MN 21

Measurement Notes

Note 21

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Instrumentation Guidelines for EMP Testing

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Abstract

This note reviews the important factors to be considered when instrumenting a system for EMP testing. The areas of pulsed field/instrumentation interaction, vehicle/instrumentation interaction and instrumentation system selection are examined. Guidelines for instrumentation selection and installation on a system are discussed. Recommendations for further study in these areas are presented.

Acknowledgement

The writer wishes to express his appreciation to Capt. R. A. Vopalensky for his encouragement in this effort.

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APPENDIX

I. Factors to be Considered for EMP Test Instrumentation

EMP testing presents some special challenges in the area of instrumenting the system under test. Typically, experimental activities on real systems include examination of the response of subsystems, systems and vehicles to a pulsed field environment. In tests of this type, three areas are of primary concern: (1) pulsed field/instrumentation interaction; (2) instrumentation/vehicle interaction; and (3) selection of an instrumentation system which will monitor the desired quantities within required accuracy bounds. Each of these areas is discussed briefly below.

A. Pulsed Field/Instrumentation Interaction

In the process of exposing a test vehicle to a pulsed field (simulated EMP) and of monitoring some desired response (such as charge density or skin current density) some part of the instrumentation system is also exposed to the incident field. As a minimum, the sensor (HSD, MGL, etc.) and some portion of the cabling from the sensor are exposed. Figure 1 shows a typical installation (reference 1). Often, as illustrated in Figure 2, it is also necessary to mount the entire on-board instrumentation system, including the rf data link on exterior of the vehicle under test, exposing the whole system to the pulsed field environment. If the system (sensor, cabling, and rf transmitter) is not properly shielded and grounded to the skin of the vehicle, this instrumentation system can interact with the incident field such that the instrumentation pickup (noise) will seriously perturb or completely mask the system response (signal) it is desired to monitor. One aspect of the guidelines to be presented in the next section will be to provide rules which assist in minimizing this type of noise coupling.

The importance of properly bonding instrumentation cabling and sensors can be illustrated by examining the results of a sensor bonding investigation performed on a real system, the AGM-28A missile (reference 1). With the missile positioned in the vertical orientation, a limited investigation was performed to investigate the effects of improper sensor bonding. Sheets of mylar were placed between the B-dot and D-dot sensors and response monitored. Data were also taken with the sensors properly bonded. The intent was to perform a comparative study with and without the sensors being properly bonded. It should be noted that the instrumentation cable was still grounded to the missile skin at 12 to 18 inch increments with the first tie-down point being approximately 4 inches from the sensor connector. Although the sensor isolation provided by the mylar may be somewhat more pronounced with the mylar sheets than with typical missile and aircraft paints, similar effects would be expected. The thickness of the surface paint at the locations monitored was slightly larger than the .010 inch thickness of a single sheet of mylar. However, the dielectric constant of the mylar is expected to be higher than that of the paint. Theoretically, one would expect a more significant effect on the D-dot measurement due to the capacitor action between the missile skin and the sensor ground plane.

Figure 3 shows the oscilloscope waveforms of the B-dot measurement with the sensor properly bonded and with the sensor isolated from the missile skin with one sheet of mylar. As was expected, isolating the B-dot

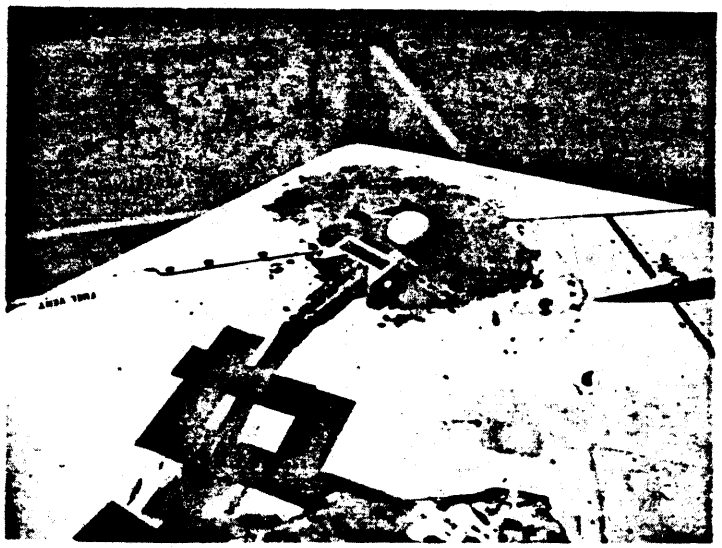


Figure 1. Typical Installation, External Sensor Mounting for EMP Testing of a Vehicle in a Pulsed Field Simulator

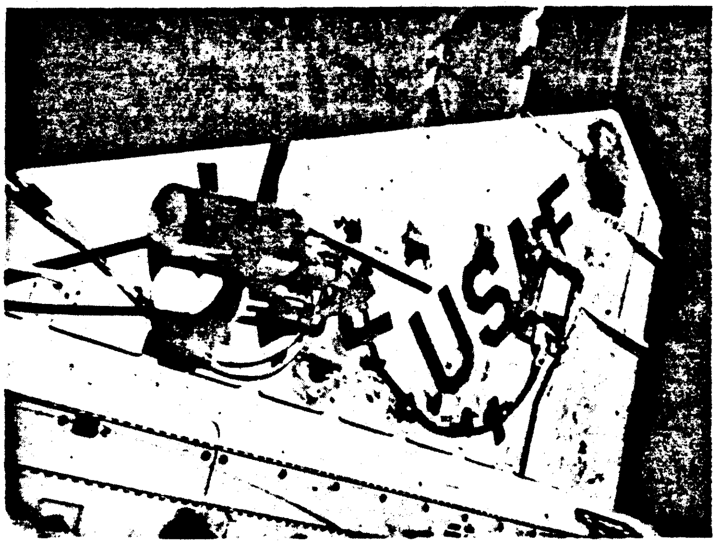
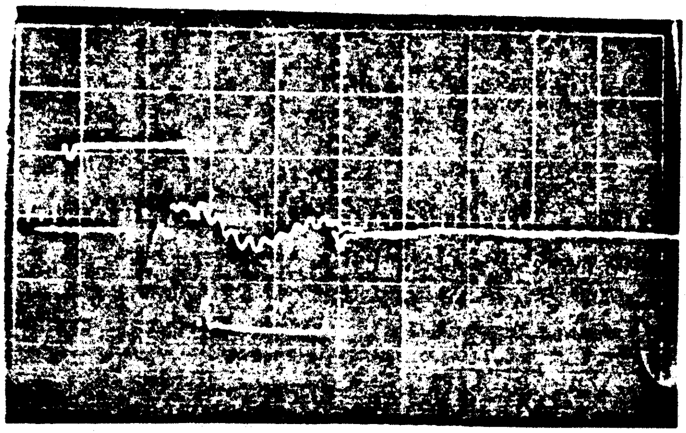
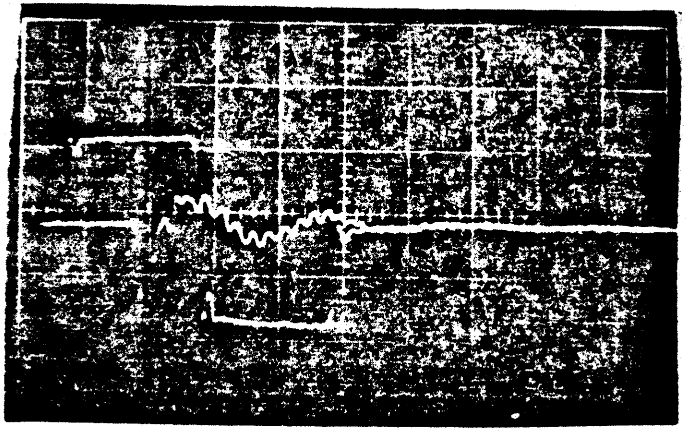


Figure 2. Typical Installation, Externally Mounted Data Transmission Link (and Sensor) for EMP Testing of a Vehicle in a Pulsed Field Simulator



(a) Sensor Properly Bonded



(b) Sensor Isolated W/One Sheet Mylar

Figure 3. B-dot Sensor - Bonding Effects on Derivative Data

sensor had negligible effect on the measurement. Figure 4 shows the oscilloscope waveforms on the D-dot measurement with (1) the sensor properly bonded, (2) isolated from the missile skin with one sheet of mylar and (3) isolated from the missile skin with five sheets of mylar. As can be observed on the derivative data waveforms, isolating the D-dot sensor from the missile skin had a pronounced effect. The net result was the superposition of a higher frequency (proportional to the resonance of the LC network formed by isolating the sensor) on the derivative response data. With one sheet of mylar, the superimposed frequency was 32 MHz; with five sheets of mylar, the frequency shifted up to 85 MHz.

Figures 5 and 6 further show the integrated time domain response data and the Fourier transforms respectively. The Fourier transforms were calculated using:

$$F(\omega) = \int_{-\infty}^{\infty} F(t)e^{-j\omega t}\,dt$$

The results for the sensor properly bonded and for the sensor isolated are displayed together for ease of comparison. The superimposed frequency is most evident in the integrated time plot where the sensor was isolated with one sheet of mylar. Similarly, the corresponding Fourier transform plot shows a sharp resonance at the superimposed frequency. The integrated time plot where the sensor was isolated with five sheets of mylar does not show as pronounced an effect, primarily due to the smoothing characteristics of the numerical integration routine. The superimposed frequency of 85 MHz is clearly evident on the corresponding Fourier transform.

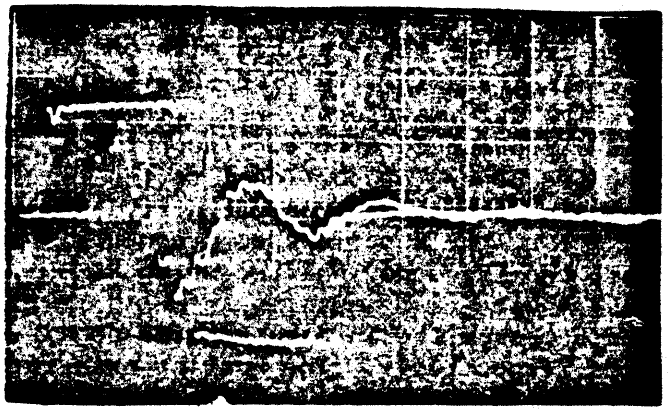
In addition to the waveform variations discussed above, there was a 10% decrease in the integrated time domain amplitude (O-Peak). The decrease was approximately the same for the sensor isolated with both one and five sheets of mylar.

B. Instrumentation/Vehicle Interaction

The installation of instrumentation on a test vehicle can perturb the response of the vehicle to the pulsed field. For instance, the presence of a screen box in the vicinity of a probe (HSD or MGL) which is monitoring charge density or skin current density can scatter the incident field and seriously disturb the measurement.

When measurements, such as cable or wire currents, are being made internal to the vehicle, instrumentation cabling can distort the quantities being monitored. In this case, instrumentation cabling shields may carry currents which would otherwise flow on vehicle wiring. The presence of the instrumentation cabling can perturb the interior fields, and may introduce paths which shift the interior resonances of the system. Accordingly, the guidelines presented in Section II will address techniques designed to minimize these effects.

To illustrate the perturbation which can result from the installation of instrumentation, and to demonstrate the significance of employing the proper bonding techniques, the data in Figure 7 have been extracted from the Instrumentation Effects Experiment performed on the AGM-28A (reference 2). The instrumentation system used for these measurements is described in the Appendix.



9.5 volts/div.

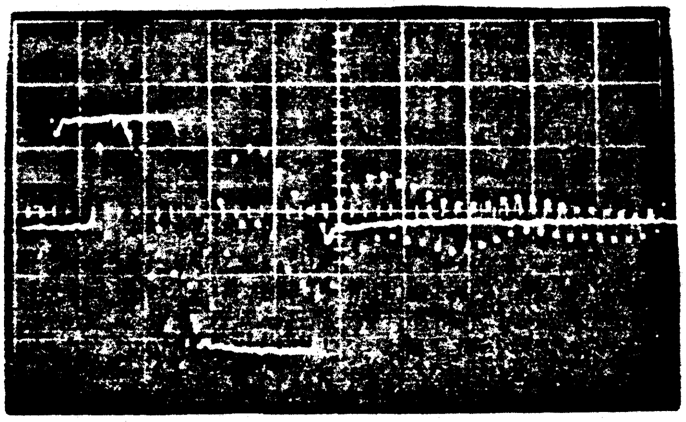
50 NS/Division

(a) Sensor Properly Bonded

6.53 volts/div

50 NS/Division

(b) Sensor Isolated W/one Sheet Mylar



6.75 volts/div.

50 NS/Division

(c) Sensor Isolated W/five Sheets Mylar

Figure 4. D-dot Sensor - Bonding Effects on Derivative Data

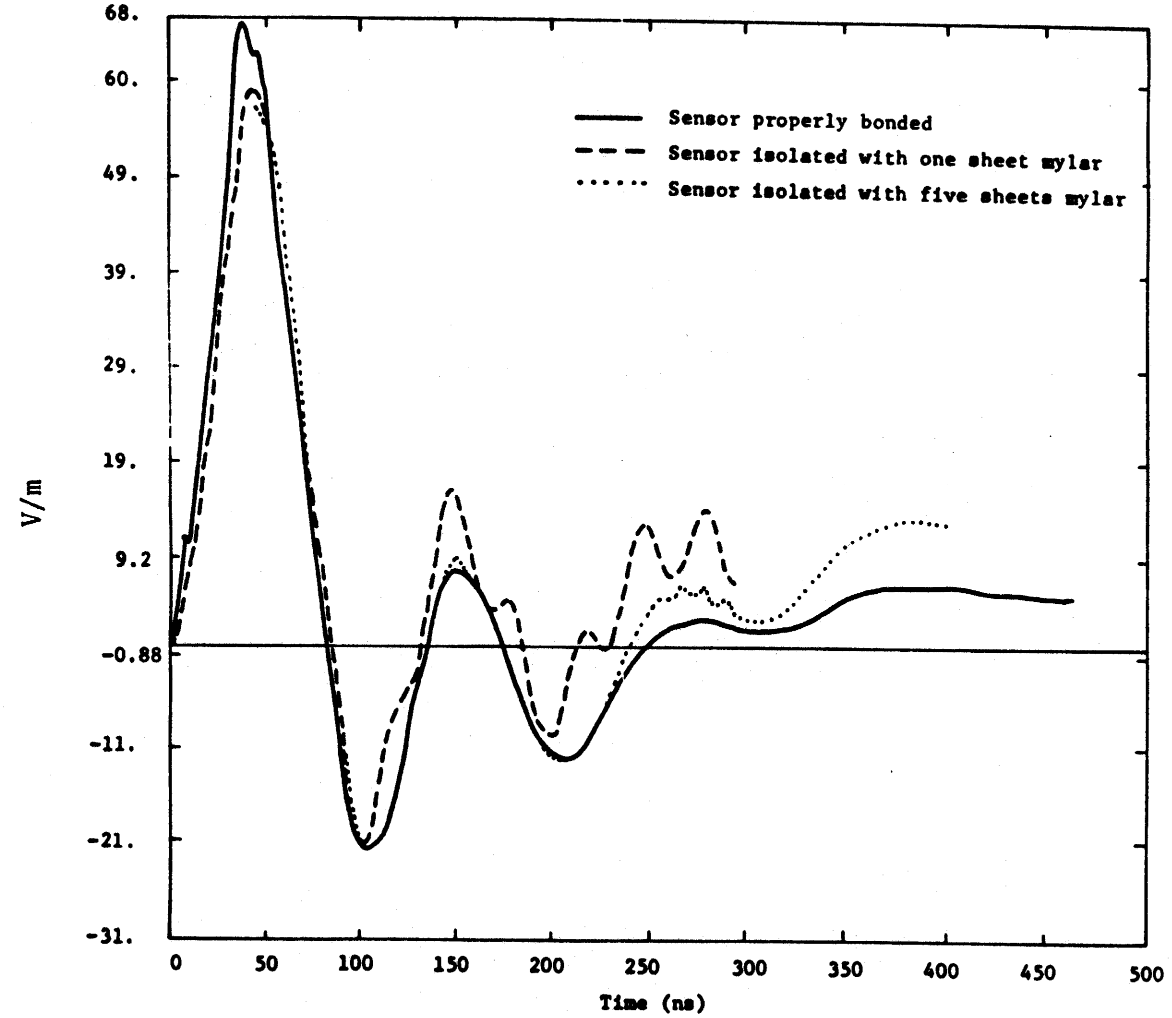


Figure 5. Sensor Bonding Effects on Measured E-field at Missile Surface

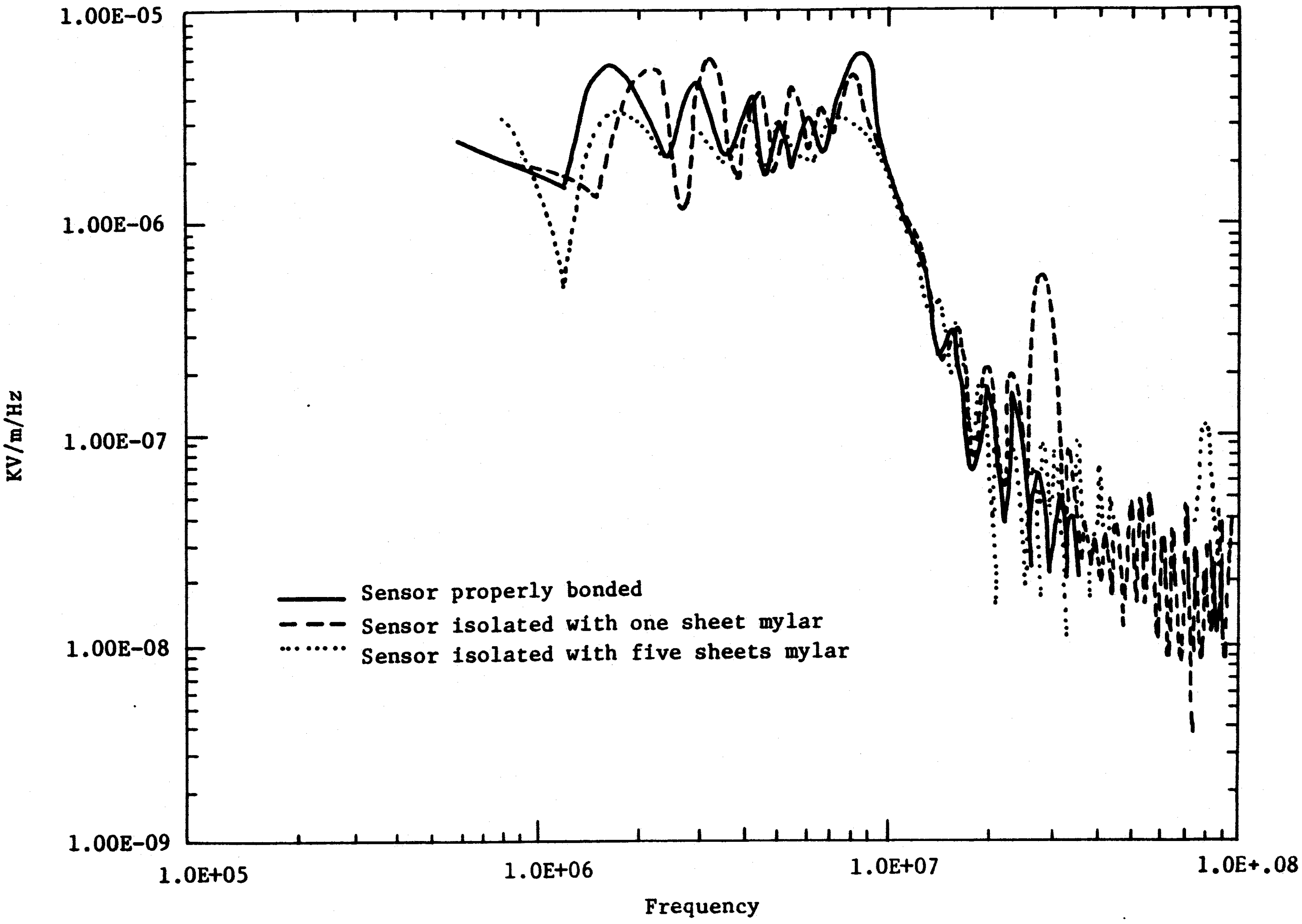
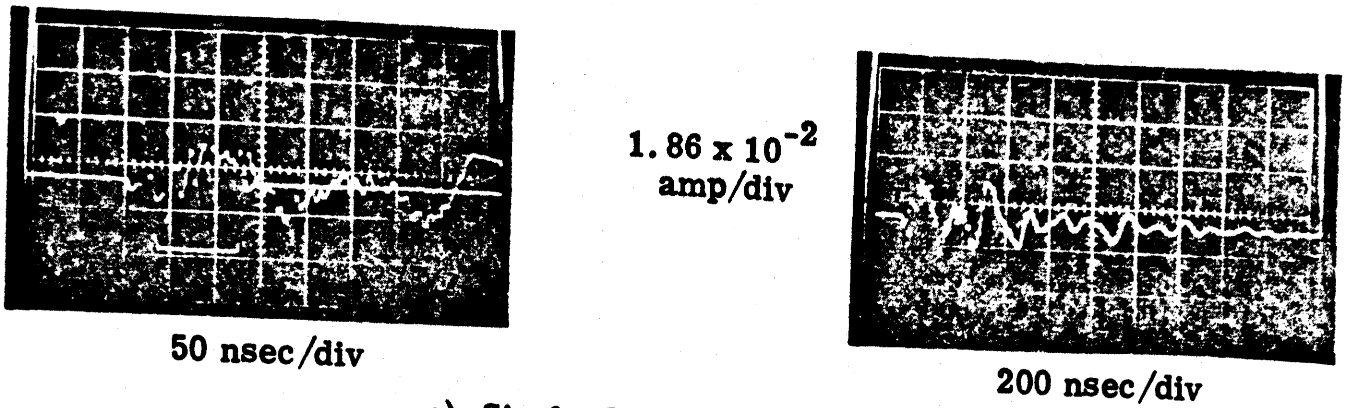
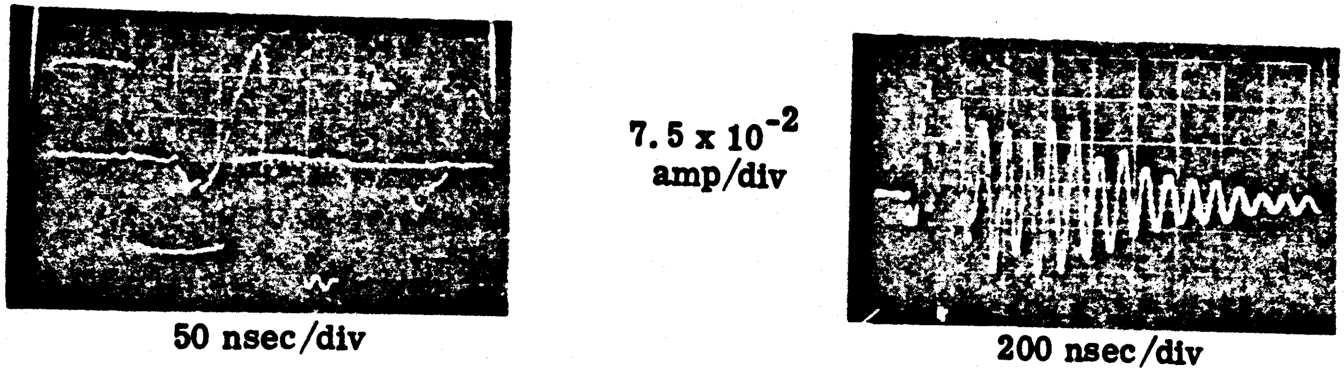


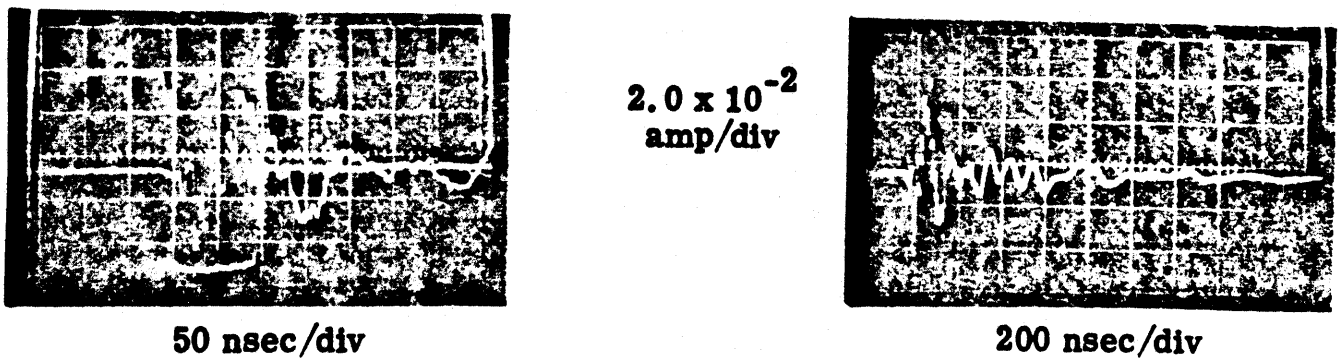
Figure 6. Sensor Bonding Effects of Fourier Transform (D-dot Sensor)



a) Single-Channel Measurement



b) 4 Channels, Instrumentation Cables Not Grounded



c) 4 Channels, Instrumentation Cables Grounded

Figure 7. Instrumentation Effects Measurements

Single channel data were taken with only a single probe and cable in the internal compartment. Subsequently the cabling for the multiple measurement instrumentation system was installed and the same point was measured again. The result of this measurement is shown in Figure 7b . The peak-to-peak amplitude increased by approximately a factor of 12 and the waveshapes were totally different with a 10 MHz ringing dominant in the multiple channel (4 channel) data as shown in Figure 8a. The differences in the frequency domain were reasonably consistent with those observed in the time domain results.

This anomalous data for the 4-channel, ungrounded instrumentation cables led to a thorough investigation of the instrumentation system. All instrumentation cables (except for those in the nose cone) were foiled and the foil bonded to the missile metal structure at approximately every foot. Nevertheless, the problem persisted. The data exhibited fluctuations from shot to shot and were very sensitive to small physical changes of the instrumentation cables near the connector feedthrough panel.

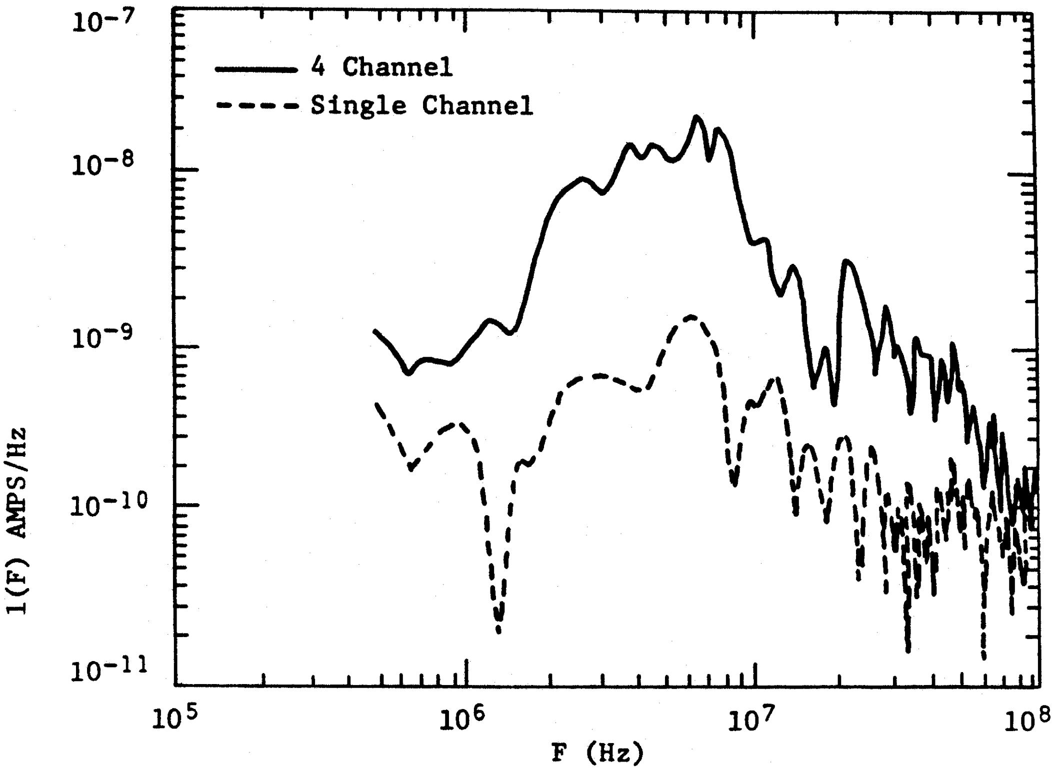
Several variations in tying the cable foil to the missile structure and shielding the feedthrough panel helped, but did not produce satisfactory results when compared to single-channel data. All of the instrumentation cables inside the vehicle were foiled and tied to the missile skin or structure at approximately every foot. The measurement was repeated and the results are shown in Figure 7c.

A comparison in the frequency domain of the single channel data and of the properly grounded multichannel data for that particular test point is shown in Figure 8b.

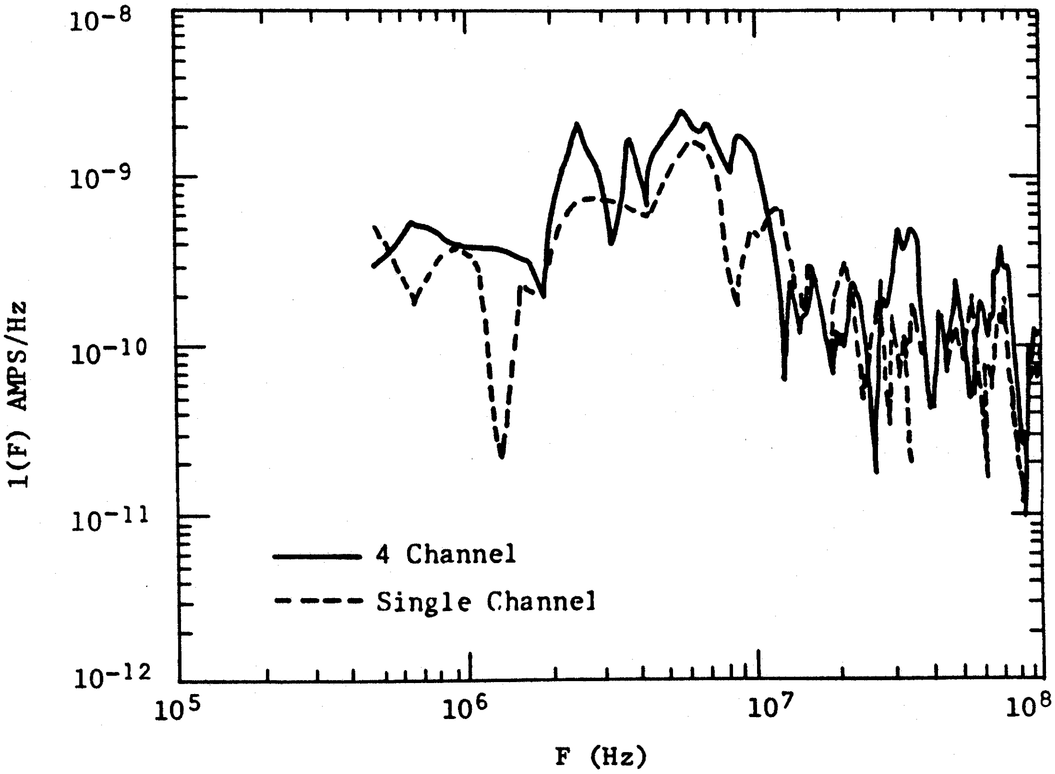
C. Instrumentation System Design

The instrumentation system should, as much as possible, be tailored to accommodate each particular measurement being made during a test sequence. Normally, vehicle response instrumentation is supplied as a part of the equipment provided in the simulation facility. The "system design" effort then primarily consists of selecting appropriate sensors, cabling, data transmission links, display and recording equipment and matching devices.

Even when selecting from existing equipment, care must be exercised. It is in this area that pretest predictions are of great value. The instrumentation engineer needs requirements: (1) expected peak amplitude, (2) maximum and minimum frequencies of interest, (3) desired accuracy, (4) type of quantity to be monitored, etc. from which he can develop the instrumentation system. The ultimate use of the test results and the amount and type of data processing need also be known to establish the need for time-tying, calibration markings, etc. Section II will contain an outline of the factors important in the specification of instrumentation system requirements.



a) Single-Channel Compared to 4-Channel, Cables Ungrounded



b) Single-Channel Compared to 4-Channel, Cables Grounded

Figure 8. Location 3-12 Frequency Domain Comparisons

II Instrumentation Guidelines

The guidelines presented in this section are not intended to be all inclusive. Indeed, the subsequent section, Section III, presents Recommendations for further study in areas which, now are considered inadequate. One pertinent area, then, which provides considerable technical challenge and is not addressed here is that of making voltage measurements in the presence of a pulsed field. This area is addressed under Recommendations.

The discussion which follows begins with a discussion of experimental approach including pretest analysis, the determination of error and uncertainty bounds, and instrumentation system specifications; guidelines pertaining to instrumentation hardware installation and use are then presented; followed by a discussion of the tests which can be made during the course of an experiment to assure the quality of the instrumentation system.

A. Experimental Approach

The subject of experimental approach belongs more properly to a discussion on testing in general, as opposed to instrumentation, in particular.

However, in establishing guidelines for instrumentation systems, or in applying those guidelines to a specific test effort, one needs to relate the instrumentation question to the larger frame of reference: WHAT is being measured, and WHY is it being measured?

Instrumentation system requirements are derived from a definition of the types of measurements needed (current, voltage, charge density, current density, etc.) and an estimate of the expected values (amplitude, frequency, duration). The first step in the process, then, is analysis: pretest predictions. These predictions need not be elaborate. For example, the preliminary predictions for the AGM-28A test in the VPD were made for the purpose of deriving instrumentation requirements. This prediction made use of Sassman's results (reference 3) to estimate peak center current and the spectral content of the induced current. The rescaled (frequency and time) normalized results: spectral content (Figure 9), phase (Figure 10) and time domain waveform (Figure 11) can be determined very rapidly, and with reasonable (within factors of two) accuracy.

Using these predictions as a basis, instrumentation system requirements can be specified. The primary parameters of interest are:

- Accuracy
- Amplitude Range
- Frequency Range
- Temporal Duration

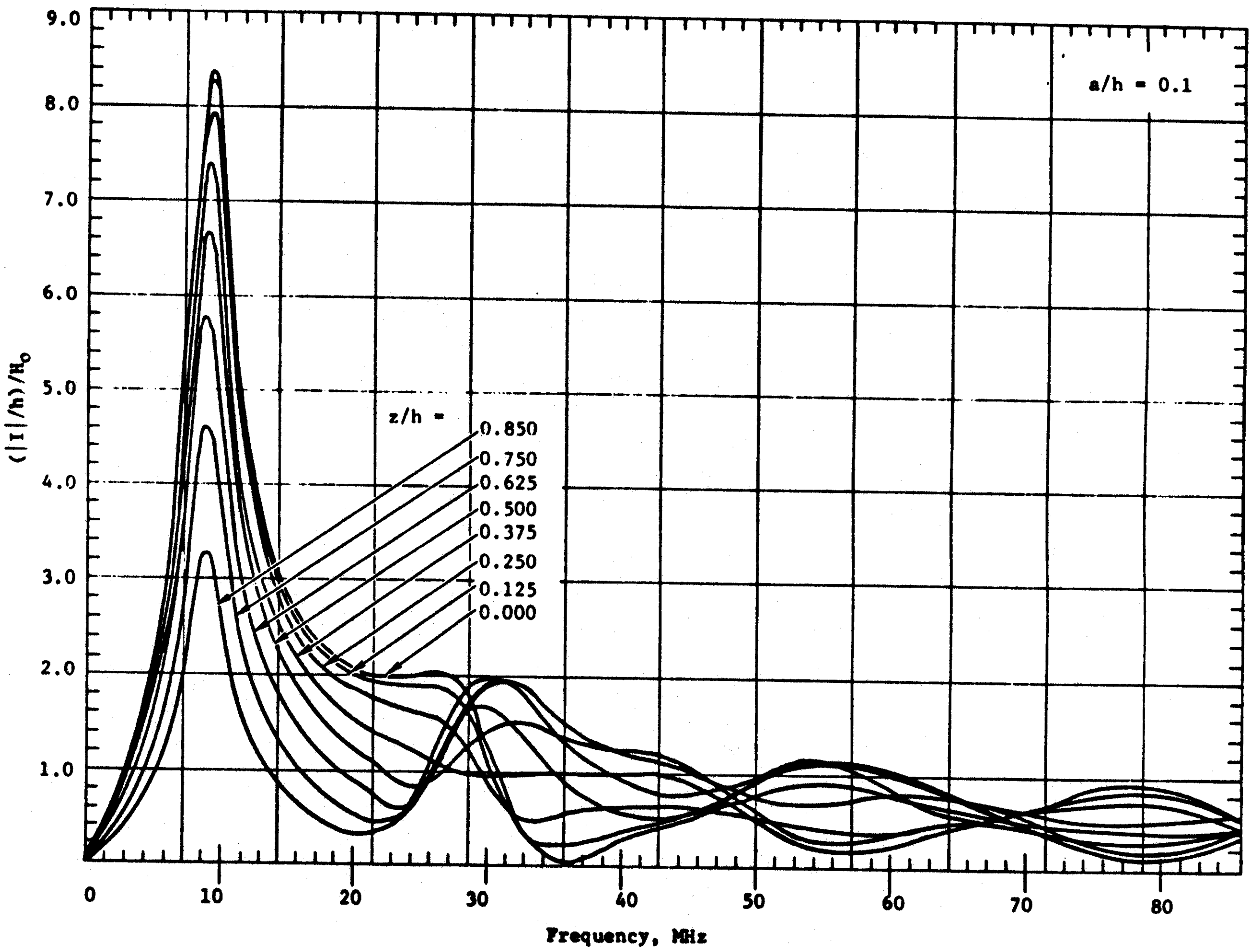


Figure 9. Magnitude of the Current on a Cylinder Scattering a Plane Wave versus f (MHz) (From IN 11)

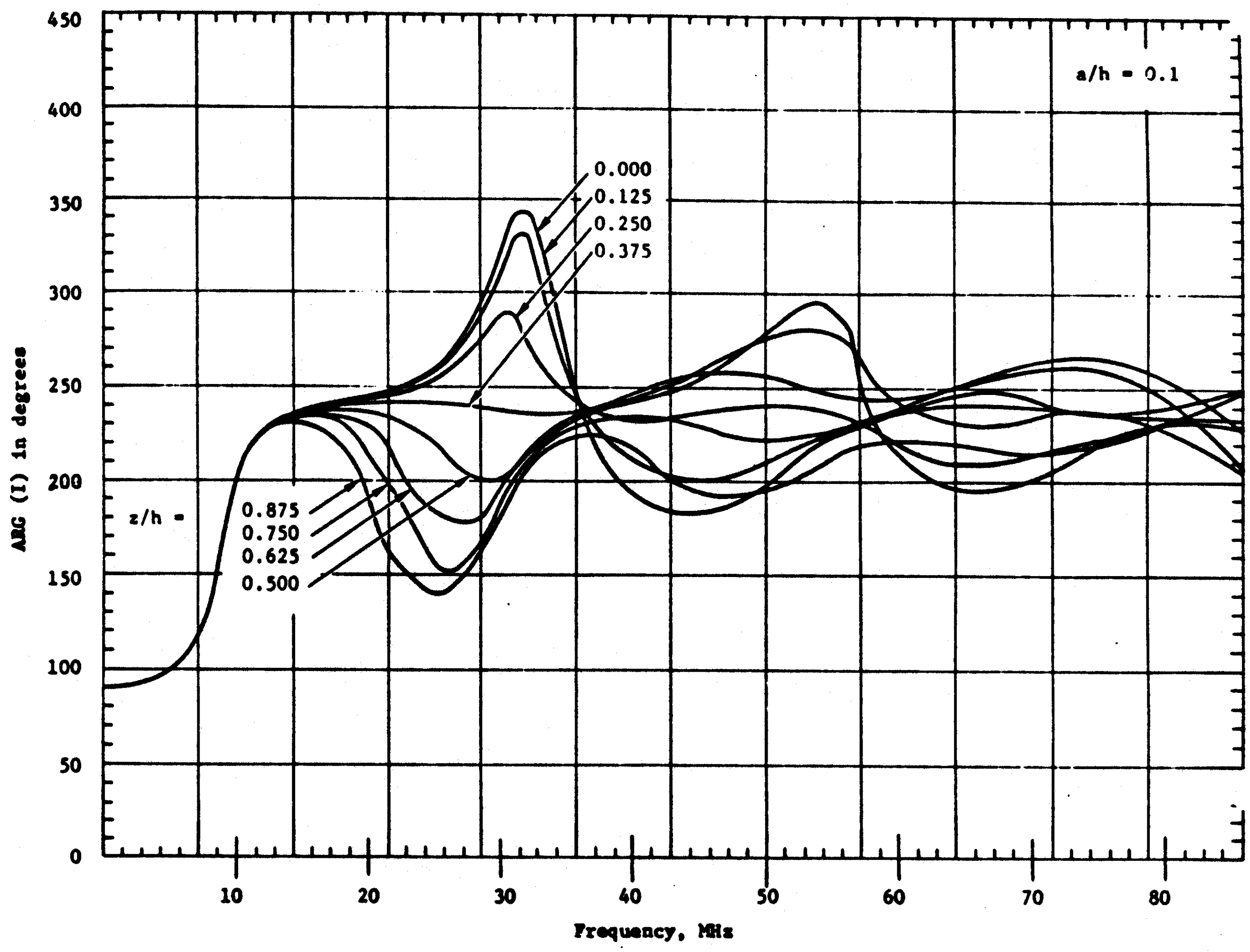


Figure 10. Phase of the Current on a Cylinder Scattering a Plane Wave versus f (MHz) (From IN 11)

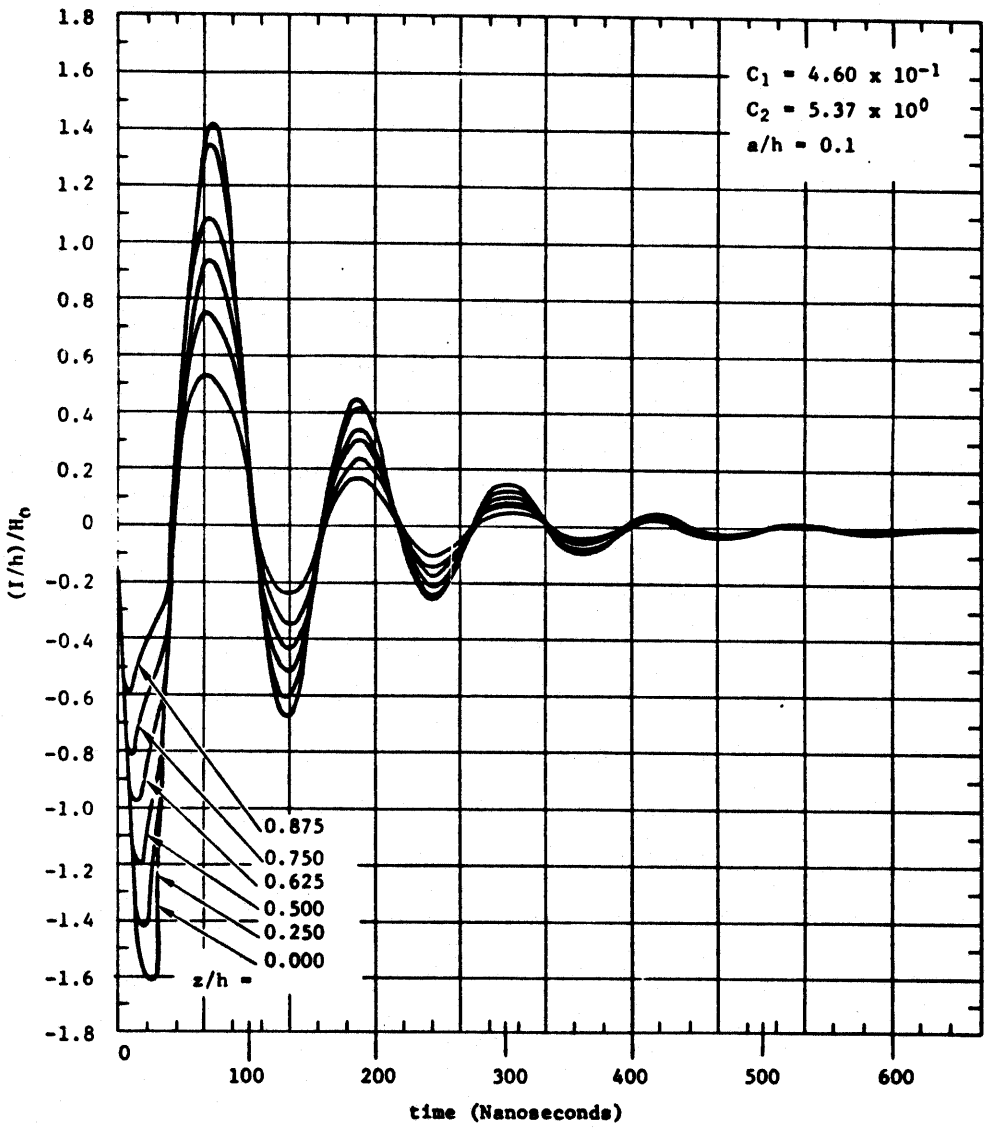


Figure 11. Current on a Cylinder Induced by the Pulse

$$\frac{H(t)}{H_o} = e^{-C_1\frac{ct}{h}} - e^{-C_2\frac{ct}{h}} \quad \text{versus t (Nsec)}$$

(From IN 11)

- Information Required for Data Processing
  - Time Ties
  - Frequency Calibrations
  - Amplitude Calibrations
- Information Required for Test Operations (Such as immediate time domain response for Quick Look Analysis)

The accuracy requirement is, in essence, a requirement on the other requirements. For instance, one wishes to know amplitude within so many dB. To specify accuracy properly, it is necessary to define the potential sources of error and uncertainty, to evaluate the range of fluctuation of each of these sources, and to combine these values in a mathematically and physically meaningful manner. For the sake of illustrating how these simplified calculations may be performed, a typical approach used is presented here. Note that the assumptions are clearly delineated. This is done purposely so that the experimenter may design tests to examine the validity of these assumptions.

In examining measurement error sources or the causes of experimental uncertainties, the question is generally approached in one of two ways:

First, one may know, a priori, the accuracy that is required for a particular experiment or test to be meaningful. In essence, one then demands the required accuracy and structures the experiment to yield data with limits within the prescribed bounds. As a typical example, consider that an analysis has been performed with a new technique or approach. Assume that the accuracy of the calculations is to be within ±6 dB, and that an experiment is to be performed to validate this technique. To demonstrate this level of accuracy, an experiment with much tighter uncertainties, say ±1 dB is required. The ±1 dB experiment, then, is a good basis for judging the validity and accuracy of the analysis.

In the second case, one is presented with an existing test facility (simulator or source, sensors, readout equipment, physical layout, etc.), and is attempting to perform an experiment utilizing this equipment. Now, he is faced with the question of determining the accuracy which can be attained with the given facility. Once the attainable accuracy is determined, one can decide which experiments can be performed in that facility which will yield meaningful results.

For example, consider the question of test vehicle positioning. It is best handled by considering it as a subset of the second case. The approach, then, is to identify and to quantify the major or significant contributors to experimental uncertainty in testing and to examine how much error can be introduced into the aircraft positioning parameter before a significant effect is seen in the overall experimental uncertainty bound.

Accordingly, in the section that follows, the main variables affecting accuracy will be identified, significant parameters for each will be estimated (μ, σ, and type of distribution) and an estimate of cumulative experimental error will be calculated. The aircraft positioning variable will then be studied to determine a limit such that significant increase to the maximum cumulative experimental error bound does not result.

In order to simplify this first order estimate of errors, we make the following assumptions:

1. Each error source is independent of the others, thus, the estimates of cumulative errors is a combination of independent variables.

2. The shape of the distribution of all variables is Gaussian. (One may invoke the Central Limit Theorem to justify this assumption provided the sample size is large.)

3. The mean value, μ, for all variables is 0. That is to say that we are not considering bias or "offset" errors.

4. All distributions are symmetric about the mean value.

Let us reiterate that these are arbitrary assumptions designed to simplify this rough analysis. They are deemed to be reasonable, but have not been unambiguously demonstrated to be irrefutable facts.

The variables considered significant are listed in Table I.

1. Environment Simulation - In this variable we are looking at the uncertainty of knowing the true value of the pulse produced, shot after shot at the test facility. (Facility environment is not being compared to a specification HAB environment.) The ±6 dB is a somewhat "off-the-cuff" estimate, and deserves to be better defined.

2. Instrumentation - This error source includes cable loss, cable-to-cable and cable-to-sensor and cable-to-oscilloscope mismatch, calibration, linearity, and drift tolerances on oscilloscopes, and the inherent limitations of presenting broadband data on Polaroid photographs. A ±3 dB tolerance seems a reasonable estimate for these sources of uncertainties.

3. Data Reduction - Much has been written by EG&G and others on this subject. The error in both digitization and the subsequent computer processing has been discussed by both EG&G and by RI-Autonetics (J. V. Locasso). For Fourier transforming, a ±1 dB error in the vicinity of the peak spectral response can be expected, but these errors grow either side of this frequency. A ±3 dB limit is deemed to be a conservative estimate.

4. Operational Effects - In the areas of data and measurement repeatability, precise sensor positioning, etc., experience dictates ±3 dB as a reasonable bound unless extreme care in every aspect of test set-up and test vehicle configuration control is exercised.

TABLE I

TYPICAL SOURCES OF EXPERIMENTAL UNCERTAINTIES IN EMP TESTING

1. ENVIRONMENT SIMULATION (±6 dB)
    - A. Peak Amplitude Variation (Shot-to-Shot)
    - B. Spectral Content
    - C. Non-Principal Components
    - D. Near Field and Test Object Scattering
2. INSTRUMENTATION (±3 dB)
    - A. Sensors
    - B. Cables and Connectors
    - C. Oscilloscopes
    - D. Photo Presentation
3. DATA REDUCTION (±3 dB)
    - A. Digitization, Fourier Transforming, Etc.
    - B. Manual Process for Response Data
4. OPERATIONAL EFFECTS (±3 dB)
    - A. Sensor Mounting
    - B. Data Repeatability
5. AIRCRAFT POSITIONING

5. Aircraft Positioning - One could rather well make a case for including this variable under operational effects, above. However, in light of the primary purpose of this example, it seems more sensible to treat it as an independent major element. At this point in the discussion, let us arbitrarily assign a ±1 dB bound, and reserve the right to revise it if the analysis shows that such can or should be done.

Let us now calculate a Cumulative Experimental Uncertainty estimate (CEU). On the assumption of the independence of all of the variables, one may view the CEU as an n dimensional vector where each parameter is an orthogonal element. Thus, one can compute the resultant, the CEU:

$$\text{CEU} = \sqrt{a_1^2 + a_2^2 + \ldots a_n^2}$$

For this case:

$$\text{CEU} = \sqrt{(6)^2 + (3)^2 + (3)^2 + (3)^2 + (1)^2}$$

$$\text{CEU} = \sqrt{64} = 8 \text{ dB}$$

This is, of course, tantamount to calculating the RSS error.

Let us now assume that ±8 dB is indeed both a desirable and achievable error bound for the proposed experiments. One now wishes to examine how much additional error would be introduced by allowing the aircraft positioning variable to increase. Figure 12 shows a plot of CEU vs. various values for the aircraft positioning variable, P.

The value of performing an accuracy analysis BEFORE design of the instrumentation system cannot be overemphasized. All factors of design: sensor selection, data link design/selection, allowable tolerances on noise are directly influenced by the results of the accuracy analysis.

In summary, then, under Experimental Approach, three significant points have been addressed:

1. Pretest predictions are essential to determining instrumentation system requirements and therefore must be performed prior to development of requirements.

2. Instrumentation system design requirements should be developed for each experiment. They should be based on the predicted observables (values/quantities to be measured) not on the capabilities and limitations of existing equipment. (One may eventually "trade off" between what is desired and what is possible, but, for the initiation of the study, requirements designed to get all desired data within desired accuracy should be stated.)

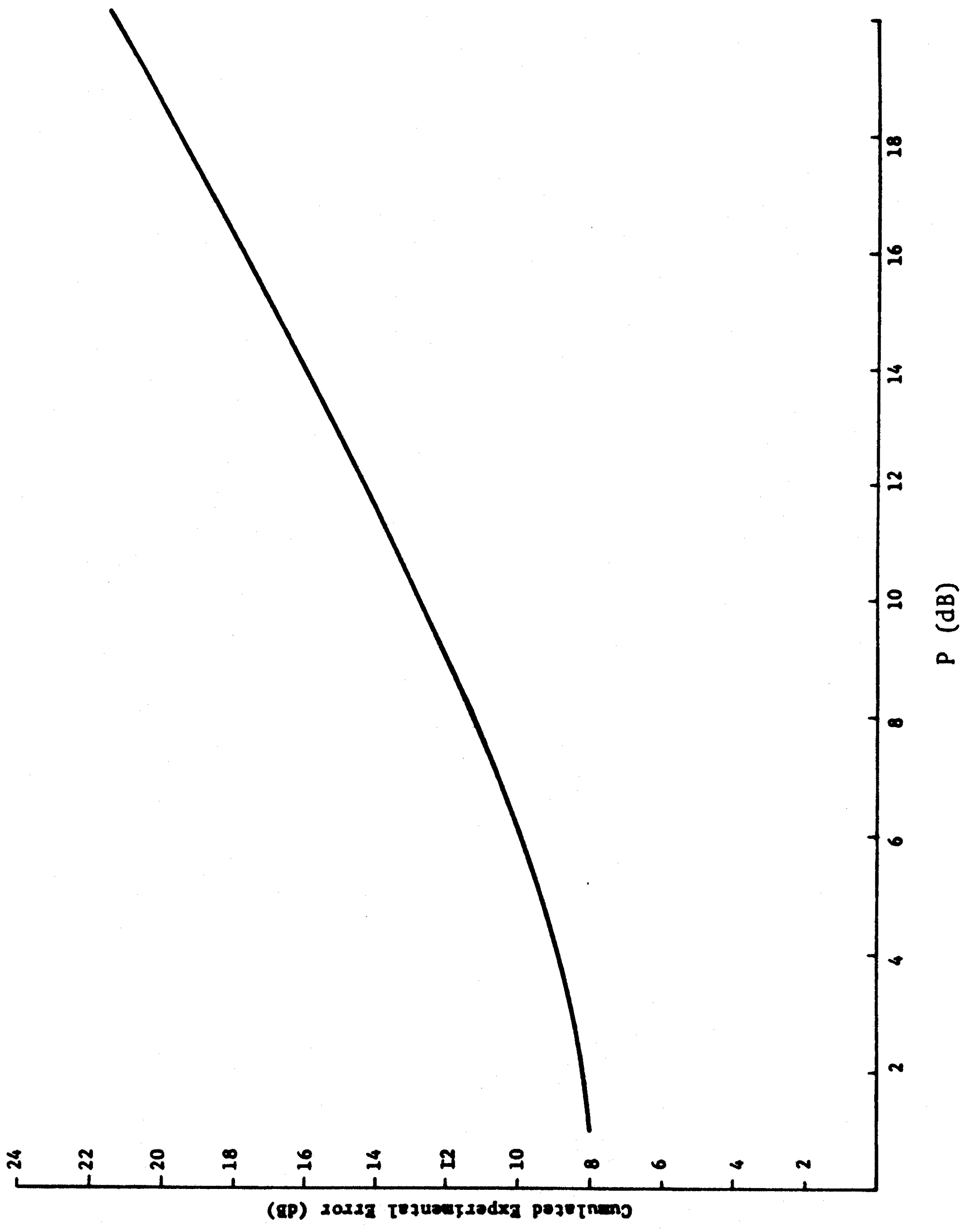


Figure 12. Aircraft Positioning Error, P (dB)

3. An accuracy analysis must be performed at the initiation of the specification/design effort. This analysis initially may be greatly simplified. It should be reviewed and refined as the experimental program becomes better defined.

B. Instrumentation Selection and Installation

The guidelines presented in this section are designed to assist in the selection of the elements of the instrumentation system such that system requirements are satisfied. Packaging and installation guidelines directed towards minimizing noise pickup and towards minimizing perturbations to the response of the vehicle under test are also presented.

In the selection of the hardware to be used in the instrumentation system, care must be exercised in the area of examining the response of the "end to end" system. As an example, consider the selection of a system to monitor skin current density. If an MGL-5 is selected as the sensor, it has a frequency response (upper bound) of 800 MHz and an equivalent area of 10^{-3} meter^2. Consider that the upper bound on the spectral content of the field of the simulator is 100 MHz. Because of the small equivalent area, the signal out of the sensor will be in the 5 millivolt range. If a Tektronix 454 oscilloscope is used to monitor this output, recall that, on the 5 mv/div. scale, the upper frequency limit is 60 MHz. Clearly, this system, then, does not satisfy the requirement of examining the skin current density across the frequency region of interest (to 100 MHz).

It is often difficult, especially when attempting to examine these "requirements vs. hardware" capabilities for large numbers and different types of measurements, to examine in the required detail, every aspect of each measurement. The matrix presented in Figure 13 is an illustration of a technique directed towards assisting in the "bookkeeping" aspects of this process. Had this skin current density measurement example cited above been worked on the matrix, the 60 MHz limitation of the RECORD DEVICE (the Tektronix 454 oscilloscope) would have been clearly evident. When this LIMITING VALUE is compared with the REQUIREMENT entry, it would have been obvious that the system proposed needed improvement. The titles on the chart are not intended to be exhaustive. Clearly, as the program and/or demands of particular experiments vary, the entries under FUNCTION will be modified as these changes demand.

It should be noted that factors such as interaction among the various elements, e.g., the loading of an amplifier by a sensor, are not accounted for in this table. The selection process, then, given the requirements, should be:

1. Select candidate hardware elements

2. Prepare a breakout matrix

3. If results from the matrix are consonant with the requirements, examine system for interaction efforts (loading).

Functions	Requirements	Hardware Elements							Limiting Value	Comments
		Sensor	Cabling	Signal Conditioners	Match. Network	Data Link	Record. Device	Data Reduction		
Upper Frequency										
Lower Frequency										
Maximum Amplitude										
Minimum Amplitude										
Time Duration										

Figure 13. Instrumentation System Requirements Breakout Matrix

In the area of instrumentation system installation and packaging, the objective is as stated above, twofold:

1. Minimize noise pickup by the instrumentation system

2. Minimize perturbation to the system under test

Guidelines for rf packaging and for shielding and grounding are presented in reference 4, "Design Guidelines for EMP Hardening of Aeronautical Systems". Those factors considered most pertinent to achieving a "good" instrumentation system installation are listed here. (A discussion quantifying the term "good" is presented following the listing of these factors.)

1. Sensors

   - Externally Mounted (HSD, MGL) - Clean surface of corrosion and paint. Then, bond sensor to surface. For temporary installations (up to a few days) copper tape is acceptable.

   - Internally Mounted (Current Probes) - Use well shielded probes. Stoddart 91550-2 is an excellent example. In areas where very high peak currents (100 amps or greater) are anticipated, it is advisable to insulate the probe shield from the wire or wire bundle under test.

2. Cabling

   - Externally Used - Shielded cable, with a solid tube used as an outer shield is preferred. (Recall that with some skin current density sensors, the signal being monitored can be very small (a few millivolts). Minimizing noise coupling is, therefore, very significant.)

   - Internally Used - Double layer braid is preferred. If the system installation permits, solid outer shield cable is superior. (Should the chosen cabling system prove inadequate, wrapping the cables - individually - with aluminum foil will usually improve the shielding effectiveness. Running the coaxial cables through a conduit will also improve performance if noise pickup on the shields is the major problem.)

3. Grounding

   - Instrumentation Package - Ideally, the instrumentation package should be mounted to yield minimum perturbation to the vehicle/system under test. Usually this is achieved by placing the package inside the vehicle. The package case should be grounded to vehicle structure.

   - Cable Shields - All cable shields should be grounded at .1 wavelength intervals of the highest frequency of interest. For tests in ALECS, ARES and VPD, 12 to 18 inch intervals are satisfactory. The structure bonding point should be clean, bare metal. A wide (1 inch) strap should be used to tie the cable to the structure. One inch wide copper tape has been used successfully in the AGM-28 free flight tests at the VPD.

4. Connectors

- Threaded connectors are preferred. Tests indicate (see reference 4) that 90 - 100 dB shielding effectiveness can be obtained with type N threaded connectors. (Carefully wrapping connector and back shell areas with aluminum foil will improve shielding in areas where connectors are found to be leaking.)

5. Cable Routing

- In achieving the objective of minimizing perturbations to the system under test, cable routing should blend in with the electromagnetic topology of the test vehicle. Thus, instrumentation cables should be routed along the walls of a bay not strung across it. External cabling should be routed along and on the metallic surface of the vehicle structure. Running cables across cracks or apertures (such as door seams or windows) should be avoided. This is true for both internal and external cable runs.

As stated above, these guidelines are directed towards achieving a "good" instrumentation system. In quantifying the term "good", two areas need to be addressed: (1) noise, and (2) system response perturbation.

In considering the specification of "acceptable noise level," it is necessary to examine both what is required and what is achievable. In terms of guaranteeing that frequency domain data derived from Fourier transforms (via computer processing - CDC 6600) of time domain waveforms are essentially unperturbed by noise, a minimum signal to noise ratio S/N of 10:1 on the time domain data is required.

Our experience in ALECS (Minuteman), ARES (Minuteman) and VPD (AGM-28A free flight) indicates that this is an achievable requirement. On the recent AGM-28A tests (reference 1) noise levels of 1.0 millivolts (O-P) were achieved. Thus, signals as low as 10 millivolts, the 10:1 S/N requirement was satisfied.

With regard to system response perturbations, real system results (reference 2) indicate that ±1 dB is an achievable bound. The discussion on accuracy bounds presented in Section II illustrates the point that, at ±1 dB, this error will not be the major contributor to the system test error bounds.

C. Tests and Crosschecks

In this section, the tests and crosschecks which can be used to assure that a good instrumentation installation has been achieved are discussed here. It is not the intent of this section to present detailed procedures for each type of test. Rather, the tests and their use are described.

1. Minimum Instrumentation Test - The purpose of this test is to determine that the perturbation to system response due to the presence of instrumentation is minimal and to quantify that perturbation. A detailed description of how this test was accomplished for the AGM-28A is contained

in reference 2. Basically a single probe and its cable is connected to a small data link (EG&G single channel microwave transmitter) and response observed at a single test point. This probe and cable are then removed and the test is repeated for another test point. The process continues until all test points have been examined or until a representative sample of test points in each bay has been monitored.

The total instrumentation system (usually multichannel) is now installed and the "control" test points are monitored with the multichannel system. The results are compared, discrepancies noted and corrective action taken.

This test is deemed mandatory in any program where large numbers of sensors and multichannel systems are employed. (For the AGM-28A a four channel data link and 16 sensors were used.)

Instrumentation system configurations employing external sensors (HSD's, MGL's) can be checked by disconnecting the cable at the sensor and shorting the signal line to shield at the connector.

2. Noise Reference Measurements - In this type of cross check, the instrumentation system is disconnected from the measurement point at the measurement point, the simulated EMP environment is applied and the response observed. The objective of this test is to determine the noise picked up by the instrumentation system. For current probe measurements, the probe is set up adjacent to the bundle or wire in which the signal is to be monitored (the wire/bundle therefore is not penetrating the probe, and no response should be observed.) This measurement should be made at every test point during the instrumentation system checkout phase of the test.

A "dummy reference" probe can also be set up in each bay where currents are being monitored. This probe should be monitored during instrumentation checkout and on every shot during the test sequence when current probes in that bay are being monitored. This reference will provide shot-by-shot confidence that the noise environment in the bay and on the system segments used in the bay are stable during the test.

3. Ambient System Noise - Several test runs should be performed with no applied EMP simulated environment. The results of these tests will serve to quantify the ambient noise levels in the instrumentation systems active electronics.

While these tests are reasonably straight forward to describe, they are time consuming to perform. However, their value to the program should not be underestimated. Knowing the noise level in the instrumentation and knowing that it is not perturbing the measured data is vital to a successful test effort.

III. Recommendations for Further Study

The guidelines presented here clearly do not address all cases or include all areas of concern and interest. Accordingly, recommendations for initiating or continuing efforts in this area are presented here.

1. It is recommended that standard instrumentation checkout procedures be developed. These procedures should be written on two levels: (1) subsystem and (2) instrumentation installed in the test vehicle.

2. It is recommended that standard specifications be provided for instrumentation elements. This effort is largely in process at AFWL (EMP Sensor Handbook, etc.). However, areas such as cable shielding specifications, etc., should be included.

3. It is recommended that, rather than operating on guidelines, standard installation procedures be developed for sensor installation, cabling installation, etc.

4. It is recommended that a uniform approach for determining test accuracy be developed. The approach should be structured so that the results of the standard instrumentation checkout tests can be used as the "instrumentation system" error term in the accuracy calculations.

5. It is recommended that standard procedures be developed for periodic "in vehicle" checkout of the instrumentation systems.

6. It is recommended that calibration traceability to the National Bureau of Standards be examined for each of the elements (sensors, cabling, data link, display and recording) in the instrumentation system.

IV. References

1. C73-676.3/201, "Final Test Report, VPD/AGM-28A, Limited External Coupling Experiment," W. H. Cordova, Autonetics, 31 August 1973

2. AL-977, "Final Report, VPD/AGM-28A Instrumentation Effects Experiment," M. Bumgardener, EG&G, Inc., 15 August 1973

3. IN 11, "The Current Induced on a Finite Perfectly Conducting, Solid Cylinder in Free Space by an Electromagnetic Pulse," R. W. Sassman, July, 1967

4. C72-451/201, "Design Guidelines for EMP Hardening of Aeronautical Systems," G. E. Morgan, J. C. Erb, Autonetics, 9 August 1972

APPENDIX

Description, Instrumentation System Used to Acquire Experimental Data.

The experimental results presented in this note were obtained during the testing of the AGM-28 Missile at the AFWL Vertically Polarized Dipole Facility. Two instrumentation systems were used for these experiments. Both are 50 ohm single ended systems, using a microwave data transmission link. Dielectric waveguide is used to connect the transmitter in the test vehicle to metallic waveguide on the ground plane of the test facility. Receivers and oscilloscopes were placed in a solid metal screen room to ensure adequate shielding.

For "minimum instrumentation" measurements, the single channel configuration shown in Figure 1 was used. A single short (less than 2 feet) instrumentation cable to only one probe was installed. Tektronix 454 oscilloscopes were used to record the data.

For "full-up" instrumentation system measurements, the four channel system shown in Figure 2 with cables of whatever length was necessary to connect to the measurement locations was used. Again, Tektronix 454 oscilloscopes were used for recording data.

A detailed description of these systems is presented in reference 2.

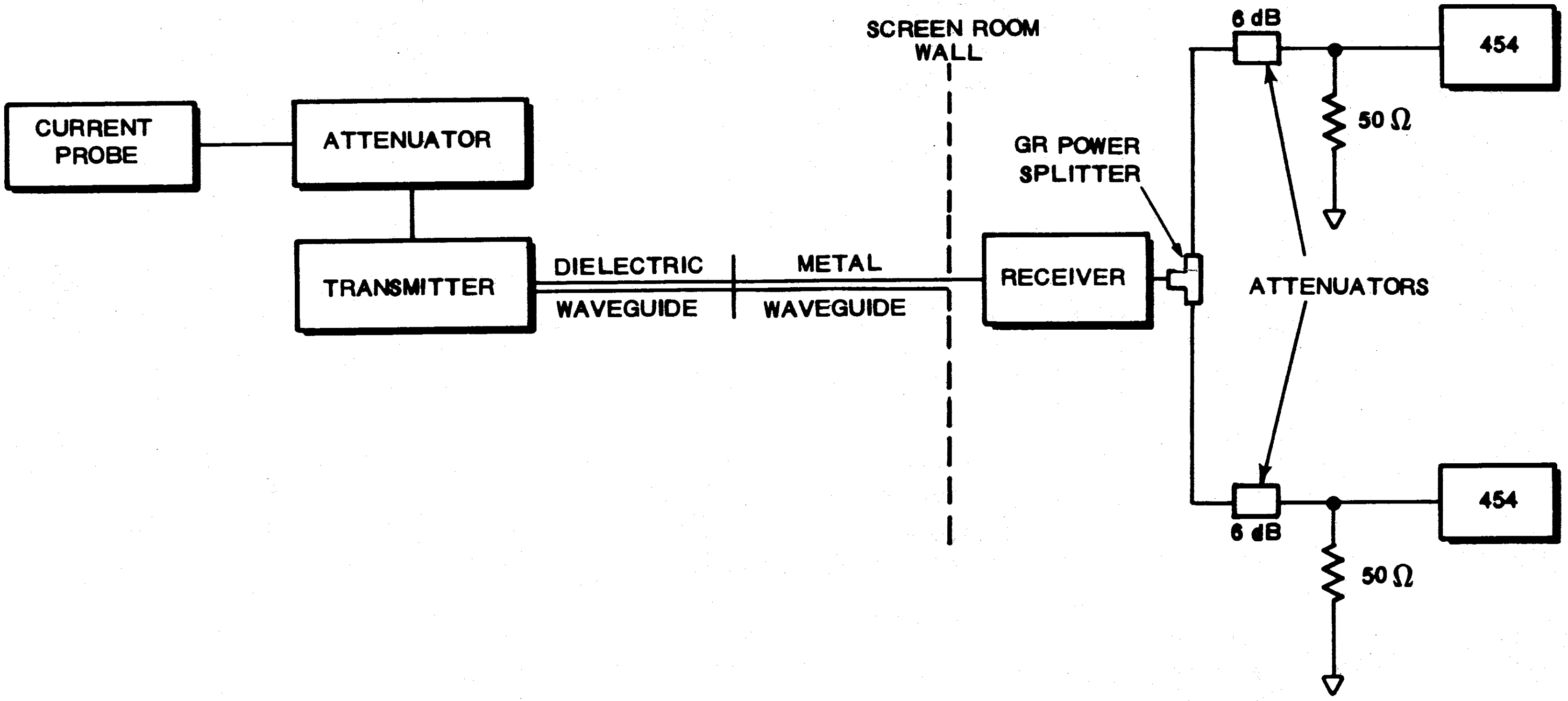


Figure 1. AGM-28A Single-Channel Instrumentation

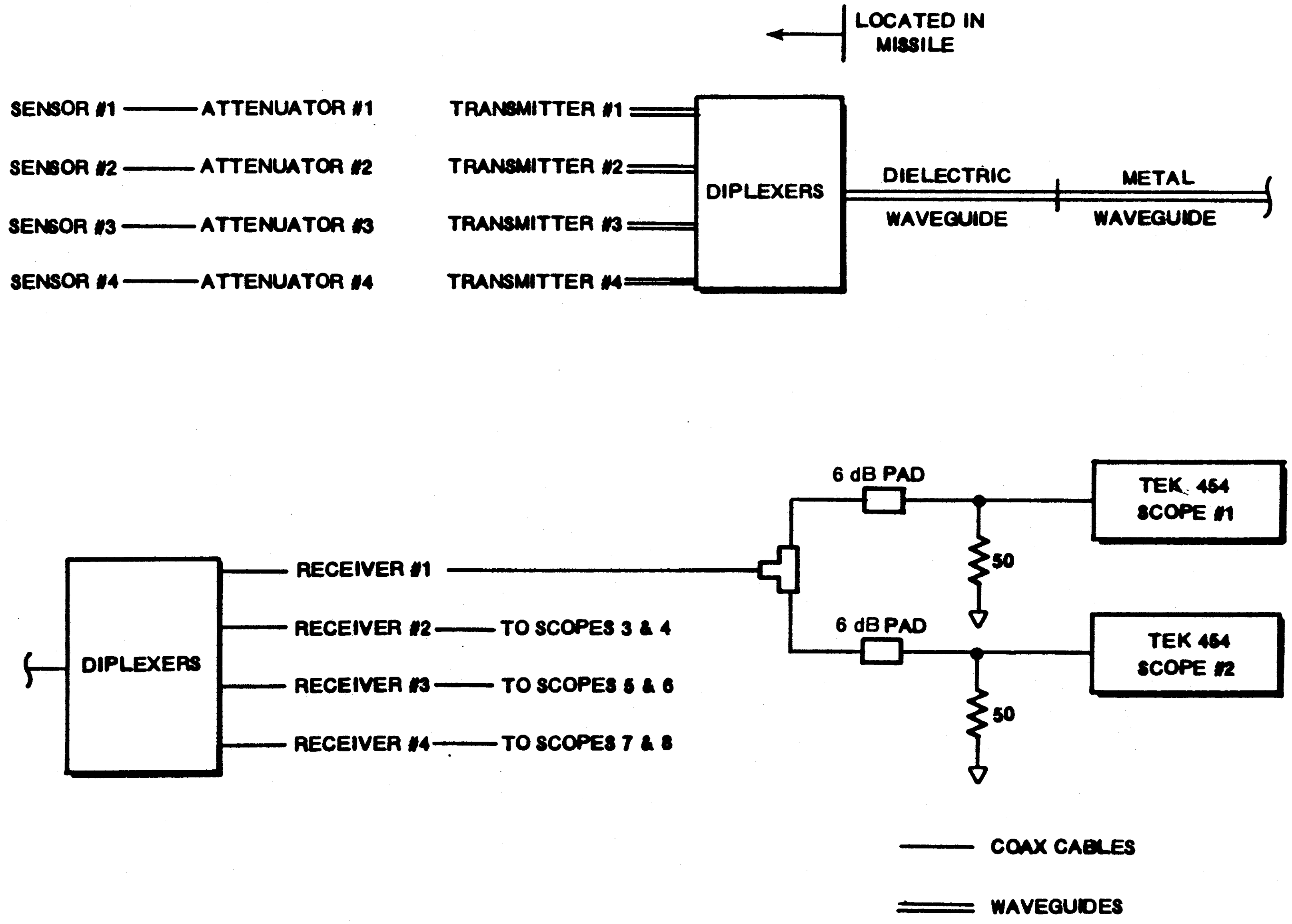


Figure 2. AGM-28A Four-Channel Instrumentation