Remembering Carl E. Baum
- Tribute to a distinguished scientist -

F. Sabath[1], *W. D. Prather*[2], *and D. V. Giri*[3]

[1]Federal Ministry of Defense, Armament Directorate IV 6, Fontainengraben 150, 53123 Bonn, Germany, Frank.Sabath@ieee.org

[2]Air Force Research Laboratory, High-Power Microwave Division, william.prather@ieee.org

[3] Pro-Tech, Alamo, CA, United States, giri@dvgiri.com

Abstract

This contribution is a tribute to a career that spanned more than four decades. Dr. Carl E. Baum was a remarkably creative engineer who introduced innumerable new concepts in mathematics, electromagnetic theory, and system design, many of which remain the standards of excellence today. From his earliest designs in electromagnetic pulse (EMP) sensors and simulators to the latest developments in high-power microwave and ultra-wideband antenna and system design, his research has remained ever on the forefront of technology. His advances in EM theory have left an indelible mark and a lasting legacy on the technical world, and have led to much of what we do today in EMP, high-power microwaves (HPM), and target identification (ID). Dr. Baum continued to be a prolific writer and publisher, and has written many technical notes, articles, and books. He was the Editor of the Note Series that has published state-of-the-art research results for the past 40 years. Among other things, he established SUMMA Foundation in 1984, a non-profit organization that awards grants to deserving young researchers the world over and sponsors short courses, symposia, and the publication of books.

1. Curriculum vitae

Dr. Carl E. Baum was born in Binghamton, New York, on February 6, 1940. He received his BS (with honors), MS, and PhD degrees in Electrical Engineering from the California Institute of Technology, Pasadena, CA, in 1962, 1963, and 1969, respectively. Following his BS, he received his commission in the Air Force and was stationed at the Air Force Weapons Laboratory at Kirtland AFB, Albuquerque, NM. He served from 1963 until 1971 as an officer, and then accepted the civilian position, and retired as Senior Research Engineer in 2005. Since than he was with the Department of Electrical and Computer Engineering at the University of New Mexico as a Distinguished Professor.

Figure 1. Dr. Carl E. Baum (Feb. 6, 1940 – Dec. 2, 2010)

During his military career, he was awarded the Air Force Research and Development Award and the Air Force Nomination to Ten Outstanding Young Men of America. His scientific contributions were notable. He wrote innumerable technical notes, articles and textbooks. He was the Editor of the well-known *Note Series* on the nuclear electromagnetic pulse (EMP) and related subjects that has published state-of-the-art research results for the past 45 years. He published four books: *Transient Lens Synthesis, Differential Geometry* in *Electromagnetic Theory*; *Electromagnetic Symmetry*; *Ultra-Wideband, Short-Pulse Electromagnetics-3*; and *Detection and Identification of Visually Obscured Targets*.

Dr. Carl E. Baum received the Richard R. Stoddart award of the IEEE EMC Society (1984), the Harry Diamond Memorial Award (1987), the AFSC (Air Force Systems Command) Harold Brown Award (1990), and the Air Force Basic Research Award (Honorable Mention) (1999) as well as five Best Paper Awards from the AMEREM /EUROEM Awards Committee. In addition, he and his research team were honored by AFOSR as a Star Team for their work in basic research in 2000-2002 and received the first annual R. Earl Good Award from AFRL (Air Force Research Laboratory) (2004) for their work in target identification. He was named an IEEE Fellow in

978-1-4244-6051-9/11/$26.00 ©2011 IEEE

Figure 2. Carl accepting the Honorary Doctorate of Engineering from Otto von Guericke University in Magdeburg, Germany

1984, an EMP Fellow in 1986, and the first AFRL Fellow in 1996. However, the honors that meant the most to him came in July of 2004 when he was bestowed an Honorary Doctorate of Engineering by Otto von Guericke University in Magdeburg, Germany, during the EUROEM 2004 meeting, and received a special honor from his colleagues in Russia for his lifetime of achievements. The Institute of Electrical and Electronics Engineers (IEEE) honored him with the John Kraus Antenna Award (2006) and the Electromagnetics Award (2007). He was also a member of Commissions A, B, and E of the US National Committee of the International Union of Radio Science (URSI). He was the founder and President of the SUMMA Foundation, which sponsors various electro-magnetics-related activities, including scientific conferences, publications, short courses, fellowships, and awards. During his career, Dr. Baum led EMP short courses and HPE (high-power electromagnetics) workshops around the globe. He was also an active organizer of scientific conferences and workshops that brought together colleagues from all over the world to share the latest in electromagnetic research.

On the personal side, Carl Baum enjoyed classical music. As a student he played the piano and the trombone. During his whole life he continued playing the piano and creating his own musical compositions. He was at one time the choir director of his church in Albuquerque. Twenty-three of his compositions have been recorded. In addition Carl had a notable knowledge of US and European history.

Carl took his last breath peacefully on December 2, 2010, in Albuquerque, New Mexico. He is survived by his two nephews, George and Spenser, and his sister-in-law, Martha Baum.

2. Essential scientific contributions

In a career that has spanned more than four decades, this remarkably creative engineer introduced innumerable new concepts in mathematics, electromagnetic theory, and system design, many of which remain the standards of excellence today. From his earliest designs in electromagnetic pulse (EMP) sensors and simulators to the latest developments in high-power microwave and ultra-wideband antenna and system design, Dr. Carl Baum`s research has remained ever on the forefront of technology. His advances in EM theory have left an indelible mark and a lasting legacy on the technical world, and have led to much of what we do today in EMP, high-power microwaves (HPM), and target identification (ID).

In order provide the reader with a brief impression on the breadth and quality of Dr. Baum`s scientific work, we dedicate the second part to a brief description of his essential scientific contributions. As a detailed description of all topics investigated by Carl Baum would exceed the space of this article we limit the description to an itemization of topics with only one describing sentence.

2.1. Electromagnetic Theory

- **Parallel-Plate Transmission Lines:** Much of the early research in EMP was devoted to transmission lines, especially parallel-plate transmission lines, which were the basis for some of the EMP simulators, such as ALECS, ARES, and ATLAS-I (Trestle).

- **Multi-Conductor Transmission Lines:** Advances in transmission-line theory also found widespread use in the design of EMP sensors and instrumentation, and new analytical tools to help understand the interaction of this wideband electromagnetic fields with test objects. Understanding of multi-conductor transmission lines was also important because it was a part of the development and application of EM topology, as seen below.
- **SEM and EEM:** Dr. Baum conceived of the Singularity Expansion Method (SEM) and its companion, the Eigenmode Expansion Method (EEM), in order to better understand the coupling of EMP to aircraft and missiles. It was, of course, later applied quite extensively to the new theory of resonant scattering for target identification of aircraft, unexploded ordnance (UXO), and concealed objects of various kinds.
- **Target Identification:** Dr. Baum combined the best features of SEM, EEM, and symmetry to form the theoretical basis for his work in target identification.
- **EM Topology and Topological Decomposition:** The concept of electromagnetic topology was developed to insure that an electromagnetic shield is designed properly. Topological decomposition is a method of breaking down a shielded system into smaller pieces, in order to make the analysis more tractable.
- **Norms and Bounds:** Dr. Baum devised ways of understanding the complex coupling phenomena via a set of scalar norms and upper bounds. Each of these norms is associated with an effect in the electronic subsystem or component. The bounds permit one to predict that somewhere in the deep layers of the system, the coupled signals can not exceed certain levels.
- **Symmetry:** Anyone who has worked with Dr. Baum gets used to hearing about symmetry.

2.2. Electromagnetic Pulse Sensors and Simulators

- **Sensors:** One of the first applications of electromagnetic pulse (EMP) sensor technology was the development of the Weapon Effects Buoy System that (then) Lt. Baum and his colleagues developed and tested in the Bahamas. Later, with assistance and manufacturing capability from EG&G, he created a whole catalog full of electromagnetic field and current sensor designs, which are still the standard today.
- **Simulators:** As part of his EMP related work Dr. Baum has designed numerous EMP Simulators. As his sensor and simulator concepts and designs found increasing use in the US, other countries began to build their own systems. At last count, EMP simulators were being built and used in at least 12 other countries worldwide.
  - The **Radiating Electromagnetic Simulator (RES) I** was one of the first EMP simulators to be fielded. The RES I or Flying Dipole, as it came to be known, consisted of a 2.3 MV Marx generator feeding a 120-ohm bi-cone in the center. The late-time antenna was a 100-foot-long inflated fiberglass dipole with periodic resistive loading to shape the late-time radiated field. The system was manufactured in both horizontal and vertical versions and was carried over the test site by a Chinook helicopter.
  - Some of the early nuclear electromagnetic pulse (NEMP) simulators, such as ALECS, ARES, and SIEGE, were vertically polarized, parallel plate simulators. **DISCUS** was a concept that was demonstrated to simulate the high-frequency propagation along the air-Earth interface and the low-frequency penetration of **fields** into the ground. The design included a parallel-plate transmission line under the ground.
  - **ATHAMAS I** was an elliptical loop type of simulator with a largely horizontal electric field. **ATHAMAS II** was a resistively loaded mono-cone radiator that generated a vertically polarized NEMP simulation. ATHAMAS II has also been used in EMP tests of an aircraft in flyby mode.
  - **ATLAS-I** the world's largest parallel- plate transmission-line simulator produced a horizontally polarized, horizontally propagating EMP environment for testing large aircraft. ATLAS-I was designed by Dr. Baum to avoid the ground bounce, and was thus suitable for simulated tests of aircraft in flight.

2.3. Lightning

Beginning in the late 1970s, Dr. Baum applied his many skills developed in EMP to the problem of understanding lightning. This work began with the application of the new sensors developed in EMP research to a lightning facility called the Kiva, located on South Baldy Peak in south-central New Mexico. He applied his expertise in atmospheric physics and electromagnetic theory to better understand the complex nonlinear behavior of lightning and its interaction with systems. In the process, he became a much-sought-after advisor for several large lightning measurement programs in the United States and Europe. Finally, he applied the theory and data to quantify the differences between lightning and EMP on the surface of an aircraft.

- **Lightning Measurements:** The EMP sensors and recording devices introduced by Dr. Baum allowed the recording of lightning waveforms as long as 20ms, having risetimes as fast as 10ns. By the time the measurements were complete, in the 1980s, the Kiva facilities were able to simultaneously measure lightning currents, fields, and brightness, thereby opening the door to new understanding and fundamental comparisons with newly developed lightning models.
- **Analysis:** The analysis program was an important adjunct to the experimental program, since it allowed Dr. Baum to correlate various parts of the data sets and to set proper limits. The fundamental limits came from a new, nonlinear transmission-line model that he developed and the resulting characterization of the electromagnetic shock.
- **System Tests and Analysis** Dr. Baum's first fundamental contribution was to show that the effect of surface charge is as important as that of the surface currents on the internal response of an aircraft. That understanding, the experimental work on lightning, and his pioneering work in electromagnetic analysis led many to seek his advice and guidance on large experimental programs.

2.4. High Power Microwaves

- **Hypo or Narrowband HPEM Systems:** Dr. Baum introduced a number of novel concepts into the hypo-band (narrowband) high-power electromagnetic (HPEM) world. Among these are the Phaser (pulsed high-amplitude sinusoidal electromagnetic radiation), the COBRA, and, most recently, the Traveling Wave Array Antenna.
    - **The Phaser** concept, developed in collaboration with Dr. D. V. Giri. A Mark N Phaser is nominally defined by an output power of 10N GW at a frequency of ~1 GHz: thus, a Mark 0 Phaser has an output power of 1 GW, nominally at 1 GHz. It consists primarily of a high-power microwave source and a paraboloidal reflector antenna illuminated by a pyramidal horn.
    - **The Coaxial Beam-Rotating Antenna** (**COBRA**), developed in collaboration with Dr. C. Courtney, is a combination of a mode converter and a radiating structure. It can produce either linearly or circularly polarized fields, and is surprisingly broad-band.
    - For HPM tubes that deliver their energy via a rectangular waveguide, the **Traveling Wave Array Antenna** concept was developed, in order to be able to deliver large bursts of power without causing air breakdown. The concept is to segment the waveguide, thereby dividing up the energy, and to then spread the field out before depositing it into the atmosphere.
- **Meso- or Moderate-Band HPEM Systems**: Carl Baum described certain concepts that switch a high-voltage transmission-line oscillator into a wideband antenna. The oscillator consisted of a quarter-wave section of transmission line, charged by a high-voltage source. It employed a self-breaking switch at the lower end of the transmission line. When the switch closed, the system generated a damped-sinusoidal signal that was fed into a UWB antenna, such as half of an impulse- radiating antenna (IRA). An initial working model of this type of source, called the **MATRIX** began full-scale testing at AFRL during 2003.
- **Hyper-Band HPEM Systems**: Dr. Baum suggested design concepts for two kinds of impulse-radiating antennas (IRAs): a balanced design and an unbalanced design.
    - The original IRA, developed and fielded in 1994 was a balanced design that used a high-pressure hydrogen switch, a focusing lens, and a four-arm TEM horn to produce an intense hyper-band pulse from a 3.67 m reflector. With a charge of only ±60 kV, this system generated a transient signal with a peak electric field of 4.6 kV/m at a distance of 305 m and a maximum pulse-repetition frequency (PRF) of 200 Hz.
    - In order to avoid the need of a balun, Dr. Baum suggested designing a half-IRA over a symmetry plane so that the high voltage signal can be fed directly to the antenna from below the ground plane with a coaxial transmission line. Under Dr. Baum's leadership, one such unit, named Jolt, was built by the Air Force Research Laboratory in 1997-99.