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Founded 1909

In Memoriam

ARTHUR ANDREWS COLLINS

1909 - 1987

Founded 1909, New York, U.S.A.

The Radio Club of America, Inc.

324 SOUTH 3rd AVENUE, HIGHLAND PARK, N.J. 08904

Price $2.50

Organized for the interchange of knowledge of the radio art, the promotion of good fellowship among the members thereof, and the advancement of public interest in radio.

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TREASURER'S REPORT FOR FISCAL YEAR 1986
(October 1, 1985 — September 30, 1986)

RECEIPTS

Dues	$ 7,427
Entrance Fees	816
Senior Grade & Life Membership Fees	385
Contributions to Grants-in-Aid	2,518
Interest & Dividends	7,015
Advertising	1,451
Sale of Pins and Plaques	682
Miscellaneous Receipts (banquet, Yearbooks, etc.)	3,434
Total Receipts	$24,517

DISBURSEMENTS

Grants-in-Aid Scholarships	$ 6,000
Consulting Fees	2,750
Publication Expenses	7,116
Rent	577
Printing & Stationery	967
Purchase of Computer Equipment	2,090
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Telephone	360
Postage	899
Newsletters & Balloting	1,554
Legal & Accounting	1,100
Purchase of Pins & Plaques	516
Meetings	1,844
Miscellaneous	72
Total Disbursements	$27,331

Excess Disbursements over Receipts....... $ 2.814

Arthur A. Collins — Shaper of the Art and Science of Communications

"He helped shape the art and science of communications," said Dr. Joseph McCabe in the funeral eulogy. "He advanced the welfare of mankind from Antarctica to Space."

Born in Kingfisher, Oklahoma in the same year that The Radio Club was founded, Arthur Collins' career spanned the entire history of amateur radio as a pioneer and a prophet, and his success as an entrepreneur brought forth superior radio communications for his country and many others.

It started when he was about nine years old. That's when he and a friend built their own crystal radio receivers around oatmeal boxes wound with copper wire, and pieces of galena crystal. His parents realized his potential and provided money for whatever experimental equipment that he wanted. The year was 1918 — the dawn of the radio age, and Arthur Collins was at the forefront.

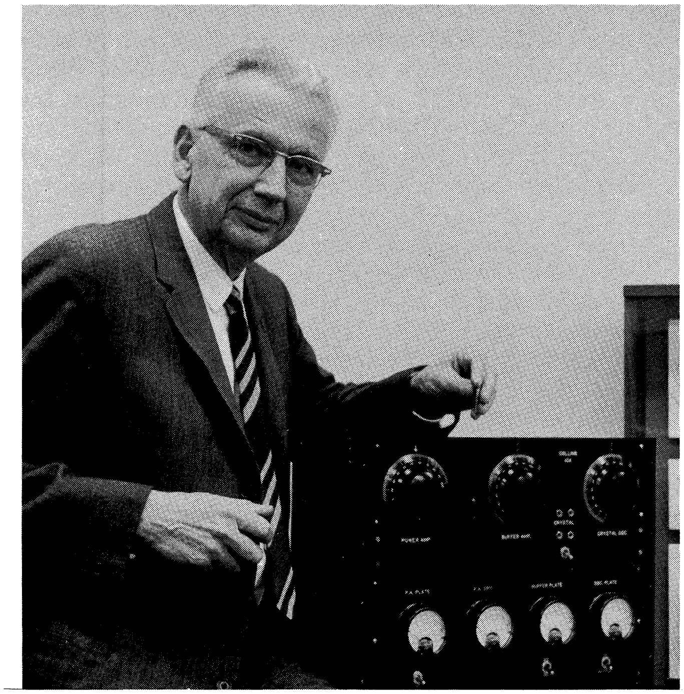
His keen interest in radios lead Collins through the experimentation which, in turn, lead to successively more reliable, higher-performance radios. In 1923, at the age of 14, he got his Amateur license from the Federal Radio Commission and, two years later, received national newspaper coverage when he made radio contact with the MacMillan scientific expedition to Greenland. The expediton was to make daily reports to the U.S. Naval Radio Station in Washington, DC but, because of atmospheric problems, the Washington station was unable to consistently receive messages from the ship.

However, Collins was making contact and, throughout the Summer, he accomplished a task difficult for the Navy. Using a Ham radio that he himself had built, his signals reached the expedition more clearly than any other. After each transmission he took the messages from the expedition to the Cedar Rapids, IA. telegraph office and relayed to Washington the scientific findings that the exploratory group had uncovered that day.

In 1926, before he was 17 years old, *Radio Age* magazine published a Collins' article: "Full Details of a Short Wave Transmitter." That year, he enrolled in Coe College and, a year later, transferred to Amherst where he remained for a year. While never graduating from college, extensive reading and practical experience qualified him for the task ahead.

By the end of 1931, he had set up a shop in the basement of his home and began manufacturing Amateur radio transmitters to order. He told *Forbes* magazine, years later: "I picked what I was interested in, and looked for a way to make a living." The Collins Radio Company was born.

An important break for the young firm occurred in 1933 when Collins radio equipment was chosen to keep the 115-man Byrd expeditation to the Antarctic in touch with the rest of the World. On February 3, 1934, Rear Admiral Richard E. Byrd made his first formal broadcast from the Antarctic continent. The broadcast was received clearly in America, some 10,000 miles away.



Collins poses with a 30W transmitter, one of the first radios he built.

The performance of the Collins equipment in transmitting voices from Antarctica produced a boom in orders for equipment from Amateurs and commercial buyers worldwide. The publicity and prestige established the Collins Radio Company as one to watch closely in the years ahead.

And those who did watch, read about a series of company "firsts" over the years: new products for police communications, radio broadcasting equipment, the first radio communication equipments supplied to an airline (Braniff — 1936), the invention of the Autotune, the first high reliability TACAN in 1955, the first communications equipment for manned spacecraft (Mercury — 1962), and the development of business aviation autopilots and systems.

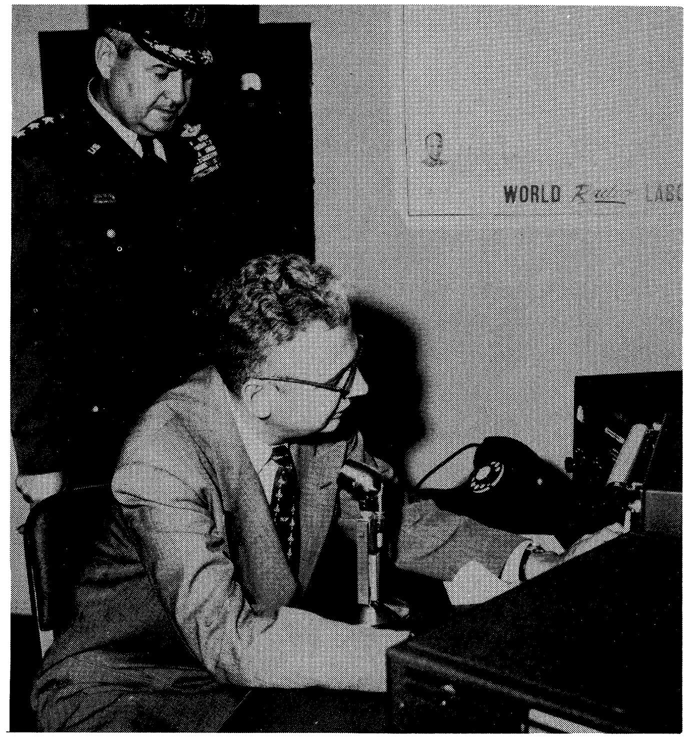
Forbes magazine reported in 1968: "For all of his studying, he never bothered to pick up any sort of degree. Collins had more important things on his mind." And indeed he did. By the time of his death, he had been awarded 24 patents.

His inventions include the Autotune and, with that, Collins Radio Company entered the world of aviation. In early 1940, the U.S. Navy evaluated transmitters of three companies and the transmitter submitted by Collins Radio Company, the autotuned AN/ART-13, "won the competition overwhelmingly" according to one of the officers conducting the tests. The company produced 26,000 of the transmitters during World War II.

Collins never was afraid of supporting new projects, and his company became involved in trans-horizon communication techniques, scatter propogation, observation of total eclipse of the Moon through radio telescopes, bouncing UHF signals off the Moon, microwave communications, single-sideband modulation, antenna research, two-way radio voice communications via artificial satellite, communications for the U.S. manned-space flight program, and digital computers to handle both data processing and telecommunication message switching. In all of these, Arthur Collins worked with his engineering staff — inventing, supporting, advising, encouraging.

Arthur Collins personified the best of the free enterprise system. The success of his company derived from his own personality and drive. He never ceased working at various kinds of research and often labored day and night in inventing, developing, and perfecting new and more reliable communications equipment. As with his parents who had supplied him with the equipment needed to conduct his boyhood experiments, he insisted that his employees have a good working environment together with the best tools and supplies. In turn, he told those who worked for him: "Whatever your field may be, your progress will depend on your individual imagination. Give it free rein."

He shall be remembered as a founder, a pioneer, and a man who through his genius, literally made history. Friends and acquaintances describe him as "a great man", "a pioneer', "an innovator." He was often referred to as a "genius". And well he may have been all of these.



SAC Visit — In 1956, Collins, seated, visited Strategic Air Command headquarters at Offutt Air Force Base in Nebraska to meet with General Curtis LeMay, commander-in-chief of SAC. The Military Affiliate Radio System station there had just installed new Collins radio equipment.

Following the merger of Collins Radio Company with Rockwell International in 1973, Arthur Collins left to begin another company in Dallas, Arthur A. Collins, Inc. The company conducted system engineering studies in the communications and computer fields.

Arthur A. Collins joined The Radio Club of America in 1974 and was named a Fellow in 1975. In 1977, he was awarded the Armstrong Medal. In 1926, he joined the IEEE and was elected a Fellow in 1952; was a member of the National Academy of Engineering, SMPTE, the American Association for the Advancement of Science, and was the awardee of numerous recognitions from technical societies. Also, he was the author of *Telecommunications — A Time for Innovation.*

Jerry S. Stover, former Chairman of Communication Industries, Inc. and a Director of The Radio Club, in his eulogy said: "Some craftsmen leave behind beautiful buildings as monuments to their talents. Arthur's monuments are far more pervasive. At this very instant, the air around us is filled with signals from Collins radio transmitters guiding thousands of aircraft safely to their destinations. It will be that way every moment of this day and every day far into the next century."

Arthur A. Collins died February 25, 1987. In remembering him, J. Erik Jonsson, a founder of Texas Instruments Corp., said: "The man was brilliant and a good manager. He left behind him a reputation for integrity and good will."

That was the essence of the man.

This article was prepared with the assistance of Ms. Wilma Shadle, Secretary to Arthur Collins, 1965-1971; Mr. Gary Frederick (F); Mr. Jerry S. Stover (F); Mr. Luther Pulley (F); and the staff of the Rockwell News.

ELECTROMAGNETIC PULSES: THEORY, THREATS, AND DEFENSES

by Lt. Claudius E. Watts, IV (U.S.A.F.)

ABSTRACT

Electromagnetic Pulses (EMPs) are generated by all nuclear explosions. Because of their ability to upset and/or destroy electronic and electrical circuitry, EMPs are capable of rendering most communications systems, power systems, and weapons systems useless. This threat to U.S. national security has become an important issue in defense and engineering circles. The theory of, the threat of, and the defenses against EMPs are discussed.

INTRODUCTION

The nuclear arms issue is one of the most heatedly debated topics of our time. While the issue is in the forefront of American life today, it is rarely debated intelligently or logically. Instead, it is debated on an almost exclusively emotional level. This lack of intelligent debate is caused by insufficient understanding on the part of the general public and a portion of the scientific and engineering community.

The purpose of this paper is to provide the average scientist, or engineer who has a basic understanding of physics and calculus with a technical explanation of one specific and particularly dangerous effect of nuclear detonations: electromagnetic pulses (EMPs). EMPs, while not violently destructive like the blast and radiation effects of nuclear detonations, are dangerous because of their capability to render large portions of a country's weapons and communications systems useless by destroying EMP-sensitive electronic circuity. Surely there exists the temptation of a country to bloodlessly incapacitate another country's war-fighting ability. If a country were attacked and its national leaders were out of contact with their military leaders, would it retaliate? And if it would, at what level would it retaliate? In these uncertainties lies the danger of EMPs.

The paper is organized into three sections. The first section explains the theory of EMPs, while the second and the third sections discuss the threat of and the defenses against EMPs, respectively. While the effects and characteristics of EMPs which are generated by nuclear bursts at all altitudes are discussed, those generated by exoatmospheric bursts are emphasized because of their particularly potent threat.

This paper is designed to encourage the engineer, scientist or layman to study further the facts surrounding the issue of nuclear arms and to contribute to the debate which surrounds the nuclear arms issue.

GENERATION AND CHARACTERISTICS OF EMPs

Background

The phenomenon of EMP or "radio flash" is not new. EMPs always have been present in high-explosive detonations and were predicted by scientists throughout the development of nuclear weapons. However, at the time nuclear weapons were being developed, and up until very recently, scientists, engineers, and military personnel were almost exclusively concerned with blast and radiation effects.[1] With the advent of more sophisticated weapons and communications systems and their inherently EMP-sensitive electronic circuitry, the effects of EMPs have become a major concern of engineers and military leaders alike.

EMPs, which are generated by nuclear explosions, produce intense electric and magnetic fields with extremely short rise times and frequency spectra ranging from near zero to over 100 MHz. The characteristics of EMPs vary with the location of the burst itself and the distance of it.[2] Before the generation and characteristics of EMPs can be discussed further, the regions of nuclear bursts should be defined. A nuclear burst which occurs on the surface of the earth or up to 0.2 km above the surface is termed a surface burst. A burst between 2.0 km and 20 km above the surface is defined as an air burst, and a burst 30 km or higher above the surface is defined as a high altitude burst. Bursts which occur between 0.2 km and 2.0 km above the surface share the characteristics of air and high altitude bursts.[3] A comparison of EMP regions can be seen in Figure 1.

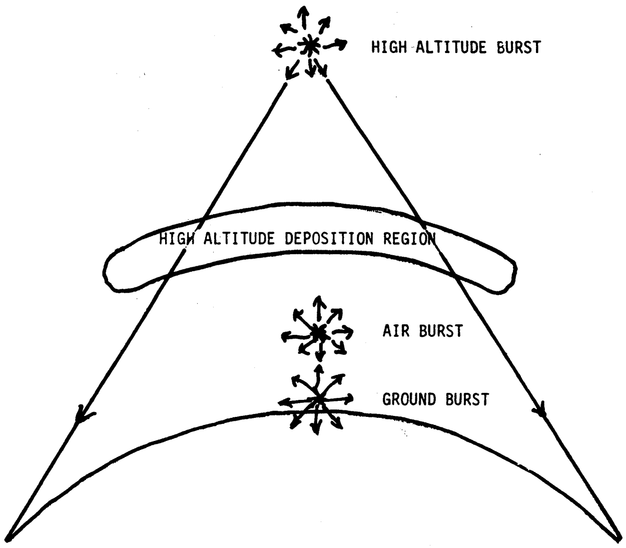


Figure 1. Simple Comparison of EMP Regions.[4]

The Compton Process

One process which is involved in every nuclear burst, regardless of region, is the Compton process. This process converts high energy photons into EMPs. The process begins with detonation and the release of an intense pulse of gammas with a rise time in the order of nanoseconds. The gammas collide, much like "billiard balls", with electrons in molecules.[5] Thus, a portion of an incident gamma's energy and momentum is transferred to an electron, and a lower-energy scattered gamma ray emerges from the collision. When considering gamma ray energies normal for nuclear detonations, the Compton scattering process is the main interaction between gamma rays and air molecules. The Compton process is illustrated in Figure 2.

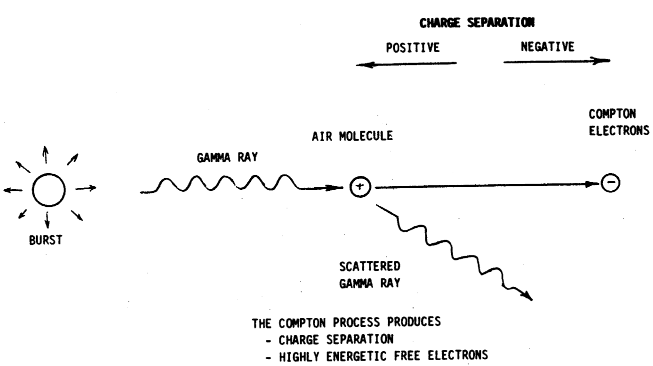


Figure 2. The Compton Process.[6]

The gamma rays are released radially at the speed of light and scatter the electrons as well as the remaining positive ions in the same general direction. But because the electrons move much faster than the positive ions do, there is initially a net current flow, the Comptron current, toward the source (the burst), which is followed by a net current flow away from the source. This flow away from the source occurs when the charged particles begin to combine under the influence of the electric field which is caused by the huge charge displacement. The integrated effect of the displacement and movement of the charged particles are, in accordance with Maxwell's equations:

$$\nabla \times \mathbf{E} = -\frac{\delta \mathbf{B}}{\delta t} \qquad (1)$$

and

$$\nabla \times \mathbf{B} = \mu \mathbf{J} + \mu\varepsilon \frac{\delta \mathbf{E}}{\delta t} \qquad (2)$$

where

$\mathbf{E}$ = electric-field vector,
$\mathbf{B}$ = magnetic-field vector,
$\mathbf{J}$ = current-density vector,
μ = permeability of the region,
ε = permittivity of the medium,

the principal source of the high intensity EMP.[7]

EMP ENVIRONMENTS

General

Having already classified bursts in terms of altitude, it is important to note that the two major characteristics of EMPs — time signature and spatial extent — depend primarily on the burst altitude and the location of the burst relative to the observation point.[8] In addition, two regions surrounding a burst are significant in EMP considerations. The first region, the deposition (source) region, is the space surrounding the explosion in which the EMP is generated and contains intense electric and magnetic fields as well as highly conducting plasma.[9] The height of the burst, the geomagnetic field and/or asymmetries in the environment can cause the source regions to radiate beyond the deposition region and form the second region which is termed the radiation region. This region contains less intense fields which have the characteristics of an outwardly radial direction of propagation, an inversely proportional relationship between distance and amplitude in the far-field case, and planar propagation of the electric- and magnetic-field vectors (see Figure 3).[10]

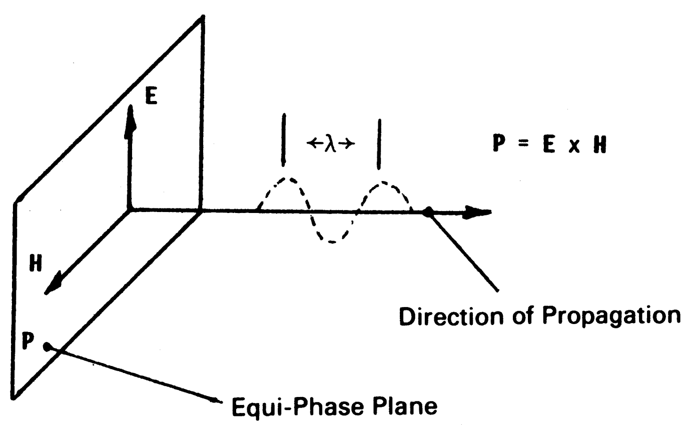
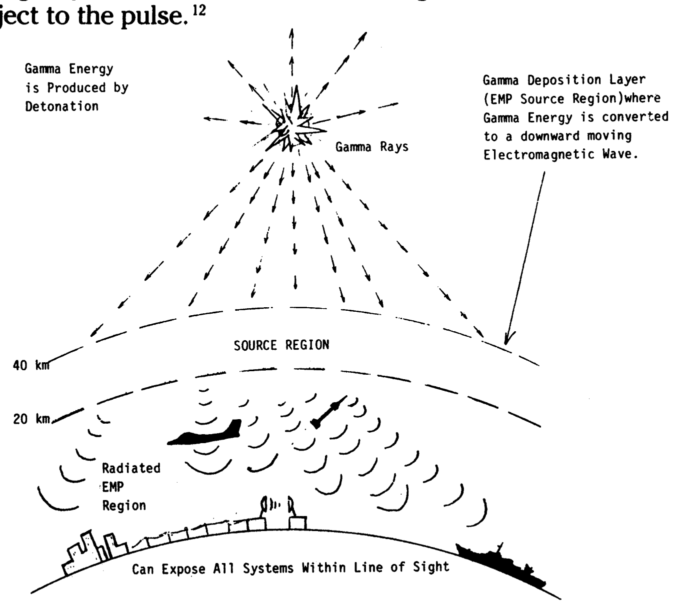


Figure 3. Propagation of a Uniform Plane Wave.[11]

High-Altitude EMP

As noted earlier, a burst which occurs over 30 km above the surface is a high altitude burst. A high altitude burst is unique because its major effect is the generation of high altitude EMPs (HEMPs). In addition, its HEMPs irradiate huge geographic areas.

After a high altitude burst occurs, gamma rays travel outwardly in all directions. Because the density of the atmosphere at high altitudes is extremely low, there is little attenuation in the upward and horizontal rays. Those that travel downward toward the surface, however, eventually encounter the denser atmosphere and produce Compton recoil electrons. At between 20 and 40 km, the gamma ray attenuation length becomes equal to the atmospheric scale heights. This region is the deposition region for HEMPs. If the initial electron direction is at an angle with respect to the earth's magnetic field, then the field will give the electron a transverse acceleration and cause it to turn with a radius of about 100 meters. The resultant transverse Compton current is the primary source of HEMPs. From the observation point, the EMP generation process occurs with high phase coherence and thus produces an EMP with an extremely quick rise time. Finally, the gamma rays, Comptron electrons, and EMPs all travel at roughly the speed of light along a line of sight. Therefore, any ground-based or inflight systems that are in the line of sight of a burst are subject to the pulse.[12]



FEATURES OF HIGH ALTITUDE EMP (HEMP)

- Wide Area Coverage
- High Field Strengths (50 kV/m)
- Broad Frequency Band (10 kHz-100 MHz)
- Absence of Most Other Nuclear Weapons Effects

Figure 4. HEMP Overview.[14]

The ground coverage of HEMPs is solely dependent on the altitude of the burst. Significant HEMP levels on the surface range out to the target radius and go beyond for frequencies below 100 kHz. The target radius is the arc length from where the line of sight from the burst is tangent with the earth's surface to the point on the surface directly beneath the burst (surface zero).[13] If one assumes that the earth is spherical, then the tangent radius is

$$R_t = R_e \cos^{-1}[R_e/(R_e + HOB)] \qquad (3)$$

where
R_t = tangent radius (km),
R_e = radius of earth (6370 km),
HOB = burst altitude (km).

The total surface area A_t covered by HEMPs is

$$A_t = 2\pi R_e^2 (HOB)/(R_e + HOB).$$

Figure 5 shows At plotted as a function of burst altitude for a burst occuring over the central United States.

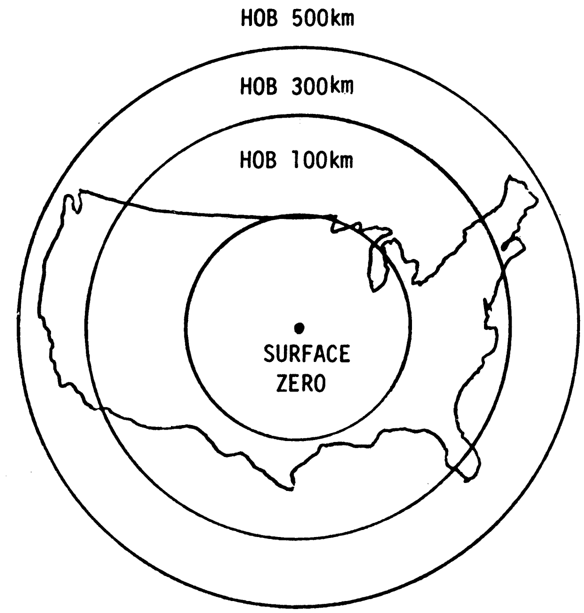


Figure 5. HEMP Ground Coverage for High Altitude Bursts at 100, 300 and 500km.[16]

The radiated fields which are incident on the surfaces can be modelled locally with planar electromagnetic waves such that the ratio of the magnitude of the electric-field strength E to the magnitude of the magnetic-field strength H is the impedance of free space:

$$\frac{E}{H} \simeq 377\Omega.^{15}$$

These field strengths are significant out to the tangent radius; however, the precise field strength, as a function of surface location, is dependent on several factors. The observer location with respect to the burst is important because HEMPs are generated by electron motion that is transverse to the earth's magnetic field. As a result, those electrons travelling in the direction of field do not radiate. For a burst at high geomagnetic latitudes that include the United States and Europe, the pattern shown in Figure 5 would result. As the Figure 5b illustrates, there would be a region of near zero field strength just north of surface zero, where the magnetic field lines from the burst location intersect the earth. In addition, there would be a wide band of high field strength corresponding to electron trajectories which are perpendicular to the geomagnetic field. Outside those areas and out to the tangent radius, the field amplitude is approximately one half of the peak amplitude.[17]

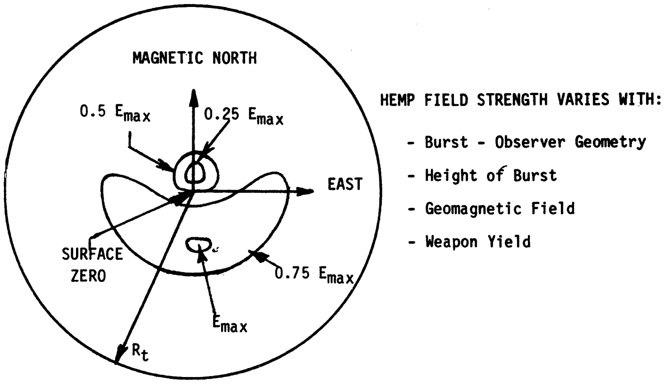


Figure 5b. HEMP Field Strength as a Function of Ground Position.[17]

In addition to observer location, the burst altitude, weapon yield (especially gamma yield), and geomagnetic field which will vary with geomagnetic latitude, also affect the HEMP strength. As the geomagnetic latitude moves toward the equator, the peak HEMP fields are smaller, and the field strength patterns are changed significantly.

Having discussed the dependence of HEMPs on position and medium, the discussion now turns to time dependence and the HEMP waveform characteristics or "time signature". An approximate mathematical representation of HEMP, which combines upper-bound values for rise time, duration, and peak amplitude which are reasonable results for different explosions and various observation locations outside the HEMP deposition region, has been developed. The waveform is represented by

$$E(t) = E_0 k(e^{-\beta t} - e^{-\alpha t}), \quad t \geq 0 \tag{6}$$

where

E = electric field (V/m),
E_0 = peak electric field (V/m),
α = rise constant ($4.76 \times 10^8\ s^{-1}$),
β = decay constant ($4.0 \times 10^{-6}\ s^{-1}$),
k = 1.050.

The factor k is included so that E(t) may reach its peak value Eo. The rise time for the waveform is approximately 5.0 ns, and the time to half-value is about 200 ns.[18] Figures 6a and 6b show the time signature plotted on the linear time scale and a logarithmic time scale, respectively. While the logarithmic scale alters the waveform, it better illustrate the rise time.

Because many important EMP energy collectors are frequency selective, it is essential to know the HEMP energy distribution as a function of frequency. When the Fourier transform of the generalized wave equation is taken, the following equation,

$$E(\omega) = 2.47 \times 10^{13} / (j\omega + 4 \times 10^6)(j\omega + 4.76 \times 10^8) \tag{7}$$

where

E = electric field,
ω = radian frequency,
j = unit imaginary number,

results and is plotted in Figure 6c. As the figure illustrates, the field strength is fairly constant between 10 kHz and 1 MHz, decreases by a factor of 100 between 1 MHz and 100 MHz, and decreases rapidly over 100 MHz.

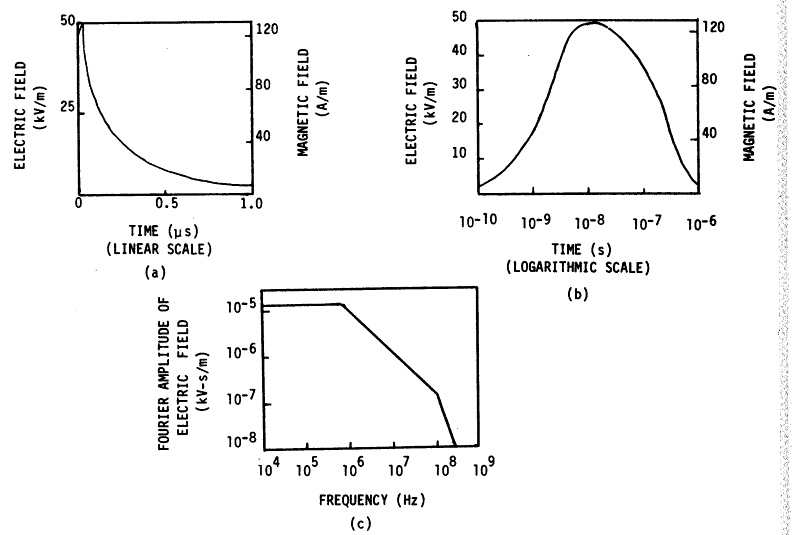


Figure 6. HEMP Waveform Characteristics.[51]

The energy density content can be represented as a function of frequency

$$S(\omega) = \frac{|E(\omega)|^2}{\eta_0} \tag{8}$$

S = energy density per bandwidth ($J/m^2 \cdot Hz$),
η_0 = free space wave impedance (377 Ω).

The total energy density is approximately 0.9 J/m^2.[19]

Ground-Burst EMP

A nuclear explosion which occurs at or just above the earth's surface is called a ground burst, and its resultant EMPs are termed surface burst EMPs (SBEMPs). When a ground burst occurs, the deposition region extends to a few kilometers and, in this region, gammas and the generated Comptron current flow radially away from the burst point. The separation of charge causes this Compton current to flow and thus sets up a radial electric field. In the air and at short distances (less than 2.0 km), the electric field builds up until it drives a conduction current that offsets the Compton current. At these distances, the field goes into saturation and increases no further. Average peak values of the radial electric field are thousands of volts per meter and have vey short rise times.[20]

In the earth, the gammas and recoil electrons penetrate only a few feet but, because of the high conductivity of the earth, the radial electric field just over the surface is disturbed, and the conduction current close to earth tends to flow into the ground. Thus current loops are formed with recoil electrons flowing outward from the detonation in the air and conduction currents moving towards the burst point in the ground. These current loops generate an azimuthal magnetic field which is strongest at the earth's surface, but is diffused by the "skin effect" in the air and ground.[21] Reasonable peak values for the magnetic field are on the order of 100 gauss and also have extremely short rise times.

In the air, transverse and vertical dipole electric fields decay much slower and stay at voltage levels of many volts per meter for a long time. Because of the increasing resistivity of the air that is caused by the recombination of electrons and positive ions, the power that can be delivered to the fields is limited.

When the observation point is moved out of the deposition region, the effects of the Compton current and conductivity are trivial. At greater distances, the magnetic and electric fields propagate like waves in the deposition region but fall off with the reciprocal of the distance. This attenuation is caused by the air-ground interface which only allows Compton current flow away from the surface and thus appears as an electric dipole signal to a distant observer.

Air-Burst EMP

When a nuclear detonation occurs at altitudes higher than those of ground bursts, air-burst EMPs (ABEMPs) are generated. At higher burst altitudes, the azimuthal magnetic field, the transverse electric field, and the long distance field radiation are all reduced. Furthermore, the radial electric field does not depend on the ground for its existence.[22] As the burst altitude increases, there is concurrent increase in the radius of the deposition region. This increase is due to the decrease in attenuation of the gamma pulse in the less dense air. Finally, air bursts do produce radiated fields which are due to the earth's geomagnetic field and air density gradient asymmetries, but they are usually smaller than those generated by ground bursts and much smaller than those generated by high altitude bursts.[23]

THE EMP THREAT
General

An international crisis is in progress. The Early Warning System alerts the North American Air Defense headquarters in Colorado that missiles have just been launched at the United States. Commanders immediately act to determine if the alert is real or a result of computer malfunction. In minutes, the alert is confirmed, the news of the attack is conveyed to the President.

Seconds later, three 10-megaton thermonuclear weapons detonate in quick succession 400 km above the United States. Within milliseconds, electromagnetic pulses (EMPs) from these explosions knock out the entire electrical power grid of North America and the entire civilian telephone network. They damage or destroy nearly every unprotected piece of electronic equipment in the country: computers, television sets, radios, electronic controls in planes and cars, instruments in laboratories and hospitals, electronic networks in factories and mills. The pulses simultaneously destroy or cripple large sections of the military command, control, and communications (C^3) system, disorganizing the network only seconds after the attack is confirmed and greatly weakening U.S. ability to respond to the attack.[24]

This scenario, while hypothetical, accurately outlines the threat which HEMPs pose to the United States national security. There is evidence that indicates that the President of the United States and the other members of the National Command Authorities (NCA), including the military, may not be able to order an all-out "doomsday" response, much less a precise limited response to a nuclear attack.[25] Obviously, an inability, or even a degraded ability, to respond to a nuclear attack puts the very essence of U.S. strategic defensive doctrine, deterrence, on a shaky foundation at best.

There are two major areas of EMP impact: coupling and interaction of EMPs with exposed systems and system generated EMPs (SGEMPs). Coupling and interaction usually involve flying aircraft and ground based systems, while SGEMPs generally affect most space platforms. In discussing these two areas, the effects of HEMPs will be emphasized.

Coupling and Interaction
Background

The interaction between EMP and electrical systems inside structures such as buildings, aircraft, missiles, and satellites can be divided into three separate processes. These processes are external coupling, internal coupling, and the excitation of the internal electrical system.[26] There are many factors that affect these three processes in penetrating conductors. Among these factors are the HEMP wave form characteristics including magnitude, rise time, duration, and frequency, conductor characteristics, including geometry, electric and physical properties, and degree of shielding and, for overhead and buried cables, soil conductivity. Soil conductivity is important because as it increases, so do HEMP attenuation in the ground and reflection from the ground.[27]

EMP Coupling Mechanisms

There are two basic mechanisms by which currents and voltages are induced by conductors: electric and magnetic induction. In the electric induction process, the electric field exerts a force on the mobile electrons in a conductor and generates a current. The voltage related to the force is equal to the integral of the tangential component of E along the length of the conductor. In the example illustrated in Figure 7, the voltage across the left portion of the conductor is equal to ℓE. This result is calculated assuming that the electric field is constant over the length of the conductor and parallel to it.[28]

Figure 7 also shows an example of the second method by which EMP couples to conductors — magnetic induction. Magnetic induction occurs because of changes in the magnetic field inside the loop and is described by Faraday's Law. The law relates the time rate of change of the magnetic field to a produced electric field which induces a voltage if a loop is present.[29] In the example, the voltage for a loop of area A is equal to the product of the area of the loop and the time-rate of change of the magnetic field. The magnetic field is assumed to be constant across the entire area of the loop and normal to the loop. Obviously, a fast rise time of the magnetic field, typical of HEMPs, would yield a large time-rate of change and thus large currents and voltages in the loop.

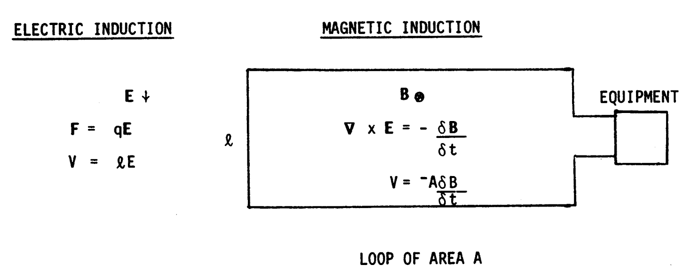


Figure 7. Two Mechanisms of EMP Coupling.[30]

The Coupling Threat

As already discussed, the coupling of HEMPs causes large currents to flow in an electric system. When these currents penetrate to the interior of a system, problems begin to occur. There are two major modes of penetration involved with HEMP coupling. First, EMP can be coupled into a system through either deliberate or unintentional antennas. Obviously, the deliberate antennas are easily identified, but because HEMP operates across such a large frequency spectrum, unintentional antennas can be almost anything metal and of any length. Some examples are exterior cables, wave guides, booms, and telephone lines.[31] Along with antennas, apertures in a structure's shell are sources of penetration. The apertures can be any size opening from a seam that is micrometers in width to an air intake port that is a meter in diameter.

Any cables or electronic boxes that are on the interior of the system and are within the reach of the HEMP field penetrations have currents induced on them which are comparable to those induced on the exterior of the system. These currents can upset, damage, or burn out much of the sensitive electronic circuitry in the electronic boxes, thus rendering the system useless. Table 1 shows the spectrum of burnout and upset energies for some typical electronic parts.

Table 1. Effects of EMP-Induced Currents on Electronic Components.[32]

ENERGY (Joules)	POSSIBLE DAMAGE
10^{-7}	Microwave mixer diodes burnout
10^{-6}	Linear IC's suffer upset and burnout
10^{-5}	Low power transistors and bipolar IC's upset and burnout
10^{-4}	CMOS logic, medium power transistor and diodes and capacitors suffer permanent damage
10^{-3}	Zeners, SCR, JFET's high power transistor and thin film resistors damaged

As one can clearly see, severe damage to electronic circuitry can be achieved with very low energy levels. Perhaps the most alarming statistic is now shown in the table: computer memory erasures and state changes may be achieved with two orders of magnitude less energy than is required to damage integrated circuits.[33]

SYSTEM GENERATED EMP

Background

System generated EMPs (SGEMPs) are produced when a system is directly exposed to incident photons from a nuclear burst. SGEMP differs from "regular" EMP in that the electron source that drives Maxwell's equation is the system itself instead of intervening air or other material.[34] Therefore, because gamma ray and x-rays are attenuated in the atmosphere, SGEMPs are particularly significent when discussing exoatmospheric detonations.

Coupling Modes

The SGEMP generation process begins with the interaction of x-rays and gamma rays with the subject system materials to produce free electrons.[35] The electrons that are emitted from the internal walls generate currents and, therefore, electromagnetic fields inside the system's cavities. This resultant field pulse is termed internal EMP (IEMP). Coupling occurs by both electric and magnetic induction directly on the signal cables and by replacement current flow on cable shields and group systems. Electron emission from the outer skin generates surface currents and can cause additional internal coupling if aperatures are present in the outer shell.

The SGEMP Threat

The threat that SGEMPs pose to unprotected U.S. satellites is truly awesome. Because the weapon gammas and x-rays are not attenuated in the absence of atmosphere, the area that would be affected by an exoatmospheric burst is tremendous. The following equation describes the edge of the area at which damage to an unprotected satellite would start to occur:

$$\frac{6.4Y}{R^2} = 10^{-5}\ \text{cal/cm}^2$$

where

Y = yield of weapon in (kilotons),

R = distance from the blast (km).[36]

Perhaps the best way to illustrate the threat posed by SGEMP is with an example. If a 2.0 megaton nuclear device were detonated at an altitude of 14,000 km above the earth's surface, electric fields ranging in magitude from 100 kV/m to 1.0 MV/m would be generated on the skin of an exposed satellite. These electric fields caused by gamma ray displacement of Compton electrons would produce large internal currents in the satellite and probably destroy all electronic equipment on board.[37] Any satellite within the line of sight of the burst and within a geo-synchronous orbit (36,000 km) would be subject to these effects.[38]

DEFENDING AGAINST EMPs

General Approach

The purpose of EMP hardening "is to prevent the electromagnetic pulse produced by a nuclear detonation from causing an electronic/electrical system to malfunction in such way that the mission needs of the system can no longer be met."[39] An example of such a system malfunction is the reset of a flip-flop in a digital circuit, caused by an EMP-induced transient, and resulting in a radar failing. An EMP transient could also cause the burnout of integrated circuits or the shorting of a major power supply due to arcing insulation breakdown in its connectors and cables. Looking at these examples, one can see the broad range of systems which require EMP protection.

The techniques for EMP protection or "hardening" are largely dependent on the response of the overall system to EMP, so the best hardening techniques are those that are applied when the system is first designed.[40] Accordingly, those system that are designed with EMP protection in mind from the beginning are generally more resistant to EMP effects so that there is less chance of an upset in system logic. There follows a general description of the topological approach to the EMP hardening problem and a brief discussion of the individual protection elements involved in the approach.

The Topological Approach

The topological protection scheme consists of barrier elements, each of which helps to attenuate the electromagnetic energy of EMP and contributes to an overall attenuation sufficient enough to insure that the electromagnetic environment to which the system's electric and electronic elements are exposed does not affect the system's ability to perform its mission.[41] A system's topology is made up of one or more boundaries between the outside environment, both radiated and conducted, and the actual equipment. Figure 8 illustrates a generalized topology which shows features of this protection concept.

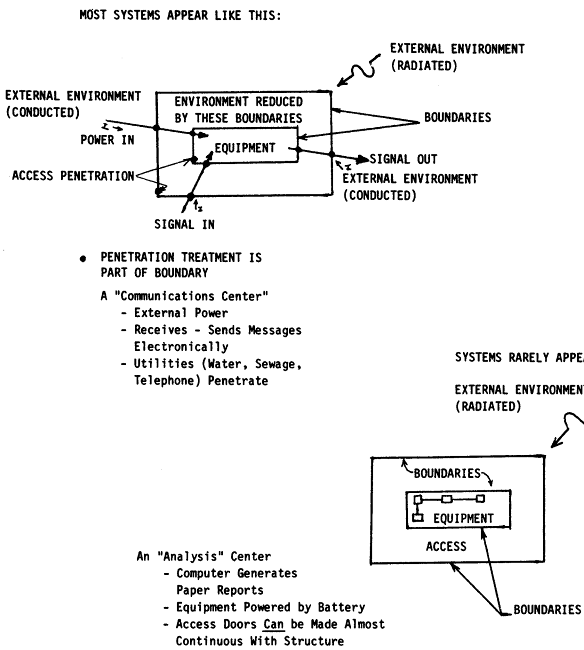


Figure 8. Generalized Topological Protection.[52]

As already stated, topological boundaries serve to reduce the external EMP environment to an inconsequential level. Ideally, such a boundary would be a Faraday shield that featured a continuous, perfectly conducting enclosure; but because of the necessity of power lines, other utility connections, and antennas in most systems, ideal shielding is not practical. Obviously then, different types of elements in the topology are required to adequately protect a system from the EMP threat. Topological elements that attenuate the radiation and thus reduce the coupling to cables, wires, and interior conductor surfaces are called shielding elements, while topological elements that reduce and/or nullify conducted transients are called transient suppression devices. In addition, a third type of element is called an isolation device. An isolation device is a device that functions to interrupt current flow or is virtually immune to coupling but, at the same time, provides connectivity between mechanical systems and electric or electronic signals.[43]

Figure 9 illustrates the use of the topological elements. It is important to note that the term "external environment" refers to the area external to the actual equipment — not the building or the outside casing of a particular component.

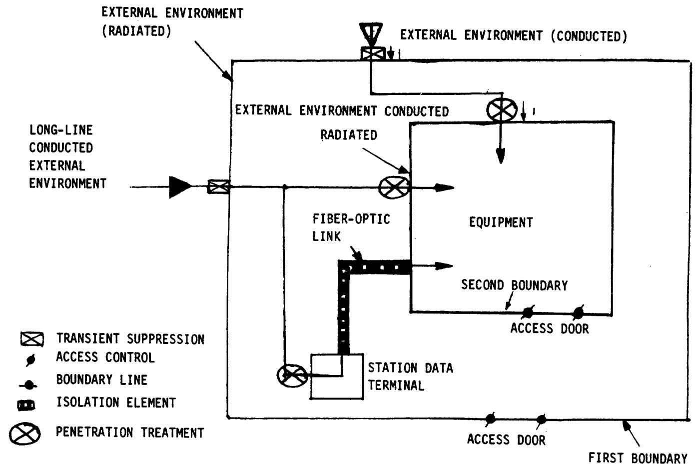


Figure 9. Topological Elements.[45]

Protection Elements
Definition

As already discussed, protection topology involves three different topology elements: shielding elements, transient suppression devices, and isolation devices. The term protection elements refers to the different kinds of devices that are included in topology element category.

Shielding Elements

In a typical hardening problem, the first topological boundary is the external surface which encloses the system. The function of this boundary is to reflect and to attenuate the initial EMPs as well as to divert currents on penetration. It is obvious that if the external surface is to act as a shield, it must be metal so that it can provide both the functions of attenuation and current diversion. Just having a metallic surface, however, is not a qualifier of a shield in itself. The structure must also have all of its openings and aperatures treated in such a manner as to reduce penetration. Furthermore, the penetrations that do occur must be channeled in such a manner that they can be nullified by other protection elements. The sources of penetrations include anything from power lines and antennas, to sewer lines and waterlines.[44]

The second type of shielding elements are equipment enclosures which shield individual system elements with the external surface. The same principles of shielding that apply to external shielding also apply to equipment shielding. Again, all sources of penetrations have to be dealt with in order to provide effective protection.

The last type of shielding to be discussed is cable shielding. Cable shielding is utilized in order to extend the boundaries formed by equipment enclosures and external surfaces and to allow connectivity between individual hardened elements, thus producing a hardened system. From the standpoint of EMPs, the shield lowers coupling levels within the first topological boundary as a signal travels along the cable towards the receiver. In addition, the shield also performs the reciprocal function of preventing signals from radiating out of the cable once it has entered the external surface volume.[46]

Transient Suppression Devices

"Transient suppression devices fill a critical gap in the concept of topological protection." [47] Because most facilities require power and communication capabilities via cables and antennas, and because most power lines, communication lines, and antennas are not shielded, the suppression devices are absolutely essential to solving the EMP hardening problem. A suppression device typically acts to divert surge currents onto the external surface. Furthermore, a suppression device performs its function in response to some unusual input current frequency or amplitude from the exterior environment. Those devices that respond to frequency inputs are defined as filters, and those that respond to amplitude inputs are defined as nonlinear devices. Some examples of filtering devices are power line filters, transformers and ferrite beads, while examples of nonlinear devices are varistors, Zener diodes, spark gaps, and rectifying diodes. [48]

The use of filters is usually preferred because nonlinear devices sometimes produce high frequency noise when activated. Unfortunately, however, the amplitudes of EMP transient usually require the use of nonlinear devices. In this case, the noise can be removed by placing a filter in series with the nonlinear device on the system side of the circuit. [49]

Isolation Devices

The last category of topology elements to be discussed is isolation devices. In general, an isolation element is one which is either immune to the effects of EMPs or provides a current interruption when EMPs are present. Elements which are immune to EMP effects, such as fiber optic links, have a greater potential for application, but are still found in relatively few systems. These elements provide an ideal method of safely penetrating the topological boundary. Just the opposite, interrupters, because of their usual small size relative to the wavelengths involved, do not appear to have much application at the present time. [50]

CONCLUSION

There can be no doubt that EMPs, especially HEMPs, pose a serious threat to the national security of our nation. The vulnerability of our communications, weapons, and power systems is great and should be corrected with all possible speed. As long as the vulnerability remains at its present level, the United States offers itself as a target of opportunity for an adversary which possesses nuclear weapons and space capability. A vulnerable United States is a liability to the cause of world peace.

As the EMP threat is great, so should be the efforts to eliminate the threat. This should include efforts on the part of individual citizens, especially scientists and engineers who have the ability to undersand such a technical problem, to insist that adequate effort and funds be spent to correct the vulnerability. This will require the scientific and engineering communities to further this knowledge, and perhaps become more active politically on the EMP issue and on nuclear arms issues in general.

This paper was written under the direction of Professor J.F. Scoggin, Jr. (F), and with the research support of Professor H.W. Askins, Department of Electrical Engineering, The Citadel, the Military College of South Carolina.

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Editor's Note: This paper was written as a thesis by Claudius E. Watts IV while a senior at The Citadel, the Military College of South Carolina. Watts received the degree of B.S. in EE. in May 1983, ranking 31st of 434 graduates. As a student at the military college, he became Cadet Lieutenant Colonel and a battalion commander. He received several awards for academic and military excellence; became a member of Tau Beta Pi, Phi Kappa Phi, and the IEEE; and was listed in Who's Who in American Colleges and Universities. He is now a pilot officer in the U.S. Air Force, with the rank of First Lieutenant.

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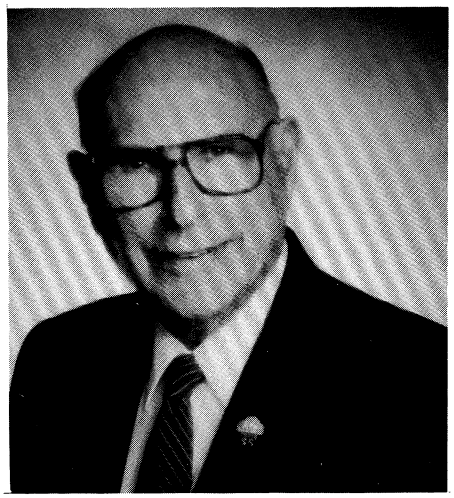
BRIG. GENERAL LELAND W. SMITH RESPONDS FOR FELLOWS



President Link, distinguished members of The Radio Club of America, ladies and guests:

Words inadequately communicate the honor that it is to stand before you and respond for our members who were elevated to the status of Fellow, this year. Having some knowledge of the achievements and contributions of these newly selected Fellows makes me all the more honored and humble.

Memory brings to mind other personal experiences when, standing in the presence of peers and superiors, recognition also was humbly accepted. One of those was when I was promoted to Private First Class in the Marines, fifty years ago. Another was when, thirty years later, the Commandant of the Marine Corps pinned the stars of a general officer on my shoulders. Those two events are especially meaningful, tonight, because much of my services as a Marine was in communications, radar and electronics. If I were to inquire more deeply into the lives of our recipients, experiences more impressive than these might emphasize even more of the significance of this occasion for us.

It is no news to you that we live in the most marvelous, exciting and challenging time in history. We are reminded that possibly 95 percent of the advancement in radio and electronics has taken place during our lifetimes. Further, we also should remember with pride that most of these achievements have come about within the time-frame of The Radio Club of America. It would not be news, either, to mention that many of the innovations and advances in our art are attributable to the technical ability and scientific inquisitiveness of many of our members. One could venture that no other field of farsighted research, experimentation and practical application has made a more lasting impact on so much of the World.

There is one factor, however, of which the public, and especially the younger generation, may not be aware. Many of the individual and cooperative contributions to the art of communciation by radio were joyful and exciting experiences, and for the sole reward of the satisfaction of having accomplished something for mankind.

Future generations of Radio Club of America members will remember, respect and be grateful for our radio pioneers: amateur and professionals alike. They will appreciate the opportunity and challenge to carry on the work of their predecessors who used Creator-given communication talents to change-for-the-better the way people live. Hopefully, they will take pride in also being contributors to a medium that brings citizens of all countries closer, and appreciative of a common understanding of life's purposes.

On behalf of those being honored as Fellows this evening, I respond for them with mixed humility and pride. We appreciate being associated with you. In turn, we assure you that we will continue to the best of our abilities to work toward making our marks, however small or large, alongside yours in the ever accelerating and wonderful art of radio communications. Thank you.

The annual meeting and banquet comemmorating the 77th anniversary of The Radio Club of America was held November 21, 1986 at the New York Athletic Club. Approximately 250 members and guests attended.

Dr. George H. Brown was the keynote speaker at the banquet and addressed the audience on the influence of Senatore Guglielmo Marconi on the lives of many persons.

A highlight of the banquet was the first presentation of The Fred M. Link Award established in recognition of pioneering work in the development of land mobile radio. The initial recipient was Mr. Fred M. Link, president of The Radio Club.

The annual meeting held during the afternoon included a technical seminar directed by Stuart F. Meyer, Executive Vice President. The technical speakers were: Brother Patrick Dowd, who discussed the history of the vacuum tube and described the collection at Manhattan College, of which he is curator; Nat Schnoll who presented a paper on the effects of Halley's Comet on radio communications; and Professor H. Thurman Henderson of the University of Cincinatti who described the progress in establishing the University's museum of radio artifacts in cooperation with The Radio Club. A reception for members and guests followed.

The meeting concluded with the formal announcing of the election of directors by Secretary Emeritus Frank Shepard during the dinner session.

The achievements of 34 members of the Club were recognized by their advancement to the grade of Fellow. Twenty-three were present at the Awards Dinner and received plaques from President Fred M. Link. Awards and citations also were made to Club members for distinguished services to the art and science of radio communications; those receiving recognition were: Dr. George H. Brown (F) — Armstrong Medal; Kenneth M. Miller (LF) — Sarnoff Citation; William H. Sayer (M) — Allen B. DuMont Citation; Frank A. Gunther (LF) — Henri Busignies Memorial Award; Donald K. deNeuf (F) — Ralph Batcher Memorial Award; O. James Morelock (LF) — Pioneer Citation; Mal Gurian (F) — Special Services Award; Arch C. Doty, Jr. (LF) — President's Award; and Maurice Zouary (M) — Lee deForest Award.

Again, the successes of the meeting, reception, and banquet resulted from the generous contributions of 22 industry sponsors and friends of the Club plus the hard work of the Banquet and Meetings Committees.

THIRTY-FOUR MEMBERS BECOME FELLOWS

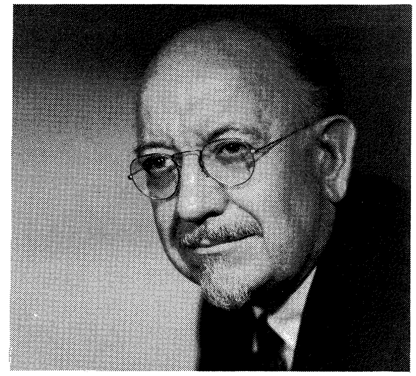
Twenty-three of the thirty-four members who were elected to the Grade of Fellow in 1986 were present at the Annual Awards Dinner and appear in the photo above. Seated: (L to R) David W. Winter, Woodhaven, NY; Sam L. Dawson, Los Angeles, CA; Mrs. Marguerite Warshaw, Valley Cottage, NY; John C. Beaman, Vancouver, WA; Dan L. Roszell, Newberry, SC; Roy E. Anderson, Schenectady, NY; Leland F. Heithecker, Springtown, TX; and Brig. General Leland W. Smith, Jasper, AR.

Standing: (L to R) Robert E. Bloor, Westlake, OH; Amandus G. Wentzel, Jr., Trenton, NJ; Don L. Fox; Tallahassee, FL; Weldon P. Hale, Owings Mill, MD; Dr. John H. Davis, Holmdel, NJ; Robert C. Corwin, Dallas, TX; David S. Simmonds, Pickering, Ont., Canada; George K. Starace, Plano, TX; Charles M. White, Houston, TX; Scott R. McQueen, Campbell, CA; David E. Weisman, Esq., Washington, DC; Emil J. Beran, Basking Ridge, NJ; Harry Tarbell, Beaverton, OR; Dr. William C.Y. Lee, Corona del Mar, CA; and Evan B. Richards, Schaumburg, IL.

1986 Fellows not in photo: Edward F. Barnhart, Charleston, WV; Norman E. Fowlkes, Houston, TX; Gary M. Frederick, Marion, IA; Dr. Roger E. Fudge, Watford, Herts., England; Herbert Hoover III, San Marino, CA; John B. Johnston, Derwood, MD; Byron O. McCollum, Penns Park, PA; Richard L. Miller, Palmdale, CA; Louis Perlmutter, Hallandale, FL; and Byron G. Ryals, Sunnyvale, CA.

ON THE TRAIL OF MARCONI

by George H. Brown, Ph.D. (M 1985, F 1986)



Dr. George H. Brown was the guest speaker at the 1986 Annual Awards Banquet where, earlier that evening, he had been awarded the prestigious Armstrong Medal. Dr. Brown has retired from RCA Corporation where he was Executive Vice President of Research and Engineering. He is a member of the National Academy of Engineering and a Fellow of the Institute of Electrical and Electronics Engineers, and of the Royal Television Society of Great Britain.

While I was in the sixth grade in Green Bay, Wisconsin, the class read of the Wonderful Wizard of Oz in our afternoon reading session and, at night, I read of another mythical character, Guglielmo Marconi, the Wizard of Wireless.

My family then moved to Portage, Wisconsin. There, I learned that an older boy — a high school student — was a radio Amateur with a transmitter, a receiver, and a license. I timidly approached George Flanders one day as he came out of the high school building and asked him to tell me what to read. He took me home with him to show me his rig. He transmitted in code and at low power. He had made very few contacts but his enthusiasm was high.

George loaned me a book and a few copies of *QST*. This got me started on a simple crystal-detector receiver. The crystals were the result of a five-mile bicycle ride from Portage to a cluster of houses in a settlement appropriately named Galena where products of a lead mine were being loaded into railroad gondolas. I returned home with a brown paper bag filled with hundreds of shiny nuggets, one or two of which allowed me to received code signals from some now-forgotten Amateur station. Soon I was able to receive WHA, the University of Wisconsin station, thirty-five miles distant, provided that I had placed the cat whisker on a sensitive spot on the crystal detector and that there were no loud noises in the house.

One evening, George Flanders telephoned me and told me to come to his house to hear the news. I dashed over. George had just heard of the spanning of the Atlantic by the relatively short waves of 200 meters. The American Radio Relay League had sponsored Paul Godley on a trip to Great Britain in an attempt to receive signals from a transmitter in Greenwich, Connecticut. This transmitter was contructed and operated by Major Edwin H. Armstrong and five other enthusiasts. A complete message was transmitted by this station, 1BCG, late in the evening of December 11, 1921, and received by Paul Godley in a field and a tent near Ardrossan, Scotland. Because of the five-hour time difference between Connecticut and Scotland, Godley received the message on December 12, exactly twenty years to the day after Marconi, near St. John's, Newfoundland, received the first transatlantic wireless signal from Poldhu, Cornwall, on a very-long wavelength.

Many years ago, Paul Godley told me of this adventure. He departed from New York on the *Aquitania* on November 15, 1921, carrying two receivers: one a regenerate set with two stages of audio amplification; and the other a ten-tube superheterodyne set built especially for the tests. He told me that when he boarded the *Aquitania,* he had not yet settled in his mind as to the type of receiving antenna to be used. Sailing on the *Aquitania* was Harold H. Beverage who, at that time, was a research engineer in charge of communication receiver development for RCA Communications, Inc. Beverage had just completed his researches on a system of wave antennas for which he was later awarded the Liebmann Memorial Prize of the Institute of Radio Engineers. Naturally, Beverage and Godley talked a great deal about their mutual interests.

So, in Scotland near the Firth of Clyde, Paul Godley erected a Beverage wave antenna and used the superheterodyne receiver to receive the message from Connecticut as well as to receive signals from more than thirty American amateur stations on a wavelength of the order of 200 meters. This feat, together with other contributions to the radio art, was recognized by the Veteran Wireless Operators Association by awarding him, in 1947, the Marconi Memorial Gold medal.

Although I had a reasonably active imagination, it would have been difficult for me as I sat in George Flander's radio room in December, 1921, to look into a future where I would be a professional colleague and associate of Paul Forman Godley and Dr. Harold Beverage as well as a consultant to Major Armstrong.

I first encountered Armstrong in 1937 when he retained me as a consultant to help him with the Turnstile antennas which he had caused to be mounted on a 400 foot tower at Alpine, New Jersey. He telephoned me almost every Sunday morning to talk about his antenna systems and he had me come to Alpine many times. He consistently called the antennas Turnstills. I tried to correct him to no avail. His name was Edwin Howard Armstrong so when he said, "Turnstill," I would say, "Turnstile, Edward." Finally, after one such exchange, he said, "Look here. Why not call me Howard as my other friends do?" and he continued to say "Turnstill."

On July 24, 1937, four days after the death of Senatore Marconi, I was occupied in the task of installing a directional antenna system for Radio Station WSMB, in New Orleans. I was sitting beside a road many miles from the transmitter with a pair of headphones and a radio receiver equipped for measuring the strength of the radio signal. Suddenly I heard an announcement of a program to be broadcast — *The Human Side of Marconi* — followed by voices of a number of my friends and professional associates. One of the speakers was H.E. Hallborg, at that time an engineer with RCA Communications. He related that, in 1912, he was one of of a group of American Marconi engineers sent to Ireland to study the huge Marconi transmitter near Clifden on the Connemara peninsula. Day after day, while they were in the Clifden station, they would see Mr. Marconi come to the station with mysterious packages under his arm. Sometimes these would prove to be a new form of spark gap or a jigger for receiving, and the next step would be to try his device in practice.

One cold rainy night, Mr. Marconi came in quite unexpectedly, having walked several miles from the railway station, but carrying the usual package — this time unusually large. Everyone eagerly watched the unwrapping. It was not a condenser this time or a new magnetic detector, but instead of dozen phonograph records.

"I thought you young men from the States might be rather lonely out here," said Mr. Marconi rather shyly, "so I brought you some gramophone records."

So saying, he placed the first one on the machine and the homesick Americans thrilled to the strains of "Everybody's Doing It Now."

Seven years after Guglielmo Marconi trudged the dreary miles from Clifden railway station to the transmitter, Mr. John Alcock and Lieutenant Arthur Whitten-Brown were the first men to fly non-stop across the Atlantic in a heavier-than-air machine. On their way to London, their Vickers Vimy biplane crashed in a bog in front of the Clifden station, in County Galway. On that fateful day, June 15, 1919, the Marconi operators rescued Alcock and Brown from the wreck, served them tea, and sent the news to the outside world by Clifden's direct landline to Marconi's London office. The two heroes were then placed in a flange-wheeled railcar for a trip from the wireless station across the peat bogs toward Clifden. Apparently Senatore Marconi became weary of toting phonograph records across the bogs and had made railroad track available.

A few years ago, my wife and I, accompanied by two grandsons, set out to see what remained of the historic Clifden transmitting station. After much questioning in Clifden, we finally encountered one elderly citizen who was able to direct us south on the narrow coast road. About four miles from Clifden, we found the bog, unencumbered by signs except one which stated "ROAD NOT SUITABLE FOR MOTOR VEHICLES" — somewhat of an understatement for the two ruts plunged into a lake several feet in depth. In the distance, we spied one concrete tower base and a pile of rust which appeared to be the remains of an alternator. Closer to us was a vertical steel rail about three feet tall, the last remaining relic of the Marconi light railway.

On a nearby hillside stands a white stone in the general shape of a aircraft tail fin, erected by Aer Lingus. This memorial points to a white cairn a mile away in the bog where the Alcock-Brown aircraft landed. In the town, another memory of the aviators stands as the Alcock and Brown Hotel. But not a sign to tell one of the fifteen years when the giant Marconi transmitter linked the British Isles with North America. Two photographs in my old copy of *"The Principles of Electric Wave Telegraphy and Telephony"* by J.A. Fleming show the huge engine and boiler house, the large condenser house; the giant antennas, and even a commodious residence for the operators. It is a shock to realize that only a concrete block, a steel rail, and pile of rust remain.

My interest in Marconi's life and career persisted until finally my wife and I visited Bologna. As a first step, I walked past the Marescalchi Palace on Via IV Novembre where Marconi was born. Then we proceeded to the Villa Grifone which was his boyhood home and where he conducted his first experiments. While we were viewing the mausoleum at the foot of the hill near the road, a caretaker informed our taxi driver that the house was undergoing repairs and visitors were not permitted to enter. The taxi driver did not know what to do with this information for he was no more able to speak English than was the caretaker. When I addressed the caretaker in her own language, she beamed at us and suggested that we drive to the top of the hill to visit the house and take coffee with her. This we did and we found the house being completely refurbished, with a large meeting room being prepared for technical conferences, and a laboratory being re-established on the top floor. It is a magnificent building with high ceilings, marble floors, and huge fireplaces. The fields around, on a high plateau, fade off in the distance to a series of rolling hills, affording an excellent location for radio-propagation experiments.

A marble commemorative tablet on the front wall of the house, facing the village of Pontecchio, is inscribed: —

Onore al merito di Guglielmo Marconi il quale in questa casa facendo le prime prove ancora giovanetto col suo ingegno e collo studio invento il telegrafto senza filo nell'anno 1895 ammirato dall'Italia e dall'Europa.

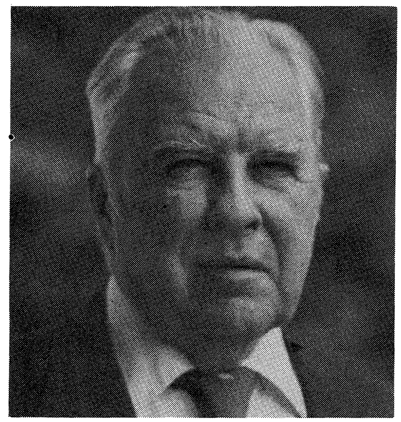
That is to say, "Honor to the achievement of the young man who, making the first tests in this house and inventing wireless telegraphy in 1895, is admired by Italy and Europe."

Apparently my unpublicized visits to Clifden and to Villa Grifone established me as a pseudo-authority on Marconi for I was invited to speak at the Marconi Centenary session at the annual meeting of the American Association for the Advancement of Science held in San Francisco during February, 1974. It was a fitting climax to my long time pursuit of lore concerning the Senatore.

The speakers were introduced by Signore Egidio Ortona, the Italian Ambassador to the United States, and one of Marconi's daughters, Gioia Marconi Braga, was one of the speakers. When I learned of her participation from an advance program, I anticipated that this figure from the past was likely to appear in a wheelchair. To my surprise, she was a handsome and gracious lady, ten years my junior. The day was made memorable for me when we were invited to have dinner that evening at the home of Marconi's grandson, Dr. Francesco Paresce. During the course of the evening, Gioia made the wry comment that she found the aircraft beacon on a radio tower near her home in Alpine, New Jersey, to be very annoying as the red lights flashed through her windows. Actually this was the tower erected at Alpine in the thirties by Major Armstrong. I commented that she had little cause for complaint since her father had made radio towers possible.

A HIGH RELIABILITY ELECTRONIC INTERCONNECT BUS SYSTEM

by Jerry B. Minter (LF)



ABSTRACT

This paper provides the background of design and manufacturing details which resulted in a new electronic packaging system for use in the U.S. Navy Standard Missile System.

Ten years of production experience for the U.S. Navy with a record of zero contact failures has proven the reliability of this new interconnect system.

HISTORICAL BACKGROUND

Early electronic packaging used turret-like modules made from octal-tube bases to plug into tube sockets. Many of the first digital electronic counters used this method of packaging. This seemed logical at the time since solid state technology had not yet been developed, and an array of tube sockets was convenient and available.

For military applications using discrete components, the "cordwood" package was used to save space and weight. The "cordwood" package consisted of two etched circuit boards mounted parallel with the components suspended between. The leads of each component were soldered to the outer faces of the circuit boards so that the components located in the central volume were inaccessible for replacement. If a single component failed, the "cordwood" module had to be discarded. In many cases, the defective components could not be located since disassembly of the "cordwood" packages usually damaged many of the components.

For commercial applications, the use of circuit boards with contact tabs along one edge has become standard practice. The component parts can be removed easily from the plug-in board and replaced, if necessary. The method of making contact to these edgeboard tabs by conducting spring fingers is well known and widely used.

For military missile applications, the vibration and shock forces associated with launch profiles, in addition to other requirements, mitigates against such simple pressure contacts. The white-noise vibration portion of the A2 launch profile requires that all components on a circuit board be potted in either silicone or other suitable compound. For missiles, expanded polyurethane foam is used frequently to save weight. This foam penetrates in between pressure contacts and the tabs and results in open circuits; therefore, it is necessary to solder secure all such pressure contacts if they are to be foamed into place.

CONTACT RELIABILITY

For highest reliability, it is recognized that a wiping action contact is preferable to a simple pressure contact because small foreign particles will be pushed out of the path with the wiping action instead of being trapped by a simple pressure contact.

In many electronic circuits, very little current flows between the contacts and it is necessary to provide high unit pressure during the wiping action in order to penetrate surface coatings such as oxides, dust, smoke film, etc. This high unit pressure is best obtained from a ball surface wiping against a flat planar surface.

The material used for such wiping contacts should have good conductivity with a minimum of insulating surface oxides. The spring force which determines the relatively high unit pressure must not fatigue with operation, vibration, or time.

In 1942, I designed a Standard Signal Generator — the Model 80 — which used pairs of ball contacts floating in a rigid post, to contact either side of the moving flat blade on the coil turret. Beryllium copper springs apply symmetrical force to the ball contacts. Thus, the application of the contact force did not deflect the blades from their proper path during engagement.

Figure 1 shows the arrangement of the Model 80 turret contact system. The ball contact was cold-headed from coin silver, and the blades were made of rolled-edged coin silver flat strip. The rolled edges of the blade prevented cutting or galling of the ball surfaces during contact engagement.

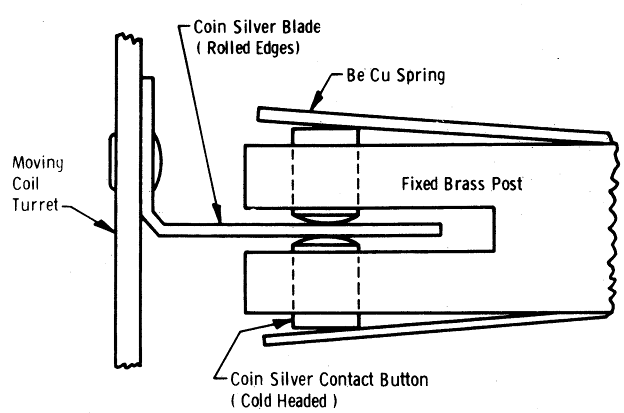


Figure 1. Model 80 Turret Contact

The original Model 80 is still in use as are many thousands manufactured over the years since 1942. No contact problems have developed even though the currents through the contacts are low and frequencies up to 400 MHz are involved.

Since solid coin silver when cold worked is very hard and durable, the contact wear on these Model 80 turrets has been negligible. The beryllium copper heat-treated springs have maintained the contact force for reliable, low electrical resistance over years of service.

Thus, the long-term reliability of the ball contact has been well established.

In 1960, I became involved in the design of spacecraft electronics for the Goddard Space Flight Center, at Greenbelt, Md. The need for light, reliable interconnections between sub-systems led to the design of the DIGI-KLIP® edgeboard connector system covered by U.S. Patent #3,340,440. The principle of the ball contact was again utilized but in a manner to minimize weight and space.

Figure 2 illustrates the path made on a circuit board tab by a ball contact. The amount of deformation has been exagerated for illustrative purposes.

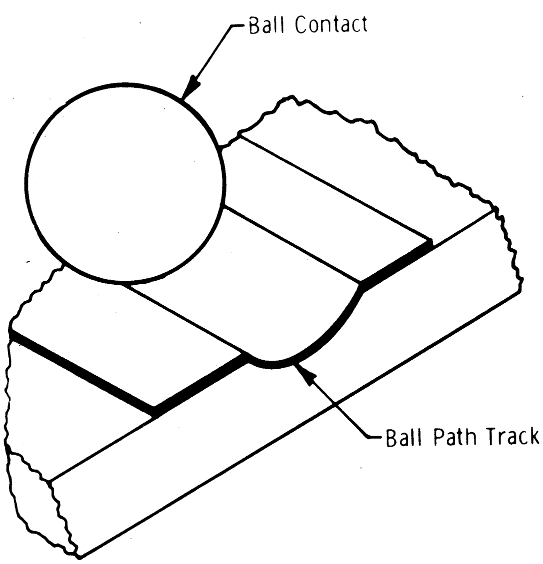


Figure 2. Ball Contact Path Track

Figure 3 shows the conventional flat contact when a foreign particle is present on the contact tab of the circuit board. The particle was first encountered at "A" and then pushed to position "B" during contact engagement. A surface scratch in the tab has resulted. Repeated insertions will wear down the surface plating of the copper tab and eventually begin to cut into the copper itself.

If the edges of the flat contacts have burrs, these burrs also will scratch the surface of the tabs and repeated insertions will result in poor electrical contacts.

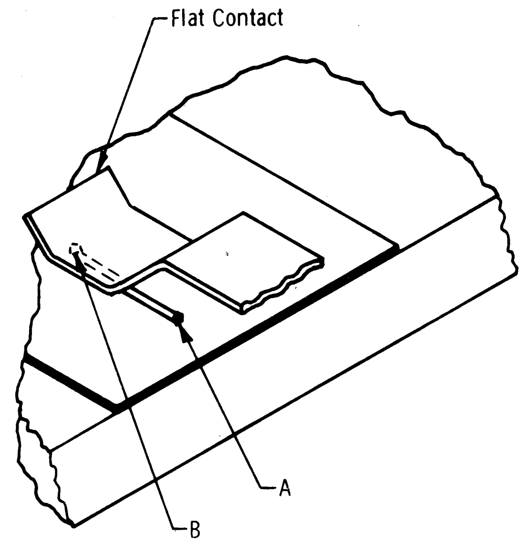


Figure 3. Flat Contact Path Track

CONTACT PRINCIPLE

The premise is simple: to provide long term and reliable contact in demanding applications, a card edge contact must be a good spring. The connector must exhibit no reduction in pressure over years of mated service, and it must provide a wiping action. The DIGI-KLIP® series of contacts are manufactured from the highest grade of beryllium copper alloy wire which is heat treated for optimum spring temper after forming. Because of this design and process, the resulting contact provides a true wiping action point contact with exceptionally high unit force. This allows for a "gas tight" mating junction, eliminating the need for precious metal plating in most applications. Consistent contact "normal" forces are ensured regardless of time or multiple insertion/withdrawal cycles.

A ball contact is effectively achieved with the DIGI-KLIP® by using a small diameter wire and bending it so that the actual contact occurs at the bend radius. Very low contact resistance is obtained between the standard bright-finish beryllium copper and the tinned circuit board tab commonly used commercially. The reliability under adverse corrosive exposures can be improved by plating of the DIGI-KLIPS® and circuit board tabs. Both electro-tin plating and gold plating have been used depending upon the degree of corrosion protection desired.

The ball contact wiping action of the DIGI-KLIP® actually burnishes the circuit board tab if the board is inserted repeatedly into a row of DIGI-KLIPS®. Test have been run to thousands of insertions without fatigue of the spring action or any measurable change in the contact resistance.

Figure 4 indicates the track path of the DIGI-KLIP® connector on the plated circuit board tab. The foot-print of the connector is slightly oval rather than circular since the wire radius is smaller than the bend radius at the contact area.

Hundreds of thousands of these connectors are flying in spacecraft with no reports of contact trouble. Again, the principle of the ball contact has been well documented as to reliability.

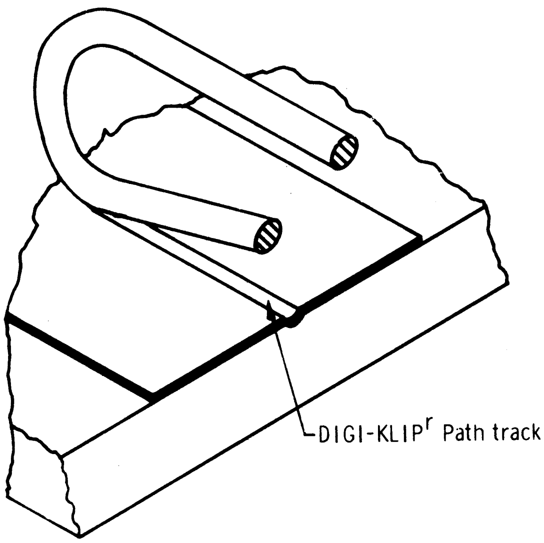


Figure 4. DIGI-KLIP® Path Track

MISSILE APPLICATION

In 1968, the Standard Missile was under design by the Pomona Division of the General Dynamics Corporation for the U.S. Navy. Their engineering design group was interested in the application of a special Tandem DIGI-KLIP® Connector for electrical interconnections in the Standard Missile. The electronics package is illustrated in Figure 5.

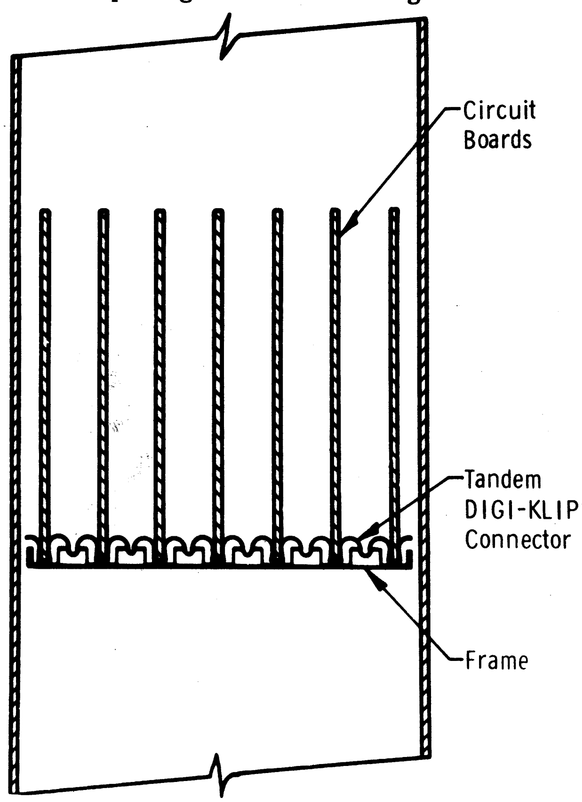


Figure 5. Standard Missile Package

A frame molded of high-temperature insulation with parallel slots to accommodate the Tandem DIGI-KLIP® Connector was used instead of the usual mother board. Figure 6 shows a cross section of this molded frame.

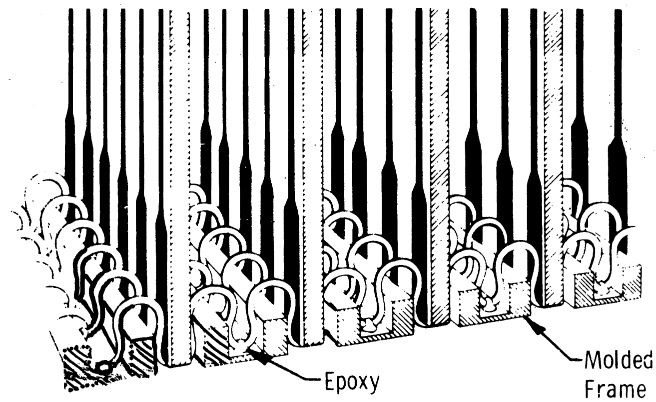


Figure 6. Detail of frame/board assembly

The special version of the connector was developed to provide a means of wave soldering of the completed contact after all tests have been completed. This assures compliance with MIL-E-5400K, Section 3.2.1.1.8 which specifies: ". . . pressure contacts shall not be used." Essentially, the connector eliminates the etched circuit in the mother board since the clip itself provides the continuous path for interconnection.

During assembly, the Tandem DIGI-KLIP® connectors are held in place by slotted metal jig fixtures while quick-setting epoxy is applied to the bottom of the grooves as indicated on the drawing. The resulting array of busses connect the various circuit boards together for all common interconnections.

Paths at right angles can be provided by circuit paths in the actual plug-in boards. If a crossover connection is required, the path is made through one of the plug-in boards as shown in Figure 7. The Tandem DIGI-KLIP® connector may be cut short at the cross-over, and the other end used for another cross-over, if necessary. Double-sided plug-in boards are generally used to permit cross overs across any or all of the busses by using the rear for the cross-over connection.

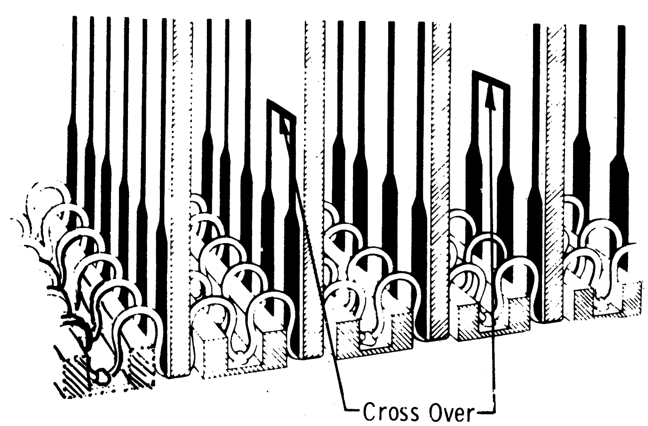


Figure 7. Buss Cross over method

Cables between the package and other electrical components of the missile are made by soldering directly to the loops at the end of the Tandem DIGI-KLIP® connector buss.

Flat type cables also can be connected to a plug-in board as shown in Figure 8.

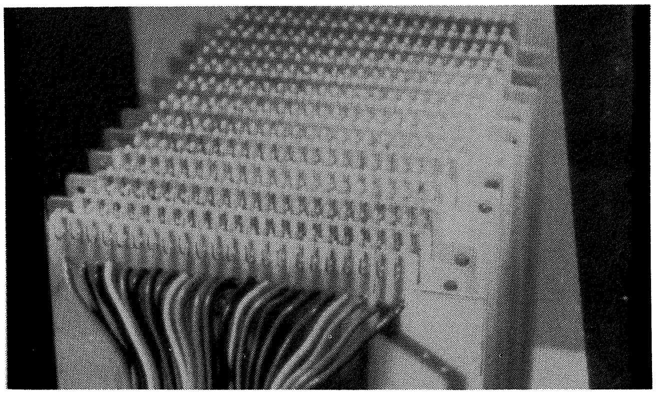


Figure 8. Flat Cable Connection

After the frame has been assembled and the cables connected, the various circuit boards are plugged into place and electrical testing can begin. Circuit burn-in, temperature cycling, and operational testing can be completed prior to the final potting of the assembly.

Before potting, the frame, with all plug-ins in place, is passed over a wave solder bath and the individual contacts are solder-secured to prevent subsequent foamed potting from separating the contacts. The final, foamed package is then checked out again and then mounted in the missile case, and the entire unit is ready for storage.

During lengthy storage, the missile is checked out from time-to-time for proper electrical performance. In the event that some defect becomes apparent, the foamed package can be removed and the various circuit plug-ins separated by passing a thin saw blade between the plugged in boards. Next, the foam is removed below the frame and the frame is passed through the solder bath to loosen a particular board which then can be unplugged.

This individual board then can be analyzed in detail to locate the source of the trouble. A board repair or replacement can be resoldered into place and the package re-foamed for return to service. The use of eutectic solder at a temperature well below the 700°F. anneal of the berrylium copper does not affect the reliability of the spring force of the contact.

The possibility of repair of the package is in sharp contrast to previous military packages such as "cordwood" types which are inaccessible for analysis by non-destructive means.

MANUFACTURING METHODS

Beryllium copper is well known for its combination of good conductivity and stable spring properties. Therefore, all DIGI-KLIPS® are fabricated from beryllium copper wire which is heat treated after forming. Novel tooling techniques in combination with precision heat treatment make it possible to assure a consistent spring temper with close dimensional tolerances.

In order to form the Tanden DIGI-KLIP® connectors from soft beryllium copper wire, it is necessary to use wire that is fully annealed after the last draw. The engineering department of General Dynamics insisted that the wire be nickel plated before forming and heat treating.

Most nickel platings tend to peel from wire when it is formed into sharp bends so a special nickel plating process was developed to assure that the nickel would adhere securely and survive the 625°F, of the heat treatment necessary to harden the beryllium copper after being formed from the soft wire stock.

A special wire forming machine was designed and built to form the Tanden DIGI-KLIP® connectors There are two different spacings of the loops so the machine had to be converted easily from one type to the other.

The basic spacing is determined by an accurately-drilled bar which has floating pins inside the holes. These floating pins are kicked up once each 300° stroke to allow wrapping the wire around another pin. The process is complicated since the pins alternate in diameter. After the proper number of loops have been wrapped, the machine stops automatically and the wrapped wire is stripped from the bar. The pins are kicked down by a special row of stripper pins so that the formed wire can be removed.

Next, the formed wire must be heat treated while held in accurate position on special fixtures. To assure that proper hardness had been obtained, a new hardness test was developed and accepted by the U.S. Navy. After heat treatment, each fixture (holding about 20 pieces) has one or two test extensions bent sharply by a pair of long-nose pliers to observe the angle at which the wire breaks. It must break between certain limits in order to assure that proper hardness has been obtained. The batches are numbered for traceability.

After the test for heat treatment, the connectors are dipped in eutectic hot solder to provide a bright solder coating of about 100 millionths of an inch thickness. There must be no areas without solder; pin holes are not allowable. There must be no lumps or uneven coatings. The finish must not be frosty in appearance.

After final inspection, the connectors are packaged individually in sealed plastic sleeves to prevent any possibility of contamination during storage. Each traceable lot has a test sample extension for incoming inspection of hardness by General Dynamics.

CONCLUSIONS

An electronic packaging system has been described which meets all of the reliability requirements for military use in missile applications. Over ten years of continuous use by the U.S. Navy has resulted in zero defects. No contact failures in over ten million contacts, to date.

The U.S. Navy has released this system for commercial use as it continues in production for the Standard Missile.

Editor's Note: This article was prepared from papers presented by Mr. Minter at the Eleventh Annual Connector Symposium on October 25, 1978, and at the Thirteenth Annual Connector Symposium on October 9, 1980.

Jerry B. Minter holds a B.S. degree in Electrical Engineering from the Massachusetts Institute of Technology. He holds 14 patents with additional patents pending. He is a Fellow of the IEEE and a member of the North Jersey Awards Committee, and served as the first chairman of the North Jersey Subsection after being its founder.

He is a Life Fellow of The Radio Club of America, and served as its president during 1948-1949 and 1965-1966. Presently, he is a Director Emeritus for Life and serves as chairman of the Club's Awards Committee. Mr. Minter has received the Armstrong Medal (1968), The President's Award (1981), and the Henri Busignies Memorial Award (1985).

He is a Life Fellow and Past President of The Audio Engineering Society, and is a member of the American Society for Metals, SPIE the SMPTE, QB, AOPA, and ESCG.

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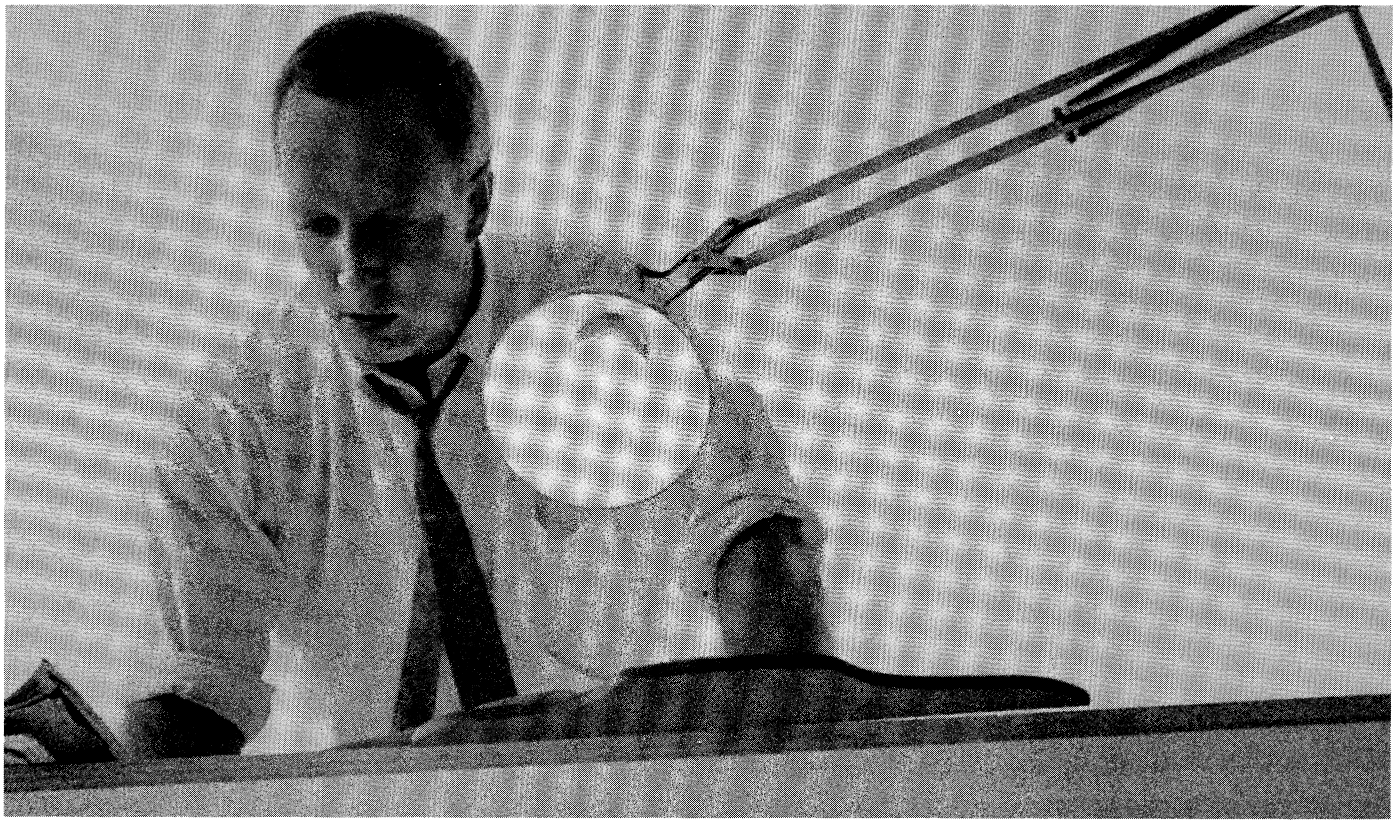

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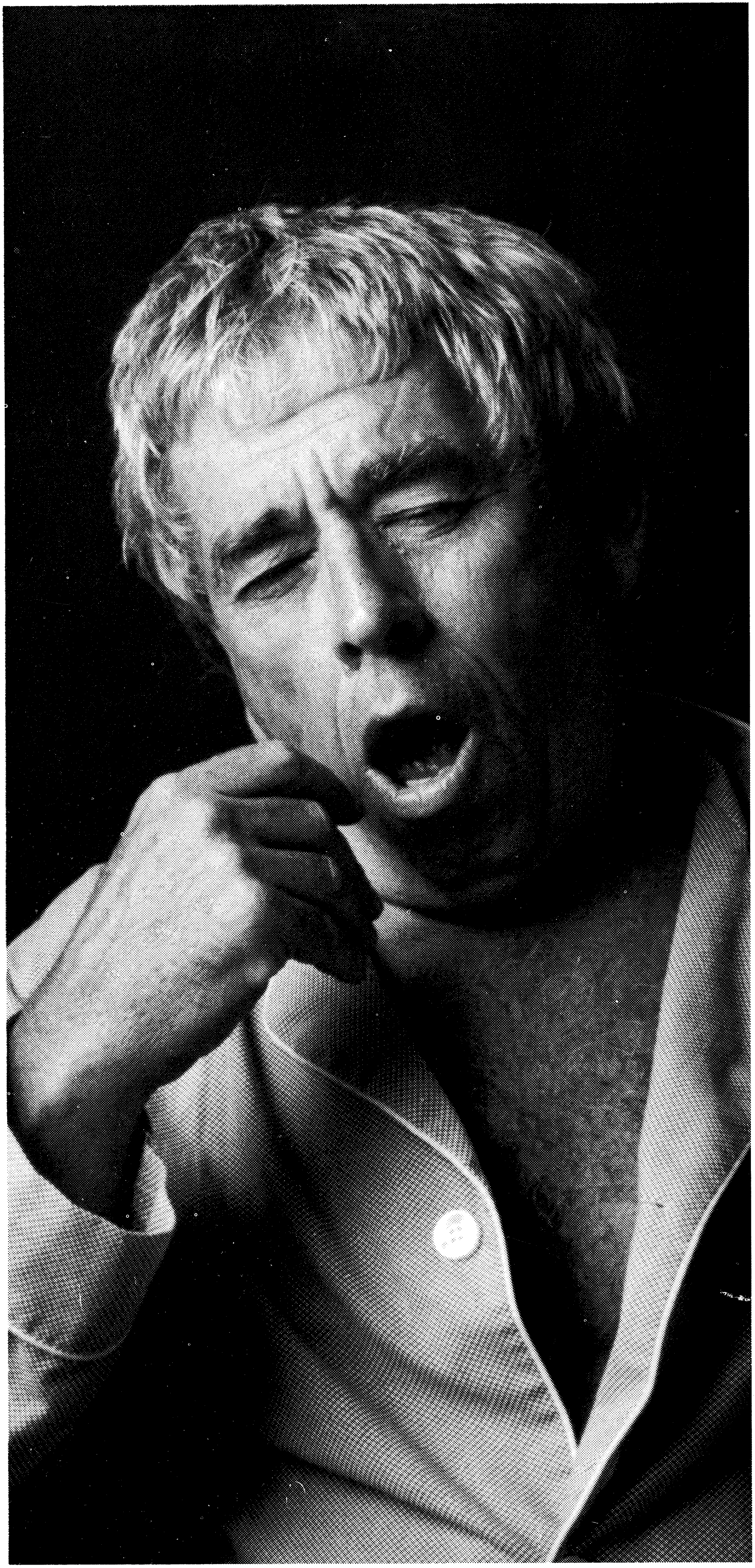

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