ELECTRO MAGNETIC PULSES

Imagine a very bright flash in the sky! No one is hurt. But, your transistor radio stops playing, your car won't start, the telephone doesn't ring, lights stay off, and we find ourselves in the stone age!

THE developement of modern high-tech semiconductor devices have paralleled unsettled relations between the nations of the world with resulting technological advances affecting the lives of every citizen of North America. Communications have been made faster, automobiles more fuel-efficient and maintenance-free, TV sets, video-tape recorders, and virtually every other piece of electronics equipment have been improved by the advent of the semiconductor and its high-tech advancements. The relationship between nuclear weapons and the recent electronics advances may seem unclear, but a nuclear attack on the North American continent could make that relationship glaringly apparent.

ALL nuclear explosions produce electromagnetic pulses (EMP's) and the ensuing induced voltages and currents produced in conductors (wires and cables) are comparable in strength to the strongest of lightning bolts. EMP's may reach 3 million volts and 10,000 amperes for a total of 30-billion watts of energy.

The largest commercial radio stations in the U.S. and Canada radiate 50,000 watts, or approximately one-millionth that much power! The major difference between EMP's and lightning is that EMP's are induced simultaneously over an entire wide area, while lightning occurs at a single location.

Significance of the Problem

THREE ten-megaton thermonuclear weapons detonated 250 miles (400 kilometers) above the United States or Canada would produce EMP's strong enough to knock out the entire electrical power grid of North America including the entire civilian-telephone network, and just about every broadcast station.

Virtually every piece of unprotected electronic equipment in the country -- radios, TV sets, computers, electronic controls in homes, office buildings, factories, cars, airplanes, and instruments in hospitals -- would be damaged, if not destroyed. The pulses would also damage or destroy large portions of the military command's control and communication (C3) system.

A chain reaction could be set in motion at nuclear power plants, due to electromagnetic pulses. Although it is a point that is frequently disputed, the possibility exists that reactor core meltdowns might occur as a result of EMP's. The meltdowns would be a by-product of electronic control system failure. The control systems are used to monitor and control the processes at the plants. The EMP's could cause the system to fail and result in partial or complete loss of control over vital functions, causing subsequent meltdowns. We know that those nuclear plants are designed to be fail safe, but has anyone considered the possibility of every circuit breaker in a plant failing at the same instant?

Characteristics of EMP's

AT an altitude of 250 miles, the gamma rays produced in the first few nano-seconds (billionths-of-a-second) of a nuclear explosion can travel hundreds of kilometers before colliding with electrons in atmospheric molecules.

That kind of collision may take place in a region 2,000 miles in diameter and 6-miles thick. Electrons are accelerated by those collisions, a phenomenon referred to as the Compton effect; and upon reaching the earth's magnetic field, they set up electromagnetic pulses that radiate downward toward earth (Fig.1). Due to the extremely large area of collision, vast amounts of ground area are exposed to electromagnetic fields with strengths up to 50,000-volts per meter. The ground area exposed to electromagnetic pulses could cover the entire continental United States and most of Canada by one nuclear blast; if not, certainly large regions such as New England would be electrically and electronically devastated.

FIG. 1 -- Electrons set into motion by gamma rays from a nuclear explosion in space will produce enormous electromotive pulses (EMP's) when the negative charges enter the Earth's magnetic-field. It is estimated that the ideal height for such an explosion should be 250 miles above the Earth's surface.

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:                                    :
:              O - Nuclear Explosion :
:                                    :
:            /  /                    :
:           /  /   - Gamma Rays      :
:   ---------------------------      :
:  <  Earth's Magnetic Field   >     :
:   ---------------------------      :
:   *******   *******   *******      :
:    *****     *****     *****       :
:     ***  EMP  ***  EMP  ***        :
:    *****     *****     *****       :
:   *******   *******   *******      :
: ===============================    :
:           EARTH                    :
:                                    :
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Vulnerability

THE effects that electromagnetic pulses would have on a mass of circuitry are difficult to predict because the interactions are complex. But, the more complex the components, the easier they are to damage. Power lines are one avenue for EMP damage, and a company making a shielded tubing to go over power and signal carrying conductors obviously had EMP in mind when they invented their "Zippertubing". That covering acts as a partial shield to EMP's.

FOR each component, damage would come from the internal pickup of the circuit itself, as well as surges fed to it by all other attached conductors (power lines, other circuits,and metal parts). ANOTHER concern is that generators and motors with their numerous internal windings of copper wire could be rendered useless in an EMP attack; and with subsequent inoperative water pumping stations, desert population-centers could persih. In the dead of winter, motors in heating units would be destroyed and the chilling freeze in the northern portions of the North American continent would bring those areas to a standstill. Food and fuel shipments would halt because fusible links and electronic ignitions would be destroyed in cars and trucks. It's difficult to conceive a family anywhere on the continent not suffering extreme hardships.

THE more complex the electronics components, the more vulnerable they are to electromagnetic pulses. Hardness describes the vulnerability of an electrical device and it is best for old-style vacuum tubes, less for semi-conductors, and even less for microcircuitry. It would take 100 times more EMP energy to damage the tubes than integrated circuits. Computers may be upset through memory erasure with 100 times less energy than required to damage integrated circuits; refer to Fig. 3. Aircraft in the air and parked on open surfaces would be disabled, because electronics controls the crafts' flight instruments and control surfaces.

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:(-8)(-6)(-4)(-2) (1) (2) (4) (6) (8) :
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:                         ######     :
:                                    :
:         $$$$$$$$                   :
:                                    :
:      %%%%%%%%                      :
:                                    :
:    &&&&&&&                         :
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:(-8)(-6)(-4)(-2) (1) (2) (4) (6) (8) :
:( Powers of TEN)       <Fig. 3>     :
:::::::::::::::::::::::::::::::::::::
:  RANGE OF THRESHOLD ENERGY, JOULES  :
:::::::::::::::::::::::::::::::::::::
: # = Motors and Transformers        :
: $ = Vacuum Tubes                   :
: % = Low-Power Transistors          :
: & = Integrated Circuits            :
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Hardening Communications Equipment

HARDENING of electronics communications equipment is vital to the military, and, to a lesser extent, the civilian populace. The Department of Defense has established an Electromagnetic Compatibility Program (EMCP) to ensure that all military Communication-Electronic (CE) equipment subsystems, and systems are protected from electromagnetic interference of all kinds.
That program was implemented to ensure that electromagnetic compatibility is maintained through design, acquistion, and operational phases. Numerous semi-conductor manufacturers now produce what are called "radiation-hardened" integrated circuits, just for that reason.
THERE are three major design criteria which must be considered when hardening against EMP's. They are cost, the equipment's ability to survive EMP, and failure rates of the shielding components.
COST includes both installation and maintenance. Some protection practices, such as shielding the entire communication site, may be attractive from a technical point of view, but are impractically expensive.
THE electronic equipment's ability to survive an EMP attack must be measured in order to determine how much EMP protection is needed. A testing device for measuring the radiated electromagnetic susceptibility of an electronic device is a Transverse Electromagnetic Mode (TEM) cell. A TEM cell consists of a group of electronic instruments and a special specimen holder that simulates an environment of free space. The TEM cell is used for performing electromagnetic interference/electromagnetic compatibility (EMI/EMC) measurements and evaluating protection devices.

Shielding Methods

IN order to predict the effect of an electromagnetic pulse on electronic equipment, it is necessary to assess the enviroment. The structures housing the electronic equipment are made in various shapes and sizes, and are connected to the outside world by conductors such as utility lines and pipes, communication lines, and access and ventilation structures.(Refer to fig.5)
That combination of criteria makes the exact determination of the interaction of an EMP with such a variety of structures extremely difficult. However, for complex systems, it is convenient to have several layers of shielding. (Refer to Fig. 6).

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:   EMP              Lightning    :
:  ////              V V V       :
:   -----------------------------    :
:   !*          Building       !    :
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:P--+**                          !    :
:   !*                           !    :
:   !   EMP Penetration          !    :
:   !                            !    :
:   !                            !    :
: +-+    *                       !    :
: ! !   ***                      !    :
: ! -----!------------------------    :
: !      !                            :
:=!======!========================== :
:Gnd     ! - Buried Cable             :
:--------+                            :
::::::::::::::::::::::::::::::::::::::
:  P = Power Lines        Fig. 5. --  :
: -- A sealed metal box is an ideal   :
: structure for eliminating EMP pen-  :
: etration. However, power lines and  :
: signal cables require entry ports   :
: thus compromising the integrity of  :
: a shielded building. Obviously, it  :
: is apparent that doors and windows  :
: would have a greater leakage effect.:
::::::::::::::::::::::::::::::::::::::
:              Shield 1               :
:         ********************        :
:        *  Zone 1 (internal) *       :
:       *    ==============    *      :
:      *    =    Zone 2    =----*     :
:      * g =   ##########   = g *     :
:      * r =  ############  = r *     :
:      * o =--###ZONE 3###  = o *     :
:      * u =  ############--= u *     :
:      * n =   ##########   = n *     :
:      * d =   (cabinet-    = d *     :
:       *---= environment) =   *      :
:        *   ==============   *       :
:         *   Shield 2       *        :
:          *****************          :
:    !------!                         :
:    !                                :
:    !       Zone 0 (External-        :
:    !               Environment)     :
:----!--------------------------------:
:    =     EARTH                      :
:                                     :
::::::::::::::::::::::::::::::::::::::
: Fig. 6 -- More than one shield can  :
: be used to secure the environment of:
: the machinery and electronic mat-   :
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: erial contained within a building.  :
: The building can provide the initial:
: shield. Shielded rooms or metal cab-:
: inets may provide a second shield.  :
: A third shield (not diagrammed)     :
: would protect entry cables from     :
: violating the shielded area of      :
: zone 3.                             :
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Shield 1
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A structure composed of a great deal of metal is well shielded against electromagnetic pulses, while a building made primarily of wood is virtually unshielded against EMP's. Continuous, closed sheet-metal shields are, by far, the most effective electromagnetic shields. It is imperative that the internal environment of zone 1 be connected to the outside world. That fact makes a closed sheet-metal shield impossible. Aperatures in shield 1 create a special problem in protecting communication sites from EMP penetration.

THE electromagnetic field penetration depends on the aperature size. If a given area of wall opening is subdivided into ten small openings having the same total area, the penetrating EMP fields at an interior point will be 1/SQR(10) as large as for a single large opening of the same total area. (Refer to Fig. 7).

Therefore, it is better for a structure to have more small openings than just a few larger openings.

A common treatment for such openings is to cover them with a conducting screen or mesh so that the large opening is converted to a multitude of small openings, or use a glass impregnated with metal. That glass, despite having metal in it, offers approximately the same degree of visual attenuation or lack of clarity as looking through a screen door from within the house.

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:       !!          !!              :
: ###### !!  ######### !!              :
:      # !!        # !!              :
: EMP *==!!        # !!              :
:      # !!        # !!              :
:      # !!    E   *==!!              :
: EMP *==!!    M  **==!!              :
:      # !!    P  **==!!              :
:      # !!       *==!!              :
: EMP *==!!        # !!              :
:      # !!        # !!              :
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:     # !!        # !!             :
: EMP *==!!        # !!             :
:     # !!        # !!             :
:     #           #                :
: ######     ########               :
:   Shield      Shield            :
::::::::::::::::::::::::::::::::::::
: Fig. 7 -- The electromagnetic field :
: penetration into a ported shield is :
: minimized by reducing the size of   :
: the openings. In the diagram the    :
: open area of the port of the example:
: on the right is equal to the sum of :
: the areas in the example at left.   :
: The diagram clearly shows that the  :
: penetration of an EMP is less when  :
: equal areas are summed from several :
: small ports.                        :
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Shields 2 and 3
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THE second-level shield seperates the internal environment from the sensitive small-signal circuits within the electronic equipment found within Zone 2. Shielding here may be accomplished by electrically grounding the metal cabinets and equipment.

SHIELD 3 involves the shielding of the interconnection of the equipment. That could involve elaborate design of interconnecting signal transmission lines. Fiberoptic signal transmission shows great promise here because it is not effected by any type of electromagnetic interference.

Hardening Aircraft and Missles
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GENERALLY, the EMP interaction with electrical systems inside structures such as aircraft and missles depends upon a multitude of factors. Aircraft and missles usually have a nearly complete metallic exterior covering that serves as a shield from electromagnetic fields. However, that shield alone is not enough protection against electromagnetic pulses.

Missles and Aircraft are equipped with computers that cannot be upset even for an instant. They must be partically well hardened.

AT the present time, there is no agreement on the most effective ways to harden aircraft and missles. Heavy shielding, like the type used at communication sites, is obviously impractical because of the added weight that the aircraft has to carry. Instead, EMP resistance is designed into the aircraft's equipment. One example of that would be in the area of circuit design. Small loops make better antennas for EMP's than short straight lines; therefore, circuits are designed in tree or branching layouts rather than in more conventional circuit loops.

Is Shielding Help on the Way?

IN the last decade, electronic devices have proliferated in all areas of our lives. That influx of products has caused a problem: Noise Pollution, or EMI/RFI (electromagnetic/radio frequency interference). Over 80,000 cases of noise pollution were reported to the FCC (Federal Communications Commission) in 1982.

STRANGE as it may sound, the plastics industry is coming to the rescue with plastic electronic-equipment enclosures specifically designed for both EMI containment and shielding. Obviously, with EMP's as an external disturbance, the containment of a field is academic, but the shielding from an outside field is crucial. The parameter describing that is Shielding Effectiveness (SE) and the equation for shielding effectiveness is

$$SE = A + R,$$

or shielding effectiveness equals Absorbed plus Reflected energy.

HIGHLY conductive materials such as pure metal shields reflect approximately 99 percent of the energy and adsorb 1 percent. But plastics with metallic composite fillers, metallic paints and sprays, or even impregnated wire meshes still reflect 80 percent of the energy and absorb 20 percent. If EMP's and the disturbing effects of electromagnetic fields still seem like an abstraction or a physicist's dream, consider that event.

A manufacturer of buses designed for city use had just delivered a fleet when, during a test drive, a problem was discovered. After going over the top of a hill, the driver tried to brake, only to discover he had no brakes until he got to the bottom of the hill. Upon logical investigation of that problem, field-strength meters demonstrated that a local television station had a lobe-shaped radiation pattern that intersected the hill's apex. The microprocessor-controlled anti-skid braking system on the bus had sensitive circuitry that became inoperative because of the TV signal. The bus, though, was made safe by properly shielding the enclosure housing the electronics. Graphite, a moderately good conductor, is fabricated within large plastic sheets for applications such as that.

IF a signal as small as that can effect circuitry that drastically, you can imagine what an EMP could do and likewise you can see how crucial EMI shielding is. But will EMI shielding be universally implemented into new equipment?

The Military's Involvement

THE military is very concerned with EMP's. The Army has established its Aurora Tree test facility in Aldelphi, Maryland. The Navy has the Casino and Gamble-2 x-ray emitting facilities, but the Air Force probably has the most interesting project of all. It is the Trestle, after the railroad structure it resembles.

THAT 12-story (118 feet) high, 58-meter (200-foot) square deck is flanked by a 50-foot wide adjoining ramp upon which aircraft to be tested are rolled up. The Trestle can support aircraft weighing 550,000 pounds and is built with one-foot by one-foot wooden columns using no nails or metal of any kind. That largest glue-laminated structure in the world uses 250,000 wooden bolts to hold its six-million board feet of lumber together --- enough for 4,000 frame houses. The structure at Kirtland Air Force Base, New Mexico cost approximately 58-million dollars.

THE Trestle has two 5-million volt pulsers that discharge energy into wire transmission lines surrounding the aircraft under test. Sensors capture aircraft response signals and fiber-optic channels transmit that sensor data to computers for processing. The processing equipment, though, naturally resides inside a very well shielded structure.

The B-52G's OAS (Offensive Avionics System) is one of numerous studies directed primarily at testing the electronic hardening of military systems.

The Future

THE effects of EMP on our lives is becoming known to many on the North American continent as it is being discovered by all the citizens of the free world. Its political implications are not the topic here, but rather the facts in this article reveal to what EMP is and what it can do to the technological devices we rely on every minute of the day.

The next time a solar flare disrupts radio communications around the world for a few hours, or maybe a few days, recall that man with one nuclear device can outshine the damage old Sol creates by many fold.

GLOSSARY OF TERMS

ElectroMagnetic Pulse (EMP): An electromagnetic field of high intensity and short duration that may be caused by a nuclear explosion.

Electromagnetic Field: A magnetic field produced by electricity (the flow of current in a wire or electrons through a medium such as a vacuum). It is usually expressed in volts per meter.

ElectroMagnetic Compatibility (EMC): The ability of an electronic device to deal with electromagnetic interference and function properly.

ElectroMagnetic Interference (EMI): Any adverse effect on electronic equipment due to an electromagnetic field.

Shielding or Hardening: A method used to protect electronic devices from EMP interruption or damage.

Written: Art Reichert / March 21, 1988