ELECTROMAGNETIC SUSCEPTIBILITY

Susceptibility

"The characteristic of electronic equipment that permits undesirable responses when subjected to electromagnetic energy". That's how MIL-STD-463 defines it. Let's see what that means to the electronics engineer faced with designing and testing to the susceptibility requirements of MIL-STD-461 or any of several other documents. First, what sorts of things are we dealing with? Exactly what are the ways in which equipments may be vulnerable to interfering energy? Some of the many causes and effects of undesired responses and malfunctions are discussed below.

Overloading

Overload by the desired signal itself may cause distortion of the intelligence or even complete loss of information. There will also be a finite time lag between removal of the signal or its decrease below the overload level which may also result in loss of desired intelligence. Effects can include erroneous or suppressed electromechanical outputs. Circuit designers must consider this factor.

Blocking

When an undesired input (for example; an off-channel signal type of interference) reaches any one of a number of points in the receiving device at sufficient strength, blocking (loss) of the desired signal will occur.One of the more common instances of this is when a wide-band receiver such as a TV set is overloaded by a signal outside its nominal passband, with consequent loss or degradation of the desired input. Blocking may also occur as a result of intermodulation. (See below).

Dielectric heating

At the higher frequencies, most dielectric materials exhibit losses. If sufficient energy is present, heating to an unacceptable degree can occur. Probably the most serious consequences of such heating can occur in the case of electroexplosive or pyrotechnique devices (EEDs or "squibs"). The material between the bridge wire and the case of the squib may be heated to the point at which initiation of the squib will take place. At radio frequencies, spurious currents may be considerably higher than would be expected from consideration of only the DC resistance of the device. Resonances within the unit itself or in the wiring associated with it may result in much higher energy levels being present, with resultant malfunction - even to the extent of loss of a missile or other vehicle.

Static charges

At ground locations, blowing dust or snow may cause buildup of electrostatic potentials to the degree that discharges will occur, both within and external to electronic equipments. Damage to circuitry, or loss of information (particularly digital) may ensue. At lower levels, charge buildups may result in false signals within the equipment. Bear in mind that such charging also occurs quite frequently in aerospace vehicles. MIL-E-6051, (the system electromagnetic compatibility specification) and MIL-B-5087, (the aerospace systems electrical bonding and lightning protection specification) both devote considerable attention to this area. The latter document should be carefully reviewed by all electronic designers since it contains much useful guideline type information.

Stray resonances

Mentioned above in connection with EEDs, such resonances not infrequently occur in electronic circuits, resulting in parasitic oscillations, deterioration of receiver sensitivity, undesired feedback in amplifiers, and degraded rejection of undesired signals or interference voltages. For example, at 10 MHz, a 5000 pF disc ceramic capacitor will become series-resonant with a total lead length of one centimeter! Above resonance, the impedance of the capacitor/lead combination will increase, with resultant decrease in its effectiveness as a bypass element.

Subaudio interference

Some important aspects of subaudio interference are:

- It can be very difficult to pin down;
- It may last for only a short period - a few seconds or so;
- More often than not, it is superimposed on the desired signal flow and may be accompanied by higher frequency components and noise.

Subaudio interference can be generated, for example, when airborne vehicles exhibit dynamic structural resonances. Typical frequency ranges for such vehicle assembly resonances are:

- Total vehicle - less than one to a few hertz;
- Other structural resonances - up to about ten hertz;
- Bulkheads and equipment racks - in the tens to hundreds of hertz range.

These resonant flexures and vibrations affect electronic equipments in two principle ways:

(1) Transducers and sensors may detect the displacements as velocity or acceleration changes and generate undesired output signals;

(2) Wires and cables may be moved through strong fields, with resultant induction of voltages. Under such conditions, rate gyros have produced enough output to cause gross guidance disturbances.

Limiting and clipping

Both of these, when introduced either intentionally or unintentionally, can result in frequency components which may couple fortuitously to circuits in which their presence can produce undesired responses.

Intermodulation

Two or more signals flowing in a non-linear circuit element can result in the generation of great numbers of sum-and-difference products. Remember that any non-linear element can act as a mixer. Many designers have been unpleasantly surprised to find that such items as rf connectors can act in this manner when sufficient levels of energy are present. Cross-modulation, a special case of intermodulation, occurs when a desired signal is modulated by an undesired signal. Both of these effects are most likely to occur in receiver front-ends, but may happen at other points in a device.

High-density electromagnetic environments

Most receivers are currently designed with few, if any, precautions against the effects of the high power environments in the vicinity of many military electronic complexes and civilian installations. Some recent measurements have revealed that levels in the tens-of-volts range are not uncommon in typical urban and suburban locations. The proliferation of transmitters in the Citizens Radio Service and other land mobile services has resulted in rather high probabilities that any electronic device will sooner or later be subjected to such environments. Equipment designers should take the necessary precautions to eliminate susceptibility to rf levels of the order mentioned above.

Susceptibility test requirements

Now, let's have a look at the different types of susceptibility tests called for in widely-used requirements documents. Table 1 lists the basic tests and indicates how these are performed. Note that the use of several instruments and components not in the category of general laboratory test equipment is specified. When procurement of such items is being considered, particularly the special generators, a number of significant factors must be evaluated. Look for features which could provide both time and fiscal savings in performing tests. For example, a special transformer suitable for injection of audio frequencies for powerline susceptibility tests may also be used for coupling to the lines for conducted emission testing. Thus, savings might be realized in both test setup time and equipment budget. Let's look at another instance in which cost-effectiveness considerations would enter. The added expense of a source with a broadband output network might be recoverable after a few tests. Consider that labor costs are going to pile up rapidly when a unit requiring frequent retuning is used.

Here are some important features to look for:

(1) Protection against internal damage under any condition of source/load VSWR;
(2) Minimal tuning and/or bandswitching;
(3) Faithful reproduction of required modulation (AM, FM, pulse) on the output signal;
(4) Compatibility with reactive loads (LISNs, antennas);
(5) Freedom from harmonics and other spurious products;
(6) Versatility;
(7) Minimal passband ripple effects; and
(8) Low inherent intermodulation tendencies (Class A (preferably), or Class B output stage - *not*, Class C).

Conducted Susceptibility

Application of susceptibility signals to power lines may not always be a simple matter. Use of a current probe will, indeed, provide good isolation between the susceptibility source and the powerline. However, losses in the probe may result in the line not being excited with the proper level of susceptibility signal. Also, at higher levels of source power, the matching resistors in the probe may be damaged. Remember that the power lines must be monitored with an oscilloscope or electronic voltmeter to assure that the required levels of susceptibility signal are actually present.

Capacitors are used to couple the susceptibility signals into lines over the 50 kHz to 400 MHz range. The reactance of such capacitors must be small (less than five ohms) at the frequency of operation to avoid significant voltage drops. Bear in mind that as the test frequency is raised, the reactance of the capacitors will decrease. Thus, if the line impedance is low, the susceptibility source may be loaded down to the degree that the required voltage levels cannot be achieved with a particular source. One important precaution - with higher power susceptibility sources, it may even be possible to damage the EUT at levels below those specified. Control and test plans should reflect this point if the equipment designer has any logical reasons for believing that such damage could occur.

Below 50 kHz, the special transformers used have their secondaries connected in series with the line being tested. Therefore, this winding must have negligible reactance over the test frequency range. The susceptibility signal is applied to the primary and the input power current is then "modulated" by the signal. At power frequencies, the line voltage may feed back to the susceptibility source sufficiently to damage it. See the Analysis, Recording and Measurement section of ITEM for details of a test setup which will minimize the possibility of such damage.

Radiated Susceptibility

Radiated susceptibility tests are performed to assure that the EUT will operate in typical radiated rf environments. Levels are either specified in a particular requirements document, or may be based on knowledge or prediction of the intended environment. For example, if a particular equipment item must operate near a microwave oven, a radio or television broadcasting station, or a communications complex, response to such fields should be evaluated. Measurement or calculation can define the field intensity (or power density) and spectrum of the environment. Then, by proper choice of antennas and susceptibility sources, it can be adequately simulated in the shielded enclosure.

MIL-STD-461, the most widely-used government requirements document, specifies frequency ranges, test setup geometries, field levels and test antennas. Some flexibility is permitted - the following statement is included: "Antennas other than those specified can be used if described in the test plan and approved by the procuring activity". Levels higher than the "1V/meter" level specified in the original issue of MIL-STD-461 have been imposed by various of the Notices thereto. These levels have been found to be respresentative of actual operational environments. Radiated levels of the order required can not be generated by use of standard laboratory signal sources - amplifiers or special susceptibility generators are a necessity! The 200V/M requirement per the forthcoming MIL-STD-461B will require special laboratories and equipment.

Consumer product manufacturers are now becoming aware that the rf environments in which their equipments are being operated can be quite rigorous. (See above). Investigations have revealed that a major cause of vulnerability to undesired signals in receivers and other electronic devices is direct pickup of fields by the circuits themselves. Therefore, the conducted susceptibility tests which check for front-end rejection will not indicate the true vulnerability of a device. Keep in mind that the same sort of intermodulation effects which can occur in receiver front-ends can also occur when circuits in *any* electronic device are exposed to two or more extraneous signals.

Spike susceptibility tests do provide some indication of the vulnerability of an item to fast-risetime pulses. However, neither these tests nor the modulated CW checks adequately simulate the spectrums of fluorescent lamps, motor commutator hash, or automotive ignition systems. One source which has been used successfully to give some idea of equipment vulnerability to repetitive transients is the "chattering relay"; (i.e., a relay with its coil connected in series with one of its normally-closed contacts.) Coupled to the EUT via loop or capacitive probes, this source can be a great aid in determination of specific paths of entry of transient interference.

TABLE 1
SUSCEPTIBILITY TESTS AND TEST METHODS

TESTS	METHODS
Conducted	
Powerlines	
30 Hz to 50 kHz	Injection from audio source via special transformer (1)
50 kHz to 400 MHz	Injection from signal generator via low-reactance capacitor
	Injection from signal generator via current probe (2)
Spike	Injection from spike generator via integral transformer (3)
Intermodulation	Receiver front-end injection from two signal generators with isolation network(s) (4)
Undesired signal rejection	Receiver front-end injection from two signal generators with isolation network(s) (4)
Cross-modulation	Receiver front-end injection from two signal generators with isolation network(s)
Squelch circuits	
Impulse/input only	Receiver front-end injection from impulse generator
Sub-threshold signal plus impulse input	Receiver front-end injection from impulse generator and signal generator
Radiated	
Magnetic field, loop	Equipment case exploration with loop energized from audio source (5)
Magnetic induction	
Cases	Equipment case wrapped with several turns of wire energized with power frequencies and with spike generator
Cables	Interconnecting cables wrapped with several turns of wire and energized as for cases
Electric field (6)	
14kHz to 10 GHz	Rod, dipole and conical log-periodic antennas energized from signal generators/amplifiers (7)
14 kHz to 30 MHz	Parallel-plate line energized from signal generators/amplifiers (8)
14kHz to 30 MHz	Radiating loop/line energized from signal generators/amplifiers (9), (10)
	Crawford Cells, energized from signal generators/amplifiers (11)

NOTES:

(1) The special transformer may also be used to obtain conducted emission data. See the Analysis, Recording and Measurement section of ITEM for procedures.

(2) Method approved for use in testing avionics equipments over the range of 15 kHz to 150 MHz in accordance with RTCA Document DO-160 (Obtainable from Radio Technical Commission for Aeronautics, 1717 H St., NW, Washington D.C. 20006)

(3) 50-ampere secondary winding on the integral output transformer is standard. Available from at least one manufacturer with 100-ampere secondary on special order.

(4) Internal impulse-generator calibration sources of some EMI measuring instruments have front-panel output connections which enable them to be used for performing these tests.

(5) Instructions for the fabrication of this loop appear in MIL-STD-461.

(6) With the test setup geometries specified in requirements documents, the EUT is in a region in which the predominant electromagnetic components over most of the specified ranges are the magnetic induction field and the static dipole field (also known as the electric induction field or radial electric field). Vector coefficients and phase angles, particularly the former, change significantly over very small distances in this region. Refer to Table 1, page 25-2, of the 5th edition of ITT's *Reference Data for Radio Engineers* to see how radically the magnitudes vary.

(7) Amplifiers are required to obtain the field levels specified by certain of the Notices to MIL-STD-461. Octave-band low pass filters will probably be necessary to reduce harmonic and other spurious outputs to levels which will prevent false indications of susceptibility within a particular frequency octave.

(8) Fabrication instructions for a widely-used parallel-plate line and a "transmission-line" (or "loop-line") antenna are given in this section of ITEM. Directions for making another type are contained in MIL-STD-462. The former will accomodate larger equipment case sizes and accept higher excitation powers.

(9) Directions for installation and adjustment of a suitable radiating line are contained in Notice 3 to MIL-STD-462. CAUTION: If this test setup is to be used for generating field levels in the tens to hundreds of volts ranges, consideration should be given to using larger conductors than those mentioned in Notice 3, and to using symmetrical, radial arrangements of paralleled resistors at the line input and end terminations.
WARNING: POWER LEVELS REQUIRED TO OBTAIN THE HIGHER FIELDS SPECIFIED IN CERTAIN REQUIREMENTS DOCUMENTS WILL RESULT IN THE RADIATION OF ENERGY AT LEVELS SUFFICIENT TO CAUSE HARMFUL INTERFERENCE TO COMMUNICATIONS AND OTHER SERVICES AT CONSIDERABLE DISTANCES FROM THE TEST LOCATION. ALL SUCH TESTING MUST BE PERFORMED IN SHIELDED ENCLOSURES OF ADEQUATE ATTENUATION CAPABILITIES. THE SPECIFIED LEVELS ARE ALSO ABOVE THE LIMITS ESTABLISHED BY OSHA AND OTHER AGENCIES FOR HUMAN EXPOSURE TO RADIATION. TEST PERSONNEL MUST NOT BE INSIDE THE ENCLOSURE DURING SUCH TESTING.

(10) Depending on shielded enclosure dimensions, some difficulties may be encountered in adjusting the terminations. Under such conditions, a slight change in the excitation frequency will usually make it possible to perform the required checks and adjustments.

(11) Frequency ranges dependent on cell dimensions. Consult manufacturers for recommended usable ranges.

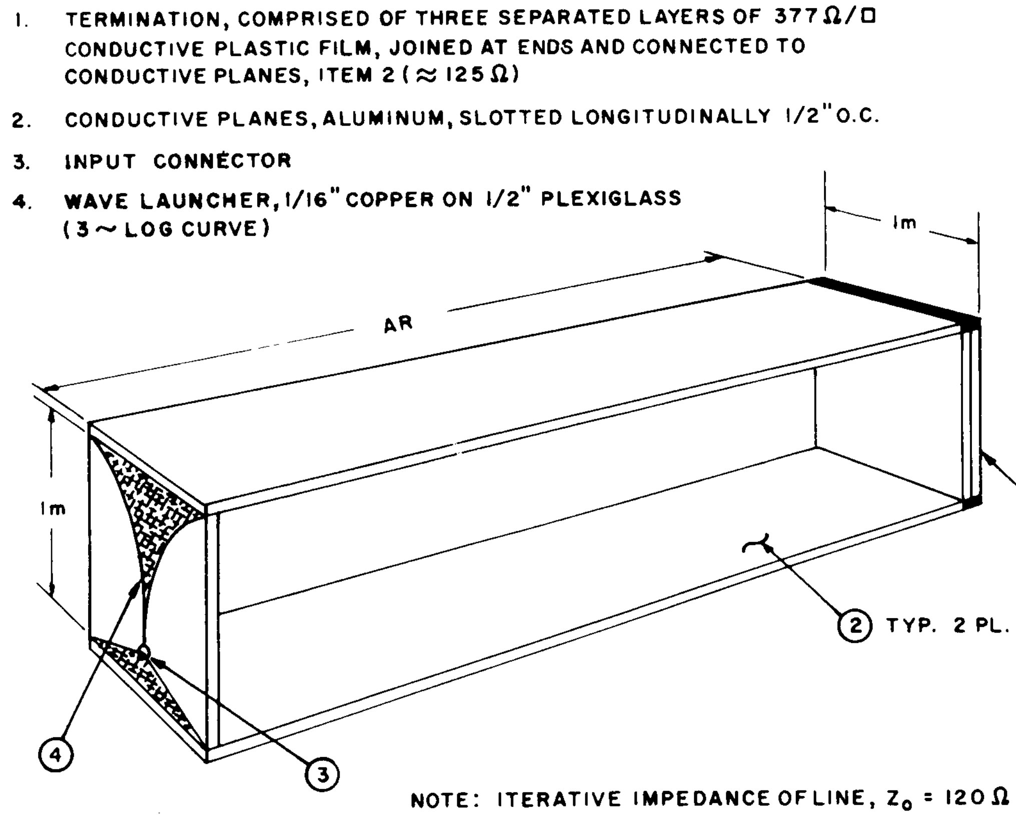

Figure 1: Parallel Plate Line

Figures 1 through 3 illustrate the construction of a state-of-the-art parallel plate lines. (These figures are taken from chapter 6, section 6B of AFSC DH 1-4.) This design incorporates many good features and improvements as follows:

a. The longitudinal slots in the paralled plates prevent transverse current and help to maintain the TEM mode of propagation.

b. The termination reduces coupling between the end of the line and the shielded room wall. Each layer of conductive plastic (377 ohms/square) reduces the energy passing through by 6dB/later so that coupling is reduced by 36dB for the 3 layers.

c. The input is designed as a wave launcher rather than a matching section. The shape of the launcher has been determined empirically to minimize variations of wave front homogeneity at the sending end. The input is suitable for low-impedance (4 ohms) spike generators or conventional 50-ohm signal sources.

Grounding Investigations have indicated that grounding the bottom plate to the ground plane along its entire length creates a nonuniform field, concentrated along the grounded side. It is recommended that the bottom plate be grounded only at the termination, over the entire width of the bottom plate.

RF Power The parallel plate line will accept 250 watts continuously. Figure 4 shows that the typical RF power required to generate a 10 V/meter field. Each line should be calibrated individually.

Transmission Line Figure 4 illustrates the "electrical" construction of a transmission line atenna. Framing, bracing and supports are not shown. This antenna will accept 250 watts continuously.

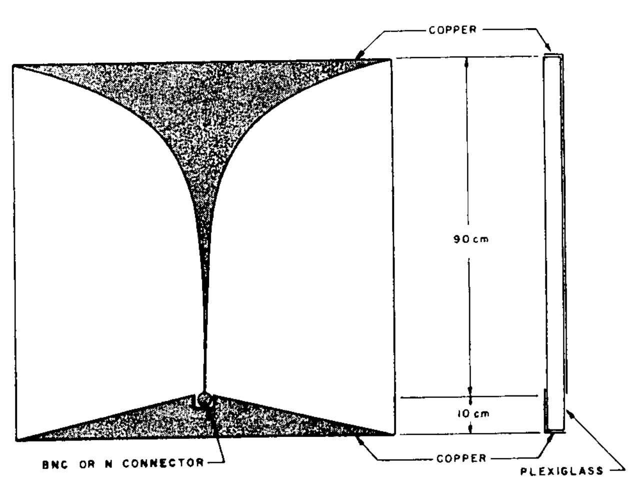

Figure 2: Wave Launcher Detail

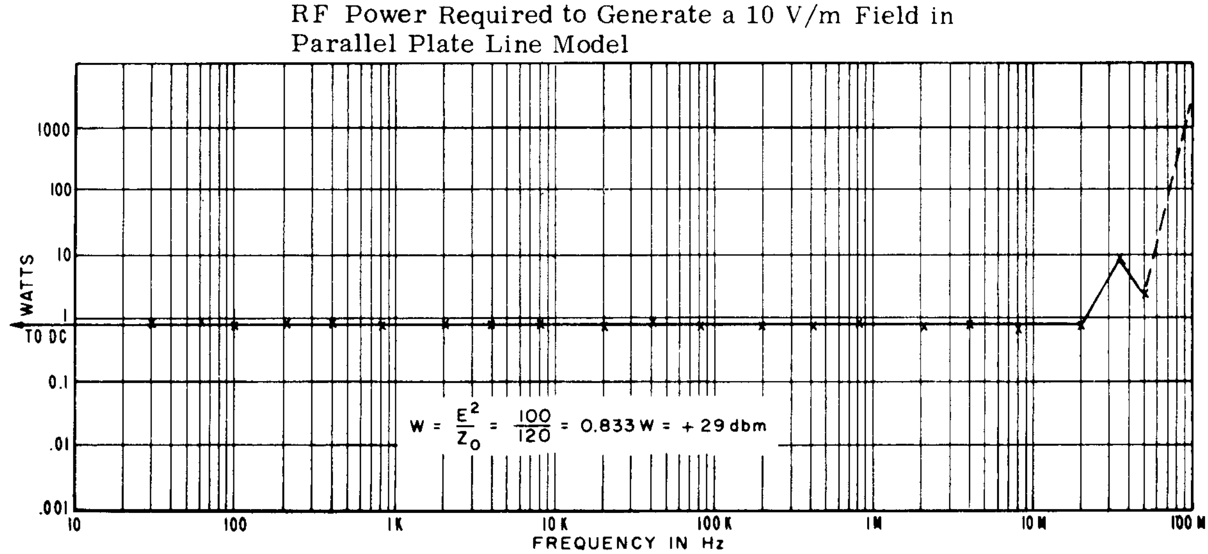

Figure 4: RF Power Required to Generate a 10 V/m Field in Parallel Plate Line Model

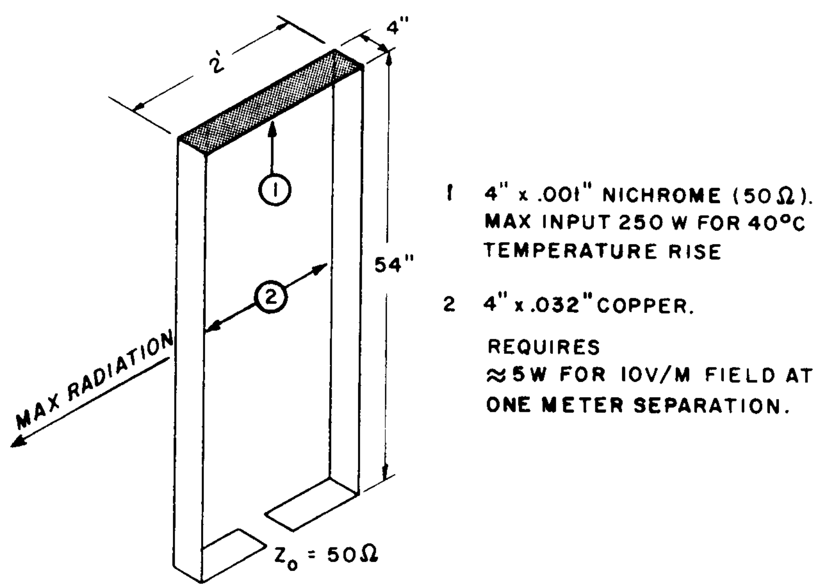

Figure 5: Transmission Line Antenna

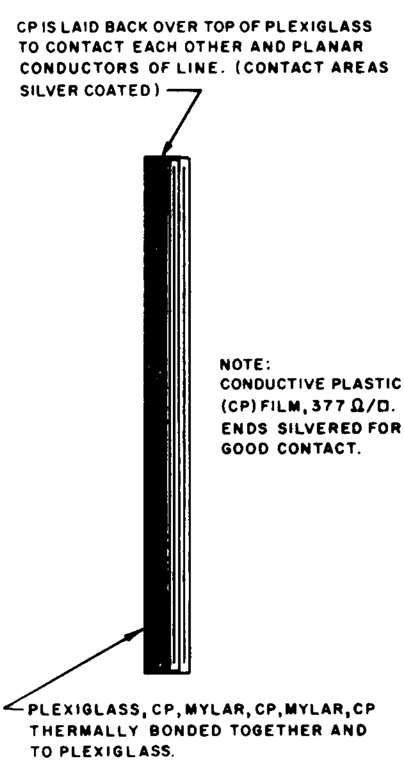

Figure 3: Termination Detail

Test Facilities

Conducted susceptibility tests may be performed in the same way as other bench-type tests. However, remember that the susceptibility signals may be propagated along powerlines and affect other equipment, both within and external to a facility. Since this energy can also be radiated, proper precautions must be taken. Line filters should be used, both to protect other equipment in a test laboratory and to prevent interference to the numerous services using the spectrum.

In all shielded enclosures, reflection effects will begin to be noticed when the major dimension of the room is of the order of one-tenth of the wavelength or so. For typical enclosures, this usually occurs somewhere in the HF range. At higher frequencies, cavity resonances begin to appear, with resultant anomalies in field levels and orientations. Rf absorbing materials are available which are effective in alleviating these conditions in the VHF and higher ranges. However, both the cost and volume of such materials are rather large, particularly for absorbers which are effective in the lower VHF region. Some EMI testing and consultant organizations have anechoic facilities available, (such as Dayton T. Brown Inc.) which may be contracted for when needed.

The above material was prepared by Charles F. W. Anderson, Associated Editor for ITEM.