EMI SUSCEPTIBILITY GENERATORS

What is an EMI Susceptibility Generator? It is a signal generator, a power amplifier, a broadband power source, a spark gap and coil, or any device with a power output of sufficient magnitude to determine the susceptibility or vulnerability of an object under test.

Susceptibility is a term used in the Interference Technology to describe an equipment or systems' undesirable response to externally applied energy. This energy can be applied to an antenna to establish a radiation environment, and is commonly called radiated susceptibility test. It is also applied to power and other lines through coupling capacitors or current probes, and is commonly referred to as conducted susceptibility test.

Radiated Susceptibility

Radiated susceptibility tests are usually performed to assure that the test specimen will operate in its intended radiated environment. The irradiation levels are either specified by a standard, or determined through a study or prediction of the intended environment. For instance, if you know that your equipment has to operate near a microwave oven, a radio or TV antenna installation, or close to communications equipment, the equipments' response to these fields should be tested in the laboratory. A measurement or calculation can define the field intensity (volts per meter) or power density (watts per square meter), and frequency of the environment. Then, by obtaining the proper antennas and power sources, it can nearly be duplicated in the laboratory.

Military and other specifications define the fields which must be generated and imposed on electronic equipment. The earlier specifications merely defined the type of antenna to use as a function of frequency, specified the open circuit voltage into the antenna terminal, and the distance between the antenna and the test specimen. The frequency ranged from 150KHz to 106Hz. The Signal Corps was the only service to specify field intensity rather than antenna applied voltage.

The most widely used modern-day Government specification, MIL-STD-461A, specifies the required frequencies, test distances, field intensities and test antennas. However, considerable flexibility is allowed by the statement, "Antennas other than those specified can be used if described in the test plan and approved by the procuring activity." For several years, the standard required a susceptibility field strength of 1 volt/meter from 14kHz through10GHz. However, in its Notice 3 and 4 revision the levels were increased. MIL-STD-461B uses a variety of high levels for RS03 by applying MIL-HDBK-235.

Obviously, radiated levels of this order of magnitude cannot be generated using standard laboratory equipment. The military has found these levels to be realistic of intended environments. The consumer product manufacturer may also be surprised to learn the environments in which his products are operated.

A major drawback of the EMI specifications, and a trap that many product manufacturers may fall into, is the unchallenged application of a single modulated CW frequency. Often, there are two or more radiators generating the severe intended environment, and the combined effects on products or systems can be considerably different from that of a single CW signal. An undesirable response to a single CW signal can be referred to as a spurious response, but multiple signals produce intermodulation and cross-modulation products which can result in an undesirable response of the equipment under test. Also, a CW signal cannot realistically simulate the radiated environment of a fluorescent light, commutator noise from a motor, or automotive engine noise.

When considering the purchase of an EMI susceptibility generator, you should look for features which could provide considerable time savings in the performance of tests. For instance, the peaking of the signal at each test frequency could take enough labor costs to pay for an expensive broadband source which is commercially available after one lengthy test. Some of the important features you should look for are:

1. Protection against damage under any magnitude or phase of source and load VSWR;
2. No tuning or band-switching (broadband);
3. Reproduction of AM or FM modulation appearing on the input signal;
4. Compatibility with reactive antennas;
5. Suppression of harmonic products;
6. Versatility in use for other purposes; and
7. Bandpass ripple.

Conducted Susceptibility

The application of a susceptibility signal to a power line may not be as simple as it may first seem. The use of a current probe will provide impedance isolation between the line and the power source. However, the probe which inductively couples the energy into the line may have losses. There is a danger of burning out the impedance matching resistors in the probe when applying high levels of energy. The lines must be monitored to determine the amount of energy pick-up by the line.

When susceptibility voltages are specified, capacitors are often used as the coupling device. The impedance of the capacitor must be small at the frequency of operation to avoid significant voltage drops across the device. Although the capacitor provides isolation between the source and line at low and power line frequencies, no isolation is present at the test frequency. Thus, when the line impedance is low, it will tend to load down the power source making it difficult to develop the desired voltage level. With an unlimited power source, it may be possible to burn out the equipment under test without ever reaching the desired or maximum safe voltage level.

For frequencies below 50 KHz, an isolation transformer is used as the coupling device. The secondary winding of the transformer is connected in series with the line under test, and must have a negligible impedance at the test frequency. The power is then applied to the primary winding and "modulates" the line. At power line frequencies, there is some danger of power being fed back to the power source causing damage to the source.

Test Facilities

Conducted susceptibility tests may be performed in the open laboratory. However, the susceptibility signal may propagate through the laboratory's power lines and interfere with other equipment. The power lines also have the capability of radiating the energy. To protect the rest of your laboratory, power line filters should be used. An inductor should be placed between the filter and the coupling device so that the filter will not load down the susceptibility signal source or in other ways effect the results of the test.

A shielded anechoic chamber would probably provide the best facility in which to perform radiated susceptibility tests. The anechoic material is absorbative usually above 100MHz (depending upon size and shape of the anechoic material), and reflections from the walls are 30 dB or more down at the point of the test sample. Significant reflections and perhaps standing waves will be present at frequencies below the cut-off frequency of the anechoic material. However, the FCC, OTM, other laboratory users and the general public would greatly appreciate the containment of these high signal levels. Many cities and towns have ordinances to this effect, especially when your signals may interfere with police and fire communications.

Commercial Applications

Once an almost completely neglected aspect of EMC/EMI, susceptibility has within the past few years assumed extremely important status. The earliest military rf interference specifications (such as AN-I-24 and Navy 16E4) had no susceptibility requirements at all. Not until the appearance of MIL-I-6181 in 1950 was there a document with susceptibility limits and test methods. Progressive expansion of susceptibility requirements in military EMI documents paralleled that of the emission aspects thereof. However, in the civilian sector, susceptibility considerations were essentially ignored, except in a few documents covering commercial airline avionics equipments. The Federal Communications Commission (FCC) Rules and Regulations contain emission limits and test methods for receivers in Part 15; but requirements for susceptibility have never been established for consumer equipment in the U.S. This has led to a near-chaotic situation within the past few years; in which by the beginning of 1982, the FCC will have been presented with about 300,000 complaints of interference to consumer-owned electronic equipments in two years. Efforts in the Congress to alleviate the situation by specifically authorizing the FCC to establish susceptibility requirements for civilian electronic equipment have come to nought thus far.

Origins of Susceptibility

Susceptibility may originate in many ways. Some of these are:

1. Receiver front-end overload.
2. Intermodulation product generation in non-linear elements, both intentional (such as mixers) and unintentional (such as mixers) and unintentional (such as audio IC's).
3. Demodulation of environmental rf signals in low-level audio circuits.
4. Spurious system resonances in sub-audio to gigahertz frequency ranges.
5. Power line noise and transients.
6. Electrostatic discharge.

Table 1 summarizes the various conducted and radiated susceptibility test frequency ranges and briefly describes the basic test methods used.

Particularly for military equipments and systems, requirements which are more stringent and/or in frequency ranges not covered by a particular document may be imposed by the system or equipment specification.

Conducted Susceptibility

Electronic devices and many equipments usually considered electrical may be vulnerable to external signals or noise entering their circuits on their power leads. The low-frequency 30Hz-50kHz conducted susceptibility requirements, CSO1 of MIL-STD-461, are intended primarily to assure that a particular equipment item will perform satisfactorily when operated from power sources which may be contaminated with spurious emanations; for example, power frequency harmonics, motor commutator ripple, or DC/DC converter oscillator powerline modulation.

Figures 1 and 2 indicate the relationship between conducted susceptibility requirements and power characteristics for aircraft 28-volt DC systems as defined in MIL-STD-704.

It is obvious that a margin of safety is provided between the maximum permissible 28-volt/DC bus ripple voltage envelope and the susceptibility test voltages specified. It should also be noted that Figure 2 shows that equipment designed for supplies other than 28 volts should be able to function properly with up to 10 percent of the nominal supply voltage (to a maximum of five volts) applied to its power leads at frequencies up to 1500Hz with decreasing levels above that point.

Spike-type susceptibility is covered by Requirement CSO6 of MIL-STD-461, which specifies the characteristics of the transients to be applied to the power input leads. As an example of vulnerability of presumably well-designed equipment to spikes injected on power input leads, a few years ago one of the more widely used computing systems (this one installed at a non-military facility) was found to be susceptible to transients at levels significantly below the specified 100 volts of CSO6. Reduction of susceptibility to transient is rapidly becoming of importance in commercial and consumer electronic equipment. Micro- and mini-computers are entering the market, in vehicular and household applications. For instance, a fine roast could be overcooked when the solid-state controller in a microwave oven malfunctions because of its vulnerability to transients generated by the SCR speed regulator in a hair dryer being used in the same house. Quantitative information on spike susceptibility requires the use of a transient generator with controllable repetition rate and amplitude; however, some qualitative idea of the vulnerability of an item to transients may be obtained by connecting a relay "multivibrator" across the input to the device. This is a relay wired so that its coil is in series with one of its normally-closed contacts.

Conducted rf susceptibility (50 kHz and above) requirements are aimed at assuring that an equipment item will be able to function properly in typical environments. Powerlines act as antennas and will pick up any rf signal which impinges on them. Such signals can, in turn, propagate along the lines and arrive at the power input terminals of the device.

Once inside, coupling of the spurious signal into vulnerable circuits can occur by many different paths. The recent explosive growth of both communications and non-communications rf sources in public and private use means that this aspect of susceptibility can no longer be considered as only of importance in complex military systems.

The family of conducted susceptibility requirements represented by CSO3, CSO4, CSO5 and CSO7 is intended to assure that receivers are capable of operating compatibility in radiated rf environments in which they will be used. Althrough rf ambient levels are much higher in most military usage situations, the proliferation of communications transmitters mentioned above has resulted in a corresponding increase in interference incidents involving receivers used by the general public and by the numerous municipal, county and state government agencies. CSO3 establishes intermodulation requirements; while CSO5 sets out those for cross-modulation (which is generally considered to be a special case of intermodulation). CSO4 requirements cover front-end rejection of undesired signals. It is quite important that both the testing and the analyses of results for the above three sets of requirements be performed by competent personnel. Differentiation between true spurious responses (e.g., a higher-order image or an IF feed-through) and the more complex intermodulation products may be difficult, indeed, even for relatively experienced engineers and technicians. Computer or programmable-calculator analytical techniques must be resorted to in this area in many situations. The CSO7 requirements apply only to receivers having squelch circuits, and are intended to establish reasonable levels of resistance to radiated impulse noise. Test 1 of CSO7 uses only an impulse generator as the input; while Test 2 uses both an impulse generator and a signal generator (applied simultaneously via isolation networks), with the output of the latter set at a level below the squelch-break point.

TABLE 1
SUSCEPTIBILITY TESTS AND TEST METHODS

TESTS	METHODS
Conducted	
Powerlines	
30 Hz to 50 kHz	Injection from audio source via special transformer (1)
15 kHz to 150 MHz	Injection from signal generator via current probe (2) (6)
50 kHz to 400 MHz	Injection from signal generator via low-reactance capacitor (6)
Spike	Injection from spike generator via integral transformer (3)
Intermodulation	Receiver front-end injection from two signal generators with isolation network(s)
Undesired signal rejection	Receiver front-end injection from two signal generators with isolation network(s)
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 special loop energized from audio source (4)
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 (5) (6) (7)	
14 kHz to 10 GHz	Rod, dipole and conical log-periodic antennas energized from signal generators/amplifiers
14 kHz to 30 MHz	Parallel-plate line energized from signal generators/amplifiers (8)
14 kHz to 30 MHz	Longwire antenna in shielded enclosure, energized from signal generators/amplifiers (9)
	Crawford Cells, energized from signal generators/amplifiers (10)

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 commercial avionics equipments per 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) Instructions for the fabrication of this loop appear in MIL-STD-461.

(5) See footnote under Radiated Susceptibility in this section.

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

(7) Field levels at location of EVT should be checked, using a sensor/remote readout arrangement such as the Instruments for Industry type EFS-1/LMT/LDI.

(8) Fabrication instructions for a widely-used parallel-plate line and a "transmission-line" (or "loop-line") antenna are given in Air Force Design Handbook DH1-4. Directions for making another parallel-plate type are contained in MIL-STD-462. The former will accommodate 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 non-inductive resistors at the line input and end terminations. 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.
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 SOME AGENCIES FOR HUMAN EXPOSURE. TEST PERSONNEL SHOULD NOT BE INSIDE THE ENCLOSURE DURING SUCH TESTING.

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

Radiated Susceptibility

Almost any electronic device—not merely intentional receivers—may be vulnerable to electromagnetic fields. This has become especially apparent as more and more consumer-oriented electronic devices have come into use. The majority of the cases of interference reported to the FCC within recent years have involved, as victims, equipments not intended to act as receivers.

The magnetic field susceptibility requirements of RSO1 and RSO2 of MIL-STD-461 are primarily of interest to designers of equipment for military and other rigorous environments. RSO1 testing involves use of a specified multi-turn coil energized from a variable-frequency source. The coil is used to probe all surfaces of an equipment case. RSO2, Test 1 requirements are aimed at ensuring that the inter-connecting cables of an equipment or system will not be adversely affected by the relatively constant-amplitude magnetic fields set up by ac powerlines, or by the high-level transient magnetic fields incident to energization or de-energization of large inductive loads (e.g., solenoids and motors). RSO2 requirements are intended to accomplish similar ends for the equipment "black boxes" themselves. The cable and case tests are performed both with a power-frequency source and with a spike generator source.

The tests of RSO3 involve exposure of equipments to rf electric (nominally) fields.[1]

It is interesting to note that orders-of-magnitude increases in the levels specified for these tests have been implemented since the original V/meter given in MIL-STD-461 in 1967. Notice 3 to MIL-STD-461A, issued in May 1970, raised the test levels from 5 to 200 V/m, depending on frequency and usage location, for U.S. Air Force procurements. The U.S. Army Electronics Command in Notice 4, dated February 1971, established test levels of up to 50V/m also frequency- and usage-dependent. The above changes reflect military experience in typical deployment situations.

Considerably more detailed treatment of susceptibility requirements with respect to category of usage has been written into MIL-STD-461B. Table 2 shows the parts and the conducted spikes.

Recognition of the substantial increases in rf environmental levels in recent years has not been confined to military situations. The Scientific Apparatus Manufacturers Association (SAMA), issued a standard covering radiated rf susceptibility of industrial and process control instrumentation. Three basic classes, each with three subclasses, are established; for low-, moderate-, and high-level rf environments. Field strengths to which the equipment is to be exposed are 3, 10 and 30 volts per meter, respectively. To offset increased costs of providing the required modifications to obtain the necessary degree of protection, some manufacturers are offering the susceptibility fixes as an extra-cost option package. Even the highest of the above levels is not at all unrealistic, considering that in many industrial facilities, a number of employees will be using VHF transceivers with 5-watt output capability within intimate distances of sensitive monitoring and controlling devices.

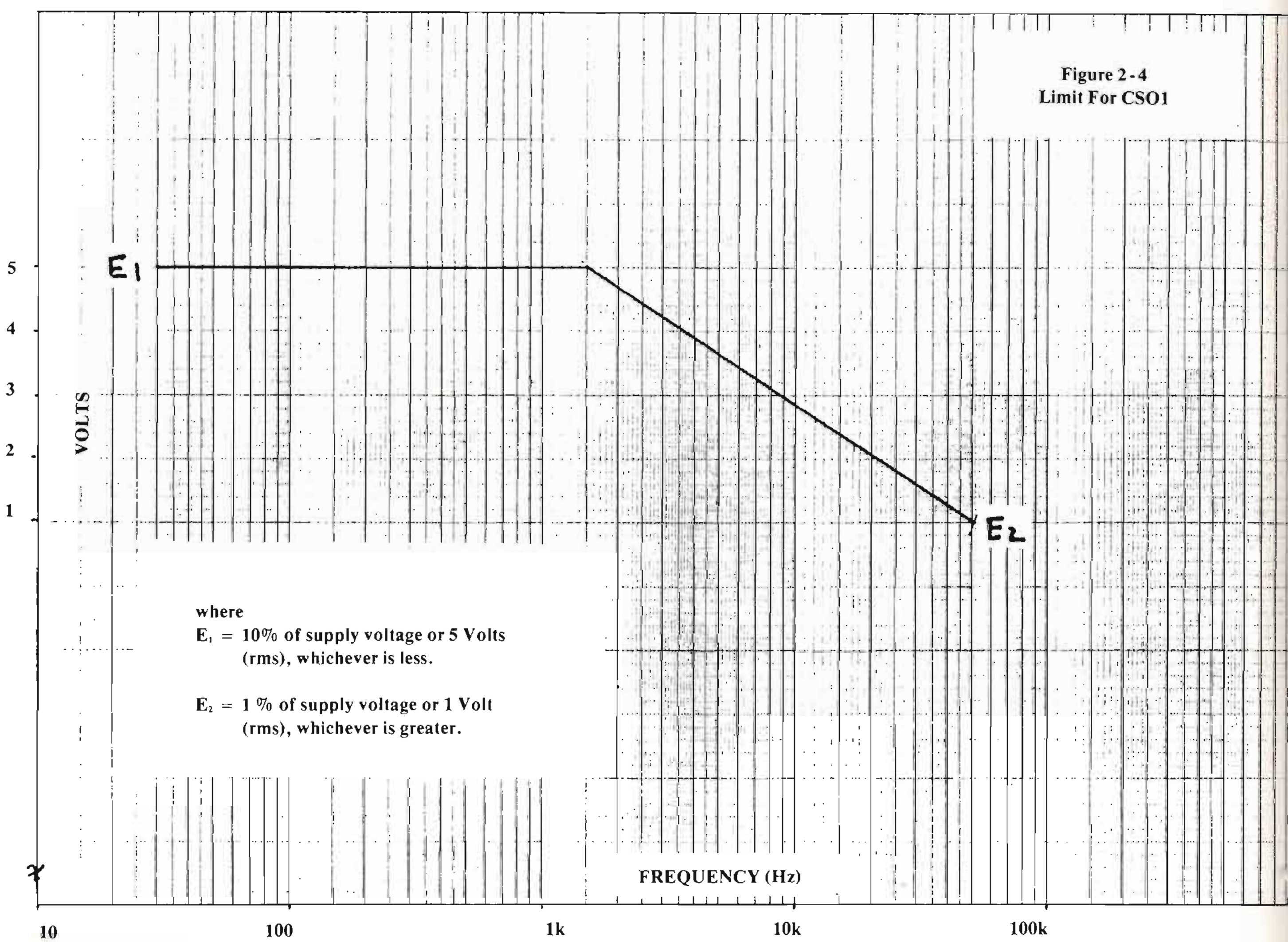

Figure 1. Conducted Susceptibility Limits CSO1

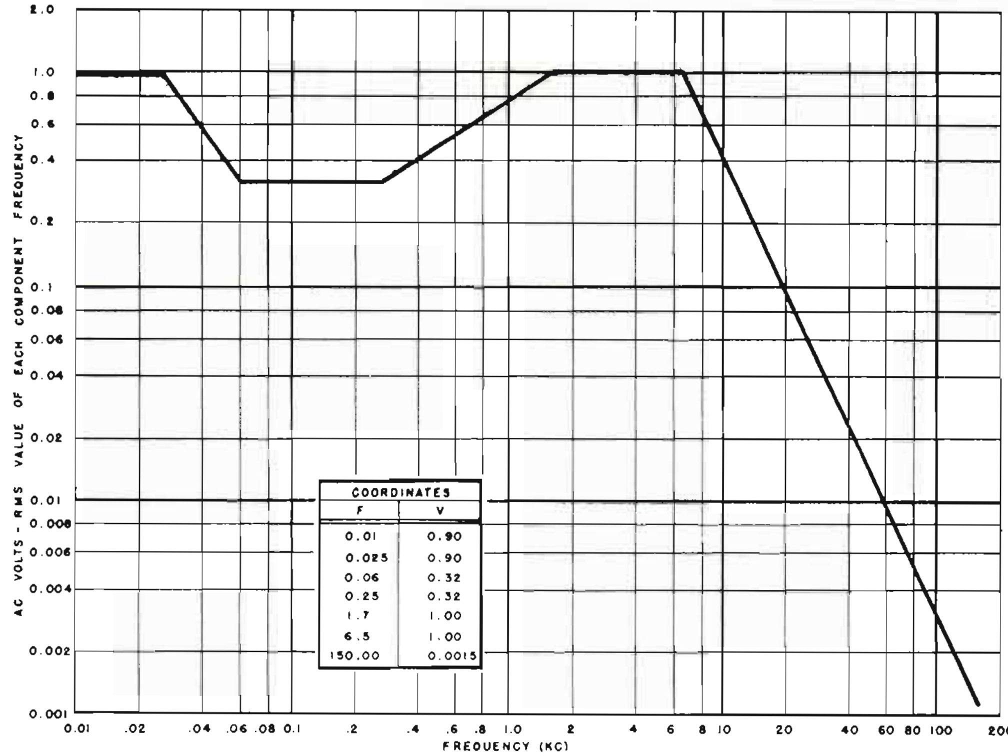

Figure 2. Frequency characteristics of ripple in 28 volt dc electric systems.

Definitions of Susceptibility

Susceptibility has been defined variously in a number of the government and other requirements documents. MIL-STD-463 (Military Standard Definitions and Systems of Units, Electromagnetic Interference Technology) defines it as "the characteristic of electronic equipment that permits undesirable responses when subjected to electromagnetic energy." Somewhat more specifically, the Society of Automotive Engineers'ARP 937 uses the following definition: "That characteristic which causes an equipment to malfunction or exhibit an undesirable response when its case of any external lead or circuit is subjected to electromagnetic voltages or fields." However defined, susceptibility is, indeed, a highly significant aspect of EMC/EMI engineering.

TABLE 2
CONDUCTED SPIKES (CSOG)

Peak and Duration	PART					
	2	3	4	5	6	7
100v, ≤ .10μs						
100v, ≤ .15μs		x	x			
200v, ≤ 10μs	x	x				
200v, ≤ .15μs	x					
400v, ≤ 5μs			x	x	x	x

Overloading: Overloading is caused by an increase in the amplitude of the desired signal. The increase may drive the channel into saturation so that no output response will result from an input command. There is a time lag between the period that the device goes into saturation and recovers from it. When the device becomes overloaded or saturated the position of the shaft may drift or run to its zero position or to the extreme unbalance at one or the other ends of its excursion.

Blocking: Blocking occurs in systems when an undesired input renders a channel ineffective, e.g., the blocking of the radar receiver by the transmitted radar pulse. Because of space and complexity limitations, the same waveguide and antenna system is often used for both transmitter and receiver. Although the radar receiver is isolated from the antenna and waveguide assembly during the time the transmitter is on, the transmitted pulse still leaks into the receiver. The receiver sees this RF energy as a returned signal of high amplitude. It saturates the radar receiver and when the pulse is over the receiver remains blocked. Unintentional blocking of one function by another can occur on a continuous basis or it may only produce a blind spot in a cycle of the operation. Continuous blocking can almost always be detected during the functional checkout and testing if the offering source or jammer is activated. The intermittent or partcycle blocking usually occurs when different equipments are integrated together into one system.

Offsets: Offsets may occur as a result of conducted, coupled, or radiated energy which may be internal or external to the system. Equipment is susceptible when its output may be offset or biased from that which should occur for given command inputs.

Dielectric Heating: At high frequency, dielectric materials exhibit a loss phenomenon which is analogous to hysteresis loss in magnetic materials. The material between the bridge wire and the case of a squib is susceptible to such effects. In the presence of high power jamming or radar equipment, squib action can occur due to dielectric heating.

Heating Value: When AC or DC current flows through any resistive device, the energy dissipated in the form of heat is I^2R. Heat can act as an undesirable signal and can cause heating of devices which should not be heated without the application of a specified control current or which have operating characteristics dependent on temperature. The AC resistance cannot, in general, be assumed to be the same as the DC resistance. Squibs, for example, which have DC resistances under one ohm characteristically exhibit 30-40 ohms at UHF frequencies. I^2R loss is further dependent on the reactance portion of the AC impedance. The reactance of a squib varies from zero to several hundred ohms at UHF and changes from inductive to capacitive. No power can be dissipated in a reactance, but it does control the current flowing through the AC resistance in series with it.

Spark-Through: Static voltages can build up on isolated or floating circuits. Winds blowing over ungrounded wires have resulted in static voltages which have caused inadvertent squib detonation. Squibs which employ ungrounded and shielded input cabling are subject to spark-through and placing a short across the squib input terminals will prevent inadvertent firing. Static buildup in other circuitry causes the ungrounded secondary of a transformer feeding an ungrounded amplifier grid to be subject to error.

False Triggering: If a stray or false signal exhibits the characteristics of the true signal there is no way that a device (mechanical, electronic or human) can detect it.

False Signals: Bandwidth is the important consideration when evaluating susceptibility to false signals. Closed loops, servomechanisms, and regulators can often tolerate high levels of noise and false signals because of narrow bandwidth. Susceptibility to broadband noise is evaluated by determining the frequency spectra of the noise. Give consideration to the response of the system loop beyond its normal cutoff frequency. These characteristics are important because a high level interfering signal may exist a few octaves above the normal cutoff frequency and may be strong enough to penetrate the attenuation.

Stray Resonances: High-gain amplifiers are particularly subject to stray resonances. Capacitors which should ideally exhibit low impedances toward self-resonsance and a high effective reactance to ground. Lead length inductance may be high enough to resonate with bypass capacitances below the normal frequency of operation. For example, at 10 MHz, a 1000-pf bypass capacitor will series resonate with only ¼ -μh inductance.

Subaudio Interference: Some important aspects of subaudio interference susceptibility are that it is not often sustained for more than a few seconds; that it is difficult to detect; and that it is usually superimposed on desired signal flow and marked by higher frequency hash, which is ignored by the loop. Subaudio interferences are generated as airborne vehicles exhibit dynamic structural resonances. The approximate frequencies of different vehicle assemblies resonate as follows: (1) the total vehicle resonates at a few hertz, (2) structural resonances go up to 10 hertz, and (3) bulkhead and equipment racks resonate at hundreds of hertz. Equipments and cable bundles vibrate as the airborne vehicle experiences agitation and electrical disturbances result in two ways: either transducers and sensors "see" the resultant displacement, velocity, or acceleration and generate an undesired output signal; or wires, cables, and bundles are moved through electric and magnetic fields. Induced voltages and current result, and under these conditions, rate gyros have produced enough undesired output to cause gross guidance disturbances.

Clipping: Clipping can generate unintentional effects in demodulator and detector circuits.

Limiting: When a desired signal frequency is intentionally limited, the output waveform is distorted. The networks to which the limited waveform is fed may be responsive to the harmonic frequencies of the distortion and produce a false output. Tuned circuits may exhibit spurious resonances at those frequencies. As limiting action is made stronger, the wave form of the original signal will be made steeper and will have higher frequency components which couple across transformers, resistors, amplifiers, stray capacitances, etc.

Receiver Sensitivity: All receivers exhibit an on-frequency sensitivity variation which is frequency-dependent. The image response of all receivers also varies as the receiver is tuned across the band. At a specific high frequency the shielding, decoupling, and bypassing components become self-resonant. At this point the interference begins to flow through the receiver by electrostatic coupling.

High Power Environments: Receivers are now designed without precautions against operation in high-power environments. In such an environment undesired responses can be categorized as destructive heating of front-end components, image responses, local oscillator harmonic heterodyne responses, stray resonant responses and high-end electrostatic coupling. The kilowatt and megawatt peak-power levels are capable of destructive effects in receiver front-ends. In addition, modulation characteristics can be detected by the receivers. The stray responses vary widely due to nonuniform components, wiring inductance, stray capacity, and layout variations.

1. With the test setup geometries specified in requirements documents, the equipment under test (EUT) is in a region in which the predominant electro-magnetic field components over most of the specified frequency ranges are the magnetic induction field and the static dipole field (also known as the electric induction field or radial electric field). Refer to Chapter 6 of "Noise Reduction Techniques in Electronics Systems," Henry W. Ott, Wiley-Interscience, 1976; for a discussion of wave impedance variations in the near field region.