Electromagnetic Pulse and the Radio Amateur - Part 3

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Electromagnetic Pulse and the Radio Amateur

Part 3: In Part 2, we told how the EMP transient-protection devices were tested individually under isolated conditions. Now, the protectors are connected to Amateur Radio equipment and retested.†

By Dennis Bodson, W4PWF
Acting Assistant Manager,
Technology and Standards
National Communications System
Washington, DC 20305-2010

The tests described in the previous installment subjected 56 selected protection devices to several different injection pulses that simulated the waveforms and energies associated with EMP and lightning discharges. Those protective devices found acceptable during the first test program were then connected to several types of radio equipment and tested for their effectiveness in a typical Amateur Radio installation.

Since there is a large number of possible combinations of protection devices and radio equipment, low-cost devices were evaluated first. If they were found unacceptable, higher-cost protection devices were installed and tested until an acceptable protection scheme was developed. After completing the testing of the low-cost commercial devices (see Table 6), several homemade units, assembled from previously tested components (see Table 7), were checked. This was done with an eye toward finding a very low-cost protection device that could be built by the radio amateur. Six of these units will be described in the next installment of this series.

Sixteen system configurations (see Table 8) were tested at frequencies from 1.8 to 435 MHz. These systems included both new and old gear (some no longer manufactured, but available on the used-equipment market), and tube-type and transistorized radios. The equipment tested was manufactured by Drake, ICOM, Kenwood, Swan and Yaesu.

Measurements were taken of the radio system's performance before and after each pulse or pulse series to compare the radio's

†Parts 1 and 2 appear in the Aug and Sep issues of *QST*, respectively. Part 4 will appear in a subsequent issue.

Table 6
Commercial Protection Devices Tested

Manufacturer	*Part Number*	*Description*
Fischer	FCC-250-300-UHF	Coaxial line suppressor
Fischer	FCC-250-350-UHF	Coaxial line suppressor
Fischer	FCC-250-150-UHF	Coaxial line suppressor
Fischer	FCC-250-120-UHF	Coaxial line suppressor
Fischer	FCC-450-120-UHF	Coaxial line suppressor
Joslyn	2031-35-B	Miniature gas-tube surge protector (MSP)
General Electric	V36ZA80	Metal oxide varistor (GE-MOV)
Polyphaser Corp	IS-NEMP	Coaxial line protector
Polyphaser Corp	IS-NEMP-1	Coaxial line protector
Polyphaser Corp	IS-NEMP-2	Coaxial line protector
TII	Model 428	Plug-in power line protector
Siemens	S14K130	Metal oxide varistor (SIOV)
Siemens	B1-A350	Button type surge voltage protector
Alpha Delta	Transi-Trap R-T	Coaxial line protector
Archer	61-2785	Three-outlet ac power strip/protector

Table 7
Homemade Transient Protection Devices Tested

Device Name	*Description*
SIOV ac test box	Three Siemens MOVs (S14K130) installed in an ac receptacle box. One MOV wired from hot to ground, one from neutral to ground and one between hot and neutral
GE MOV	One GE MOV (V36ZA80) installed across the 12-V dc power line between hot and ground.
SIOV RF test box	The Siemens MOV (S14K130) installed in a metal box. The box had UHF connectors attached to both ends and a wire connected between the center conductors of the two connectors. The MOV was connected to the wire on one side and to the box on the other side.
Siemens UHF test box	Two Siemens gas-gap tubes (BI-A350) installed in the UHF connector box described above. The tubes were wired in series from the center conductor to the side of the box.
Joslyn UHF test box	Two Joslyn gas-gap tubes (2031-35B) installed in the UHF connector box in series from the center conductor to ground.
UHF coaxial T	Two Siemens gas-gap tubes (BI-A350) installed in series between the center conductor and case, on one leg of a coaxial T connector.

Table 8

Amateur Radio System Configurations and Ancillary Equipment Tested

System 1
Yaesu FP-757HF power supply
FT-757GX all-mode transceiver
FC-757AT antenna matching network

System 2
Yaesu FP-757HF
FT-757GX

System 3
Yaesu FT-726 VHF/UHF all-mode transceiver

System 4
ICOM IC-745 HF Transceiver
IC-PS35 internal power supply
IC-SM6 desk microphone
IC-AT100 antenna matching network
IC-SP3 external speaker

System 5
ICOM IC-745 HF transceiver
IC-PS35 internal power supply

System 6
ICOM IC-27A 2-m mobile transceiver

System 7
ICOM IC-02AT 2-m hand-held transceiver

System 8
ICOM IC-271A 2-m transceiver

System 9
ICOM IC-471A 430- to 450-MHz transceiver

System 10
Kenwood TS-430S HF transceiver
PS-430 power supply
MC-80 desk microphone
AT-250 antenna matching network
ST-430 external speaker

System 11
Kenwood TS-430S HF transceiver
PS-430 power supply
MC-80 microphone

System 12
Kenwood TR-7930 2-m mobile transceiver

System 13
Kenwood TR-2600 2-m hand-held transceiver

System 14
Drake T-4XC HF transceiver
R-4C HF receiver
4B power supply

System 15 (Not tested)
Collins KWM-2A HF transceiver
KWM-2A power supply

System 16
Swan 250 HF transceiver
117Z power supply

Antennas
Mosley JRS TA33 3-element tribander
Cushcraft AV-5 80- to 10-m vertical

Other Items
Astron VS-35 power supply
Honda EG 650 generator

transmitter power output and receiver sensitivity. First, stand-alone (equipment unwired) radio systems were subjected to a field-pulse wave. This disclosed any inherent design weaknesses and identified the internal areas that required protection. Damaged equipment was repaired and returned for further testing. After a series of field-only pulse tests, the simultaneous field and injection pulse tests were made.

Test Program

Threat Definition

The peak values used in these tests were:

EMP simulator pulse field:	50 kV/m
RF drive pulse:	275 A, 13.75 kV
Ac drive pulse:	130 A, 6.5 kV

In the *Simulator Field Tests,* the radio system was placed in the working volume of a large parallel-plate EMP simulator. The simulator's Marx pulse generator was discharged into the pulser wire elements with sufficient energy to produce a 50 kV/m field strength with a 10-nanosecond pulse rise time. For the *Simultaneous Field and Injection Pulse Tests,* the radios were kept in the same environment and two L-shaped wires were attached to the equipment.

Transient Injection Methods

The working volume of the parallel-plate simulator used for these tests, while large, was not sufficient to house an entire radio station including an antenna and residential power-line drop. Therefore, the station equipment was placed in the chamber, and pulses were injected that simulated the stresses carried to the equipment by the power lines and antenna. The maximum transient expected from the power line was about 6 kV since household wiring should limit the transient to this level. Antenna connections, however, are limited only by the spark-over levels of the installed antenna cabling.

Power-Source Transient Injection

Power for the systems in the test chamber was provided by an isolated generator that would prevent interaction with the pulser and data links used in the experiment. To simulate the connection of a typical residential supply, 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 chamber. The antenna was connected to the hot lead of a power plug inserted close to the protective device under test. When a commercial plug-in device was used, the transient was injected into the same receptacle into which the device was plugged. If a fabricated protection device was used, the transient was injected into the device receptacle alongside the equipment power plug. 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 protection device. The dimensions of the L-shaped antenna were adjusted until a current of 130 A was produced in a 50-ohm load.

Antenna Transient Injection

A larger L-shaped antenna was constructed within the test chamber for evaluation as an injection pulse generator for the antenna port of the equipment under test. Current, measured through a 50-ohm load resistor, was limited to about 80 A when two short lengths of coaxial cable were used between the antenna and load. Results of the removal of the cable from the transient path led to the conclusion that the coaxial cable and connectors greatly limit the magnitude of the transient imposed on radio equipment. The L antenna used 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.

Test Equipment

A parallel-plate EMP simulator 24 feet long, 20 feet wide and 11 feet high (Fig 11) was used. The Marx generator 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. These wire elements extended from the Marx generator through a 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 30-kV charge to the Marx generator was sufficient to provide a 50-kV/m field strength with a pulse rise time near 10 ns inside the working volume. The 30-kV charge to the Marx generator produced a 240-kV charge on the pulser elements.

A round and a square H-field sensor were used to provide daily calibration of the simulator and to measure the field strength during each test. Normally, only one sensor was used during the actual test. Four current sensors measured the output of Amateur Radio antennas erected in the

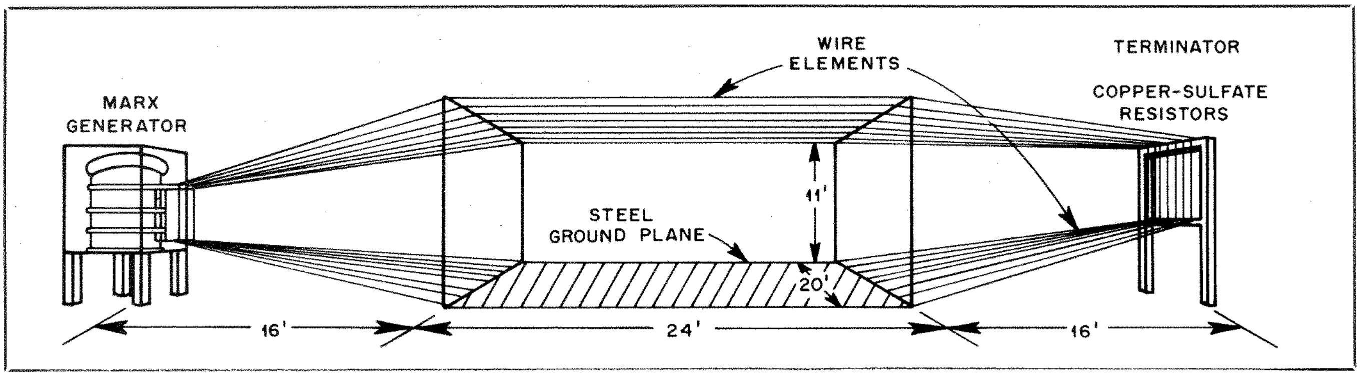

Fig 11—A drawing of the large parallel-plate EMP simulator used in the tests. The Marx generator is a high-voltage pulse generator in which several capacitors are charged in parallel through a high-resistance network. When the charge reaches a critical value, discharge occurs through spark gaps.

pulser field. The sensors also measured the output of the L-shaped wire antennas that were used to drive the ac power lines and antenna coaxial cables. A shielded coaxial probe and a fiber-optic system with a battery-powered, shielded transmitter took H- and E-field measurements. Sensor measurements were recorded on an oscilloscope. Photographs of the oscilloscope display were taken for each simulator pulse. Other test equipment included four signal generators and a wattmeter.

Radio System Tests

Each radio system was checked before and after each pulse. Transmitter power output was measured in the CW mode. This was done with and without any transient-protection devices in the feed line. That provided an evaluation of the protection device's suitability for that particular radio system, by showing its ability to pass the transmitted signal without clamping or without contributing a substantial loss of power output. Voice modulation was checked by observing the deflection of the wattmeter needle while speaking into the microphone. In some tests, the transmitter was monitored on a similar radio.

Receivers were placed on a set frequency in the USB mode with the RF amplifier on (if selectable) and the RF gain control set to maximum. The output of a signal generator was increased until the receiver's S meter read S5. (Receivers without an S meter were measured by listening for an audible signal in the speaker.)

Series A

For these tests, the radio equipment was placed on wooden carts 34 inches above the simulator floor. No interconnecting wires were attached to the equipment. All permanently attached external wires (such as power cords) were coiled and placed under the case of the radio equipment. This test evaluated the susceptibility of the radio's internal wiring and components to self-generated transient pulses resulting from exposure to a field pulse. All radios (with the exception of one, System 15, that was dropped from the test for prolonged maintenance problems) passed these tests with no measurable degradation.

Series B

Again, the radios were placed on the wooden carts. They were unpowered and ungrounded, but this time the interconnecting wiring and power cords were in place. This second test was designed to evaluate the radio's susceptibility to transient pulses generated by the internal wiring, and any external wires including microphone and power cords. All radios passed this test except for two, Systems 3 and 8. The receivers in these two systems exhibited decreased sensitivity: that of System 3 by 26 dBm and 8 dBm for System 8. Since a strong signal was still audible, the two systems were considered not to be seriously degraded and were accepted for further testing.

Series C

Only System 2 was used for this test. The transceiver was placed on the pulser floor and grounded to the pulser ground plane. All wiring was attached except for the coaxial feed line to the antenna. Tests were performed first with no ac power applied, then with power on. No degradation of the transceiver performance was measured.

Series D

This was a power-on test of the equipment with all external wiring and peripherals in place, including the coaxial antenna cable. Commercial transient-protection devices were installed in the ac power and antenna feed lines. Then, the ac power line and coaxial antenna cable were driven by an injected signal at the threat levels described earlier. All the devices, except one, provided adequate protection. System 2 sustained some internal damage during a test when the Alpha Delta R-T Transi-Trap was in the circuit. The Transi-Trap devices had performed satisfactorily during the first test program. [Note: As a result of this report, Alpha Delta has a new "EMP series" R-T and LT design. The new version has a clamping level three times lower than previous designs for maximum safety—Ed.]

Another protective device failed a post-test check. The Fischer FCC 450-120-UHF would not pass RF signal power. It was replaced.

Series E

Now, five assembled (experimental) transient-protection devices were tested (see Table 7). Of these five, one was an ac-line unit and four were RF assemblies. These tests were designed to find a low-cost solution to the transient-protection requirements of the radio systems under test. All of the units provided adequate protection of the radio equipment during the test pulse. Further testing revealed that three of the devices blocked the transmitted signal. The Siemens Metal Oxide Varistor (SIOV) RF Test Box containing a large-capacitance varistor blocked the signal over a wide frequency range. The Siemens UHF Test Box and Joslyn UHF Test Box containing the gas gaps were adequate at HF, but blocked the signal at higher frequency ranges. Although these three devices are adequate for receiver use, they are not recommended for use with a transmitter.

The UHF coaxial T was the best assembled device; it provided transient protection and could pass the transmitted signal over the full range of test frequencies. Also, the SIOV AC Test Box repeatedly provided necessary power protection required by the radio equipment. These two devices will be discussed in more detail in the next installment.

Series F

This series of field and injection tests had three configurations. First, the radio systems were fully protected. Then, transient protection was removed from the coaxial feed line. Finally, protection was removed from the ac power line as well. As expected, some equipment damage was experienced. However, the most surprising result of this test series was that only one radio system (System 2) experienced significant, permanent performance degradation. The other radios suffered various amounts of lowered transmitter power output and receiver sensitivity, but were still operational in their damaged state. A contributing factor in the survivability of the equipment was the influence the RG-8 coaxial cable had on the RF injection pulse (discussed later).

Antenna Tests

Measurements were taken of the response of two amateur antennas to the simulator pulse field in several different configurations. These included measurements taken with a 75-foot length of RG/8 cable attached and with a connection to the pulser ground plane directly through a 50-ohm resistor. The Mosley JRS TA33 Jr antenna generated a maximum of 152 A through 50 ohms for a 7.6 kV pulse level. The Cushcraft AV-5 produced a maximum output of 170 A through the 50-ohm resistor for an 8.67 kV pulse level.

An L-shaped wire antenna was placed in the pulser field to generate a drive current that could be injected into the coaxial cable attached to the radio equipment under test. The maximum measured output of this antenna was 175 A through a 50-ohm resistor for a maximum pulse level of 13.75 kV.

Two "rubber ducks" were tested. The maximum measured current was 8 A producing 400 V through 50 ohms. This low current was not sufficient to cause any degradation of the hand-held transceivers.

Coaxial Cable Effects

Measurements were made to determine the response of RG/8 coaxial cable in the pulse field alone and when attached to three different antennas: two amateur antennas and the RF-drive antenna. At the antenna side of the cable, large currents (250-290 A) could be found, but at the opposite end—with the 50-ohm resistor connected to ground—only 50-110 A was measured. We suspected that the coaxial cable was arcing. To test this, a piece of RG/8 cable was connected to a high-voltage dc supply and the supply voltage was slowly increased. Arcing between the center conductor and the coaxial connector began at a potential of 4 kV; the cable began arcing internally at 5.5 kV. We concluded that the RG/8 cable was acting as a spark-gap protector for the equipment under test. Given this condition, the protection devices installed in the feed line were needed only to suppress the approximate 4.4-kV pulse that would get through the cable.

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. Short wires—microphone, power cord and internal wiring—did not generate sufficient transient pulse energy to produce observable damage to the radio equipment. When power lines and antennas are attached to radio equipment, however, protection must be provided. With long external wires attached and no protection provided, a single pulse could cause disruption of the microprocessor-controlled displays, cause frequency shifts and permanently damage the radio's internal components. Two notable exceptions are the handheld and mobile radios. Even with antennas attached, no equipment degradation was noted.

Other equipment used by the radio amateur can be damaged by transient pulses. A line-operated dc power supply (Astron VS-35) failed when pulsed with an unprotected power source. A hand-held transceiver's (ICOM IC-02AT) 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. A Honda portable power generator was fully stressed with field and injection pulses and was unharmed. System 1 sustained damage to its antenna matching network, but the attached transceiver was unhurt. (In this case, the matching network may have protected the transceiver.) When System 4 was pulsed in an unprotected configuration, its matching network did not provide adequate protection for the transceiver; the transceiver's frequency display was temporarily disrupted.

Conclusions

Most Amateur Radio equipment should be protected from lightning and EMP to prevent damage that can degrade the equipment's performance. Adequate transient-pulse protection for most radio systems can be obtained by adding the proper protection devices to the ac power lines and the transmission line. Battery chargers for hand-held transceivers and line-operated dc power supplies should also be protected. With a minimum amount of protection, radio systems should survive transient pulses produced by lightning strikes and EMP. A direct lightning strike is another matter.

[Editor's Note: This series of articles is condensed from the National Communications System report (NCS TIB 85-10) *Electromagnetic Pulse/Transient Threat Testing of Protection Devices for Amateur/Military Affiliate Radio System Equipment.* A copy of the unabridged report is available from the NCS. Write (no SASE required) to Mr Dennis Bodson, Acting Assistant Manager, Office of Technology and Standards, National Communications System, Washington, DC 20305-2010, or call 202-692-2124 between the hours of 8:30 AM and 5 PM Eastern.] QST