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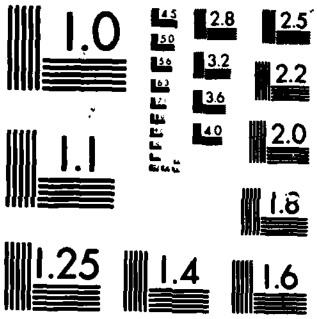

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NCS TIB 85-10

NATIONAL COMMUNICATIONS SYSTEM

VOLUME I

ELECTROMAGNETIC PULSE/TRANSIENT THREAT TESTING OF PROTECTION DEVICES FOR AMATEUR/MILITARY AFFILIATE RADIO SYSTEM EQUIPMENT

OCTOBER 1985

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This technical report discusses the vulnerability of equipment used by amateur/MARS radio operators in the United States to disruption or damage by transient electromagnetic effects such as lightning, voltage surges, and electromagnetic pulse (EMP) waves. It also reports the results of two test programs; one to evaluate existing transient suppression devices and components, and one to evaluate the response of amateur radio equipment to an EMP transient environment.

Based on the test results, the report recommends procedures and a low-cost installation scheme which will significantly increase the operational survivability of amateur type communications equipment in a lightning or EMP environment.

This report consists of three volumes. Volume I (200 pages) contains the test results and recommendations for transient protection of amateur radio equipment. Volume II

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(136 pages) contains supporting documentation including: the test plans for the two EMP tests, descriptions/specifications of the tested transient suppression devices and the amateur radio equipment, and photographs of the test facilities and test set-ups. Volume III (1298 pages) contains the raw test data in the form of oscilloscope photographs attached to the test data sheets for both test programs, as well as, written test descriptions and bench check measurements from the equipment test program. For most purposes Volume I should provide sufficient information. Volume II would be required to obtain more detailed descriptions of the test programs and tested devices and equipment. Volume III would only be required if a separate analysis of the test data is being made.

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NCS TECHNICAL INFORMATION BULLETIN 85-10

ELECTROMAGNETIC PULSE/TRANSIENT THREAT TESTING OF PROTECTION DEVICES FOR AMATEUR/MILITARY AFFILIATE RADIO SYSTEM EQUIPMENT

OCTOBER 1985

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FOREWORD

The National Communications System (NCS) is an organization of the Federal government whose membership is comprised of 22 Government entities. Its mission is to assist the President, National Security Council, Office of Science and Technology Policy, and Office of Management and Budget in:

- o The exercise of their wartime and non-wartime emergency functions, and their planning and oversight responsibilities.
- o The coordination of the planning for and provision of National Security/Emergency Preparedness communications for the Federal government under all circumstances including crisis or emergency.

In support of this mission the NCS has executed a Memorandum of Understanding with the American Radio Relay League. Its purpose is to establish a broad framework for a cooperative and close working relationship with volunteer radio amateurs for support of national emergency communications functions. It is intended through joint coordination and exercise of the resources of both organizations, to enhance the nation-wide posture of telecommunications readiness for any conceivable national emergency. This particular Technical Information Bulletin is one of a series aimed at developing an awareness in the radio amateur community of practical, low cost EMP protective procedures, devices, and equipment which may if utilized significantly enhance the probability of amateur radio resources escaping serious damage during emergency situations involving EMP events.

Comments, on this TIB are welcome, and should be addressed to:

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ABSTRACT

This Technical Information Bulletin discusses the vulnerability of equipment used by amateur/MARS radio operators in the United States to disruption or damage by transient electromagnetic effects such as lightning, voltage surges, and electromagnetic pulse (EMP) waves. It also reports the results of two test programs; one to evaluate existing transient suppression devices and components, and one to evaluate the response of amateur radio equipment to an EMP transient environment. Based on the test results, the report recommends procedures and a low-cost installation scheme which will significantly increase the operational survivability of amateur type communications equipment in a lightning or EMP environment. The two test programs were conducted for the NCS by Electrospace Systems, Inc., at test facilities provided by the IRT Corporation in San Diego, California.

This report consists of three volumes. Volume I contains the test results and recommendations for transient protection of amateur radio equipment. Volume II contains supporting documentation including: the test plans for the two EMP tests, descriptions/specifications of the tested transient suppression devices and the amateur radio equipment, and photographs of the test facilities and test set-ups. Volume III contains the raw test data in

the form of oscilloscope photographs attached to the test data sheets for both test programs, as well as written test descriptions and bench check measurements from the equipment test program. For most purposes Volume I should provide sufficient information. Volume II would be required to obtain more detailed descriptions of the test programs and tested devices and equipment. Volume III would only be required if a separate analysis of the test data is being made.

EXECUTIVE SUMMARY

The National Communications System (NCS) in developing the National Communications System Plan for emergency use of amateur radio and Military Affiliate Radio Systems (MARS) determined that action was required to lessen the harmful effects of transient electrical pulses on the amateur/MARS radio equipment. The widespread use of solid-state electronic components in amateur/MARS radio equipment in recent years, with their inherent weakness to damaging transient electromagnetic pulses, prompted this task. The objective of this task was to identify effective, economical, commercially available transient protection accessories which would significantly increase the operational survivability of amateur/MARS type equipment in an EMP, lightning or other high voltage transient environment. This objective was accomplished. Commercial protection devices were identified and tested with 15 different, typical amateur radio systems. It was found that the necessary commercial transient suppression devices for basic protection of an amateur radio system could be obtained at an estimated cost of $100.00 per system. In addition, two protection devices were assembled from tested suppression components and validated through a test program; these devices can be assembled by the radio amateur at about one-fourth the cost of the commercial devices.

This report contains recommendations for radio operation procedures, selection of transient protection components and devices, and installation of amateur radio equipment. It also contains the results of two test programs; the first was a test of the response of selected transient suppression components and devices to a simulated electromagnetic pulse; and the second was a test of the susceptibility of selected amateur/MARS radio equipment to damaging transients, first with transient suppression protection devices and then without transient protection devices.

The first test program evaluated 56 different devices and identified 40 that substantially suppressed the simulated transient pulse. As was expected before the test, many devices operated above the manufacturer's designed maximum clamping (suppression) voltage when driven by an EMP transient pulse. The manufacturer's maximum clamping voltage is based upon the device response to a much slower transient pulse than EMP. The faster rise time of the EMP wave causes a corresponding rise in the device clamping voltage level. Therefore, to qualify a device for EMP, the test acceptance criteria allowed the device to exceed its designed maximum clamping voltage level up to 100% and still be accepted. The 100% voltage overload level was selected as the test acceptance criteria since electronic circuits are commonly designed to withstand a 100% (6dB) voltage overload for brief durations. The most consistent performer was the gas discharge tube and devices using the gas discharge tube. Eleven (11) out of 14 gas discharge tubes tested were accepted. The three tubes with the lowest published clamping voltages were not accepted, because they exceeded the 6dB test acceptance criteria. Also, one coaxial line voltage suppressor using gas-tubes was not accepted. Again this was one with the lowest published clamping voltage. Another consistent performer was the varistor (semi-conductor device). Nine out of 12 varistors tested were accepted. Again the three varistors with the lowest published clamping voltages were not accepted. The three varistors exceed their manufacturer's maximum clamping voltage level by a considerable amount. One designed to clamp at 20 volts did not clamp until 174 volts. Although not accepted at their manufacturer's maximum clamping voltages, several varistors were consistent performers and could be used with confidence at the higher measured voltage levels. One out of seven transzorbs was accepted. The transzorbs had very low published clamping voltages, and, when tested with the EMP injection pulse, exceeded their published voltages by considerable amounts.

Out of 19 low clamping voltage devices tested, only one clamped below 100 volts. More typically, the devices clamped between 100 and 200 volts, with most near 200 volts. Therefore, the test did not identify extremely low clamping voltage (less than 50 volts) devices for the EMP environment. Out of eleven coaxial line protectors tested, all except one was accepted; and out of ten AC power line protectors, all except one was accepted.

The second test program evaluated the response of 15 different amateur radio systems to a simulated EMP. The most significant finding of this test program was the ability of the radio systems to survive the free-field pulse of the large parallel plate EMP simulator when the AC power cord was not plugged in and the RF coaxial cable was not attached to the radio equipment. The radio systems survived repeated field pulses from the simulator even with the interconnecting wiring installed between the transceiver, antenna tuner, external speaker, and power supply, as long as the RF coaxial cable was not connected and the AC power cord was not plugged in. When these two lines were attached to the transceiver and driven by a large injection current, most of the radio systems were degraded. When these two lines were protected with an AC power line suppressor and an RF coaxial cable suppressor, the radio equipment was unharmed by the injected currents.

Therefore, a minimum protection scheme for an amateur radio system was found to be feasible at an estimated cost of $100.00. A Fischer coaxial line suppressor, at a cost of $55.00, could be installed between the transceiver and the antenna coaxial cable and a TII model 428 AC voltage transient suppressor, at a cost of $45.00, could be plugged-in for AC power protection. These two devices would provide a high probability of survival to the associated radio equipment.

The report recommends, that if protection devices are not used, the radio equipment must be unplugged from the commercial AC power and the antenna coaxial cable must be removed from the radio equipment's RF port for it to survive the transient threat. Also, any other long metal conductors attached to or close to the equipment should be removed. The use of a single point ground panel for all conductors going to the radio equipment was recommended, to work in conjunction with the transient protection devices, when the system is fully wired for operation.

It is concluded that the typical amateur radio system can survive both a nearby lightning strike and an EMP transient if the recommendations in this technical information bulletin are used for radio station operation and for transient suppressor selection and installation.

SECTION 1

ELECTROMAGNETIC PULSE (EMP) AND THE RADIO AMATEUR

1.1 Introduction

Radio amateurs in the United States and other countries have long been concerned with protection of their radio installations against lightning. Others have applied lightning protection where required by local codes. Traditionally, the installed protection was designed against a "slow" lightning criteria with rise times in the order of tens of microseconds, with protection from direct strokes from overhead obtained by sheltering important conductors by a grounding system.

To address the transient threat, including lightning voltage surges and electromagnetic pulse (EMP), it is necessary to protect installations against electromagnetic fields rising to peak intensity of 50 KV/M in several nanoseconds (thousandths of microseconds). While some modern devices installed for lightning protection will be effective against a lightning transient threat, the majority will not act in time to prevent the faster EMP from entering the radio equipment.

Protection of amateur radio installations is becoming more difficult as circuit components become more sensitive to transients. Integrated circuits have susceptibility to damage at transient levels smaller than that of discrete transistors, which are more susceptible than vacuum tubes. New devices for protection, such as metal oxide varistors, offer protection within one nanosecond of the arrival of a transient pulse. Such devices show promise, when properly selected and installed, of providing protection against the universal transient threat.

1.2 Background

One of the primary reasons for the existence of amateur radio is to provide a public service. This service has proven over many years to be most valuable during times of emergency. Part 97 of the Federal Communications Commission Regulations states: "*One of the fundamental purposes for the amateur radio service is the recognition and enhancement of the value of the amateur service to the public as a voluntary noncommercial communications service, particularly with respect to providing emergency communications*". At first, the amateur public emergency service existed spontaneously on an individual basis. Today it has evolved into a well established system which includes the Amateur Radio Emergency Service (ARES), the National Traffic System (NTS), the Radio Amateur Civil Emergency Service (RACES) and the Military Affiliate Radio System (MARS). The ARES and the NTS were organized by the American Radio Relay League (ARRL), a non-commercial national association of radio amateurs established for promoting interest in amateur radio communication and experimentation, for relaying messages by radio, for the advancement of radio art and for the public welfare. The ARES consists of licensed amateurs who have voluntarily registered their qualifications and equipment for communications duty in public service when disaster strikes. The NTS consists of four different levels of radio nets which operate in an orderly sequence to relay traffic from point of origin to point of destination in a timely manner. RACES provides radio communications for civil preparedness purposes, during periods of local, regional or national civil emergencies. It is administered by the Federal Emergency Management Agency and is a radio communications service conducted by volunteer, licensed amateurs, designed to provide emergency communications to local and/or state civil preparedness agencies. RACES operation is authorized by the Federal Communications Commission (FCC) upon request of a state or federal official, and is strictly limited to official civil preparedness activity in the event of an emergency communications situation. MARS is an armed forces sponsored affiliation of radio amateurs that provides military communications training for amateurs. Each military department sponsors its own MARS organization, which consists of permanent stations on military facilities that are augmented by the radio amateur's stations during exercises and emergencies. When the term "radio amateur" is used in this report it includes the MARS amateur volunteer.

Radio amateurs have responded to natural disasters such as tornadoes, hurricanes, floods, and blizzards when other forms of communications have been inadequate. The amateur traditionally responds with portable, mobile, and fixed station radio equipment that is not necessarily dependent on commercial power. In almost every community both large and small, there is a cadre of experienced radio amateurs willing to respond to the need for emergency communications.

In addition to the role amateurs fill during natural disasters, the National Communications System (NCS) has long recognized that the amateur radio community provides a great national resource, of value to not only the public, but also as a backup to augment both civil and military agencies. To enhance the nation-wide posture of telecommunications readiness for national emergencies the NCS and the ARRL have a written Memorandum of Understanding with the purpose of establishing a broad framework of cooperation and a close working relationship with volunteer radio amateurs for national emergency communications functions. Therefore, it is in the national interest to find ways to enhance the survivability of the amateur radio system in a nuclear environment.

1.3 EMP Defined

Electromagnetic Pulse (EMP) is defined as a large impulsive type electromagnetic wave generated by nuclear explosions. EMP is commonly used to refer to nuclear electromagnetic pulse (NEMP). In this usage it is a plane-wave, line-of-sight electromagnetic phenomenon that occurs as a result of an above ground nuclear detonation. NEMP has an electric field strength of 50 KV/M horizontally and 20 KV/M vertically with a pulse rise time to peak of 5 to 10 nanoseconds. There are several different types of EMP resulting from a nuclear explosion. One of the most significant types is the high-altitude EMP (HEMP) that results from a nuclear explosion above 30 miles in altitude. The HEMP is produced by the interaction of high energy photons (gamma rays) with the atmospheric molecules producing Compton electrons. These in turn decay in the earth's magnetic field emitting photons in the process. Another type, System Generated EMP (SGEMP) is produced by the direct interaction of high energy photons with systems (equipment), rather than through their interaction with atmospheric molecules. SGEMP is important because of its effects on satellite systems and in-flight missiles. The third type, Magnetohydrodynamic EMP (MHD-EMP) is different due to its distinct physical generation mechanism, later occurrence, smaller amplitude and longer duration. It is sometimes referred to as late time EMP. MHD-EMP poses a threat for very long land-lines (including telephone cables and power distribution lines) or submarine cables.

1.4 EMP Description

As previously mentioned, of the 3 types of EMP, HEMP poses the greatest threat to the amateur radio operator's equipment. This Technical Report therefore will deal primarily with HEMP and lightning.

1.4.1 Generation Process. A major threat exists to every amateur radio installation in the United States from the possibility of high-altitude nuclear explosions over the central part of the country. One such detonation at a height between 250 and 300 miles could produce an EMP/transient effect over the contiguous United States. Significant EMP levels can occur on the earth's surface at all points within line-of-sight from the explosion. If high yield weapons are used, the EMP field strength felt on the earth will not vary significantly with the height of the explosion. Therefore, a high-altitude explosion, which can cover a large geographic area, will produce essentially the same peak field strength as a low-altitude explosion, which only covers a small geographic area. Figure 1-1 illustrates the areas that EMP would cover based on height of burst (HOB) above the U.S..

1.4.1.1 The Compton Effect. During a nuclear explosion, gamma rays (high energy photons) are radiated in all directions from the explosion. These

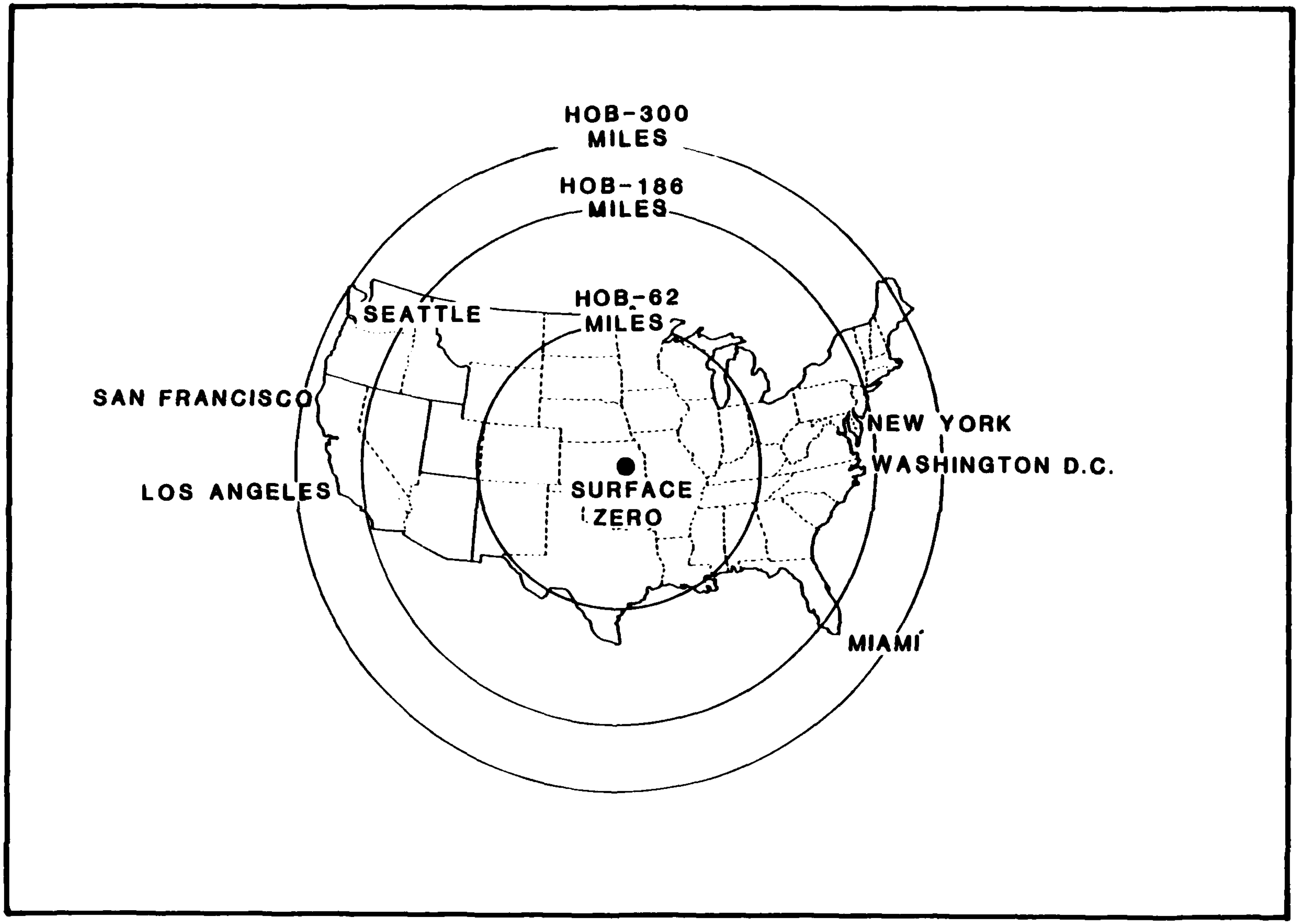


Figure 1-1. EMP Ground Coverage for High-Altitude Nuclear Explosions at 62, 186, and 300 Miles Altitude (10-Megaton)

gamma rays react with the atmosphere to produce large electrical charges and currents, which are the source of the electric and magnetic fields that comprise the EMP. The basic physical process that converts the gamma ray energy into EMP energy is known as the "Compton Effect". When a gamma ray strikes an atom in the atmosphere it knocks an electron free and drives it outward from the detonation. Since the electrons (Compton electrons) are smaller, they are moved outward more rapidly than the remaining large positively charged portion of the atom. The result is a charge separation in the atmosphere and a huge electric current is created. This charged region in the atmosphere is called the "deposition region". An additional current is generated when the Compton electrons are deflected from their original path by the earth's magnetic field and spiral around the geomagnetic field lines. They complete about one third of a revolution before they decay and are reabsorbed by the atmosphere. The current generated by this magnetic deflection is a major component of the deposition region in a high altitude nuclear blast.

1.4.1.2 Deposition Region. In a high-altitude nuclear blast (30 miles or more above the earth's atmosphere) the gamma rays radiated in a downward direction travel through the near vacuum of space until encountering a region where the atmospheric density is sufficient to produce the Compton Effect and the resulting deposition region. The deposition region is generally circular and is approximately 50 miles thick in the center and tapers toward the outer edge, with a mean altitude between 25 and 30 miles. (See figure 1-2) The radius of the deposition region is determined by the height of the burst, the yield of the nuclear device, and is limited by the curvature of the earth. The deposition region is formed very fast since the gamma rays, and the Compton electrons both travel at nearly the speed of light (186,000 ft. per sec.) in a vacuum. The rapid generation of the deposition region results in a pulse with a very fast rise time, covering a broad frequency range.

1.4.1.3 Magnetic Conjugate. A high altitude detonation also generates beta particles or free electrons, which spiral along the earth's magnetic field lines. This creates an increase in the ionization of the D layer of the atmosphere not only at the local area but also in the area known as the magnetic conjugate--in the opposite hemisphere! Figure 1-3 graphically depicts the immensity of EMP's widespread affects. Amateurs in both the local and opposite hemisphere may find a sudden loss in their ability to communicate.

1.4.2 Electromagnetic Spectrum Effects

1.4.2.1 Amplitude (Waveform). The EMP pulse has a very fast rise time and a short duration when compared to lightning surges. A high altitude EMP pulse rises to peak voltage in approximately ten billionths of a second

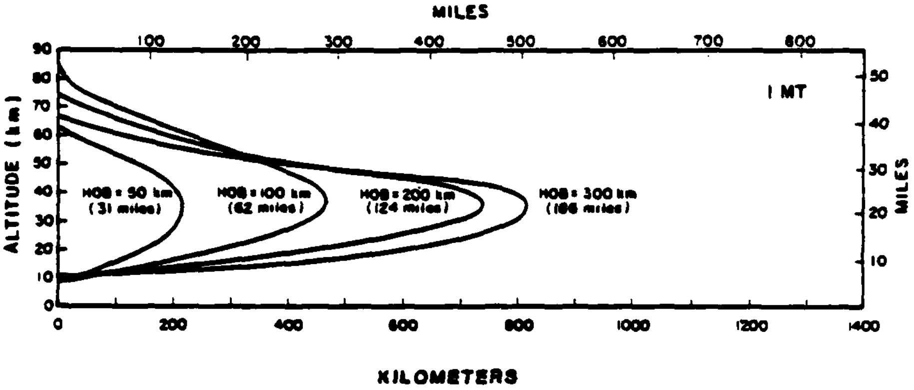


Figure 1-2A. Deposition Regions for One Megaton Nuclear Explosions at Altitudes of 31, 62, 124, and 186 Miles

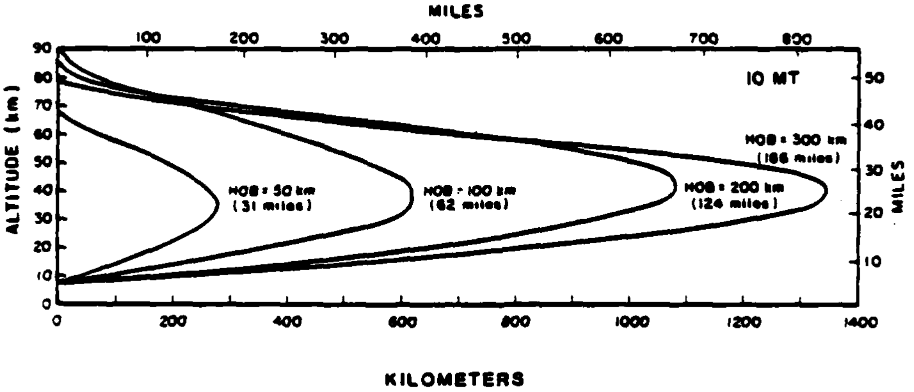


Figure 1-2B. Deposition Regions for 10 Megaton Nuclear Explosions at Altitudes of 31, 62, 124, and 186 Miles

HOB = HEIGHT OF BURST.

Figure 1-2. Deposition Regions

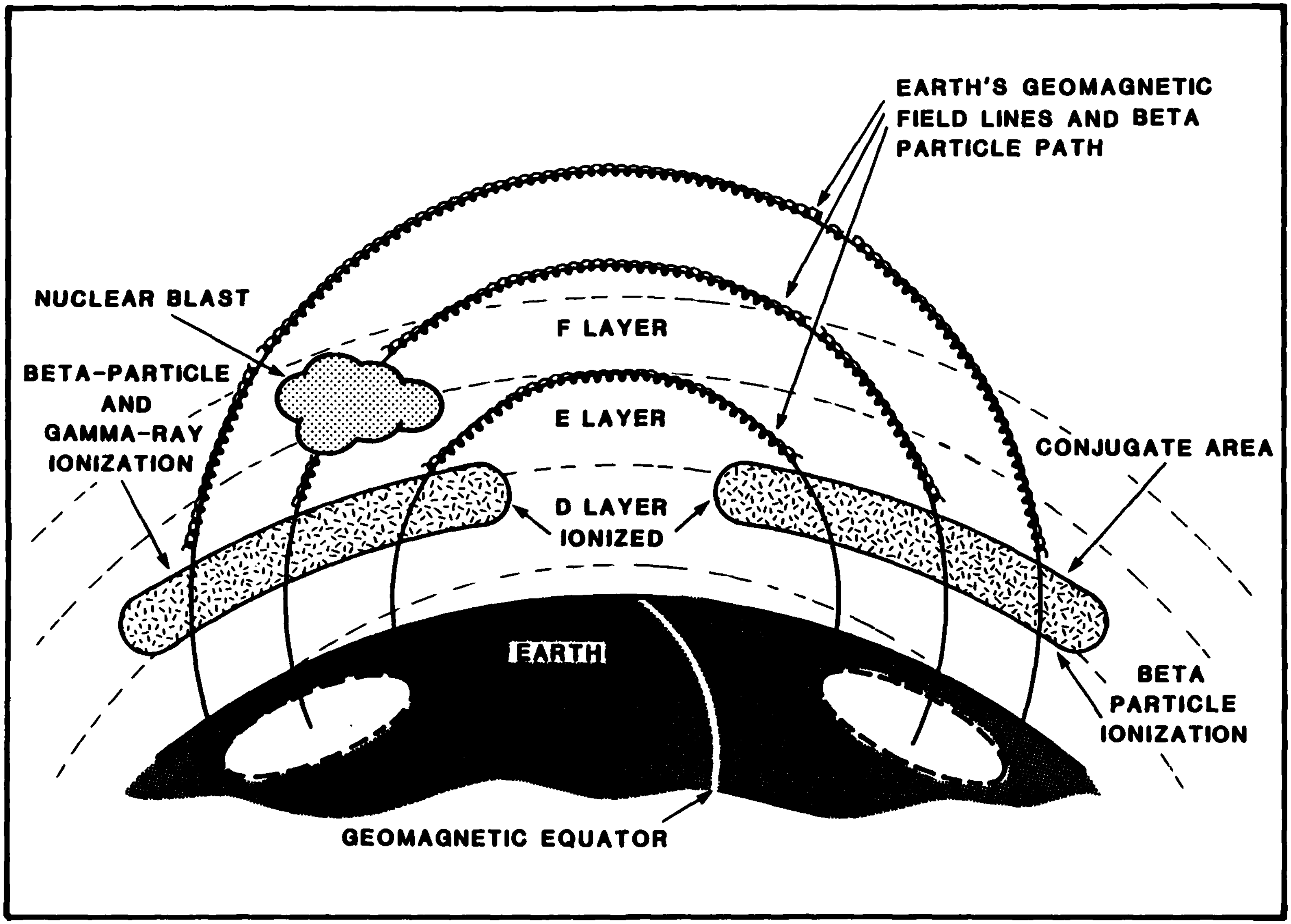


Figure 1-3. Magnetic Conjugate

(10 nanoseconds) and has a duration of approximately one millionth of a second (1 microsecond). A lightning stroke, on the other hand, rises to peak voltage in about two millionths of a second and lasts 100 times longer than an EMP pulse, one thousandth of a second (See figure 1-4). A significant difference between EMP and lightning is that EMP effects are felt over a much larger area simultaneously, not just locally. Any conductor within the area of an EMP will act as an antenna and could pick up the electromagnetic energy. The voltages and currents induced in these conductors are comparable with the very largest lightning bolts. However, the total energy of an EMP current pulse is not as large as a nearby lightning current pulse, because of the short duration of the EMP pulse.

Lightning can almost be viewed as a steady current when compared with EMP. The instantaneous peak power density for an EMP pulse is typically 6 million watts per square meter. However, since the pulse is of such short duration the total energy received on the ground is only about six tenths of a Joule per square meter. One Joule is the energy expended during one second by an electric current of one ampere flowing through a one ohm resistance. One Joule is equal to one watt-second. For example; 60 Joules (J) is a 60 watt (W) light burning for one second(S) (W = J/S).

1.4.2.2 <u>Radio Frequencies</u>. The energy of a high altitude EMP is spread over a major part of the radio frequency spectrum. Since the pulse has

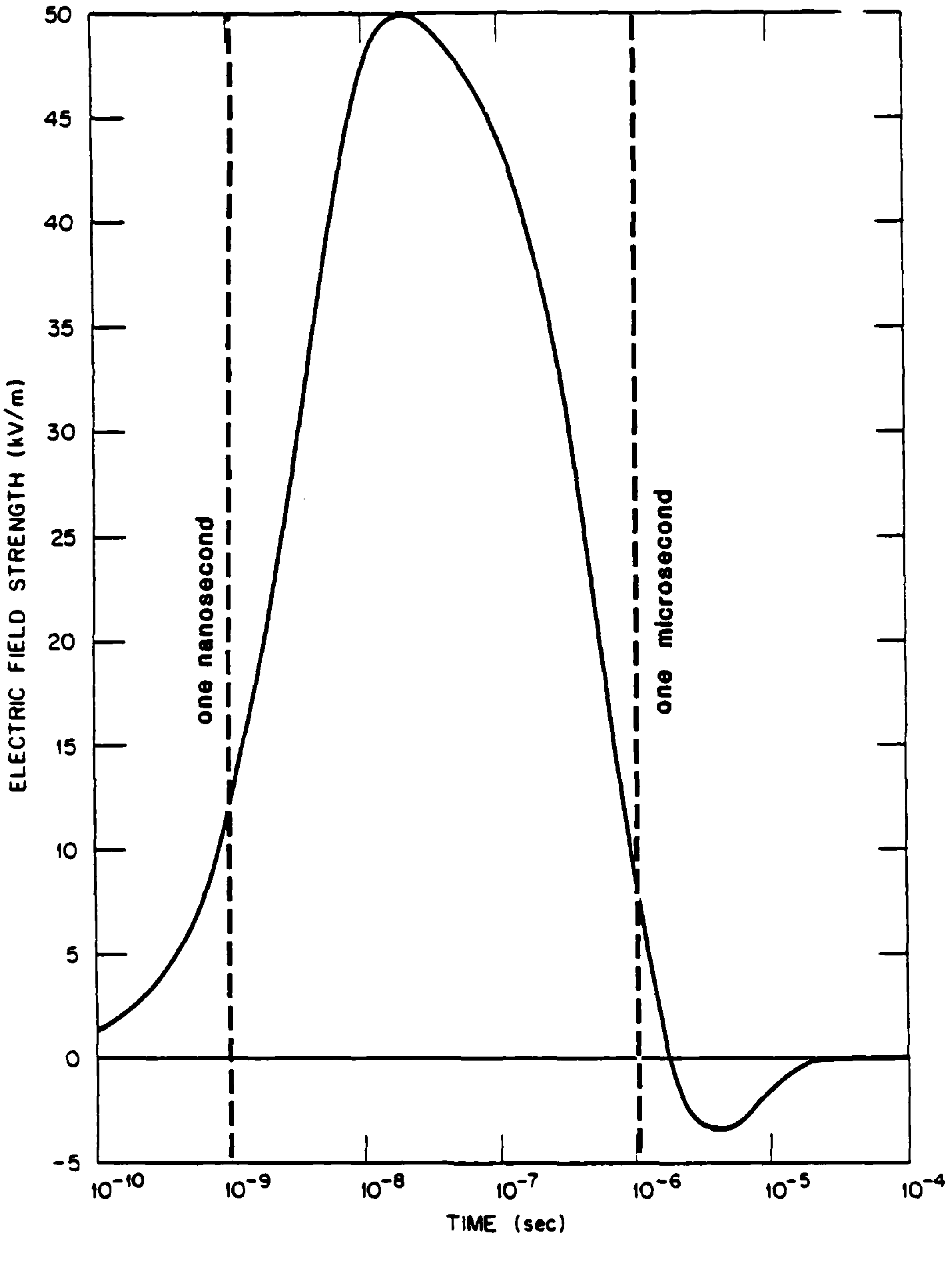


Figure 1-4. Electric Field Strength of a Typical EMP Wave

such a very fast rise time and a short duration, it produces a broad band frequency coverage extending from 10 kilohertz (kHz) to 100 megahertz (MHz). The electric field strength remains fairly constant in the 10 kHz to 1 MHz frequency band; it decreases by a factor of 100 in the 1 to 100 MHz band and continues to decrease at a faster rate for frequencies greater than 100 MHz. Most high altitude EMP energy is between 100 kHz and 10 MHz and 99% is in the frequency spectrum below 100 MHz (see figure 1-5). See figure 1-6 for the amateur radio frequency bands.

1.4.2.3 Coupling. Electromagnetic energy is radiated downward from the deposition region to the earth. Any conductor beneath or near the deposition region will act as an antenna and pick up the electromagnetic energy. Long power transmission lines are very effective in picking up the low-frequency components of the electromagnetic pulse (EMP). Short metallic conductors, including internal parts of electronic equipment, are effective in picking up the high frequency components of the EMP. A list of collectors is shown in figure 1-7. The energy on the conductor is in the form of a strong current and voltage surge which is transmitted to the attached electronic equipment. Figure 1-8 illustrates EMP induced surges on conductors.

The equipment does not have to be attached directly to a collector (conductor) to be damaged; EMP/transient pulse energy can be coupled to the

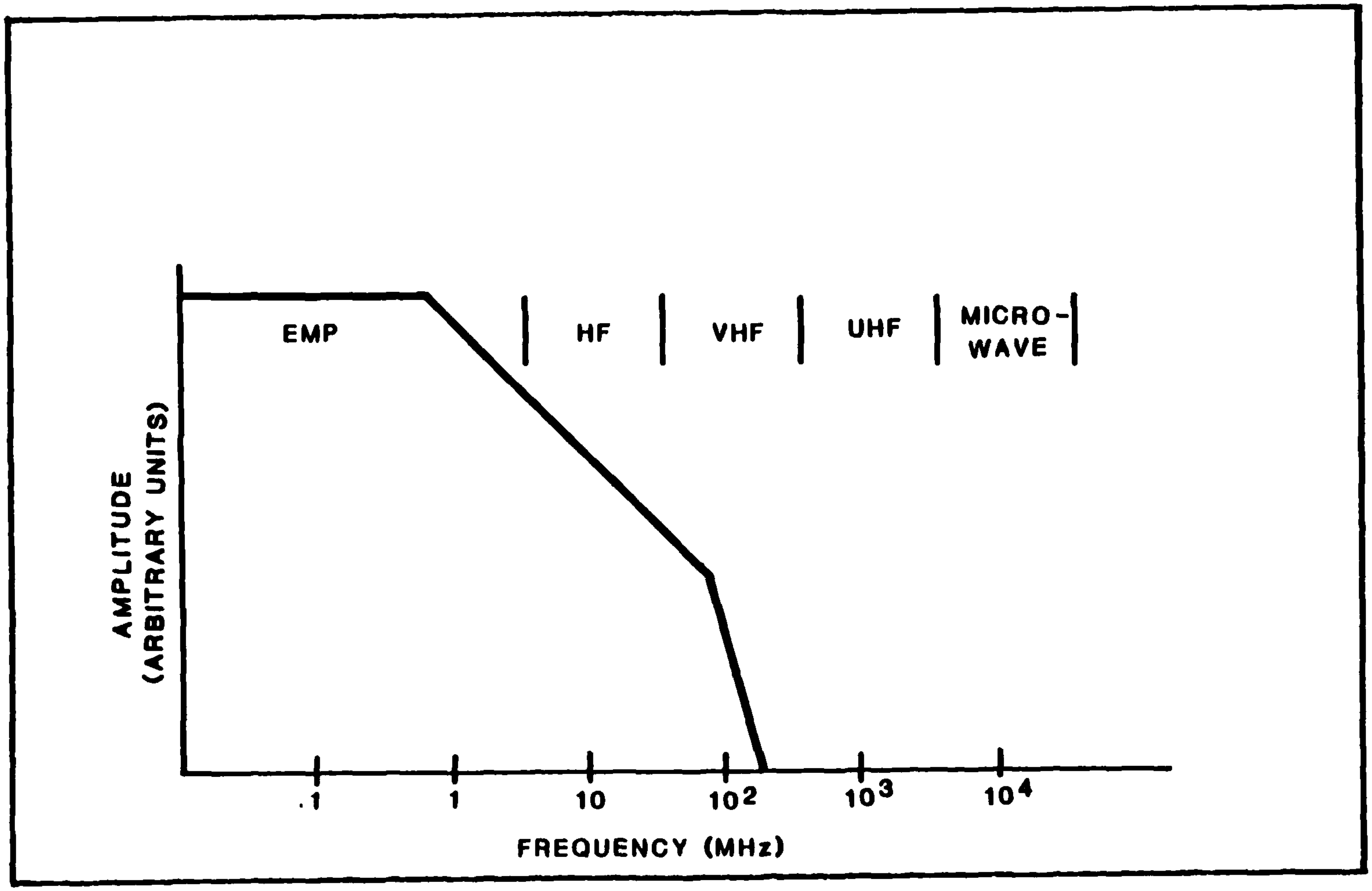
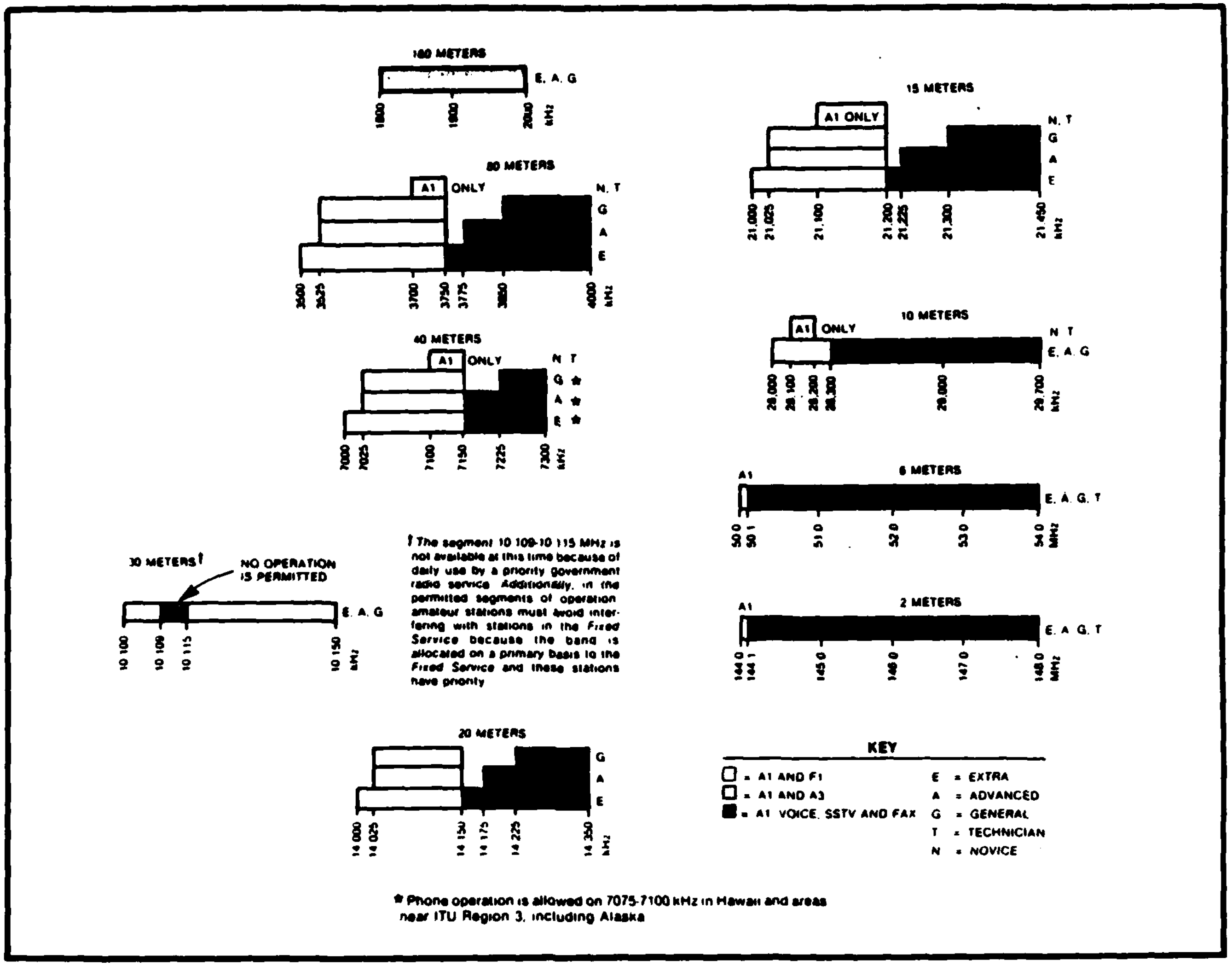


Figure 1-5. Frequency Spectrum of EMP



† The segment 10 109-10 115 MHz is not available at this time because of daily use by a priority government radio service. Additionally, in the permitted segments of operation amateur stations must avoid interfering with stations in the *Fixed Service* because the band is allocated on a primary basis to the *Fixed Service* and these stations have priority

★ Phone operation is allowed on 7075-7100 kHz in Hawaii and areas near ITU Region 3, including Alaska

Figure 1-6. Amateur Radio Frequency Bands

Long runs of cable, piping, or conduit

Large antennas, antenna feed cables, guy wires, antenna support towers

Overhead power and telephone lines and support towers

Long runs of electrical wiring, conduit, etc., in buildings

Metallic structural components, girders, reinforcing bars, corrugated roof, expanded metal lath, metallic fencing

Railroad tracks

Aluminum aircraft bodies

Figure 1-7. Typical Collectors of EMP Energy.

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 X 10^{6}	10^{3} - 10^{4}
Unshielded telephone and	10^{-8} - 10^{-6}	100 - 10^{4}	1 - 100
AC power line at wall plug	10^{-7} - 10^{-5}	10^{3} - 5 X 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

Figure 1-8. EMP - Induced Surges on Conductors.

equipment in other ways. For example, an electric current can be induced or a spark can jump from a primary conductor which collects the EMP energy to a nearby secondary conductor which is connected to the equipment but not to the primary conductor.

There are three basic ways to couple the EMP energy from a high-altitude nuclear explosion to a conductor on the earth. They are electric induction, magnetic induction and resistive coupling (direct charge deposition). Electric induction occurs when a current is induced in a conducting element by the component of the electric field which is in the same direction as the conductor's length. Magnetic induction is induced in conductors which are in the form of a closed loop. The magnetic field component moving perpendicular to the plane of the closed loop, causes a current to flow in the conducting loop. Resistive coupling occurs when a conductor is located in another conducting medium, for example the earth, salt water or the air. When a current is flowing in the conducting medium, the conductor provides an alternative current path and shares the current with the medium. Resistive coupling can be generated as a by-product of electric or magnetic induction.

1.4.2.4 <u>Nuclear Weapons Effects on Radio Signals</u>. Nuclear Weapons can degrade and black out radio signals far from the immediate blast zone. Degradation of radio signals by nuclear weapons varies with the explosion yield, distance, and altitude. Signal degradation may include high noise levels, absorption, attenuation, ionization and partial or complete blackout. The effects may extend hundreds to thousands of miles and last from minutes to hours. Normal HF ionospheric propagation paths (below the Maximum Usable Frequency (MUF)) may be disrupted at the same time that new paths are created in the upper HF or low VHF bands that were previously not available. However, it is by no means certain that HF communications will be completely disrupted under all circumstances. (See figure 1-9)

1.5 Lightning

Lightning and EMP have similar characteristics. Both take the form of a fast rising electromagnetic pulse which can generate large currents in conductors. Earlier studies generally stated that the effects of EMP exceeded those of lightning, but more recent reports indicate that lightning effects can be equal or exceed those of EMP in the lower frequency spectrum, while EMP effects are more severe in the higher frequency spectrum.

1.5.1 Lightning Description. Lightning is a natural transient, high current electrical discharge occuring in the atmosphere. Lightning occurs when a region of the atmosphere attains a huge electric charge with the associated electric fields large enough to cause electrical breakdown of the air, creating a discharge path for the charge.

FQ BAND	DEGRADATION MECHANISM	SPATIAL EXTENT AND DURATION OF EFFECTS	COMMENTS
VLF	Phase changes, amplitude changes	Hundreds to thousands of miles; minutes to hours	Ground wave not affected, lowering of sky wave reflection height causes rapid phase change with slow recovery. Significant amplitude degradation of sky wave modes possible.
LF	Absorption of sky waves, defocusing	Hundreds to thousands of miles; minutes to hours	Ground wave not affected, effects sensitive to relative geometry of burst and propagation path
MF	Absorption of sky waves	Hundreds to thousands of miles; minutes to hours	Ground wave not affected
HF	Absorption of sky waves, loss of support for F-region reflection, multipath interference	Hundreds to thousands of miles, burst region and conjugate; minutes to hours	Daytime absorption larger than nighttime, F-region disturbances may result in new modes, multipath interference
VHF	Absorption, multipath interference, or false targets resulting from resolved multipath radar signals	Few miles to hundreds of miles; minutes to tens of minutes	Fireball and D-region absorption, circuits may experience attenuation or multipath interference
UHF	Absorption	Few miles to tens of miles; seconds to few minutes	Only important for line-of-sight propagation through highly ionized regions

Figure 1-9. Effects of Nuclear Detonations on Radio Systems

The most common lightning path is the intracloud discharge path. However, from an electrical equipment standpoint the cloud-to-ground lightning discharge path has the highest potential to cause power disruption and equipment damage. Typically, the upper portion of the thunder cloud carries a greater positive charge while the lower part of the cloud carries a large negative charge. In a cloud-to-ground lightning discharge the negative charge in the cloud is lowered by the dissipation of the electrons in the earth. A typical cloud-to-ground lightning discharge can last from one-fifth to one-half a second and is composed of several discharge components. The total discharge occurrence is called a flash. The typical lightning flash is composed of three to four high-current pulses called strokes. Each stroke lasts about one thousandth of a second with a delay between strokes of 40 to 80 thousandths of a second. The first stroke is initiated by a preliminary breakdown in the cloud, which channels a negative charge toward the ground in a series of short luminous steps called the step leader. As the step leader tip approaches the ground, the electric field beneath it becomes very large and causes one or more upward-moving discharges to be initiated at the ground. When the downward-moving leader contacts one of the upward-moving discharges the leader tip is connected to ground potential. The leader path ionizes the air making it a conductive plasma that is luminous. The return stroke, a ground potential wave, propagates up the ionized leader path discharging the leader channel. The return stroke produces a peak current of typically 30 KA in its lower portion, with a rise time from zero to peak in about two microseconds (2 millionths of a second). The return stroke energy heats the leader channel to temperatures approaching 60,000 degrees fahrenheit and produces a high pressure channel that expands to generate a shock wave that is heard as thunder. If a residual charge is available at the top of the channel a charge called a dart leader may propagate down the first stroke channel. The dart leader initiates the second, third and fourth return strokes, if any.

1.5.2 Lightning Energy. The normal peak current in a single return stroke will range from 10 to 40 KA (thousand Amps) with 175 KA for a severe stroke, and with a charge transfer of 2.5 C (Coulombs). The total lightning discharge when composed of several strokes can transfer a charge of 25 C. The coulomb is defined as the ampere-second. One ampere (A) is the current intensity when one coulomb (C) flows in a circuit for one second. The energy associated with a typical lightning stroke will vary depending on the dynamic resistance of the conducting channel, with values estimated to range from 250 J (Joules) to 10 MJ (million Joules).

1.5.3 Lightning and EMP Compared. A direct or nearby lightning strike can equal or exceed the electromagnetic field strength of EMP. To compare a direct lightning strike with EMP, 35 KA will be used as an average value of the peak current of the first return stroke and 175 KA as the value of the peak current of a severe first return stroke. At one meter from a direct lightning ground hit the energy of the magnetic field for the average return stroke (35KA) is equal to the EMP at a frequency near 10 MHz and exceeds the EMP at frequencies below 10 MHz. At one meter from a direct lightning ground hit the energy of a severe lightning return stroke (175KA) exceeds the EMP to frequencies above 10 MHz. At 50 meters from a severe lightning stroke (175 KA) the energy of the total electric field exceeds that of EMP at frequencies below about 1 MHz; and for the average first return stroke (35 KA), the total lightning electric field energy exceeds that of EMP below about 300 KHz. The major difference between lightning and EMP is the area affected. EMP can affect a large area of thousands of square miles wnile lightning can affect a small area of only a few square miles, with severe effects normally within a few hundred feet from a lightning discharge path. EMP can damage small electronic components and trans-mission lines; while a direct lightning strike can cause major structural damage to antennas and towers, as well as electronic equipment.

1.6 Physical Effects on Equipment

The primary effects of EMP that would be of interest to the radio amateur are those that would produce direct damage to the sensitive electronic components of his system.

However, the amateur would also be interested in the temporary blackout caused by disruption to the ionosphere. A nuclear detonation causes intense changes in the ionosphere which can either increase or decrease the amount of ionization within a particular layer of the atmosphere. This change can result in the absorption of the radio signal or change the signal path (refraction) to the extent that communication is not possible. The fireball itself can disrupt communications because it generates an opaque area that radio signals cannot penetrate.

More widely known are blackout (the complete disruption of electromagnetic signals for a short period), and scintillation (the scattering of signal energy due to fast changing ionization irregularity) which should not be confused with EMP. Neither can damage equipment like EMP can. Radio propagation degradation, through refraction and absorption, usually lasts for a few minutes to a few hours depending on the frequency concerned. It is important only where continuous communications is of vital importance, because blackout/scintillation is only temporary and produces no permanent damage to primary or ancillary radio equipment. However, EMP produces almost instantaneous and possibly permanent damage to sensitive electronic components. Figure 1-10 shows how propagation of RF signals may be affected.

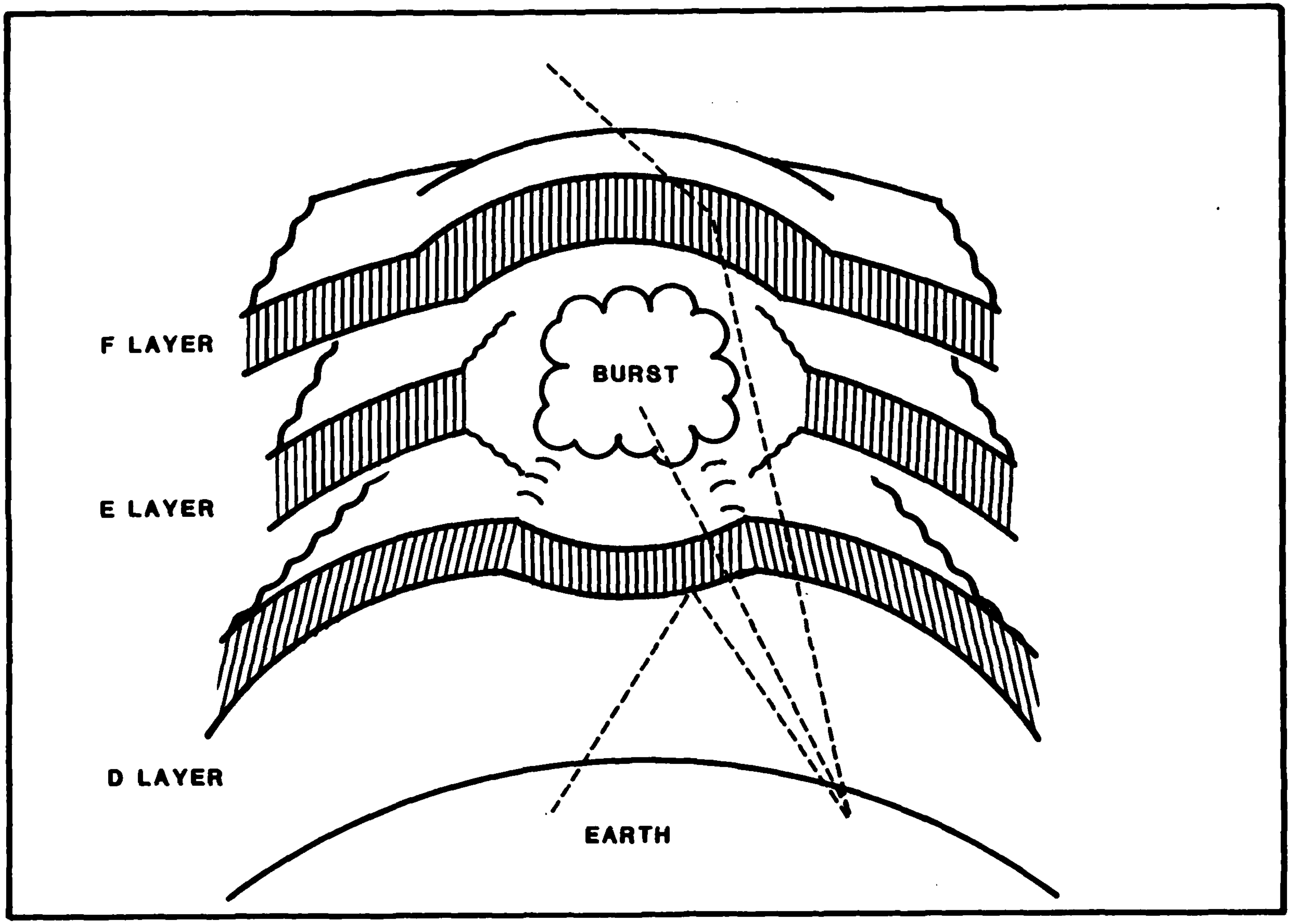


Figure 1-10. Atmospheric Disruption and Warping of the Earth's Atmosphere

The components of the amateur's radio system which can be most affected are those directly attached to a primary collector (conductor) of EMP energy. The amateur's transceiver is most sensitive where it is connected to the commercial power lines and the antenna transmission line. Other sensitive connection points include the microphone, telephone lines and any remote control lines.

There are a large number of electronic and electrical components that can be permanently damaged by the voltage and current surges induced by EMP/transients. As a general rule, smaller components are more susceptible to damage than larger ones. The most susceptible components are integrated circuits, next are discrete transistors. Somewhat less susceptible are components such as capacitors, resistors and inductors. Least susceptible are the large components such as solenoids, relays, circuit breakers, motors and transformers (see figure 1-11).

1.6.1 Transceivers. The typical amateur's transceiver is subject to EMP/transient damage and temporary effects from a number of sources. The primary sources would be EMP energy collected by RF antennas, RF transmission lines, and electrical power lines; and to a lesser extent by remote control lines, telephone lines, microphone lines, speaker lines, etc. The transceiver would be damaged primarily where these lines enter the transceiver at the antenna tuner, the internal power supply, telephone patching equipment, microphone interface, speaker interface, etc.

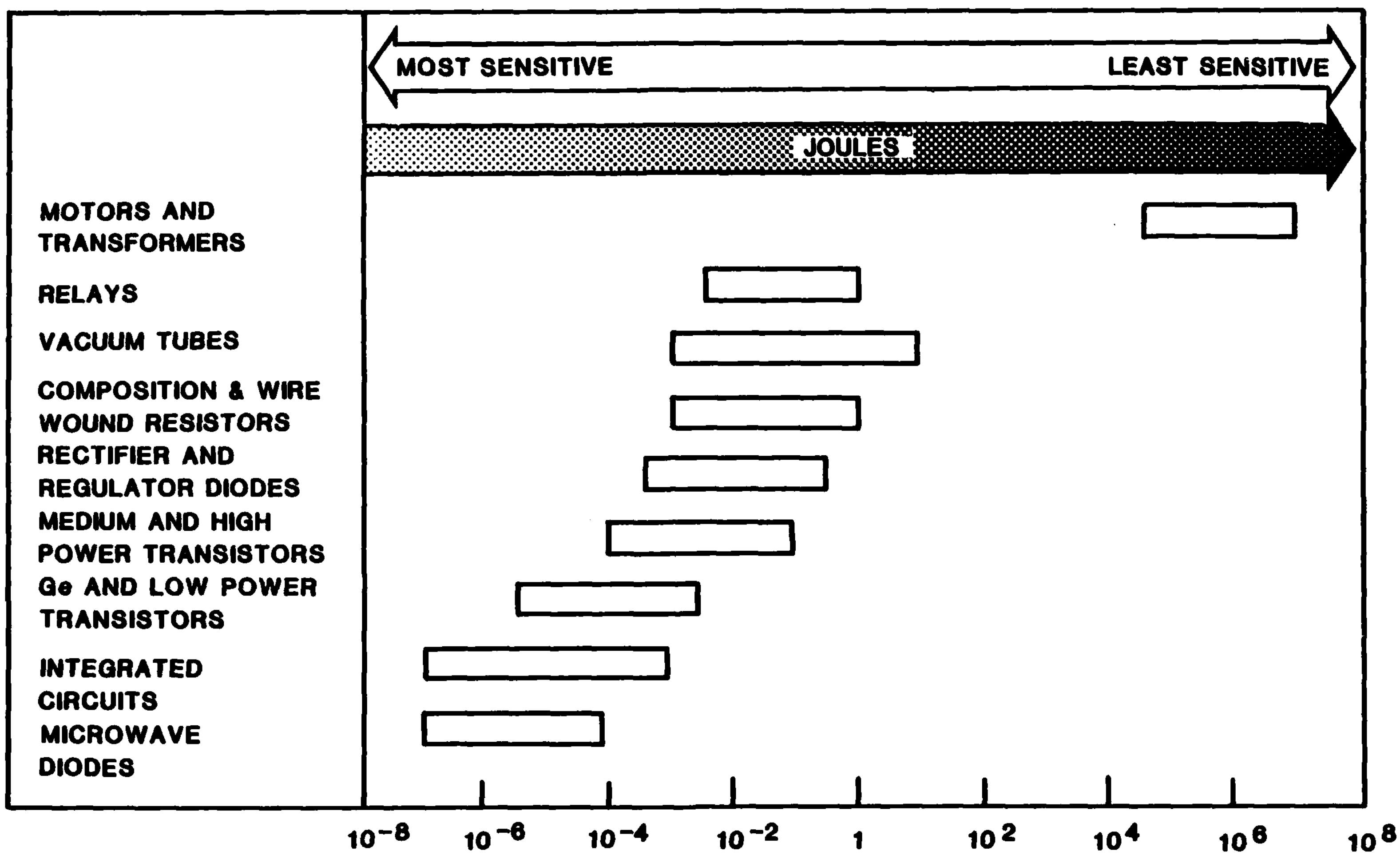


Figure 1-11. Range of Sensitivity of Elecronic Components to Damaging Energy in Joules

The transceiver's equipment case may provide enough shielding to prevent damage from EMP energy collected directly by the transceiver's internal wiring and circuits if the case is metallic.

Where EMP energy does enter the transceiver it may burn out sensitive integrated circuits used to control the transmitter, or it may destroy the field-effect transistor front-ends of receivers. More hardy components, when not destroyed completely, may have degraded performance due to changes in their electrical properties. All solid-state components may experience a change in state that requires resetting or that causes temporary signal errors. Old vacuum tube equipment has shown very little vulnerability to EMP, but the newer sophisticated equipment with dense integrated circuits has high vulnerability.

Small VHF radios that are sealed in metal cases are not vulnerable if the external microphone and antenna are disconnected and the radio is physically removed from other possible external conductors such as power cords and telephone lines.

1.6.2 <u>Antennas</u>. Antennas are purposely designed to be efficient collectors of electromagnetic energy in the specific radio frequency bands in which they are to operate. An antenna designed to operate in that part of the radio frequency spectrum where EMP energy is high will result in a high coupling efficiency for EMP. It is possible for high voltages and currents to be coupled into these efficient EMP antennas. It follows that equipment attached to these efficient EMP coupling antennas will very likely be damaged by the resulting energy. However, antennas designed to operate at radio frequencies outside the EMP energy spectrum will be less likely to act as efficient couplers and may not collect high voltages and currents.

Since most high altitude EMP energy is concentrated between 100 kHz and 10 MHz, antennas in this frequency range will be subject to the strongest EMP induced voltages and currents. All antennas designed to operate between 10 MHz and 100 MHz will also be subject to high EMP induced voltages and currents, however, the EMP energy is decreasing steadily as the radio frequencies increase. In general, all antennas designed to operate at radio frequencies below 100 MHz will be subject to strong EMP coupling, since 99% of the EMP energy is found below 100 MHz (see figure 1-5). Unfortunately for the radio amateur, the High Frequency (HF) radio frequency band falls within that part of the spectrum that contains a great amount of EMP energy and a high coupling efficiency. On the other hand, the Very High Frequency (VHF) antennas used by amateurs are less efficient collectors of EMP energy since they operate above 100 MHz.

When exposed to a high altitude EMP event, the amateur's HF antenna could collect several thousand volts of energy over the antenna leads (see figure 1-8). These high voltages could physically damage the antenna line, antenna balun, and any attached electronic equipment. It should be noted that other conductors associated with a Radio Frequency (RF) antenna system can act as unintentional collectors of EMP energy. They are the control cables to the antenna rotor, the steel antenna mast, the guy wires, and even the grounding system. They can all collect high levels of voltage and current and conduct it either directly or indirectly to sensitive electronic equipment. These unintentional collectors/conductors in many instances are more efficient EMP antennas than the RF antenna they support. Their coupling efficiency is determined primarily by their length, which may be long enough to allow them to operate as an EMP antenna in the strongest part of the EMP energy spectrum. Energy from these collectors, when not directly connected to sensitive radio equipment, can jump or arc to conductors (even short conductors) that are connected, thereby damaging the radio equipment.

1.6.3 Commercial Power Equipment

1.6.3.1 Transmission Lines. Power transmission lines are extremely efficient collectors of EMP energy. The long runs of open exposed wire can couple large voltage and current transients. Long unshielded power lines can experience peak EMP induced surge voltages between 100 thousand volts and 5 million volts and peak currents between one thousand and 10 thousand amperes (see figure 1-8).

Power transmission lines act as long conductors of current with the earth acting as a return conductor (see figure 1-12). The EMP induced current flows down the line through the load (equipment) to ground. The amount of energy dissipated in the load depends on the impedance of the load path to ground. Equipment that presents a large impedance will experience larger peak voltages than equipment with smaller impedance to ground and therefore may experience more damage (see figures 1-13 and 1-14).

1.6.3.2 Power Line Transformers. Normal power line transformers will pass a part of EMP generated currents, through capacitive coupling across the windings. Commercial power transformers reduce the severity of the EMP pulse by decreasing the peak voltage and extending the rise time. In addition, internal inductive and capacitive reactance of the transformer limit the band of frequencies that will pass, making the transformer act like a band pass filter which attenuates frequencies below one and above ten megahertz.

1.6.3.3 Power Phase Differences. EMP currents that are generated in the three phases of a power line are very similar, and voltages in all three

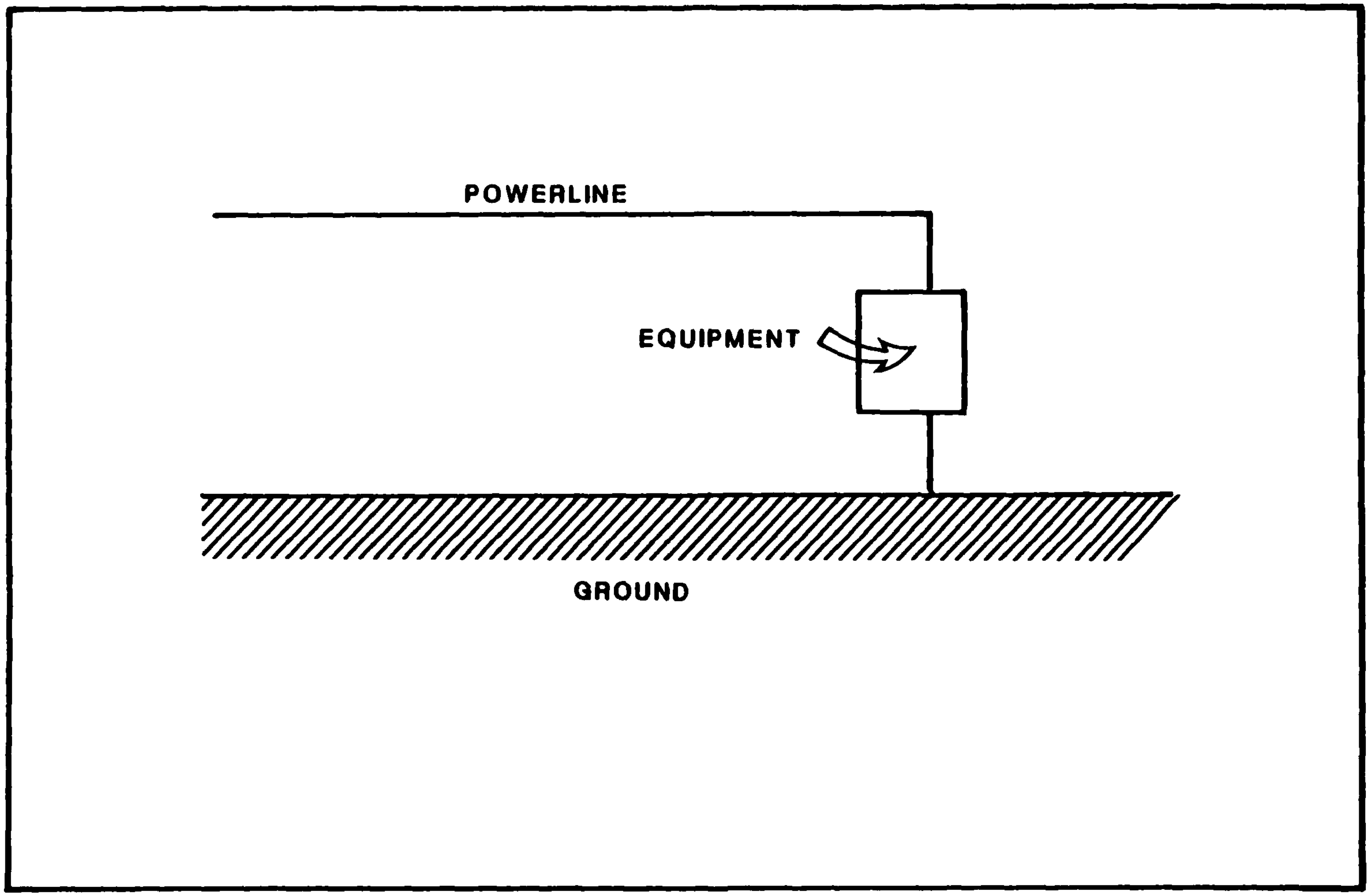


Figure 1-12. Schematic of Powerline with Equipment Load

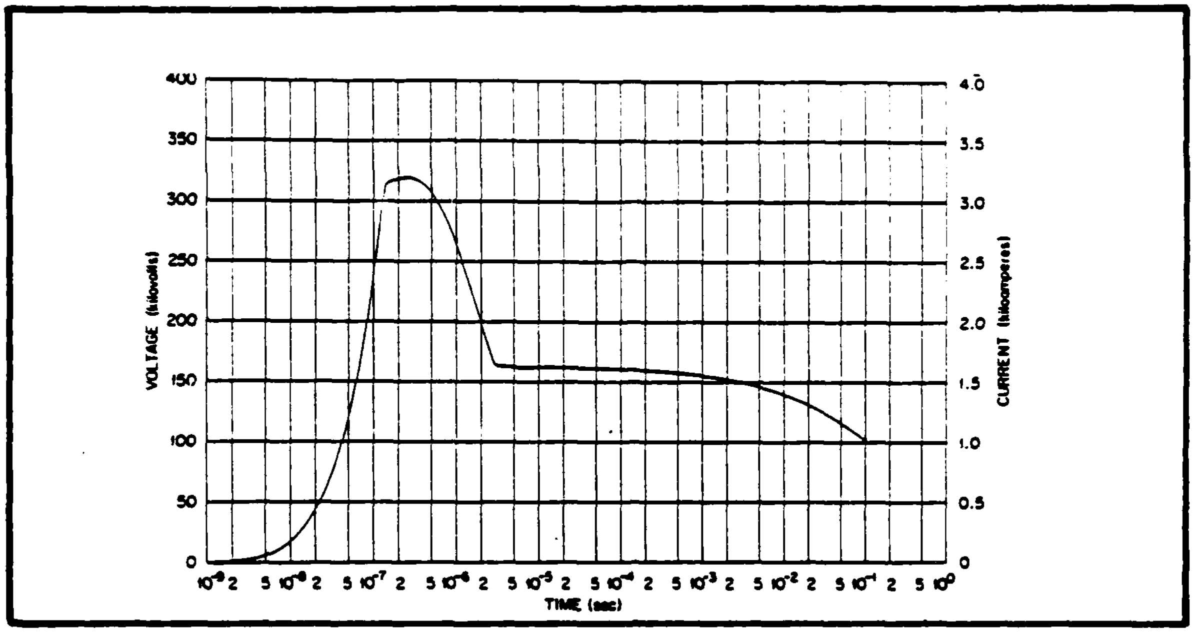


Figure 1-13. Voltage and Current Across 100 ohm Load Connected to Long Power Line Illuminated by EMP

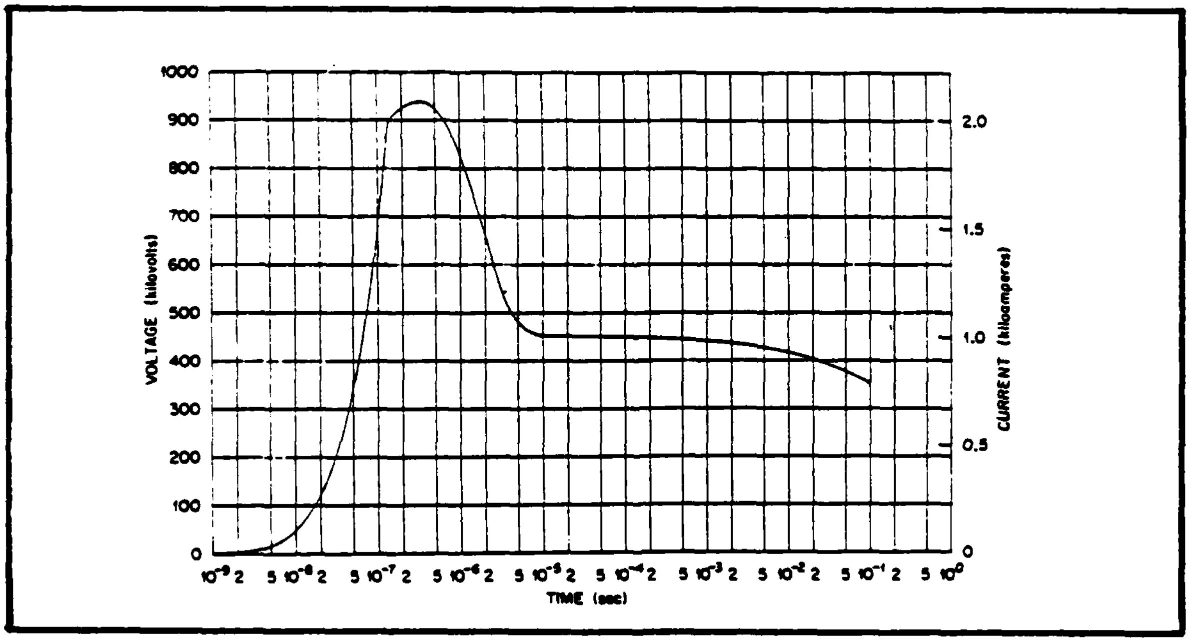


Figure 1-14. Voltage and Current Across 450 ohm Load Connected to Long Power Line Illuminated by EMP

phases are nearly equal with respect to ground. The greatest danger exists to equipment connected from one phase to neutral or ground. Less danger exists to equipment connected between phases. The typical household wall outlet is 120 volts, single phase. Therefore, amateur equipment using this 120V power source would be very susceptible to receiving damage from an EMP wave.

1.6.3.4 Household Circuit Breakers. Household circuit breakers will not offer EMP protection to the amateur's radio equipment because the damaging pulse will pass through the circuit breaker before it has time to react. However, internal arcing in the breaker box and in normal household wiring may limit the peak pulse to about six kilovolts.

The amateur should expect the local commercial power system to be damaged and experience outages from the EMP transient. These outages could be expected to last for several hours to several days. The powerline EMP transients can cause damage such as burned out integrated circuits and discrete transistors, shorted capacitors, fused or vaporized circuits or coils, and perhaps destroyed transformers.

1.6.4 Telephone Equipment. The commercial telephone system consists, in large part, of unshielded telephone switches and cable systems. Although a considerable amount of protection has been built in for lightning, there is very little protection provided for EMP voltage and current surges. An unshielded telephone line may experience a peak voltage between 100 and 10,000 volts and a peak current between one and 100 amps (see figure 1-8). In recent years the telephone companies have started using solid state switching systems that could be very sensitive to EMP pulses. However, the older, existing transient overvoltage protection for telephone circuits is robust and can withstand repeated EMP transients without damage. Even the typical telephone handset is likely to withstand EMP without damage. However, the amateur telephone patching equipment would be subject to EMP damage and should be protected.

1.6.5 Computers. One price that modern users pay for the convenience of microelectronics is a greater susceptibility to electrical transients. In computers, particularly when used with amateur radio, the same kinds of vulnerability exists as with regular "ham" gear only more so. A variety of components and architectures are available, but the most basic configuration is illustrated in figure 1-15. In a typical amateur setup, the program and data are input through a keyboard or cassette recorder, and a video display terminal (VDT) or printer serves as the output device. The capabilities of most computer systems can be enhanced by supplementing the internal storage unit with additional memory and an internal clock. There are literally hundreds of uses for amateurs to utilize a computer, from simple filing and sorting to digital signal enhancement.

As figure 1-15 indicates, control paths and data paths are both contained within the microprocessor. Microprocessors, as has been previously indicated, are especially susceptible to EMP and transient voltage surges. Damage to an amateur's computer can run the gamut from simple logic upset or temporary memory lapse or loss, to fused components and permanent memory loss (complete and irretrievable data dump). Also of concern, especially to computer operators, are transient voltage line surges. Increased voltage may destroy the cathode ray tube (CRT), and disrupt or otherwise impair disk drives and any other ancillary equipment. Procedures to alleviate these detrimental effects will be discussed in Volume I, Section 2.

1.6.6 Repeaters. Microcomputers are having a large impact on FM repeater design and on an increasing number of automated systems under program control. Repeaters are subject to the same threats as any amateur piece of equipment. Often repeaters are collocated with other communications equipment on a joint use antenna tower. This puts them at the very heart of receiving an EMP pulse. Types of damage may range from complete burn-out from transient voltage surges, to loss of logic sequences.

1.6.7 Antenna Rotators. As shown in figure 1-11, heavy duty motors are less susceptible to EMP than smaller, less rugged electronic components. Antenna rotators, although fairly immune to EMP effects due to their

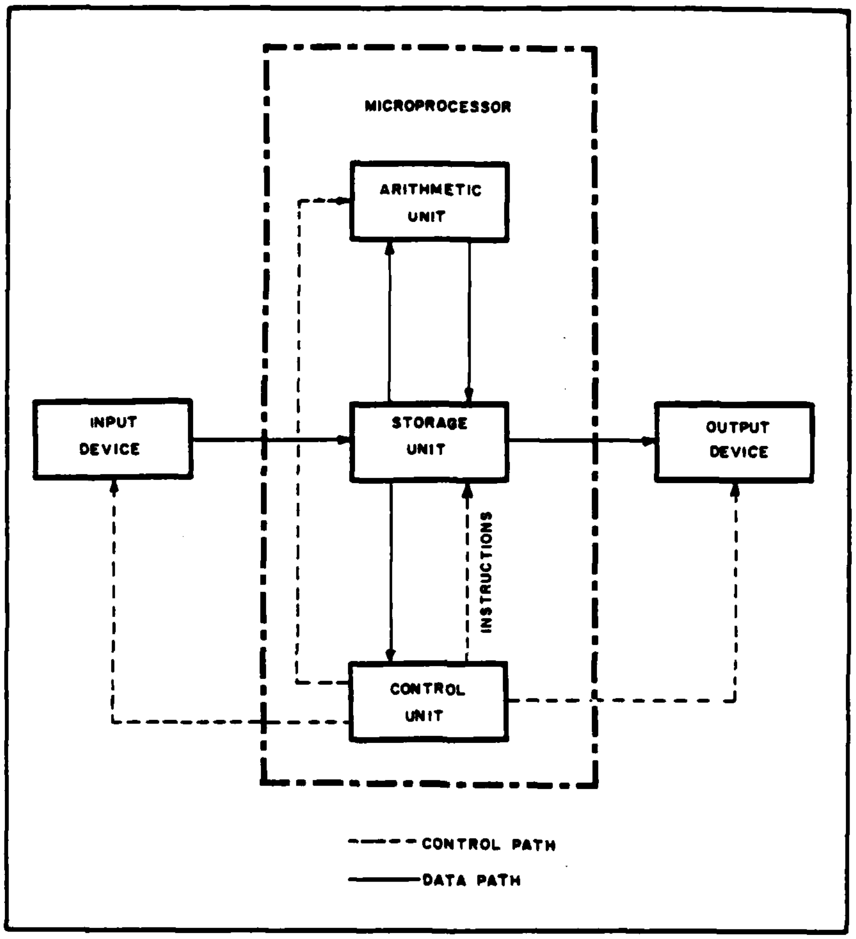


Figure 1-15. Basic Computer Configuration

normally heavy metal cases and large components, may be rendered useless if there is a transient line voltage surge to the rotator remote control box, which is more likely to have smaller components. The line surge need not necessarily be caused by an electromagnetic pulse. Steps should be taken to minimize the threat to an amateur's ability to rotate his RF antenna. These steps will be discussed in Volume I, Section 2 and Section 6.

1.6.8 Satellite Transceivers and Antennas. Just as amateur radio in general has grown and expanded well beyond just experimental curiosity into a sophisticated communication service, the amateur satellite program has emerged and progressed from a 2 meter beacon barely able to send its own name, into a highly technological, modern, efficient, communications system.

As more satellites have become available and increasingly more complex, ground stations and their operations have had to keep pace. With satellites and ground stations improving, increasing numbers of users use the orbiting satellites daily. The potential user population has expanded to the point where careful coordination of satellite operations is now necessary for the full potential of these spacecraft to be used.

Due to the sophisticated nature of satellite transmitters and receivers and especially of their antenna systems, EMP and transient line voltages remain a serious problem. As noted previously, the satellite itself is susceptible to system generated EMP (SGEMP). The very delicate satellite transceivers are especially vulnerable because of their high concentration of solid state components.

Satellite antenna systems, because they need both azimuth and elevation capability, usually employ remotely controlled motors to orient the system. These motors are fairly resistant to EMP. However, the antenna tower or mast and the remote control lines are very likely to pick up large surge currents from EMP and lightning. The AC power supply to the antenna, if not protected, may fail, leaving the motor driven antenna array useless, or making it extremely difficult to aim. With the advent of both the computer/microprocessor and satellite transceiver, and often the marrying of the two for mutual support and enhancement, the degree to which a station becomes vulnerable is greatly increased. Essentially the same problems that may affect typical "ham" equipment will also affect the satellite operator's equipment. The additional vulnerability to the satellite "ham" would be in the area of his antenna motors. Virtually all stations, regardless of the type of amateur equipment, will be hostage to the commercial power supply unless served by a separate emergency back-up power source.

SECTION 2

EMP/TRANSIENT PROTECTION PROCEDURES FOR AMATEUR/MARS EQUIPMENT

2.1 Introduction

What can be done to protect the amateur radio installations from EMP/transients? Before this question can be answered, one needs to take a look at the typical radio amateur and his equipment.

2.2 The Radio Amateur

A 1980 study conducted for the American Radio Relay League disclosed that the typical radio amateur:

- is 44 years old.
- has invested $1668.00 in his present radio station (both fixed and mobile equipment including antennas and towers)
- spent approximately $308.00 in the last 12 months on amateur radio equipment, supplies, etc.
- spends six (6) hours a week on "ham" activities

The study also disclosed that the overall amateur community:

- has the following level of emergency preparedness:
  - 51% have one or more VHF/UHF mobile stations
  - 24% have VHF/UHF hand-held equipment
  - 20% have one or more HF mobile stations
  - 20% have emergency power for HF fixed station
  - 17% participate in traffic or emergency training nets
  - 16% spend 1 to 2 hours per week on traffic, emergency training, or service nets
  - 11% are members of ARES or RACES
- considers preparation for and provision of emergency communications:
  - 64% very important
  - 34% important
  - 2% not important

The study further disclosed that:

- 63% of the amateur stations are located in a single family residence on less than one acre

- 20% of the remaining amateur stations are located in a single family residence on more than one acre

When you consider that there are over 413,000 radio amateurs in the United States, this level of interest and activity in emergency communications represents a substantial capability.

2.3 The Radio Amateur's Equipment

2.3.1 Base Station. Each radio amateur's base station has its own unique characteristics. However, some general statements can be made about the configuration of the current equipment being used. In contrast to past practice when the radio amateurs built much of their equipment, today's amateurs tend to purchase all of their equipment from commercial sources or from other hams. The typical amateur's transceiver is all solid-state and very likely of Japanese manufacture. The station will have two different antennas, one of which will be a half-wave dipole. Usually, the base station is located on the ground floor or in the basement of a single family residence. The typical amateur base station has the following configuration:

- one (1) HF Transceiver
    - Commercial - usually Japanese manufacture

- All solid-state (compact), metal cabinet (case)
- Full coverage of all amateur bands

  (160 -10 meter bands)
- External power supply
- External antenna tuner
- 100 to 250 watts output
- Operating Modes
  - CW
  - AM
  - FM
  - LSB
  - USB
- Desk Microphone

o two (2) - Antennas

one (1) - half-wave dipole

one (1) - other type

- Yagi
- Long-wire
- Beam
- Quad

- Transmission Lines
  - 50 ohm coaxial cable
  - 60 to 80 feet in length

- Grounding Systems
  - copper rod - earth ground.

2.3.2 Mobile. The typical amateur mobile radio has the following configuration:

- commercial equipment
- all solid-state transceiver
- 5 to 50 watts output
- handheld microphone
- magnetic mount vertical antenna
- FM mode of operation
- usually passenger vehicle installed

2.3.3 Hand-held Radio. The typical amateur hand-held radio, "Handi-Talkie", has the following configuration:

- commercial equipment
- solid-state transceiver

- 2 meter band
- 2 to 5 watts output
- built-in microphone
- vertical antenna "Rubber Duck"
- battery charger located in "ham shack"

2.4 Protecting the Amateur's Equipment

Techniques used to "harden" a system against EMP include the use of grounding, shielding, the application of electronic components on shield penetrators, and the implementation of various protective procedures.

Decisions concerning electrical protection involve tradeoffs. For example, the cost of retrofitting an existing system with shielding for all of the structures would be prohibitive; however, shielding on the individual equipment level appears to be economically feasible.

To insure that the amateur radio equipment is fully protected from EMP/voltage transients, the equipment must be isolated from all external sources of damaging voltage and current pulses. The degree to which this isolation can be accomplished depends upon the physical configuration of the amateur's radio equipment and installation. Complete isolation can be accomplished by treating both the radio equipment and the external conductors that are related to it. The radio's internal components must be enclosed in an electromagnetic shield. External conductors, especially antenna and power, must either be removed, or another path to ground (other than through the equipment) must be provided for the damaging EMP voltage and current pulses.

For a VHF hand-held radio, complete isolation may be accomplished by simply removing the antenna and the external microphone, speaker and headphones if any. The metal case of the radio, if available, would provide the necessary shielding for the internal components.

For a compact solid-state transceiver, complete isolation can be accomplished by removing all external conductors and shielding the equipment. The conductors should be disconnected where they interface with the equipment case. Although it will help to unplug the AC power cord at the wall outlet, it would be much better to disconnect it from the back of the equipment case. Other conductors which should be removed include: the RF antenna line, the external ground line, the telephone patch line, the microphone line, the external speaker and the headsets. Also, all other accessories should be disconnected including the external antenna tuner and external linear amplifier. The major disconnected components should then be stored in a grounded metal case, such as a metal file cabinet.

Although complete isolation is desirable, it may be impractical and for short external conductors, may not be fully required. Paragraph 2.5 discusses recommendations for other than complete isolation that still provide good protection from EMP/voltage transients.

2.4.1 Improving the Amateurs' Procedures. What improvements can be made in the amateurs' procedures to increase the survivability of their radio system? The first thing amateurs should do is become aware of the EMP threat to their equipment and make other amateurs aware of this threat. Amateurs should be aware that increased world political tension would be expected to precede a nuclear event and they should take more stringent protective measures for their equipment during those times.

Amateurs should learn what components in their own particular radio equipment and antenna system are most likely to be damaged by EMP. They should then know how to repair the damaged equipment unassisted.

Amateurs should learn how to reestablish communications after an EMP event, taking into consideration its adverse effects on the earth's atmosphere and their equipment. One of the first things that would be noticed, providing their equipment is still working, is a sudden silence in radio transmissions across all radio frequency bands below approximately 100 MHz. This silence would be due in part to the damage to unprotected radio equipment by the EMP transient. Transmissions from one direction, the direction of the nuclear blast, would be completely out. This would be due to the RF signal loss by absorption and attenuation by the nuclear fireball.

After an EMP event, the amateur should be prepared to operate in a continuous wave (CW) mode. CW gives the most signal power under the adverse conditions that would exist. It also provides a degree of message security from the general public.

Amateurs should develop the capability and flexibility to operate in more than one frequency band. The lower/ground wave frequencies should be useful for long distance communications immediately after an EMP event; and the line-of-sight (LOS) VHF frequencies would be of value for local communications purposes. (see figure 1-9)

2.5 Recommendations

What can be done to increase the survivability of the amateurs' radio system? The following are some recommended changes that can be made immediately in most cases:

To insure adequate protection from EMP/voltage transients, disconnect all external EMP collectors (conductors) from the radio equipment. The conductors should be disconnected from the equipment case wall. Not even short conductors should extend from the equipment case. The conductors that should be removed from the transceiver and its accessories include: the antenna line, the commercial or emergency power lines, the external ground, the telephone lines, control lines, external speakers, microphone, linear amplifier, antenna tuner, and any other ancillary equipment. Also isolate the radio equipment from all non-system EMP collectors. This includes the metallic objects in the vicinity of the equipment; water pipes, electrical conduits, reinforcing steel, and metal windows and tables. Either remove the metal conductors from the area or move the equipment away from the conductors. Finally, place the radio equipment in a grounded metal container such as a metal storage cabinet.

Although it is desirable, most amateurs consider it impractical to keep their transceivers completely disconnected when not in use. Still there are several things amateurs can do if they elect to keep the equipment connected.

1. If the amateur has spare equipment, it should be kept disconnected and only the primary equipment used. The spare equipment would then be available after an EMP event.

2. Keep the equipment turned off and disconnect the antenna and power lines at the equipment when not in use.

3. Only connect those external conductors necessary for the current mode of operation. (i.e., disconnect the phone patch, or external speaker if not needed.)

4. Tie all fixed equipment to a single point earth ground to prevent closed loops through the ground.

5. Obtain schematics of the electronic equipment for future reference and repair actions.

6. Have on-hand spare parts for those sensitive components of the radio equipment and antenna system.

7. Learn how to repair or replace the sensitive components of the radio system.

8. Use non-metallic guy lines and antenna structural parts where possible.

9. Obtain the necessary tools to be self sufficient in repair of equipment.

Some of the other things the amateur can do are:

1. Obtain an emergency backup power source and operate from it during periods of increased world political tension. The emergency power source should be completely isolated from the commercial power lines.

2. If the power lines are not disconnected when the equipment is not in use, install a local circuit breaker switch on the commercial power line. This switch should be installed near the equipment and should be kept in the off position when the equipment is not operating.

3. If the RF antenna line is not disconnected when the equipment is not in use, install an antenna switch with one position going directly to earth ground. Keep the antenna RF line switched to the ground position when the equipment is not in use.

4. Have a replacement antenna and transmission line on hand to replace a damaged antenna system.

5. Install EMP surge arrestors and filters on all primary conductors attached to the equipment and antenna.

6. Retain old tube type radio equipment and components. Keep them maintained, in good working order, and have spare parts available.

7. Do not rely on a microprocessor to control the station after an EMP event. Be able to operate without microprocessor control.

2.6 Summary

In summary, the first step in solving the EMP/transient problem is acquiring the knowledge that the problem exists.

Hardening the Amateur Radio system en masse as a result of public awareness is, at best, improbable. However, simple practical procedures will greatly enhance survivability. Maintain flexibility. Obtain communications capability in more than one band. Establish LOS communications on VHF or ground wave frequencies. Acquire redundancy. Keep old tube type equipment. If older solid-state equipment is unused, keep it disconnected from the antenna and power source. Do not depend on a single microprocessor to control your station. Achieve a degree of independence, especially from utilities. Capitalize on any battery powered or battery capable equipment. Better yet, obtain and use your own source of emergency commercial grade power. If amateurs use their creativity, innovativeness, keen common sense and individualism, along with the basic procedures recommended herein, their station's chances for survival will be greatly enhanced.

SECTION 3

TEST RESULTS OF
EMP/TRANSIENT THREAT TESTING OF
PROTECTION DEVICES FOR
AMATEUR/MARS EQUIPMENT

3.1 Test Purpose

The widespread use of solid-state electronic components in recent years, with their inherent weakness to damaging transient electrical pulses has stimulated the electronics industry to develop and market a large variety of improved transient protection devices. The suitability of these new devices *for the low cost protection* of amateur radio equipment needs to be investigated.

The purpose of this test program was to identify those low cost, commercially - available devices that are capable of providing electrical transient/electromagnetic pulse protection for amateur/MARS radio equipment. A variety of different protective devices will be needed to provide full protection of amateur radio equipment from the damaging voltage and current transients generated by lightning and electromagnetic pulses. An extensive market search was made and a representative number of protective devices were obtained for this test. These included the most current types of devices for the protection of amateur radio equipment where it interfaces with commercial powerlines, radio antenna systems, communications lines and other potential transient sources.

3.2 Test Objectives

There was no common test procedure for determining success in transient pulse protection that has been generally applied to different types of protection devices. It was the objective of this test to initiate a common test procedure to ascertain the average performance of a wide variety of devices against the same fast-rising (nanoseconds) and powerful (kilovolt) transient pulses that are expected to be generated by lightning or electromagnetic pulses (EMPs).

Three standard electromagnetic pulses were used to simulate the expected transient waveform associated with: (1) AC power connections, (2) short interconnecting wires and (3) long exterior conductors that are found in the typical amateur radio station (see paragraph 3.3.1).

The objective of this test was to measure the voltage response to these three pulse waveforms with respect to the ability of the devices to suppress the transient voltage spike level and duration. The ultimate objective was to identify and select the most effective protective devices for further testing on amateur radio equipment and eventually to design a complete protection system for the typical amateur radio system.

Another objective of this test was to identify and reject those protection devices that do not satisfactorily pass the test criteria. Devices that allow a voltage spike to exceed the initial clamping voltage by 100 percent (6 dB) or with a significant delay in the response time were to be rejected. Those devices that suppressed the initial voltage spike to an acceptable level, less than two times the clamping voltage, were to be accepted for further testing. The 100% (6 dB) overload voltage level was selected as the test acceptance level for devices, because it is common to design electronic circuits to withstand a 6 dB voltage overload for short durations.

3.3 Test Program

3.3.1 Threat Definition. Qualification was desired against both EMP and lightning transients in this program. Other than the case of a direct lightning strike, EMP was generally considered a more stringent threat to electrical systems than lightning. Consequently, the qualification test pulses approximated the characteristics of EMP, rising to full strength in approximately 10 nanoseconds and decaying exponentially in about one microsecond. The waveform that is frequently used in unclassified work was used for this test and is expressed in the exponential equation:

$$E(t) = 5.25 \times 10^{4} \ \exp(-4 \times 10^{6} t) - \exp(-4.76 \times 10^{8} t)$$

E is volts per meter and t is seconds.

The transient threat to electrical hardware does not come directly from the free field, but rather from the interaction of the electric and magnetic fields with electrical conductors. For this test program, it was considered likely that voltage and current transients in conductors would exhibit rise times slower than the free field, and would oscillate or decay at a much slower rate than the free field. However, approximation of the free field waveform in injected current or voltage test transients is a reasonable worst case transient pulse and it was used in this program.

For currents, peaks in excess of thousands of amperes have been predicted as a response to EMP. Similarly, voltages may reach hundreds of kilovolts. However, in practice, the physical dimensions and characteristics of the conductors themselves will tend to limit currents and voltages, although not always without physical damage to the conductors. For example, it has been proposed that the highest transient voltage transmitted through a residential power distribution breaker box would be limited by air discharge breakdown. Conversely, antenna leads and signal cables in an amateur radio station may not posses such close tolerances, and the peak transients experienced, if limited at all, would be determined by the lengths and configurations of conductors exposed to the fields, and the dielectric strength of their electric insulation.

The following peak values were used in the protective device qualification tests for this program:

CONDUCTOR	PEAK VOLTAGE VOLTS	PEAK CURRENT AMPS	TEST CLASS
Power connections	600	120	A
Box interconnections	600	20	B
Exterior Conductors	4500	1000	C

These peak values were used because they were representative of the transient pulses expected to interface the typical amateur radio system and they could be readily reproduced in a laboratory test environment.

In addition, the highest pulse level obtainable in the laboratory (25000 volts) was used to test for insulation breakdown of the protective devices. Each protective device was subjected to ten equal pulses, in order to ensure that protection was not circumvented by the first threat transient received. A cooling time of approximately one second was allowed between pulses.

3.3.2 Direct Testing. Direct device testing consisted of driving the device terminals with a differential mode signal from a pulse generator. The direct test was conducted once with source impedance appropriate to the tabulated voltages and currents listed previously, and once with the tabulated voltage and a source impedance of fifty ohms. Fifty ohms was chosen because it is most commonly encountered in house wiring and antenna connections. The input and output pulse magnitudes were recorded by photograph on a suitable scale vs time. A comparison was made of the input and output voltages with and without the device in the circuit and a transient rejection ratio was calculated in decibels using the relationship:

$$RR_{dB} = 20 \log_{10} \frac{\text{Peak Signal In}}{\text{Peak Signal Out}}$$

For each type of protective device, from one to 15 devices were tested as described in the test plan. When ten identical devices had been tested with both forward and reverse polarity, the data was statistically analyzed to determine if further testing was required. For statistical analysis, ten items were considered to provide a representative sample of the device's performance, since the devices performed very consistently.

3.4 Test Equipment

This test used two different pulse generators; one for pulses below 5000 volts (600V and 4500V tests) and another for pulses above 5000V (25,000V test).

3.4.1 Pulses Below 5000 Volts. Transient pulses for this test were generated by manually firing a mercury wetted switch to discharge a storage capacitor through a copper sulphate source resistance of the appropriate size to generate the desired current pulse. The capacitor was charged by a quick recovery high voltage power supply to the desired voltage level. The transients were fired across a 100 ohm load resistor protected by the device under test (see figure 3-1).

Data was recorded by photographing the display of an oscilloscope calibrated to the appropriate settings for amplitude and time. For repeated pulse requirements, the camera shutter was held open to record all (nominally 10) of the pulses of one polarity, and then, after removal of the device under test, to record the applied transient on the same exposure. Reverse pulse measurements were obtained by reversing the leads of the device under test and repeating the photography sequence.

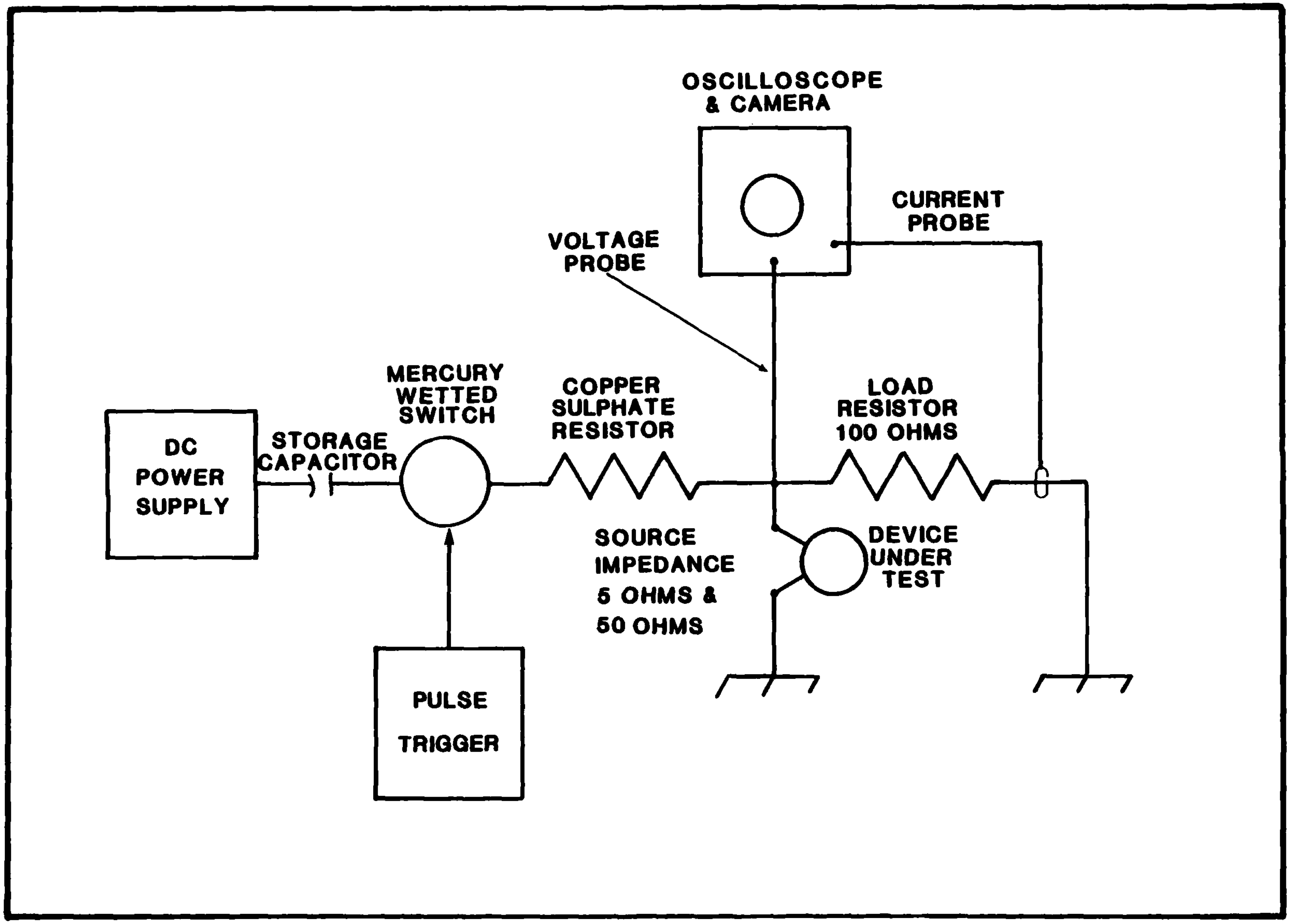


Figure 3-1. Low Voltage Pulser - Below 5,000 Volts.

A transient pulse generator was utilized to generate fast rising step function pulses at low output level for calibration of the oscilloscope display. Performance of the pulse sensor system was evaluated by means of a network analyzer.

3.4.2 Pulses Greater Than 5000 Volts. Transient pulses for this test were generated by manually firing a two inch spark gap to discharge a 0.1 mfd. storage capacitor through a five ohm copper sulphate source resistance to generate the desired current pulse. The capacitor was charged to the desired voltage level by a quick recovery high voltage power supply. The transients were fired across a 100 ohm load resistor protected by the device under test (see figure 3-2).

Data was again recorded by photographing the display of an oscilloscope calibrated to the appropriate settings for amplitude and time. Both current and voltage were recorded for the initial pulses of each device. The voltage probe was attenuated by a flexible copper sulphate resistance of suitable value. For repeated pulse requirements, the camera shutter was held open to record five of the pulses and the reference in a similar manner to the lower voltage measurements described previously. The second set of five pulses were not reversed, although the screen scale was usually adjusted to improve resolution of the response, and the current trace was usually omitted from the second data set.

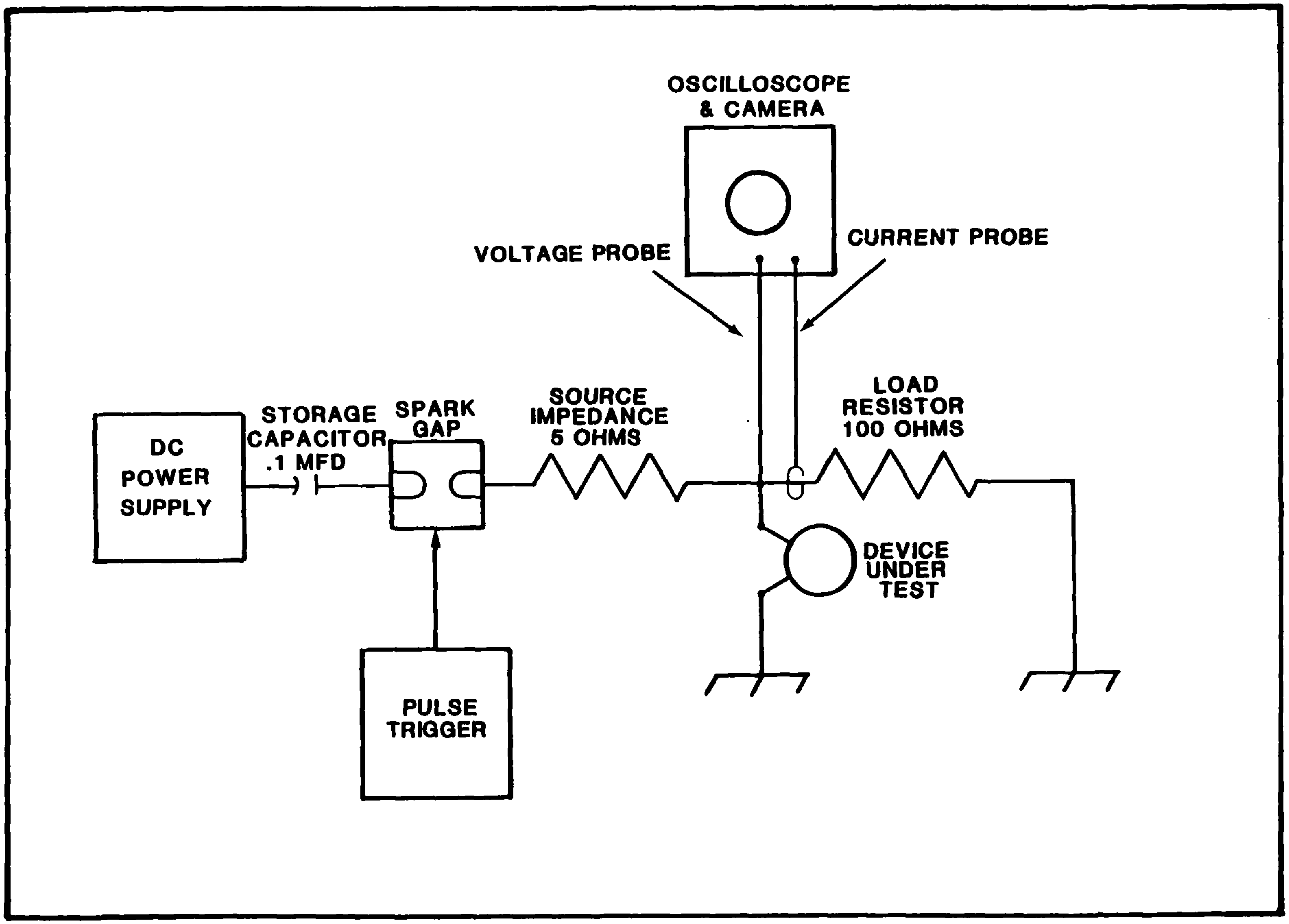


Figure 3-2. High Voltage Pulser – Above 5,000 Volts.

3.4.3 Small device Tests. For physically small devices, test measurements were conducted inside a metal enclosure. Penetrations of the enclosure were the high voltage lead from the mercury switch, the system ground, and the voltage probe. Currents were measured by a sensor on the system ground, but were not regularly recorded as part of the test data. The voltage probe was run in solid coax to the metal enclosure, and the internal probe was shielded by a metal braid to within a few millimeters of the probe tip.

Shunt protective devices were connected between the high voltage input terminal and system ground. The voltage probe and load resistor were also connected to the same terminal. For device combinations containing series elements, the line side of the device was connected to the input terminal, and the voltage probe and load resistor connected between the load side terminal and ground.

3.4.4 Large Devices. For devices with special connectors too large to fit within the test chamber, connecting adapters were constructed of straps and braid to provide the lowest impedance circuit available. In many cases, however, the inductance of the connection did affect the measurement, particularly in the case of determining the reference grounds.

3.4.5 Tests Under AC Power.

A short activity was performed to test the ability of the devices to function when connected in a 120 volt AC circuit. The AC was provided from an isolation transformer connected to the device through a large inductance. If the device continued to arc or pass current after the pulse, the transformer was manually disconnected, but not always before melting of the device had occurred.

3.5 Test Results

A total of 56 different devices were tested. All of the devices substantially suppressed the test pulse; however, not all of the devices suppressed the test pulse to an acceptable voltage level on every test.

Twenty-six (26) of the 56 devices passed the low impedance drive tests and forty (40) passed the high impedance drive test. To pass the test the device had to suppress the peak voltage pulse to less than two times the published, designed clamping voltage for the device, or exhibit an acceptable response waveform. To be acceptable the initial voltage spike of the suppressed signal could not exceed two times the following suppressed, constant voltage level (see paragraph 3.2).

From one to 15 identical items of a device were tested by the three qualification pulse waves and from one to five identical items of a device were tested with the 25 KV failure test pulse wave. This resulted in a test program which exceeded 1600 individual test points. Each test point measurement taken required the pulser to triggered from 10 to 20 times to record a reference pulse and then a data pulse image on the oscilloscope camera. Each test point has a data sheet and a photograph of the associated pulse waveforms included as part of this report. This information is contained in Volume III, Sections 1 through 4.

The test results were tabulated in the following data formats: one listing all data points taken (table 3-3), one listing devices having acceptable clamping voltages in low impedance drive testing (table 3-1), and one listing devices having acceptable clamping voltages in high impedance drive testing (table 3-2).

3.5.1 Low Impedance Testing. The low impedance test was conducted at two different voltage levels (600 volts and 4500 volts). The devices were tested with both positive and reverse polarity pulses with no significant difference in response noted due to the different polarity pulses, with the exception of certain General Semiconductor Transzorbs.

Twenty-six (26) devices were considered to have acceptable pulse suppression characteristics to the low impedance drive test pulses.

The most consistent device was the metal oxide varistor. The varistors suppressed the leading edge of the pulse wave to less than two times the designed clamping voltage. Table 3-1 shows those devices that have an acceptable clamping performance. The accepted devices have rejection ratios that range from 0.75 dB to 16.47 dB for the 600V test pulse and from 13.06 dB to 21.47 dB for the 4500V test pulse.

The gas-discharge-tubes and devices containing only gas-discharge-tubes did not respond well to the 600 volt pulse. The rise time (10 nanoseconds) and the low voltage level (600 volts) were not sufficient to cause the tube to ionize and begin conducting the test pulse to ground within the (10 nanosecond) rise time. With ten pulses being injected at a one second repetition rate, the gas tube ionization was delayed for periods up to 4000 nanoseconds for each pulse, and in some cases the measurements were off the observable scale. This slow response time makes the gas-discharge-tube an unacceptable device to use as the sole protection device for a low voltage pulse with a slow rate of rise such as experienced with the 600 volt pulse which had a rate of rise of only 60 volts per nanosecond.

The varistors all responded well to the 600 volt pulse. The slow rate of voltage rise allowed the varistors to fully suppress the leading edge of the pulse to a very acceptable level.

The devices were evaluated with respect to their published maximum clamping voltages. The published clamping voltage of a device is the average voltage level where the device will change from a non-conducting state to a conducting state (i.e., clamping voltage, sparkover voltage or breakdown voltage).

The manufacturer normally establishes the maximum clamping voltage using a much slower pulse (8 microsecond rise time and a 20 microsecond decay) than the expected electromagnetic pulse and the test pulse (10 nanosecond rise time and a 1 microsecond decay). The DC breakdown voltage was used as the reference clamping voltage for some of the devices. Therefore, the measured clamping voltage of the devices were expected to be higher than the published clamping voltage. These higher clamping voltages were found during the test program with a very few exceptions.

Twenty devices were considered to have acceptable measured clamping voltages on the low impedance test when compared to their published clamping voltages. Six other devices had a satisfactory response waveform and were accepted, although their clamping voltage was over two times their published/designed clamping level. Not all of the devices were tested at the 600 volt level. However, of the ones that were tested, the varistors and the AC powerline protection devices were the best performers.

3.5.2 High Impedance Testing. The high impedance test was conducted only at the 4500 volt level. The devices were tested with both positive and reverse polarity pulses, with no significant differences in response noted due to the different polarity pulses, with the exception of the transzorbs.

Forty devices were considered to have acceptable pulse suppression characteristics to the high impedance drive test; six from a pure waveform standpoint and 34 when considering their designed performance characteristics.

The most consistent devices during this test were the gas-discharge-tubes, especially when considering their designed clamping voltages.

The 4500 volt,, 50 ohm test pulse was considered to be the most accurate simulation of the expected electromagnetic pulse energy that will be impressed upon the AC power and coaxial cable line interfaces with the amateur's radio equipment. Therefore, the results of this test pulse were expected to be the most significant of the test program.

3.5.3 Varistors. The devices with adequate performance during the test were the varistors. The General Semiconductor, General Electric and Siemens varistors performed consistently against the high impedance drive pulse.

Varistors are voltage dependent devices which behave in a nonlinear electrical manner similar to back-to-back zener diodes. When subjected to high voltage transients the varistor's impedance changes over a large range from a near open circuit to a highly conductive circuit, thereby switching the transient voltage to ground or some other point. Varistors are designed with a large assortment of switching voltages, also called clamping voltages. The varistors tested had clamping voltages ranging from 0.85 volts at the low end to 350 volts at the high end. The average measured varistor clamping voltage during the test ranged from a low of 168 volts to a high of 436 volts. Three of the varistors designed to clamp at a low voltage did not clamp until the voltage exceeded an acceptable level. Nine varistors designed to clamp at a high voltage level were within an acceptable level. Therefore, nine out of twelve varistors tested were found to have acceptable clamping voltages with respect to their stated design characteristics and the test acceptance criteria. The three varistors that exceeded their designed clamping voltage did perform consistently and could be used at a higher voltage level if desired.

3.5.4 Gas-Discharge-Tubes. A consistent performer during this test was the gas-discharge-tube. Out of a total of 14 gas tubes from Joslyn and Siemens, 11 were considered to have acceptable voltage clamping levels. Just as with the varistors, the gas tubes with the lowest published voltage clamping levels were not accepted.

The tubes tested were sealed gas-discharge-tubes consisting of two or three electrodes properly separated by insulators and filled with a rare gas. These tubes were designed to switch rapidly at a specific voltage level (breakdown voltage/clamping voltage) from a non-conductive to a conductive state (arc mode) when subjected to a fast rising voltage transient. When the voltage across the tube's electrodes was increased, ionization of the inert gas occurred and the tube conducted across the electrode gap. The breakdown voltage level was determined by the design of the tube's electrode spacing and the gas pressure.

The advantage of using a gas-discharge-tube is its ability to handle large power transients for short periods. One of the disadvantages of gas tubes is that once they begin to conduct, a continuous AC or DC operating voltage of the proper level will keep the tube in the conduction mode after the pulse has passed. This characteristic can result in the destruction of the tube, as was experienced during another phase of this test program. Several gas tubes were destroyed when attached to an isolated AC power source and then pulsed with a 25 KV pulse. The pulse started the tube's conduction (arc) mode and the AC power sustained the tube's ionization and conduction until the tube was destroyed.

In another special test, two gas tubes were connected in series between the pulse source and system ground. An AC current was impressed across the source circuit and then through a 100 ohm resistor to ground. The gas tubes did not begin to conduct until they were pulsed. When pulsed, the two gas tubes ionized and conducted the pulse to ground and then shut off after the pulse had passed. The AC power did not sustain the ionization across the two gas tubes when they were connected in series.

In a similar test a gas tube and a varistor were connected in parallel to ground with an AC current on the circuit. Again when pulsed, the tube ionized and conducted the transient current to ground while sharing the current with the varistor, and then shut down without being destroyed. Therefore, it was concluded that gas tubes could be used for their high power handling capabilities but only when used in the proper voltage levels or with another device to suppress the continuous conduction mode of the tube. This design adaptation was found in commercial AC power protection devices and radio frequency RF devices using gas tubes during the test program.

3.5.5 Radio Frequency Protection Devices (Coaxial Line Protector). Eleven radio frequency protection devices from three different suppliers, Fischer Custom Communications, Polyphaser Corporation and Alpha Delta Communications, Inc., were tested. All of the devices, with the exception of the device with the lowest clamping voltage, were accepted.

All of these devices were designed to be placed in the RF coaxial transmission line. Several different devices with different clamping voltages were tested to evaluate the EMP suppression effectiveness of the devices at different clamping voltage levels. With the exception of the Fischer device (FCC-450B-75-BNC) which was rated to clamp at 75 volts, all devices clamped within the acceptable range. However, the Fischer device FCC-450B-75-BNC did suppress the 4500 volt pulse down to an average of 210 volts and was given a rejection ratio of 26.62 dB, which was still a very good performance for a device.

The devices tested had a range of clamping voltages that started at 75 volts and went to a high of 650 volts. The measured clamping voltages obtained ranged from a low of 120 volts (for a device rated at 120 volts) to a high of 720 volts (for a device rated at 635 volts). The radio frequency coaxial protectors had a very high rejection ratio to the 4500 volt high impedance pulse, starting at a low of 16.15 dB for the Alpha Delta, Transi Trap RT and going to a high of 30.14 dB for the Polyphaser, IS-NEMP devices. One Fischer device FCC-250-350-UHF clamped 90 volts below its rated clamping voltage of 350 volts. This was not considered a problem, but a larger drop could potentially interfere with the RF transmitted signal.

3.5.6 AC Powerline Protection Devices. There are numerous AC powerline protection devices available, but the selection for this test was limited to the lowest cost devices that were available. Ten devices from seven different sources were tested. This included devices from General Semiconductor, Joslyn, Fischer, TII, Electronic Protection Devices, Radio Shack and S.L. Waber.

All of the devices tested, with the exception of the Fischer model FCC 120 F-P, Joslyn model 1250-32 and the General Semiconductor models 587B051 and PHP 120, could be plugged directly into an AC wall outlet. Internally the devices consisted of a combination of gas-discharge-tubes, varistors or other protective circuitry.

Of the ten (10) devices tested, all except one were found to be acceptable. The published clamping voltages ranged from a low of 190 volts to a high of 650 volts. For several devices the designed clamping voltage was not known so a 300 volt level was assigned for comparison. The measured clamping voltages ranged from a low of 300 volts to a high of 1000 volts.

3.5.7 Transzorbs. Seven transzorbs all from General Semiconductor were tested in an effort to find a device that would clamp at a very low voltage level. The transzorb with the lowest rated clamping voltage was the ICTE-5 with a clamping voltage of 7.1 volts, and the transzorb with the highest rated clamping voltage was the LCE-130A with a rated clamping voltage of 209 volts. The average measured clamping voltages ranged from a low of 124 volts to a high of 250 volts. Only one of the transzorbs was accepted; the LCE-130A, which was rated at 209 volts and had an average clamping voltage of 210 volts. All of the other transzorbs exceeded their rated clamping voltages by a considerable amount and were not accepted.

In the same family as the transzorbs is the GHV-12 which is a bi-directional surge suppressor. Its published characteristics breakdown voltage is 8 volts, but its average measured breakdown voltage with the simulated EMP test pulse was 218 volts. Therefore, it was not accepted.

3.5.8 Test to Failure. The larger of the two pulse generators was used to generate a 25 kilovolt pulse at four kiloamperes over a one micro-second duration for a total energy output of 100 Joules. Up to five each of 36 different devices were tested with only three devices approaching failure. The three AC power protection devices experienced excessive internal arcing, although they did not fail completely. All of the other devices survived the 10 pulses and suppressed the voltage transient without failure.

After the test-to-failure series was completed, several special test reference points were taken using a special device holder. These test points are all listed as TR-25 (Test Reference 25 KV). During this special test series, a single device or combination of devices was connected to an AC power source and then pulsed. Several gas-discharge-tubes and a small transzorb were destroyed during this series of tests.

3.6 Conclusions

Out of the 56 devices tested there was a wide selection of devices that had acceptable voltage transient suppression capabilities. Suitable devices were identified which can be used for the protection of amateur radio equipment where it interfaces with the hostile electromagnetic pulse environment. These devices include those ready-made devices for direct connection with the AC power lines and the antenna coaxial lines, and those smaller devices that can be used alone (varistors) or in combinations (gas-tube/varistor) to protect the other interface points.

Table 3-1
DEVICES HAVING ACCEPTABLE CLAMPING VOLTAGES
LOW IMPEDANCE DRIVE TESTS

MANUFACTURER	DEVICE	DESIGNED MAXIMUM CLAMPING VOLTAGE (MCV)	AVERAGE MEASURED PEAK VOLTAGE @ 600V/4500V (APV)	ACCEPTABLE CLAMPING VOLTAGE (APV ≦ 2 MCV)
FISCHER				
1	FCC-120F-P	300(1)	200	300
2	FCC-250-300-UHF	300	1333	
3	FCC-250-350-UHF	350	1633	
4	FCC-450B-75-BNC	75	670	
5	FCC-250-150-UHF	150	1700	
6	FCC-250-120-UHF	120	1700	
7	FCC-450-120-UHF	120	800	
JOSLYN				
8	2027-23-B	230	600	
9	2027-35-B	350	1940	
10	1270-02	190	400	
11	1250-32	350	2300	
12	1663-08	66		
13	2027-09-B	90	1820	
14	2027-15-B	150	1620	
15	2022-44	250	1460	
16	2031-23-B	230	1560	
17	2031-35-B	350	1360	
GENERAL ELECTRIC				
18	V39ZA6	76	132	76
19	V82ZA12	147	230	147
20	V180ZA10	300	428	300
21	V8ZA2	20	120/690	60(3)
22	V36ZA80	63	120	63
POLYPHASER CORPORATION				
23	IS-NEMP	200(2)	380	200
24	IS-NEMP-1	200(2)	380	200
25	IS-NEMP-2	200(1)	600	

Table 3-1
DEVICES HAVING ACCEPTABLE CLAMPING VOLTAGES LOW IMPEDANCE DRIVE TESTS (Cont'd)

MANUFACTURER	DEVICE	DESIGNED MAXIMUM CLAMPING VOLTAGE (MCV)	AVERAGE MEASURED PEAK VOLTAGE @ 600V/4500V (APV)	ACCEPTABLE CLAMPING VOLTAGE (APV ≦ 2 MCV)
TII				
26	MODEL 428	280	350	280
SIEMENS				
27	S10K11	40	120/690	
28	S20K25	80	131/720	80
29	S14K50	125	220/620	125
30	S10K60	160	265/710	160
31	S14K130	340	464/1050	340
32	B1-C75	75(2)	600/910	
33	B1-C90/20	90(2)	600/938	
34	B1-C145	145(2)	600/880	
35	B1-A230	230(2)	600/960	
36	B1-A350	350(2)	632/1020	
37	S8-C150	150(2)	600/4500	
38	T61-C350	300(2)	672/990	
ALPHA DELTA COMMUNICATIONS, INC.				
39	LT	635(1)	4500	
40	RT	635(1)	400	635
GENERAL SEMICONDUCTOR				
41	587B051	650	290	650
42	ICTE-5	7.1	112/560	60(3)
43	ICTE-15	20.1	116/580	60(3)
44	ICTE-8C	11.4	119/510	
45	LCE-6.5A	11.2	239/780	
46	LCE-15A	24.4	158/590	
47	LCE-51	91.1	188/770	
48	LCE-130A	209	270/830	209
49	PHP-120	319	-	-
50	GHV-12	8	155/590	80(3)
51	GSV-101	.85	115/500	60(3)
52	GSV-201	1.7	120/570	60(3)

AD-A164 430 ELECTROMAGNETIC PULSE/TRANSIENT THREAT TESTING OF 2/3
PROTECTION DEVICES FOR..(U) ELECTROSPACE SYSTEMS INC
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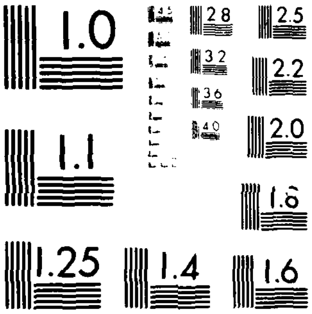
UNCLASSIFIED NCS-TIB-85-10-VOL-1 DCA100-85-C-0010 F/G 20/14 NL



MICROCOPY RESOLUTION TEST CHART

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Table 3-1
DEVICES HAVING ACCEPTABLE CLAMPING VOLTAGES LOW IMPEDANCE DRIVE TESTS (Cont'd)

MANUFACTURER	DEVICE	DESIGNED MAXIMUM CLAMPING VOLTAGE (MCV)	AVERAGE MEASURED PEAK VOLTAGE @ 600V/4500V (APV)	ACCEPTABLE CLAMPING VOLTAGE (APV ≦ 2 MCV)
ELECTRONIC PROTECTION DEVICES, INC.				
53	LEMON	300(1)	380	300
54	PEACH	300(1)	350	300
S.L. WABER				
55	LG-10	300(1)	550	300
ARCHER				
56	61-2785	300(1)	90	300

(1) ESTIMATED/CALCULATED
(2) DC BREAKDOWN VOLTAGE
(3) ACCEPTABLE ABOVE 2 MCV

Table 3-2
DEVICES HAVING ACCEPTABLE CLAMPING VOLTAGES
HIGH IMPEDANCE DRIVE TEST

MANUFACTURER	DEVICE	DESIGNED MAXIMUM CLAMPING VOLTAGE (MCV)	AVERAGE MEASURED PEAK VOLTAGE @ 4500V 50 OHMS (APV)	ACCEPTABLE CLAMPING VOLTAGE (APV ≦ 2 MCV)
FISCHER				
1	FCC-120F-P	300(1)	420	300
2	FCC-250-300-UHF	300	393	300
3	FCC-250-350-UHF	350	260	350
4	FCC-450B-75-BNC	75	210	
5	FCC-250-150-UHF	150	220	150
6	FCC-250-120-UHF	120	240	120
7	FCC-450-120-UHF	120	120	120
JOSLYN				
8	2027-23-B	230	310	230
9	2027-35-B	350	366	350
10	1270-02	190	600	500(3)
11	1250-32	350	940	
12	1663-09	66	90	66
13	2027-09-B	90	378	
14	2027-15-B	150	242	150
15	2022-44	250	294	250
16	2031-23 B	230	336	230
17	2031-35-B	350	291	350
GENERAL ELECTRIC				
18	V39ZA6	76	254	150(3)
19	V82ZA12	147	254	147
20	V180ZA10	300	388	300
21	V8ZA2	20	174	
22	V36ZA80	63	170	100(3)
POLYPHASER CORPORATION				
23	IS-NEMP	200(2)	140	200
24	IS-NEMP-1	200(2)	150	200
25	IS-NEMP-2	200(2)	160	200

Table 3-2
DEVICES HAVING ACCEPTABLE CLAMPING VOLTAGES HIGH IMPEDANCE DRIVE TEST (Cont'd)

MANUFACTURER	DEVICE	DESIGNED MAXIMUM CLAMPING VOLTAGE (MCV)	AVERAGE MEASURED PEAK VOLTAGE @ 4500V 50 OHMS (APV)	ACCEPTABLE CLAMPING VOLTAGE (APV ≦ 2 MCV)
TII				
26	MODEL 428	280	410	280
SIEMENS				
27	S10K11	40	186	100(3)
28	S20K25	80	190	150(3)
29	S14K50	125	234	125
30	S10K60	160	232	160
31	S14K130	340	436	340
32	B1-C75	75(2)	220	
33	B1-C90/20	90(2)	210	
34	B1-C145	145(2)	200	145
35	B1-A230	230(2)	218	230
36	B1-A350	350(2)	230	350
37	S8-C150	150(2)		
38	T61-C350	300(2)	250	300
ALPHA DELTA COMMUNICATIONS, INC.				
39	LT	635(1)	700	635
40	RT	635(1)	720	635
GENERAL SEMICONDUCTOR				
41	587B051	650	600	650
42	ICTE-5	7.1	134	
43	ICTE-15	20.1	146	
44	ICTE-8C	11.4	124	
45	LCE-6.5A	11.2	250	
46	LCE-15A	24.4	200	
47	LCE-51	91.1	220	
48	LCE-130A	209	210	209
49	PHP-120	319	400	319
50	GHV-12	8	218	
51	GSV-101	.85	168	
52	GSV-201	1.7	174	

Table 3-2
DEVICES HAVING ACCEPTABLE CLAMPING VOLTAGES HIGH IMPEDANCE DRIVE TEST (Cont'd)

MANUFACTURER	DEVICE	DESIGNED MAXIMUM CLAMPING VOLTAGE (MCV)	AVERAGE MEASURED PEAK VOLTAGE @ 4500V 50 OHMS (APV)	ACCEPTABLE CLAMPING VOLTAGE (APV ≦ 2 MCV)
ELECTRONIC PROTECTION DEVICES, INC.				
53	LEMON	300(1)	580	300
54	PEACH	300(1)	1000	750(3)
S.L. WABER				
55	LG-10	300(1)	600	300
ARCHER				
56	61-2785	300(1)	300	300

(1) ESTIMATED/CALCULATED
(2) DC BREAKDOWN VOLTAGE
(3) ACCEPTABLE ABOVE 2 MCV

Table 3-3

DEVICE TEST RESULTS LISTING ALL DATA POINTS TAKEN

LEGEND

COLUMN	DESCRIPTION
1	Test point number
2	Device part number
3-5	Low impedance test data
3	Voltage spike (volts)
4	Rejection ratio (dB)
5	Response time for spike to fall to a constant level (nanoseconds)
6-8	High impedance test data
6	Voltage spike (volts)
7	Rejection ratio (dB)
8	Response time for spike to fall to a constant level (nanoseconds)
9-10	Destructive test data
9	Voltage spike (volts)
10	Rejection ratio (dB)
11	Test notes

Table 3-3. Test Data

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
1 AL-N-0	FCC-120F-P	200	9.54	0	420	20.60	0	1100	27.13	HI Z AT C LEVEL
2 CX-N-0	FCC-250-300 UHF	200	27.04	90	400	21.02	90	0	0.00	
3 BX-N-0	FCC-250-350-UHF	600	0.00	70	300	23.52	80	0	0.00	HI Z AT C LEVEL
4 CX-N-A	FCC-250-300-UHF	2000	7.04	90	400	21.02	100	0	0.00	
4 CX-N-B	FCC-250-300-UHF	1800	7.96	70	380	21.47	90	0	0.00	
5 CX-N-A	FCC-250-350-UHF	2500	5.11	80	260	24.76	70	0	0.00	
5 CX-N-B	FCC-250-350-UHF	1800	7.96	70	220	26.21	80	0	0.00	
6 CX-N-0	FCC-450B-75-BNC	670	16.53	150	210	26.62	80	0	0.00	
7 CX-N-0	FCC-250-150-UHF	1700	8.43	50	220	26.21	90	0	0.00	
8 CX-N-0	FCC-250-120-UHF	1700	8.43	50	240	25.46	90	0	0.00	
9 CX-N-0	FCC-450-120-UHF	800	14.99	60	120	31.48	100	0	0.00	
10 BX-N-A	2027-23-B	600	0.00	360	280	24.12	100	1400	25.00	HI Z AT C LEVEL
10 BX-N-B	2027-23-B	600	0.00	350	450	20.00	100	1400	25.04	HI Z AT C LEVEL
10 BX-N-C	2027-23-B	600	0.00	380	290	23.81	90	2400	20.35	HI Z AT C LEVEL
10 BX-N-D	2027-23-B	600	0.00	340	240	25.46	100	2400	20.35	HI Z AT C LEVEL
10 BX-N-E	2027-23-B	600	0.00	380	290	23.81	80	1900	22.38	HI Z AT C LEVEL
10 BX-N-F	2027-23-B	600	0.00	330	0	0.00	0	0	0.00	
10 BX-N-G	2027-23-B	600	0.00	380	0	0.00	0	0	0.00	
10 BX-N-H	2027-23-B	600	0.00	340	0	0.00	0	0	0.00	
10 BX-N-I	2027-23-B	600	0.00	450	0	0.00	0	0	0.00	ERRATIC DELAY
10 BX-N-J	2027-23-B	600	0.00	500	0	0.00	0	0	0.00	
11 CX-N-A	2027-35-B	1800	7.96	100	360	21.94	90	0	0.00	
11 CX-N-B	2027-35-B	1900	7.46	110	340	22.43	140	0	0.00	
11 CX-N-C	2027-35-B	2100	6.61	120	350	22.18	140	0	0.00	
11 CX-N-D	2027-35-B	2000	7.04	120	400	21.02	140	0	0.00	
11 CX-N-E	2027-35-B	1900	7.46	110	380	21.47	100	0	0.00	
11 CX-N-F	2027-35-B	0	0.00	0	0	0.00	0	2400	20.35	
11 CX-N-G	2027-35-B	0	0.00	0	0	0.00	0	2400	20.35	
11 CX-N-H	2027-35-B	0	0.00	0	0	0.00	0	2900	18.71	

Table 3-3. Test Data (Continued)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
11 CX-N-I	2027-35-B	0	0.00	0	0	0.00	0	2400	20.35	
11 CX-N-J	2027-35-B	0	0.00	0	0	0.00	0	2400	20.35	
12 AX-N-O	1270-02	400	3.52	160	600	17.50	0	1800	22.85	HI Z AT C LEVEL
13 CL-N-O	1250-32	2300	5.80	150	940	13.59	130	0	0.00	
14 CX-N-O	1663-08	0	0.00	0	90	33.98	0	900	28.87	
15 CX-N-A	2027-09-B	1900	7.46	100	380	21.47	90	0	0.00	
15 CX-N-B	2027-09-B	1800	7.96	110	450	20.00	90	0	0.00	
15 CX-N-C	2027-09-B	1800	7.96	90	250	25.11	90	0	0.00	
15 CX-N-D	2027-09-B	1900	7.46	90	600	17.50	110	0	0.00	
15 CX-N-E	2027-09-B	1700	8.43	90	210	26.62	70	0	0.00	
16 T25-N-A	2027-09-B	0	0.00	0	0	0.00	0	2400	20.35	
16 T25-N-B	2027-09-B	0	0.00	0	0	0.00	0	2400	20.35	
16 T25-N-C	2027-09-B	0	0.00	0	0	0.00	0	2400	20.35	
16 T25-N-D	2027-09-B	0	0.00	0	0	0.00	0	2400	20.35	
16 T25-N-E	2027-09-B	0	0.00	0	0	0.00	0	2400	20.35	
17 CX-N-A	2027-15-B	1900	7.46	90	240	25.46	110	0	0.00	
17 CX-N-B	2027-15-B	2000	7.04	100	240	25.46	90	0	0.00	
17 CX-N-C	2027-15-B	1000	13.06	90	240	25.46	100	0	0.00	
17 CX-N-D	2027-15-B	1600	8.97	90	250	25.46	90	0	0.00	
17 CX-N-E	2027-15-B	1600	8.97	90	240	25.46	110	0	0.00	
18 T25-N-A	2027-15-B	0	0.00	0	0	0.00	0	2400	20.35	
18 T25-N-B	2027-15-B	0	0.00	0	0	0.00	0	2400	20.35	
18 T25-N-C	2027-15-B	0	0.00	0	0	0.00	0	2400	20.35	
18 T25-N-D	2027-15-B	0	0.00	0	0	0.00	0	2400	20.35	
18 T25-N-E	2027-15-B	0	0.00	0	0	0.00	0	2400	20.35	
19 CX-N-A	2022-44	1600	8.97	80	230	25.83	100	0	0.00	
19 CX-N-B	2022-44	1500	9.54	90	470	19.62	110	0	0.00	
19 CX-N-C	2022-44	1200	11.48	90	300	23.52	90	0	0.00	
19 CX-N-D	2022-44	1500	9.54	100	230	25.83	80	0	0.00	

Table 3-3. Test Data (Continued)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
19 CX-N-E	2022-44	1500	9.54	90	240	25.46	80	0	0.00	
20 T25-N-A	2022-44	0	0.00	0	0	0.00	0	2400	20.35	
20 T25-N-B	2022-44	0	0.00	0	0	0.00	0	2400	20.35	
20 T25-N-C	2022-44	0	0.00	0	0	0.00	0	2400	20.35	
20 T25-N-D	2022-44	0	0.00	0	0	0.00	0	2400	20.35	
20 T25-N-E	2022-44	0	0.00	0	0	0.00	0	2400	20.35	
21 CX-N-A	2031-23B	2000	7.04	90	270	24.43	80	0	0.00	
21 CX-N-B	2031-23B	1400	10.13	60	280	24.12	80	0	0.00	
21 CX-N-C	2031-23B	1400	10.13	60	310	23.23	90	0	0.00	
21 CX-N-D	2031-23B	1500	9.54	80	270	24.43	80	0	0.00	
21 CX-N-E	2031-23B	1500	9.54	50	310	23.23	90	0	0.00	
22 CX-N-A	2031-23B	0	0.00	0	280	24.12	90	0	0.00	
22 CX-N-B	2031-23B	0	0.00	0	450	20.00	250	0	0.00	
22 CX-N-C	2031-23B	0	0.00	0	600	17.50	110	0	0.00	
22 CX-N-D	2031-23B	0	0.00	0	290	23.81	90	0	0.00	
22 CX-N-E	2031-23B	0	0.00	0	300	23.52	70	0	0.00	
23 CX-N-A	2031-35B	1200	11.48	60	300	23.52	90	0	0.00	
23 CX-N-B	2031-35B	1500	9.54	70	290	23.81	70	0	0.00	
23 CX-N-C	2031-35B	1500	9.54	80	290	23.81	60	0	0.00	
23 CX-N-D	2031-35B	1200	11.48	90	280	24.12	60	0	0.00	
23 CX-N-E	2031-35B	1400	10.13	50	290	23.81	70	0	0.00	
24 T25-N-A	2031-35B	0	0.00	0	0	0.00	0	2400	20.35	
24 T25-N-B	2031-35B	0	0.00	0	0	0.00	0	2400	20.35	
24 T25-N-C	2031-35B	0	0.00	0	0	0.00	0	2400	20.35	
24 T25-N-D	2031-35B	0	0.00	0	0	0.00	0	2400	20.35	
24 T25-N-E	2031-35B	0	0.00	0	0	0.00	0	2400	20.35	
25 BX-N-A	V39ZA6	134	13.01	0	200	27.04	0	0	0.00	HI Z AT C LEVEL
25 BX-N-B	V39ZA6	124	13.68	0	300	23.52	0	0	0.00	HI Z AT C LEVEL
25 BX-N-C	V39ZA6	130	13.27	0	300	23.52	0	0	0.00	HI Z AT C LEVEL

Table 3-3. Test Data (Continued)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
25 BX-N-D	V39ZA6	140	12.63	0	300	23.52	0	900	28.87	HI Z AT C LEVEL
26 CX-N-A	V39ZA6	0	0.00	0	170	28.46	0	2400	20.35	
26 T25-N-B	V39ZA6	0	0.00	0	0	0.00	0	1100	27.13	
26 T25-N-C	V39ZA6	0	0.00	0	0	0.00	0	1600	23.88	
26 T25-N-D	V39ZA6	0	0.00	0	0	0.00	0	2400	20.35	
27 BX-N-A	V82ZA12	220	8.69	0	260	24.76	0	0	0.00	HI Z AT C LEVEL
27 BX-N-B	V82ZA12	235	8.13	0	250	25.11	0	0	0.00	HI Z AT C LEVEL
27 BX-N-C	V82ZA12	235	8.13	0	250	25.11	0	0	0.00	HI Z AT C LEVEL
27 BX-N-D	V82ZA12	230	8.30	0	240	25.46	0	1400	25.04	HI Z AT C LEVEL
28 CX-N-A	V82ZA12	0	0.00	0	270	24.43	0	1400	25.04	
28 T25-N-B	V82ZA12	0	0.00	0	0	0.00	0	1900	22.38	
28 T25-N-C	V82ZA12	0	0.00	0	0	0.00	0	1900	22.38	
28 T25-N-D	V82ZA12	0	0.00	0	0	0.00	0	1900	22.38	
29 BX-N-A	V180ZA10	420	3.05	0	370	21.70	0	0	0.00	HI Z AT C LEVEL
29 BX-N-B	V180ZA10	420	3.05	0	380	21.47	0	0	0.00	HI Z AT C LEVEL
29 BX-N-C	V180ZA10	420	3.05	0	380	21.46	0	0	0.00	HI Z AT C LEVEL
29 BX-N-D	V180ZA10	450	2.48	0	410	20.80	0	1900	22.38	HI Z AT C LEVEL
30 CX-N-A	V180ZA10	0	0.00	0	400	21.02	0	2400	20.35	
30 T25-N-B	V180ZA10	0	0.00	0	0	0.00	0	2400	20.35	
30 T25-N-C	V180ZA10	0	0.00	0	0	0.00	0	2400	20.35	
30 T25-N-D	V180ZA10	0	0.00	0	0	0.00	0	2400	20.35	
31 BX-N-A	V8ZA2	120	13.98	0	0	0.00	0	0	0.00	
31 BX-N-B	V8ZA2	120	13.98	0	0	0.00	0	0	0.00	
31 BX-N-C	V8ZA2	120	13.98	0	0	0.00	0	0	0.00	
31 BX-N-D	V8ZA2	120	13.98	0	0	0.00	0	0	0.00	
31 BX-N-E	V8ZA2	120	13.98	0	0	0.00	0	0	0.00	
32 CX-N-A	V8ZA2	600	17.50	40	160	28.98	50	0	0.00	
32 CX-N-B	V8ZA2	700	16.15	50	160	28.98	70	0	0.00	
32 CX-N-C	V8ZA2	1000	13.06	50	150	29.54	60	0	0.00	

Table 3-3. Test Data (Continued)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
32 CX-N-D	V8ZA2	400	21.02	100	200	27.04	60	0	0.00	
32 CX-N-E	V8ZA2	750	15.56	150	200	27.04	60	0	0.00	
34 BX-N-A	V36ZA80	120	13.98	0	180	27.96	0	0	0.00	HI Z AT C LEVEL
34 BX-N-B	V36ZA80	120	13.98	0	180	27.96	0	2400	20.35	HI Z AT C LEVEL
34 BX-N-C	V36ZA80	120	13.98	0	160	28.98	0	1900	22.38	HI Z AT C LEVEL
35 CX-N-A	V36ZA80	0	0.00	0	160	28.98	0	2400	20.35	
35 CX-N-B	V36ZA80	0	0.00	0	170	28.46	0	1900	22.38	
35 T25-N-C	V36ZA80	0	0.00	0	0	0.00	0	1600	23.88	
36 CX-N-O	IS-NEMP	380	21.47	80	140	30.14	70	0	0.00	
37 CX-N-O	IS-NEMP-1	380	21.47	80	150	29.54	100	0	0.00	
38 CX-N-O	IS-NEMP-2	600	17.50	100	160	28.98	100	0	0.00	
39 AX-N-O	PWRLINE PROT MOD 428	350	4.66	0	410	20.80	0	1800	22.85	
40 BX-N-A	S10K11	120	13.98	0	0	0.00	0	0	0.00	
40 BX-N-B	S10K11	120	13.98	0	0	0.00	0	0	0.00	
40 BX-N-C	S10K11	120	13.98	0	0	0.00	0	0	0.00	
40 BX-N-D	S10K11	120	13.98	0	0	0.00	0	0	0.00	
40 BX-N-E	S10K11	120	13.98	0	0	0.00	0	0	0.00	
40 BX-N-F	S10K11	120	13.98	0	0	0.00	0	0	0.00	
40 BX-N-G	S10K11	120	13.98	0	0	0.00	0	0	0.00	
40 BX-N-H	S10K11	120	13.98	0	0	0.00	0	0	0.00	
40 BX-N-I	S10K11	120	13.98	0	0	0.00	0	0	0.00	
40 BX-N-J	S10K11	120	13.98	0	0	0.00	0	0	0.00	
40 BX-N-K	S10K11	120	13.98	0	0	0.00	0	0	0.00	
40 BX-N-L	S10K11	120	13.98	0	0	0.00	0	0	0.00	
40 BX-N-M	S10K11	120	13.98	0	0	0.00	0	0	0.00	
40 BX-N-N	S10K11	120	13.98	0	0	0.00	0	0	0.00	
40 BX-N-O	S10K11	120	13.98	0	0	0.00	0	0	0.00	
41 CX-N-A	S10K11	700	16.15	130	150	29.54	0	0	0.00	
41 CX-N-B	S10K11	500	19.08	100	220	26.21	0	0	0.00	

Table 3-3. Test Data (Continued)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
41 CX-N-C	S10K11	700	16.15	120	220	26.21	0	0	0.00	
41 CX-N-D	S10K11	800	14.99	140	170	28.46	0	0	0.00	
41 CX-N-E	S10K11	750	15.56	110	170	28.46	0	0	0.00	
42 T25-N-A	S10K11	0	0.00	0	0	0.00	0	2400	20.35	
42 T25-N-B	S10K11	0	0.00	0	0	0.00	0	2400	20.35	
42 T25-N-C	S10K11	0	0.00	0	0	0.00	0	2400	20.35	
42 T25-N-D	S10K11	0	0.00	0	0	0.00	0	2400	20.35	
42 T25-N-E	S10K11	0	0.00	0	0	0.00	0	2400	20.35	
43 BX-N-A	S20K25	140	12.63	0	0	0.00	0	0	0.00	
43 BX-N-B	S20K25	125	13.62	0	0	0.00	0	0	0.00	
43 BX-N-C	S20K25	130	13.27	0	0	0.00	0	0	0.00	
43 BX-N-D	S20K25	135	12.95	0	0	0.00	0	0	0.00	
43 BX-N-E	S20K25	125	13.62	0	0	0.00	0	0	0.00	
44 CX-N-A	S20K25	800	14.99	130	210	26.62	0	0	0.00	
44 CX-N-B	S20K25	700	16.15	140	200	27.04	0	0	0.00	
44 CX-N-C	S20K25	800	14.99	120	170	28.46	0	0	0.00	
44 CX-N-D	S20K25	700	16.15	130	180	26.96	0	0	0.00	
44 CX-N-E	S20K25	600	17.50	120	190	27.49	0	0	0.00	
45 T25-N-A	S20K25	0	0.00	0	0	0.00	0	2400	20.35	
45 T25-N-B	S20K25	0	0.00	0	0	0.00	0	2400	20.35	
45 T25-N-C	S20K25	0	0.00	0	0	0.00	0	2400	20.35	
45 T25-N-D	S20K25	0	0.00	0	0	0.00	0	2400	20.35	
45 T25-N-E	S20K25	0	0.00	0	0	0.00	0	2400	20.35	
45 BX-N-A	S14K50	220	8.69	0	0	0.00	0	0	0.00	
46 BX-N-B	S14K50	230	8.30	0	0	0.00	0	0	0.00	
46 BX-N-C	S14K50	220	8.69	0	0	0.00	0	0	0.00	
46 BX-N-D	S14K50	200	8.69	0	0	0.00	0	0	0.00	
46 BX-N-E	S14K50	210	9.10	0	0	0.00	0	0	0.00	
47 CX-N-A	S14K50	600	17.50	100	250	25.11	0	0	0.00	

Table 3-3. Test Data (Continued)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
47 CX-N-B	S14K50	600	17.50	100	250	25.11	0	0	0.00	
47 CX-N-C	S14K50	800	14.99	130	260	24.76	0	0	0.00	
47 CX-N-D	S14K50	600	17.50	140	200	27.04	0	0	0.00	
47 CX-N-E	S14K50	500	19.08	100	210	26.62	0	0	0.00	
48 T25-N-A	S14K50	0	0.00	0	0	0.00	0	2400	20.35	
48 T25-N-B	S14K50	0	0.00	0	0	0.00	0	2400	20.35	
48 T25-N-C	S14K50	0	0.00	0	0	0.00	0	2400	20.35	
48 T25-N-D	S14K50	0	0.00	0	0	0.00	0	2400	20.35	
48 T25-N-E	S14K50	0	0.00	0	0	0.00	0	2400	20.35	
49 BX-N-A	S10K60	260	7.23	0	0	0.00	0	0	0.00	
49 BX-N-B	S10K60	280	6.61	0	0	0.00	0	0	0.00	
49 BX-N-C	S10K60	270	6.93	0	0	0.00	0	0	0.00	
49 BX-N-D	S10K60	260	7.23	0	0	0.00	0	0	0.00	
49 BX-N-E	S10K60	280	6.61	0	0	0.00	0	0	0.00	
49 BX-N-F	S10K60	280	6.61	0	0	0.00	0	0	0.00	
49 BX-N-G	S10K60	280	6.61	0	0	0.00	0	0	0.00	
49 BX-N-H	S10K60	260	7.23	0	0	0.00	0	0	0.00	
49 BX-N-I	S10K60	270	6.93	0	0	0.00	0	0	0.00	
49 BX-N-J	S10K60	260	7.23	0	0	0.00	0	0	0.00	
49 BX-N-K	S10K60	255	7.42	0	0	0.00	0	0	0.00	
49 BX-N-L	S10K60	270	6.93	0	0	0.00	0	0	0.00	
49 BX-N-M	S10K60	270	6.93	0	0	0.00	0	0	0.00	
49 BX-N-N	S10K60	270	6.93	0	0	0.00	0	0	0.00	SPIKE 100 W/L COIL
49 BX-N-O	S10K60	270	6.93	0	0	0.00	0	0	0.00	SPIKE 220 W/3 BEADS
49 BX-N-P	S10K60	200	9.54	0	0	0.00	0	0	0.00	W/3 BEADS IRT
50 CX-N-A	S10K60	900	13.98	150	250	25.11	0	0	0.00	
50 CX-N-B	S10K60	800	14.99	100	230	25.83	0	0	0.00	
50 CX-N-C	S10K60	600	17.50	100	220	26.21	0	0	0.00	

Table 3-3. Test Data (Continued)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
50 CX-N-D	S10K60	600	17.50	100	230	25.83	0	0	0.00	
50 CX-N-E	S10K60	650	16.80	100	230	25.83	0	0	0.00	
51 T25-N-A	S10K60	0	0.00	0	0	0.00	0	2400	20.35	
51 T25-N-B	S10K60	0	0.00	0	0	0.00	0	2400	20.35	
51 T25-N-C	S10K60	0	0.00	0	0	0.00	0	2400	20.35	
51 T25-N-D	S10K60	0	0.00	0	0	0.00	0	2400	20.35	
51 T25-N-E	S10K60	0	0.00	0	0	0.00	0	2400	20.35	
52 BX-N-A	S14K130	460	2.28	0	0	0.00	0	0	0.00	
52 BX-N-B	S14K130	460	2.28	0	0	0.00	0	0	0.00	
52 BX-N-C	S14K130	460	2.28	0	0	0.00	0	0	0.00	
52 BX-N-D	S14K130	470	2.08	0	0	0.00	0	0	0.00	
52 BX-N-E	S14K130	470	2.08	0	0	0.00	0	0	0.00	
53 CX-N-A	S14K130	1000	13.06	90	430	20.39	0	0	0.00	
53 CX-N-B	S14K130	1200	11.48	140	440	20.19	0	0	0.00	
53 CX-N-C	S14K130	1000	13.06	110	440	20.19	0	0	0.00	
53 CX-N-D	S14K130	1000	13.06	120	430	20.39	0	0	0.00	
53 CX-N-E	S14K130	1050	12.63	110	440	20.19	0	0	0.00	
54 T25-N-A	S14K130	0	0.00	0	0	0.00	0	2400	20.35	
54 T25-N-B	S14K130	0	0.00	0	0	0.00	0	2400	20.35	
54 T25-N-C	S14K130	0	0.00	0	0	0.00	0	2400	20.35	
54 T25-N-D	S14K130	0	0.00	0	0	0.00	0	2400	20.35	
54 T25-N-E	S14K130	0	0.00	0	0	0.00	0	2400	20.35	
55 BX-N-A	B1-C75	600	0.00	380	0	0.00	0	0	0.00	
55 BX-N-B	B1-C75	600	0.00	700	0	0.00	0	0	0.00	ERRATIC
55 BX-N-C	B1-C75	600	0.00	370	0	0.00	0	0	0.00	SPIKE 70 WITH L COIL
55 BX-N-D	B1-C75	600	0.00	325	0	0.00	0	0	0.00	
55 BX-N-E	B1-C75	600	0.00	220	0	0.00	0	0	0.00	
56 CX-N-A	B1-C75	850	14.46	110	200	27.04	100	0	0.00	
56 CX-N-B	B1-C75	900	13.98	110	220	26.21	80	0	0.00	

Table 3-3. Test Data (Continued)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
56 CX-N-C	B1-C75	1000	13.06	140	220	26.21	90	0	0.00	
56 CX-N-D	B1-C75	750	15.56	160	210	26.62	80	0	0.00	
56 CX-N-E	B1-C75	1050	12.63	110	250	25.11	80	0	0.00	
57 T25-N-A	B1-C75	0	0.00	0	0	0.00	0	1900	22.38	
57 T25-N-B	B1-C75	0	0.00	0	0	0.00	0	1900	22.38	
57 T25-N-C	B1-C75	0	0.00	0	0	0.00	0	2400	22.35	
57 T25-N-D	B1-C75	0	0.00	0	0	0.00	0	1900	22.38	
57 T25-N-E	B1-C75	0	0.00	0	0	0.00	0	1900	22.38	
58 BX-N-A	B1-C90/20	600	0.00	250	0	0.00	0	0	0.00	
58 BX-N-B	B1-C90/20	600	0.00	270	0	0.00	0	0	0.00	
58 BX-N-C	B1-C90/20	600	0.00	320	0	0.00	0	0	0.00	
58 BX-N-D	B1-C90/20	600	0.00	250	0	0.00	0	0	0.00	
58 BX-N-E	B1-C90/20	600	0.00	350	0	0.00	0	0	0.00	
59 CX-N-A	B1-C90/20	900	13.98	120	200	27.04	70	0	0.00	
59 CX-N-B	B1-C90/20	850	14.46	110	220	26.21	80	0	0.00	
59 CX-N-C	B1-C90/20	1000	13.06	100	210	26.62	70	0	0.00	
59 CX-N-D	B1-C90/20	1000	13.06	110	220	26.21	80	0	0.00	
59 CX-N-E	B1-C90/20	900	13.98	120	200	27.04	80	0	0.00	
60 T25-N-A	B1-C90/20	0	0.00	0	0	0.00	0	1900	22.38	
60 T25-N-B	B1-C90/20	0	0.00	0	0	0.00	0	1900	22.38	
60 T25-N-C	B1-C90/20	0	0.00	0	0	0.00	0	1900	22.38	
60 T25-N-D	B1-C90/20	0	0.00	0	0	0.00	0	1900	22.38	
60 T25-N-E	B1-C90/20	0	0.00	0	0	0.00	0	1900	22.38	
61 BX-N-A	B1-C145	600	0.00	90	0	0.00	0	0	0.00	
61 BX-N-B	B1-C145	600	0.00	45	0	0.00	0	0	0.00	
61 BX-N-C	B1-C145	600	0.00	45	0	0.00	0	0	0.00	
61 BX-N-D	B1-C145	600	0.00	40	0	0.00	0	0	0.00	
61 BX-N-E	B1-C145	600	0.00	45	0	0.00	0	0	0.00	50-100 PULSE TRACE
62 CX-N-A	B1-C145	900	13.98	100	200	27.04	70	0	0.00	

Table 3-3. Test Data (Continued)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
62 CX-N-B	B1-C145	900	13.98	130	200	27.04	60	0	0.00	
62 CX-N-C	B1-C145	900	13.98	140	200	27.04	80	0	0.00	
62 CX-N-D	B1-C145	850	14.46	130	200	27.04	80	0	0.00	
62 CX-N-E	B1-C145	850	14.46	110	200	27.04	70	0	0.00	
63 T25-N-A	B1-C145	0	0.00	0	0	0.00	0	1900	22.38	
63 T25-N-B	B1-C145	0	0.00	0	0	0.00	0	1900	22.38	
63 T25-N-C	B1-C145	0	0.00	0	0	0.00	0	1900	22.38	
63 T25-N-D	B1-C145	0	0.00	0	0	0.00	0	1900	22.38	
63 T25-N-E	B1-C145	0	0.00	0	0	0.00	0	1900	22.38	
64 BX-N-A	B1-A230	600	0.00	1000	0	0.00	0	0	0.00	
64 BX-N-B	B1-A230	600	0.00	750	0	0.00	0	0	0.00	
64 BX-N-C	B1-A230	600	0.00	1500	0	0.00	0	0	0.00	
64 BX-N-D	B1-A230	600	0.00	4000	0	0.00	0	0	0.00	ERRATIC DELAY
64 BX-N-E	B1-A230	600	0.00	450	0	0.00	0	0	0.00	
65 CX-N-A	B1-A230	950	13.50	130	230	25.83	90	0	0.00	
65 CX-N-B	B1-A230	950	13.50	110	220	26.21	90	0	0.00	
65 CX-N-C	B1-A230	1000	13.06	140	210	26.62	80	0	0.00	
65 CX-N-D	B1-A230	1000	13.06	110	210	26.62	80	0	0.00	
65 CX-N-E	B1-A230	1000	13.06	140	220	26.21	80	0	0.00	
66 T25-N-A	B1-A230	0	0.00	0	0	0.00	0	1900	22.38	
66 T25-N-B	B1-A230	0	0.00	0	0	0.00	0	1900	22.38	
66 T25-N-C	B1-A230	0	0.00	0	0	0.00	0	1900	22.38	
66 T25-N-D	B1-A230	0	0.00	0	0	0.00	0	1900	22.38	
66 T25-N-E	B1-A230	0	0.00	0	0	0.00	0	1900	22.38	
67 CX-N-A	B1-A350	1000	13.06	100	210	26.62	80	0	0.00	
67 CX-N-B	B1-A350	1000	13.06	110	250	25.11	80	0	0.00	
67 CX-N-C	B1-A350	1000	13.06	120	240	25.46	80	0	0.00	
67 CX-N-D	B1-A350	1000	13.06	110	220	26.21	80	0	0.00	
67 CX-N-E	B1-A350	1100	12.23	120	230	25.83	80	0	0.00	

Table 3-3. Test Data (Continued)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
68 CX-N-A	B1-A350	650	16.80	100	0	0.00	0	0	0.00	2 BEADS ON INPUT
68 CX-N-B	B1-A350	800	14.99	110	0	0.00	0	0	0.00	2 BEADS ON INPUT
68 CX-N-C	B1-A350	460	19.81	140	0	0.00	0	0	0.00	2 BEADS ON INPUT
68 CX-N-D	B1-A350	400	21.02	160	0	0.00	0	0	0.00	2 BEADS ON INPUT
68 CX-N-E	B1-A350	850	14.46	110	0	0.00	0	0	0.00	2 BEADS ON INPUT
69 T25-N-A	B1-A350	0	0.00	0	0	0.00	0	1900	22.38	
69 T25-N-B	B1-A350	0	0.00	0	0	0.00	0	1900	22.38	
69 T25-N-C	B1-A350	0	0.00	0	0	0.00	0	1900	22.38	
69 T25-N-D	B1-A350	0	0.00	0	0	0.00	0	1900	22.38	
69 T25-N-E	B1-A350	0	0.00	0	0	0.00	0	1900	22.38	
70 BX-N-A	S8-C150	600	0.00	150	0	0.00	0	900	28.87	
70 BX-N-B	S8-C150	600	0.00	150	0	0.00	0	900	28.87	
70 BX-N-C	S8-C150	600	0.00	160	0	0.00	0	400	35.92	
70 BX-N-D	S8-C150	600	0.00	150	0	0.00	0	1900	22.38	
70 BX-N-E	S8-C150	600	0.00	200	0	0.00	0	1900	22.38	
70 BX-N-F	S8-C150	600	0.00	150	0	0.00	0	0	0.00	
70 BX-N-G	S8-C150	600	0.00	80	0	0.00	0	0	0.00	
70 BX-N-H	S8-C150	600	0.00	500	0	0.00	0	0	0.00	
70 BX-N-I	S8-C150	600	0.00	200	0	0.00	0	0	0.00	
70 BX-N-J	S8-C150	600	0.00	350	0	0.00	0	0	0.00	
70 BX-N-K	S8-C150	4500	0.00	100	0	0.00	0	0	0.00	TEST AT C LEVEL
70 BX-N-L	S8-C150	4500	0.00	100	0	0.00	0	0	0.00	TEST AT C LEVEL
70 BX-N-M	S8-C150	4500	0.00	100	0	0.00	0	0	0.00	TEST AT C LEVEL
70 BX-N-N	S8-C150	4500	0.00	100	0	0.00	0	0	0.00	C LEVEL W/SM BEAD
70 BX-N-O	S8-C150	4500	0.00	100	0	0.00	0	0	0.00	C LEVEL TEST
71 CX-N-A	T61-C350	1100	12.23	120	280	24.12	90	0	0.00	
71 CX-N-B	T61-C350	900	13.98	130	270	24.43	90	0	0.00	
71 CX-N-C	T61-C350	1000	13.06	140	230	25.83	90	0	0.00	
71 CX-N-D	T61-C350	950	13.50	120	220	26.21	80	0	0.00	

Table 3.3. Test Data (Continued)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
71 CX-N-E	T61-C350	1000	13.06	120	250	25.11	90	0	0.00	
72 CX-N-A	T61-C350	800	14.99	130	0	0.00	0	0	0.00	RISE TIME OBSCURED
72 CX-N-B	T61-C350	380	21.47	0	0	0.00	0	0	0.00	
72 CX-N-C	T61-C350	400	21.02	0	0	0.00	0	0	0.00	
72 CX-N-D	T61-C350	400	21.02	0	0	0.00	0	0	0.00	
72 CX-N-E	T61-C350	390	21.24	0	0	0.00	0	0	0.00	
73 T25-N-A	T61-C350	0	0.00	0	0	0.00	0	1400	25.04	
73 T25-N-B	T61-C350	0	0.00	0	0	0.00	0	1400	25.04	
73 T25-N-C	T61-C350	0	0.00	0	0	0.00	0	1400	25.04	
73 T25-N-D	T61-C350	0	0.00	0	0	0.00	0	1900	22.38	
73 T25-N-E	T61-C350	0	0.00	0	0	0.00	0	1900	25.04	
74 CX-N-O	TRANSI TRAP LT	4500	0.00	80	700	16.15	140	0	0.00	SIM FOR 600 VOLTS
75 CX-N-O	TRANSI TRAP R-T	400	21.02	80	720	15.92	130	200	41.94	NEARLY ZERO SPKE TTF
76 AX-N-O	587B051	180	10.45	0	0	0.00	0	0	0.00	
76 CX-N-O	587B051	400	21.02	100	600	17.50	0	200	41.94	ALMOST ZERO AT TTFL
77 BX-N-A	ICTE-5 TRANSZORB	110	14.73	0	0	0.00	0	0	0.00	
77 BX-N-B	ICTE-5 TRANSZORB	110	14.73	0	0	0.00	0	0	0.00	
77 BX-N-C	ICTE-5 TRANSZORB	115	14.34	0	0	0.00	0	0	0.00	
77 BX-N-D	ICTE-5 TRANSZORB	115	14.34	0	0	0.00	0	0	0.00	
77 BX-N-E	ICTE-5 TRANSZORB	110	14.73	0	0	0.00	0	0	0.00	
78 CX-N-A	ICTE-5 TRANSZORB	550	18.26	140	120	31.48	50	0	0.00	
78 CX-N-B	ICTE-5 TRANSZORB	700	16.15	80	150	29.54	60	0	0.00	
78 CX-N-C	ICTE-5 TRANSZORB	550	18.26	90	140	30.14	60	0	0.00	
78 CX-N-D	ICTE-5 TRANSZORB	500	19.08	100	140	30.14	50	0	0.00	
78 CX-N-E	ICTE-5 TRANSZORB	500	19.08	110	120	31.48	60	0	0.00	
79 T25-N-A	ICTE-5 TRANSZORB	0	0.00	0	0	0.00	0	1900	22.38	
79 T25-N-B	ICTE-5 TRANSZORB	0	0.00	0	0	0.00	0	1900	22.38	
79 T25-N-C	ICTE-5 TRANSZORB	0	0.00	0	0	0.00	0	1900	22.38	
79 T25-N-D	ICTE-5 TRANSZORB	0	0.00	0	0	0.00	0	1200	26.38	

Table 3-3. Test Data (Continued)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
79 T25-N-E	ICTE-5 TRANSZORB	0	0.00	0	0	0.00	0	1200	26.38	
80 BX-N-A	ICTE-15 TRANSZORB	115	14.34	0	0	0.00	0	0	0.00	
80 BX-N-B	ICTE-15 TRANSZORB	115	14.34	0	0	0.00	0	0	0.00	
80 BX-N-C	ICTE-15 TRANSZORB	115	14.34	0	0	0.00	0	0	0.00	
80 BX-N-D	ICTE-15 TRANSZORB	115	14.34	0	0	0.00	0	0	0.00	
80 BX-N-E	ICTE-15 TRANSZORB	120	13.98	0	0	0.00	0	0	0.00	
81 CX-N-A	ICTE-15 TRANSZORB	900	13.98	100	1400	10.13	60	0	0.00	
81 CX-N-B	ICTE-15 TRANSZORB	500	19.08	130	1500	9.54	60	0	0.00	
81 CX-N-C	ICTE-15 TRANSZORB	500	19.08	100	1500	9.54	60	0	0.00	
81 CX-N-D	ICTE-15 TRANSZORB	500	19.08	110	1400	10.13	60	0	0.00	
81 CX-N-E	ICTE-15 TRANSZORB	500	19.08	120	1500	9.54	60	0	0.00	
82 T25-N-A	ICTE-15 TRANSZORB	0	0.00	0	0	0.00	0	1100	27.13	
82 T25-N-B	ICTE-15 TRANSZORB	0	0.00	0	0	0.00	0	900	28.87	
82 T25-N-C	ICTE-15 TRANSZORB	0	0.00	0	0	0.00	0	1200	26.38	
82 T25-N-D	ICTE-15 TRANSZORB	0	0.00	0	0	0.00	0	1200	26.38	
82 T25-N-E	ICTE-15 TRANSZORB	0	0.00	0	0	0.00	0	1200	26.38	
83 BX-N-A	ICTE-8C TRANSZORB	120	13.98	40	0	0.00	0	0	0.00	
83 BX-N-B	ICTE-8C TRANSZORB	115	14.34	40	0	0.00	0	0	0.00	
83 BX-N-C	ICTE-8C TRANSZORB	120	13.98	40	0	0.00	0	0	0.00	
83 BX-N-D	ICTE-8C TRANSZORB	120	13.98	40	0	0.00	0	0	0.00	
83 BX-N-E	ICTE-8C TRANSZORB	120	13.98	40	0	0.00	0	0	0.00	
84 CX-N-A	ICTE-8C TRANSZORB	500	19.08	100	100	32.23	60	0	0.00	
84 CX-N-B	ICTE-8C TRANSZORB	500	19.08	100	120	31.48	60	0	0.00	
84 CX-N-C	ICTE-8C TRANSZORB	500	19.08	100	120	31.48	60	0	0.00	
84 CX-N-D	ICTE-8C TRANSZORB	500	19.08	100	110	30.78	70	0	0.00	
84 CX-N-E	ICTE-8C TRANSZORB	550	18.26	120	140	30.14	70	0	0.00	
85 T25-N-A	ICTE-8C TRANSZORB	0	0.00	0	0	0.00	0	1200	26.38	
85 T25-N-B	ICTE-8C TRANSZORB	0	0.00	0	0	0.00	0	1200	26.38	
85 T25-N-C	ICTE-8C TRANSZORB	0	0.00	0	0	0.00	0	1200	26.38	

Table 3-3. Test Data (Continued)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
85 T25-N-D	ICTE-8C TRANSZORB	0	0.00	0	0	0.00	0	600	32.40	
85 T25-N-E	ICTE-8C TRANSZORB	0	0.00	0	0	0.00	0	400	35.92	
86 BX-N-A	LCE6.5A TRANSZORB	240	7.96	80	0	0.00	0	0	0.00	NO REVRSE FIRING
86 BX-N-B	LCE6.5A TRANSZORB	235	8.13	80	0	0.00	0	0	0.00	NO REVRSE FIRING
86 BX-N-C	LCE6.5A TRANSZORB	220	8.69	80	0	0.00	0	0	0.00	NO REVRSE FIRING
86 BX-N-D	LCE6.5A TRANSZORB	260	7.23	80	0	0.00	0	0	0.00	NO REVRSE FIRING
86 BX-N-E	LCE6.5A TRANSZORB	240	7.96	80	0	0.00	0	0	0.00	NO REVRSE FIRING
87 CX-N-A	LCE6.5A TRANSZORB	850	14.46	100	250	25.11	200	0	0.00	W/REVRSE FIRING
87 CX-N-B	LCE6.5A TRANSZORB	700	16.15	100	250	25.11	200	0	0.00	W/REVRSE FIRING
87 CX-N-C	LCE6.5A TRANSZORB	800	14.99	110	0	0.00	0	0	0.00	W/REVRSE FIRING
87 CX-N-D	LCE6.5A TRANSZORB	850	14.46	100	0	0.00	0	0	0.00	W/REVRSE FIRING
87 CX-N-E	LCE6.5A TRANSZORB	700	16.15	100	0	0.00	0	0	0.00	W/REVRSE FIRING
89 BX-N-A	LCE15A TRANSZORB	180	10.45	0	0	0.00	0	0	0.00	NO REVRSE FIRING
89 BX-N-B	LCE15A TRANSZORB	180	10.45	0	0	0.00	0	0	0.00	NO REVRSE FIRING
89 BX-N-C	LCE15A TRANSZORB	120	13.98	0	0	0.00	0	0	0.00	NO REVRSE FIRING
89 BX-N-D	LCE15A TRANSZORB	180	10.45	0	0	0.00	0	0	0.00	NO REVRSE FIRING
89 BX-N-E	LCE15A TRANSZORB	130	13.27	0	0	0.00	0	0	0.00	NO REVRSE FIRING
90 CX-N-A	LCE15A TRANSZORB	650	16.80	120	210	26.62	200	0	0.00	W/REVRSE FIRING
90 CX-N-B	LCE15A TRANSZORB	500	19.08	100	190	27.49	200	0	0.00	W/REVRSE FIRING
90 CX-N-C	LCE15A TRANSZORB	600	17.50	120	0	0.00	0	0	0.00	W/REVRSE FIRING
90 CX-N-D	LCE15A TRANSZORB	600	17.50	110	0	0.00	0	0	0.00	W/REVRSE FIRING
90 CX-N-E	LCE15A TRANSZORB	600	17.50	100	0	0.00	0	0	0.00	W/REVRSE FIRING
92 BX-N-A	LCE51 TRANSZORB	240	7.96	0	0	0.00	0	0	0.00	NO REVRSE FIRING
92 BX-N-B	LCE51 TRANSZORB	140	12.63	0	0	0.00	0	0	0.00	NO REVRSE FIRING
92 BX-N-C	LCE51 TRANSZORB	180	10.45	0	0	0.00	0	0	0.00	NO REVRSE FIRING
92 BX-N-D	LCE51 TRANSZORB	200	9.54	0	0	0.00	0	0	0.00	NO REVRSE FIRING
92 BX-N-E	LCE51 TRANSZORB	180	10.45	0	0	0.00	0	0	0.00	NO REVRSE FIRING
93 CX-N-A	LCE51 TRANSZORB	500	19.08	100	190	27.49	80	0	0.00	W/REVRSE FIRING
93 CX-N-B	LCE51 TRANSZORB	700	16.15	130	250	25.11	100	0	0.00	W/REVRSE FIRING

Table 3-3. Test Data (Continued)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
93 CX-N-C	LCE51 TRANSZORB	900	13.98	110	0	0.00	0	0	0.00	W/REVRSE FIRING
93 CX-N-D	LCE51 TRANSZORB	850	14.46	120	0	0.00	0	0	0.00	W/REVRSE FIRING
93 CX-N-E	LCE51 TRANSZORB	900	13.98	110	0	0.00	0	0	0.00	W/REVRSE FIRING
98 BX-N-A	LCE130A TRANSZORB	330	5.15	0	0	0.00	0	0	0.00	NO REVRSE FIRING
98 BX-N-B	LCE130A TRANSZORB	260	7.23	0	0	0.00	0	0	0.00	NO REVRSE FIRING
98 BX-N-C	LCE130A TRANSZORB	250	7.60	0	0	0.00	0	0	0.00	NO REVRSE FIRING
98 BX-N-D	LCE130A TRANSZORB	260	7.23	0	0	0.00	0	0	0.00	NO REVRSE FIRING
98 BX-N-E	LCE130A TRANSZORB	250	7.60	0	0	0.00	0	0	0.00	NO REVRSE FIRING
99 CX-N-A	LCE130A TRANSZORB	850	14.46	150	200	27.04	90	0	0.00	W/REVRSE FIRING
99 CX-N-B	LCE130A TRANSZORB	800	14.99	150	220	26.21	150	0	0.00	W/REVRSE FIRING
99 CX-N-C	LCE130A TRANSZORB	800	14.99	150	0	0.00	0	0	0.00	W/REVRSE FIRING
99 CX-N-D	LCE130A TRANSZORB	900	13.98	100	0	0.00	0	0	0.00	W/REVRSE FIRING
99 CX-N-E	LCE130A TRANSZORB	800	14.99	150	0	0.00	0	0	0.00	W/REVRSE FIRING
101 AX-N-O	PHP 120 TRANSZORB	0	0.00	0	400	21.02	0	1700	23.35	HI Z AT C LEVEL
102 BX-N-A	GHV-12 BIDIR SURGE	160	11.48	0	210	26.62	100	0	0.00	ALSO TESTED CL & CH
102 BX-N-B	GHV-12 BIDIR SURGE	150	12.04	0	220	26.21	100	0	0.00	ALSO TESTED CL & CH
102 BX-N-C	GHV-12 BIDIR SURGE	150	12.04	0	230	25.83	100	0	0.00	ALSO TESTED CL & CH
102 BX-N-D	GHV-12 BIDIR SURGE	160	11.48	0	230	25.83	100	0	0.00	ALSO TESTED CL & CH
102 CX-N-A	GHV-12 BIDIR SURGE	600	17.50	120	0	0.00	0	0	0.00	SAME DEV AS 102B
102 CX-N-B	GHV-12 BIDIR SURGE	580	17.79	120	0	0.00	0	0	0.00	SAME DEV AS 102B
103 BX-N-A	GSV101 VARISTOR	115	14.34	0	0	0.00	0	0	0.00	
103 BX-N-B	GSV101 VARISTOR	115	14.34	0	0	0.00	0	0	0.00	
103 BX-N-C	GSV101 VARISTOR	115	14.34	0	0	0.00	0	0	0.00	
103 BX-N-D	GSV101 VARISTOR	115	14.34	0	0	0.00	0	0	0.00	
103 BX-N-E	GSV101 VARISTOR	115	14.34	0	0	0.00	0	0	0.00	
104 CX-N-A	GSV101 VARISTOR	500	19.08	90	170	28.46	100	0	0.00	
104 CX-N-B	GSV101 VARISTOR	500	19.08	110	180	27.96	90	0	0.00	
104 CX-N-C	GSV101 VARISTOR	500	19.08	110	170	28.46	80	0	0.00	
104 CX-N-D	GSV101 VARISTOR	500	19.08	100	170	28.46	70	0	0.00	

Table 3-3. Test Data (Continued)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
104 CX-N-E	GSV101 VARISTOR	500	19.08	110	150	29.54	70	0	0.00	
106 BX-N-A	GSV201 VARISTOR	120	13.98	0	0	0.00	0	0	0.00	
106 BX-N-B	GSV201 VARISTOR	120	13.98	0	0	0.00	0	0	0.00	
106 BX-N-C	GSV201 VARISTOR	120	13.98	0	0	0.00	0	0	0.00	
106 BX-N-D	GSV201 VARISTOR	120	13.98	0	0	0.00	0	0	0.00	
106 BX-N-E	GSV201 VARISTOR	120	13.98	0	0	0.00	0	0	0.00	
107 CX-N-A	GSV201 VARISTOR	500	19.08	130	170	28.46	90	0	0.00	
107 CX-N-B	GSV201 VARISTOR	550	18.26	130	200	27.04	100	0	0.00	
107 CX-N-C	GSV201 VARISTOR	550	18.26	100	190	27.49	80	0	0.00	
107 CX-N-D	GSV201 VARISTOR	700	16.15	140	160	28.98	90	0	0.00	
107 CX-N-E	GSV201 VARISTOR	550	18.26	120	150	29.54	80	0	0.00	
109 AX-N-O	ECI (LEMON)	380	3.92	0	580	17.79	0	700	31.06	CL INVALID - CH GOOD
110 AX-N-O	ECI (PEACH)	350	4.66	0	1000	13.06	0	2900	18.71	CL INVAL-CH GOOD
111 AX-N-O	LG 10	550	0.75	0	600	17.50	0	2900	18.71	CL ALSO GOOD 1000V
112 AX-N-O	61-2785	90	16.47	0	300	23.52	100	2800	19.02	
113 CX-N-O	SG, MOV, BEADS	60	37.50	0	0	0.00	0	300	38.42	
114 CX-N-O	SG, TZB, BEADS	70	36.16	0	0	0.00	0	400	35.92	
115 TR25-1-0	TR1	0	0.00	0	0	0.00	0	25000	0.00	
115 TR25-2-0	TR2	0	0.00	0	0	0.00	0	1600	23.88	
115 TR25-3-0	TR3	0	0.00	0	0	0.00	0	1500	24.44	
115 TR25-4-0	TR4	0	0.00	0	0	0.00	0	1600	23.88	REPEAT
115 TR25-5-0	TR5	0	0.00	0	0	0.00	0	1500	24.44	
115 TR25-6-0	TR6	0	0.00	0	0	0.00	0	0	0.00	
115 TR25-7-0	TR7	0	0.00	0	0	0.00	0	0	0.00	
115 TR25-8-0	TR8	0	0.00	0	0	0.00	0	0	0.00	
115 TR25-9-0	TR9	0	0.00	0	0	0.00	0	0	0.00	
115 TR25-10-0	TR10	0	0.00	0	0	0.00	0	0	0.00	
115 TR25-11-0	TR11	0	0.00	0	0	0.00	0	1600	23.88	
115 TR25-11A-0	TR11A	0	0.00	0	0	0.00	0	1600	23.88	

Table 3-3. Test Data (Continued)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
115 TR25-12-0	TR12	0	0.00	0	0	0.00	0	1700	23.35	
115 TR25-12A-0	TR12A	0	0.00	0	0	0.00	0	1600	23.88	
115 TR25-13-0	TR13	0	0.00	0	0	0.00	0	1650	23.61	
115 TR25-14-0	TR14	0	0.00	0	0	0.00	0	1800	22.85	
115 TR25-15-0	TR15	0	0.00	0	0	0.00	0	1800	22.85	
115 TR25-16-0	TR16	0	0.00	0	0	0.00	0	1800	22.85	
115 TR25-17-0	TR17	0	0.00	0	0	0.00	0	1700	23.35	
115 TR25-18-0	TR18	0	0.00	0	0	0.00	0	1000	27.96	
115 TR25-19-0	TR19	0	0.00	0	0	0.00	0	1650	23.61	
115 TR25-20-0	TR20	0	0.00	0	0	0.00	0	1000	27.96	
115 TR25-20A-0	TR20A	0	0.00	0	0	0.00	0	1000	27.96	TR20 ON LONGER TIME
115 TR25-21-0	TR21	0	0.00	0	0	0.00	0	2400	20.35	
115 TR25-22-0	TR22	0	0.00	0	0	0.00	0	1700	23.35	
115 TR25-23-0	TR23	0	0.00	0	0	0.00	0	1000	27.96	REPEAT TR 18
115 TR25-24-	TR24	0	0.00	0	0	0.00	0	800	29.90	GROUND REFERENCE
116 TR25-1-0	TR18 WITH SHRT LEADS	0	0.00	0	0	0.00	0	670	47.96	100 V OVER GRND REF
116 TR25-2-0	TR18 WITH SHRT LEADS	0	0.00	0	0	0.00	0	1900	26.97	1120 V OVER GRND REF
116 TR25-3-0	TR18 WITH SHRT LEADS	0	0.00	0	0	0.00	0	400	53.98	50V OVER GRND REF
116 TR25-4-0	TR18 WITH SHRT LEADS	0	0.00	0	0	0.00	0	50	53.98	
116 TR25-5-0	TR18 WITH SHRT LEADS	0	0.00	0	0	0.00	0	3000	18.41	OK W/120 V ON
116 TR25-6-0	TR18 WITH SHRT LEADS	0	0.00	0	0	0.00	0	3600	16.83	120 V PWR ON
116 TR25-7-0	TR18 WITH SHRT LEADS	0	0.00	0	0	0.00	0	2400	20.36	120 V PWR ON
116 TR25-8-0	TR18 WITH SHRT LEADS	0	0.00	0	0	0.00	0	2720	19.77	120 V PWR ON
116 TR25-9-0	TR18 WITH SHRT LEADS	0	0.00	0	0	0.00	0	1920	22.29	W/O 120 V PWR ON
116 TR25-10-0	TR18 WITH SHRT LEADS	0	0.00	0	0	0.00	0	200	41.94	W 120 V PWR ON
116 TR25-11-0	TR18 WITH SHRT LEADS	0	0.00	0	0	0.00	0	2000	21.94	W 120 V PWR ON FAIL
116 TR25-12-0	TR18 WITH SHRT LEADS	0	0.00	0	0	0.00	0	25000	0.00	FAIL AFTER ONE HIT
116 TR25-13-0	TR18 WITH SHRT LEADS	0	0.00	0	0	0.00	0	25000	0.00	FAIL AFTER ONE HIT
116 TR25-14-0	TR18 WITH SHRT LEADS	0	0.00	0	0	0.00	0	25000	0.00	FAIL AFTER ONE HIT

SECTION 4

TEST RESULTS OF EMP/TRANSIENT THREAT TESTING OF AMATEUR/MARS RADIO EQUIPMENT AND PROTECTION DEVICES

4.1 Test Purpose

This was the second of a two part test program with the purpose of testing and evaluating low cost transient protection schemes for Amateur/MARS radio equipment against the fast rising electromagnetic pulses associated with nuclear detonations and lightning. The first test in this program was completed in June 1985; it subjected 56 selected protection devices to several different injection pulses, which simulated the waveforms and energies associated with electromagnetic pulses and lightning (see Section 3). Those protection devices found acceptable during the first test program were installed with the appropriate radio equipment and tested again during this test program to determine their suitability in a typical amateur radio installation configuration.

There were two major purposes for this second test program. The first was to determine the protection requirements for fifteen typical radio amateur systems (see table 4-18 for a complete list of equipment tested by systems); and the second was to determine the effectiveness of the previously evaluated protection devices in providing the needed protection.

The overall purpose of the two test program was to find a low cost method to enhance the survivability of the typical Amateur/MARS radio equipment that is currently in use throughout the amateur community, including both tube-type and solid state. This radio equipment included HF transceivers, mobile VHF transceivers, handheld VHF transceivers and satellite transceivers.

4.2 Test Objectives

The objective of this test was to determine both the protected and the unprotected response of several typical amateur radio systems to a simulated electromagnetic pulse. The protection was provided by previously tested protection devices. Since there was a large number of possible combinations of devices and equipment, it was the objective of the test to only evaluate the low cost devices; and if they were not acceptable, then evaluate higher cost devices until an acceptable protection scheme had been determined. After completing the testing of the low-cost commercial devices, several breadboard devices were assembled from previously tested components. These assembled devices were tested with the objective of finding a very low-cost protection device design, that could be built by the radio amateur. Six of these assembled devices are described in this report (see table 4-19).

The objective of the main body of this test program was to step the radio systems through a series of tests, starting with less stringent transient pulse configurations and progressively moving to more threatening transient pulse configurations, and finally going to the most stringent threat environment, which provided a full EMP test to an unprotected, fully wired, power-on, radio system. This last test would serve to validate the earlier tested protection schemes. All of the tests were conducted at a nominal electric field strength of 50 kilovolts per meter.

The radio systems were first subjected to a stand-alone (equipment unwired) field pulse wave, which was used to disclose any inherent design weaknesses and identify the necessary protection points (i.e., points of damage), internal to the equipment. Any damaged equipment was to be repaired and returned for further testing. After a series of field only pulse tests, the simultaneous field and injection pulse tests were made. It was the objective to progress the radio systems from an unpowered, stand-alone, unconnected configuration, through a series of power-on, receive and transmit configurations, in order to stress the radio systems in their typical user modes of operation.

Measurements were taken of the radio system's performance before and after each pulse or pulse series. The purpose of these measurements was to compare the radio system's transmitter power output and receiver sensitivity before and after the pulse so that any equipment degradations would be attributed to that particular test configuration (i.e., protection scheme, devices, etc.). This testing scheme would allow a progressive method of determining the required protection points for the particular radio system under test, the acceptable and unacceptable protection schemes and devices, the radio system's inherent protection capabilities or weaknesses, and finally, the susceptibility of an unprotected radio system to a full EMP stress level. This last test series (series F tests) provided some unexpected results which are described in this section.

4.3 Test Program

4.3.1 Threat Definition. (See Section 3, Vol 1). The following peak values were used in this combined equipment and transient protection device test program:

EMP Simulator Pulse Field: 50 KV/M

RF Drive Pulse:	275 A	13.75 KV
AC Drive Pulse:	130 A	6.5 KV

4.3.2 Simulator Field Testing. Simulator Field Testing consisted of placing the radio system under test in the working volume of the large parallel plate EMP simulator and discharging the simulator's MARX pulse generator into the pulser wire elements with sufficient energy to produce a 50KV/meter field strength with a 10 nanosecond rise time within the simulator's working volume. Field testing was used for every test series.

4.3.3 Simultaneous Field and Injection Pulse Testing. The simultaneous (D,E & F Test Series) field and injection pulse testing consisted of placing the radio equipment in the working volume of the Large Parallel Plate EMP Simulator and attaching two "L" shaped wires to the equipment through a hook-up scheme.

4.3.3.1 Transient Injection Methods. The working volume of the parallel plate simulator used for testing, while large, was not sufficient to house an entire radio station including outdoor antenna and house power drop. Therefore, it was planned to put the station equipment inside the test volume and simultaneously inject suitable pulses to simulate the stresses carried to the equipment by the power system and the radio antenna. The maximum transient expected from the power line was limited to about six kilovolts since household wiring is expected to limit the transient to this level. The antenna connections, however, would only be limited by the sparkover limitations of the antenna cabling installed. Hence, it was necessary to determine a suitable level for injection of the antenna signal.

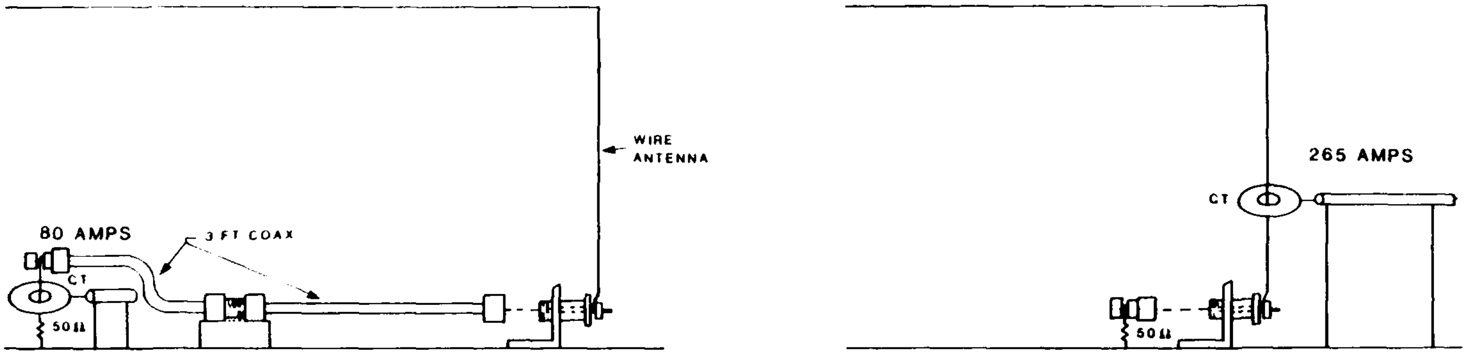
4.3.3.2 Power Transient Injection. Power for systems in the test chamber was provided by an isolated generator set to prevent interaction with the pulser and data links used in the experiment. To simulate the connection of a typical residential supply, both the neutral and ground leads of the isolated system were grounded to the pulser ground plane at a single supply box within the transient field. A transient injection pulse was generated by an "L" shaped wire antenna within the test volume which was connected to the hot lead of a power plug inserted closest to the protective device under test. When a commercial "plug-in" device was used, the transient was injected into the same receptacle in which the device was plugged. When the fabricated device was used, the transient was injected into the device receptacle alongside the equipment plug. It was considered that this maximized the stress on the equipment while offering an opportunity for the free field transient to couple with the equipment power cord after the protective device. The dimensions of the "L" antenna were adjusted until a current of 130 amps was produced into a 50 ohm load. This was used as the power transient threat throughout testing.

4.3.3.3 Antenna Transient Injection. A larger "L" shaped antenna was constructed within the test volume for evaluation as an injection pulse generator for the antenna port of the equipment under test. Measurement of current through a 50 ohm load resistor was limited to about 80 amps when two short lengths of coaxial cable were used between the antenna and load.

The results of removal of the coax from the transient path are depicted in figure 4-1 and lead to the conclusion that the coaxial cable and connectors do, in fact, greatly limit the magnitude of the transient imposed on radio equipment. Therefore, the "L" antenna used for transient injection in this test was considered adequate to stress any antenna connection terminal (at the equipment end) with a pulse as large as the coaxial cable could transmit. A possibility exists in a real transient situation that the coaxial cable itself may be damaged if not protected at the antenna end, but this condition could not be tested by the configuration used here.

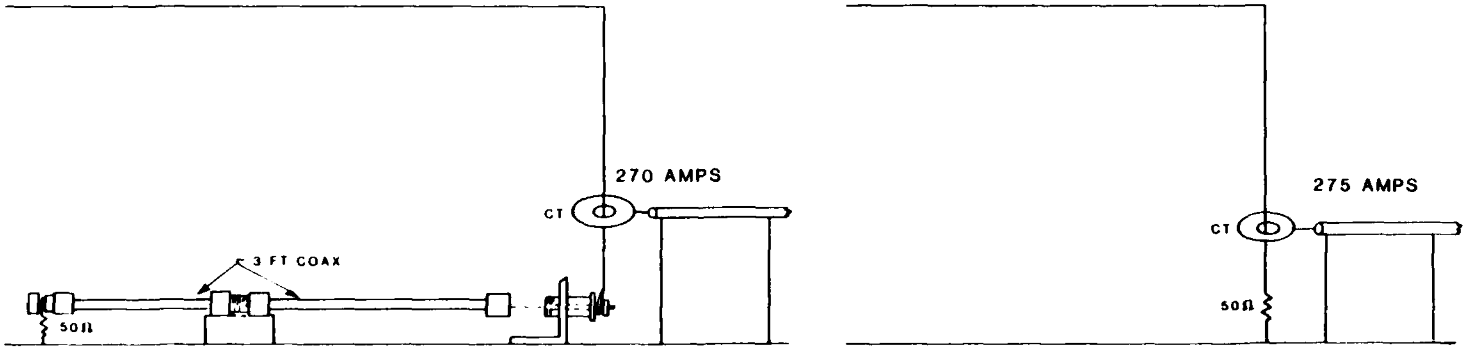
4.4 Test Equipment

4.4.1 Large Parallel Plate EMP Simulator (Pulser). A large parallel plate EMP simulator (figure 4-2) was used for this test program. A working volume 24 feet long, 20 feet wide and 11 feet high was provided by the simulator. A MARX generator parallel capacitor bank was charged by a high power DC power supply and discharged through a spark gap bank and output capacitor into the simulator's wire elements. The simulator's wire elements extended from the MARX generator through a 16 foot transitional section to a height of 11 feet above a 24 foot by 20 foot square metal ground plane and then through another 16 foot long transitional section to a bank of copper sulfate load resistors, which provided a termination load resistance (110-130 OHMS) for the pulser. A 30KV charge to the MARX



(A) CURRENT AFTER TWO 3 FOOT SECTIONS OF RG 8 COAX WITH A BARREL AND CONNECTOR · THROUGH 50 OHM RESISTOR TO GROUND

(C.) CURRENT THROUGH COAXIAL CONNECTOR AND 50 OHM RESISTOR TO GROUND



(B) CURRENT BEFORE TWO 3 FOOT SECTIONS OF RG-8 COAX, WITH A BARREL AND CONNECTOR, AND THROUGH 50 OHM RESISTOR TO GROUND

(D.) CURRENT THROUGH 50 OHM RESISTOR TO GROUND

Figure 4-1. Antenna Transient Injection

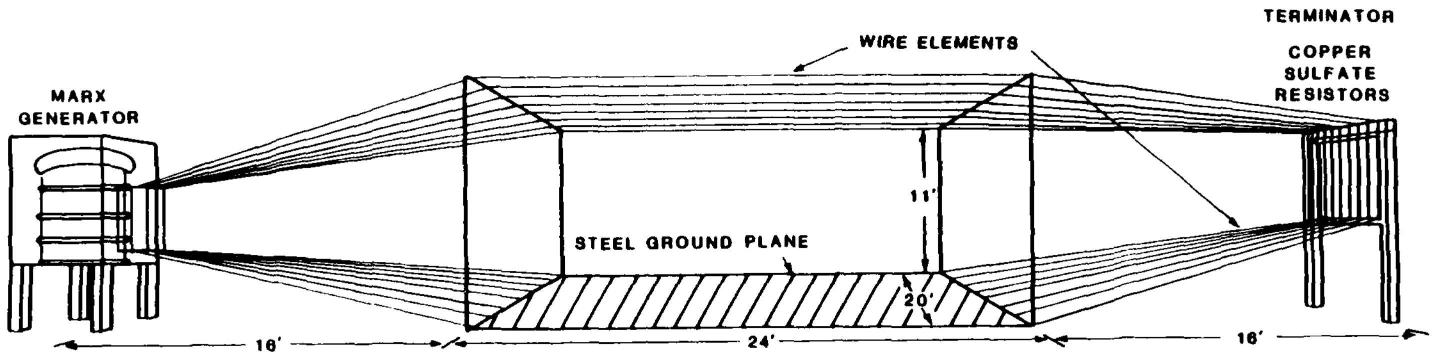


Figure 4-2. Large Parallel Plate EMP Simulator

generator was sufficient to provide a 50KV/m field strength inside the working volume of the pulser with a rise time near 10 nanoseconds. The 30 KV charge to the MARX generator generated a 240 KV charge on the pulser elements.

4.4.2 <u>H Field Sensors</u>. Two H field sensors were used during this test to provide the daily calibration of the simulator and to measure the field strength during each test. Both a round H field sensor and a rectangular H field sensor were placed in the simulator's field to obtain reference pulses. The output of the two sensors was compared for the daily calibration of the pulser. Normally only one H field sensor was used during the actual equipment/device testing.

4.4.3 <u>Current Sensors</u>. Four current sensors were used to measure the ouput of amateur radio antennas that were erected in the pulser field and to measure the output from the L shaped wire antennas that were used to drive the AC power lines and antenna coaxial cables during the test. These sensors are listed in table 4-1.

4.4.4 <u>Shielded Probes</u>. Two shielded probes were used during the test to take H field and E field measurements within the simulator field. A solid metal coaxial shielded probe and a fiber optic system with a battery powered shielded transmitter were used to take the H field and E field measurements. These probes were calibrated frequently during the test program.

4.4.5 Data Recorder. Sensor measurements were recorded on an oscilloscope adjusted to the proper scale for the data being recorded; and a photograph of the oscilloscope display was made for each simulator pulse.

4.4.6 Bench Check Equipment. Four different signal generators and a watt meter were used before and after each equipment test to measure the radio system's receiver sensitivity and transmitter power. This equipment is listed in table 4-1.

4.5 Test Series.

The test program consisted of six different test series (series A through F). The test series started with the less stringent, field tests with no power-on the equipment, and progressively moved to the more stringent, field tests with power-on and the antenna and power ports driven by an injection pulse.

4.5.1 Series A Tests. This was a test of the equipment's susceptibility to the simulator field in a completely unwired and unpowered configuration. This first test in the series was designed to evaluate the susceptibility of the equipment's internal wiring and components to self-generated transient pulses resulting from exposure to a field pulse. The radio

Table 4-1. Test Equipment

Sensors

1.	Singer	91550-2	100A - 0.1-100 MHZ ZT - 1 OHM
2.	Singer	91550-4	500A - 0.02 - 100 MHZ ZT - 0.1 OHM
3.	Pearson	110	1 HZ - 35 MHZ 5000 A Peak TRANSFER ZT - .05 OHMS INTO 50 OHMS
4.	Tektronix	CT2	1.2 KHZ - 200 MHZ PEAK PULSE - 36A SATURATION - 50 MICRO/AMPS/SEC. ZT - 1 OHM (1MV/MA) 500 PICO SEC RISETIME 160 MICRO SEC DECAY TIME

Signal Generators

Hewlett Packard	HP 606
Hewlett Packard	HP 608D
Hewlett Packard	HP 540B
Boonton	202H

Watt Meter

Bird Model 43 with 3 plug-in Modules
250H (2-30 MHZ -250 Watts)
50C (100-250 MHZ -50 Watts)
25D (200-500 MHZ - 25 Watts)

equipment was placed on wooden carts 34 inches above the simulator floor. None of the interconnecting wires were attached to the equipment. All permanently attached external wires (i.e., power cords) were coiled and placed under the case of the radio equipment. All antennas were removed. The radio equipment was not grounded. Radio systems failing this test would require internal transient protection.

4.5.2 Series B Tests. This was a test of the equipment's susceptibility to the simulator field with all interconnecting wiring and power cords in place, but still in an unpowered configuration. This second test was designed to evaluate the susceptibility of the equipment to transient pulses generated by the short interconnecting wiring, microphone cords, power cords and any other short external wires associated with the radio system under test. The radio equipment was placed on a wooden cart 34 inches above the simulator floor with all wiring in place, as stated above, in an unpowered and ungrounded configuration.

4.5.3 Series C Tests. This was a series of tests of the equipment's susceptibility to the simulator field in a power-on, grounded condition but without transient protection applied. The radio equipment was placed on the pulser floor and grounded to the pulser ground plane, with all wiring installed except for the antenna coaxial cable. Tests were made first unpowered and then with AC power on, with the transceiver in the receive mode of operation. This test series was designed to provide the most stringent test of the radio equipment's inherent susceptibility to a pulse field from its internal and external wiring (with the exception of the external antenna coaxial cable).

4.5.4 Series D Tests. This was a series of tests of the equipment susceptibility, with transient protection applied. This test series was designed to evaluate the effectiveness of commercial transient protection devices in protecting the radio systems from the pulser field and from transient pulses injected onto the AC powerlines and antenna coaxial lines. This was a power-on test of the equipment with all external wiring and peripherals in place, including the antenna coaxial cable. The AC power and antenna coaxial cable were driven by an injection signal appropriate to the threat levels described before.

4.5.5 Series E Tests. This was a series of tests to evaluate the effectiveness of assembled (experimental) transient protection devices in protecting the radio systems from a simulated EMP environment. The devices were assembled from previously tested components. This test series was designed to find a low cost solution to the transient protection requirements of the radio systems under test.

4.5.6 Series F Tests. This was a series of tests of the susceptibility of the equipment to the simulator field with the power and antenna ports driven by an injection signal appropriate to the threat level, with all wiring and peripherals in place and with no transient protection devices in use for the final test.

This series of tests was designed to evaluate the equipment susceptibility to a full EMP simulation without protection. Equipment degradation or failure during this test series would validate the effectiveness of the previously tested transient protection schemes. Equipment surviving this test series would have demonstrated an extremely low susceptibility to the EMP simulation, in an unprotected configuration.

4.6 Test Results

The test results were obtained by the characterization of the radio systems before and after a single pulse. The radio system's transmitter power output in watts was measured with the radio in a standard configuration, the keyed continuous wave (CW) mode of operation. The radio system was then switched to upper side band (USB) and the voice modulation was checked by observing the deflection of the watt-meter needle while talking into the microphone. In some tests the radio transmitter was monitored on another similar radio. The radio systems' receivers were characterized by measuring the receivers' sensitivity in dBm before and after the pulse. The radio's tuner was placed on a set radio frequency in USB with the RF amplifier on and the RF gain in the maximum position. The output of a signal generator was increased until the receiver's built-in-meter showed a deflection to the S-5 level. Radios without an S-meter were measured by listening for an audible signal on the receiver's speaker. The transmitter output power was measured both with and without the transient protective device in the RF coaxial line. This provided an evaluation of the transient protection device's suitability for that particular radio system, by showing its ability to pass the transmitted power without clamping or without contributing a substantial loss of power output. The results of the measurements taken are shown in tables 4-2 through 4-16.

The following is a summary of the results obtained for the entire test series.

4.6.1 <u>Series A Tests</u>. All radio systems (with the exception of system 15 that was dropped from the test for prolonged maintenance problems) <u>passed</u> the series A tests with no measurable degradation in post-test transmitter power output or receiver sensitivity. The radio systems in the A configuration were not susceptible to degradation or damage from the pulser field alone.

4.6.2 <u>Series B Tests</u>. All of the radio systems passed the series B tests, with two exceptions. System 3 dropped receiver sensitivity by 26 dBM and

System 8 dropped 8 dBm. However, the two systems were not considered to be seriously degraded since a strong signal was still audible. Both radio systems were considered operational and were accepted for further testing. The Series B tests again proved that most radio systems were not susceptible to degradation from the pulser field alone, even when external wiring had been installed.

4.6.3 Series C Tests. This was a series of power-on tests using only System 2. This was the last test series using only the pulse field; and was before the start of simultaneous field and injection tests. System 2 passed the test series with no measurable degradation of system performance. Based on these results all of the systems were advanced to the series D tests.

4.6.4 Series D Tests. This was a series of tests with commercial transient protection devices installed in the AC power line and the RF coaxial line. All of the devices tested (listed in table 4-17) provided adequate protection for the radio systems tested with one exception. After pulsing System 2 with the Alpha-Delta Transi Trap - RT device in the coaxial line, System 2's receiver became very noisy. In an earlier test, (test D1) System 2 was tested with the Fischer FCC-250-300 UHF coaxial "T" protection device in the RF coaxial line. System 2's post-test D1 characterization measurements showed no measurable degradation to the system. The Fischer device was replaced with the Transi Trap - RT and system 2 was tested again (Test D-15). After test D-15 the receiver noise level remained at the S-5 level on the transceive.'s S-meter. However, a tone from the signal generator was audible above the noise level at the pre-test dBm levels. When the power output was measured, system 2's transmitter power output had increased by 19 watts in several frequency bands. These two changes indicate that system 2 did sustain some internal damage during test D15 while the Alpha Delta Transi Trap RT was in the circuit. The Transi-Trap devices performed satisfactorily during the first test program. During post-test check, one FISHER FCC 450-120-UHF would not pass RF signal power. It was replaced with another FCC 450-120-UHF which would pass the RF signal.

4.6.5 Series E Tests. Five assembled transient protection devices were evaluated during the test series (see table 4-19). One AC protection device and four RF protection devices were tested with four different radio systems. All of the assembled devices provided adequate protection of the radio equipment during the test pulse. Further testing revealed that three of the devices blocked the RF output signal. The Siemens Metal Oxide Varistor (SIOV) RF Test Box containing a large capacitance varistor blocked the RF signal over a wide frequency range. The Siemens UHF Test Box and the Joslyn UHF Test Box containing the gas-gaps were adequate in the HF frequencies, but blocked the RF signal in the higher frequency ranges.

Although these three devices would be adequate for a receiver, they are not recommended for a transmitter.

Two assembled devices proved to be very acceptable. The UHF coaxial "T" was the best assembled RF device; it provided both transient protection and could pass the RF signal over the full range of test frequencies. Also, the SIOV AC Test Box repeatedly provided necessary power protection required by the radio systems. These last two devices are described in detail in Volume I, Section 5.

4.6.6 Series F Tests. The Series F tests were field and injection tests in three different configurations. First, radio systems were tested in a fully protected configuration; next, the radio systems were tested with the protection removed from the RF antenna-coax; and finally, the radio systems were tested with the protection removed from both the RF antenna coax and from the AC power lines.

As was expected, in this last unprotected test series some equipment damage was experienced. However, the most surprising result from this test series was that only one radio system (System 2) experienced significant permanent degradation. The other radio systems suffered various amounts of degradation in their transmitter power out and receiver sensitivity, but were still operational in their degraded state. A contributing factor in these excellent survivability results was the influence that the RG-8 coaxial cable had on the RF injection pulse (discussed later in this section). After the F test, System 2's power output was 210 watts, which is 110 watts above the system's specification of 100 watts (PEP/DC). System 2's receiver sensitivity dropped from - 109 dBm (at a frequency of 7.3 MHZ) to -25 dBm.

4.6.7 Antenna Tests. Two large amateur antennas were assembled and placed in the simulator pulse field. Measurements were taken of the antennas' response to the simulator pulse field in several different configurations, including measurements taken with a 75 foot RG 8 coaxial cable attached, and with a direct wire through a 50 ohm resistor to the pulser ground plane. The Mosley JRS TA 33 JR antenna generated a maximum of 152 A through 50 ohms resistance for a 7.6 KV pulse level. The Cushcraft AV-5 antenna generated a maximum output of 170 A through the 50 ohms resistance for a maximum 8.67 KV pulse level.

Based upon these two antenna outputs, an "L" shaped wire antenna was placed in the pulser field to generate a drive current that could be injected into the RG-8 coaxial cable attached to the radio equipment under test. The maximum measured output of this "L" shaped antenna (RF drive antenna) was 175 A through a 50 ohm resistor for a maximum pulse level of 13.75 KV.

In addition to the large antenna test, two small antennas, "rubber ducks", used on handheld radios were tested. The maximum measured current was 8 amps or 400V over 50 ohms. This low current was not sufficient to cause any disruption or degradation to the handheld transceivers.

4.6.8 Coaxial Cable Effects. Measurements were taken to determine the response of the RG-8 coaxial cable in the pulse field alone and when attached to three different antennas, two amateur radio antennas and the RF drive antenna.

When measurements were taken on the antenna side of the coaxial cable, large currents (270 ± 20A) could be found, but when measurements were taken on the opposite end with the 50 ohm resistor connected to ground, only (80 ± 30 A) could be obtained. It was suspected that the RG-8 coaxial cable was arcing. To verify this condition a piece of RG-8 coaxial cable was connected to a high voltage DC power supply and the power slowly increased - arcing between the center conductor and the coaxial connector began at 4KV DC. The RG-8 cable began arcing internally at 5.5 KV DC. Therefore, it was concluded that the RG-8 was acting as a spark gap protector for the equipment under test beginning at approximately 80 amps and 4.4 KV. Given this condition, the installed protection devices on the antenna coaxial cable were needed only to suppress the approximate 4.4 KV pulse that would get through the coax.

A 75 foot section of RG 8 coaxial cable with no antenna connected was tested in the pulser field. One end of the cable shield was grounded and the center conductor was grounded through a 50 ohm resistor. There was no measurable current flow in the center conductor when the cable was pulsed.

4.6.9 Test Observations. Most of the solid state and all of the tube type radios were not susceptible to the simulator field pulses, until long external wires were attached. The short wires (microphone, power cord and interconnecting wires) did not generate sufficient transient pulse energy to produce observable damage to the radio equipment. Even with the antenna attached to the handheld radios, no observable damage was received from the field pulse. However, when the power lines and antennas are attached to the radio equipment, protection must be provided. When these long external wires were simulated with no protection provided, a single pulse could cause disruption of the micro-processor controlled displays, cause shifts in radio frequency and cause permanent damage to the transceivers' internal components. The two notable exceptions were the handheld and mobile radios; even with antennas attached, no observable degradation was noted.

Therefore, adequate transient pulse protection for most radio systems can be obtained by adding protection on these two external sources of damaging transient energy; the AC power lines and the RF antenna transmission lines.

Several types of low-cost transient protection devices have been tested and have demonstrated their effectiveness during this test program.

Other supporting equipment used by the radio amateur can be damaged by transient pulses. For example, a DC power supply (ASTRON VS-35) failed when pulsed with an unprotected AC power source. A handheld (ICOM-02AT) radio's display was permanently damaged when the radio was plugged into its battery charger and then into an unprotected AC power source. The battery charger was also damaged. However, a Honda portable power generator was fully stressed with field and injection pulses and was unharmed. System 1 sustained damage to the antenna tuner, but the attached transceiver was not damaged. In this case the antenna tuner may have protected the transceiver. When System 4 was pulsed in an unprotected configuration, its antenna tuner did not provide adequate protection for the radio transceiver. The transceiver's frequency display was temporarily disrupted.

4.7 Conclusions

Most of the tested amateur radio equipment should be protected from both lightning and electromagnetic pulses to prevent damage which can degrade the equipment's performance. As a minimum, the AC power and antenna ports should be protected on the equipment. The two exceptions were the handheld and mobile radios, which were not degraded during the test. The handheld battery charger and the DC power supply should also be protected. With this mimimum protection, and considering the low susceptibility of the tested equipment to the transient pulse field, the radio systems should survive nuclear and lightning generated electromagnetic pulses. As always, the one big exception to this statement is the direct lightning strike.

Table 4-2. Test Measurements - System 1

TRANSMITTER POWER (WATTS)

TEST NUMBER

FREQUENCY MHZ	PRE TEST	A	B1	B2	D (1,2)	D (1,3)	F (1,2)	F (1,3)	F (3,4)
1.8	102	104	101	103	94	95	96	100	106
3.8	100	102	100	101	95	95	90	98	102
7.3	104	106	102	104	92	89	94	92	102
10.3	107	109	103	105	95	94	89	88	99
14.3	106	107	102	104	84	80	68	92	98
18.3	106	110	99	101	83	82	65	97	101
21.3	104	106	92	93	73	74	67	99	105
24.8	101	98	82	83	80	72	70	94	108
28.3	94	88	75	75	75	68	68	94	96

RECEIVER SENSITIVITY (dBM)

TEST NUMBER

FREQUENCY MHZ	PRE TEST	A	B1	B2	D (1,2)	D (1,3)	F (1,3)
1.8	-105	-108	-107	-106	-103	-103	-102
3.8	-107	-108	-107	-107		-105	-103
7.3	-105	-107	-107	-107	-104	-104	-101
10.3	-102	-103	-103	-103		-100	-98
14.3	-103	-103	-103	-103		-100	-98
18.3	-101	-101	-102	-102	-99	-100	-99
21.3	-100	-101	-102	-102		-99	-99
24.8	-103	-104	-105	-104		-101	-100
28.3	-102	-104	-104	-104	-102	-102	-97

BENCH-CHECK SETUP NOTES:

(1) WITH ANTENNA TUNER
(2) WITHOUT PROTECTIVE DEVICE IN COAXIAL LINE
(3) WITH PROTECTIVE DEVICE IN COAXIAL LINE
(4) WITHOUT ANTENNA TUNER

Table 4-3. Test Measurements - System 2

TRANSMITTER POWER (WATTS)

TEST NUMBER

FREQUENCY MHZ	PRE TEST	A	B2	C1	C2	C3	C4	D1 (1)	D1 (2)	E	D15 (1)	D15 (2)	F1/2 (5)
1.8	107	107	107	107	106	106	107	107	106	107	130	130	185
3.8	104	105	105	105	105	105	105	104	104	105	117	119	225
7.3	110	111	112	110	110	110	110	110	109	110	121	122	210
10.3	112	115	116	112	112	111	113	112	112	112	125	125	210
14.3	115	118	119	112	113	112	112	112	112	115	128	126	210
18.3	119	118	120	115	115	115	115	115	113	119	135	134	195
21.3	119	119	120	115	115	115	106	115	112	120	139	135	185
24.8	120	121	123	115	114	115	115	113	110	121	140	135	165
28.3	116	121	122	109	108	110	110	106	103	115	134	125	160

RECEIVER SENSITIVITY (dBM)

TEST NUMBER

FREQUENCY MHZ	PRE TEST	A	B2	C1	C2	C3	C4	D1 (1)	D1 (2)	E (3)	D15 (1,4)	F1/2 (6)
1.8	-109	-109	-106	-106	-105	-106	-106	-106	-105	-108	-99	-65/S-9
3.8	-111	-110	-107	-106	-106	-106	-107	-106	-106	-108	-101	-55/S-15
7.3	-109	-110	-106	-105	-105	-105	-105	-105	-105	-108	-104	-25/S-15
10.3	-103	-103	-102	-102	-100	-101	-103	-100	-101	-102	-101	-35/S-7
14.3	-107	-106	-103	-103	-103	-103	-103	-103	-102	-104	-103	-44/S-20
18.3	-106	-104	-101	-101	-101	-101	-101	-100	-100	-102	-103	-78/S-6
21.3	-104	-104	-97	-96	-98	-98	-100	-94	-98	-100	-100	-81/S-0
24.8	-108	-107	-102	-100	-101	-104	-102	-101	-102	-104	-102	-82/S-0
28.3	-107	-106	-100	-100	-100	-101	-101	-101	-101	-102	-105	-55/S-4

BENCH-CHECK SETUP NOTES:

(1) WITHOUT PROTECTIVE DEVICE IN COAXIAL LINE
(2) WITH PROTECTIVE DEVICE IN COAXIAL LINE
(3) E TEST WAS CONDUCTED BETWEEN D1 AND D15
(4) RECEIVER VERY NOISY AT S-5 LEVEL
(5) TRANSMITTER DESIGNED FOR 100 WATTS OUTPUT
(6) S FIGURE IS NOISE LEVEL -dBM READING IS FIRST AUDIBLE SIGNAL ABOVE THE "S" NOISE LEVEL

Table 4-4. Test Measurements - System 3

TRANSMITTER POWER (WATTS)

TEST NUMBER

FREQUENCY MHZ	PRE TEST	A	B2	D8 (1)	D8 (2)	D19-22 E12-15	F (1)	F (2)
144.5	15.0	12.0	12.6	13.0	12.9	15	16	15.8

RECEIVER SENSITIVITY (dBM)

TEST NUMBER

FREQUENCY MHZ	PRE TEST	A	B2	D8 (1)	D8 (2)	D19-22 E12-15	F (1)	F (2)
144.5	-96	-92	-70	-69	-70	-71	-38	-42

BENCH-CHECK SETUP NOTES:
(1) WITHOUT PROTECTIVE DEVICE IN COAXIAL LINE
(2) WITH PROTECTIVE DEVICE IN COAXIAL LINE

Table 4-5. Test Measurements - System 4

TRANSMITTER POWER (WATTS)

TEST NUMBER

FREQUENCY MHZ	PRE TEST	A	B1	B2	D (1)	D (2)	F (2)	F (1)	F (3)
1.8	98	99	98	102	99	100	98	100	101
3.8	98	100	94	95	94	94	93	95	101
7.3	105	105	100	101	99	100	99	101	106
10.3	106	106	102	104	102	102	101	102	107
14.3	103	104	99	100	99	100	98	99	104
18.3	98	100	96	97	95	96	95	96	100
21.3	101	102	99	98	97	98	96	97	100
24.8	104	105	102	102	101	102	99	101	105
28.3	104	105	102	101	101	101	99	101	105

RECEIVER SENSITIVITY (dBM)

TEST NUMBER

FREQUENCY MHZ	PRE TEST	A	B1	B2	D	F (1)
1.8	-87	-89	-89	-87	-87	-86
3.8	-87	-89	-89	-87	-85	-84
7.3	-92	-94	-93	-92	-90	-90
10.3	-93	-94	-94	-92	-90	-91
14.3	-92	-94	-93	-92	-90	-90
18.3	-89	-88	-87	-87	-86	-83
21.3	-90	-92	-92	-91	-90	-89
24.8	-89	-85	-85	-86	-82	-88
28.3	-91	-92	-92	-92	-89	-89

BENCH-CHECK SETUP NOTES:
(1) THROUGH ANTENNA TUNER WITH PROTECTIVE DEVICE
(2) THROUGH ANTENNA TUNER WITHOUT PROTECTIVE DEVICE
(3) WITHOUT ANTENNA TUNER WITH PROTECTIVE DEVICE

Table 4-6. Test Measurements - System 5

TRANSMITTER POWER (WATTS)

TEST NUMBER

FREQUENCY MHZ	PRE TEST	A	B2	D (1)	D (2)	F10 (1)	F10 (2)	F11 (1)	F11 (2)
1.8	100	101	102	104	102	100	100	102	104
3.8	100	103	103	105	103	101	100	103	104
7.3	106	109	108	109	109	107	106	108	110
10.3	108	111	110	111	110	110	109	110	110
14.3	106	109	108	110	109	107	106	108	110
18.3	101	105	103	106	105	103	102	104	104
21.3	105	106	106	108	108	104	103	105	104
24.8	108	108	108	111	111	109	108	109	109
28.3	108	110	109	111	110	106	105	106	105

RECEIVER SENSITIVITY (dBM)

TEST NUMBER

FREQUENCY MHZ	PRE TEST	A	B2	D (1)	F10 (1)	F11 (2)
1.8	-93	-92	-87	-89	-88	-87
3.8	-93	-92	-93	-89	-87	-87
7.3	-98	-99	-94	-96	-94	-90
10.3	-98	-99	-94	-96	-94	-90
14.3	-98	-99	-93	-96	-93	-89
18.3	-95	-97	-91	-93	-91	-87
21.3	-96	-97	-91	-93	-91	-89
24.8	-95	-96	-91	-92	-90	-89
28.3	-96	-98	-93	-94	-93	-89

BENCH-CHECK SETUP NOTES:
(1) WITHOUT PROTECTIVE DEVICE IN COAXIAL LINE
(2) WITH PROTECTIVE DEVICE IN COAXIAL LINE

Table 4-7. Test Measurements - System 6

TRANSMITTER POWER (WATTS)

TEST NUMBER

FREQUENCY MHZ	PRE TEST	A	B	D (1)	D (2)	F (1)	F (2)
144.0 (25W)	19	19	19.5	19.2	17.2	22.5	21
144.0 (5W)	4	3.9	4	3.9	4.0		

RECEIVER SENSITIVITY (dBM)

TEST NUMBER

FREQUENCY MHZ	PRE TEST	A	B (3)	D (1)	D (2)		F (2)
144.0	-93	-96	-76	-95	-94		-94

BENCH-CHECK SETUP NOTES:
(1) WITHOUT PROTECTIVE DEVICE IN COAXIAL LINE
(2) *WITH PROTECTIVE DEVICE IN COAXIAL LINE*
(3) QUESTIONABLE VALUE

Table 4-8. Test Measurements - System 7

TRANSMITTER POWER (WATTS)

TEST NUMBER

FREQUENCY MHZ	PRE TEST	A	D (1)	D (2)(3)	F (4)
145.0 (HI)	4.6	4.1	4.0	0	3.8
145.0 (LO)	0.7	0.6	0.8	0	0.5

RECEIVER SENSITIVITY (dBM)

TEST NUMBER

FREQUENCY MHZ	PRE TEST	A	D (1)	D (2)	F (5)
145.0	-95	-96	-94	-94	-120

BENCH-CHECK SETUP NOTES:

(1) WITHOUT PROTECTIVE DEVICE IN COAXIAL LINE
(2) WITH PROTECTIVE DEVICE IN COAXIAL LINE
(3) DEVICE FCC-450-120-UHF WOULD NOT TRANSMIT, A LIKE REPLACEMENT WOULD
(4) EXACT FREQUENCY NOT KNOWN - LIQUID CRYSTAL DISPLAY FAILED DURING F SERIES TESTS
(5) STRONG AUDIBLE SIGNAL AT -120 dBM

Table 4-9. Test Measurements - System 8

TRANSMITTER POWER (WATTS)

TEST NUMBER

FREQUENCY MHZ	PRE TEST	A	B	D (1)	D (2)	F (1)	F (2)
144.0	25	24	24	26	24	25	27

RECEIVER SENSITIVITY (dBM)

TEST NUMBER

FREQUENCY MHZ	PRE TEST	A	B	D (2)	F (2)
144.0 (3)		71	77	76	69
(4)	106	102	80	80	91

BENCH-CHECK SETUP NOTES:

(1) WITHOUT PROTECTIVE DEVICE IN COAXIAL LINE
(2) WITH PROTECTIVE DEVICE IN COAXIAL LINE
(3) HEWLETT PACKARD SIGNAL GENERATOR 608D
(4) BOONTON

Table 4-10. Test Measurements - System 9

TRANSMITTER POWER (WATTS)

TEST NUMBER

FREQUENCY MHZ	PRE TEST	A	B2	D (1)	D (2)	F (1)	F (2)
430.0	22.5	18.9	19				
435.0	24	20	21	19	11.5	22	12

RECEIVER SENSITIVITY (dBM)

TEST NUMBER

FREQUENCY MHZ	PRE TEST	A	B2	D (1)	F
432.0	-102	117	-130	-120	-132

BENCH-CHECK SETUP NOTES:
(1) WITHOUT PROTECTIVE DEVICE IN COAXIAL LINE
(2) WITH PROTECTIVE DEVICE IN COAXIAL LINE

Table 4-11. Test Measurements - System 10

TRANSMITTER POWER (WATTS)

TEST NUMBER

FREQUENCY MHZ	PRE TEST	A	B1 (1)	D (2)	D (3)	F (4)	F (5)
1.8	94	96	95	94	94	84	84
3.8	104	106	106	104	104	88	90
7.3	105	109	110	105	105	97	96
10.3	105	108	109	105	104	96	96
14.3	106	110	111	105	105	95	95
18.3							
21.3	99	107	109	99	99	85	87
24.8							
28.3	95	94	96	91	90	80	77

RECEIVER SENSITIVITY (dBM)

TEST NUMBER

FREQUENCY MHZ	PRE TEST	A	B1 (1)	D (3)	F (4)
1.8	-86	-83	-87	-81	-84
3.8	-86	-85	-88	-85	-86
7.3	-84	-83	-86	-79	-82
10.3	-87	-86	-89	-84	-87
14.3	-87	-86	-88	-84	-86
18.3	-86	-85	-87	-82	-84
21.3	-87	-85	-88	-83	-83
24.8	-83	-81	-85	-79	-81
28.3	-83	-82	-86	-78	-85

BENCH-CHECK SETUP NOTES:

(1) ANTENNA TUNER OUT OF CIRCUIT
(2) ANTENNA TUNER OUT OF CIRCUIT WITHOUT PROTECTIVE DEVICE
(3) ANTENNA TUNER OUT OF CIRCUIT WITH PROTECTIVE DEVICE
(4) ANTENNA TUNER IN CIRCUIT WITH PROTECTIVE DEVICE
(5) ANTENNA TUNER IN CIRCUIT WITHOUT PROTECTIVE DEVICE

Table 4-12. Test Measurements - System 11

TRANSMITTER POWER (WATTS)

TEST NUMBER

FREQUENCY MHZ	PRE TEST	A	B2	D/E5	E6 (1)	E6 (2)	E7/8 (2)	D18 E9/ 10/11	F7 (1)	F7 (2)
1.8	97	97	98	97	95	90	96	97	98	98
3.8	108	108	109	108	105	106	106	107	109	108
7.3	110	111	111	110	109	109	108	110	110	110
10.3	110	111	111	111	108	107	107	109	109	108
14.3	110	112	112	110	109	108	109	110	108	108
18.3										
21.3	107	108	110	107	106	105	105	106	107	107
24.8										
28.3/8	100	96	98	97	99	90	93	99	99	100

RECEIVER SENSITIVITY (dBM)

TEST NUMBER

FREQUENCY MHZ	PRE TEST	A	B2	D/E5	E6	E7/8	D18 E9/ 10/11	F7 (2)
1.8	-88	-88	-83	-84	-84	-84	-84	-85
3.8	-89	-88	-85	-86	-85	-86	-85	-86
7.3	-86	-85	-81	-82	-82	-81	-81	-81
10.3	-89	-89	-84	-84	-85	-85	-84	-86
14.3	-90	-89	-84	-84	-85	-85	-84	-86
18.3	-89	-88	-84	-85	-85	-86	-84	-87
21.3	-88	-88	-82	-82	-84	-84	-82	-86
24.8	-85	-84	-82	-79	-79	-78	-78	-79
28.3/8	-87	-86	-81	-83	-84	-82	-83	-81

BENCH-CHECK SETUP NOTES:

(1) WITHOUT PROTECTIVE DEVICE IN COAXIAL LINE
(2) WITH PROTECTIVE DEVICE IN COAXIAL LINE

Table 4-13. Test Measurements - System 12

TRANSMITTER POWER (WATTS)

TEST NUMBER

FREQUENCY MHZ	PRE TEST	A	B	D (1)	D (2)	F (1)	F (2)
144.0 (25W)	23.5	23.1	24.5	23	22	26	27
144.0 (5W)	5.7	5.6	5.8		6		

RECEIVER SENSITIVITY (dBM)

TEST NUMBER

FREQUENCY MHZ	PRE TEST	A	B	D (1)	D (2)	F (2)
144.0	-106	-110	-90	-107	-105	-107

BENCH-CHECK SETUP NOTES:

(1) WITHOUT PROTECTIVE DEVICE IN COAXIAL LINE
(2) WITH PROTECTIVE DEVICE IN COAXIAL LINE

Table 4-14. Test Measurements - System 13

TRANSMITTER POWER (WATTS)

TEST NUMBER

FREQUENCY MHZ	PRE TEST	A	D (1)	D (2)	F
145.0 (HI)	4.0	4.0	4.0	4.0	4.0
145.0 (LO)	0.5	0.4	0.5	0.5	0.4

RECEIVER SENSITIVITY (dBM)

TEST NUMBER

FREQUENCY MHZ	PRE TEST	A	D (1)	D (2)	F
145.0	-97.2	-94	-96	-96	-97

BENCH-CHECK SETUP NOTES:
(1) WITHOUT PROTECTIVE DEVICE IN COAXIAL LINE
(2) WITH PROTECTIVE DEVICE IN COAXIAL LINE

Table 4-15. Test Measurements - System 14

TRANSMITTER POWER (WATTS)

TEST NUMBER

FREQUENCY MHZ	PRE TEST	A	B	D (1)	D (2)	F (1)	F (2)
1.8							
3.8	90	65	107	71	71	35	38
7.3	87	75	125	72	105	40	35
10.3							
14.3	90	120	99	90	62	50	40
18.3							
21.3	75	105	90	48	50	80	75
24.8							
28.3							

RECEIVER SENSITIVITY (dBM)

TEST NUMBER

FREQUENCY MHZ	PRE TEST	A	B	D (1)	D (2)	F (1)	F (2)
1.8							
3.8	-55	-91	-88	-84	-84	-85	-85
7.3	-56	-91	-90	-83	-83	-84	-85
10.3							
14.3	-56	-82	-87	-82	-82	-79	-81
18.3							
21.3	-52	-82	-80	-77	-77	-73	-75
24.8							
28.5	-54	-82	-82				

BENCH-CHECK SETUP NOTES:
(1) WITHOUT PROTECTIVE DEVICE IN COAXIAL LINE
(2) WITH PROTECTIVE DEVICE IN COAXIAL LINE

Table 4-16. Test Measurements - System 16

TRANSMITTER POWER (WATTS)

TEST NUMBER

FREQUENCY MHZ	PRE TEST	A	B	D (1)	D (2)	F (1)	F (2)
52.0	75	105	85	93	91	88	88

RECEIVER SENSITIVITY (dBM)

TEST NUMBER

FREQUENCY MHZ	PRE TEST	A	B	D (1)	D (2)	F (1)	F (2)
52.0	-120	-120	-120	-120	-120	-120	-120

BENCH-CHECK SETUP NOTES:
(1) WITHOUT PROTECTIVE DEVICE IN COAXIAL LINE
(2) WITH PROTECTIVE DEVICE IN COAXIAL LINE

Table 4-17. List of Devices and Components Tested

COMMERCIAL

ITEM	MANUFACTURE	PART	DESCRIPTION
1	FISCHER	FCC-250-300-UHF	SPIKEGUARD SUPPRESSOR COAXIAL LINE
2	FISCHER	FCC-250-350-UHF	SPIKEGUARD SUPPRESSOR COAXIAL LINE
3	FISCHER	FCC-250-150-UHF	SPIKEGUARD SUPPRESSOR COAXIAL LINE
4	FISCHER	FCC-250-120-UHF	SPIKEGUARD SUPPRESSON COAXIAL LINE
5	FISCHER	FCC-450-120-UHF	SPIKEGUARD SUPPRESSOR COAXIAL LINE
6	JOSLYN	2031-35-B	MINIATURE GAS-TUBE SURGE PROTECTOR (MSP)
7	GENERAL ELECTRIC	V36ZA80	METAL OXIDE VARISTOR (GE-MOV)
8	POLYPHASER CORP	IS-NEMP	COAXIAL LINE PROTECTOR
9	POLYPHASER CORP	IS-NEMP-1	COAXIAL LINE PROTECTOR
10	POLYPHASER CORP	IS-NEMP-2	COAXIAL LINE PROTECTOR
11	TII	MODEL - 428	PLUG-IN POWERLINE PROTECTOR
12	SIEMENS	S14K130	METAL OXIDE VARISTOR (SIOV)
13	SIEMENS	B1-A350	BUTTON TYPE SURGE VOLTAGE PROTECTOR
14	ALPHA DELTA	TRANSI TRAP R-T	COAXIAL LINE SURGE PROTECTOR
15	ARCHER	61-2785	3 OUTLET VOLTAGE SPIKE PROTECTOR

Table 4-18. Amateur Radio Systems/Equipment Tested

ITEM	SYSTEMS/EQUIPMENT
	SYSTEM 1
1	YAESU - FP-757HF - POWER SUPPLY
2	YAESU - FT-757GX - HF ALL MODE TRANSCEIVER
3	YAESU - FC-757AT - ANTENNA TUNER
	SYSTEM 2
4	YAESU - FP-757HF - POWER SUPPLY
5	YAESU - FT-757GX - HF ALL MODE TRANSCEIVER
	SYSTEM 3
6	YAESU - FT-726R - V/UHF ALL MODE TRI BANDER
	SYSTEM 4
7	ICOM - 1C-745 HF TRANSCEIVER
8	ICOM - 1C-PS35 INTERNAL POWER SUPPLY
9	ICOM - 1C-SM6 DESK MICROPHONE
10	ICOM - 1C-AT100 ANTENNA TUNER
11	ICOM - 1C-SP3 EXTERNAL SPEAKER
	SYSTEM 5
12	ICOM - 1C-745 HF TRANSCEIVER
13	ICOM - 1C-PS35 INTERNAL POWER SUPPLY
	SYSTEM 6
14	ICOM - 1C-27A 2 METER MOBILE TRANSCEIVER
	SYSTEM 7
15	ICOM - 1C-02AT 2 METER HANDHELD TRANSCEIVER
	SYSTEM 8
16	ICOM - 1C-271A 2 METER TRANSCEIVER
	SYSTEM 9
17	ICOM - 471A 430-450 MHZ TRANSCEIVER
	SYSTEM 10
18	KENWOOD TS-430S HF TRANSCEIVER
19	KENWOOD PS-430 POWER SUPPLY
20	KENWOOD MC-80 DESK MICROPHONE
21	KENWOOD AT-250 ANTENNA TUNER
22	KENWOOD ST-430 EXTERNAL SPEAKER

Table 4-13. Continued

	SYSTEM 11
23	KENWOOD TS-430S HF TRANSCEIVER
24	KENWOOD PS-430 POWER SUPPLY
(20)	KENWOOD MC-80 DESK MICROPHONE
	SYSTEM 12
25	KENWOOD TR-7930 2 METER MOBILE TRANSCEIVER
	SYSTEM 13
26	KENWOOD TR-2600 2 METER HANDHELD TRANSCEIVER
	SYSTEM 14
27	DRAKE T-4XC HF (TUBE) TRANSMITTER
28	DRAKE R-4C HF (TUBE) RECEIVER
29	DRAKE 4B HF POWER SUPPLY
	SYSTEM 15 (NOT TESTED)
30	COLLINS KWM-2A - HF (TUBE) TRANSCEIVER
31	COLLINS KWM-2A POWER SUPPLY
	SYSTEM 16
32	SWAN 250 HF (TUBE) TRANSCEIVER
33	SWAN 117Z POWER SUPPLY
	ANTENNA's
34	MOSLEY JRS TA33 3 ELEMENT TRIBANDER ANTENNA
35	CUSHCRAFT AV-5 80 TO 10 METER ANTENNA
	OTHER ITEMS
36	ASTRON VS-35 POWER SUPPLY
37	HONDA EG 650 POWER GENERATOR

Table 4-19. Assembled Transient Protection Devices

ITEM	DEVICE TEST NAME	DESCRIPTION
1	SIOV AC TEST BOX	3 ea Siemens Metal Oxide varistors, type - S14K130 were installed in an AC power receptacle box - one from hot to ground, one from neutral to ground, and one between hot and neutral.
2	GE MOV	1 ea GE Metal Oxide varistor, type - V36ZA80 was installed across the 12 Volt DC power line between hot and ground.
3	SIOV RF TEST BOX	1 ea Siemens metal oxide varistor, type - S14K130 was installed in a metal box. The box had UHF connectors attached to both ends and a wire going between the center conductors of the two connectors. The varistor was connected to the wire on one side and to the box on the other side.
4	Siemens UHF Test Box	2 ea Siemens gas-gap tubes type BI-A350, were installed in the UHF connector box described above in series from the center conductor to the side of the box (ground).
5	Joslyn UHF Test Box	2 ea Joslyn gas-gap tubes, type 2031-35B, were installed in the UHF connector box in series from the center conductor to ground.
6	UHF Coaxial "T"	2 ea Siemens gas-gap tubes, type BI-A350, were installed in series between the center conductor and ground (case), on one leg of a coaxial "T".

SECTION 5

PROTECTION DEVICE RECOMMENDATIONS AND COST

5.1 Introduction

The recommendations in this section are based upon the results of the device and equipment test programs, discussed in the previous two sections. In addition to the test results, the recommendations take into account the relative cost, the ease of installation and other technical characteristics of the selected devices. The lowest cost device was not always recommended such as when a moderately priced transient protection device had an overall better protection performance during the test program and cost for adequate protection was still economical.

5.2 Minimum Basic Protection Recommendations

The equipment test program demonstrated that most amateur radio systems can be protected from harmful EMP and lightning transients with a very basic protection scheme. The tests showed that most of the radio equipment was not susceptible to damage when it was in a stand-alone (equipment unwired) configuration with all interconnecting wiring installed. This stand-alone configuration can be duplicated by the radio amateur by simply unplugging the AC power cord from the AC outlet, disconnecting the RF antenna coaxial cable from the back of the equipment, and isolating the equipment from any other long metal conductors. It can also be duplicated by adding two transient protection devices to the radio system.

The equipment test demonstrated that when the AC power line and the RF coaxial cable were attached and driven with large transient currents, the amateur radio equipment could sustain some damage. Therefore it was concluded that, as a minimum, the AC power lines and the RF coaxial cable interface points with the amateur radio equipment should have transient protection. Protecting these two points alone would significantly decrease the susceptibility of most amateur radio systems to damaging transients. Several of the transient protection devices tested during the device test program can be used to provide the necessary protection at these two protection points.

Protecting these two points is recommended as a minimum basic protection scheme for all amateur equipment with one exception. That exception is that no protection is being recommended for the antenna port on amateur handheld radios as long as the "rubber duck" antenna is being used. If a larger antenna system is used, protection is recommended. When tested in an EMP simulator the "rubber duck" antenna did not generate sufficient energy to damage the handheld radio. However, handheld radios are commonly used in a mobile configuration where they are attached to two meter mobile antennas. These antennas are from 18 to 50 inches long. The transient energy that can be generated by these longer antennas and the associated coaxial cable pose a threat to the attached handheld radios. Therefore, protection is recommended.

5.2.1 Basic AC Powerline Protection. AC power protection for amateur radio equipment can be provided with an easy to install, plug-in transient protection device. Ten different AC power protection devices were tested (see Table 5-1). Six were plug-in devices which can be plugged directly into an AC outlet. Four were modular devices which require more extensive installation and, in some cases, more than one module.

The plug-in devices are the best overall choice for the typical amateur installation. They provide all of the basic transient protection needed; they are easy to install; and they can be easily moved with the equipment to other operating locations. The modular devices tested are the second choice since they all require some installation and none of the devices tested provided full EMP protection for all three wires of the AC power system.

The highest recommendation goes to the TII Model 428, Plug-In Powerline Protector. This device is considered to be the best overall protector. It

TABLE 5-1

AC POWER PROTECTORS

Manufacturer	Device	Estimated Cost	High Z Measured Clamping Voltage
FISCHER	FCC-120F-P (MODULE)	55.00	420
JOSLYN	1270-02 (PLUG-IN)	49.00	600
JOSLYN	1250-32 (MODULE)	31.00	940
TII	428 (PLUG-IN)	45.00	410
GENERAL SEMICONDUCTOR	587B051(MODULE)	56.00	600
GENERAL SEMICONDUCTOR	PHP 120 (MODULE)	49.91	400
ELECTRONIC PROTECTION DEVICES	LEMON (PLUG-IN)	44.90	580
ELECTRONIC PROTECTION DEVICES	PEACH (PLUG-IN)	59.90	1000
S.L. WABER	LG-10 (PLUG-IN)	12.87	600
ARCHER	61-2785 (PLUG-IN)	21.95	300

provides transient paths to ground from both the hot and the neutral lines (common mode), as well as a transient path between the hot and neutral lines (normal mode). It employs three metal oxide varistors and a three electrode gas-tube arrestor to provide both fast operation and large power dissipation capabilities. It was tested repeatedly during both test programs and successfully operated without failure. The estimated price is $45.00 and the average measured clamping voltage is 410 volts (peak).

Several of the other plug-in transient protection devices also provided full three wire protection, but all operated at higher clamping voltages. Other lower cost plug-in devices either lacked the three wire protection capability or had substantially higher clamping voltages. Some of these devices are mentioned below:

> The Joslyn 1270-02 provided full three wire transient path protection (both common mode and normal mode) but at a slightly higher cost ($49.00) and at a higher clamping voltage (600 volts).
>
> Two plug-in devices were manufactured by Electronic Protection Devices, Inc. The "LEMON" device provided full three wire protection (both common mode and normal mode) but at a high clamping voltage (580 volts) and the "PEACH" at a dangerously high clamping voltage (1000 volts).

The Radio Shack's Archer 3 outlet voltage spike protector - 61-2785 provided an excellent clamping performance (300 volts) at a low cost ($21.95), but it only provided normal mode protection (a transient path between the hot and neutral leads) and no common mode protection. It would provide some protection for lightning transients but not enough for EMP.

The lowest cost device the S.L. Waber LG-10 ($12.87) did not provide full three wire protection (only normal mode) and operated at a clamping voltage of 600 volts. This device can provide limited transient protection for lightning, but not the three wire protection recommended for EMP transients.

5.2.2 Basic DC Power Protection. The current amateur radio transceivers are designed to operate on (13.8 volts) DC power. This includes all of the new HF, VHF and UHF transceivers tested. Even the handheld radio can be converted to 13.8 volts DC power with a separate power supply. In a fixed installation these transceivers require an AC to DC power supply to provide the 13.8 volts required for DC operation. For mobile operation the manufacturer provides a two line DC power cord. One end plugs into the back of the transceiver and the other end is attached to a DC power source (i.e. auto battery, etc.). This DC power cord normally has fuses in both lines. To provide transient protection for the radios when using this cord, a metal oxide varistor (MOV) should be installed between the positive and the negative lines.

A General Electric MOV (V36ZA80) is recommended for this installation. This MOV was thoroughly tested and provided the lowest measured clamping voltage (170V) during the test program. Its estimated price is $1.49.

5.2.3 Basic RF Protection. The radio amateur's equipment can be protected from the large currents impressed upon the radio's antenna system by lightning and EMP by providing a path to ground for the transient energy before it reaches the radio equipment. Basic protection can be provided for the radio transceiver equipment by installing a transient protection device between the antenna transmission line and the transceiver's antenna port. A single protection device installed at the transceiver's antenna port will protect the transceiver, but will not protect the antenna transmission line. To protect the antenna transmission line, an additional device would have to be installed between the antenna and the transmission line.

It is recommended that, as a minimum, a transient protection device be installed between the transceiver's RF port and the RF transmission line. This would provide the minimum basic protection, and would reduce the susceptibility of damage to the amateur radio transceiver from lightning and EMP transients. This single point installation would still leave the transmission line unprotected. However, a spare transmission line could be obtained at less cost than an additional protection device in most cases. The only exception to this recommendation is the hand-held radio, which tests have shown, does not need protection as long as the "rubber duck" antenna is used. The "rubber duck" antenna is too short to generate sufficient energy from an EMP field to damage the handheld radio. The "rubber duck' antenna generated 400 volts though 50 ohm resistance when subjected to the EMP simulator pulse field.

Radio frequency (R.F.) transient protection devices from three different manufacturers were tested (See Table 5-2). All of the devices tested could be installed directly in the coaxial cable transmission line. RG-8 coaxial cable with UHF connectors was used during the test program. The RF transient protection device may be aided by the effects of the coaxial cable. During the tests with the EMP simulator the RG-8 coaxial cable acted like a filter suppressor, arcing the damaging EMP energy from the center conductor to the cable shield when the voltage level approached 5.5KV.

Both low price and low clamping voltages had to be considered in the selection of the recommended RF transient protection device. However, the lowest cost devices had the highest clamping voltages and the highest cost

TABLE 5-2

RF COAX PROTECTORS*

Manufacturer	Device	Estimated Cost	High Z Measured Clamping Voltage
FISCHER	FCC-250-300-UHF	55.00	393
FISCHER	FCC-250-350-UHF	55.00	260
FISCHER	FCC-250-150-UHF	55.00	220
FISCHER	FCC-250-120-UHF	55.00	240
FISCHER	FCC-450-120-UHF	55.00	120
POLYPHASER	IS-NEMP	82.95	140
POLYPHASER	IS-NEMP-1	82.95	150
POLYPHASER	IS-NEMP-2	82.95	160
ALPHA DELTA	LT	19.95	700
ALPHA DELTA	RT	29.95	720

* The transmitter output power, frequency bands, and antenna transmission line VSWR must be considered when selecting any of these devices.

devices had the lowest clamping voltages. This situation led to the selection of the medium priced devices, manufactured by Fischer Custom Communications. The Fischer Spikeguard Suppressors for coaxial lines are recommended. They are priced at $55.00 each and can be made-to-order to operate at a specific clamping voltage. During the device test program, all of the Fischer devices performed in an acceptable manner. The one exception was a very low clamping voltage device that operated 60 Volts above the test acceptance voltage. This device was not included in these recommendations since it was being evaluated for use with a handheld radio, and protection for the handheld radio is not required.

During both the device and the equipment test programs, the Fischer devices satisfactorily suppressed the damaging transient pulses, passed the RF output power without interfering with the signal, and operated effectively over a wide range of frequencies.

The devices made by Polyphaser Corporation were also very effective in providing the necessary transient protection. However, the available devices limited the RF output power to 100 watts or less. At an estimated cost of $82.95, they are the second recommended devices.

The Alpha Delta Transi Trap devices were the least effective in suppressing the transient pulse. A clamping voltage of over 700 volts was present during the device test series and a transceiver was degraded while a Transi-Trap device was installed. Although the devices are very low cost, they are not as suitable for EMP suppression due to their high clamping voltages.

When selecting one of these RF protection devices, consideration must be given to the transmitter RF power output, the voltage standing wave ratio, and the radio frequency operating range required.

5.2.3.1 Calculation of Clamping Voltage. It is desirable to obtain a protection device with the lowest possible clamping voltage to provide the most protection from the incoming transient energy. However, the protection device must also allow the outgoing RF transmission signal to pass without clamping. The required clamping voltage must be calculated for each particular amateur installation.

The RF power input to a coaxial cable will develop a corresponding voltage level which becomes important when a voltage surge arrestor is in the cable. The voltage standing wave ratio (VSWR) also becomes important because of its influence on the voltage level developed in the cable. The maximum voltage that is developed for a given power input is determined by the equation:

$$V = \sqrt{P \times Z} \times VSWR$$

where P = Power in Watts (either RMS or Peak)

Z = Impedance of coaxial cable in Ohms

V = Voltage across the cable (either RMS or Peak)

and V peak = V RMS x 1.414

VSWR = Voltage Standing Wave Ratio

To determine the desired clamping voltage level for a protection device for a particular radio system, the preceeding equation should be used to arrive at the peak voltage in the RF transmission line. The voltage level at which an RF device will clamp is not a fixed value, since these devices use gas discharge tubes. A safety margin must be added to the calculated peak voltage to arrive at a final clamping voltage level for a device. The peak voltage in the transmission line should be multiplied by three (3) and the figure obtained used as the final clamping voltage level. This calculation will work quite well when specifying a clamping voltage for an RF suppressor.

The following is a calculation for a typical HF amateur radio system. This example uses the specifications from the Yaesu FT-757-GX transceiver and an RG-8 coaxial cable. First, the voltage standing wave ratio (VSWR) of the amateur's antenna system must be measured. For this calculation a ratio of 1.5 to 1 will be used. The Yaesu FT-757-GX transmitter power output is

100W (watts) PEP (peak-envelope-power). The RG-8 coaxial cable has an impedance of 52 ohms. Therefore:

$P = 100W$ (peak power)

$Z = 52$ ohms

$VSWR = 1.5$

Substituting in the equation gives:

$V \text{ peak} = \sqrt{100 \times 52} \times 1.5$

Voltage is peak since power is peak.

$V \text{ peak} = \sqrt{5200} \times 1.5$

$V \text{ peak} = 72.1 \times 1.5$

$V \text{ peak} = 108.15$ volts

This is the calculated peak voltage in the coaxial cable.

To determine the final clamping voltage the peak voltage in the coaxial cable must be multiplied by three (3) to provide the safety margin. Therefore:

Final clamping voltage (FCV) = V peak x 3

$FCV - 108.15 \times 3$

$FCV = 324.45$ volts

Therefore the amateur should order an RF suppressor which clamps at or above 324 volts.

This added safety margin is required to assure that the transmitter's RF output power will pass through the transient suppression device without causing the device to clamp the RF signal to ground. The final clamping voltage obtained will be high enough to allow normal operation of the radio transmitter, while providing the lowest possible clamping voltage for the transient suppression device and, thereby, providing the maximum protection possible for the radio system.

5.3 Cost for Basic Protection

The cost for a two point minimum basic protection is estimated to be \$100.00 per fixed amateur system. This would include one TII Model 428 plug-in power line protector at a cost of \$45.00 and one Fischer coaxial line protector at a cost of \$55.00. This is the recommended first phase transient protection approach that should be used by the radio amateur.

5.4 Assembled Transient Protection Devices Tested.

After completion of the initial phases of the equipment test program, it was evident that all equipment under test could satisfactorily survive the transient field environment. However, it was considered desirable to provide protection against the injected threat pulse on the power cord and the antenna connection. Commercial devices were tested and proved that the radio equipment could survive when protected. Inexpensive devices were then fabricated and tested. The simplest power and antenna protection devices are described below:

5.4.1 Power Protection (SIOV AC TEST BOX). A power protection device as shown in Figure 5-1 was fabricated by installing a duplex receptacle in a metal electrical box. Power was brought to the box by a six foot, three wire power cord. A fuse was installed on the incoming "hot" wire to guard against harmful effects if one of the protective devices shorted. Protective devices, metal-oxided varistors, SIEMENS S14K130, were installed between the hot and neutral terminals, between hot and ground, and between neutral and ground with the shortest possible lead lengths. This protective device performed flawlessly throughout the tests, and was observed to prevent failure of one item of equipment which did fail when the device was removed from the circuit. The estimated cost of all items required to assemble this AC protection device is $11.00.

5.4.2 Antenna Connection Protection (UHF COAXIAL "T"). The radio antenna connection was protected by a simple device fabricated by installing two spark gaps, SIEMENS BI-A350, in series in one end of a coaxial cable "tee" connector as shown in Figure 5-2. The two spark gaps were soldered together in series with the shortest practical lead length between them (about 1/4 inch). One lead was then bent and forced between the split

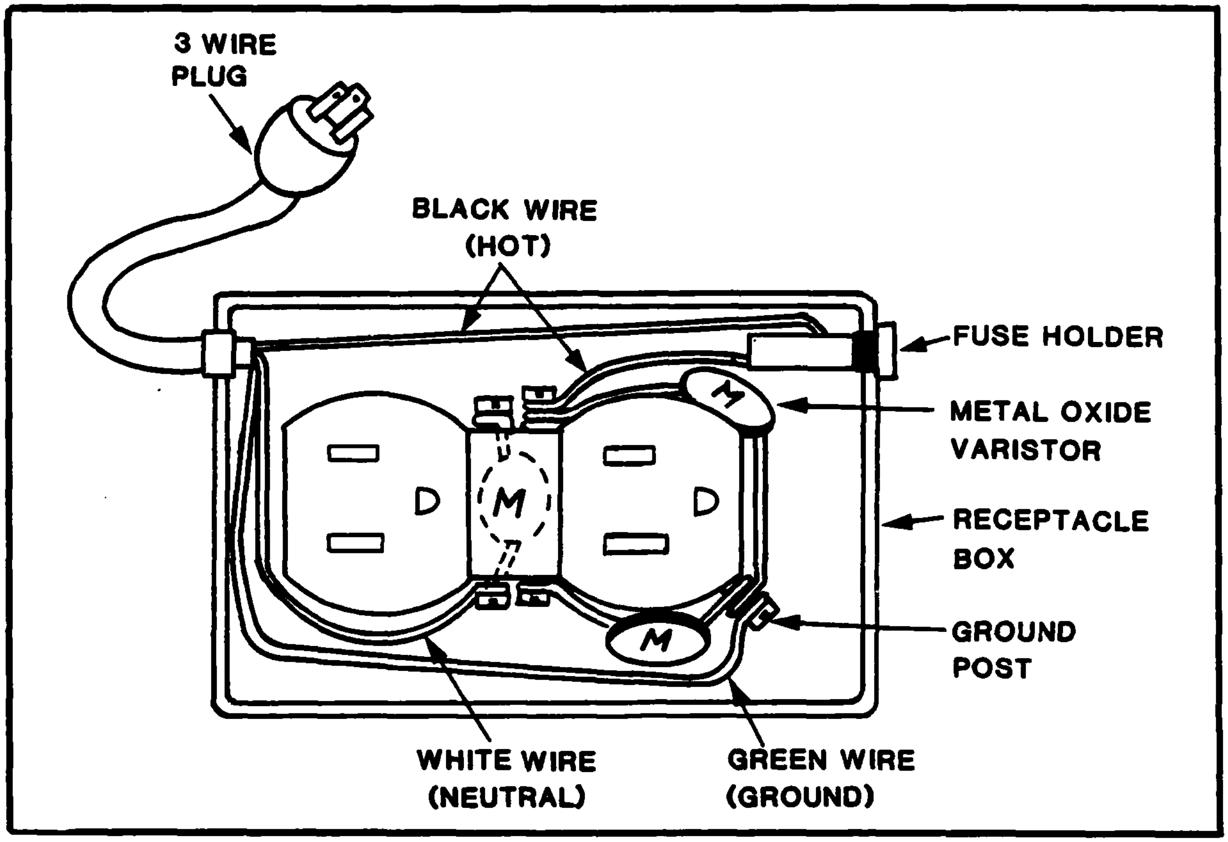


Figure 5-1. AC Power Protector

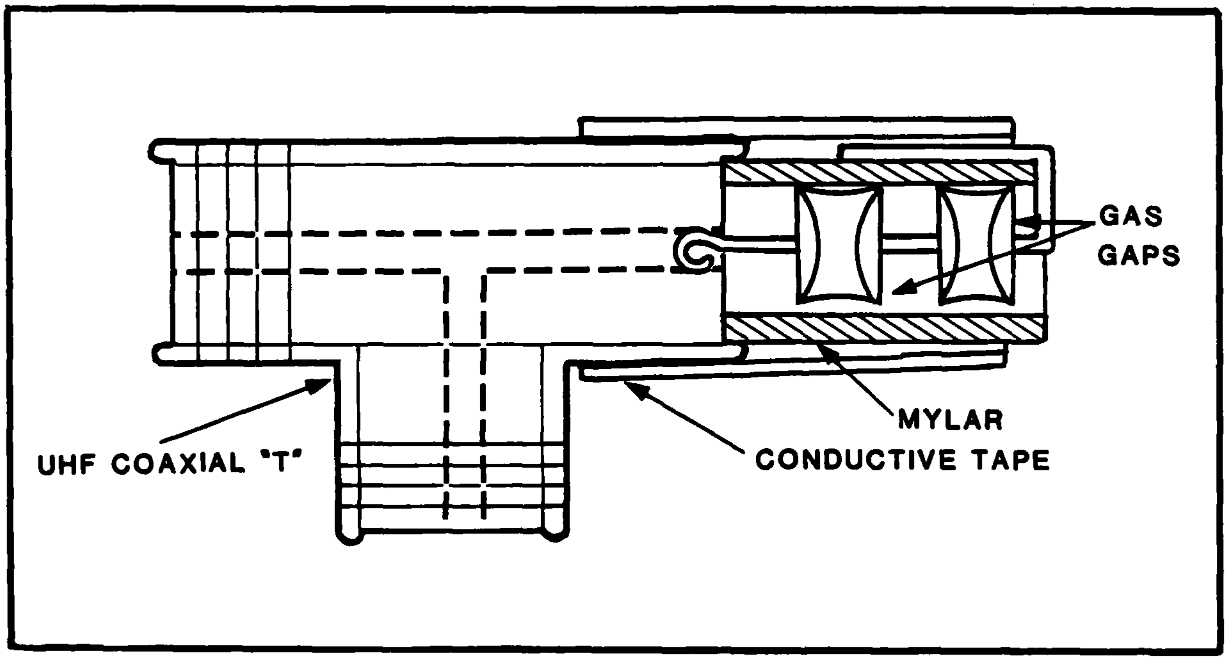


Figure 5-2 Antenna Connection Protector

sections of the inner coaxial connector until the spark gaps approached the body of the connector. A short length of mylar insulation was rolled around the spark gaps and temporarily held in place inside the outer shell of the connector. The other lead of the spark gap combination was brought over the mylar and fastened with metal tape around both the mylar and the outer shell of the connector. This construction proved durable through many insertions and removals of the device during testing, and protected the antenna connections of the equipment without appreciable degradation of either power output or sensitivity of the equipment. The estimated cost of all items required to assemble this UHF protection device is $9.00. This device and the SIOV AC test box can also be made from other tested and accepted components manufactured by Joslyn, General Electric, General Semiconductor, or Siemens (see Table 5-3).

5.5 Protection Device and Equipment Recommendations

Table 5-3 lists the recommended device and radio equipment combinations for the amateur radio systems tested. All of the radio systems tested are recommended for use in a lightning and EMP transient environment. When properly protected, all of the radio systems tested were able to survive a full EMP simulation without significant degradation.

Table 5-3. Device and Equipment Recommendations

MANUFACTURER	DEVICE	DESIGNED MAXIMUM CLAMPING VOLTAGE (MCV)	AVERAGE MEASURED PEAK VOLTAGE @ 4500V 50 OHMS (APV)	ESTIMATED COST (dollars)	RECOMMENDED APPLICATION
FISCHER					
1	FCC-120F-P	300(1)	420	$55.00	ALTERNATIVE AC TRANSIENT VOLTAGE SURGE SUPPRESSOR.
2	FCC-250-300-UHF	300	393	55.00	RECOMMENDED RF SURGE SUPPRESSOR FOR SYSTEMS 1, 2, 14 & 16
3	FCC-250-350-UHF	350	260	55.00	RECOMMENDED RF SURGE SUPPRESSOR FOR SYSTEMS 4, 5, 10 & 11
4	FCC-450B-75-BNC	75	210	55.00	TESTED FOR HANDHELD RADIOS - BUT IT IS NOT REQUIRED.
5	FCC-250-150-UHF	150	220	55.00	RECOMMENDED RF SURGE SUPPRESSOR FOR SYSTEM 3
6	FCC-250-120-UHF	120	240	55.00	RECOMMENDED RF SURGE SUPPRESSOR FOR SYSTEMS 6, 8, 9, 12
7	FCC-450-120-UHF	120	120	55.00	RECOMMENDED FOR USE AT THE TRANSCEIVER, WITH FCC 250-120 UHF AT THE ANTENNA FOR COAXIAL CABLE PROTECTION.
JOSLYN					
8	2027-23-B	230	310	3.00	ACCEPTABLE COMPONENT
9	2027-35-B	350	366	3.00	ACCEPTABLE COMPONENT
10	1270-02	190	600	49.00	ALTERNATIVE AC TRANSIENT VOLTAGE SURGE SUPPRESSOR.
11	1250-32	350	940	31.00	NOT ACCEPTED
12	1663-08	66	90	63.00	ACCEPTABLE DATA LINE TRANSIENT PROTECTOR (DC TO 20 KHZ)
13	2027-09-B	90	379	3.25	NOT ACCEPTED
14	2027-15-B	150	242	3.25	ACCEPTABLE COMPONENT
15	2022-44	250	294	5.00	ACCEPTABLE COMPONENT
16	2031-23-B	230	336	3.05	ACCEPTABLE COMPONENT
17	2031-35-B	350	291	3.05	ACCEPTABLE COMPONENT
GENERAL ELECTRIC					
18	V39ZA6	76	254	.87	ACCEPTABLE COMPONENT
19	V82ZA12	147	254	.87	ACCEPTABLE COMPONENT
20	V180ZA10	300	388	1.29	ACCEPTABLE COMPONENT
21	V8ZA2	20	174	.78	NOT ACCEPTED
22	V36ZA80	63	170	1.49	RECOMMENDED DC (13.8 VOLTS) TRANSIENT VOLTAGE SURGE SUPPRESSOR.
POLYPHASER CORPORATION					
23	IS-NEMP	200(2)	140	82.95	ALTERNATIVE RF SURGE SUPPRESSOR FOR SYSTEMS 1, 2, 3, 8, 9, 12, 14 & 16
24	IS-NEMP-1	200(2)	150	82.95	ALTERNATIVE RF SURGE SUPPRESSOR FOR SYSTEMS 3, 6, 8, 9 & 12
25	IS-NEMP-2	200(2)	160	82.95	ALTERNATIVE RF SURGE SUPPRESSOR FOR SYSTEMS 6, 8, 9 & 12
TII					
26	MODEL 428	280	410	45.00	RECOMMENDED AC TRANSIENT VOLTAGE SURGE SUPPRESSOR ALL AC APPLICATIONS.

NOTES:
(1) ESTIMATED/CALCULATED
(2) DC BREAKDOWN

Table 5-3. Device and Equipment Recommendations (Cond't)

	MANUFACTURER	DEVICE	DESIGNED MAXIMUM CLAMPING VOLTAGE (MCV)	AVERAGE MEASURED PEAK VOLTAGE @ 4500V 50 OHMS (APV)	ESTIMATED COST (dollars)	RECOMMENDED APPLICATION
	SIEMENS					
27		S10K11	40	186	$ .37	ACCEPTABLE COMPONENT
28		S20K[illegible]	80	193	.64	ACCEPTABLE COMPONENT
29		S14K[illegible]	125	239	.33	ACCEPTABLE COMPONENT
30		S10K60	160	232	.29	ACCEPTABLE COMPONENT
31		S14K130	340	436	.35	RECOMMENDED COMPONENT FOR AC POWER PROTECTOR BOX
32		B1-C75	75(2)	220	1.38	NOT ACCEPTED
33		B1-C90/20	90(2)	210	1.23	NOT ACCEPTED
34		B1-C145	145(2)	230	1.10	ACCEPTABLE COMPONENT FOR AC POWER PROTECTION
35		B1-A230	230(2)	218	1.20	ACCEPTABLE COMPONENT
36		B1-A350	350(2)	230	1.57	RECOMMENDED COMPONENT FOR RF COAXIAL "T" PROTECTOR
37		S8-C150	150(2)		2.35	NOT ACCEPTED
38		T61-C350	300(2)	250	2.05	ACCEPTABLE COMPONENT FOR COMMUNICATION CIRCUIT APPLICATIONS
	ALPHA DELTA COMMUNICATIONS, INC.					
39		LT	635(1)	700	19.95	ALTERNATIVE RF SURGE SUPPRESSOR FOR SYSTEMS 1, 2, 3, 4, 5, 6, 8, 10, 11, 12, 14 & 16
40		RT	635(1)	720	29.95	ALTERNATIVE RF SURGE SUPPRESSOR FOR SYSTEMS 1, 2, 3, 4, 5, 6, 8, 9, 10, 11, 12, 13, 14 & 16
	GENERAL SEMICONDUCTOR					
41		5878051	650	600	56.00	ALTERNATIVE AC TRANSIENT VOLTAGE SURGE SUPPRESSOR
42		ICTE-5	7.1	134		NOT ACCEPTED
43		ICTE-15	20.1	146		NOT ACCEPTED
44		ICTE-8C	11.4	124		NOT ACCEPTED
45		LCE-6.5A	11.2	250		NOT ACCEPTED
46		LCE-15A	24.4	200		NOT ACCEPTED
47		LCE-51	91.1	220		NOT ACCEPTED
48		LCE-130A	209	210	3.45	ACCEPTABLE COMPONENT FOR PROTECTION OF AC SIGNAL LINE.
49		PHP-120	319	400	49.91	ALTERNATIVE AC TRANSIENT VOLTAGE SURGE SUPPRESSOR
50		GHV-12	8	218		NOT ACCEPTED
51		GSV-101	.85	168		NOT ACCEPTED
52		GSV-201	1.7	174		NOT ACCEPTED
	ELECTRONIC PROTECTION DEVICES, INC.					
53		LEMON	300(1)	580	44.90	ALTERNATIVE AC TRANSIENT VOLTAGE SURGE SUPPRESSOR
54		PEACH	300(1)	1000	59.90	NONE - DUE TO HIGH CLAMPING VOLTAGE
	S.L. WABER					
		LG-10	300(1)	600	$12.87	NONE (NORMAL MODE ONLY)
	ARCHER					
[illegible]		61-278[illegible]	300(1)	300	21.95	ALTERNATIVE AC TRANSIENT VOLTAGE SURGE SUPPRESSOR (NORMAL MODE ONLY)

NOTES:
(1) ESTIMATED/CALCULATED
(2) DC BREAKDOWN

SECTION 6

INSTALLATION RECOMMENDATIONS FOR LOW COST TRANSIENT PROTECTION

6.1 Introduction

This section provides recommended installation methods for the three typical amateur radio configurations: fixed (ham shack), mobile and hand-held.

6.2 Fixed Installation Recommendations

The fixed installation is the most complex of the three types of installations. The radio amateur's ham shack can consist of a single desktop transceiver and small antenna; or it can consist of a large array of transceivers, antennas, towers, power systems and grounding systems. In Volume 1, Section 5, the minimum basic transient protection recommendations required that a transient suppressor be installed on the antenna coaxial line, and a plug-in transient suppressor be used on the AC power outlet. This minimum transient protection for a single transceiver and antenna system costs approximately $100.00. For larger radio systems with several transceivers and antennas, the estimated cost would be larger by at least $100.00 for each additional system protected. This section provides installation recommendations for a ham shack with single transceiver, antenna, tower, antenna rotator and grounding system. Figure 6-1 provides a diagram of a fixed station with transient protection. Figure 6-2 provides a low cost installation plan.

6.2.1 Commercial Power Installation. The typical household is served with 60 cycle, 110-120 volts, single phase electrical power. Tests have indicated that household electrical wiring limits the maximum transient that it will pass to approximately 120 amps. Therefore, the amateur's ham shack should, if possible, be installed away from the house AC entrance panel and breaker box to take advantage of the transient limiting effects of normal household wiring.

6.2.1.1 Plug-in Transient Suppressor. The plug-in transient suppressor recommended (T11 Model 428) should be plugged into a three wire AC outlet (hot, neutral and ground). The outlet should be tested to determine if all three wires are properly connected. In older houses, an AC ground may have to be installed by a qualified electrician. The AC ground must be available for the plug-in transient suppressor to function properly. The AC ground from the AC receptacle should be attached to the ham shack ground panel (bus-bar ground). Recommend the AC plug-in receptacle be installed on the ground panel behind the radio equipment.

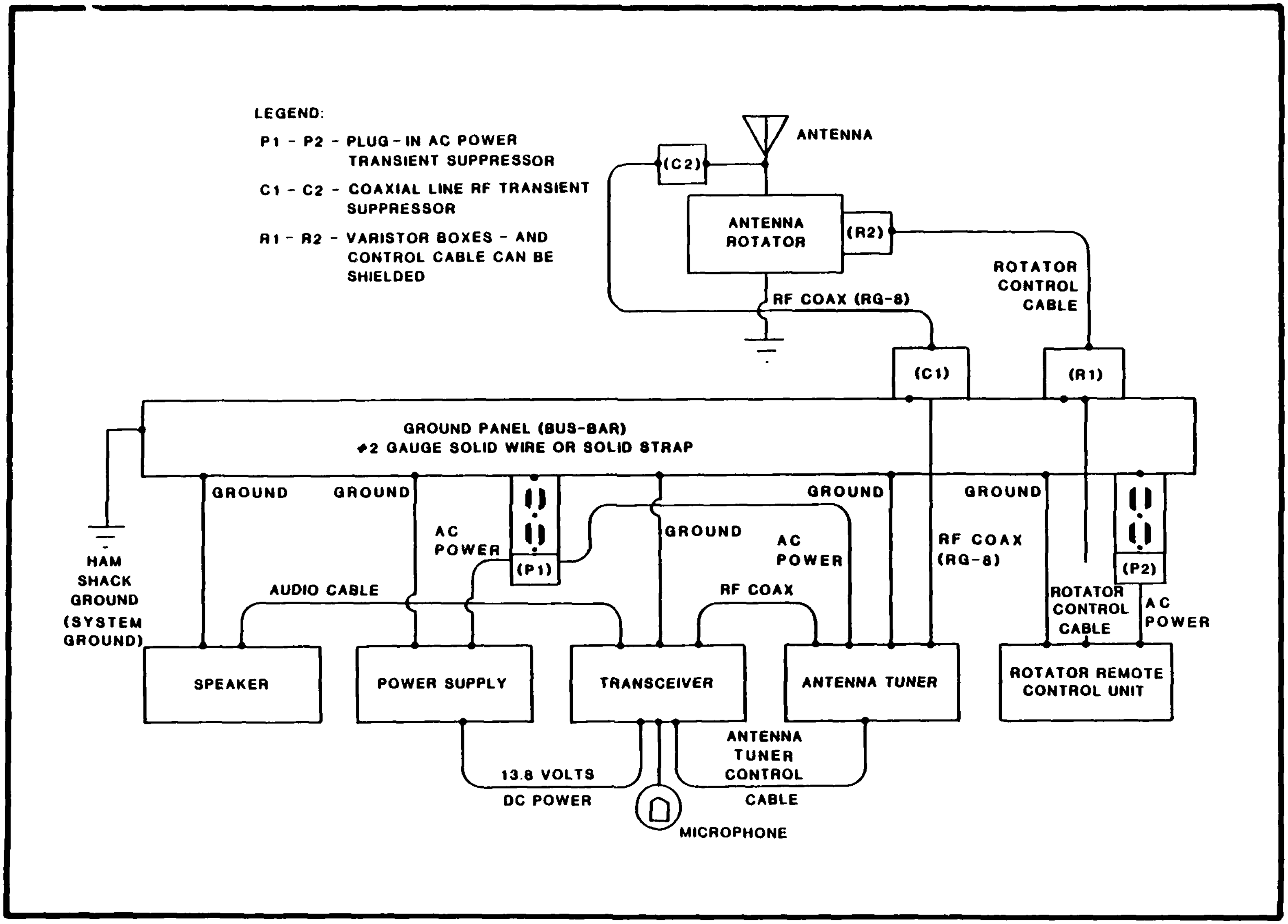


Figure 6-1. Fixed Station ("Ham Shack") Transient Protection

Installation Plan for Low Cost Fixed Station Transient Protection (Refer to Figure 6-1)			
EQUIPMENT	PHASES		
	1	2	3
Transceiver (includes: Antenna tuner, power supply and speaker)	Install P-1 C-1 ($100.00) (Est)	Install Single Point Ground ($45.00) (Est)	Shield Audio Cable and Antenna Tuner Control Cable ($10.00) (Est)
Antenna and Tower		Install C-2 ($55.00) (Est)	
Antenna Rotator System			Install P2 R1 R2 ($60.00) (Est) Shield Rotator Control Cable ($30.00 Est)

Figure 6-2 Installation Plan

6.2.1.2 Assembled AC Transient Protection Devices. Transient suppression of the AC power lines can be obtained by the assembly of plug-in devices from available components, by directly installing selected components on the household circuits, or by directly installing components in the radio transceiver.

A simple plug-in AC power suppressor can be constructed (using three Siemens SIOV's, S14K130) as described in Volume I, Secton 5. If more than two outlets are required, a plug-in outlet strip can be assembled using the same wiring arrangement. The advantage of using plug-in transient suppressors is that they can be moved with the transceiver to different operating locations. A qualified electrician can also install the same components directly in the AC wall outlets or on the load side of the AC main circuit breaker box. For older equipment, the components could be installed on the transceiver's power supply inside the equipment case. For newer equipment, this would be the last alternative since the installation could void the manufacturer's warranty.

6.2.2 Emergency Power Generators. The use of emergency power generators provides two major transient protection advantages. First, when on emergency power, the ham shack is disconnected from the commercial AC power system. This isolates the ham's radio equipment from a major source of damaging transients. Second, tests have shown that the emergency power generator may not be susceptible to EMP transients. Therefore, it will likely survive an EMP event; this was demonstrated during the Honda generator tests. The emergency power generator can be used directly to power the amateur's radio equipment; or it can be wired into the household's electrical system by a qualified electrician.

When the emergency power generator is used to directly power the radio equipment, transient protection may not be needed. If the transceiver equipment is plugged directly into the generator's outlets using only the short transceiver AC power cords, an AC protection device is not necessary. If, however, an extension cord or household wiring is used, transient protection such as a plug-in device should be used.

The emergency power generator should be wired into the household AC circuitry only by a qualified electrician. When wired into the household electrical circuitry, a switch (single throw switch) must be used which simultaneously disconnects the commercial AC power when it connects the emergency power generator. This switching arrangement must prevent feedback of emergency power onto the commercial power system. Should this feedback not be prevented it could cause death or injury to unsuspecting commercial linemen, thinking they are working on unpowered lines. The recommended household emergency power system is one that is completely separate, but parallel to the commercial wiring system going to the minimum required positions within the ham shack.

6.2.3 Antenna Rotators. The antenna rotator system can be protected by plugging the remote control box into a protected AC power source and by adding protection on the control lines going to the antenna rotator. When control lines are in a shielded cable, the shield should be grounded on both ends. Metal oxide varistors of the proper size should be installed on both ends of the control cable lines. In the ham shack, the remote control cable should be installed in a small metal box that is grounded to the ground bus-bar. Varistors should be attached from each conductor to ground inside the metal box. On the antenna end of the control cable the varistors can be placed inside the rotator case or another small metal box can be used and grounded. The Alliance HD73 antenna rotator is a typical example of a commercial rotator. It has a six conductor unshielded control cable with a maximum control voltage of 24.7 volts AC on the control links. To select a varistor clamping voltage level for these lines add a 10% safety margin to 24.7 volts. This safety margin will allow the control voltage to pass through the control lines without causing the varistor to operate (clamp the signal to ground), thus permitting normal operation of the antenna rotator. This 10% safety margin provides a voltage level of 27.17 volts. The varistor selected to protect these control lines should have a maximum continuous voltage rating that is above 27.17 volts. The

Siemens (SIOV) S14K50 has an AC rated voltage of 50 volts (RMS). It has a specified maximum clamping voltage of 125 volts. It was tested, and a measured peak clamping voltage of 234 volts was found in response to the simulated EMP pulse. Although the Alliance HD73 was not a part of the test program, it could benefit from the protection provided by these tested varistors.

6.2.4 Varistor Safety Recommendation. Due to the unpredictable energy content of a near-by lightning strike or other large transient, it is possible for a varistor to be subjected to an energy surge in excess of its rated capabilities. This may result in the destruction of the varistor by rupture of the varistor package, resulting in the expulsion of hot fragments. These fragments can cause damage to nearby components and possibly ignite flammable material. Therefore, the varistor should be physically shielded.

6.2.5 Grounding Installation. A proper grounding system is a key factor in achieving protection from lightning and EMP transients. A low impedance, low resistance grounding system for the entire ham shack and antenna system should be installed to eliminate unnecessary transient paths through the radio equipment to ground and to provide a good physical ground for the transient suppression devices.

Especially in a fixed installation, the large transient energies generated on long conductors (antennas, coaxial cables, AC power lines and telephone lines) by lightning and EMP must be prevented from flowing through the equipment's internal circuitry and case to ground. Large voltage differentials and currents on conductors going to the radio equipment must be suppressed. Properly installed transient voltage suppressors can shunt these transients to ground before they can damage the equipment.

A single point grounding system is recommended. It should tie all of the ham shack grounds together into a larger single ground. Figure 6-3 illustrates the correct way to tie the outside grounds together. Inside the ham shack the single point grounding can be provided by installing a single ground panel (ground bus-bar). All external conductors going to the radio equipment should enter and exit the ham shack through this ground panel. Transient suppression devices should be installed directly on the ground panel. This includes the AC power, antenna coax, and telephone lines, if any. The radio equipment cases should be grounded to the ground panel with the shortest possible length of solid wire (#6 gauge).

When properly installed, this single point ground will eliminate unnecessary paths to ground through the equipment. When not installed, transients will flow through the radio equipment to other grounds, such as the ham shack ground, the AC power ground and the telephone ground, if

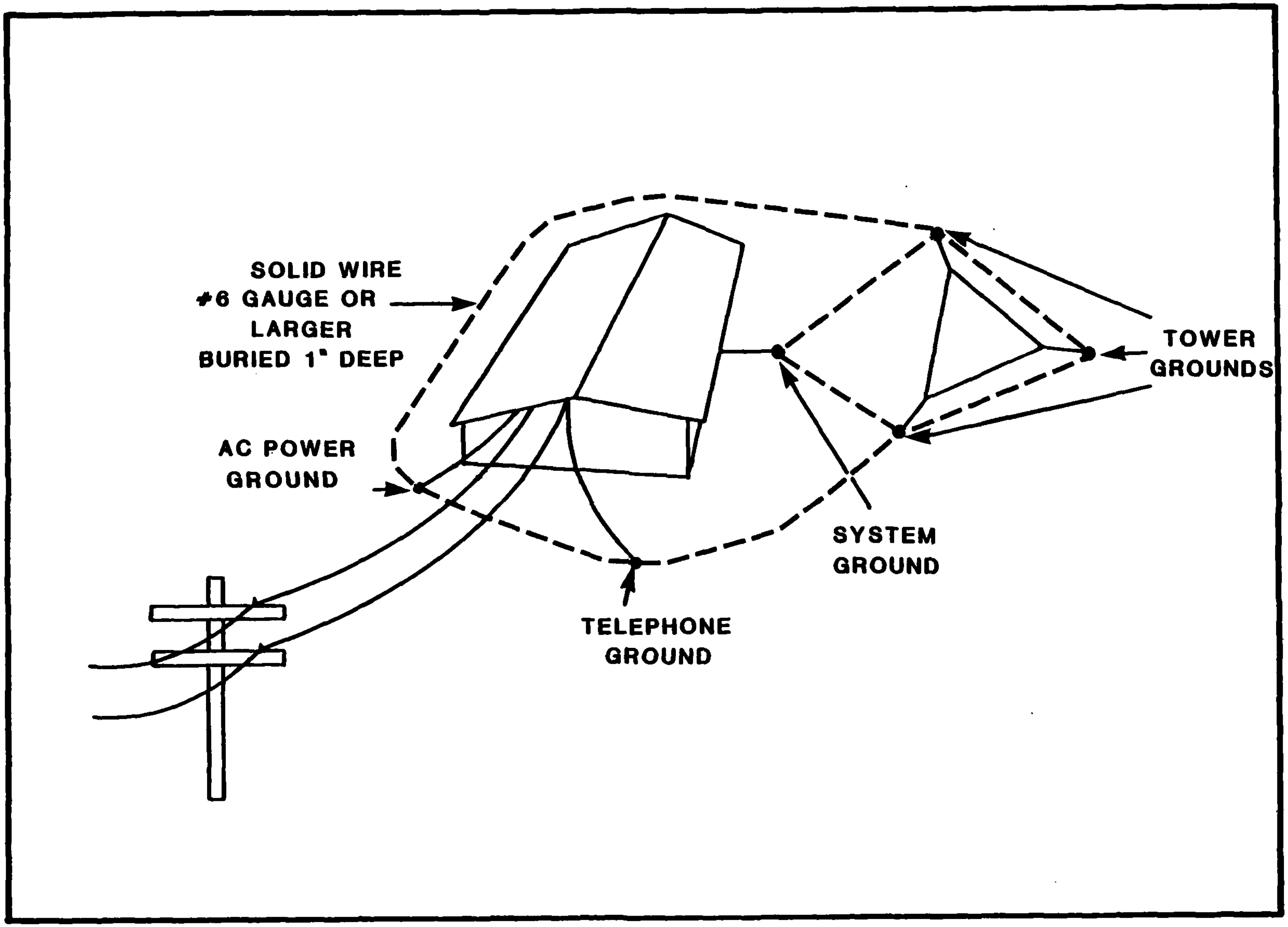


Figure 6-3. Proper Method of Tying All Ground Points Together

connected. An effective coaxial transient suppressor can eliminate the transient voltage differential between the center conductor and the cable shield; and it can even eliminate the transient current on the center conductor. However, it cannot stop the current flow on the coaxial shield. This must be done by the grounding system. Figure 6-4 illustrates the paths to ground through an improperly grounded, unprotected radio system. Figure 6-5 illustrates the path to ground after the installation of a single point ground and after the proper installation of the transient suppressors on the ground panel (bus-bar).

6.2.6 <u>Installation of RF Transmission Line Coaxial Cable</u>. Coaxial cable is the recommended RF transmission line. Tests have shown that a coaxial cable by itself provides a certain amount of transient surge protection for the attached equipment; first, by shielding the center conductor from the transient field, and second, by limiting the maximum conducted transient voltage on the center conductor by arcing the differential voltage from the center conductor to the grounded cable shield. Table 6-1 provides the characteristics of the RG-8 cable. The RG-8 provides satisfactory operational characteristics on most frequency bands of interest to the radio amateur. The table also lists a maximum operating voltage level of 4000 volts/RMS (5656 Volts Peak). When this voltage level is exceeded, the arcing between the center and outer conductor begins, as was shown during the test program.

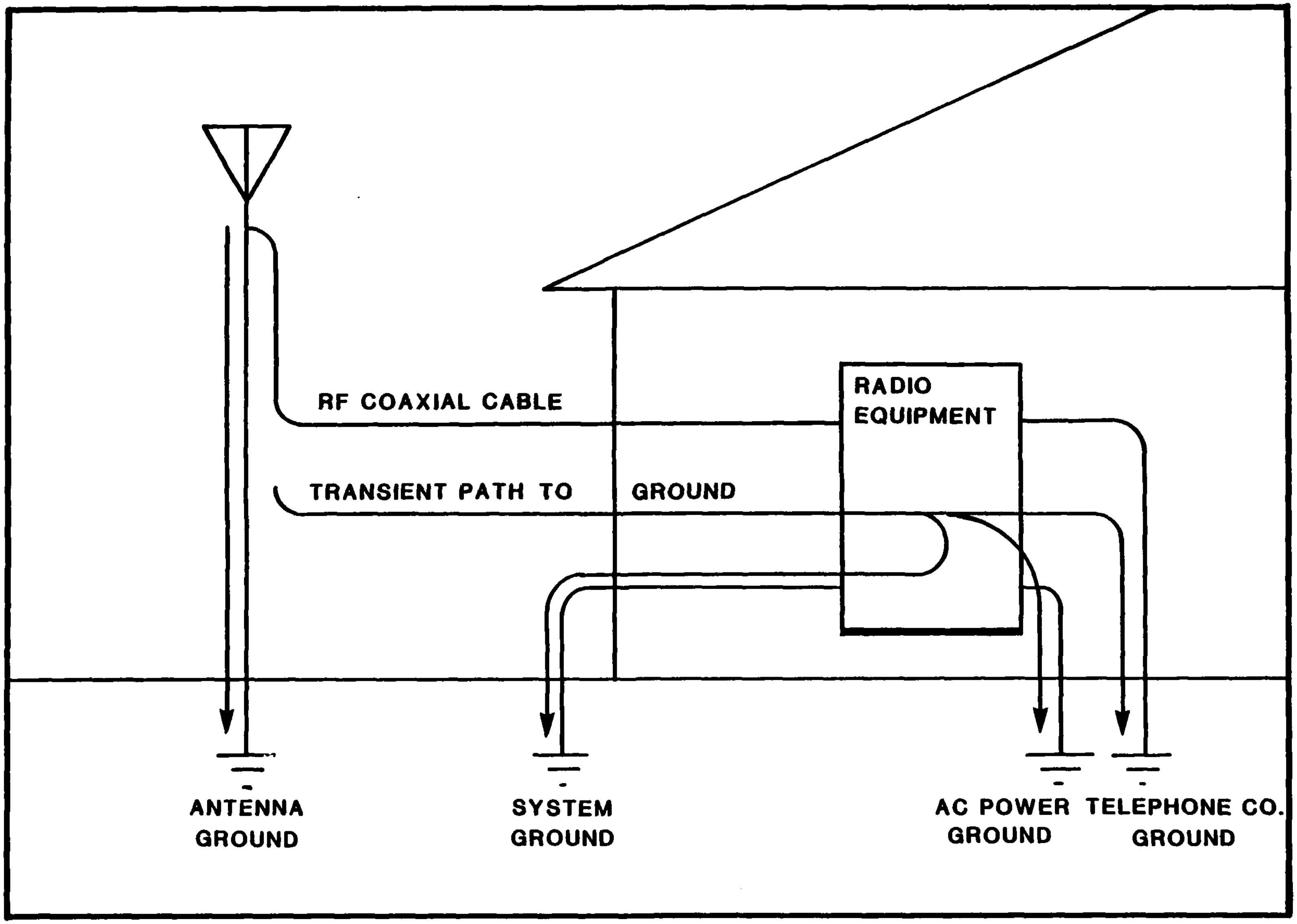


Figure 6-4. Transient Path to Ground Through Improperly Grounded Equipment

AD-A164 430 ELECTROMAGNETIC PULSE/TRANSIENT THREAT TESTING OF 3/3
PROTECTION DEVICES FOR..(U) ELECTROSPACE SYSTEMS INC
ARLINGTON VA D BODSON ET AL. 31 OCT 85
UNCLASSIFIED NCS-TIB-85-10-VOL-1 DCA100-85-C-0010 F/G 20/14 NL

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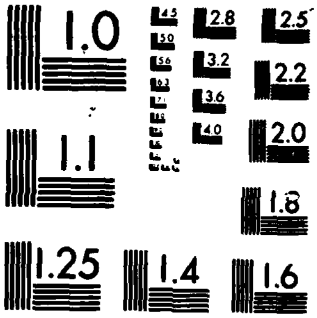

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

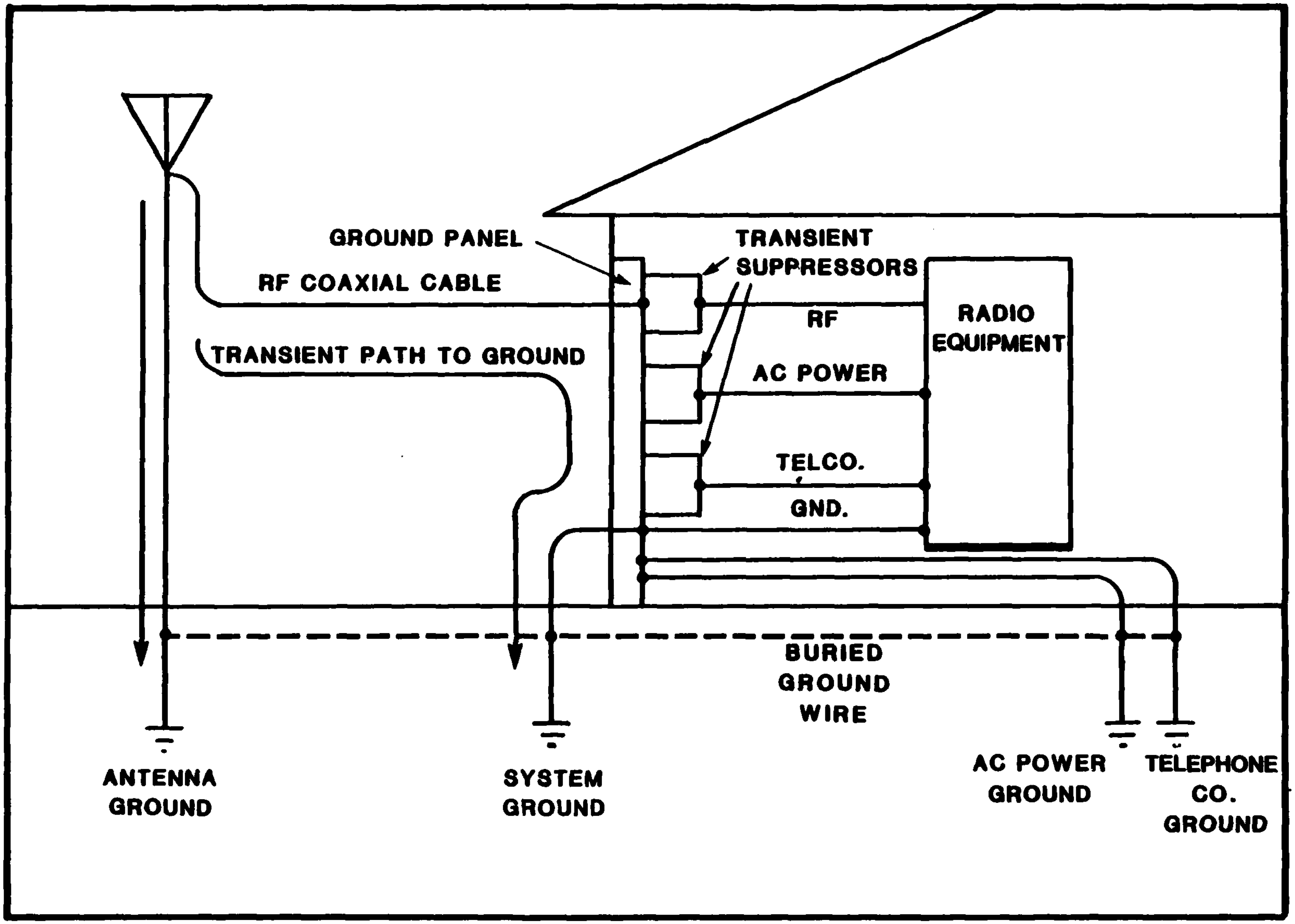

Figure 6-5. Transient Path to Ground with Ground Panel (Single Point Ground) and Transient Suppressors

TABLE 6-1

RG 8 COAXIAL CABLE CHARACTERISTICS

(A)
MAXIMUM POWER HANDLING CAPABILITY

FREQUENCY IN MHZ
AVERAGE INPUT POWER IN WATTS

MHZ-	10	50	100	200	400	1000	3000	5000	10000
WATTS-	3700	1300	850	450	350	190	95	65	37

(B)
NOMINAL LOSS CHARACTERISTICS

FREQUENCY IN MHZ
DECIBELS PER HUNDRED FEET

MHZ-	10	50	100	200	400	1000	3000	5000	10000
DECIBELS-	.66	1.50	2.20	3.20	4.60	9.00	19.00	28.00	47.00

(C)
PHYSICAL DESCRIPTION

Inner Conductor	O.D. (Inch)	Weight (lbs/ft)	Nominal Imped. (ohms)	Nominal Capacitance (pf/ft)	Max. Oper. Temp. Range (°C)	Max. Oper. Voltage (Volts RMS)
0.0855"	0.405	0.106	52.0	29.5	-40 + 80	4,000

6.2.6.1 RF Coaxial Protector Installation. The RF coaxial protector should be mounted on a common ground bus-bar for the ham shack. If the Fischer device is used, it should be attached to a grounded UHF receptacle which will serve as a hold-down bracket. The UHF receptacle will create a conductive path between the Fischer coaxial protector outer shield and the bus-bar. The Polyphaser device can be mounted directly to the bus-bar with the bracket provided. The Polyphaser bracket will provide an electrical path to ground for the transient pulse. The transceiver or antenna tuner should be attached to the grounded protector with a short (6 foot or less) piece of coaxial cable. Although the coaxial cable shield provides a ground path to the bus-bar from the radio equipment, it is not a satisfactory ground path for transient protection of the transceiver. Another ground should be installed between the transceiver case and the bus-bar using a solid wire (#6 gauge).

The coaxial cable shield should be grounded to the antenna tower leg at the base of the tower. Each leg of the tower should have an earth ground and be connected to the single point ground system as shown in Figure 6-3.

6.3 Mobile Installation

The mobile installation is quite simple when compared with the fixed installation. However, the automobile (boat or airplane) can present some transient hazards to the radio equipment in addition to EMP and lightning. Currents as high as 300 Amps are switched when starting the motor, and this can produce voltage spikes up to 210 Volts on the vehicle's electrical system. Lightning and EMP are not likely to impact the vehicle's electrical system as much as they would in a fixed installation, since the automobile chassis is not normally attached to earth ground. This would not be the case if the vehicle is inadvertently grounded; for example, when the automobile is accidentally parked against a grounded metal conductor.

The mobile radio system has two advantages over a fixed installation; first, lightning is almost never a problem and second, the vehicle battery is a natural surge suppressor.

6.3.1 Mobile Power Installation. The mobile radio equipment should be installed in a manner that takes advantage of the protection provided by the battery. To do this the radio's positive power lead must be connected directly to the positive battery post; not to intermediate points in the electrical system such as the fuse box or the auxiliary contacts on the ignition switch. The negative power lead should be connected to the chassis on the battery side of the quick disconnect connector. The alternative direct connection of the negative power lead to the battery post is not recommended from an EMP standpoint; although it would help prevent alternator whine.

An in-line fuse holder and fuse should be installed on the positive lead where it attaches to the battery post to prevent equipment damage or fire should the positive lead short out. A metal oxide varistor (GE-MOV-V36ZA80) should be installed between the positive and negative leads of the power cord near the equipment. (See Figure 6-6).

6.3.2 Mobile Antenna Installation. Although the equipment tests indicated that the mobile radios tested could survive an EMP transient without protection on the antenna system, the radios still require protection from lightning transients. Therefore, a coaxial line transient suppressor should be installed on the chassis between the antenna and the radio's RF port.

The recommended Fischer coaxial line spikeguard suppressor can be attached to a UHF receptacle that is mounted on and grounded to the vehicle chassis. The Polyphaser EMP protector can be mounted on and grounded to the vehicle chassis with the permanently attached flange. A short section of coaxial cable should be installed between the radio and the transient suppressor.

6.4 Portable Installation

EMP simulation tests have shown that portable radios are not susceptible to damage from an EMP field, even with the "rubber duck" antenna attached.

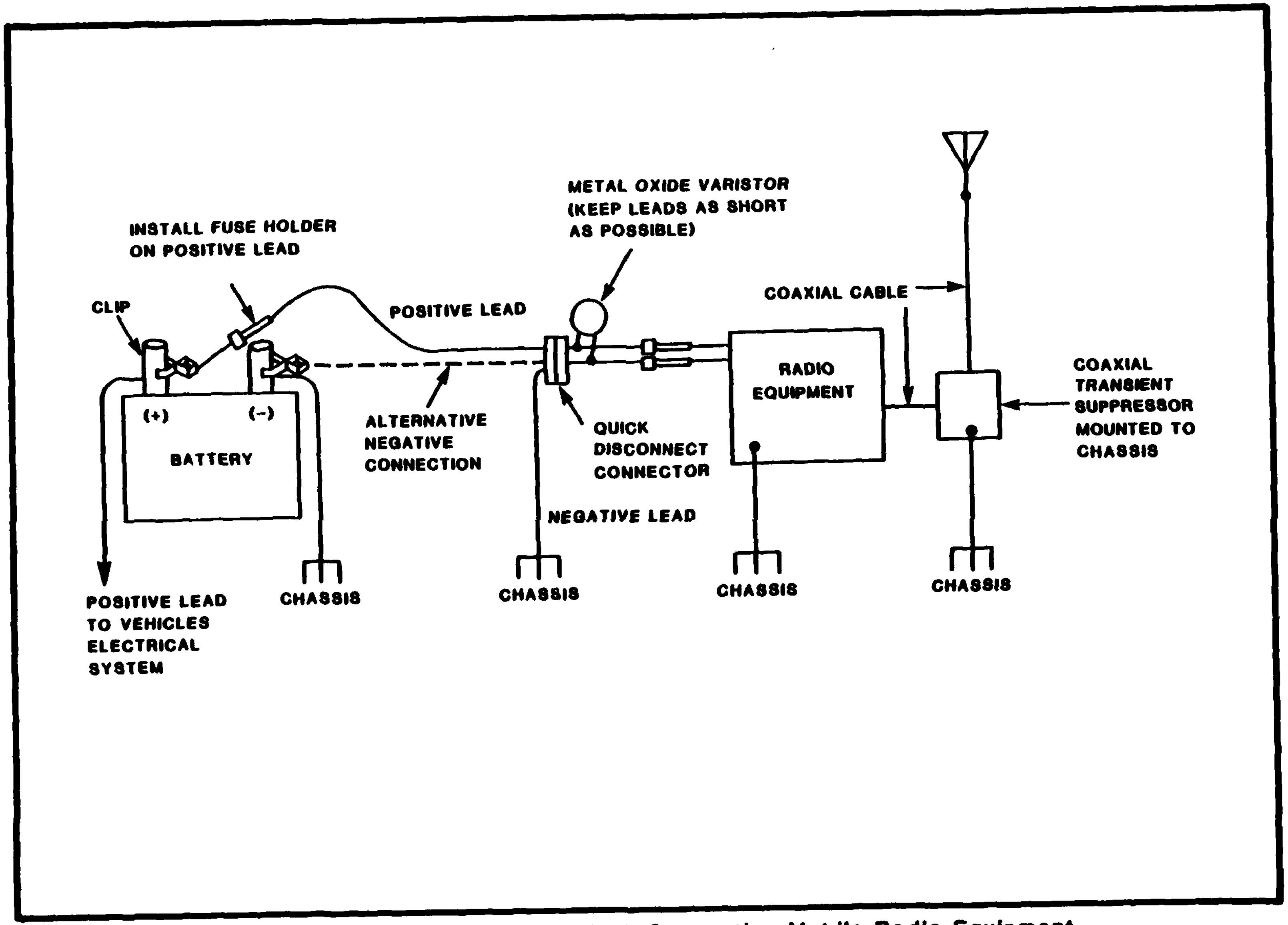

Figure 6-6. Recommended Method of Connecting Mobile Radio Equipment To Battery and Antenna.

Therefore, transient suppressors do not need to be installed on the portable's antenna or battery when the radio is being used in a purely portable configuration. However, when a portable radio is installed in a vehicle and used in a mobile configuration it should be protected from the more hazardous mobile transient environment as was described before.

The portable battery chargers can be damaged by EMP and lightning transients found on the commercial AC power outlets. Therefore, the portable battery charger should only be used with a protected AC power outlet. A plug-in AC power transient suppressor is recommended, since it can be taken with the portable to any location. The portable radio should never be connected to the AC power system through the battery charger. The battery should be removed and charged separately.

The portable radio should be kept away from other electronic equipment and long conductors when being stored or used, since there is always the possibility of an arc through the radio to ground.

SECTION 7

CONCLUSIONS

7.1 Major Conclusions

There were two major conclusions emanating from this effort. First, amateur radio equipment can be given a very high probability of survival from the damaging effects of large electromagnetic transients associated with lightning and EMP. The equipment can be protected by a very basic protection scheme. Second, the equipment can be protected by commercially available devices at a very low cost ($100.00) per system.

7.2 Other Conclusions

There are numerous effective devices available commercially that can be used to protect the amateur's radio equipment. Fifty-six (56) transient suppression devices/components were tested in an EMP simulation and 40 were found to have acceptable transient suppression characteristics for both EMP and nearby lightning events. It was concluded that the modern solid state amateur radio equipment was more survivable in an EMP transient environment than had been anticipated. Tests with a large parallel plate EMP simulator subjected fifteen (15) protected amateur radio systems to the full effects of an EMP transient, and the radio systems survived. The internal circuits and components of the tested radio systems can survive EMP and nearby lightning electrical and magnetic fields when the equipment is in an unwired configuration. The internal circuits and components are protected by the metal equipment cases and do not pick up sufficient energy from the fields to cause damage to the radio equipment.

The tested radio equipment was not susceptible to damage from the EMP fields even with the short interconnecting wires installed between the transceiver and the power supply, the antenna tuner, the speaker, and the microphone. The radio equipment did not need EMP protection because the wires were short enough that they did not pick up damaging energy from the EMP fields.

The long conductors associated with a radio system had the potential to cause damage to the radio equipment. Transient protection should be installed on these long conductors. The two long conductors of primary interest are the AC power lines and the antenna system. Tests have demonstrated that when these two conductors are connected to the unprotected radio equipment, the equipment can be damaged. When an AC power transient suppressor and a coaxial cable transient suppressor were used, the radio equipment was not damaged. Therefore, as a minimum, the interface points between the radio equipment and these two long conductors (AC power and antenna systems) should be protected from transient energy.

The one exception was the handheld radio. No protection was recommended for the handheld radio antenna port when the small "rubber duck" antenna was being used.

It was observed during the equipment test program that the RG-8 coaxial cable was acting like a filter suppressor to the transient pulse by arcing the energy on the center conductor to the cable sheath. In addition, it was noted that normal household wiring also acts like a filter suppressor to transient energy. When these two conditions were simulated during the test program, some unprotected radio equipment survived the transient pulses. Under certain installation conditions these two natural filters may suppress the transient energy enough to allow some radio systems to survive without protection.

However, the overall conclusion is that amateur radio systems should have protection applied to the AC power and antenna ports.

The recommendations contained in this report were developed under a low cost criteria and are not intended to cover all possible combinations of equipment and methods of installation that may be found in the amateur community. Each amateur should look at his own particular requirements and use this report as a guideline in providing protection for his equipment. There are certainly numerous other solutions to the EMP and lightning transient problem that could possibly provide increased protection at increased cost.

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