINITE DIFFERENCE TIME DOMAIN APPROACH

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With the advent of the finite difference time domain (FDTD) technique for solving electromagnetic scattering problems, some new alternative approaches to the buried object detection problem have arisen.

The one developed here is based on three key elements:

1) FDTD can model time reversed electromagnetic propagation
2) The starting point for the analysis can be the target rather than the incident field or the scattered field
3) Currents on a target uniquely define the incident field required to excite these currents and the scattered field produced by these currents.

Using time reversed FDTD, the fields are calculated backwards in time yielding the incident fields needed to excite these target currents. Using FDTD to predict forward in time the scattered fields are determined.

Thus a target centered approach emerges in which a specified target current response determines the required incident field for its excitation and the scattered field signature. A starting point for the current is the impulsive response of the unburied object with broadside incidence. A nearly impulsive response can readily be found using the FDTD technique. The incident and scattered fields associated with these currents strongly depend on the target orientation, the properties of the surrounding media and the burial depth. The scattered field corresponding to each different target type will have a unique signature since different target types have different resonances because of differences in target size and shape.

The target centered approach cannot overcome physical limits set by conductivity and burial depth. The analysis must be iterative in that the initial currents assumed will change since the sources available to produce the excitation must be above ground and cannot surround the target. Even so, the target centered approach provides an analytic approach that facilitates exploiting the target's physical characteristics. The incident field determined with this approach selectively illuminates a target with a unique position, orientation and soil type and produces a scattered signal unique to this situation. The subsequent processing then determines what can be extracted. What has been achieved here is that the probability of detection has been significantly enhanced by starting with the target and its unique characteristics.

Time Domain Electromagnetic Metal Detectors - History, Case Histories, Future

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Abstract Category: UXO

Time domain electromagnetic (TDEM) sensors have been employed in mineral exploration for some 20 years. An important objective for these sensors is to explore for highly conductive targets (e.g. massive sulfide ore bodies). TDEM sensors gained wide acceptance for that purpo: quickly, because they allowed definition of position, shape, dimensions, and conductivity of targets. Moreover, targets could be detected in different environments, such as in the resistive rocks of the Canadian Shields, as well as under conductive overburden in the North-Central Stat of the US and under conductive weathering layers in Australia.

The requirements for detection of buried metal objects for Unexploded Ordnance (UXO) and Exploded Ordnance Waste (EOW) have similarities to exploration for highly conductive ore bodies. In both cases, targets are several orders of magnitude more conductive than the surrounding soils or rocks. The differences are in the dimensions of the target, depth of investigation, and cost constraints.

The first TDEM metal detector, the Geonics EM61 has already proven effective on a number of UXO surveys (Ft. Monroe, Jefferson Proving Ground, and over volcanic rocks in Hawaii). Characteristic features of TDEM sensors for UXO expected from basic principles and proven in practice are:

1) anomaly shape and to some extent amplitude, nearly independent of soil type;
2) low background noise; and,
3) simple anomaly shape.

The Geonics EM61 TDEM metal detector was designed primarily for detection of drums, underground storage tanks, landfills and trench boundaries delineation and utility detection. The success of the EM61 suggest that instrument enhancements, improved interpretation, and modeling capabilities will lead to better UXO detection sensors. Enhancements can be based on sound theoretical foundations and field experiences, largely developed by the mineral exploration industry. The instrument modifications required to detect smaller UXO targets and to provide better definition of target depths and dimensions will require multi-component measurements (both vertical and horizontal magnetic fields), and recording of a number of time gates. Some experimental measurements made over inert targets confirm this.

THE VERY EARLY TIME ELECTROMAGNETIC (VETEM) INSTRUMENT: A TIME-DOMAIN NEAR-SURFACE PROFILING SYSTEM

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The very early time electromagnetic (VETEM) system is a prototype time-domain system, using fast signal averaging, that has potential applications to direct detection of non-aqueous phase liquids as well as to the detection of buried objects. It is designed to operate in environments that are too conductive for ground penetrating radar (GPR) to be effective, and to provide better shallow resolution than standard geophysical electromagnetic (EM) systems. The VETEM system is a faster profiling complement to the frequency-domain high frequency sounder (HFS).

Early field tests of the VETEM system were carried out in June and July, 1995 at the Rabbit Valley Geophysics Performance Evaluation Range, west of Grand Junction, Colorado, operated by RUST Geotech Inc. This range has a wide variety of buried objects at known locations. Among the buried objects over which the VETEM system was operated were: a pair of oil-filled bladders, metal disks at varying depths, metallic and non-metallic spheres, and a steel culvert. VETEM and GPR were run over some of the same targets for baseline comparison. VETEM was also run at the Cold Test Pit at the Idaho National Engineering Laboratory (INEL) in November, 1995, as part of the Electromagnetics Integrated Demonstration (EMID) where it responded to both near-surface soil differences and to buried objects.

VETEM is equipped with identical loop antennas for transmitting and receiving and an alternative electric dipole receiving antenna. Vertical and horizontal loops for transmitting and receiving were used. There was better real-time target sensitivity when the transmitting and receiving antennas were cross-polarized to eliminate the primary field. Responses were stronger over metal objects, but some dielectric targets were seen. Some targets that are not discernable on the real-time display or data play-backs are evident when an average waveform is subtracted. At INEL we averaged 2048 waveforms while moving the system at 10 cm/s with a spatial data density of about 6 cm.

Identification of Buried Highly Conducting Objects Using Low Frequency Magnetic Fields

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This paper concerns the identification of buried highly conducting objects based on their low frequency electromagnetic scattering signatures. In particular, as demonstrated by Baum (Low-Frequency Near .. etc. Interaction Note 499), a finitely conducting buried object excited by a steady magnetic field will, when the excitory field is removed, exhibit a response characterized by a sum of damped exponentials in time, $\sum a_n \exp(-\sigma_n t)$, where a_n and σ_n are real constants (i.e. system poles reside on the negative real axis). Distinct damping coefficients for distinct objects forms the basis for identification.

Once a set of damping constants for each object in the "target library" has been determined, either by measurement or analytical means, the next step is to apply standard hypothesis testing techniques (Detection, Estimation, and Modulation Theory - Part I Van Trees) to decide which object in the "target library" is responsible for a particular measured signature. Results are presented as percent correct identification versus signal-to-noise ratio.

The experimental setup consists of an n-turn "primary" loop driven with a steady current in the presence of a finitely conducting object (target) which, to first order, can be viewed as a magnetically coupled "secondary" loop with a resistive load. When the primary loop is decoupled from the source and switched to the large input impedance of an oscilloscope, the response is, for all practical purposes, controlled by the secondary loop since its time constant is only a small fraction of that of the primary. Experimental data collected for various objects will be presented and constitutes the library of known target signatures.

GEM-2: A NEW MULTI-FREQUENCY ELECTROMAGNETIC SENSOR FOR DETECTING BURIED UNEXPLODED ORDNANCE

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A new broadband electromagnetic sensor, GEM-2, has been tested at several environmental sites for detecting buried, unexploded ordnance (UXO) and other man-made objects. A hand-held, digital, multi-frequency sensor based on an earlier, similar helicopter-towed sensor, GEM-2 operates in a frequency range of 300 Hz to 18 kHz, and can transmit an arbitrary waveform containing multiple frequencies. The unit is capable of transmitting and receiving any digitally-synthesized waveform by means of the pulse-width modulation technique. Owing to the arbitrary nature of its broadcast waveform and high-speed digitization, the sensor can operate either in a frequency-domain or in a time-domain mode.

Depth of exploration for a given earth medium is determined by the operating frequency. Therefore, measuring the earth response at multiple frequencies is equivalent to measuring the earth response from multiple depths. Hence, such data can be used to image a 3-D distribution of subsurface objects. Results from several UXO sites indicate that the multifrequency data from GEM-2 is far superior in characterizing buried targets to data from conventional single-frequency EM sensors.

Of the many geophysical sensors, the EM method provides significant advantages for UXO characterization. Unlike seismic or ground-penetrating radar methods that involve heavy logistics and labor-intensive field work, GEM-2 requires only a single operator, does not touch the earth (thus, is less intrusive), and can operate at stand-off distance. Compared with typical dipolar magnetic anomaly resulting from a buried target, EM anomalies are commonly monopolar and, thus, easier to interpret. GEM-2 is an ideal instrument for many environmental and geotechnical applications including mapping underground storage tanks, landfill and trench boundaries, certain contaminant plumes, and buried ordnance.

Despite many compelling advantages, the broadband EM method has not received sufficient attention from the geophysical community. With the advent of digital, multifrequency data, we have opened a new dimension in data quality and quantity for imaging and characterizing buried subsurface features. GEM-2 is only the beginning of a new generation of many broadband EM sensors.

REAL TIME MICROWAVE TOMOGRAPHIC INSPECTION TOOL FOR THE DETECTION OF BURIED OBJECTS : ASSESSMENT CAMPAIGN

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ABSTRACT

The French company SATIMO has developed an Imaging Radar equipment for the French National Poli (CREL DGPN) devoted to the detection of buried objects. This Radar so called « Microwave Tomograph Inspection Tool » (MTIT) offers quasi-real time capabilities for analysing ground profile of one met depth by one meter large [1]. In comparison with all existing GPR equipments, the MTIT is composed an array of sensors with an adequate ground discriminator data processing needed for preparing proper data on which Tomographic Algorithm is applied. Microwave Tomographic Algorithm [2,3] has bee already assessed on a previous equipment designed by SUPELEC and realized by SATIMO for th detection of metallic bars in concrete structures [4]. This paper presents the MTIT equipment operating a large frequency range and shows results obtained on an operational outside site. It will be shown ho the MTIT equipment is robust to low and high frequency disturbing movements.

RADIO WAVE HOLOGRAPHIC IMAGING OF BURIED PROJECTILES AND LAND MINES

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Imaging buried ordnance and mines can accelerate clearance by providing identification. This paper describes an imaging method and tests on two buried objects. One object was a metallic, projectile, length 27", at depth 46". The other object was a 2" diameter simulated plastic mine, depth 2". The method was radio wave holography; apparatus for the two objects differed.

The procedure was to radiate and receive radio waves with antennas near the ground. (O-C. Yue, et al. IEEE Trans. on Computers, Vol. C-24, 1975, p. 381). Measured complex-valued reflectance was Fourier transformed, backward propagated, and then inverted to form plan view images of the projectile and of the mine.

For the projectile, the apparatus was a seven antenna array, towed by a vehicle, to synthesize a data swath. Wave polarization was orthogonal to the travel direction. Frequencies were discrete, in the range 200 to 500 MHz. Measurements were made in 1994 and 1995. Polarization and travel direction relative to the projectile differed in the two tests. Images were generated for both cases; they show object shape and give depth. Images depended on several factors including polarization, soil dielectric constant, and travel direction relative to the projectile.

For the simulated mine, measurements were made with a single antenna that was manually positioned. Measurements were made at 76 distinct frequencies in the range 8 GHz to 11.8 GHz. The paper presents images for single frequencies and for images formed by summing images formed at 76 frequencies.

Measures of Performance for UXO Detection Systems and Implications for UXO Cleanup: The Jefferson Proving Ground Story

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There is great debate regarding the efficacy of currently fielded unexploded ordnance (UXO) detection, identification, and remediation systems. There is a similarly fierce debate regarding the most appropriate methods for evaluating the performance of these systems. In this paper, we define the measures of performance used to evaluate the demonstrated systems at JPG. We discuss the importance of each parameter in determining the utility of systems for actual UXO cleanup and further discuss the implications of the capability demonstrated at the 1994 UXO Detection, Identification and Remediation Advanced Technology Demonstration, Jefferson Proving Ground, Indiana. We focus predominantly on the ground-based detection and identification systems demonstrated at JPG.

The efficacy of UXO cleanup is driven largely by detection capability. In this regard, a high probability of detection is desirable. Decades of experience with sensors used for the detection and identification of a myriad of items have shown that it is possible to increase the probability of detection simply by lowering the threshold of the system. This, however, also increases the false alarm rate. Therefore, it is important to consider both detection capability and the corresponding false alarm rate. In another paper (see *Performance of UXO Detection Systems in the 1994 and 1995 Jefferson Proving Ground Demonstrations*), we discuss the use of a receiver operating characteristic (ROC) curve based on gaussian noise to compare systems with widely different probabilities of detection and false alarm rates. Such a ROC curve illustrates diminishing returns. In this paper, we use a trade-off curve, analogous to the ROC curve, that shows how increased probability of ordnance recovery is related to the percentage of the site dug up.

To determine the relative importance of location accuracy on remediation, we compare the minimum surface area that must be disturbed to recover all emplaced ordnance items against the surface area that must be disturbed when both the location inaccuracy and the false alarms are considered. Demonstrators with above average distance accuracy typically disturb 5 times the minimum amount of surface area required; most demonstrators disturb between 10 and 100 times the minimum surface area required. Nevertheless, we show that at JPG, the effect of false alarms is an order of magnitude more detrimental than location inaccuracies.

The importance of discrimination and classification is illustrated using an example impact area; we show that the detection of ordnance-related items and debris are likely to dominate the remediation resources. Clearly, further increases in detection capability without concomitant increases in discrimination capability would increase the fraction of both hazardous and non-hazardous items detected. The ability to distinguish between potentially hazardous ordnance items and other non-hazardous items would reduce both the cost and the time required for remediation efforts. The classification capability demonstrated at JPG indicates that it is not currently possible to distinguish ordnance from nonordnance and ordnance debris, much less specific ordnance items from one another. Most demonstrators at JPG showed no appreciable ability to provide even coarse classification sufficient to guide remediation equipment choices, i.e, shovel or backhoe.

The prevalence of contaminated land in the United States and abroad requires that UXO detection surveys be conducted as rapidly as possible. One would expect some tradeoff between the speed of survey and the reliability of the survey. The demonstrators with the fastest survey rate were those that searched the entire site in the allotted 40-hour time period. We might expect some of the demonstrators with slower survey rates, i.e., those that did not search the entire site, to have higher detection capabilities than those that searched the entire site. This is not the case. The demonstrators with the highest survey rate are also those with the highest probability of detection.

In this paper, we show that careful choice and interpretation of the performance parameters used to assess system capabilities is important to understanding the state of the art in UXO detection technology and hence to designing appropriate policy strategies.

This paper is excerpted from IDA Paper P-3114, which has been approved for public release, distribution unlimited.

day, May 31, 10:40 AM **Room: Aztec**

EM-26 **Simulators: General**

Chair: *G. Sower, EG&G, Albuquerque, NM*

0:40 AM **THE "IMPULSE-6" SIMULATOR FOR CREATION OF PULSED CURRENTS IN SHIELDED OBJECTS**, *A.V. ANISIMOV, O.A. ZAJACHKOVSKI and Y.V. PARFENOV, Russian Federation Ministry of Defense, Moscow, Russia; and V.A. ADAKIN and V.A. TANANAKIN, Federal Nuclear Center of Russia* 364

1:00 AM **HPD PULSER UPGRADE TO MEET DOD-STD-2169B**, *S.J. FRAZIER, Naval Air Warfare Center, Patuxent River, MD; JIM HERBERT, R&B Enterprises, West Conshohocken, PA; K.R. RUNYAN, United International Engineering Inc., Alexandria, VA; and L. KITSEMBEL and Y.G. CHEN, Maxwell Laboratories Inc., San Diego, CA* 365

1:20 AM **CHARACTERIZATION OF THE PORTABLE ELLIPTICUS ANTENNA SIMULATION MODIFIED TO ALLOW DIRECTIONAL ILLUMINATION**, *E. DRESSEL, M. ROGERS, G. SALO, W. KUCHAR, M. JARAMILLO and M. BORKY, BDM Federal, Albuquerque, NM; K. CALAHAN, Los Alamos National Laboratories; T. DANA and A. VILLALOBOS, EG&G, Albuquerque, NM; and W. PRATHER, Phillips Laboratory, Kirtland AFB, NM* 366

11:40 AM **ELECTROSTATIC DISCHARGE (ESD) CODE/DATA COMPARISONS USING SPARKGUN**, *M.A. MESSIER and W.A. RADASKY, Metatech Corporation, Goleta, CA* 367

12:00 AM **DESIGN AND DEVELOPMENT OF THE GERMAN HYBRID NEMP SIMULATOR**, *H. SCHILLING, Wehrwissenschizftliches Institut fur Schuztechnologie ABC-Schutz (WIS), Munster, Germany; and K. NIELSEN, Physics International Company, San Leandro, CA* 368

THE "IMPULSE-6" SIMULATOR FOR CREATION OF PULSED CURRENTS IN SHIELDED OBJECTS

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Defense Ministry of Russian Federation

V.A. Adakin, V.A. Tananakin
Federal Nuclear Center of Russia

The "IMPULSE-6" simulator is intended for pulsed current generation in shielded objects under conditions of simultaneous action of radiation. The construction of the simulator is based on the following principles:

- compatibility of various simulating installations, included in a structure of the simulator;
- uniform element base of electrotechnical devices;
- unified circuits and devices of low-voltage and high-voltage synchronization;
- modular construction;
- transportability;
- high stability of parameters.

Two installations are now created and put into operation: "IMPULSE-6-2" and "IMPULSE-6-5".

The "IMPULSE-6-2" installation permits to create in object a pulsed current with amplitude of 15 kA, rise time of 15 ns and full width at half-maximum of 1000 ns. The so-called "distributed" pulsed voltage generator is used in this installation. The design of the generator and current form system permits to change over a wide range parameters of a current, to receive non-uniform distribution of a current in the body of object and also enable to create in object a sequence of pulses with an interval less than 1000 ns.

In "IMPULSE-6-5" installation a modular principle of construction is also used. The system from seven X-ray diodes provides creation of a wide beam of X-ray or synchronous irradiation of several units of the equipment. The irradiated area is 200 cm^2 with peak doze rate not less than 10^9 rad /s (Si). After modernization the level of irradiation will be increased up to 10^{10} rad /s (Si).

The synchronization of work of installations "IMPULSE-6-2" and "IMPULSE-6-5" is provided with accuracy not less then 2 ns.

HPD PULSER UPGRADE TO MEET DOD-STD-2169B

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Abstract

A 5 megavolts HPD pulse generator was developed and delivered to U.S. Navy's Naval Air Warfare Center Aircraft Division in Patuxent River, MD in 1985. The pulser has been in operation for more than 10 years. Detail description of this pulser was published in the 5th IEEE International Pulsed Power Conference. The key element of this pulser is a multi-megavolts, high pressure SF6 dielectric filled spark gap switch. For mechanical safety consideration, the SF6 pressure was limited to 100 psig. A gap of more than 10 centimeter was needed to deliver 5 megavolts output. A 10-90 rise time of 7.6 nanoseconds was achieved.

Since the early 1980's, the electromagnetic pulse requirements for weapon systems has been updated to a faster risetime. The Navy has funded an improvement program to reduce the risetime of the electromagnetic pulse environment to less than 4 nanoseconds while retaining the energy in the present environment. This improvement will provide a Major Range and Test Facility Base test and evaluation capability accessible to all services for testing both fighter and large strategic aircraft to the latest DOD-STD-2169B requirements.

Risetime Requirements for drastic reduction in risetime to less than 4 nanoseconds. One of the scheme to improve risetime of a high voltage pulser is to replace the SF6 dielectric with transformer oil. The dielectric strength of transformer oil has been demonstrated to exceed 1 MV/cm in the time domain of effective time less than 100 nanosecond. Thus, an oil gap of around 4 centimeter is expected to reduce the risetime to less than 4 nanoseconds. The hydraulically controlled variable gap oil switch has been designed and manufactured. The field test is scheduled in the mid of March 1996. Detail design of this switch and test results will be presented.

Althouth the risetime has been quickened, the pulser output waveform peak and falltime remain unchanged. These parameters exceed the requirements of DODSTD-2169B. The New design will allow a certain degree of variable risetime and variable amplitude. However, extensive field mapping will be required to fully characterize system performance.

CHARACTERIZATION OF THE PORTABLE ELLIPTICUS ANTENNA SIMULATOR MODIFIED TO ALLOW DIRECTIONAL ILLUMINATION

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The portable Ellipticus antenna is a low level continuous wave (CW) simulator that generates relatively uniform electromagnetic (EM) fields over a large working volume, yet is portable enough to be deployed at remote sites. Ferrite bead loading at 0.5 m intervals along the 87 m antenna structure allows Ellipticus to radiate fields within the test volume that simulate far field illumination with a wave impedance of nearly 377 ohms over a very wide frequency range. Recent modifications extend the utility of Ellipticus by allowing it to illuminate test objects from three distinct angles of incidence (23° and 41° in addition to overhead illumination at 90°) by simply relocating the radiating balun feed to any of three specific, well supported positions on the elliptical radiating structure.

A NEC-4 model of the portable Ellipticus simulator was developed to predict the field distributions generated by the new illumination angles so that the uniformity and coupling characteristics of the fields could be evaluated. Predictions of the model complement test data because characterization of the fields in the entire test volume is too labor and data intensive to be accomplished entirely by test. Sample contour plots of field components at selected frequencies at each of the three angles of incidence will be presented to illustrate the EM footprint of the simulator across the test volume. Also, 3D isosurfaces of the dominant electric field component at selected frequencies for each of the three angles of incidence near the center of the test volume will be presented to visualize the planarity (or lack of planarity) of the fields within the test volume.

The numerical model was also used to provide pre-test predictions to support a field mapping test. Swept CW field mapping measurements over a frequency range of 0.3 - 1000 MHz were made at numerous field point locations both on and off symmetry axes at all three angles of incidence. Brief descriptions of the test instrumentation, the signal paths, and the matrix of data taken, and representative comparisons of numerical model predictions to field mapping measurements will be presented.

In summary, the portable Ellipticus antenna in its new configuration is an enhanced test capability that provides broad band, quasi-plane wave, CW illumination over large test volumes at remote sites from multiple angles of incidence. The field distributions have been successfully modeled for each of the illumination angles to provide a good understanding of the illumination characteristics of the antenna. Numerical results have been validated against measurements taken under actual field test conditions.

ELECTROSTATIC DISCHARGE (ESD) CODE/DATA COMPARISONS USING SPARKGUN

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During the EUROEM Conference in 1994 a paper (Messier, 1994) was presented which described a detailed method to compute the air breakdown process involved in a typical electrostatic discharge (ESD) event. This method resulted in a 2-D computer code SPARK2D which employs a full EM solution simultaneously with a detailed water-vapor-dependent air chemistry model in a finite difference solution.

In this paper the authors have analyzed a recent problem of interest for which measurements have been made (Pommerenke, et al, EOS/ESD Symposium, 1994 and 1995). In particular, time-domain E and H measurements were made as a function of distance from ESD arcs initiated from different ESD hand-held simulators (IEC 801-2, 1000-4-2). The understanding of these measurements is important as these high-frequency (100 - 1000 MHz) fields can couple well through equipment container apertures, potentially producing unfavorable system responses.

For our calculations, the SPARK2D code has been modified to include the important features of the ESD hand-held simulators; this code has been named SPARKGUN. The code has been designed to allow analyses for both the contact and air gap modes of simulation. The calculations performed were done in a parametric fashion examining factors including:

1) charging voltage of the simulator,
2) rate-of-rise of the arc current,
3) background ionization due to cosmic rays,
4) water vapor in the air.

The results obtained indicate that the calculated EM fields peak at levels exceeding 10 kV/m at a range of 10 cm which is consistent with the measured data. The r^{-1} behavior of the peak fields is also confirmed. Some details concerning pulse shape agreements do not agree as well and will be discussed in the presentation.

DESIGN AND DEVELOPMENT OF THE GERMAN HYBRID NEMP SIMULATOR

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Abstract

A bounded wave NEMP simulator called DIESES was developed and built at WIS, Munster, Germany during the late 1970s. This simulator used a 1 MV, 10 ns rise pulser, which has been upgraded by eliminating the use of freon-12 and resulting in a 970 kV, 7 ns pulse generator. In addition a 500 kV, 1 ns rise, pulse generator was also built to drive the same simulator. This simulator provides a vertically polarized, horizontally propagating electromagnetic transient wave for NEMP testing.

After a detailed study of the results of NEMP testing of the same test object with horizontal and vertical polarization, it was determined that a horizontally polarized simulator would enhance the German NEMP test capabilities. We decided to develope and build a horizontally polarized hybrid type of NEMP simulator, albeit at a sub-threat level and with a fast risetime capability.

The underlying test philosophy is to conduct the NEMP tests of military and certain civilian assets at full threat level in the vertically polarized bounded wave simulator (DIESES). This test will then be followed by a sub-threat level, fast risetime electromagnetic pulse in the hybrid simulator. The hybrid simulator will provide the transfer functions from the exterior fields to currents and voltages at selected test points in the interior volume of the test object. Suitable extrapolations will then complete the testing and result in the vulnerability assessment. The only missing feature will be the non-linear effects , under horizontal polarization excitation.

With the above test philosophy in mind, the hybrid simulator under development has the following characteristics. The simulated electric field will have a time-domain peak of > 10 kV/m, and a test volume size of 10m x 10m x 4m (high). The pulse generator will be at a height of 8 m from the ground and the elliptical antenna will have a major axis of 30m and semi-minor axis of 8 m. The pulser waveform into a dummy load will be a double exponential with a peak amplitude of about 300 kV and a 10-90% risetime of about 2 ns. The exponential decay time into a dummy load of 150 Ohms shall be about 150 ns. The pulse generator will be in a biconical configuration of 150 Ohms. The pulser has been built and tested. The antenna is under development and the simulated environment will be reported in a future paper.

iday, May 31, 1:30 PM **Room: Galisteo**

PEM-27 System Testing

CoChairs: G.K. Deb, Electronics Research & Development Centre of India, Calcutta, India
R.L. Hutchins, BDM Federal, Albuquerque, NM

1:30 PM **INTRODUCTION & ANNOUNCEMENTS**

1:35 PM **THE EVALUATION OF HIGH POWER RF (HPRF) EFFECTS ON AIRCRAFT ELECTRONICS SYSTEMS USING THE SYSTEM INTEGRATION LABORATORY (SIL)**, *H. Del AGUILA, Phillips Laboratory, Kirtland AFB, NM; R. HUTCHINS, BDM Federal, Albuquerque, NM; D. McLEMORE and G. DeMUTH, Kaman Sciences Corporation, Albuquerque, NM; and W. FEAR, Fiore Industries Inc., Kirtland AFB, NM.* 370

1:55 PM **WIDEBAND MICROWAVE CROSS SECTIONS**, *A. NAMENSON, T. ANDREADIS, J. KIDD, W. QUADE and T. WIETING, Naval Research Laboratory, Washington, D.C.; and C. AVALLE and R. ZACHARIAS, Lawrence Livermore National Laboratory, Livermore, CA* 371

2:15 PM **E3 QUALIFICATION OF THE V-22 OSPREY TILT ROTOR AIRCRAFT**, *M.P. SQUIRES and S.J. FRAZIER, Naval Air Warfare Center, Patuxent River, MD* 372

2:35 PM **E-6A STRATEGIC AIRCRAFT PRECIPITATION STATIC ASSESSMENTS**, *J.D. HAINES, M.R. CLELLAND and M. WHITAKER, Naval Air Warfare Center, Patuxent River, MD; and W. DePASQUALE and B.S. LUBOSCH, Dual Incorporated, Lexington Park, MD* 373

2:55 PM **QUALIFICATION TEST OF THE U.S. AIR FORCE C-17 AIRCRAFT**, *S.J. FRAZIER, M.P. SQUIRES and M. WHITAKER, Navy Air Warfare Center, Patuxent River, MD; and J. WELCH, Wright Patterson AFB, Dayton, OH* 374

3:15 PM **BREAK**

3:40 PM **COUPLING OF EM FIELDS INTO IMPLANTED CARDIAC PACEMAKERS IN THE FREQUENCY RANGE 50 TO 1000 MHZ**, *B. ROMER, German Amed Forces Scientific Institute for Protection Technologies - NBC-Protection, Munster, Germany* 375

4:00 PM **ANALYSIS OF E&H FIELD EMI SITUATION NEAR A DIPOLE ANTENNA OF CELLULAR RADIO**, *G.K. DEB, Electronics Research & Development Centre of India, Bidhannagar, Calcutta* 376

THE EVALUATION OF HIGH POWER RF (HPRF) EFFECTS ON AIRCRAFT ELECTRONICS SYSTEMS USING THE SYSTEM INTEGRATION LABORATORY (SIL

Hector Del Aguila*
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The Phillips Laboratory developed the SIL to investigate HPRF effects on aircraft electronics. consists of an interconnected and operating set of electronics subsystems in a laboratory vers an operational aircraft test bed. HPRF environments are impressed on one or more of t subsystems, and the response of the whole electronics system is monitored. A set interconnected subsystems is required since local subsystem tests do not indicate the importa system level responses. The test bed is based on F-16 electronics hardware. However because some common electronics subsystem and architecture features, results are indicative of F-15, 117, B-52, B-1 and B-2 responses. At the present time, these electronics subsystems a configured on a laboratory bench called the Hot Bench Mock-Up (HBMU). To provi increased realism, we will move the electronics subsystems to an F-16 forward fuselage sectio This fuselage based test bed is called the SIL. The HBMU employs direct injection type HPI tests while the fuselage based SIL will support both direct injection and free field illuminati type tests. The HMBU or SIL provide several advantages over an operational aircraft test b including configuration flexibility and physical access. In addition, one obtains considerab lower hardware costs and increased test efficiency. The potential weakness of this laborato test bed is its response fidelity when compared to an operational aircraft. Nonethele comparisons of available laboratory and aircraft based HPRF test data show similar responses

This paper will provide an overview of the SIL test bed including: the HBMU and the fusela based configurations, the electronics subsystems used with their associated architecture, th power, air conditioning and safety support systems, the HPRF sources and test fixtures, th HPRF diagnostics, and the functional diagnostics which are based standard messag exchanged on the MIL STD 1553 data bus connecting the various electronics subsystems. I addition, we will present some of our "lessons learned" on using this type of test methodolog

Wideband Microwave Cross Sections

Arthur Namenson*, Tim Andreadis, John Kidd, Wayne Quade and Terence Wieting
Naval Research Laboratory, Washington, DC

and

Carlos Avalle and Richard Zacharias
Lawrence Livermore National Laboratory, Livermore, CA

Wideband microwave cross sections for random points inside a missile were measured for frequencies between 0.5 and 1.5 GHz. The distribution of cross sections in space and in frequency was almost always consistent with a lognormal distribution and in no case consistent with a chi-squared distribution with two degrees of freedom. The full paper will present these results and briefly speculate on any theory behind this effect.

The missile was placed in an anechoic chamber and irradiated with pulses of about 1ns width from a Bournlea pulser. An SCD-5000 digitizing oscilloscope recorded voltages at 11 random points within the missile and at a D-dot sensor used to determine the intensity impinging on the missile. Fast Fourier transforms were used to determine Fourier components of the 11 voltages as well as the normalizing Fourier components for the incident field. The estimated measurement error is negligible compared to the fluctuations in cross section.

Probability plots were used to show that the cross sections as a function of either position or frequency are generally consistent with a lognormal distribution and inconsistent with a chi-squared distribution with two degrees of freedom. A typical plot is shown in Figure 1.

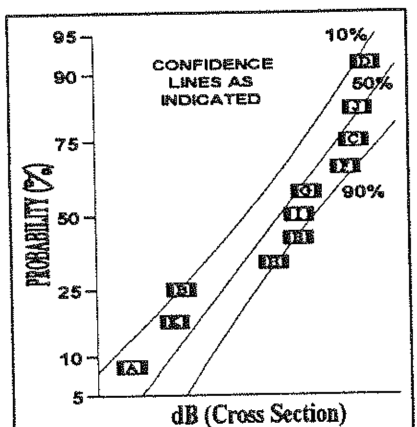

Figure 1 *Decibels of Cross Section at 11 random locations in missile.*

Because of the low power levels used in the measurement, we surmise that the wideband cross sections should be similar to narrowband cross sections. However, in particular cases, non-linearities in the system may cause some discrepancies. Interestingly, these discrepancies do not change the lognormal form of the distribution.

E[3] QUALIFICATION OF THE V-22 OSPREY TILT ROTOR AIRCRAFT

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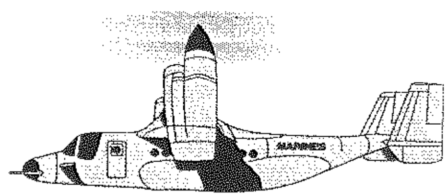
Abstract

The V-22 Osprey is one of the most radical aerodynamic systems to be deployed in the last 40 years. The V-22 is a tilt rotor vertical/short takeoff and landing aircraft who's design is mostly composite material. The specific V-22 being qualified is a general utility transport. A special operations system is in development. There are many different derivatives being considered for this aircraft including Electronic and Antisubmarine Warfare, and Executive transport.

Every flight critical system has met the requirements of MILSTD-462C. The objective of the qualification is to determine satisfactory V-22 system's integration and compatibility as well as compatibility with various shipboard and land base emitters and systems. The qualification period also provides the program manager with an opportunity to characterize the V-22's performance and limitations in various electromagnetic environments and scenarios.



Briefing of the major tests and facilities used to qualify the V-22 EMD aircraft for operational use. Topics include the overall objectives and schedule as well as specific tests such as Intersystem and Intrasystem EMC, EMP, Lightning, electrostatics and TEMPEST.

Intrasystem EMC - Verification and characterization of the source - -victim matrix of subsystems .

Intersystem (HIRF) - Illumination of the aircraft using the emitter characteristics expected within the V-22's operational environment.

Emission Control (EMCON) - Verifying minimum V-22 EM emission detectability thresholds, at a specified distance.

Lightning - Indirect effects using the waveforms specified in MIL-STD-1795, with a coaxial return around the aircraft, and inductively coupled Direct Drive.

EMP - Horizontally and vertically polarized threat level environments and Inductively coupled Direct drive.

Precipitation Static - Exterior spraying of the surface, identification of victimized systems and measurement and quantification of system degradation.

E-6A STRATEGIC AIRCRAFT PRECIPITATION STATIC ASSESSMENTS

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Abstract

Electromagnetic Environmental Effects (E^3) is a serious concern in today's Navy. As part of the E^3 life-cycle effort, the Hardness Maintenance/Hardness Surveillance (HM/HS) program was implemented to ensure that the level of electromagnetic pulse (EMP) hardening be maintained throughout the life of the E-6A aircraft,. HM is a set of comprehensive procedures to ensure that Fleet operations, logistic support, and/or maintenance do not degrade the designed EMP hardness. HS includes system level and field surveillance tests and inspections performed throughout the aircraft life-cycle to monitor hardness integrity. As part of the HM/HS plan, Precipitation Static (P-Static) assessments of the Take Charge and Move Out (TACAMO) Fleet aircraft are being conducted. These assessments are used to monitor aircraft bonding integrity and maintenance procedures throughout the aircraft life-cycle. To minimize the problems associated with E^3, aircraft bonding integrity must be maintained.

A P-Static assessment is a quick-look method for finding bonding inconsistencies on the skin of the aircraft. Working hand in hand with the Fleet, problem areas can be identified and maintenance actions initiated to correct them. In the future, the P-Static assessments will be incorporated into the Enhanced Phase Maintenance (EPM) procedures.

The P-Static assessments consist of power off testing along with dc bonding measurements of the static discharging system. The Fleet receives a brief report describing problems found during the assessment with recommended fixes. A database will be developed to document all problem areas and note any similarities between aircraft.

QUALIFICATION TEST OF THE U. S. AIR FORCE C-17 AIRCRAFT

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Abstract

The Naval Air Warfare Center Aircraft Division (NAWCAD), Patuxent River, MD is U. S. Department of Defense Major Range and Test Facility Base and E^3 Center of Excellence. The NAWCAD Electromagnetic Transients Branch was tasked to conduct a indirect effects lightning evaluation of the USAF C-17A aircraft. The test demonstrated the flight worthiness and equipment performance of the C-17A in a lightning environment and concentrated on the C-17A's Flight Critical Equipment and Mission Essential Equipment. Testing consisted of two phases: 1) a passive systems phase to produce and measure equipment cable stress responses by injecting up to 50 kiloamperes on to the airframe, and 2) an active systems phase using bulk current injection techniques while the aircraft systems were powered to determine equipment performance during a lightning strike.

The verbal and video presentation includes discussions of the overall lightning test program. Details are provided on the test approach used on the largest aircraft ever to undergo extensive indirect effects lightning testing. Technical issues such as test setup, simulation equipment, and the data acquisition system will be presented. The technique used to isolate the aircraft from ground will be presented. Also design and construction of a coaxial return test fixture will be discussed. Presentation will also give details of the Direct Drive system, instrumentation, and analysis techniques.

The C-17A indirect effects lightning test program was conducted without mishap. Some aircraft susceptibilities were identified and corrected. A Safety of Flight assessment was made as a result of the successful test program conducted at Patuxent River. The C-17A now operates with no flight restrictions imposed due to atomspheric hazards.

COUPLING OF EM FIELDS INTO IMPLANTED CARDIAC PACEMAKERS IN THE FREQUENCY RANGE 50 TO 1000 MHz

Berthold Römer
German Armed Forces Scientific Institute for Protection Technologies - NBC-Protection

Abstract:
There exists a lack of information for coupling of EM fields into implanted cardiac pacemakers (CPM) in the high frequency range, especially above 50 MHz. This paper presents new methods to determine the transfer-functions of EM-fields into CPM for frequencies above 50 MHz. It is possible to determine the safety distances of implanted CPM, if the EM environment and the sensitivity levels of CPM are known. The sensivity levels are different for pulse, cw and modulated cw signals.
The complex problem will be solved by a combination of the known results, of experimental measurements and numerical calculations and of a rough theoretical estimate.

The following experiments were made by using a network analyser:

- Determination of the natural resonances on an original CPM-electrode

  a) in air
  b) in a medium which simulates the EM properties of muscels

- Determination of transferfunctions by means of a human phantom

  a) determination of the path EM field from transmitter to surface of the chest (network analyser and 'Specific Absorption Rate' measurement)
  b) determination of the path EM field from the surface to the CPM electrode
  c) determination of the short currents and open voltages on a CPM-model for the same transmitter configuration

- Determination of the transferfunctions by means of a simplified human phantom (box)

The following numerical calculations were made by using a MoM - code (CONCEPT II):

- Determination of the the transferfunctions by means of a simplified human phantom (box)

The analysis shows that the new transferfunctions in the frequency range 50 MHz to 1000 MHz are

$$T (Upp / Eg) / dB = 20 * LOG [24.1 / (50 + 2 f + f^2 / 50]$$

$$T (Upp / Hg) / dB = 20 * LOG [9091 / (50 + 2 f + f^2 / 50]$$

Upp := peak to peak voltage in V from the CPM-electrode to the CPM-entrance
Eg := averaged electrical fieldstrength in V/m in the absence of the patient
Hg := averaged magnetical fieldstrength in A/m in the absence of the patient
f := frequency in MHz

The simple theoretical estimate shows that the following effects determine the EM coupling:

- The skin dephts of the phantom
- The frequency dependent impedance of the CPM-electrode
- The effective electrical length of the CPM-electrode

A comparison of these effects shows that the reduction of the electrical length of the CPM-electrode is the most important effect in this frequency range.

ANALYSIS OF E & H FIELD EMI SITUATION NEAR A DIPLOE ANTENNA OF CELLULAR RADIO

BY

BRIG.DR.G.K.DEB

DIRECTOR, ELECTRONICS RESEARCH & DEVELOPMENT CENTRE OF INDIA (ER&DCI),
DEPARTMENT OF ELECTRONICS, GOVT. OF INDIA,
WEBEL BHAVAN, BLOCK EP&GP, SECTOR V, BIDHANNAGAR, CALCUTTA - 700 091.

ABSTRACT

The paper discusses potential source of Radio Frequency Interference in electronic devices like the implanted heart pacemakers and earphones due to antenna radiated EM phenomena of a cellular radio used by a greater section of population these days. It is well known that the interference phenomena in the close vicinity of Radio frequency cellular transmitter sources are mainly due to the voltage induced in an electronic circuit by electric and magnetic energy emanated from these sources. In fact, the crowded PC boards with complicated metallisation patterns almost cancel the voltage effects generated by E-fields of the antenna in its nearfield. However, the interest lies in the magnetic field effects which are responsible for most of the interference situations from resonant dipole antenna as seen by EM field analysis. The paper deals also with the analysis of the deleterious effects of interference phenomena induced by H fields linked with electronic circuits in close vicinity to dipole antenna. A simulated pace maker test indicates that EM fields interact with devices differently when the electronic device, viz, pacemakers are in different positions.

Mathematical Formulation:

In this paper, first of all the mathematical flux density of sinusoidal current source from an arbitrary half wavelength antenna has been analytically expressed. If we are interested in the worst case of a possible interference due to the incident magnetic field, it has seen from the analytical expression that strongest field effects will be located at the centre of the antenna. In fact then the expression of the magnetic field becomes simpler.

Experimental Setup:

Secondly, the paper deals with an experimental set up which includes an artificial human chest made of plastic container filled with radio 0.9% (in weight) saline solution. The near E&H fields from the cellular radio inside the artificial chest are measured by emplcying the relevant instrumentation. The pacemakers are used in this programme and they are expected to be positioned near antennas hanging over the saline bath. It could be observed that interference of relevance is measured only with the cellular digital radios. Most of the results both analytical and experimental radios are shown in graphical forms.

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day, May 31, 1:30 PM Room: Cimarron

EM-28 **Shielding Test Methods**

CoChairs: J.I. Lubell, Mission Research Corporation, Colorado Springs, CO
C.D. Lin, Phillips Laboratory, Kirtland AFB, NM

:30 PM **INTRODUCTION & ANNOUNCEMENTS**

:35 PM **ELECTROMAGNETIC EVALUATION OF PHILLIPS LABORATORY'S REVERBERATION CHAMBER**, *E. JOHNSON, H. Del AGUILA, and C. YOUNGER, Phillips Laboratory, Kirtland AFB, NM* 378

:55 PM **MEASUREMENT OF TRANSMISSION CROSS SECTION OF APERTURES BY USE OF NESTED MODE-STIRRED CHAMBERS**, *M. BACKSTROM and O. LUNDEN, National Defence Research Establishment, Linköping, Sweden* 379

:15 PM **MEASURED DIRECTION DEPENDENCE OF MICROWAVE COUPLING INTO SHIELDED STRUCTURES**, *L. JANSSON, J. LOREN and M. BACKSTROM, National Defence Research Establishment, Linköping, Sweden; and P.G. LANDGREN, Bofors Missiles, Karlskoga, Sweden* 380

2:35 PM **ON THE IMPOSSIBILITY OF DETERMINING SHIELDING PROPERTIES OF THICK CONDUCTIVE SAMPLES USING COAXIAL TEM CELLS**, *M. BADIC and M-J MARINESCU, Research Institute for Electrical Engineering, Bucharest, Romania* 381

2:55 PM **ANOTHER METHOD TO ESTIMATE THE EFFECTIVENESS OF A SHIELD**, *P.G. LANDGREN, Bofors Missiles, Karlskoga, Sweden* 382

3:15 PM **BREAK**

3:40 PM **COMPARATIVE EMP TESTING OF A MOBILE COMMUNICATIONS SHELTER AT TWO EMP TEST LABORATORIES**, *T. THEILER, T. DIKVALL, and K.G. LOVSTRAND, Defence Material Administration, Linköping, Sweden; and A. WORSHEVSKY and V. KOPRIENKO, Elecom Ltd., St. Petersburg, Russia* 383

ELECTROMAGNETIC EVALUATION OF PHILLIPS LABORATORY'S REVERBERATION CHAMBER

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USAF Phillips Laboratory, 3550 Aberdeen SE. Kirtland AFB, NM 87117
(505) 846-4608

Electromagnetic (EM) immunity testing of electronic systems and subsystems has traditionally been done inside anechoic chambers. Free field testing inside an anechoic chamber is a widely accepted method that lends itself easily to analysis, but is relatively slow and expensive compared to electromagnetic excitation in an electronic mode stir chamber (EMSC). In the EMSC technique developed by the Phillips Laboratory, a narrow-band white Gaussian noise (NDWGN) signal is injected into a reverberation chamber to create statistical field uniformity in the chamber and to eliminate the need to illuminate the test object at a variety of aspect angles. This capability has recently been incorporated into PL's testing resources. To add this capability, PL has converted an exiting screen room into a reverberation chamber.

The modifications made to convert the screen room into a reverberation chamber were to seal the apertures inside the screen room to insure a more uniform configuration, removing light fixtures and conduits, emergency lights, and capped feed throughs in access panels. Highly reflective fabric and conductive sealants were used to seal apertures and seems inside the chamber. Measurement of the EM performance of this chamber were then performed using the EMSC technique.

The optimal performance of a reverberation chamber depends upon the chamber's Quality factor (Q) and the EM field uniformity. These measurements were performed both before and after the chamber modifications to determine the improvements. Q measurements were carried out using the cavity relaxation time method. It was found that the modifications resulted in a 60% improvement in chamber Q, and field uniformity of better than 3 dB was achieved throughout the chamber at several noise bandwidths.

Field uniformity predictions were performed for each of five chosen noise bandwidths. The predictions were found by taking the number of independent modes (NQ) excited within the chamber for that particular noise bandwidth and putting this number in to a Monte Carlo simulation to find the resulting predicted standard deviation from which the field uniformity was calculated. The worst case difference in power densities were taken between two of the five randomly place and oriented B-dot probes to find the relative frequency distribution (RFD) of differences between the two probe power densities. This RFD helped to calculate the standard deviation which lead to field uniformity value for that noise bandwidth. We found that the field uniformity results matched well with the Monte Carol simulation field uniformity predictions.

This paper will describe all chamber modification, including the type of materials used, material performance and their implementation. In addition, theoretical prediction as well as experimental results before and after chamber modifications are also presented.

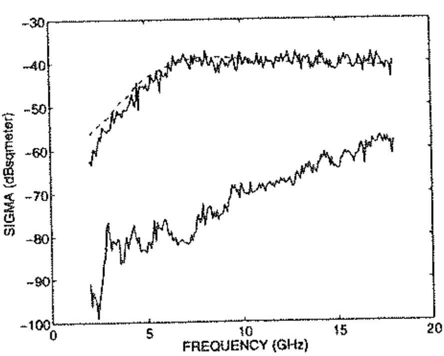
MEASUREMENT OF TRANSMISSION CROSS SECTION OF APERTURES BY USE OF NESTED MODE-STIRRED CHAMBERS

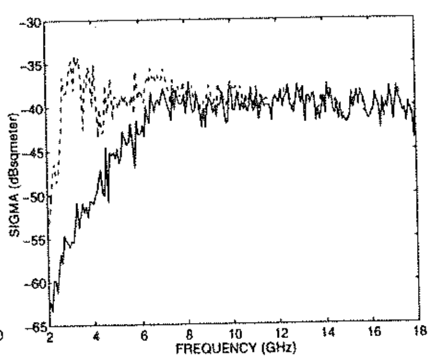
Mats Bäckström* and Olof Lundén
National Defence Research Establishment, P.O. Box 1165, S-581 11 Linköping, Sweden

Knowledge of the transmission cross section of apertures, σ_a, constitutes an important factor in design and analysis of electrically large shielded structures. Given the power density of the incident field the transmission cross section can be used to calculate the absolute level of power transmitted through an aperture, something which is not possible using data from a MIL-STD 285 type of measurement of an aperture's shielding effectiveness (SE). Therefore, knowledge of σ_a allows contributions from different POE's of a cavity to be compared in an absolute way. Moreover, if the σ_a's are known the SE of an electrically large cavity can be estimated using $SE = 2\pi V/\sigma_a \lambda Q$, provided the volume (V) and the Q of the cavity are known.

The usefulness of σ_a requires that it can be measured or calculated for real apertures (and that it essentially does not depend on the characteristics of the cavity backing the aperture). This paper shows that σ_a can be measured using nested mode-stirred chambers. The FOA (National Defence Research Establishment) MSC facility consists of two mode-stirred chambers, one located inside the other. Their dimensions are 2.4x2.4x3.6 m^3 and 9.7x4.9x3.0 m^3. The DUT is mounted on a flange located on a wall of the smaller chamber. The DUT consists of an aperture furnished panel with size 35 cm x35 cm. A HP 8510C network analyzer, controlled by a PC with HP-VEE software, is used for the coupling measurements.

The measured transmission cross section for a circular hole with a diameter of 20 mm is shown in the left figure. The figure also includes the background level (lower curve) and the exact solution (dashed line). The right figure shows the deteriorating effect of penetrating the 20 mm circular aperture with a 40 mm long metal stick, thickness 2 mm, centrally and symmetrically positioned in the hole (dashed curve).





As can be seen there is a good agreement between measured data and the exact solution. Measurements of other apertures, such as slots and riveted aircraft seams, will be presented.

MEASURED DIRECTION DEPENDENCE OF MICROWAVE COUPLING INTO SHIELDED STRUCTURES

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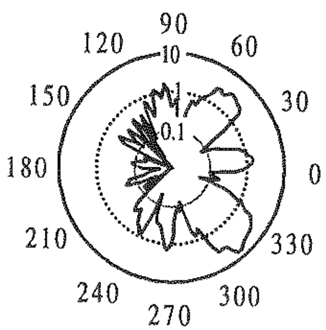
Bofors Missiles, S-691 80 Karlskoga, SWEDEN

A mode-stirred chamber (MSC) can be used to make high level measurements for radiated susceptibilty (RS) tests as well as low level coupling measurements (to obtain data for shielding effectiveness (SE) determinations). Time saving measurement techniques and the possibility to generate high field levels are some of the reasons for using a MSC. In addition, a MSC is less expensive than an anechoic chamber.

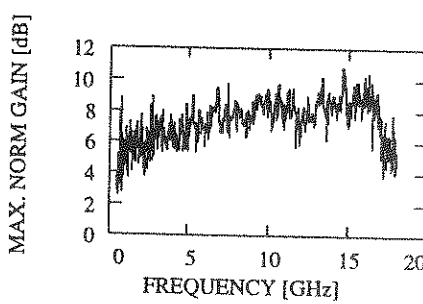
A parameter, often neglected, that has to be considered when making RS testing and coupling measurements in a MSC is the directivity of the test object. Since the microwave power that is radiated in a MSC illuminates the test object more or less isotropically, i.e. from almost all directions simultaneously, the directivity of the test object will be masked and thus a coupling measurement will indicate a better SE, compared to the free space worst case.

To get an indication of how high the directivity can be, two arbitrary test objects have been measured at the National Defence Research Establishment. One is a generic missile and the other is an avionic box from a combat aircraft.

The left figure shows the variation of the normalized gain, measured in one plane only, of the avionic box as a function of angle at 5.24 GHz. (Normalized gain is the measured gain divided by the average gain in the plane.) The right figure shows the maximum normalized gain of the avionic box, measured in the same plane as mentioned above.



NORMALIZED GAIN [logarithmic scale]



This paper will present further results from directivity measurements and discuss their implications on coupling measurements and RS tests made in a MSC compared to measurements in an anechoic chamber.

ON THE IMPOSSIBILITY OF DETERMINING SHIELDING PROPERTIES OF THICK CONDUCTIVE SAMPLES USING COAXIAL TEM CELLS

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Research Institute for Electrical Engineering, Splaiul Unirii 313, Bucharest 74299, ROMANIA

The paper intends to reveal the theoretical limitations of shielding effectiveness measurements made by means of coaxial TEM cells. Generally, the starting point for evaluating the shielding capability of a material is the ideal case of infinite plane shield, homogeneous and isotropic, placed in the free space in the Fraunhoffer zone. The mathematical description of this case is relatively simple, but experimental verification implies great difficulties, and that's why modelling techniques are used. The coaxial holder test method is a simple way to determine the far-field shielding effectiveness of plate composite materials being based on the isomorphism between its configuration and the one of infinite plane shield. The relations which describe this isomorphism allow to calculate SE (shielding effectiveness) for the infinite plane shield in free space case (D.R.J. White, "Electromagnetic Shielding". Don White Cons. Inc., 1980), and respectively IA (insertion attenuation) for the TEM coaxial cells case.

Experiments were performed on 4 metallic samples starting from low frequencies to 500 MHz using a TEM coaxial cell with 50 Ω impedance, results being shown in paper. The deviations which appear in comparison with theoretical curves are due to technical sources of errors, especially to impedance mismatching between generator, measuring cell and receiver. All measurements were performed in the thin samples domain from electrical point of view ($\gamma d \ll 1$). In the paper it is demonstrated that for the thick samples case it is theoretically impossibile to perform experiments. Besides the theoretical limitations of the above mentioned isomorphism (M. Badic, M.J. Marinescu & C. Paun, Proceedings of EUROEM 94 BORDEAUX, 1265-1274, 1994) there is also a theoretical problem concerning using TEM cells for tests on thick conductive ($\sigma \gg \varepsilon\omega$) samples: it is impossible to fulfill simultaneously the two conditions ($\sigma \gg \varepsilon\omega$ and $\gamma d \gg 1$) up to GHz frequencies (Fig.1). Over 1 GHz it is not possible to use TEM cells because of higher modes appearance. So, circular coaxial holder test method can offer results only for the domain where SE does not vary with frequency, but same results can be obtained by measuring d.c. σ and applying a known mathematical relation (Y. Haitao & L. Yiming, Proceedings of IEEE-EMC'92 ANAHEIM, 412-415,1992).

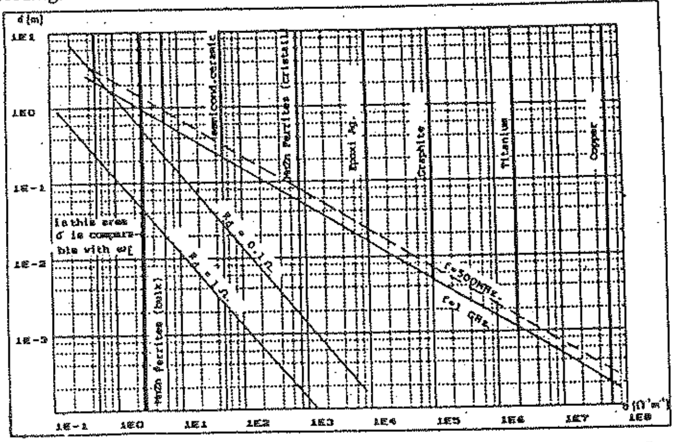

Fig.1 Thin (-) and thick (=) samples conditions versus σ for conductive materials (R_d is total resistance between inside and outside conductors of coaxial holder).

ANOTHER METHOD TO ESTIMATE THE EFFECTIVENESS OF A SHIELD

Peter G. Landgren
Bofors Missiles, S-691 80 Karlskoga, SWEDEN

When you are working with susceptibility issues, is it often interesting to be able to measure or at least estimate how much energy that can be transferred from the external environment to the internal components in a system. This is however difficult, specially on small systems, where every introduction of measuring devices changes the presumtion for the measurement.

One solution to this dilemma is to use a non conducting measurement probe. I. e. some type of fibre optics. There is no very small current or voltage fibre optic sensor available on the market today. However, if you can measure another parameter, such as the heat dissipated in a selected resistor on a printed circuit board inside the system under test, there are available possibilities. Photonetics Inc. of Wakefiled, MA, produces a small, about 0.1 mm diameter fibre optic temperature sensor. The sensitivity is about 0.1 °C. The sensor can be attached to a small surface mount resistor with some kind of holder.

When heat is dissipated in a resistor it starts slowly to get warmer. It is not only the resistor that is influenced. The traces on the printed circuit board and the board itself are also going to warm up, very little and very slowly. We can thus find three different thermal time constants involved in this heat transfer process. These time constants can be estimated by driving DC pulses, with different duration, through the resistor. This should give a good estimate of the optimal pulse width and repetition rate to be used. If the incident field during the measurement has the same time characteristics as the optimal DC pulse, an estimate of the high frequency current can be made. This will give a transfer function from energy to current as a function of frequency. Other levels than the test level can be analysed later. It is very important that the fixture is very rigid and that the sensor does not change position after the DC calibration procedure.

Preliminary results show that this idea is possible to implement. There are some limitations. The method is not a low level type. The method can only be used when the test frequency is close to the resonanses in the test circuit. In this case the power requirement of the illuminating field is not too high. The instrumented resistors should be in the 10 Ω to 100 Ω range. It is difficult to dissipate enough heat for most other values.

This paper will present further detailed results with respect to time constants, frequency range, resistance range and illuminating power requirements. More precise limits on the applicability will also be discussed.

COMPARATIVE EMP TESTING OF A MOBILE COMMUNICATIONS SHELTER AT TWO EMP TEST LABORATORIES.

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Dr. Alexander Worshevsky and Dr. Vassilij Koprienko
Elemcom Ltd., Lotsmanskaya 3, St. Petersburg 190008, Russia

Test object. Comparative EMP testing of a complex test object was performed at two test laboratories. The test object consisted of a well shielded light mobile communications shelter connected to a 10 m tall mast with a transmitting antenna and a 2 kW mobile electric power plant. The system was grounded via a short ground rod and was connected to a long external two-lead telephone wire terminated at the far end.
Initial testing in Sweden. The initial testing was performed at the Defence Materiel Administration Test Labs in Linköping. A 90 m long and 17 m tall Bounded-wave simulator was used. At the testing the test object was positioned on an insulating support at the metallic ground plane in the test volume. The telephone line was extended along the simulator and elevated 2 m over the ground plane thus simulating a line on a lossy ground. A 1 MV pulser generated a 4/130 ns vertical test field of threat level. A Low-Level Swept frequency Coupling method was used in order to investigate the influence of the metallic ground plane. At the LLSC testing the test object was positioned on a lossy ground surface and was illuminated from about 100 m distance by a vertical monopole antenna. The complex transfer functions (amplitude and phase) were determined over the frequency range 0.1-100 MHz to various test points from the incident EM field near the shelter. Comparisons were made by Fourier transforming the frequency domain data. Non-linear coupling paths (via transient protection devices) were treated separately.
Alternative testing in Russia. The alternative testing was performed at an EMP test laboratory near St. Petersburg in Russia. A very long Bounded-wave simulator was used. It was 10 m tall and 15 m wide and had a 45 m long break in the ground plane. This enabled the test set up to include the effects of a lossy ground at the test volume. The simulator had a 6 MV pulse generator that at low output level generated a vertical field of threat level amplitude with a rise time of about 25 ns. The generator was adjusted to 150 ns pulse duration approximately the same as that of the Swedish simulator. The distortion of the pulse along the lossy ground part of the bounded wave simulator was analysed.
Diagnostics. Induced current densities were recorded at the shelter surface. Induced currents and voltages were determined at external cables and inside the shelter. The recordings were made with a test system consisting of wide band probes, fiber optic links and 1 GHz sampling rate digitizers. The bandwidth of the test system was > 300 MHz.
Results and conclusions. The comparative testing demonstrated that the test set up has an influence on individual recordings. Including a real ground plane in the test volume render a more realistic test set-up. A simulator having a metallic ground plane is not ideal for testing of objects that are intended for ground use. The ground positioned test object with some distributed units and a long external telecom cable was selected in order to demonstrate this problem. The longer rise time of the Russian simulator did not excite some HF resonances and the break in the ground plane induced some distortions of the generated pulse. The important features of the test systems were analysed. As a general conclusion it was observed that the compared results agrees well regarding the overall system hardness.

day, May 31, 1:30 PM — Room: Aztec

O-9 **UXO Detection & Identification IV**

Chair: *H. Hambric, Night Vision & Electronic Sensors Directorate, Ft. Belvoir, VA*

:30 PM **INTRODUCTION & ANNOUNCEMENTS**

:35 PM **TESTING OF SURFACE UNEXPLODED ORDNANCE DETECTION VIA AN ACTIVE/PASSIVE MULTISPECTRAL LINE SCANNER SYSTEM**, *H.H. BENNETT, JR., U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS* 386

:55 PM **AN OVERVIEW OF THE IMPROVED GROUND MOBILE MINE DETECTION TESTBED**, *P.G. Johnson, EG&G MSI, Albuquerque, NM* 387

:15 PM **MULTI SENSOR VEHICULAR MINE DETECTION TESTBED**, *D.R. BROWN, J. BENDAHAN, G. BORGONOVI and D. HADDOCK, Science Applications International Corporation, Santa Clara, CA; and J. REGNIER, CECOM RDEC NVESD, Ft. Belvoir, VA* 388

:35 PM **REMOTE CONTROLLED SURFACE/NEAR SURFACE UXO DETECTOR**, *J. BENDAHAN, G. BORGONOVI, D. BROWN and D. WILL, Science Applications International Corp., San Diego, CA; and T. BROACH and R. MEHTA, Night Vision Electronic Sensors Directorate, Ft. Belvoir, VA* 389

:55 PM **DETECTION OF DEPLETED URANIUM (DU) IN SOIL**, *K. BERNSTEIN, Antech Services, Inc., Chatsworth, CA; and F. DUNFRUND, U.S. Army Yuma Proving Ground, Yuma, AZ* 390

3:15 PM **BREAK**

3:40 PM **ROBOTIC SURVEYS FOR DEPLETED URANIUM CONTAMINATION IN THE PRESENCE OF PROXIMITY FUSED UXO**, *R.J. SELFRIDGE, M.S. BLAIR, C.R. FLYNN and R.R. HIGHFILL, Chemrad Tennessee Corporation, Oak Ridge, TN* 391

4:00 PM **PORTABLE TURNKEY UXO DETECTION SYSTEM**, *G. VALLON and O. DIETZ, Vallon GmbH, Eningen, Germany; and R. HITCHLER, Security Search Product Sales, Littleton, CO* 392

4:20 PM **MINE DETECTION WITH MODERN DAY METAL DETECTORS**, *G. VALLON and O. DIETZ, Vallon Gmbh, Eningen, Germany; and R. HITCHLER, Security Search Product Sales, Littleton, CO* 393

4:40 PM **STEEL CRATER GROUND-PENETRATING RADAR PROGRAM**, *V.R. MARINELLI, K.A. KAPPRA, L. HAPP and M.A. KOLODNY, U.S. Army Research Laboratory; and T.O. GROSCH, MIT Lincoln Laboratory* 394

TESTING OF SURFACE UNEXPLODED ORDNANCE DETECTION VIA AN ACTIVE/PASSIVE MULTISPECTRAL LINE SCANNER SYSTEM

Hollis H. (Jay) Bennett, Jr.
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3909 Halls Ferry Road, Vicksburg, MS 39180-6199

ABSTRACT

Many Department of Defense (DoD) sites with unexploded ordnance (UXO) contamination must undergo cleanup. Existing technologies for detection and remediation of UXO are expensive, dangerous to personnel, labor intensive, and technologically inefficient. The need for dual-use technology is becoming greater with the budget reductions taking plac in the DoD. The use of a helicopter mounted multispectral data acquisition/processing system originally designed for remote minefield detection is being adapted to detect surface UXO. The use of airborne remote detection minimizes the risk to personnel during the environmental assessment and analysis of the site. The system consists of an active/passive multispectral line scanner, real-time processing and display equipment, and navigational equipment. The scanner collects three channels of optically aligned image data consisting of two active laser channels, one polarized reflectance and the other total reflectance, and one passive thermal infrared channel. The real-time processing and display system is based on parallel processor technology. The system can be flown at low altitude (130 feet) with a forward speed of 30 knots to characterize the site for the presence of surface UXO. This altitude and forward speed allow for the surface resolution to be 1.9 by 1.9 inch square. Th system also incorporates onboard recording and the insertion of differential Global Positioning System (GPS) coordinates. GPS coordinate information will allow contaminated areas to be added into a Geographical Information System (GIS) so that UXO locations can be overlaid on the base maps. The detection is based on the remote identification of surface anomalies and materials which indicate the presence of surface UXO contamination. Results of UXO detection from Jefferson Proving Ground, Indiana will be presented. The design of the test suite used for the collection of experimental data will also be reviewed to determine the level of classification the system can obtain on UXO materials. The experiment is funded by the Environmental Security Technology Certification Program and managed through the Army Environmental Center. The system shows promise in the dual-use area fo surface UXO detection.

An Overview of the Improved Ground Mobile Mine Detection Testbed

Philip G. Johnson: EG&G MSI

ork performed under contract to the United States Army Night Vision and Electronic Sensors rectorate.

3&G has designed and developed an advanced testbed for the detection of land mines. Field sting will be completed this summer on a multispectral system using data fusion and an artificial ural network to reduce false alarm rates while maintaining a high probability of detection. The stem includes arrays of Ground Penetrating Radar, Impulse Metal Detectors and video and dual nd infrared cameras to support detection of a wide variety of mines. This presentation will ovide a description of the system as now fielded and will discuss results obtained to date.

ıe system differs from existing systems and from others under development in speed, swath and gree of automation. As a testbed, the IGMMDT may also prove useful in the development and aluation of other sensors.

ıe Army plans to fund follow on work to take the vehicular mounted mine detection chnologies to operational systems by the end of the century. The work described in this paper ıd others detailing specific systems should provide major support in accomplishing this vital ilitary mission.

Multi Sensor Vehicular Mine Detection Testbed

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A multi-sensor vehicular buried mine detection testbed (VMDT) was integrated and tested as part of the Government Operational Capability Demonstration Test (OCDT). This system will also be tested during 1996 with buried UXO. To the maximum degree, the VMDT employed commercial off-the-shelf subsystems. The tele-operated vehicle platform was a robotized Melroe Bobcat. The sensor system included a 2-meter flexible metal detector array manufactured by Schiebel of Austria, a thermal neutron analysis (TNA) sensor developed by SAIC, and commercial cameras to provide images in the visual, infrared, and ultraviolet bands. The Visible, UV and IR sensors were forward-looking and were to be used to spot surface-laid or shallow-buried mines. The metal detector was the primary mine detector and the TNA sensor was used for confirmation. The metal detector was set with a discrimination threshold consistent with the desired high probability of detection for minimum metal mines and scanned the path in front of the vehicle. Suspicious spots that triggered the metal detector were interrogated by the TNA sensor.

The VMDT was field tested at Ft A.P. Hill, Virginia during the week of 6-12 November, 1995 on various test areas including a grassy field, a NATO and Warsaw pact mine field, an unimproved dirt road, and roads paved with asphalt and concrete. The 2-meter metal detector array was shown to be very sensitive to metal, both to mines and to metal clutter on the test range and it performed well as a primary buried mine sensor. The TNA sensor detected all anti-tank mines and the larger anti-personnel mines. The TNA sensitivity was also shown to be unaffected by the various soils, road surfaces and buried metal clutter. Overall, the TNA showed its ability to act as a secondary sensor, and could act as a primary sensor on paved roads for interrogating filled pot holes. In combined operation on an unimproved road, the metal detector and TNA sensor worked well together. The TNA confirmed the mines and cleared the clutter alarms.

This paper describes the VMDT system, reviews the test results and discusses the application to buried UXO detection.

REMOTE CONTROLLED SURFACE/NEAR SURFACE UXO DETECTOR

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T. Broach, R. Mehta
Night Vision Electronic Sensors Directorate, Ft Belvoir, VA

The purpose of the program is to develop a system that can detect unexploded ordnance typically found in the first foot of soil. The major components of the system are a remotely controlled vehicle and a control station. The vehicle supports a metal detector array, a Thermal Neutron Analysis (TNA) detector, and a video camera for visual navigation. In addition, the vehicle carries equipment for two way communication with the control station and navigation equipment (differential GPS, wheel encoders, and compass) for determining and recording its path.

The ultimate objective of the program is to demonstrate an integrated system which can detect metal objects and then assess the probability that the detected object contains an amount of explosive larger than a given threshold. The approach to the program is to first test the individual components separately, and then gradually proceed with integration. The system is being assembled in part using components from a previous demining program.

The first objective is to demonstrate the system capability to remotely scan areas, insuring complete coverage and producing an accurate map of the metal detector signal over the region covered. The second objective is to demonstrate that the system can remotely return to a position identified as suspect and carry out a TNA assessment of the presence of explosives. We plan to reach the two objectives above in tests to be conducted along parallel lines at Socorro, NM. Subsequently, the system will be integrated in such a way that an assessment of the explosive presence by TNA can be carried out shortly after obtaining an indication from the primary detector. Further tests of the integrated system are planned to be conducted at the Yuma Proving Grounds.

The paper discusses the status of the program and presents preliminary results obtained during the first phase, as well as the plan for the Socorro tests.

DETECTION OF DEPLETED URANIUM (DU) IN SOIL

* Karl Bernstein, Ph.D. ANTECH Services, Inc.
Frank Dunfrund U.S. Army Yuma Proving Ground

Detection and recovery of depleted uranium (DU) is expected to be a required step in the process of environmental cleanup of many military facilities, including some in the United States. The U.S. Army Yuma Proving Ground (YPG) initiated a program to develop an effective DU detection system. The program has culminated in a successful field demonstration in December, 1994.

Although the special purpose vehicle intended to carry the planned four detector system was not yet complete, all parties agreed that a field test would be of value to the program. The project team decided to install a two detector system in a small station wagon. An available small vehicle was chosen, and the equipment was installed in the wagon, tested, and packed in a van for the trip to YPG.

The test was conducted on a DU detection test course set up for the purpose at YPG by Mr. Dunfrund and other YPG personnel. The course had a total of five sites, in four of which DU specimens were buried. One site was refilled without DU, to serve as a "blank" for the measurements. The sites were arrayed in a straight line, with a spacing of approximately 40 feet between sites. The test required operator control of the instrumentation, unlike the operation expected with a fully implemented instrument. The operator, who had no advance knowledge of the course, was located at a position in the wagon such that he had no useful view of the DU range ahead or behind the vehicle.

Detection of buried DU was demonstrated reliably with a sensitivity close to that predicted on the basis of early laboratory experiments. A 7 pound specimen at a depth of 2 feet was not detected in a 4 second "search-mode only" pass, but was detected clearly in another pass. Success was achieved with a preplanned alternate search strategy featuring a longer confirming measurement following observation of a search signal somewhat smaller than that required for confirmation in the search mode alone. The same performance will be experienced at a depth of approximately 22 inches with a 1 second measurement.

Spatial variations in the test range background radiation were observed and subsequently were confirmed by another team. Data processing techniques can recognize and adjust for this phenomenon, preserving detectability, and can provide other useful information about detected DU masses.

ROBOTIC SURVEYS FOR DEPLETED URANIUM CONTAMINATION IN THE PRESENCE OF PROXIMITY FUSED UXO. R.J. Selfridge, M.S. Blair, C.R. Flynn and R.R. Highfill (Chemrad Tennessee Corp., 739 Emory Valley Rd., Oak Ridge, TN 37830)

The Remote Automatic Ordnance Locator System[1] (RAOL) is a recently developed automatic tracking and data logging system integrated with a remote controlled robotic platform. The system was designed for delineating buried Depleted Uranium (DU) contamination in the presence of proximity or piezoelectric fused unexploded ordnance (UXO). A Geonics time domain EM-61 metal detector is used to detect the buried DU. The output of the instrument is an approximate 50 watt harmonic signal, and it is not currently known whether the output signal produced by this detector is safe for fused ordinance, particularly piezoelectric and proximity fuses. To satisfy health and safety concerns, CHEMRAD integrated the survey equipment with a robotic platform to remove personnel outside the 1200 foot exclusion zone and still receive real time data.

The system employs a radio frequency (RF) controlled Andros 6X6® robot outfitted with color video , audio and data channels. An ultrasonic time-of-flight technique is used to determine the detectors location each second to an accuracy of 15 cm. The real time data acquisition system records the data from the time domain based EM-61 metal detector each second in the field computer's memory. These position-correlated data are shown in real time on the field computer's display providing a graphical aid for on-line quality assurance of the survey's coverage and findings.

The detectors location is determined each second by measuring the acoustic travel times from an ultrasonic transmitter carried on the detector to transducers mounted on tripods and distributed across the survey area. The travel times are reported to the field computer via RF transmissions. The data from the towed geophysical detector are also reported to the field computer via RF transmissions.

The use of ultrasonics gives the ability to survey in all terrains, including wooded areas, steep ravines, and in and around buildings. The on-line display of the survey's results allows areas of concern to be immediately identified. Outputs from the System include recorded video and audio tracks of the survey, site track maps showing the details of survey coverage, and color track maps which reflect the sensor's response at each sampling point. Color contour maps displaying the isopleths of the sensor's response and statistical analyses of the survey area or of selected regions of interest can also be generated.

1.The AOL System builds on the design of the USRADS® Model 2100, which was developed through a collaboration of the Health and Safety Research Division and the Instrumentation and Controls Division of the Oak Ridge National Laboratory under contract to the U.S. Department of Energy. Martin Marietta Energy Systems, as the operating contractor of the ORNL for the DOE, subsequently obtained a patent on the USRADS System. The license to this patent has been solely transferred to Chemrad under a technology transfer agreement with MMES.

PORTABLE TURNKEY UXO DETECTION SYSTEM
High Quality Data Acquisition→ Accurate Navigation→ Data Analysis

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INTRODUCTION

After many years and several generations of product development advancements, the company Vallon GmbH has responded to the market needs of the UXO user community with a fully integrated Man-portable Ordnance Locator. Reality aspects seek user friendly equipment which are cost effective (survey time + reliable data processing), to the OEW operator and provide qualified data which meet Government standards.

Equipped with proven detection technologies along with current survey and software techniques, such a system will work effectively today and into the future. The Vallon Ordnance Locator System has been designed to accept further technical improvements as the needs and components become available.

CONCLUSION

In brief, it is now possible to obtain high quality a reliable data from a UXO field survey operation. Havi stored and analyzed target data provides baseli information for the present and future survey of a giv site. An integrated "turnkey" system is now field usal and can provide a higher level of quality assurance o past manual operation methods.

MINE DETECTION WITH MODERN DAY METAL DETECTORS

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RODUCTION

ı the end of the cold war, the threat of nuclear lict has been substantially reduced. Countries nd the world view this situation with both ɔration and opportunity. One negative result has . an increase in regional conflicts over national and ːical sovereignty.

world has seen a dramatic increase in the use of mine warfare in many regions. Today, there is an nated 100+ million mines which will require ction and disposal work. One reason for this increase due to the relatively inexpensive cost of mine oyment with relationship to a highly effective tegic effect.

ponsible Governments are now challenged with the ediation of these mine saturated areas. In war zones problem is compounded with the combined nuisance)EW in the same fields.

re are a large variety of mines contaminating the net and many contain only a very small amount of ectable metallic content. Today, manufacturers must ign and produce highly reliable instruments for the ection of these mines and to insure the safety of EOD sonnel. It is currently thought that approx. 99% of placed mines contain some metal content. Therefore, dern day mine detectors with reliable technologies are y viable in meeting this remediation challenge.

CONCLUSION

Mine detection in itself can be a high-risk occupation. Apart from proper training, it is essential to have mine detectors that are electronically and physically superior for the task at hand as the highest issues are safety and confidence in detection.

The proper design and understanding of mine detectors is a specialized field from which a limited number of manufacturers possess the experience and proper knowledge to fabricate top line equipment. Users of this equipment should understand the parameters of these instruments and the essential need for high quality products.

STEEL CRATER GROUND-PENETRATING RADAR PROGRAM EXPERIMENT

Karl A. Kappra, Lynn Happ, Vincent R. Marinelli *
U.S. Army Research Laboratory

Theodore O. Grosch
MIT Lincoln Laboratory

In June 1993, the Army Research Laboratory (ARL) was selected by the Defense Intelligence Agency's Central MASINT Office to execute its Steel Crater Ground-Penetrating Radar (GPR) Program. The objective of this program is to define the utility of an airborne ground-penetrating radar: that is, to define the types of targets (from near- surface, small objects to moderately buried, large targets) an airborne GPR can detect and to determine how often and where the GPR will be successful in detecting these targets. The program's technical approach is to collect high-quality, precision data to support phenomenological investigations of electromagnetic wave propagation through varying dielectric media, which in turn supports the development of algorithms for automatic target recognition.

As part of the Steel Crater program, ARL and MIT/Lincoln Laboratory have carefully prepared a subsurface target detection test site in coordination with Yuma Proving Ground, AZ. This test site has been well characterized to support the understanding of the target and clutter data to be collected. The characterization included taking soil samples in and around the buried and surface target sites, using a ground contact radar prior to and after burying the targets for ground truthing purposes, and conducting a detailed geological survey to correlate imagery and analysis of the data collected with the actual buried target location. A tremendous variety of targets has been buried at this test site.

One of the assets collecting data at the Steel Crater site is the ARL BoomSAR--an ultra-wideband synthetic aperture radar (UWB SAR) system implemented on a 150-ft-high mobile boomlift for the purposes of collecting data on targets embedded in foliage and subsurface targets. The ability to generate high-resolution imagery with this very sensitive radar may provide a capability to detect small buried and surface targets. This BoomSAR collected subsurface target data (including unexploded ordnance) at the Steel Crater test site during the winter of 1996. This paper summarizes the Steel Crater program activities, including a description of the Steel Crater test site experiments and the BoomSAR data collection asset.

day, May 31, 1:30 PM **Room: Brazos**

:O-10 **UXO Case Studies & Applications**
Chair: *H. Bennett, U.S. Army Engineers Waterways Experiment Station, Vicksburg, MS*

:30 PM **INTRODUCTION & ANNOUNCEMENTS**

:35 PM **GROUND PENETRATING ULTRAWIDEBAND SAR SURVEY FOR UXO AT CAMP CROFT**, *S. GULATI, B. TOOMARIAN, A. FIJANY, AND J. WEIDNER, Jet Propulsion Laboratory, Pasadena, CA; R. VICKERS, SRI, Menlo Park, CA; S. MILLHOUSE, Army Corps of Engineers, Huntsville, AL; and M. GIFFORD, SC&A, McLean, VA* 396

:55 PM **RESULTS FROM THE MCCHORD AFB LIVE SITE DEMONSTRATION WITH THE AUTOMATIC ORDNANCE LOCATOR (AOL) SYSTEM – A NEW SURVEY TOOL FOR UNEXPLODED ORDNANCE**, *R.J. SELFRIDGE, M.S. BLAIR, C.R. FLYNN and R.R. HIGHFILL, Chemrad Tennessee Corporation, Oak Ridge, TN* 397

2:15 PM **UNDERWATER ORDNANCE DETECTION AND CHARACTERIZATION STUDY, SANDY HOOK, NEW JERSEY**, *R.D. LEWIS, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS; R.J. WOLD, Geometrics, Inc., Sunnyvale, CA; and T.H. BELL, Arete Engineering Technologies Corporation , Arlington, VA* 398

2:35 PM **FIELD APPLICATIONS OF A PROTOTYPE ADVANCED ELECTROMAGNETIC PROFILING SYSTEM FOR EXPEDIENT SUBSURFACE EXPLORATION**, *P. NIELSEN, U.S. Army Construction Engineering Research Laboratories, Champaign, IL* 399

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Ground Penetrating UltraWideband SAR Survey for UXO at Camp Croft[1]

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Abstract

Results of our recently completed ultra-wideband (UWB) ground penetrating SAR suvery and subsequent radar data processing for former Camp Croft Army Training Facility in Spartanburg, SC, a presented in this paper. Officially activated in 1944, Camp Croft facility consisted of 19,000 acres, and housed a training range impact area with at least 11 live ammunition training ranges, gas chamber and training area, cantonment area, and a grenade court. Not only is the Camp Croft site of vast acreage b also the extent of OEW contamination was undocumented and unknown. In addition, this site present significant complexity in foliage clutter and terrain relief. The soils are reported to be clay silts. Thus, in order to pursue a safe, cost-effective and large-scale OEW contamination survey, Army Corps of Engineers, JPL, SRI and SC&A teamed up to conduct a UWB SAR survey for surface and near-surfac UXO imaging and area delimination for further ground-based investigation of concern areas. Building a definitive radar dataset for the complete Camp Croft site was an important goal of this project. Our integrated approach brings together high resolution, polarized UWB SAR data collected by SRI's airborne sensor, new radar focusing, clutter reduction and radar image analysis algorithms, alongwith GIS-based dataset engineering, registration and interpretation tools.

The SAR radar analysis results were baselined with statistical analysis conducted using hand-hel magnetometer data for a limited, albeit known to be highly contaminated, area at Camp Croft FUDS sit (conducted by QuantiTech Inc.). Our preliminary results from this real-life case study indicate that SAI has high potential for area delimitation, particularly in densely foliated areas that are not amenable to hand-held or ground-based surveys.

Our future directions include development of a reliable "computational walkthrough" methodology for validating the SAR data analysis, and implementation of fusion algorithms for cross-correlating radar imagery with magnetometer and EM sensor data.

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[1] Collaborative JPL - SRI - ACEHND - SC&A Program

ESULTS FROM THE McCHORD AFB LIVE SITE DEMONSTRATION WITH IE AUTOMATIC ORDNANCE LOCATOR (AOL) SYSTEM -- A NEW SURVEY TOOL FOR UNEXPLODED ORDNANCE

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emrad Tennessee Corporation performed a live site demonstration at McChord AFB, ashington utilizing the Automatic Ordnance Locator System[1] which includes a Geometrics G-2L Cesium Vapor Total Field Magnetometer. The AOL System is a recently developed tomatic tracking and data logging system for use in surveys for unexploded ordnance (UXO). It nploys an ultrasonic time-of-flight technique combined with a dual compass engine to determine magnetometer sensor head location at a frequency of 10 times each second to an accuracy of 15 1. The position-correlated data are transmitted to a field computer and graphically displayed in l time. The display provides a graphical aid for on-line quality assurance of the survey's verage and findings. Survey results form the demonstration project as well as problems countered will be presented.

e AOL System consists of the following elements:

Field Sensor - Geometrics G-822L Cesium Vapor Total Field Magnetometer.
Diurnal Correction Sensor - Geometrics G-856 Proton Precessional Base Station Magnetometer.
Positioning System -USRADS Model 2200 Ultra-High Resolution Positioning System.
Data Processing Software and Graphical Display - USRADS Logger Software and Laptop Computer.

ne AOL system was designed to use existing geophysical equipment currently used for UXO rveys but increase data density and improve positional accuracy to allow improved UXO entification and delineation. The ultra high resolution positioning needed for UXO surveys was rformed by locating the magnetometer sensor utilizing a dual compass system integrated with the trasonic positioning system. The magnetometer sensor reading and location information are corded and processed to provide positional data every 0.1 second. These data are transmitted to e field computer via RF transmissions.

he on-line display of the survey's results allows areas of concern to be immediately identified. he surveyor can easily be redirected back to such an area for further investigation using the hand eld terminal which displays the coordinates of the surveyor's current location.

utputs form the System include track maps showing the details of survey coverage, color track aps which reflect the sensor's response at each sampling point, and statistical analyses of the urvey area or of selected regions of interest. Color contour maps displaying the isopleths of the ensor's response can also be generated.

he AOL System was demonstrated in the UXO Technology Demonstration sponsored by the J.S. Army Environmental Center through NAVEODTECHDIV and PRC, Inc. A 2.5 x 10^5 m^2 ite at the McChord Air Force Base in Tacoma, WA was surveyed using the AOL System during he period of October 23 through November 10, 1995.

The AOL System builds on the design of the USRADS Model 2100, which was developed through a collaboration f the Health and Safety Research Division and the Instrumentation and Controls Division of the Oak Ridge lational Laboratory under contract to the U.S. Department of Energy. Martin Marietta Energy Systems, as the perating contractor of the ORNL for the DOE, subsequently obtained a patent on the USRADS System. The icense to this patent has been solely transferred to Chemrad under a technology transfer agreement with MMES.

UNDERWATER ORDNANCE DETECTION AND CHARACTERIZATION STUDY, SANDY HOOK, NEW JERSEY

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Abstract

An underwater magnetic investigation was conducted by the US Army Corps of Engineer, Waterways Experiment Station in support of the Sea Bright beach nourishment project for the U.S. Army Engineer District, New York. The purpose was to demonstrate the use of a marine Cesium vapor magnetic gradiometer to locate and identify unexploded ordnance (UXO) in defined dredge material borrow areas. The study site is approximately 2 kilometers offshore of Sandy Hook, New Jersey which is also the site o Historic Ft. Hancock. This Formerly Used Defense Site (FUDS) commands a position on the south side (the New York harbor channel entrance. The facility has been used as a coastal defense location since pre US Revolutionary War times and has been the site of gun and mortar batteries from 3 inch to 14 inch calibers. The most predominant recovered UXO items from deeper water have been 8 and 10 inch diame coastal artillery rounds. However, a myriad of different calibers and shell types have been found, due in part to the use of the beach range as a major artillery Proving Ground from the 1870's to 1918.

Marine magnetic gradient survey data were collected over: 1) A test site of emplaced inert ordnance items 2) A 200 x 200 foot UXO disposal area; and 3) Along 6 three mile long north-south tracks which were spaced 200 feet apart. Data were collected using two Geometrics Model G-880 Cesium vapor magnetometers with the sensors separated by a distance of 2 meters and mounted on a submersible platform. The sensor array was flown at a nominal altitude of 1 to 2 meters above the sea floor with the altitude monitored to within 1 centimeter. A fiberglass hulled, aluminum decked and housed, research vessel was used to tow the platform at a 75 meter setback distance with a forward speed of 3 to 4 knots. Navigation and positioning was by a differential global positioning system.

The magnetic data were collected at a 10 Hertz sample rate and had a demonstrated noise level of less thar 0.01 nanoteslas. A large number of magnetic anomalies were detected, the majority appeared to be simple dipoles as would be expected from the anticipated ordnance. The anomalies appear to have a spatial distribution in relationship to the coastal battery locations. Complex magnetic anomalies were seen from obvious marine debris which was also identifiable with side-scan sonar. Interestingly, a notable magnetic gradient was measurable which was generated by near coast sea wave motion, even in ½ meter, 8 second period sea states.

A portion of the data were processed by Aretè Engineering Technologies Corp. (AETC) using Maximum Likelihood Estimation techniques to determine the locations (along- and cross-track position and depth below the ocean floor) and sizes of the targets. Based upon analysis of these data, it is determined that the system detects targets over a cross-track swath of twenty-five feet, and the density of targets is about one per 100 x 100 foot square. The computed spread of target sizes (2 to 16 inches) and the average calculate target size (8 inches) is very similar to the range (3 to 16 inches) and most common ordnance size (10 inches) recovered from bottom raking operations. The magnetic data indicate that only 20% of the targets appear to be resting on the sea floor. Most of the rest are calculated to be buried at less than two feet. These data are significant in accessing the mobility of the ordnance in the coastal environment and for any clean-up efforts.

FIELD APPLICATIONS OF A PROTOTYPE ADVANCED ELECTROMAGNETIC PROFILING SYSTEM FOR EXPEDIENT SUBSURFACE EXPLORATION

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Expedient and accurate non-invasive exploration of the earth's ›surface is potentially a very valuable capability. A number of :hnologies exist which can provide useful information by using the ectromagnetic properties of the earth. These include ground penetrating iar (GPR), magnetometers, and electromagnetic systems. Each of these work asonably well for certain applications. GPR is however, limited in high nductivity soils (wet clay) and non-ferrous metals are invisible to gnetometers. Both technologies require a high degree of interpretation to ce the data useful. Recent advancements in the area of electromagnetics may ve improved its relative position in the toolbox of measurement strumentation for subsoil imaging. This paper presents results of asurements conducted with a laboratory prototype advanced electromagnetic ofiling system. The instrument features an increased sensitivity, ltifrequency capability and data logging for simple and rapid terpretation.

The instrument was developed by Geophex Ltd. of Raleigh, North Carolina, der the Small Business Innovative Research program for the Environmental vision of the US Army Construction Engineering Laboratories (USACERL). It s primarily designed as a lightweight portable detection apparatus for cation of underground storage tanks (USTs). The physics of its operation ve it capabilities for potential applications well beyond its initial rpose. Such applications may include any phenomena which affects the ectrical properties of the earth. Examples include: chemical spill mapping, exploded ordnance detection, and nonintrusive soil resistivity measurement d soil moisture content determination. The instrument's unique features clude a three frequency measurement capability from which it may be possible derive depth information. It has a lightweight portable configuration and e capability for storing data from 1,100 points intended for downloading to a personal computer for analysis, generally in the form of contour or rface plots. The whole operation can readily be handled by one person.

Target size and shape resolution are functions of the sensor aracteristics and the distance interval used between data points. The ometry and operation of the instrument is such maximum resolution is obably obtained with a data point spacing of 3-5 ft. Data can be gathered a rate of approximately 200-300 points per hour on open search areas. ush, fences and other physical obstacles will slow data gathering.

The prototype instrument has been used by CERL for a variety of plications. These include the following:

Location of underground storage tanks: (1) Ft. Riley, Kansas, (2) Chicago Park District (former NIKE antiaircraft missile and antiaircraft gunnery sites, including a site with steel mill slag backfill).

Location and mapping of landfills: (1) Ft. Hood, Texas, (2) Ft. Carson, Colorado.

Other: P47 Crash site, Test area at CERL, Part of a cemetery, Buried pipeline, culvert and water pipe, Residential back yard, a variety of small ordnance and a septic tank leach system.

In addition to the CERL prototype, Geophex has built a number of omewhat similar instruments which will allow surveying up to an acre an hour. ey have used this instrument for the UXO study at Jefferson Proving Grounds, diana. A commercial version of this instrument is scheduled to be on the arket during 1996.

EVALUATION OF WHITE PHOSPHORUS CONTAMINATION IN ARMY IMPACT AREA WETLANDS

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White phosphorus (WP) has been identified as the causative agent of waterfowl mortality in the Fort Richardson Army artillery impact area in the estuarine wetlands of Eagle River Flats (Cook Inlet), Alaska. An assessment of 24 installations in the Continental U.S. identified by the U.S. Army Environmental Center to have wetlands within artillery impact areas was conducted by personnel of the Environmental Laboratory of the U.S. Army Engineer Waterways Experiment Station.

WP is used in several kinds of munitions to produce smoke as an obscurant and for spotting rounds. When a WP round bursts above water, small particles of WP may fall into the water and be extinguished. Once in the water the particles settle into the reduced sediment where they remain stored. Oxidized on the surface, the stored WP particles are then available to the waterfowl that feed in the sediment. WP is toxic to the waterfowl and may be transmitted through affected animals and carcasses to the various predators of those waterfowls where it may continue to exhibit harmful effects. The objectives of this study were (1) to evaluate the concentration of WP in permanent or semipermanent aquatic areas in wetlands, potentially attractive to the waterfowl, that are within the WP impact areas, and (2) if WP is found to be present, to quantify the concentration of WP contamination in sediments.

Nine installations were found to contain WP as a wetland contaminant in concentrations that ranged from the detection limit (<0.00096) to 450 mg Kg^{-1} wet weight. The presence of WP in impact area wetlands appears to constitute a risk to the waterfowl at only four of these installations either where there are large, open wetland areas or where impact craters have formed numerous ponds. There has not been any documented waterfowl mortality associated with WP at these installations to date.

The impact area wetlands containing WP were usually littered with UXO and while often heavily cratered as well, they generally contained high quality vegetative ecosystems. Native North American ecosystems typically depend on annual burning, and have often survived in impact areas where fire has not been withheld, and human influences have been limited. Craters formed b

vegetation. A one installation, for example, impact area wetlands contain an ecosystem of presettlement quality with more than 300 native American plant species and no introduced weeds. Remediation of such WP-contaminated wetlands would require UXO removal as well as excavation and treatment of wetland soil and sediment and the consequent loss of irreplaceable ecosystems.

The WP contamination detected in wetlands of Army impact areas in the Continental U.S. can be addressed through range management strategies. There have not been any documented instances of mortality due to WP, and potential waterfowl mortality can be averted without remediation.

DREDGING IN AN IMPACT AREA ON EAGLE RIVER FLATS, FT RICHARDSON, ALASKA

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ɡle River Flats is an estuarine salt marsh located on Ft. Richardson, Alaska. For nearly 50 ırs, it has been an impact area for the Army and Air Force. In 1982, large, unexplained die-offs waterfowl were documented, leading to several years research into the cause of this recurring ›blem. In 1990, researchers from the US Army Cold Regions Research and Engineering boratory (CRREL), in conjunction with the Ft. Richardson Environmental Resources Branch, ·ectorate of Public Works (DPW), discovered the cause of the mortality: white phosphorous. ter extensive study of the characteristics of white phosphorous (P_4) and the environment of the ıts, three remediation strategies were earmarked for further study: Covering contaminated areas th either geotextiles or bentonite; draining and exposing contaminated areas, allowing natural nediation; and dredging contaminated sediments for later treatment. This paper discusses the ›rk done to date on dredging.

.e presence of unexploded ordnance (UXOs) at Eagle River Flats (ERF) and the necessity to ›rupt the environment at a minimal level posed serious dredge system design problems. ldditionally, the only easily accessible storage and treatment area for the dredge spoils is located the explosive ordnance disposal (EOD) pad, a RCRA (Resource Recovery and Conservation :t) site. The project was therefore initially divided into two design efforts: The spoils retention d treatment basin and the design of an appropriate dredging system. This work was complished in cooperation with the Alaska District, Corps of Engineers and the Ft. Richardson ?W, with input from the Waterways Experiment Station.

ıe dredging system utilizes a small, remotely controlled augerhead dredge. The minimum stance from the dredge to the control cab, a hardened, mobile structure, is 40 m. The genset .ed to power the dredge is shore based, thus minimizing impact in case of a UXO detonation. ther design features include the use of a biodegradable vegetable-based hydraulic oil; locating imary systems, such as the slurry pump and power pack, as far from the dredgehead as feasible, ıd a cable traverse system to reduce penetrating UXO-laden sediments. An rf transmitter/receiver ·stem transmits video information and sensor data to the shore-based operator. Several strategies ere tried for dealing with the UXOs, all with the common goal of excluding the objects from the urry pump and leaving them behind. The most effective method was a cutter-and-grate system corporated into the dredgehead which excludes the UXOs from entering the pump intake line ithout clogging the grate with vegetation.

he retention basin is a 0.8 ha. structure built into the EOD Pad. Some existing material was used, ıt the presence of UXOs within the pad precluded complete construction with native materials. he base structure is constructed of consolidated gravel with 2 m high berms. The interior is lined ·ith a peaty-silt material to reduce the hydraulic conductivity to below 10^{-5} cm/sec, acceptable for apping hazardous waste sites. Extensive testing by CRREL verified the liner performance. Two m square concrete splash pads were installed in the basin to check erosion from incoming spoils, nd a drop inlet structure and weir was installed in one corner for controlled supernatant ecantation. Instrumentation was installed to monitor sediment characteristics for remediation erformance. Computer models indicated acceptable system performance.

ystem performance indicates that dredging is a viable option for consideration as a remediation trategy for Eagle River Flats. The grate system has allowed dredging to occur while minimizing ıe problems associated with UXO ingestion. Treatment studies of the P_4 contaminated retention ›asin sediments have begun, with definitive results anticipated for next season.

TOUSSAINT RIVER DREDGING WITH ORDNANCE CONTAMINATION

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The Toussaint River is adjacent to the former Erie Army Depot that was active from 1918 to September 1965. One of the depot's missions was to proof fire artillery ammunition. This was accomplished by firing at targets on or near the beach and into Lake Erie. Over the years large amounts of ammunition, both live and inert, have been washing up onto the shore and the shallow waters off the beach, and contaminating the Toussaint River channel. On September 25, 1991, while dredging the Toussaint River channel, a live 60mm mortar round got stuck in the cutterhead of the dredge and was removed by the contractor using a wedge bar.

On 10 July 1995, the Toussaint River Dredging Demonstration began. The purpose of the dredging demonstration was to evaluate the effectiveness of a clamshell, utilizing additional engineering and safety controls, in removing channel sediment containing ordnance, separating the sediment from the ordnance, disposal of dredged sediments, with the recovery and disposal of the ordnance. Shoreline Contractors, Inc. was contracted to remove the sediments over the entire length of the Toussaint River channel (approximately 2,100 x 150 feet). Human Factors Applications, Inc. (HFA) was contracted to perform Unexploded Ordnance Support for the project. Shoreline Contractors developed a system using a clam shell dredge to remove sediments from the channel. The dredged material was sifted through a screen to segregate any items of ordnance. Once ordnance was located on the screen, HFA personnel removed the ordnance to a disposal area.

This paper will explain the barge, equipment, and procedures used in this dredging demonstration.

USING SENSOR FUSION TECHNIQUES TO IMPROVE DETECTION OF BURIED UNEXPLODED ORDNANCE AT THE JEFFERSON PROVING GROUND DEMONSTRATION

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The Army Environmental Center directed a demonstration of technologies for the detection and identification of unexploded ordnance at Jefferson Proving Ground. For most types of ordnance emplaced for this test, even the best single sensor performance is substantially below what is needed for practical application to UXO clean-up. Thus, we have examined the prospects for improving performance by fusing the results from different systems. There are many different approaches to sensor fusion, including using one sensor to control resource allocation of a second, basing decisions on a set of features determined from more than one sensor, and finally merging the decisions based on the individual sensors.

The JPG phase I data, is decision level in nature, so this is the only type of sensor fusion considered here. Further, not all demonstrators searched the entire site. Thus, we constructed a reduced data set, using the common area searched of the four demonstrators who detected the largest number of emplaced ordnance items. We then devised an algorithm, based on proximity, to map declarations from a pair of demonstrators into a set of common (AND fusion) and distinct (OR fusion) declarations.

By construction, the AND fusion reduces the false alarm rate, and OR fusion increases the probability of detection. Unfortunately, AND also reduces detections and OR increases false alarms. The goal with sensor fusion is to increase probability of detection while decreasing false alarms, or at least to dramatically improve performance in one category with only a slight degradation in the other. It is not possible to accomplish this goal using AND or OR fusion with two demonstrators from the JPG phase I data. This approach was generalized to look at a variety of voting schemes using three demonstrators. Again, there appears to be no improvement in overall detection/false alarm performance.

Ideally, for the most effective sensor fusion approach, one would want to base the fusion on features measured by the sensors rather than on the decisions implied by those features. Therefore, the results here cannot be used to prove definitively that sensor fusion cannot improve the performance of systems used for the detection of UXO. Nevertheless, the inability to improve performance with decision based fusion indicates that fusing the results from multiple sensors to improve UXO performance will require understanding the target and background signatures that are to be distinguished.

:OMPUTER CODE FOR CALCULATING LONG-PERIOD ELECTROMAGNETIC FIELDS PRODUCED BY NUCLEAR CONTACT EXPLOSION, *V.M. KUVSHINNIKOV and A.A. SHVEDOV, Russian Federation Ministry of Defense, Moscow, Russia* 406

)ISTRIBUTION OF HORIZONTAL ELECTRIC FIELD IN THE TOP LAYER OF THE GROUND IN THE SOURCE REGION OF THE NUCLEAR SURFACE BURST, *V.M. KUVSHINNIKOV and A.A. SHVEDOV, Russian Federation Ministry of Defense, Moscow, Russia* 407

THE ANALYTICAL EVALUATIONS OF ELECTROMAGNETIC FIELDS IN NUCLEAR SURFACE BURST CLOSE-IN, *V.M. KUVSHINNIKOV, I.G. CHERNYSHOV and A.A. SHVEDOV, Russian Federation Ministry of Defense, Moscow, Russia* 408

EFFECTS OF IONIZING RADIATION AND OBJECT PARAMETERS ON THE EMP CHARACTERISTICS GENERATED INSIDE THE OBJECT CAVITIES, *S.V. PANTELEEV and A.V. SYSENKO, Russian Federation Ministry of Defense, Moscow, Russia* 409

SET OF TECHNIQUES FOR CALCULATING THE PARAMETERS OF ELECTROMAGNETIC PULSE GENERATED BY IONIZING RADIATION IN OBJECTS, *A.V. BEREZIN, S.V. PANTELEEV and A.V. SYSENKO, Russian Federation Ministry of Defense, Moscow, Russia* 410

COMPUTER CODE FOR CALCULATING LONG-PERIOD ELECTROMAGNETIC FIELDS PRODUCED BY NUCLEAR CONTACT EXPLOSION

V.M. Kuvshinnikov, A.A. Shvedov
UWB, SP-1 with HPEM-29:
Russian Federation Ministry of Defense

For the calculation of electromagnetic fields within 10^{-4}sec in close-in of the contact explosion ($r < 2-3$ km) nonstationary techniques are used but at later times one employs as a rule the techiques for calculating stationary EMP. However the lasts are based on the solution of the equation div(rot E) = div(J), wich at distances > 700 m begins be carried out significantly later. Therefore the code for EMP calculation in the time frame of $10^{-7}...10^{-1}$sec taking explicitly into account the physics of this phenomenon was developed at the Central Institute of Physics and Technology. It is based on the fact that by starting with $t \approx 0,1$ μsec one can neglect displacement current terms of the Maxwell's equations. Then the sistem of equations in the spherical coordinates (r,θ,φ) is reduced to second-order differential equation for the variable $H = H_\varphi \cdot r \cdot \sin\theta$:

$$\frac{1}{\sin\theta}\cdot\frac{\partial H}{\partial \tau} = \frac{\partial}{\partial \theta}\left(\frac{\xi}{r^2\cdot\sin\theta}\cdot\frac{\partial H}{\partial \theta}\right) + \frac{1}{\sin\theta}\cdot\frac{\partial}{\partial r}\left(\xi\cdot\frac{\partial H}{\partial r}\right) + \tilde{\varphi},$$

where $\xi = \frac{c}{4\cdot\pi\cdot\sigma}$, $\tilde{\varphi} = \frac{\partial}{\partial r}\left(r\cdot\frac{J_\theta}{\sigma}\right) - \frac{\partial}{\partial \tau}\left(r\cdot\frac{J_\theta}{\sigma}\right) - \frac{\partial}{\partial \theta}\left(\frac{J_r}{\sigma}\right)$

j_r, j_θ - the Compton current density.

This equation along with the relations for defining electromagnetic field components:

$$E_r = \frac{\xi}{r^2\cdot\sin\theta}\cdot\frac{\partial H}{\partial \theta} - \frac{J_r}{\sigma}; \quad E_\theta = \frac{\xi}{r\cdot\sin\theta}\cdot\left(\frac{\partial H}{\partial \tau} - \frac{\partial H}{\partial r}\right) - \frac{J_\theta}{\sigma}$$

decribe all components of electromagnetic fields.

In the soil ($\sigma = 10^{-4}...10^{-2}$ S/m) the condition $\tau/\xi > 1$ is accomplished at character times of electromagnetic fields change $\tau > 10^{-7}...10^{-9}$sec, i.e. it will be practically carried out over all time frame of interest. To solve this problem the DIF code has been developed including the method of variable directions and stream's option of the running method for solving difference equations.

To carry out calculating the parameters of the surface burst close-in EMP in time frame $10^{-9}...10^{-1}$sec, the DIF code was matched with one-dimention transverse code IBA. The code was tested by comparisons of computational results with data obtained from other calculations and with model problem solutions.

Responsibility for publishing work authenticity rests entirely with the authors.

DISTRIBUTION OF HORIZONTAL ELECTRIC FIELD IN THE TOP LAYER OF THE GROUND IN THE SOURCE REGION OF THE NUCLEAR SURFACE BURST

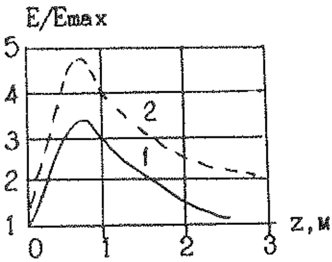
V.M. Kuvshinnikov, A.A. Shvedov
UWB, SP-1 with HPEM-29
Russian Federation Ministry of Defence

The extreme large strengths of electromagnetic fields in the source region ground top layer are conditioned by EMP sources generated in soil when the burst point is elevated above the ground surface from 30...500 meters .

In this connection the character of distribution of horizontal component amplitude of the electric field (E_ρ) with depth in ground becomes different on standard monotonic decrease E_ρ with depth as it was observed at contact burst. Indeed as computed results show for the ground surface burst the maximum horizontal component E_ρ occurs just below the surface at a depth 0,5 - 1 meter but not near the ground surface (as it was in the case of contact burst).

For example, at a distance of $\rho \cong 100$ meters from the burst point at a height of 200 meters the maximum amplitude E_ρ (in depth z=0,5...1 m) exceeds amplitude values of E_ρ near the air-ground interface by 3-4 times (Fig.1).

One can observe the described features of this E_ρ distribution within 500 meters from the point of ground surface burst. With distance from the burst point the extremum position in the field distribution moves to the ground surface. Over distances in excess of 1000 meters from the burst point the parameters of EMP from the contact burst are practically the same as from the burst above the surface.



All amplitudes are divided into $E_{max}(z=0)$ for the conductance of the ground $\sigma_g = 10^{-2}$ S/m.

Fig.1. Variation of horizontal component amplitude of electric field generated by low altitude burst versus the depth of the ground:
$1 - \sigma = 10^{-2}$ S/m; $2 - \sigma = 10^{-3}$ S/m.

THE ANALYTICAL EVALUATIONS OF ELECTROMAGNETIC FIELDS IN NUCLEAR SURFASE BURGT CLOSE-IN

V.M. Kuvshinnikov, I.G. Chernyshov, A.A. Shvedov
UWB, SP-1 with HPEM-29:
Russian Federation Ministry of Defense

The following relations for magnetic (H) and horizontal electric (E) components have been derived under the assumptions that: a) only a component of Compton current - J_ρ is taken into account (this is quite permissible in determining fields at ground surface in the domain of high air conductivities); b) displacement currents are neglected compared with conduction currents; c) ρ-coordinate derivatives are negligible; d) the air conductivity (σ) changes in time much more slowly than electric field:

$$H_0=\frac{2J_{\rho_0}\cdot\sqrt{t}}{\sqrt{\pi\cdot\mu}}\cdot S_B\cdot\left[1-\frac{1}{2\alpha}\cdot\sqrt{\frac{\pi}{t}}\cdot\frac{\sigma}{\sigma_{gr}}\left(1-e^{\alpha^2 t}\cdot erfc\left(\alpha\cdot\sqrt{t}\right)\right)\right], \quad (1)$$

$$E_0=J_{\rho_0}\cdot S_B\,/\,\sqrt{\sigma_{gr}}\cdot\left[1+\sqrt{\frac{\sigma}{\sigma_{gr}}}\cdot e^{\alpha^2 t}\cdot erfc\left(\alpha\cdot\sqrt{t}\right)\right], \quad (2)$$

where $S_B=\sqrt{\sigma_{gr}}\,/\,\left(\sqrt{\sigma\cdot\sigma_{gr}}+\sigma\right)$, $\alpha=g\,/\sqrt{\mu\cdot\sigma_{gr}}$, $g=4$,

g is a constant of exponent defining attenuation of Compton current and ground induced conductivity (σ_{gr}) with depth.

Vertical components of electrical field in the air - ground interface can be calculated from the relations

$$E_z^a=J(z_0)\,/\,\sigma, \qquad E_z^{gr}=J(z_0)\,/\,\sigma_{gr}, \quad (3)$$

($J(z_0)$ is the vertical component of the Compton current).

Note that the factors outside square brackets, parentheses, in the formulae (1),(2) are consistent with values of fields from contact burst (hb = 0 m).

The obtained asymptotic dependences differ from calculated values by about 30 percent and show that the presence of significant Compton currents in soil together with significant exceeding of the air conductivity compared with the ground conductivity is a necessary condition for the onset of electromagnetic fields of high strength.

The solution of this problem permits one not only to evaluate EMP from nuclear surface bursts but it also gives the law for extrapolation of obtained results to other yields and soil conductivities.For example,it permits one to make predictions for a specific dependence of magnetic field's strength on soil conductivity: if in the contact burst's close - in $H\sim\sqrt{\sigma_{gr}}$, then for surface bursts one can see a contrasted picture-H falls with increasing soil conductivity.

EFFECTS OF IONIZING RADIATION AND OBJECT PARAMETERS ON THE EMP CHARACTERISTICS GENERATED INSIDE THE OBJECT CAVITIES

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A set of techniques has been developed for calculating EMP characteristics in an object. It permitted one to perform investigations of the internal EMP characteristics dependence on parameters of ionizing radiation pulse affecting the object: amplitude, pulse width, rise time, spectrum were taken into account; the object properties such as material, gaseous medium density, internal structure were also taken into account. In the course of these studies a number of interesting results was obtained, particularly those related to nonlinear effects caused by the generation of radiation - induced conductivity in the object's gaseous medium (Fig.1), electromagnetic fields - currents interaction (Fig.2) and by the time parameters of the ionizing radiation pulse impacting the object (Fig.3).

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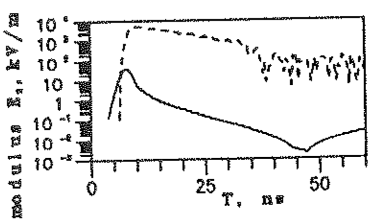

Fig.1. Electric field in the object versus time:
---- vacuum object;
—— air-filled object (p=1at.)

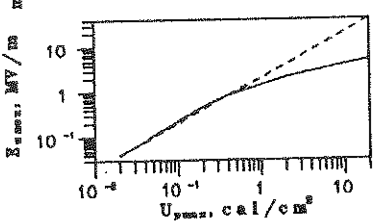

Fig.2. Maximum level of electric field in the object versus level of radiation pulse:
—— nonlinear calculation;
---- linear calculation

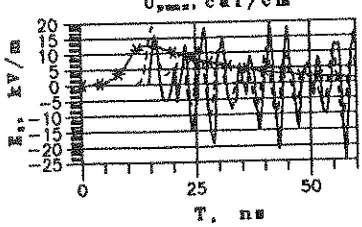

Fig.3. Electic field in the object versus time for different pulse width:
******* $\tau_{0.5}=2.1 \cdot 10^{-8}$s;**
---- $\tau_{0.5}=5 \cdot 10^{-9}$s;
—— $\tau_{0.5}=10^{-9}$s

SET OF TECHIQUES FOR CALCULATING THE PARAMETERS OF ELECTROMAGNETIC PULSE GENERATED BY IONIZING RADIATION IN OBJECTS

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Based on the analysis of the physical processes significantly affecting the EMP generation in an object (the gaseous medium density in an object, the nonlinearity of electromagmetic fields - currents interaction) it is picked out a number of practically important subproblems being particular cases of the general problem. Such an approach which the main point of is in introducting some simplifying physically grounded assumptions permits one to facilitate problem solutions. Presented here set of techniques realizes selected subproblems solution and is based on analytical calculations and numerical methods. Particularly this set include: two-dimensional analytical method (the problem solution in "quasistationary" approximation), one-dimensional nonlinear method (the problem solution under the assumption of strong nonlinearity of electromagnetic fields - currents interaction realizing at high levels of ionizing radiation affecting the object), two- and three-dimensional numerical methods (the solution of problem under the assumption of not high level of affecting radiation or under the "soft" ionizing radiation affecting the object with gaseous filling at near normal density), two-dimensional nonlinear numerical method (the problem solution taking into account nonlinear effects of the interaction between electromagnetic fields and currents which occur at high levels of ionizing radiation affecting the object). All methods were tested by comparing theoretical and experimental data.

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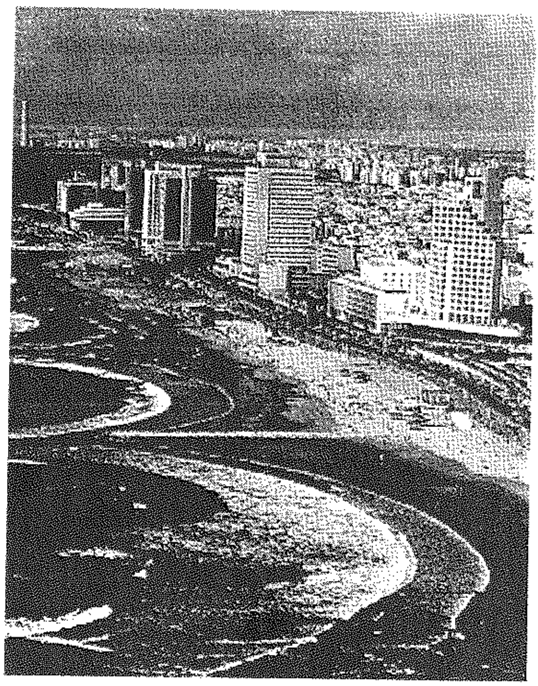

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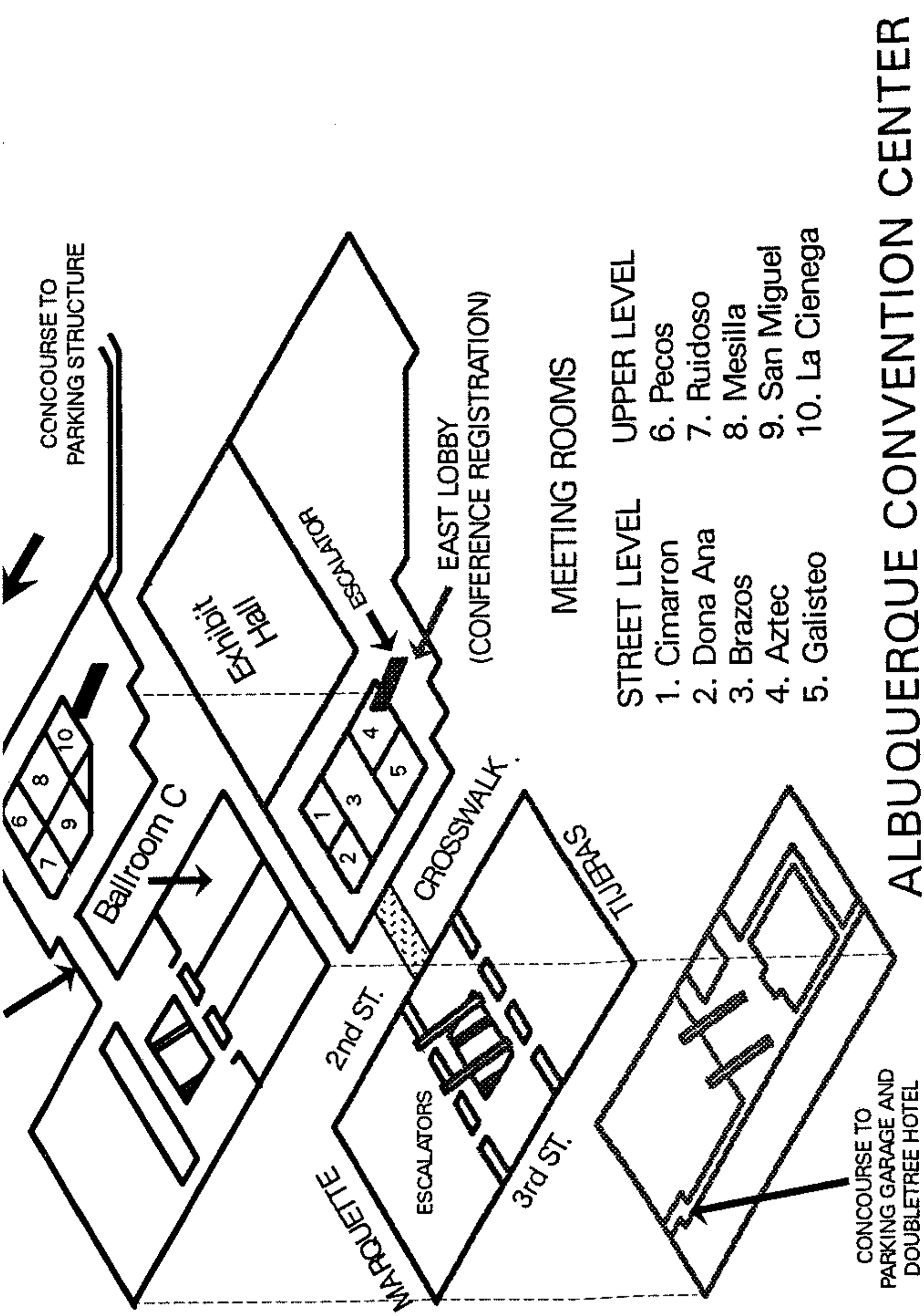

Cover Photograph: "Dusk Cityscape of Albuquerque" by Ron Behrmann, Courtesy, Albuquerque Convention and Visitors Bureau