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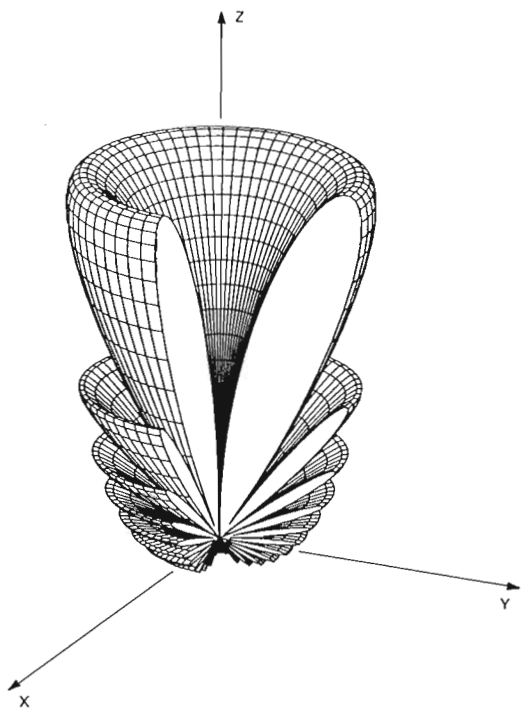
A Career (To Date) in Electromagnetics

Article by Carl E. Baum



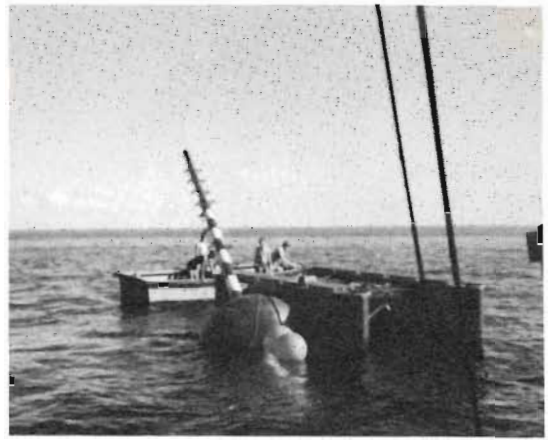
A General Program for Plotting Three-Dimensional Antenna Patterns

Feature Article by Waymond R. Scott, Jr.

A Publication of the IEEE Antennas & Propagation Society

From the Historian

William C. Croswell
Historian
625 Manor Place
West Melbourne, FL 32904
(407) 729-3110



1st Lt. Baum exercises his sea legs near the Bahamas (1965). A scene from the USS Shadwell, showing test deployment of EMP measurement system.

A CAREER (TO DATE) IN ELECTROMAGNETICS

Carl E. Baum
Air Force Weapons Laboratory (NTAAB)
Kirtland AFB, New Mexico 87117-6008

Forward

[I am pleased to offer this historical article by Carl Baum. I have known Carl since the early 70s, when much of the work described was in its early development stage. Indeed, it is interesting for me to note that Carl recommends reading the special AP issue published when I was editor of the *Transactions*. During that publication period we were having great difficulty with page limitations (700-800 pages per year), and I had a stressful time with the article-length problem. It should be noted that our present journal is nearly double the volume allowed then. Several of us at the time made a plea to AdCom to expand the length to 1,000 pages!! This was soundly defeated, because of the fear that our finances would suffer greatly, and that this change was certainly too radical a step. Perhaps this page limitation problem spurred Carl on to further expand his Notes, a worthwhile and, certainly, a widely appreciated activity. In my opinion, the growth of our Society in the past fifteen years is, in part, due to the dedication of individuals such as Carl. WFC]

A Career (To Date) in Electromagnetics

Background

How I became involved in electromagnetics is not obvious, in any early sense. My father, George, had studied mechanical engineering for two years at Pittsburgh, before taking a job with Carrier (the air-conditioning people), as a construction engineer. My pre-school years were spent six months here, six months there, etc. as George supervised the installation of air-conditioning equipment in theaters, or whatever. By the time I entered school, he was the branch construction manager in Atlanta, Georgia, where I went to school at Sacred Heart. He did see to it that my brother, Neal, and I got the best education available. When he was promoted to national construction manager in Syracuse, New York, we moved there. After a year (sixth grade) in public school, we moved into the city, and Neal and I were sent to board at Nazareth Hall Cadet School in Rochester, New York, returning to Syracuse on weekends. The nuns must have had some salutary effect, and I finished in eighth grade as Cadet Major (head cadet), with a bunch of academic medals. Among other things, I had to lead the drill team (with M-1 rifles) in various routines down the main streets of Rochester on Memorial Day, and for various other occasions. In high school I was at CBA (Christian Brothers Academy), which was a no-nonsense operation which led Syracuse in both academics and sports. Besides debate team, lead trombone in marching/concert band, and piano solo in senior musicale, I ended up valedictorian.

This led into college, and here I ended up at CalTech. As I was finishing at CBA, there was a minor conflict, in that my piano teacher wanted me to attend Eastman music school, in Rochester, where I might have studied piano, composition, directing, etc. I had given my own recitals. My father wanted me to study engineering, and he won. However, music continues to be important to me to this day, and I direct and compose for a church choir, the Cappella Choir, in Albuquerque.

And, so, I applied to and was accepted by various schools, geographically from MIT to Notre Dame, in Electrical Engineering. I guess electrical engineering related to my stereo construction in the home, and to my physics background in CBA. However, George had different ideas. I guess he liked small schools. Somehow, he heard of CalTech, and dropped in to see the Dean of Admissions on one of his many business trips to Los Angeles (where there were some Carrier subsidiaries). I was instructed to take the right college board exams, send in the application, and fly to New York City, for an interview (which was not required) with a professor, who was later my junior English professor. So, I flew off to Los Angeles, and found myself in freshman camp with professors like Feynmann. This was something of an awakening. Half the frosh had perfect scores in the advanced-math college board exam, and half were high school valedictorians. I had both, but the competition was tough.

At CalTech it was math, physics, chemistry, and then we'll think about what else. In retrospect, for an EM type, that was pretty good. With minor detours, such as chief football jock, I managed to get top engineering grades, sharing top grades with classmates

like Kip Thorne and Gary London. Also, while a frosh, I met my Fleming-student-house mate, Bill Graham, then a senior, and later President Reagan's science advisor. Both of us were in Air Force ROTC. When I graduated in 1962 with a B.S., my ROTC connection proved useful. Under an AFIT (Air Force Institute of Technology) program, I received an initial Air Force assignment, to get my MS in Electrical Engineering at CalTech. This was my first real introduction into EE, with courses in microwave devices, lasers, EM, solid-state devices, besides quantum mechanics. However, things were still quite flexible (undecided).

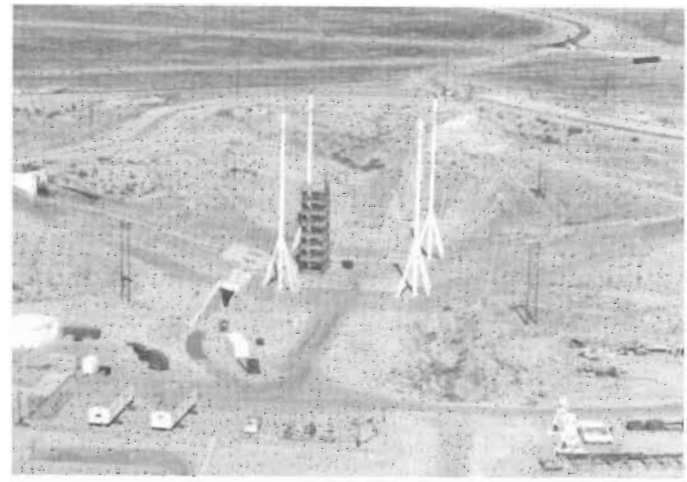
Initiation

Now it was time to go on my first real Air Force assignment. By some chance of the draw (not really, since at this time this applied to all sorts of AF ROTC types), I was sent to the "new" Air Force Weapons Laboratory. So, in 1963, I drove (with my father) from my MS ceremony to Albuquerque, New Mexico, and Kirtland Air Force Base. AFWL had an enlightened policy of having new personnel interview through the various organizations. My case, however, seemed to be an exception. It seems that I only interviewed through the Physics Branch of the Research Division. It ended up as a fight between EMP and Lasers. EMP won, basically by a ploy, to let me help Lasers by occasionally using my microwave background to measure laser-induced plasmas. Of course, that never happened.

So, Captain Henderson, the EMP chief, had me, and pointed me at the problem of EM field, air conductivity, etc., measurements in nuclear environments. It seems that the tests in 1962 had big problems. I remember touring NTS (the Nevada Test Site) and seeing antennas that might withstand the nuclear blast, but why they should measure EM parameters was beyond me. I started worrying about air conductivity (including measurements on several underground nuclear tests, noting that there was now an above-ground nuclear test ban treaty). I remember figuring out how to dramatically reduce γ-ray induced signals in B- dot measurements in some airport conversation (I forget which airport) with Dr. Ralph Partridge, of Los Alamos Scientific Laboratory (LASL). More importantly, in 1964, Ralph began the Sensor and Simulation Notes, as a way to communicate among the relevant researchers, while avoiding the bureaucracies. Quickly noting that I was writing most of the Notes, he suggested that I should take over as Editor. The rest, as they say, is history.

Meanwhile, back at AFWL, it seems I was solving some of the problems, and it was thought I should tackle some more. One Lt. (Dr.) Bill Graham (remember him, from CalTech?) was also in this group, and suggested that the testing problem was very difficult, and needed somebody (i.e., me) to tackle the simulator design problem, so we could have some facilities to produce the EMP waveforms and levels for testing real systems. So, I redesigned ALECS (AFWL/LASL EMP Calibration and Simulation – 1966) for missile testing. As we recognized at the time, ALECS was too small for the purpose, and a larger one was needed. Then one day Dr. Bill Graham, Dr. Bill Karzas (both with Rand Corporation at the time), and John Darrah put together a program to build such a simulator, and came to me for a design. By the time I went back to CalTech in 1967, ARES (AFWL/RAND EMP Simulator) was under construction.

It was really in this period, from 1963 to 1967, that I was introduced to electromagnetics by designing various kinds of special-purpose antennas. I picked up copies of books, like Smythe and Stratton, and figured out what could be done. Here were important, real problems to be solved, and I had the ability and perseverance to solve them. Noting the relatively small number in the EMP world with such skills, I decided to press on in electromagnetics and get my PhD.



Strategic missile undergoing test in ARES (about 200m long, 40m high).

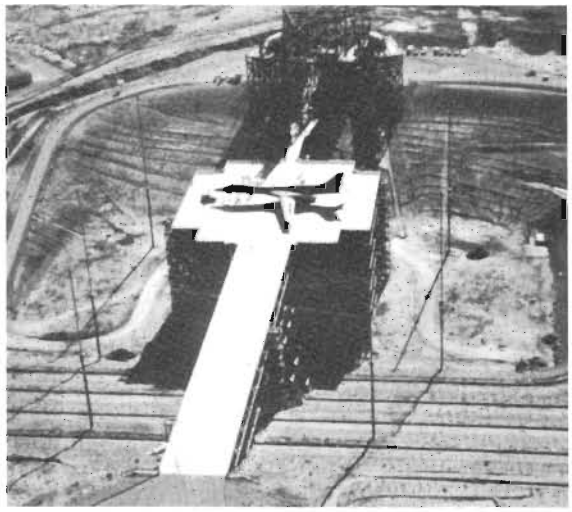
Back to School

Being then a Captain in the Air Force, I was nearing the end of my time commitment to the Air Force. At that time, there was a significant AFIT program. Under this program, both at Wright-Patterson and at various universities around the country, officers could pursue advanced degrees, in exchange for time commitments to the Air Force (then three for one).

Having been at CalTech, I had already passed "baby" orals, and taken a bunch of courses for my MS. I knew Professor Charles Papas from his EM course. With my high academic records, it was no problem to be accepted back, with Charlie as my thesis advisor. So now was the time for my "Dear AFIT" letter, for acceptance into the program. In the fall of 1967 I drove back to Pasadena. Besides school, I had other things to do for the Air Force. EMP did not stop. Arrangements were made for AFWL to write travel orders for me, so I could come to meetings in Albuquerque and elsewhere, design simulators, and participate in tests of military systems, like Minuteman. There was also a contract with the Northrop Corporate Labs, Pasadena office, for various EM computations. As the AFWL on-site monitor, I spent about every other Friday afternoon at Northrop. This is the group (now split up) that had Drs. Kelvin Lee, Ray Latham, Lennart Marin, Fred Tesche, Maury Sancer, Nasa Varvatsis, and others. Sometimes I would also go to meet with a special government committee, at TRW in Los Angeles.

As you might suspect, Major Dowler and Col. Jones (the lab commander) were busy getting me back to AFWL. I suppose the personnel system didn't know how to cope with the fact that I was coming back into the system in one year instead of two, so reason had its way (fortunately). In any event, in the fall of 1968, I drove my Corvair for the third time between Los Angeles and Albuquerque. In hand I had a "To Whom It May Concern" letter, from the Dean of Graduate Studies, saying that I had completed the requirements for the PhD. Of course, this was after an appropriate PhD party at the cabin of schoolmate Ron Pogorzelski (recent AP *Transactions* Editor) in the San Bernadino mountains.

The actual graduate time (seven academic terms in a quarter system, MS time counting) raised some eyebrows, because of the three-year residence requirement. Instead of certain course transfers, etc., which



A B1-B undergoing test in ATLAS I (central ground-plane wedge 75m high, horizontal length about 400m, width 105M, trestle test stand 36m high).

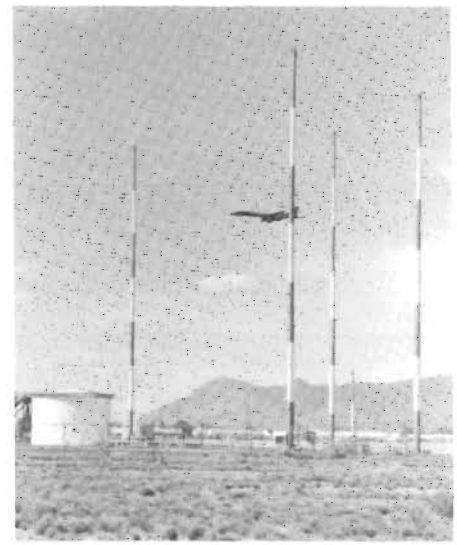
was the original plan, the faculty voted to waive the residence requirement. ("What was he supposed to do, sit on his hands for two terms?") Actually, I am told that there had been someone in physics who had completed the PhD requirements in a similar time. So, in June, 1969, it was time to monitor the Northrop contract in Pasadena, and to drop by for a graduation. Curiously enough, CalTech President Harold Brown (former Secretary of the Air Force and future Secretary of Defense), was presiding at his first commencement.

Back to the Air Force

One day after returning to AFWL, I ran into Col. Jones in the hall. He asked when I would be reassigned back here. I explained that I already was.

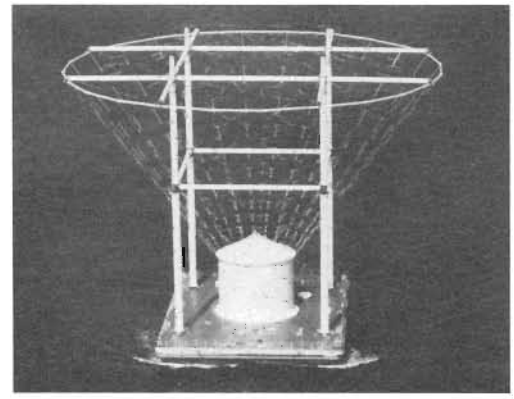
EMP simulator development was going strong. I wrote a 1969 paper, describing a simulator for large aircraft. By 1980, the ATLAS I guided-wave simulator, with the trestle test stand, was completed. Besides being a feature of the landscape when you land from the east at Albuquerque International Airport, it is a common feature on the evening news, and in newspapers and magazines. Meanwhile, the large hybrid, for systems on the earth's surface, the ATHAMAS I, and the large equivalent electric dipole, the ATHAMAS II, for things like in-flight testing, were also built. The ATHAMAS II was later used as the design concept for the EMPRESS II (on a barge), when I later helped the Navy with their own large simulator for ships (completed in 1989).

French aircraft undergoing test in ATHAMAS I (pulser 30m high, horizontal extent 150m).



ATHAMAS II, resistively-loaded wire-cage cone, 40m tall. A B1-B is landing in background.

Speaking of simulators, much of this is reviewed in the 1978 Special Joint Issue on the Nuclear Electromagnetic Pulse (January AP *Transactions*, February EMC *Transactions*), in my paper. The special EM sensors (for fields, currents, etc.), which were developed both for nuclear environments, and for the simpler environments in simulators for non-source regions, are also reviewed in another paper. This special issue was instigated by the late Dr. Tetsu Morita. Ed Vance was the Guest Editor and, as a member of the editorial board, I helped him get many of the papers. When Dick Shulz, the editor of the EMC *Transactions*, heard of the special issue, he asked to make it a Joint Special Issue. Out of this developed the Joint Technical Committee on the Nuclear Electromagnetic Pulse, which is co-chaired by Ed Vance, for EMC-S, and by myself, for AP-S.



EMPRESS II being towed at sea (40m high above barge deck).

In 1971, I left the Air Force (when my AFIT commitment was completed), and took a civil service position. The Laboratory was changing, with the leaving of the Colonels who first organized the Lab, and the influx of young technical officers was decreasing. Pressure was developing to move officers into management, and I might have been reassigned elsewhere. In general, civilian status gave me more flexibility. This was to prove useful in the late 1970s. Some did not like my views and did not want them expressed. They attempted to stop the EMP Notes, but with the help of various government agencies, allied countries, and my own money, I was able to continue until the problem went away. An interesting historical fact is that the first major bibliography of the EMP Notes was published by Derek R. Quested, of the Atomic Weapons Re-

search Establishment, Aldermaston, United Kingdom, in 1971. Since 1975, the AP-S *Newsletter* has been listing the EMP Notes as they come out.

The Interaction Problem

While work began in the 1960s on the interaction problem, the tempo became serious in the 1970s. Most of the work was on the various pieces, such as external currents and charges, antennas, apertures, cavities, cable shielding, etc. In the early 1970s, research was being funded by AFWL at various universities and a few companies, to develop a set of useful models. I remember flying around the country with Dr. Fred Tesche, who was then with Dikewood, in Albuquerque, through which most of these efforts were funded.

With the development of EMP interaction technology, it was felt that this should be compiled in some form of handbook. So, a project was born, with Dr. J. Phillip Castillo, Sgt. Harris Goodwin, and myself, on the government side, and a contractor team, headed by Dr. Kelvin Lee of Dikewood, with lots of subcontractors, involving a fair portion of the EM talent in the country. This led to "EMP Interaction: Principles, Techniques, and Reference Data," published with a public release in 1980. After various government printings, it is now available through Hemisphere Publishing Corp. (New York), and through Springer, in Europe. It is also used for an EMP short course (to be discussed later).

Perhaps more important than the pieces of the interaction problem is how to think of the whole. What are some of the general features of the interaction phenomena? Perhaps most important for system protection is the concept of EM topology, which I introduced in a paper, "How to Think About EMP Interaction." This was given in a FULMEN (Forum for Understanding the Latest Methods in the EMP Notes) meeting at AFWL, in 1974. Since then, it has appeared in various papers. It has formed the organizing principle for electromagnetic interaction with complex systems, and is used to form the basic structure of the EMP interaction book mentioned above. Besides the continuing research into the descriptive or qualitative aspects of EM topology, quantitative aspects have developed from the "good shielding approximation", followed by the use of norms (in both the frequency and time domains), to obtain bounds on system response. Being essentially the theory of electromagnetic hardening, I consider this subject to be extremely important, and one which will have to be included in engineering electromagnetics courses. It applies across the board, to protection against all sorts of interfering electromagnetic environments.

Then, there is SEM (the Singularity Expansion Method), which I introduced in 1971, for efficiently characterizing the EMP interaction problem in terms of the singularities (primarily poles) in the complex frequency plane. I called a meeting in 1971, at Northrop Corporate Laboratories, and invited various EM luminaries to discuss what might be possible. By the end of that year, I had figured out how to compute coupling coefficients, which, when added to natural frequencies and modes, completed the pole terms, and I published Interaction Note 88, with these results. This was shortly followed by notes by Drs. L. Marin and R. Latham, and by Dr. F. Tesche, treating some of the theoretical and numerical aspects, respectively. Award-winning papers, by Marin and Tesche, based on this work, appeared later in the AP-S *Transactions*.

Word spread fast. Professor Tom Senior, of the University of Michigan, asked me to present some of the results at the 1972 Spring USNC/URSI Meeting, in Washington, D.C. Then, Dr. James Wait, then of the Bureau of Commerce group in Boulder, got me to organize a special joint session at the 1973 G-AP International Symposium and USNC/URSI Meeting, at Boulder. Besides the one hundred sets of relevant EMP Notes which were passed out, another memorable occurrence was Dr. Tesche going way over his time, while Professor Sam Maley and I were trying to get him to finish up.

SEM, and its cousin, EEM (Eigenmode Expansion Method, which I introduced in 1975), seem to have generated all sorts of interest and research. Many people saw it as important for radar target identification, as well as for other aspects of remote sensing. Now I see conference announcements with lots of SEM papers, including some from people of whom I have not previously heard. Clearly, SEM has gone way beyond me and the EMP community. For summaries, one can see the 1981 special issue on Electromagnetics, and my feature article in the August, 1986, *Newsletter*. I also have book chapters in 1976 (in Felsen, *Transient Electromagnetic Fields*, Springer) and in 1978 (in Uslenghi, *Electromagnetic Scattering*, Academic Press).

In an article in 1976, in the IEEE *Proceedings*, I gave a review of transient/broadband electromagnetics. In this I pointed out that there were numerous mathematical concepts, which could be applied to EM theory, to aid in the analysis and synthesis of various EM structures. Things like topology, complex variables, and matrix and operator theory have already proven important. Differential geometry has also proven useful, for synthesizing special lenses suitable for broadband transients, such as encountered in EMP simulators and other pulsed-power applications. Professor Alex Stone, of the University of New Mexico, and I have a monograph coming out which summarizes all the results. Multi- conductor-transmission-line theory is also developing. Starting with the BLT equation for networks of such things (in my chapter in J.E. Thompson and L.H. Luessen, *Fast Electrical and Optical Measurements*, Martinus Nijhoff, Dordrecht, 1986), important new results concern the high- frequency approximation. There are other concepts which also need to be explored, like group theory for various symmetries. I had a working paper in the NSF Workshop at the PIERS Symposium at M.I.T. in July, 1989, which goes into greater depth concerning the future of EM theory.

The Europeans

From the very beginning, the EMP program developed in close cooperation with the British. For example, the pulse power for the EMP simulators is an offshoot of the work of J. C. (Charlie) Martin, of AWRE, and he was often consulted. In the late 1970s, and throughout the 1980s, other West-European countries developed programs, and started developing/purchasing EMP simulators based on my design concepts. I have often traveled to advise them on their programs. Significant programs also exist now in France, West Germany, Sweden, Holland, and Switzerland. Smaller programs exist in Norway, Belgium, and Italy. Israel is coming on strong. It is beginning to spread to third-world countries and, of course, the Eastern block is active.

Since 1979, and on odd numbered years thereafter, I have been active in organizing EMP-related sessions at the EMC Symposium, which is now held in Zurich. Symposia like this are useful, because they bring many things into the open, where they can be scrutinized by technical specialists, instead of being buried in government bureaucracy. I think that the openness of some of the West-European countries will be beneficial even to the United States.

Capt. Baum receives 1970 Air Force Research and Development Award from Secretary of the Air Force, Robert C. Seamans, Jr.

Carl Baum receives 1987 Harry Diamond Memorial Award (from IEEE Board of Directors) for "Outstanding contributions to the knowledge of transient phenomena in electromagnetics."

SUMMA Foundation

Since I was already spending my own money to publish EMP Notes, and I envisioned other support to related matters, I got an attorney to establish a not-for-profit, charitable, educational, research, etc. corporation, with all the usual legal structure. So, in 1973, SUMMA Foundation came into being. The officers now are President, myself; Vice President, Dr. Neal Baum (my brother); Secretary, Professor Shyam Gurbarani (of the University of New Mexico); and Treasurer, Dr. J. Philip Castillo (formerly of AFWL, currently with R & D Associates). Initially, the funds were donated by myself.

In the early days, the Foundation sponsored Note printing, and travel funds to get a few people to EMP meetings (people who had important contributions but no travel support). SUMMA also made a few small grants to universities, to finish up small EMP research efforts and reports. It is amazing what a few thousand dollars can occasionally do.

In 1978, we sponsored the first public NEM (Nuclear EMP Meeting), and these have been held on even-numbered years ever since. These are held in cooperation with IEEE AP-S and EMC-S, and with USNC/URSI Commissions B and E. In 1982, I chaired the Joint Symposium, in which NEM was combined with the International Antennas and Propagation Symposium and National Radio Science Meeting, in Albuquerque. In 1992, this combination is scheduled to occur again in Chicago, with Professor P. L. E. Uslenghi as Chairman. There are also discussions going on concerning possible future NEMs in Western Europe. Clearly, the NEMs have had a big impact on EMP technology through information exchange and criticism. The better papers spur on the other people to at least try to bring their efforts to a comparable level of excellence. Some questions which would otherwise be decided in government circles, based on bureaucratic turf concepts, get to be aired in the scientific community, where a consensus can be developed based on more objective criteria.

With the EMP interaction book completed and released to the public in 1980, we were in a position to use it as the basis for a short course: "EMP Interaction and Hardening" (EMP 201). With SUMMA sponsorship, it could be removed somewhat from government agency politics. This was also necessary, because we wanted a much more effective course: the students are required to work (including the evenings), instead of just sitting there. We also wanted to make the course international. It is intended primarily for industry and government engineers, who have to design EMP protection into military and/or civilian systems. It also extends into the related lightning and high-power microwave (HPM) areas.

The first course was given in 1983, in Socorro, New Mexico. Note that some isolated site is preferred, to keep the students preoccupied with the subject. Universities are often used to keep expenses down (room and board is included). Subsequent courses have been held at Nottingham, England (1984); Interlaken, Switzerland (1985); Socorro, New Mexico (1985); Yxnerum, Sweden (1986); Karmiel, Israel (1987); and Ann Arbor, Michigan (1988). The next one is planned for Bangalore, India (1989). Many distinguished EMP experts have served on the faculty (basically receiving expenses). These have included K. F. Casey, J. P. Castillo, G.H. Gurbaxani, R. L. Gardner, D. V. Giri, W. Graf, M. Ianoz, P. B. Johns (deceased), T.Karlson, K.S. H. Lee, V. Liepa, L. Marin (deceased), J. Shiloh, C.D. Taylor, F. M. Tesche, and E. F. Vance.

In the wider electromagnetics community, SUMMA has also been active. It provided a few thousand dollars to help the Electromagnetics Society and journal (begun in 1981). More recently, SUMMA has helped with the republications of classic EM books, and is beginning to help with new books.

The Future

Well, crystal balls are not very reliable. I suppose that one can extrapolate current trends a little bit into the future.

Concerning EM theory, my comments in a previous section are most appropriate, combined with the 1976 IEEE *Proceedings* article, and my upcoming NSF working paper. Basically, there are various concepts to be borrowed and adapted from other disciplines, especially mathematics and physics. The basic program is synthesis: what is possible and what is optimum? Of course, one has to ask the right questions, and here experiment has a lot to offer. After all, that's how I started looking in the direction from EMP response data to SEM.

Then there is education, particularly graduate education in EM. As I see it, there are far too few coming out of the universities, as compared to the needs of industry and government. As we know, EM is a difficult subject, so I don't really know what improvement can be made, without higher job standards in terms of academic qualifications.

I do not hazard a guess in terms of specialties with which I am not directly involved. However, the high- power transient-EM area, besides EMP and lightning, will likely expand in the HPM (high-power microwave) area, where I am thinking of rather high power microwave (GHz or so) pulses.

Concerning my own plans, besides solving more of the problems discussed above, if God gives me the time, I expect to write a few books (and encourage others to do the same) which organize the subjects discussed above.

About the Author

Carl E. Baum was born in Binghamton, New York, in 1940. He received the BS (with honor and Honeywell Award as best undergraduate engineer), MS, and PhD from Caltech in 1962, 1963, and 1969, respectively.

He was commissioned in the USAF in 1962, and was stationed at the Air Force Weapons Laboratory from 1963 to 1967, and from 1968 to 1971. Since 1971, he has served there as a civil servant in the position of Senior Scientist. He is advisor to numerous U.S. government agencies on matters related to nuclear electromagnetic pulse (EMP), and represents the U.S. in exchanging EMP information with various countries. His contributions have brought him the honors of Fellow of the IEEE, Distinguished Lecturer for the IEEE Antennas and Propagation Society, and recipient of the Stoddard Award of the IEEE EMC Society. He received the 1987 Harry Diamond Memorial Award. He has been elected to membership in Commissions B and E of the U.S. National Committee of the International Radio Scientific Union (URSI). He is known for his pioneering work in the singularity expansion method, EM topology, and differential geometry for lens design, for development of EMP simulators and EM sensors, and for editorship of the voluminous EMP Notes. He has written several book chapters and his papers have won various awards.

On a more personal note, Dr. Baum's principal hobby is music, having studied piano and baritone horn as a youth. He has kept up his interest in music throughout his adult life, and now directs the Cappella Choir in Albuquerque, New Mexico. He has composed masses and motets, in some cases with symphonic accompaniment. A singular feature of this devout Catholic is his manner of speaking in complex sentences punctuated by hearty staccato laughs. He lives a dedicated life, residing a few blocks away from his office, driving a 1962 Corvair, and has chosen to remain a bachelor.