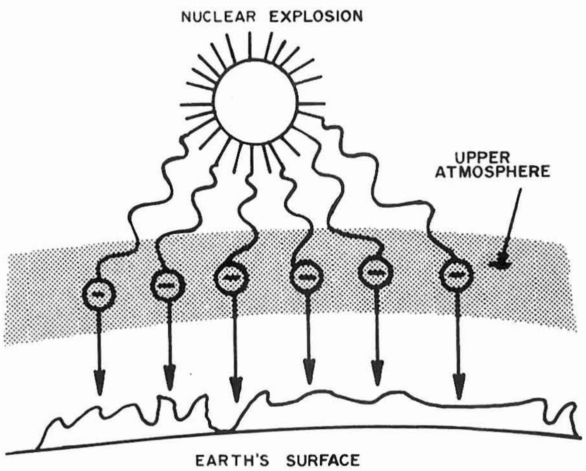
EMP and the Radio Amateur



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WHEN A NUCLEAR weapon is detonated in or above the atmosphere, an intense electromagnetic field is created. This field, called the electromagnetic pulse or EMP, has been observed and measured in nuclear testing, but its significance has been veiled by military classification until recent years. The fact that EMP can damage radio equipment hundreds or thousands of miles away from a high-altitude detonation is of great importance to the radio amateur. His understanding of EMP and how to protect himself and his equipment from its effects could make him a vital asset to this country in the event of nuclear war. In this article we will provide information on the nature of EMP and its effects on radio equipment. We will also describe protective measures which recent research has shown to be effective against these effects.

What Is EMP?

When one thinks of a nuclear explosion, he usually thinks of the devastating effects of the explosion itself: the shock wave, the heat, the ground shock, and the nuclear radiation. Another phenomenon that may be of more importance under some circumstances is the generation of EMP. The sources of the electric and magnetic fields comprising EMP are electrical charges and currents produced in the detonation. These in turn are caused by gamma rays, high-energy photons which radiate from the explosion. (X-rays can also produce EMP, but they have a very short range in air and, hence, are important only for equipment in outer space.) When a gamma ray strikes an atom in the air, it knocks an electron free from the atom and drives it outward from the detonation in a process known as the Compton effect. Since the electrons are quite small they move outward more rapidly than the remaining large, positively charged portion of the atom. Hence a charge separation and an electric current are created.

What happens next depends on the location of the detonation. If it is near the earth's surface, the gamma rays and electrons causing EMP are absorbed within a few hundred or thousand meters depending upon the weapon yield. Inside this region the EMP is very intense, with the electric field exceeding 10^5 volts/meter and the magnetic field 100 gauss. The rise time for these fields is short, less than 10^{-8} second. But people and equipment within this region would be more affected by the blast itself than by EMP, unless they were in a very good blast shelter. A smaller EMP is radiated outside of this region, but its intensity is usually not large enough to cause any damage.

The real threat to amateur radio equipment comes from the high-altitude burst, greater than 50 kilometers (30 miles) above the earth's surface. At this height there is not enough air around the weapon to create local currents, and the gamma rays travel earthward unimpeded until they strike the atmosphere at a height of 20-40 kilometers. Compton electrons are then created in a huge pancake-shaped zone, its size limited only by the curvature of the earth. But instead of moving radially, as in the surface-burst case, the Compton electrons have enough range in the thin upper atmosphere to be turned by the earth's magnetic field. The resulting transverse currents act like an enormous sheet antenna and radiate large signals down to earth. The electric field reaches 10^4-10^5 volts/meter in 10^{-8} second or less and lasts nearly 10^{-6} second. Because the signal is generated over such a large area and propagates only a short distance, the EMP intensity is substantially uniform and can extend thousands of kilometers from ground zero, depending upon the height of burst. Why would anyone detonate a nuclear weapon at these altitudes? Our Spartan antiballistic missile is

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intended for use above the atmosphere, and there are reasons why an attacker might wish to detonate missiles this high, among them being the generation of EMP.

EMP should not be confused with the more widely known blackout. Blackout is the disruption of radio communication by regions of ionized air and debris from the explosion. Propagation through the ionized region is blocked by reflection and absorption for a few minutes to hours depending on the frequency of concern. Blackout cannot damage equipment and would be important only in cases where continuous radio contact was vital.

Effects of EMP on Radio Equipment

Although the generation of EMP may be mysterious to the radio amateur, its effects should be easily understandable. The changing electric and magnetic fields induce currents and voltages in any conductor exposed to them, just as radio waves do in a receiving antenna. But, the magnitude of these currents and voltage is much larger than those caused by radio waves, although shorter in duration, because the field strength of EMP is roughly a million times larger than a strong radio signal. The closest natural analogue to EMP is a direct lightning stroke, and EMP protective devices are similar to those used for lightning. The rise time of EMP-induced surges may be one hundred times shorter than lightning surges however, so very fast-acting devices are required.

Table I shows the characteristics of surges in different conductors of interest to amateurs. As expected, the largest magnitudes are attained in long unshielded wires. Surge duration is not given because this depends very much on the wire length and termination impedance, resonances, and so forth.

The energy in a surge may be many joules, usually not enough to melt the wire, but enough to damage sensitive components attached to the wire. For example, experiments have demonstrated that vhf whip antennas on walkie-talkies can collect enough energy to destroy the front-end transistor unless special protection is provided. Since transistors can be destroyed by microjoules of energy, this result is not surprising.

For amateur radio equipment the chief causes of damage would be energy collected by antennas, electric power lines, microphone and remote-control cables, or telephone lines. Enough shielding is usually provided by equipment cases so that the energy collected by the short wires inside will not cause damage. The components most likely damaged include transistors (especially FETs), ICs, diodes, and possibly low-voltage capacitors, inductors, vacuum tubes, and relays.

The direct danger to human life is small. The fields comprising EMP are, themselves, harmless, but it is possible that contact with an insulated wire such as an antenna lead or an electric fence could cause electrocution.

The main concern to radio amateurs is that a single high-altitude detonation could damage much of the radio equipment all over the country. Amateurs have a vital role in war-time emergency communications, just as they do during peacetime disasters. Damaged equipment is useless for communications, and replacement transistors cannot be manufactured in one's basement.

Protective Measures

Radio amateurs should prepare against the EMP threat since their present lightning protection is probably not adequate for EMP. Antennas with direct-ground lightning protection and many others with standard antenna lightning arresters offer no protection

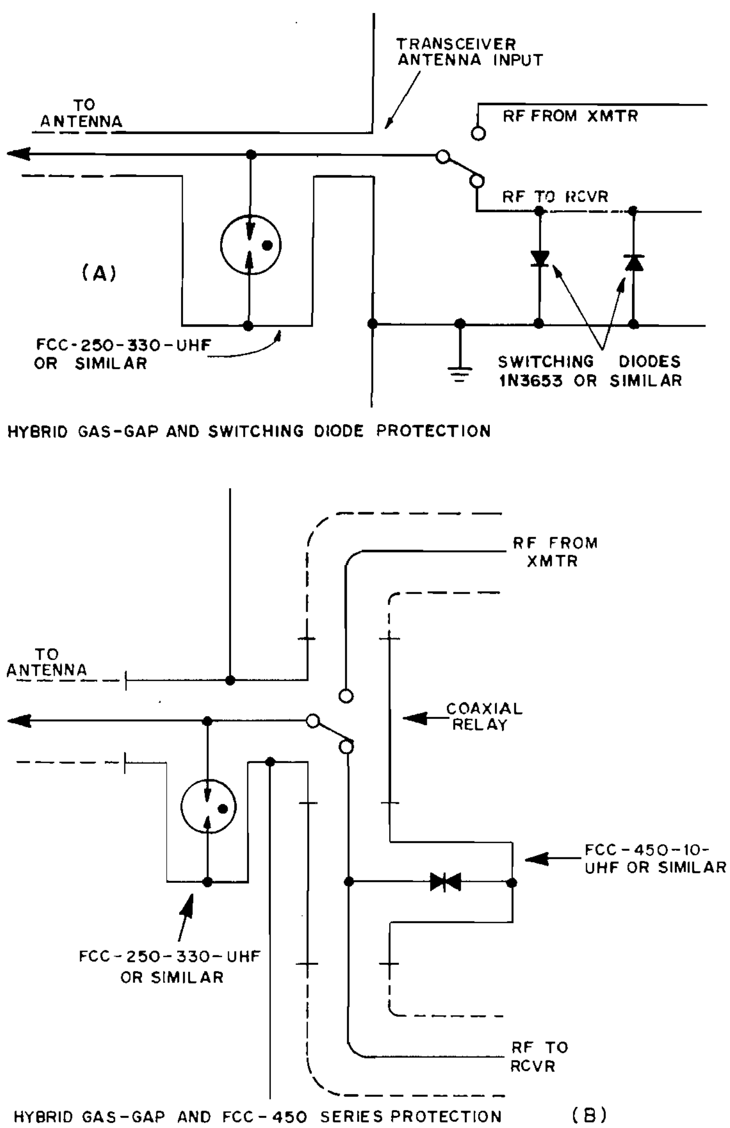

Fig. 1 — Protection from EMP surges on the antenna.

Table 1. EMP-Induced Surges on Conductors

Type of Conductor	*Rise Time (sec.)*	*Peak Voltage (volts)*	*Peak Current (amps.)*
Long unshielded wires (power lines, large antennas)	$10^{-8} - 10^{-7}$	$10^5 - 5 \times 10^6$	$10^3 - 10^4$
Unshielded telephone and	$10^{-8} - 10^{-6}$	$10^2 - 10^4$	1 – 100
AC power line at wall plug	$10^{-7} - 10^{-5}$	$10^3 - 5 \times 10^4$	10 – 100
HF antennas	$10^{-8} - 10^{-7}$	$10^4 - 10^6$	$500 - 10^4$
VHF antennas	$10^{-9} - 10^{-8}$	$10^3 - 10^5$	$100 - 10^3$
UHF antennas	$10^{-9} - 10^{-8}$	$100 - 10^4$	10 – 100
Shielded cable	$10^{-6} - 10^{-4}$	1 – 100	0.1 –50

against EMP surges. Special EMP surge suppressors are required to handle the fast rising EMP-induced transients. EMP surge suppressors also provide additional lightning protection.

We recommend that the radio amateur install EMP surge suppressors in the antenna and 120-V ac power circuits. A gas-gap diode in a coaxial tee such as the Spike Guard FCC-250-320-UHF, manufactured by Fischer Custom Communications, should be installed in the antenna feed line for all radio equipment with transmitter powers up to 300 watts. Fischer Custom Communications should be consulted concerning the Spike Guard suppressor compatible with equipment that has greater than 300 watts of output power. For solid-state equipment, a hybrid gas-gap and switching diode protection circuit as shown in Fig. 1A should be used. For equipment with a coaxial transmit-receive relay, the semiconductor portion of the hybrid protection can be provided by a Fischer-made coaxial tee device FCC-450-10-UHF as shown in Fig. 1B.

Experimental tests have shown the effectiveness of these transient suppressors. Fig. 2A shows a typical EMP voltage transient received by a vhf

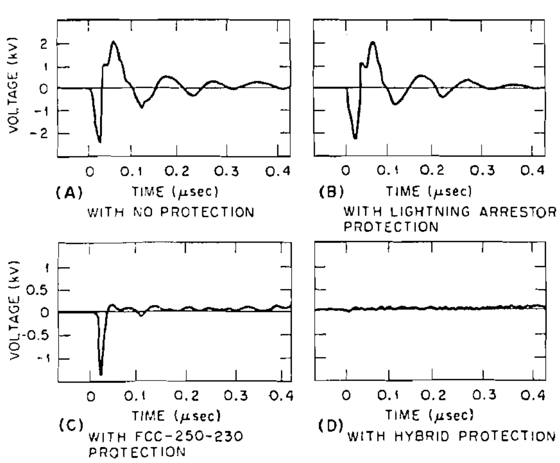

Fig. 2 – Typical EMP response of a vhf gain antenna connected to a receiver with various levels of protection.

10-dB-gain antenna. The standard "air gap" lightning arrester provides no protection, as shown in Fig. 2B. With the FCC-250-230 in the circuit, the initial voltage spike is clamped to about 1200 V and then suppressed as shown in Fig. 2C. The hybrid circuit is the most effective EMP surge suppressor, as can be seen from Fig. 2D. The semiconductor diodes in the hybrid circuit suppress the overshoot spike associated with the gas gap in the FCC-250-230 suppressor.

The hybrid approach can again be used to achieve good protection against EMP-induced power-line surges. A gas-gap diode such as the Joslyn P/N 2301-07 can be connected in parallel with a metal oxide varistor (MOV) such as the G.E. V13OLA1OA to form the hybrid protection. This hybrid circuit should be connected between the 120-V line and chassis ground. A similar arrangement, packaged as a convenient plug-in device, is the FCC-120-P made by Fischer. It should be plugged into the same wall receptacle being used by the radio equipment.

In addition to providing EMP surge protection for their present equipment, radio amateurs can also retain their old outdated equipment for use as emergency back-up communications. The back-up equipment should be stored in an out-of-the-way place and disconnected from the antenna and power line. When in use, this back-up equipment should also be protected by EMP surge suppressors.

The cost of EMP protection is estimated below:

Many of these devices can be purchased in the local parts store. If you have trouble finding them,

Number	*Item*	*Cost*
1	FCC-250-230-UHF	\$24.00
2	Switching Diodes	7.00
1	FCC-120-P	6.00
	Total	\$37.00

you can write to the manufacturer.

The Spike Guard coaxial tees can be obtained from Fischer Custom Communications, Box 581, Manhattan Beach, CA 90266. The 1N3653 switching diodes can be obtained from several manufacturers; among them are: ITT Semiconductors, 3301 Electronics Way, West Palm Beach, FL 33407, and Transistron Electronics, 168 Albion Street, Wakefield, MA 01880.

The P/N 2301-07 is a Joslyn gas gap for 120 VAC power-line applications. You can obtain it by writing: Joslyn Electronics Systems, P. O. Box 817, Goleta, CA 93017, and the G. E. MOV can be obtained by writing: General Electric, Semiconductor Products Department, Electronics Park, Syracuse, NY 13201.

It is our hope that the information presented will convince amateurs to spend a few dollars to add EMP and vastly superior lightning protection to their rather costly equipment. If clubs can pool their resources and make quantity orders, or if amateur radio vendors would make quantity purchases, the individual item costs could be greatly reduced, since the items are now priced on an individually produced basis primarily for research needs. The manufacturers listed can provide this information.