Electromagnetic Susceptibility Procedures for Vehicle Components (Except Aircraft)—SAE J1113a

SAE Recommended Practice
Completely revised June 1978

THIS IS A PREPRINT WHICH IS SUBJECT TO REVISIONS AND CORRECTIONS. THE FINAL VERSION WILL APPEAR IN THE 1979 EDITION OF THE SAE HANDBOOK.

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LAND SEA AIR SPACE

PREPRINT

ELECTROMAGNETIC SUSCEPTIBILITY PROCEDURES FOR VEHICLE COMPONENTS (EXCEPT AIRCRAFT)—SAE J1113a

SAE Recommended Practice

Report of Subcommittee on EMI Standards and Test Methods approved April 1975 and completely revised by Electronic Systems Committee June 1978.

1. Introduction

1.1 Scope—This SAE Recommended Practice establishes uniform laboratory measurement techniques for the determination of the susceptibility to undesired electromagnetic sources of electrical, electronic, and electromechanical ground-vehicle components. It is intended as a guide toward standard practice but may be subject to frequent change to keep pace with experience and technical advances, and this should be kept in mind when considering its use.

1.2 Measurement Philosophy—The need for measurement of the susceptibility of vehicle electronic components to electromagnetic sources has recently become more critical as more electronic components are used in safety-related vehicle application. Electronic and electrical equipment may be susceptible to temporary or permanent malfunctions when subjected to electromagnetic sources, either of a transient or steady-state nature.

Electromagnetic interference (EMI) may be either transient, intermittent, or continuous in nature arising from sources such as transmitters or other equipment located either on board, or adjacent to the vehicle, or from component parts of the vehicle ignition or electrical power systems.

This recommended practice sets forth uniform procedures for establishing the susceptibility levels of individual vehicle components. It does not, however, set limits on levels of EMI in which vehicle components must perform.

The most direct method of specifying the EMI environment limits is to measure the actual fields, voltages, currents, and impedances around the component or system of interest under all hazardous conditions. This will, of course, require a large enough sample of installations to determine possible variations.

Another approach to setting limits on levels of EMI would be to establish maximum levels of electric and magnetic field strength with the interconnecting wire and field impedance levels expected for all points within the vehicle, from sources of maximum power levels expected for on-board transmitters, transient sources, and external transmitters. These constitute the ambient level of EMI. Data of this type are being collected and may be supplied later as a separate report on EMI characteristics and test limits.

It is recommended that a statistically valid number of components be tested using procedures adopted as standard by the testing organization. If there is no such standard procedure, one given in Appendix A may be used for all sections of this procedure, except where destructive testing results (Section 5 and possibly Section 4). For destructive testing, such as load-dump simulation of Section 5, consult a handbook on statistical methods for details of the Karber Method or the Bruceton (stair-step) Method of sensitivity measurements. These methods eliminate the effects of cumulative degradation which often occurs during destructive testing.

It is suggested that only those portions of this recommended practice which are critical to the particular use of the component under test be applied, rather than subject the component to the provisions of the entire document. Thus, if the particular component under test is known to be susceptible mainly to transients, but otherwise well protected against conducted and radiated EMI, then only Section 5 need be applied. Or if susceptibility to radiated energy is known to be a primary cause of malfunctions, then only Sections 6 through 8 need be applied.

A list of suitable equipment is provided as an aid in Appendix B. No approval or disapproval of any manufacturer is intended, either by inclusion or exclusion from this list.

Caution must be exercised in many portions of this procedure where high voltages or intense fields may be present. (The present maximum allowable field for human exposure is 10 mW/cm^2 averaged over 6 min, which is equivalent to about 194 V/m electric field strength in the far field.)

The ϕ symbol is for the convenience of the user in locating areas where technical revisions have been made to the previous issue of the report. If the symbol is next to the report title, it indicates a complete revision of the report.

1.3 Definitions and Terminology—The following definitions apply to the terms indicated as they are used in this recommended practice:

1.3.1 Ambient Level—Those levels of radiated and conducted signal and noise existing at a specified test location and time when the test sample is in operation. Atmospherics, interference from other sources, and circuit noise or other interference generated within the measuring set compose the *ambient level.*

1.3.2 Conducted Emission—Desired or undesired electromagnetic energy which is propagated along a conductor. Such an emission is called *conducted interference* if it is undesired.

1.3.3 Electromagnetic Compatibility (EMC)—Is the condition that enables equipment, subsystems, and systems (electronic, chemical, biological, etc.) to function without degradation from electromagnetic sources and without degrading the electromagnetic environment; i.e. it is the condition which allows the coexistance of different electromagnetic sources without significant change in performance of any one in the presence of any or all the others.

1.3.4 Emission—Electromagnetic energy propagated from a source by radiation or conduction.

1.3.5 Equipment Under Test (EUT)—The device or system whose susceptibility is being checked.

1.3.6 Field Decay (Voltage)—The exponentially decaying negative voltage transient such as developed by an automotive alternator when the field excitation is suddenly removed, as when the ignition switch is turned off.

1.3.7 Field Strength—The term *field strength* shall be applied to either the electric or the magnetic component of the field, and may be expressed as V/m or A/m. When measurements are made in the far field and in free space, the power density in W/m^2 may be obtained from field strengths approximately as $(V/m)^2/377$ or $(A/m)^2 \times 377$.

1.3.8 Ground Plane—A metal sheet or plate used as a common unipotential reference point for circuit returns and electrical or signal potentials.

1.3.9 Interference Emission—Any undesirable electromagnetic emission.

1.3.10 Load Dump (Voltage)—The exponentially decaying positive voltage transient developed by an automotive alternator when disconnected suddenly from its load, while operating without a storage battery or with a discharged storage battery. Removal of the load, the resulting transient, or both in combination are commonly referred to as *alternator load dump.*

1.3.11 Radiated Emission—Radiation- and induction-field components in space. (For the purpose of this document, induction fields are classed together with radiation fields.)

1.3.12 Spurious Emission—Any unintentional electromagnetic emission from a device.

1.3.13 Susceptibility—The characteristic of an object that results in undesirable responses when subjected to electromagnetic energy.

1.3.14 Test Plan—The specific document that details all tests and limits for the particular device in question. Several general outlines exist to assist the test designer, e.g., Appendix D of NAVAIR 5335.

2. Conducted Susceptibility, 30 Hz–50 kHz—All Input Leads Including DC and AC Power

2.1 Purpose—This section covers the requirements for determining the susceptibility characteristics from 30 Hz–50 kHz of automotive electronic equipment, sub-systems, and systems to EMI injected onto all input leads, including signal and power.

2.2 Measurement Philosophy—Power-source RF impedance seen by a given type of electronic equipment is dependent upon each particular installation. The effect on the equipment of a powerline RF voltage depends upon this varying impedance, and would render susceptibility measurements meaningless unless the impedence is also measured or controlled. In order to compare measurements made at various locations, powerline impedance seen by the equipment at test frequencies shall be controlled by a shunt capacitor; this also helps to assure adequate voltage at power terminals of the test sample.

At these frequencies, the impedances seen by control and signal leads are generally under the control of the system designer and should be known.

Hence, the design values of such impedences shall be used in test measurements to simulate actual performance, as well as to provide ready comparison of measurement results made at various locations.

2.3 Grounding and Shielding—For the stated test frequencies, there are no special grounding and shielding requirements. However, the requirements of Section 3 may be utilized here, if expedient.

2.4 Apparatus—Test apparatus shall be as follows:

(a) Audio Oscillator—30 Hz–50 kHz.

(b) Audio Power Amplifier—50 W or greater with output impedance equal to, or less than, 2.0Ω (capable of delivering 50 W into a 0.5Ω resistive load connected across an isolation-transformer secondary).

(c) Measuring Instrument—Calibration Oscilloscope, VTVM or EMI Meter.

(d) A 100 μF Capacitor—required as a shunt to stabilize power-source impedence and to help obtain sufficient test voltage.

(e) Isolation Transformers—secondaries shall be capable of handling power current flow without saturation of core.

(f) DC and AC Power Supplies.

2.5 Test Setup and Procedures—The test setup is shown in Fig. 1 for signal-input circuits (no shunt capacitor) and DC power inputs; and in Fig. 2 for AC power inputs. The procedure is as specified below (see paragraph 2.6):

(a) The EUT shall be connected as shown in Figs. 1 or 2.

(b) The audio oscillator shall be tuned through the required frequency range (30 Hz–50 kHz) with the output progressively adjusted toward the maximum level. Monitor the EUT for (1) malfunction, (2) degradation of performance, or (3) deviation of parameters beyond tolerances indicated in the equipment specifications or approved test plan. The types of failure and their associated susceptibility threshold values shall be recorded.

(c) To determine the susceptibility of power leads, the required power supply voltage applied to the test sample shall be measured and maintained within the specified tolerance as indicated in the equipment specification or approved test plan during the test.

2.6 Notes—If the output impedance of the signal source looking into the secondary terminals of the isolation transformer is unknown, measurement shall be as follows:

(a) Apply a signal to the primary of the transformer and measure the open-circuit secondary voltage (V_{oc}).

(b) Connect a known load R_L, across the secondary and measure the closed-circuit secondary voltage (V_{cc}).

(c) The impedance shall be calculated as follows:

$$Z = \frac{R_L \ (V_{oc} - V_{cc})}{V_{cc}}$$

(d) Repeat the above procedure at one frequency per decade from 30 Hz–50 kHz (including 30 Hz and 50 kHz).

(e) The measured impedance shall be less than, or equal to, 0.5Ω on powerlines, and within tolerances of the designed values for signal inputs.

3. Conducted Susceptibility, 50 kHz–100 MHz—All Input Leads, Including DC and AC Power

3.1 Purpose—This section covers the requirements for determining the susceptibility characteristics from 50 kHz–100 MHz of automotive electronic equipment, subsystems, and systems to EMI injected onto all input leads, including signal and power.

3.2 Measurement Philosophy—Power-source RF impedance seen by a given type of electronic equipment is dependent upon each particular installation. The effect on the EUT of a powerline RF voltage depends upon this varying impedance, and would render susceptibility measurements meaningless unless the impedance is also measured or controlled. In order to compare measurements made at various locations, powerline RF impedance seen by the equipment shall be controlled by line-impedance stabilization networks.

3.3 Grounding and Shielding—To achieve uniform measurement conditions at RF requires that certain grounding practices be followed. Ground-requirements are that equipment:

(a) be centered on a metallic ground plane having the following minimum dimensions:

(1) Thickness—1.5 mm (0.060 in) aluminum, copper, or brass sheet.

(2) Surface Area—1 m^2 (10.8 ft^2) or underneath entire equipment plus 0.5 m^2 (5.4 ft^2), whichever is larger.

(3) Width—0.5 m (20 in).

(b) be bonded to the ground plane at its most-sensitive input-terminal(s') ground point(s).

(c) not otherwise be grounded, unless required in installation instructions. The line-impedance stabilization networks shall be bonded to the ground plane as close as possible to the EUT ground. No shielding is to be used other than that called out in installation instructions.

3.4 Power Input Lead Test

3.4.1 Apparatus—Test apparatus shall be as follows:

(a) Signal Source—A 50Ω output-impedance source with an output of 100 V or greater into a matched load.

(b) One of the following to measure RF voltage:

(1) Calibrated Oscilloscope.

(2) VTVM.

(3) EMI Meter.

(4) Spectrum Analyzer.

(c) Line-Impedance Stabilization Networks (LISN's)—as specified in Figs. 3A and 4A with 50Ω resistive RF terminations. When using an LISN, caution should be exercised to avoid load-current limiting due to series inductance in the LISN. This limiting may occur when loads switch between high- and low-impedance states. Use of an LISN may then result in increased susceptibility.

(d) Test-Source Injection Networks illustrated in Fig. 5.

(e) Power Supply - DC and AC.

3.4.2 Test Setup and Procedure—The test setup is shown in Fig. 6. The procedure is as specified below.

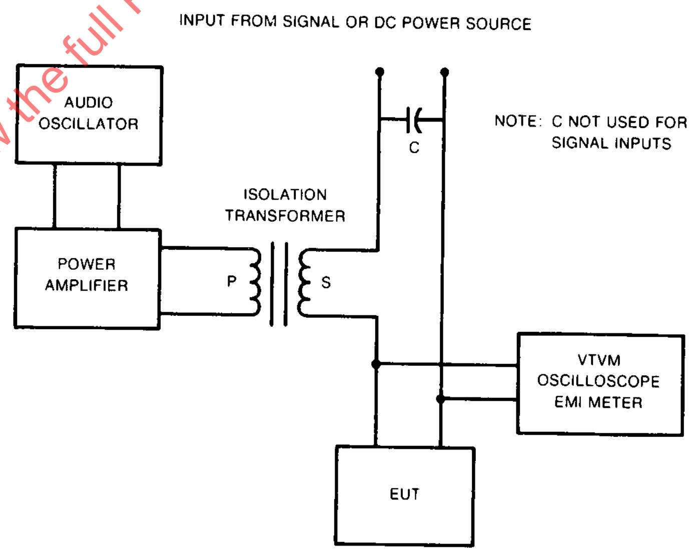


FIG. 1—TEST SETUP FOR MEASURING CONDUCTED SUSCEPTIBILITY, 30 Hz–50 kHz, SIGNAL OR DC POWER INPUT

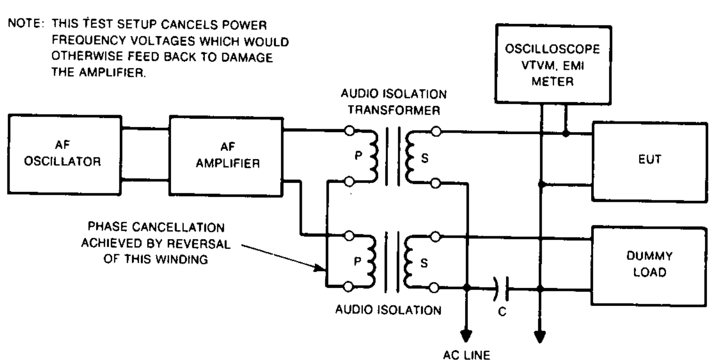
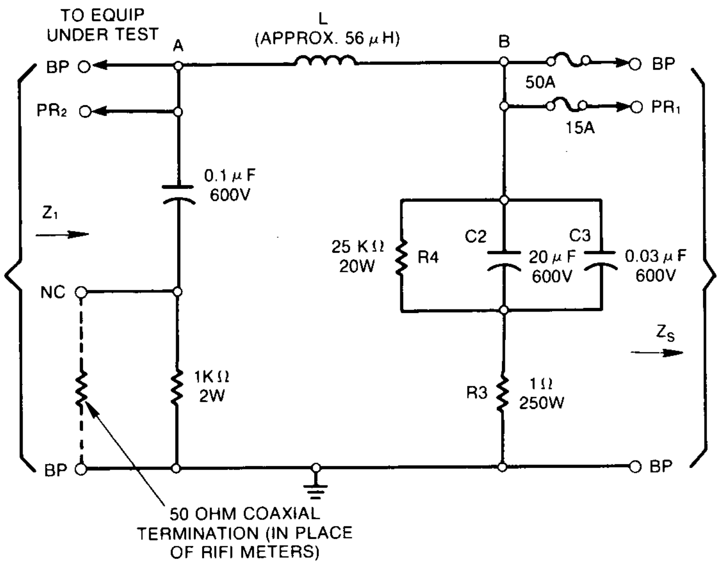


FIG. 2—TEST SETUP FOR MEASURING CONDUCTED SUSCEPTIBILITY, 30 Hz–50 kHz, AC INPUT



Z_1 - IMPEDANCE PRESENTED TO THE EQUIPMENT WHEN CONNECTED FOR MEASUREMENTS.

Z_S - IMPEDANCE OF THE POWER SOURCE USED.

BP - HEAVY DUTY BINDING POSTS (MFR. STANDARD ELECTRIC TIME CO.)

PR_1 - POWER RECEPTACLE, 115 V, 15 A (3-WIRE POLARIZED. TWIST LOCK, MALE BASE)

PR_2 - POWER RECEPTACLE, 115 V, 15 A (3-WIRE NON-POLARIZED, "U" SHAPED GROUNDING SLOT.)

NC - TYPE "N" CONNECTOR (UG-58/U) PANEL MOUNTING.

L* - COIL - 26 TURNS OF NO. 6-600 VOLTS INSULATED WIRE (STRANDED), WOUND ON 5-½" (14 cm) DIAMETER COIL FORM.

CASE: 17-½" L x 17-½" W x 8-¾" H (44.4 cm L x 44.4 cm W x 22.2 cm H) BRASS (DIVIDED IN TWO SECTIONS BY A BRASS PLATE 17-½" x 8-⅝" x 1/16" (44.4 cm x 21.9 cm x 1.6 mm) THICK.)

NOTE: DUAL LINE STABILIZATION NETWORK CONSISTS OF TWO OF THE ABOVE NETWORKS.

FIG. 3A–LINE IMPEDANCE STABILIZATION NETWORK (LISN), 50 kHz–5 MHz

(a) Each control and signal lead shall be loaded with a terminating impedance. At these frequencies, however, the impedances as seen by the control and signal leads may no longer be determined by the system designer, due to uncontrollable stray impedances. It may be possible to simulate these impedances with a simple capacitor and inductor added to the actual leads if the frequency in MHz does not greatly exceed $\frac{300}{20\pi\ell}$, where ℓ is the characteristic lead length in metres. Above that frequency, the test designer should design his test plan and setup to given uniform results.

(b) The EUT shall be connected as shown in Fig. 6, observing the grounding and shielding requirements of paragraph 3.3.

(c) Signal sources and measuring instrumentation shall be connected to an LISN through test-source injection networks. Care shall be exercised to insure sufficiently short leads on the injection networks and LISN's to minimize loss of signal due to series inductance and shunt capacitance. A current probe on the injection lead right next to the EUT can be used to monitor the signal. For signal-source and measuring-instrument impedance equal to 50Ω, use the signal-injection network of Fig. 5A. For a signal-source impedance of 50Ω and a high-impedance measuring instrument, use the signal-injection network of Fig. 5B. Note the corresponding attenuation factors.

(d) Increase the level of the test signal while continuously scanning through the required frequency range (50 kHz–100 MHz). Tests shall be conducted at not less than three frequencies per octave representing the maximum susceptibilities within that octave. Monitor the equipment under test for (1) malfunction, (2) degradation of performance, or (3) deviation of parameters beyond tolerances indicated in the equipment specification or approved test plan (see paragraph 3.6). Record the highest level before degradation was observed.

(e) See paragraph 2.5 (c).

3.5 Control and Signal Lead Test

3.5.1 Apparatus—Test apparatus shall be as follows:

(a) Signal Sources—as for powerline measurements.

(b) Measuring Instruments—as for powerline measurements.

(c) Test-Source Injection Networks—see Fig. 5.

3.5.2 Test Setup and Procedure

(a) The test setup is shown in Fig. 7. Note that the LISN remains in the powerline circuit and its RF injection terminal is loaded with 50Ω.

(b) Each control and signal terminal not under test is loaded with its terminating impedance and test signals are injected into the test terminal

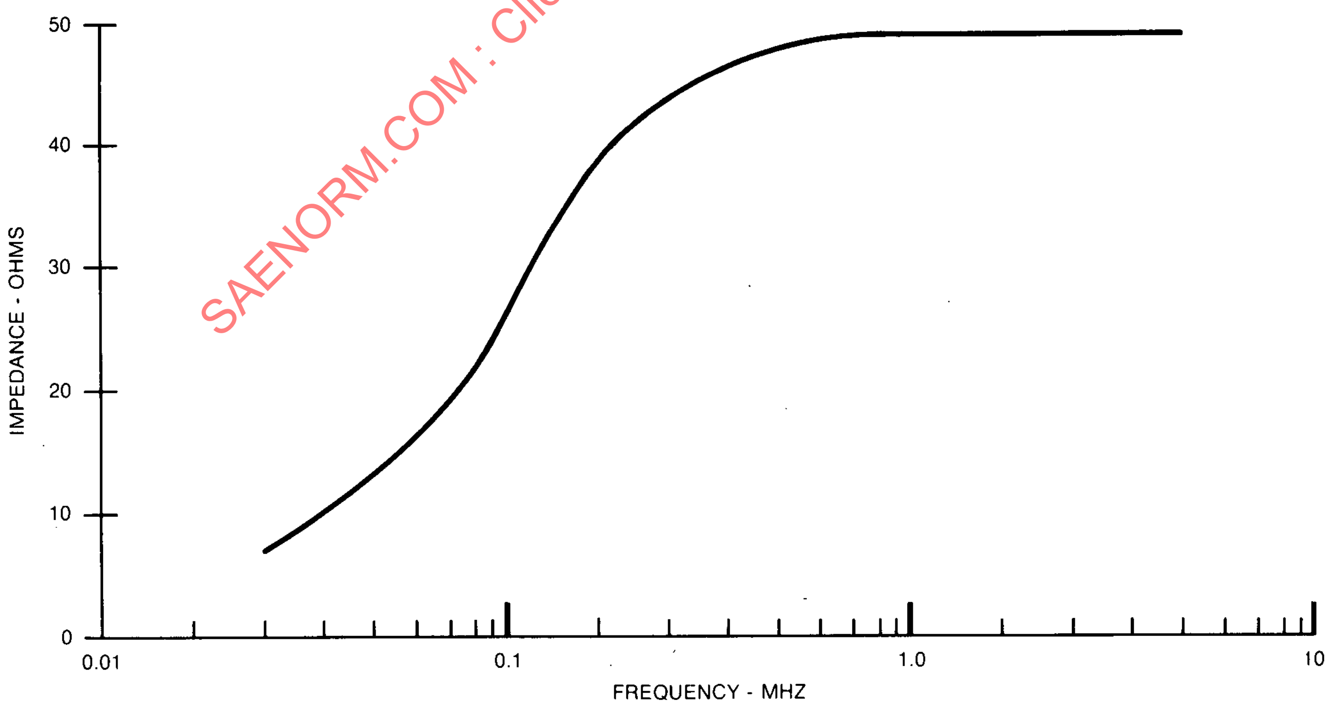


FIG. 3B–LINE IMPEDANCE STABILIZATION NETWORK REFERENCE IMPEDANCE, 50 kHz–5MHz

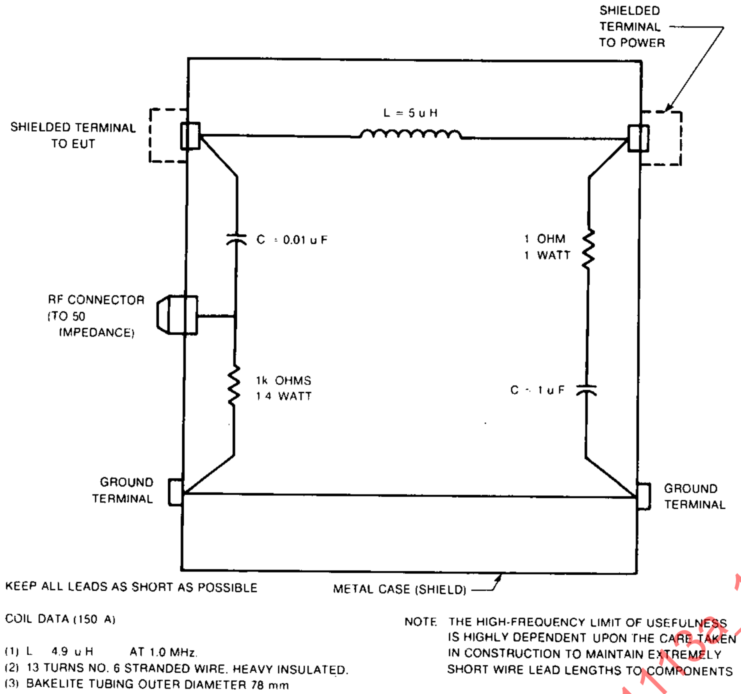


FIG. 4A–LINE IMPEDANCE STABILIZATION NETWORK (LISN), 5–100 MHz

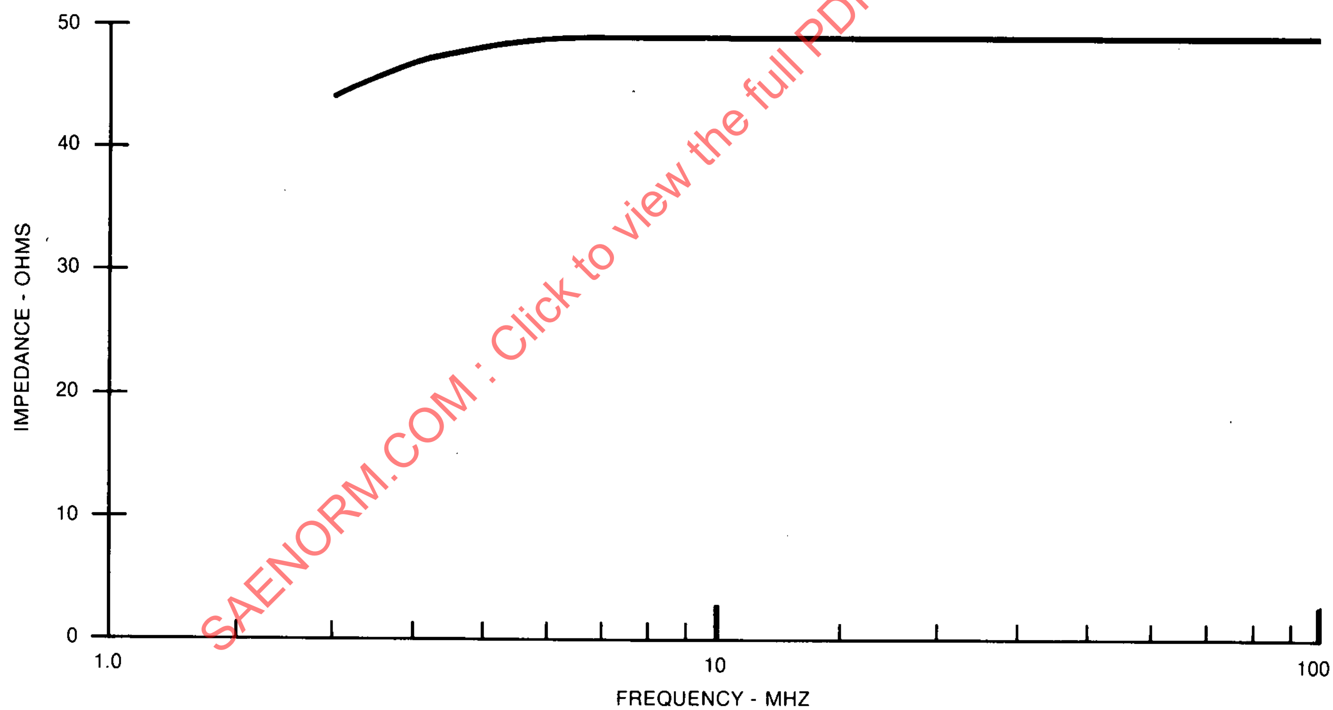


FIG. 4B–LINE IMPEDANCE STABILIZATION NETWORK REFERENCE IMPEDANCE, 5–100 MHz

as indicated in Fig. 7. At these frequencies, however, the impedances seen by control and signal leads may no longer be determined by the system designer. It may be possible to simulate the stray impedance as described in paragraph 3.4.2(a). Care shall be exercised to insure sufficiently short leads on the injection networks and LISNs to minimize loss of signal due to series inductance and shunt capacity. A current probe on the injection lead right next to the EUT can be used to monitor the signal.

(c) Increase the level while continuously scanning through the required frequency range (50 kHz–100 MHz). Tests shall be conducted at not less than three frequencies per octave representing the maximum susceptibilities within that octave. Monitor the EUT for: (1) malfunction, (2) degradation of performance, or (3) deviation of parameters beyond tolerances indicated in the equipment specification or approved test plan. (See paragraph 3.6.) The values at which these occur shall be recorded.

3.6 Notes

(a) Each LISN shall be tested over the range for which it is designed. The impedance should be within 20% of the curves in Figs. 3B and 4B. If any discrepancies occur, then the network should be modified, e.g., by adding ferrites to inductor leads to increase impedance at higher frequencies.

(b) Unless otherwise required in the equipment specifications or approved test plan, the test signals shall be modulated according to the following rules:

(1) Test samples with audio channels/receivers.

AM receivers: Modulate 30% with 1000-Hz tone.
FM receivers: Modulate with 1000-Hz signal using 10-kHz deviation.
SSB receivers: Use no modulation.
Other equipments: Same as for AM receivers.

(2) Test samples with video channels other than receivers. Modulate 90–100% with pulse of duration 2/BW and repetition rate equal to BW/1000, where BW is the video bandwidth (Hz).

(3) Digital equipment–Use pulse modulation with pulse duration and repetition rate equal to that used in the equipment under test.

(4) Non-tuned equipment–Amplitude modulate 30% with 1000-Hz tone or as otherwise specified in the test plan.

4. Conducted Susceptibility, Repetitive Spike, Power Leads

4.1 Purpose–This section describes the requirement to determine equipment susceptibility to spike interference on all AC and DC input power leads.

4.2 Measurement Philosophy–Installed equipment is powered from sources which contain, in addition to the desired electrical voltage, transients with peak values many times this value, due to the release of stored energy during the operation of relays and other loads connected to the source. This test is designed to determine the capability of equipment to withstand such transient over-voltages.

4.3 Apparatus–Test apparatus shall be as follows:

(a) Spike Generator–Characteristics as follows:

Approximately 1-μs rise time and approximately 10-μs fall time (see Fig. 8).

Pulse repetition rate of 3–10 pps.

Voltage output of 0–600 V (or as otherwise specified in the test plan) into a 0.5Ω with a decaying exponential of less than 20% overshoot (see Fig. 8).

Output for parallel or series injection into power lines (see Figs. 9 and 10).

An output transformer may be required for series injection. If so, ade-

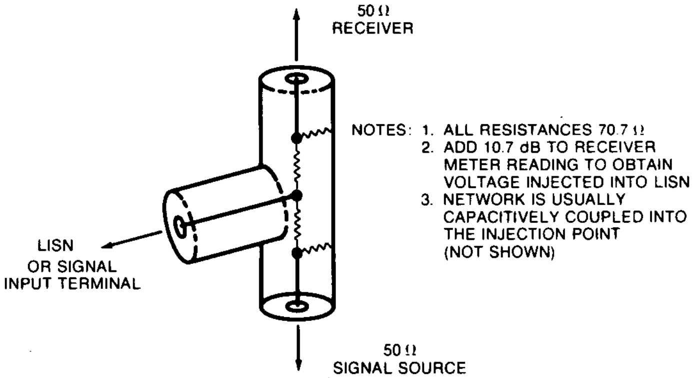


FIG. 5(A) - $Z_G = Z_R = 50\,\Omega$

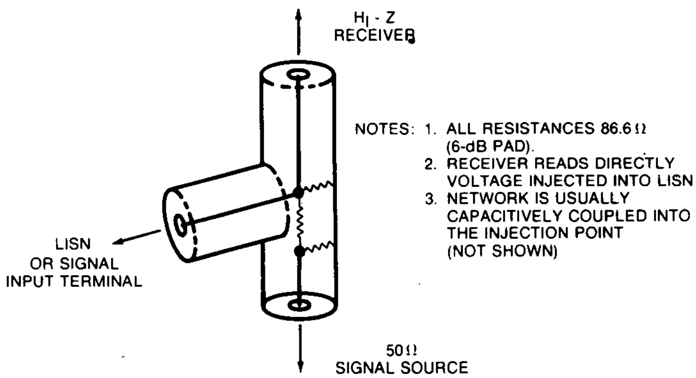


FIG. 5(B) - $Z_G = 50\,\Omega$, $Z_R >> 50\,\Omega$

FIG. 5–TEST SOURCE INJECTION NETWORK

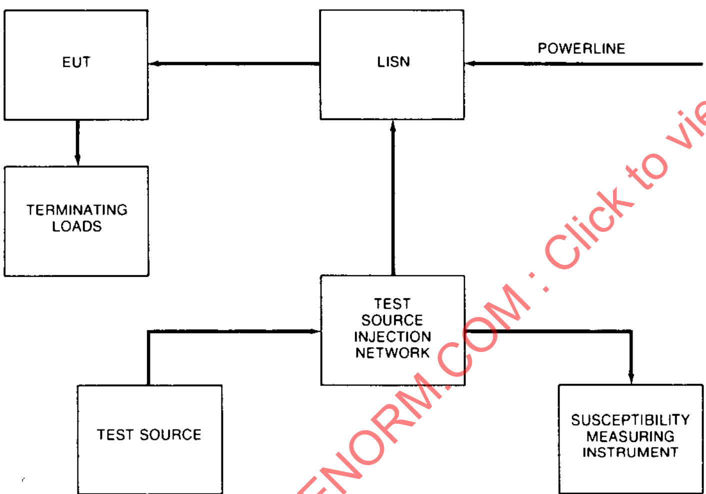


FIG. 6–EQUIPMENT BLOCK DIAGRAM FOR MEASURING CONDUCTED SUSCEPTIBILITY 50 kHz–100 MHz, POWERLINE ONLY

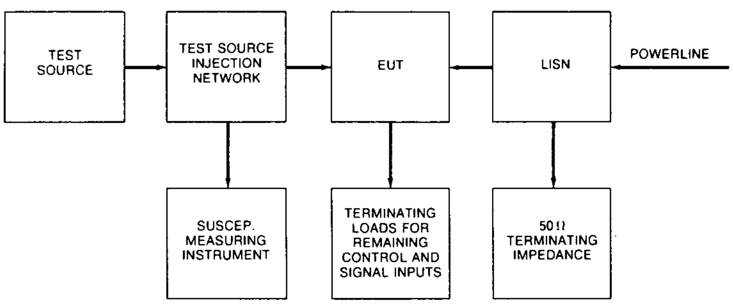


FIG. 7–EQUIPMENT BLOCK DIAGRAM FOR MEASURING CONDUCTED SUSCEPTIBILITY 50 kHz–100 MHz, CONTROL AND SIGNAL INPUTS

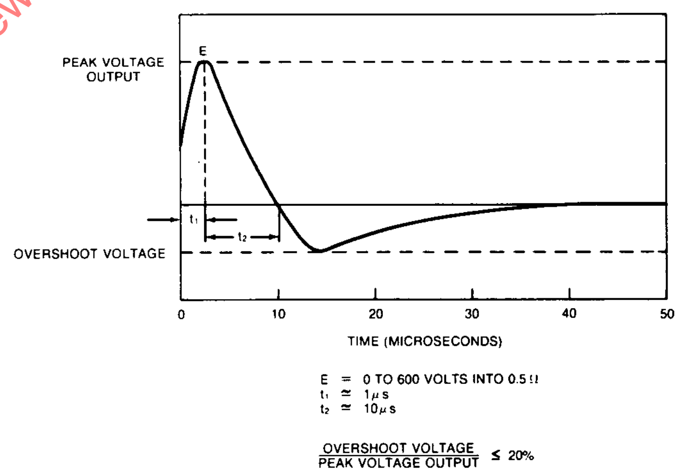


FIG. 8–SPIKE PARAMETERS

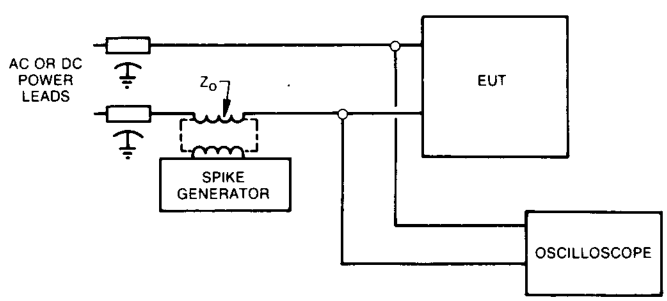


FIG. 9–TEST SETUP FOR CONDUCTED SUSCEPTIBILITY, SPIKE, POWER LEADS, INJECTION IN SERIES

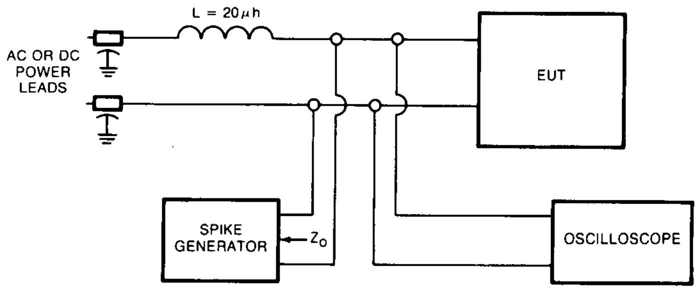


FIG. 10–TEST SETUP FOR CONDUCTED SUSCEPTIBILITY, SPIKE, POWER LEADS, INJECTION IN PARALLEL

quate current capacity of 25 A or more should be available.

Source impedance (Z_0) of 0.5Ω or less.

Both polarities of pulse.

(b) Capacitor–Two 10- µf feedthrough capacitors.

(c) Oscilloscope–Any oscilloscope with 10-MHz bandwidth and adequate sweep rates is acceptable.

(d) Inductor–A 20-µH inductor capable of carrying 20 A continuously (No. 14 wire, 4 in (102 mm) coil of 2 in (51 mm) diameter, 32 turns).

4.4 Test Setup and Procedure–Test procedure shall be as follows:

(a) Connect EUT and test instrumentation as shown in Fig. 9 or Fig. 10.

(b) For DC power leads, both series and shunt test methods shall be used. For AC power leads, only the series test method is used.

(c) Measure the applied spike amplitude, rise time, duration, and repetition rate using a calibrated oscilloscope across the input terminals of the EUT.

(d) Synchronization shall be used to position the spike to specific EUT signal conditions which will produce maximum susceptibility.

(e) Alternately, positive and negative, single and repetitive (6–10 pps) spikes shall be applied to the EUT ungrounded input lines for a period not less than 10 min or as specified in the test plan. On equipment employing gated circuitry, the spike shall be synchronized to occur within the time frame of the gate.

(f) Slowly increase the spike amplitude until (1) malfunction, (2) degradation of performance, or (3) deviation of parameters beyond specifications occurs. Adjust the amplitude as necessary to determine the susceptibility threshold level.

(g) Record the threshold levels, repetition rate, phase position on the AC waveform, and time occurrence on circuit gates, for both safe failure and unsafe failure regions as applicable.

4.5 Notes

(a) As described in paragraph 1.2, a statistical method which eliminates the effect of progressive degradation may have to be used.

5. Conducted Susceptibility, Load Dump and Field Decay (voltage) Transients, Power Leads

5.1 Purpose–This section describes the requirements to determine the capability of various electrical devices to withstand load-dump and field-decay transients which normally occur in motor vehicles.

5.2 Measurement Philosophy–Field-decay transients occur normally in automotive electrical systems when the ignition switch is turned off. This resulting sudden removal of field excitation causes a negative pulse on the order of 50–100 V to propagate through the electrical system.

The load-dump transient occurs infrequently, but it can occur suddenly and repetitively in certain vehicles under specific circumstances. The most common circumstances are: (1) a loose or corroded battery connection which causes the load (battery) to be suddenly removed from the charging circuit, or (2) sudden disconnection of a jumper battery from a vehicle with a dead battery. Either of these conditions results in a large positive voltage pulse (on the order of 75-125 V) propagating throughout the vehicle electrical system, often with catastrophic results on components of the system.

The vehicle effects of load-dump and field-decay transients depend on the impedance of the electrical system at the moment the transient occurs, the electrical location of the components relative to the alternator, characteristics of the components, and their operating temperatures.

The intent of this section is to provide a standard means of simulating non-repetitive transients in order to: (1) verify that a given component will survive a certain known transient level, or (2) to actually measure, by testing to malfunction or failure, the susceptibility level of the component. In this latter case special statistics may be required. (See paragraph 1.2.)

5.3 Apparatus–Test apparatus shall be as follows:

(a) One-shot pulse generator capable of delivering a voltage pulse of 50–150 V, positive or negative, with an exponential decay extending over an adjustable time base from 100–500 ms, across a resistive load of 10Ω. The rise time shall lie in the range of 5–10 ms. Parts lists and schematic diagrams for typical pulse generators are included in paragraph 5.6. Higher voltages and longer durations may be required in some environments.

(b) DC voltmeter and an oscilloscope for monitoring the power source and pulse generator.

(c) Equipment as may be required to perform a functional test of the component following transient application.

5.4 Test Setup and Procedure

(a) Connect a known functional EUT as shown in Fig. 11.

(b) Ensure that the ambient temperature and supply voltage V_s are maintained as required by the appropriate test specification.

(c) Set up the pulse generator to provide the polarity, amplitude, and pulse duration as specified in the appropriate test specification.

(d) Generate the test pulse.

(e) Perform the appropriate functional test to determine whether failure has occurred and record results.

(f) Repeat steps (a) through (e) for additional EUTs of the same test components until the statistical requirements of the test specification have been met.

5.5 Notes

(a) If the susceptibility level is to be determined, care must be used to eliminate the effects of cumulative deterioration such as dielectric *punch through* in semi-conductor devices.

(b) When testing to a specified level, unnoticed failures may occur which may be detected only by running life-cycle tests and comparing the results of tested components against those of untested components.

5.6 Test Equipment Description–Figs. 12 and 13 give information for building typical pulse generators. The parts lists and waveforms are shown with each schematic. If desired, the circuits of Figs. 12 and 13 may be combined into a single unit. The pulse durations shown are typical, but other pulse widths can be obtained by selecting appropriate values for C1, R6, R7, and R8.

R7 and R8 also establish pulse amplitude up to a maximum of V_c. The initial voltage V_c is set by adjusting the DC supply voltage to the pulse generator when S1 is in the position shown. The initial value of V_c can be any reasonable voltage as long as the rating of C1 is not exceeded.

The pulse is generated when S1 is switched.

6. Radiated Susceptibility, 30 Hz–15 kHz, Magnetic Field

6.1 Purpose–This section covers requirements to determine the magnetic-field susceptibility of equipment, subsystems, and systems whose largest dimension is less than 60 cm (2 ft) in the frequency range from 30 Hz–15 kHz.

6.2 Measurement Philosophy–In the low-frequency range, some devices that are susceptible to magnetic fields are not so susceptible to the equivalent free-space electric fields or to real electromagnetic power (an elementary example is a compass). For such items, a separate measurement of magnetic-field susceptibility is warranted.

6.3 Apparatus–Test apparatus shall be as follows:

(a) Hemholtz coil–1.8-m (6-ft) diameter, spacing 90 cm (3 ft), to produce a uniform field (±10%) throughout a 60-cm (2-ft) cube; to be self resonant at, or above, 15 kHz and having a known coil factor, say 0.63 G/A.

(b) Audio oscillator–30 Hz–15 kHz.

(c) Audio power amplifier–50 W or greater with output impedance equal to, or less than, 2.0Ω.

(d) Current monitor–0–30 A, 30 Hz–15 kHz.

6.4 Test Setup and Procedure–A Helmholtz-coil setup consists of two identical coaxial loops spaced approximately one radius apart to establish a uniform field in the central region when excited by an audio source as in Fig. 14. The procedure is:

(a) Place the operating EUT in the central region of the Helmholtz coil.

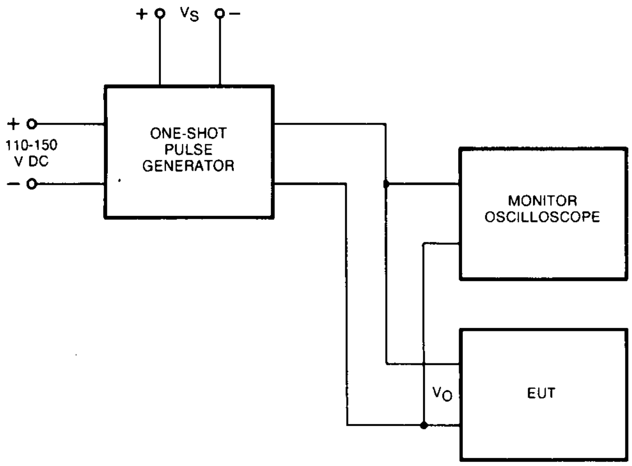
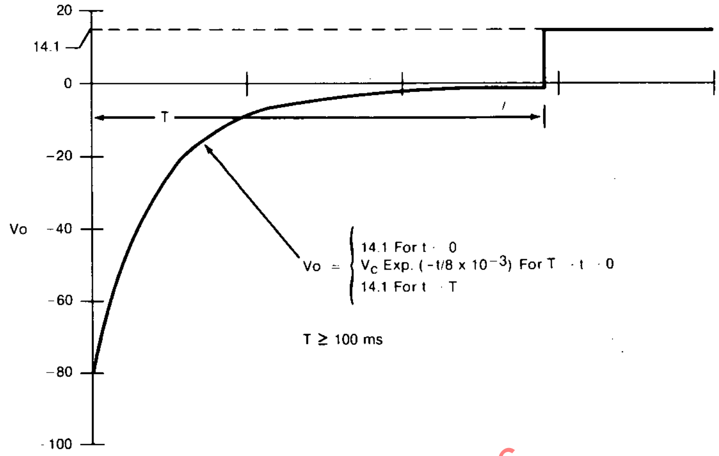
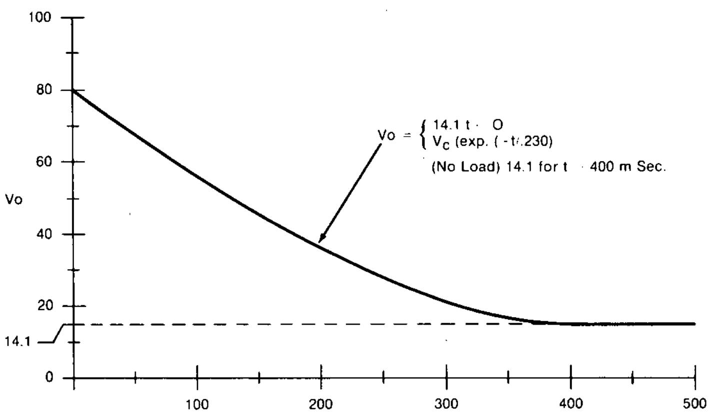
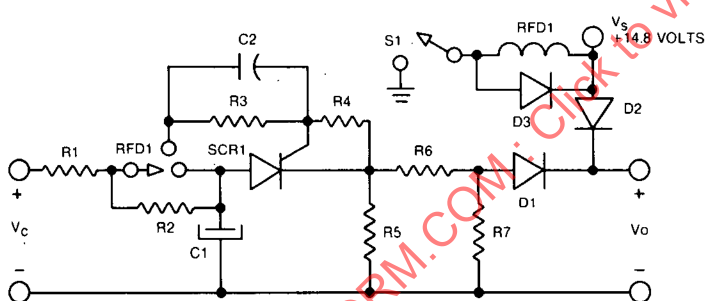


FIG. 11—TEST SETUP FOR CONDUCTED SUSCEPTIBILITY, LOAD DUMP AND FIELD DECAY, POWER LEADS





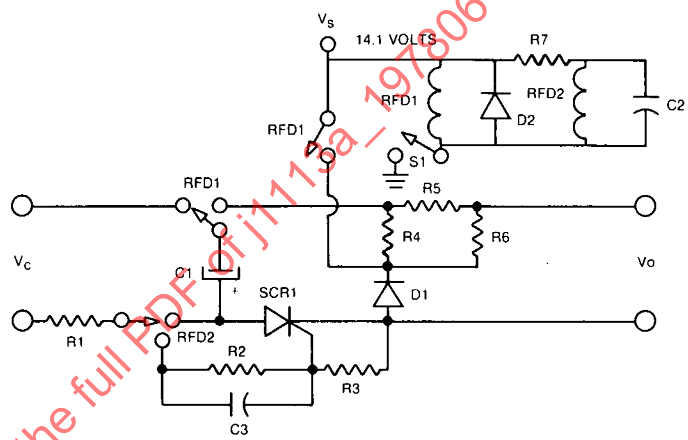


C1	28,800 μfd. 200V ELEC. LO ESR	R5	16 Ω 100W. 1% RH-100
C2	.1 μfd. 200V. MYLAR	R6	3.2 Ω 50W. RH-50 1%
D1, D2	INI188 POWER DIODE	R7	12.8 Ω 100W RH-100 1%
R1	100 Ω 50W. RH-50	S1	SPST SWITCH
R2	10K SW. 10%	SCR1	MCR-1718-6
R3	1K 20W. 10%	RFD1	SPDT 12V RELAY
R4	100 Ω 0.5W 10%	D3	IN4004

FIG. 12—TYPICAL LOAD DUMP TRANSIENT SIMULATOR

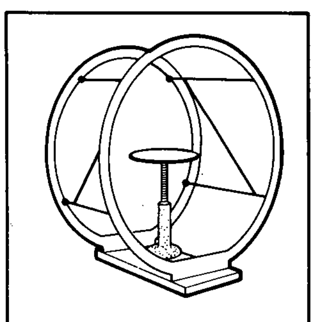
(b) Tune the audio oscillator through the required frequency range (30 Hz–15 kHz) with the output progressively adjusted toward maximum level. Monitor the EUT for (1) malfunction, (2) degradation of performance, or (3) deviation of parameters beyond tolerances indicated in the equipment specifications or approved test plan. The types of failure and their associated susceptibility threshold values of magnetic field (current times coil factor) shall be recorded.

6.5 Notes—Under certain circumstances it may be desirable or necessary to use a non-sinusoidal oscillator. One case where it might be warranted is checking susceptibility to fields next to a transformer since the saturation characteristics of the core may generate both fundamentals and harmonics.



C1	8000ufd. 250V.	C2	500 uf. 25v 10%	S1	S.P.D.T. SWITCH
C3	.01ufd. 200V.	D2	IN 4004	SCR1	MCR-1718-6
D1	IN3232	R3	100 Ω .5W. 10%	R7	10 Ω .5W 10%
R1	100 Ω 50W. 10%	R4	2 Ω RH-100 1%	RFD1, RFD2	12 v DPDT RELAY
N2	7.5K 5W. 10%	R5, R6	1 Ω RH-100 1%		

FIG. 13—TYPICAL FIELD DECAY TRANSIENT SIMULATOR



TYPICAL HELMHOLTZ COIL

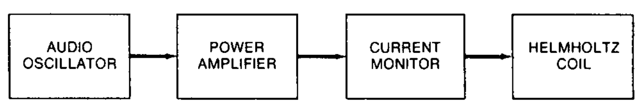


FIG. 14—TEST SETUP FOR RADIATED SUSCEPTIBILITY, 30 Hz–15 kHz, MAGNETIC FIELD

7. Radiated Susceptibility, 14 kHz–200 MHz, Electric Field

7.1 Purpose—This section covers requirements for the determination of electric-field susceptibility of equipment, subsystems, and systems (whose largest dimension is less than 15 cm) in the frequency range 14 kHz–200 MHz.

7.2 Measurement Philosophy—A TEM transmission cell is a rectangular adaptation of a coaxial line which sets up a region of uniform electric and magnetic fields in a traveling wave of essentially free-space impedance. The EUT is exposed to this electromagnetic source, but only the electric-field component is monitored. This technique also prevents disturbance to equipment not under test since the RF field source and EUT are completely self-contained within the electromagnetic enclosure.

7.3 Apparatus—The test apparatus shall consist of the following:

(a) Signal Source—Any commercially available signal source, power amplifier, and general-purpose amplifier capable of supplying at least 100 W of modulated and unmodulated power to develop the susceptibility levels specified in the test plan shall be used, provided the following requirements are met: Frequency accuracy shall be within ±2%. Harmonics and spurious outputs shall not be more than -30 dB referred to the fundamental power.

(b) RF Voltmeter—A commercially available RF voltmeter capable of measuring 100 V over the frequency range 14 kHz–200 MHz.

(c) Termination—One 100 W, 50Ω load.

(d) Frequency Counter—A frequency counter capable of measuring frequencies up to 200 MHz.

(e) TEM Transmission Cell—A transverse electromagnetic transmission cell is shown in Figs. 15 and 16. Typical dimensions for cells are given in Table 1. The dimension for a cell suggested for use in the frequency range 14 kHz–200 MHz is underlined on the table.

(f) Low-Pass Filter—Cutoff at 200 MHz, with the signal down 60 dB at frequencies greater than 240 MHz.

(g) Signal Samplers or Monitor Tees—Frequency and RF-voltage monitoring equipment.

(h) Monitors—Required test equipment to monitor the operation of the test sample.

7.4 Test Setup and Procedure

(a) The test setup should be as shown in Fig. 17A (or Fig. 17B (see Section 7.4(f))).

(b) The EUT may be placed, if normally ungrounded, midway between the bottom of the cell and the center septum; or if normally grounded, on the bottom of the cell centered with respect to width and length as shown in Fig. 16.

(c) Fields should be generated as required. The field strength, E_v, is determined by

$$E_v = \frac{V_{rf}}{d} \quad \text{volts/meter}$$

where V_{rf} is the input voltage to the cell in volts and d is the cell bottom-to-septum separation in meters.

(d) The EUT shall be operated and monitored by leads from the device to shielded feed-through connectors mounted on the bottom outer shield, as shown in Fig. 16. The leads shall be oriented to obtain minimum interaction with the cell test field.

(e) The EUT shall be oriented in each orthogonal plane within the cell to determine maximum susceptibility.

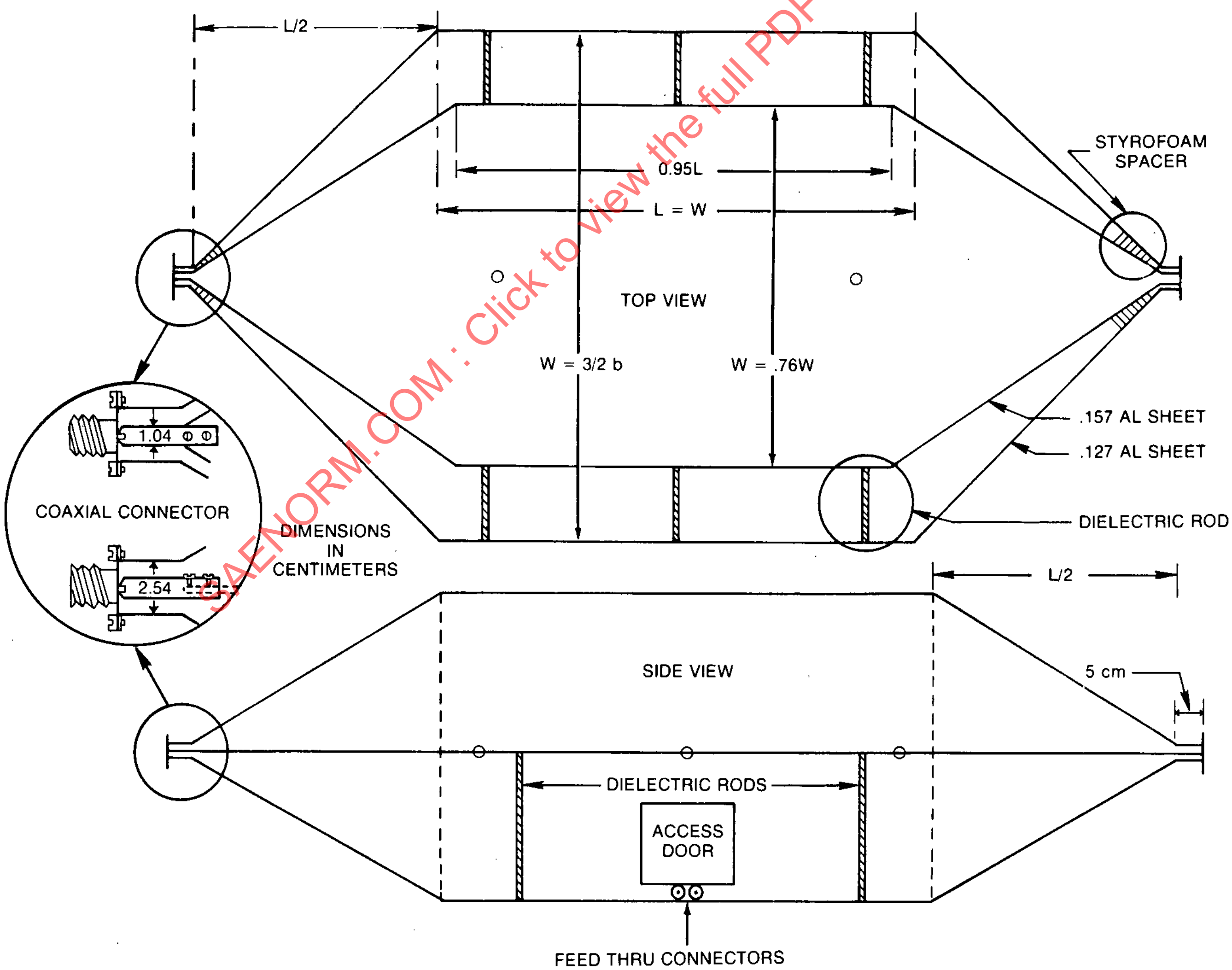


FIG. 15–DESIGN FOR RECTANGULAR TEM TRANSMISSION CELL

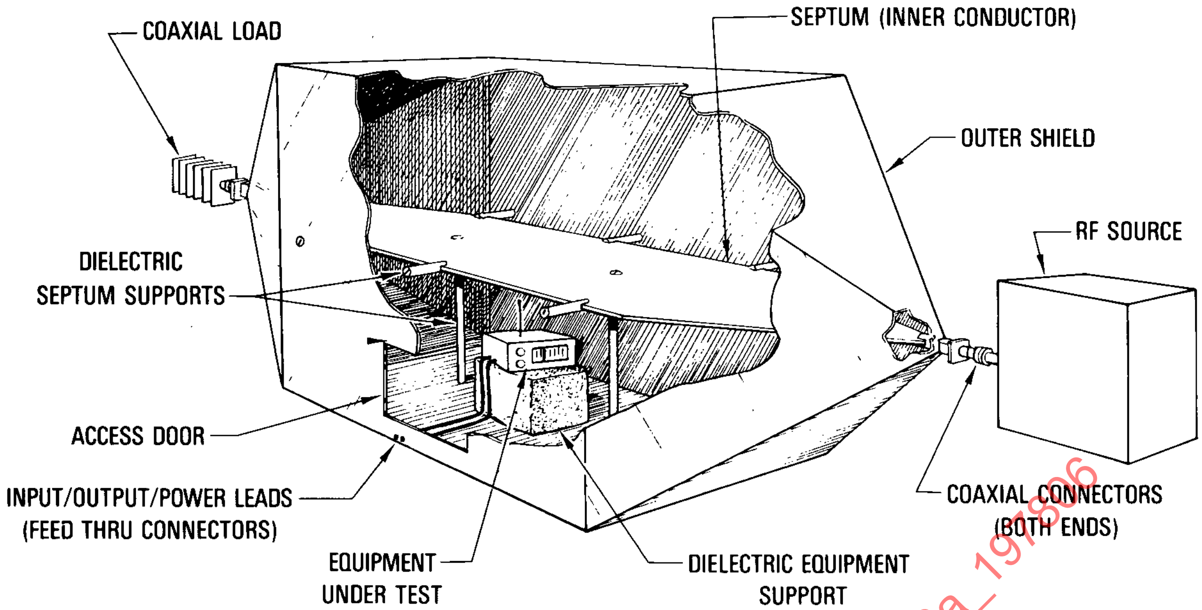


FIG. 16–CUT-AWAY VIEW OF TEM CELL BEING USED FOR EM SUSCEPTIBILITY TESTING. FIGURE SHOWS PLACEMENT OF EUT AND ASSOCIATED INPUT, OUTPUT, AND MONITORING LEADS INSIDE THE CELL

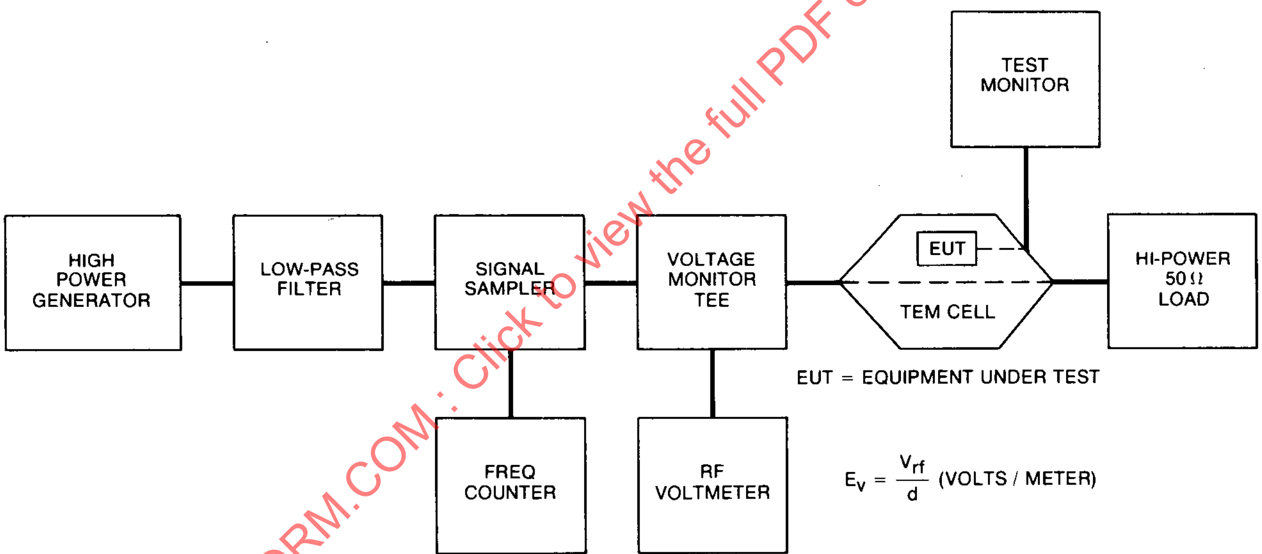


FIG. 17A–BLOCK DIAGRAM OF SYSTEM FOR SUSCEPTIBILITY TESTING OF EQUIPMENT (USED TYPICALLY BELOW 1 MHz)

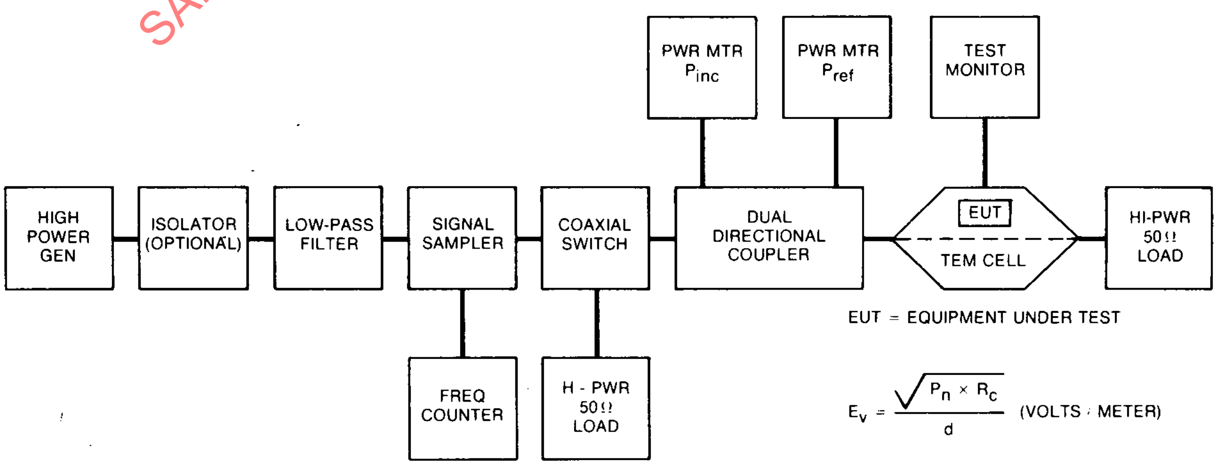


FIG. 17B–BLOCK DIAGRAM OF SYSTEM FOR SUSCEPTIBILITY TESTING OF EQUIPMENT (1 MHz–200 MHz)

(f) The entire frequency range from 14 kHz–200 MHz shall be scanned. Tests shall be conducted at not less than three frequencies per octave representing the maximum susceptibilities within that octave. In addition, tests shall also be made at the EUTs critical frequencies (local oscillator frequency, intermediate frequency, and others) as specified in the test plan. The threshold of susceptibility shall be determined by increasing the amplitude of the test field until degradation in performance is observed.

7.5 Notes

(a) Unless otherwise required in the equipment specification or approved test plan, the test signals shall be modulated according to the following rules:

(1) EUTs with audio channels/receivers

AM receivers: Modulate 30% with 1000-Hz tone.

FM receivers: When monitoring signal-to-noise ratio, modulate with 1000-Hz signal using 10-kHz deviation. When monitoring receiver quieting, use no modulation.

Other Equipment: Same as for AM receivers.

(2) EUTs with video channels other than receivers–Modulate 90–100% with pulse duration of 2/BW and repetition rate equal to BW/1000, where BW is the video bandwidth.

(3) Digital equipment–Use pulse modulation with pulse duration(s) and repetition rate(s) equal to those used in the EUT.

(4) Non-tuned equipment–Amplitude-modulate 30% with 1000-Hz tone, or as otherwise required in the test plan.

(b) This procedure also exposes the EUT to magnetic fields, and thus the cell may be calibrated for use in determining magnetic-field susceptibility.

(c) Test samples of any size could be tested using a TEM cell modeled from Table 1 to meet the criteria that the size of the EUT be less than L/3 x W/3 x b/6. (These dimensions are considered a maximum to prevent excessive impedance loading and test-field perturbation when inserting the EUT into the cell.) Thus, a small EUT could be tested at higher frequencies in small cells, and a large EUT could be tested at lower frequencies in large cells. The procedure for testing in large cells is the same as for testing in small cells but a larger signal source (higher power) and an appropriate high-power termination (50Ω) are required.

(d) The useful upper frequency for the cell may be reduced 20–30% from the cutoff/multimode frequency given in Table 1 by the loading effect of the EUT.

(e) Test samples that exceed the 1/3-linear dimension criterion could be tested in the cell, bearing in mind that excessive loading of the cell reduces the accuracy in determining the test field. This effect occurs because the sample tends to short out the test field in the region between the plates, increasing the vertically polarized test field. The error, however, can be corrected by measuring the field in the region above and below the EUT using miniature E-field probes and making an appropriate correction.

(f) Field measurement errors may result from resonances in the EUT. These resonances can be detected at frequencies above 1 MHz by using a bi-directional coupler with RF power monitors in place of the monitor tee and an RF voltmeter as shown in Fig. 17B. The bi-directional coupler and power monitors are used to measure both forward and reflected power at the cell's input giving an indication of the system SWR which may be associated with resonances of the EUT. The field strength E_V is then given as

$$E_V = \frac{\sqrt{P_n R_c}}{d} \quad \text{volts/meter,}$$

where P_n is the net power flow through the cell, R_c is the real part of the cell's complex impedance and is approximately equal to 50Ω, and d is as defined earlier.

(g) Every effort should be made to match conditions between the TEM cell and actual operating conditions. This includes, if possible, matching (1) lead lengths, (2) lead impedances, and (3) lead exposure to RF fields. If not possible, then a more modest goal of minimizing lead effects by minimizing currents on them would be in order. The lead effect could then be obtained through the use of the conducted susceptibility test.

8. Radiated Susceptibility, 200–1000 MHz, Electric Field

8.1 Purpose–This section covers the requirements for the determination of electric-field susceptibility of equipment, subsystems, and systems in the frequency range 200–1000 MHz.

TABLE 1–TEM CELL DIMENSIONS

Recommended Upper Frequency (MHz)	Plate Separation b/2 (cm)	Center Septum w (cm)	Center Septum t (cm)	Cutoff/Multimode Frequency f_{11} (MHz)
100	60	136	0.157	150
200	30	68	0.157	300
300	20	45.3	0.157	450
500	14	31.7	0.157	644

8.2 Measurement Philosophy–In this frequency range (200–1000 MHz), TEM cells become too small to test many types of equipment. However, RF-absorbing material becomes effective and measurements can be made within an RF shielded enclosure provided RF-absorbing material is used strategically to make it essentially anechoic.

8.3 Apparatus–The test apparatus shall consist of the following:

(a) Signal Source–Any commercially available signal source, power amplifier, and general-purpose amplifier capable of supplying the necessary modulated and unmodulated power to develop the susceptibility levels specified in the test plan may be used, provided the following requirements are met: Frequency accuracy shall be within ±2%. Harmonics and spurious outputs shall not be more than -30 dB referred to the fundamental power.

(b) EMI Meter or Spectrum Analyzer.

(c) Antennas–Commercial conical logarithmic spirals may be used.

(d) Output Monitor–Appropriate instrumentation to monitor the performance of the EUT shall be used.

(e) Source Antenna Hood–A hood for shielding the transmitting antenna can be obtained either by special order from RF absorber materials manufacturers (for example as listed in Appendix B) or by private construction. The hood is typically made from 1/8 in (3.2 mm) aluminum in the form of a rectangle 30 in (0.75 m) square by 40 in (1.0 m) long. The hood, with its end plate, are lined with ferrite absorbing material and mounted on a cart with casters as shown in Figs. 18 and 19.

It may be feasible to develop an antenna, such as a cavity backed spiral that would require a smaller hood; however, such an antenna, capable of transmitting high field strengths (up to 200 V/m) is not commercially available at the present time.

8.4 Test Setup and Procedure

(a) Leakage tests shall be performed in a shielded room which provides adequate attenuation so that the external field strengths do not exceed FCC limits. If a shielded anechoic enclosure covering the 200 MHz–1 GHz frequency range is available, the tests can be performed without a hooded antenna.

(b) In general, the EUT should be placed 1 m from the transmitting antenna. When a large EUT is to be immersed in a field, the transmitting antenna shall be placed at a distance sufficient to allow the entire EUT to fall within the 3-dB beamwidth of the transmitted field. If this is not feasible, the sample may be tested in segments, each segment being equal in dimension to the 6-dB beamwidth of the antenna radiation characteristic. The antenna shall normally be centered in a plane parallel to the absorbing wall behind the EUT.

(c) Fields should be generated, as required, with the specified antenna. Care should be taken so that the test equipment is not affected by the test signals. It may be necessary to place the test equipment, except for the antenna, outside the shielded enclosure.

(d) As suggested in Table 2, the wall behind the EUT should be covered with a microwave absorber material which provides at least 20-dB attenuation of reflected power at 200 MHz.

(e) The specified field strength shall be established with attendant polarization prior to the actual testing by substituting a field-measuring antenna in place of the EUT and by adjusting and recording the transmitter power required to obtain a specified field intensity from the transmitting antenna. (This calibration may be used for all subsequent testing, provided that exactly the same EUT location in the shielded enclosure is