

Electromagnetic Susceptibility Procedures for Vehicle Components (Except Aircraft) – SAE J1113 JUN84

SAE Recommended Practice
Completely Revised June 1984

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φ **ELECTROMAGNETIC SUSCEPTIBILITY
PROCEDURES FOR VEHICLE COMPONENTS
(EXCEPT AIRCRAFT)—SAE J1113 JUN84**

SAE Recommended Practice

Report of the Subcommittee on EMI Standards and Test Methods, approved April 1975, completely revised by the Electrical and Electronic Systems Technical Committee June 1984.

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 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 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.*

A direct method of specifying the EMI environment limits is to measure the actual fields, voltages, current, 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. Some example data showing fields exists in NBS Technical Note 1014, "Electromagnetic Interference (EMI) Radiative Measurements for Automotive Applications." (1)

It is recommended that a statistically valid number of components be tested using procedures adopted as standard by the testing organization. For destructive testing, such as transient on the power leads of Section 4, consult a handbook on statistical methods for details of the Karber Method or the Bruceton (stair-step) Method of sensitivity measurements. (2,3,4,5) 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 4 need be applied. Or if susceptibility to radiated energy is known to be a primary cause of malfunctions, then only Sections 6 through 10 need be applied.

Caution must be exercised in many portions of this procedure where high voltages or intense fields may be present.

ANSI and OSHA standards should be consulted concerning applicable limits on field exposure. For near field power density calculations, refer to paragraph 1.3.7.

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.

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 coexistence 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 $(A/m)^2 \times 377$. *When measurements are made in the near field and in free space, both the complex electric and magnetic vector components of the field must be fully defined.* Power density may then be obtained by use of the Poynting vector.

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.

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 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.

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 depends 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 impedance 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 impedances 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:

- Audio Oscillator—30 Hz—50 kHz.
- Audio Power Amplifier—50 W or greater with output impedance equal to, or less than, 2.0 Ω (capable of delivering 50 W into a 0.5 Ω resistive load connected across an isolation-transformer secondary).
- Measuring Instrument—Calibration Oscilloscope, VTVM, or EMI Meter.
- A 100 μ F Capacitor—required as a shunt to stabilize power-source impedance and to help obtain sufficient test voltage.
- Isolation Transformers—secondaries shall be capable of handling current flow without saturation of core.
- 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):

- The EUT shall be connected as shown in Figs. 1 and 2.
- 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.
- 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:

- Apply a signal to the primary of the transformer and measure the open-circuit secondary voltage (V_{oc}).
- Connect a known load R_L across the secondary and measure the closed-circuit secondary voltage (V_{cc}).
- The impedance shall be calculated as follows:

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

- Repeat the above procedure at one frequency per decade from 30 Hz—50 kHz (including 30 Hz and 50 kHz).
- The measured impedance shall be less than, or equal to, 0.5 Ω 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 depends 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:

- be centered on a metallic ground plane having the following minimum dimensions:
 - Thickness—1.5 mm (0.060 in) aluminum, copper, or brass sheet.
 - Surface Area—1 m² (10.8 ft²) or underneath entire equipment plus 0.5 m² (5.4 ft²), whichever is larger.
 - Width—0.5 m (20 in).
- be bonded to the ground plane at its most-sensitive input-terminal(s) ground point(s).
- 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:

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

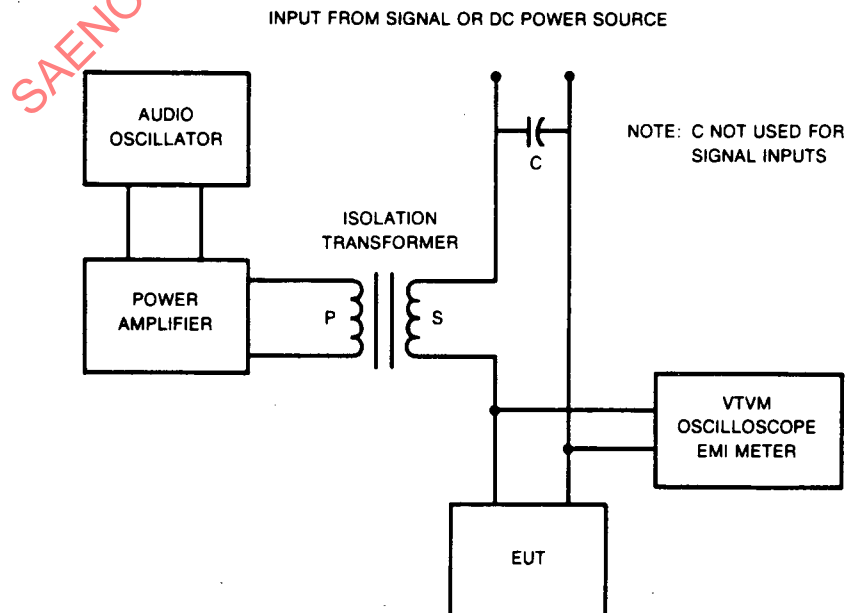


FIG. 1—TEST SETUP FOR MEASURING CONDUCTED SUSCEPTIBILITY, 30 Hz—50 kHz, SIGNAL OR DC POWER INPUT

NOTE: THIS TEST SETUP CANCELS POWER FREQUENCY VOLTAGES WHICH WOULD OTHERWISE FEED BACK TO DAMAGE THE AMPLIFIER.

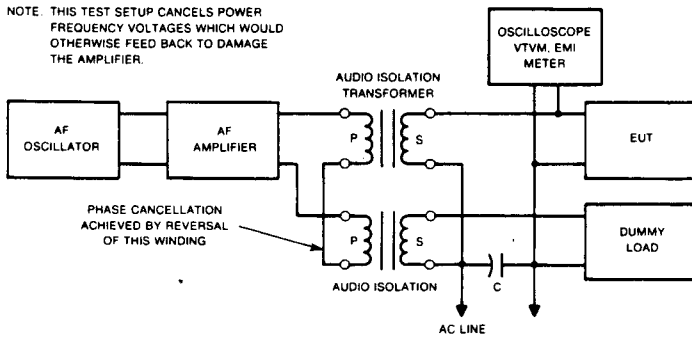


FIG. 2—TEST SETUP FOR MEASURING CONDUCTED SUSCEPTIBILITY, 30 Hz—50 kHz, AC INPUT

(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 50 Ω 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.

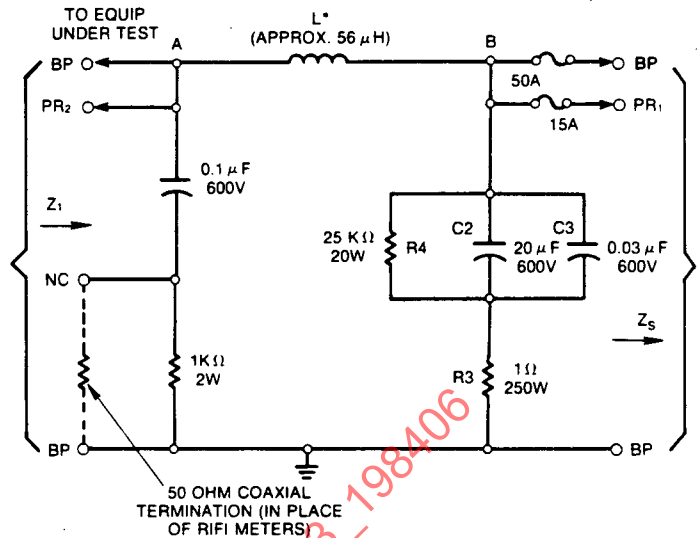
(d) Test-Source Injection Networks illustrated in Fig. 5.

(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 follows:

(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 $\frac{300}{20\pi l}$ where l is the characteristic lead length in meters. 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.



Z₁ - 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.)

PR₁ - POWER RECEPTACLE, 115 V, 15 A (3-WIRE POLARIZED, TWIST LOCK, MALE BASE)

PR₂ - 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. AWG-6 STRANDED WIRE WITH 600 V INSULATION WOUND ON 5.5 in (14 cm) DIAMETER COIL FORM.

CASE: 17-1/2" L x 17-1/2" W x 8-3/4" H (44.4 cm L x 44.4 cm W x 22.2 cm H) BRASS (DIVIDED IN TWO SECTIONS BY A BRASS PLATE 17-1/2" x 8-3/4" 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

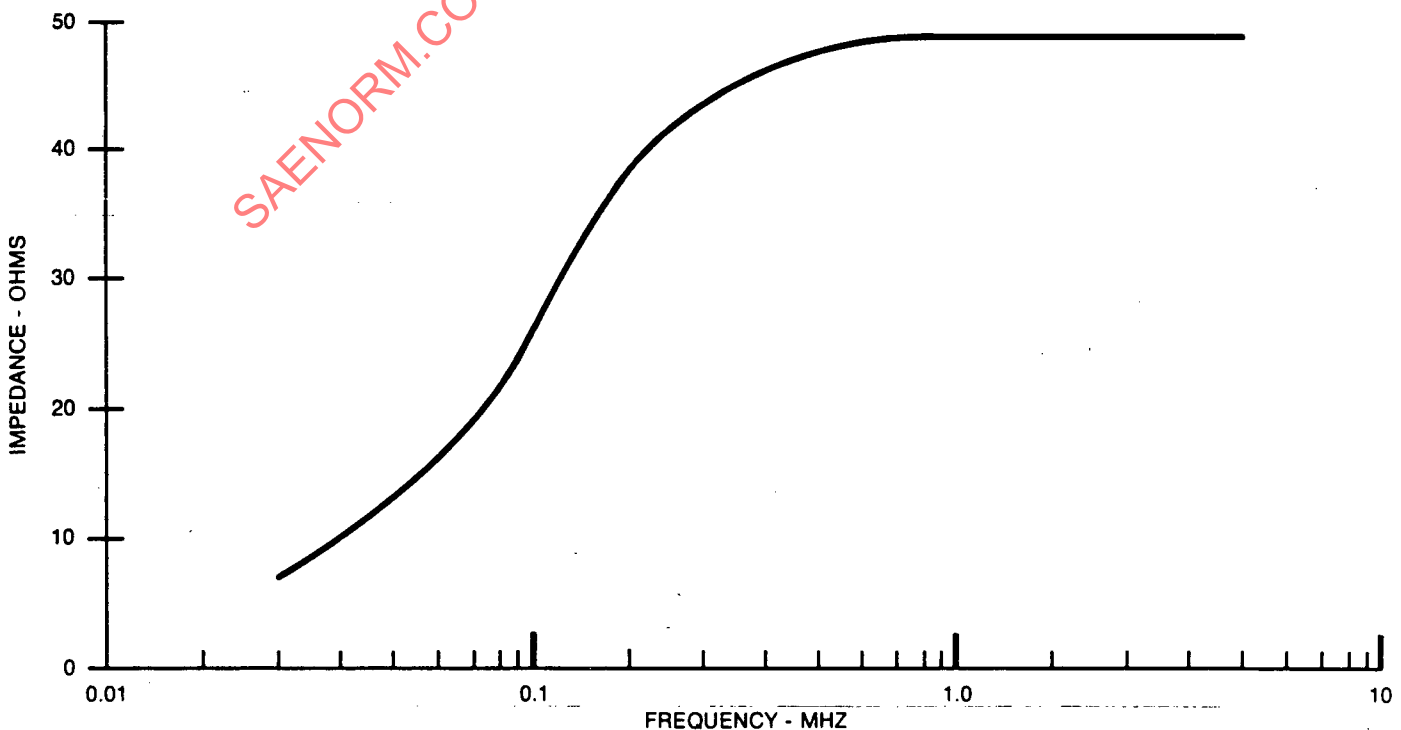
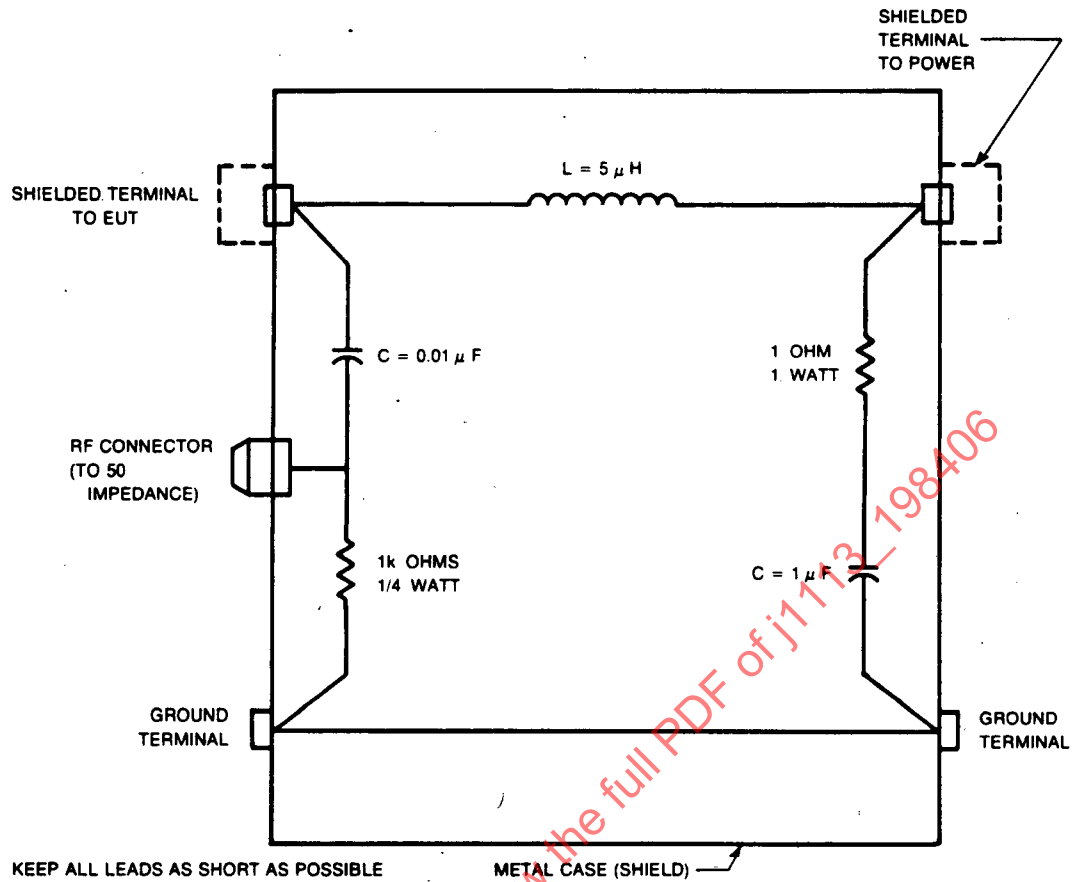


FIG. 3B—LINE IMPEDANCE STABILIZATION NETWORK REFERENCE IMPEDANCE, 50 kHz—5 MHz



COIL DATA (150 A):

- (1) $L = 4.9 \mu H$ AT 1.0 MHz.
- (2) 13 TURNS NO. 6 STRANDED WIRE, HEAVY INSULATED.
- (3) BAKELITE TUBING OUTER DIAMETER 78 mm.

NOTE: THE HIGH-FREQUENCY LIMIT OF USEFULNESS IS HIGHLY DEPENDENT UPON THE CARE TAKEN IN CONSTRUCTION TO MAINTAIN EXTREMELY SHORT WIRE LEAD LENGTHS TO COMPONENTS.

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

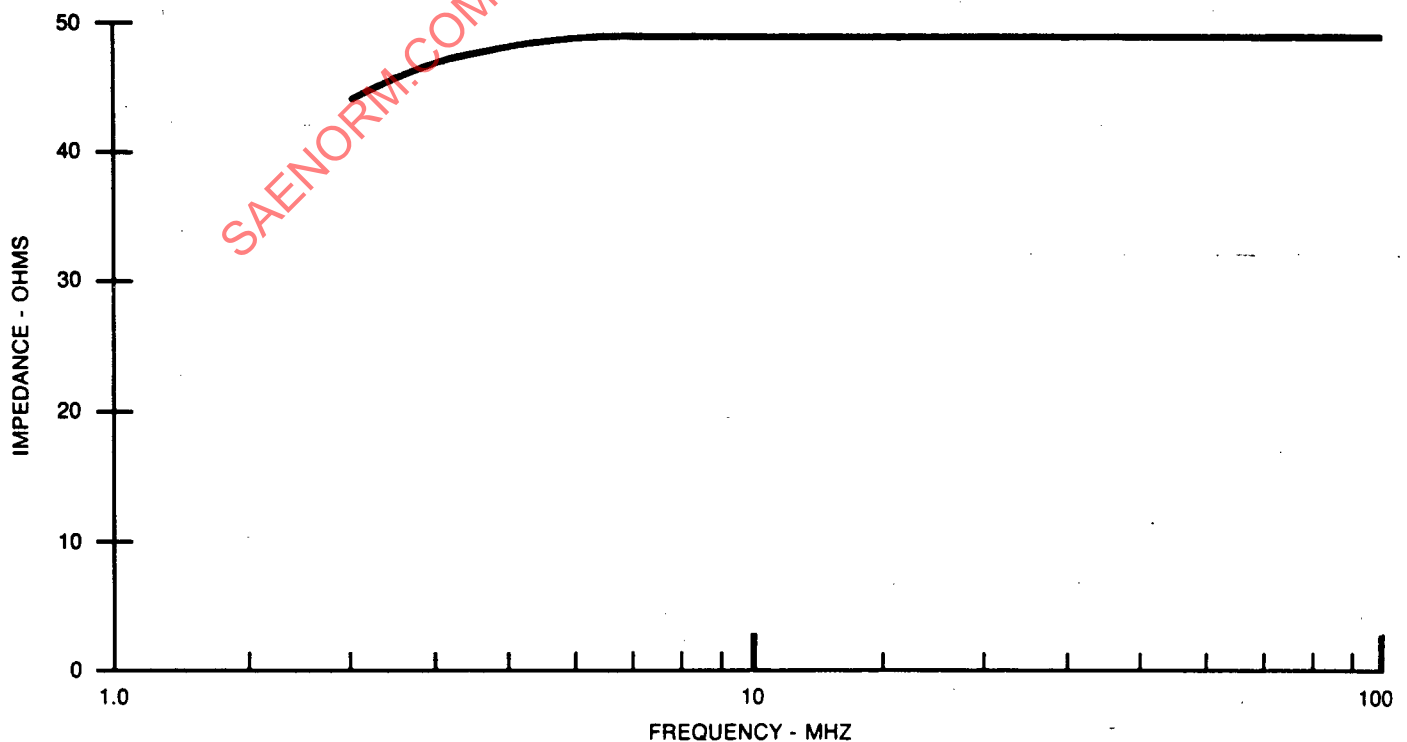


FIG. 4B—LINE IMPEDANCE STABILIZATION NETWORK REFERENCE IMPEDANCE, 5—100 MHz

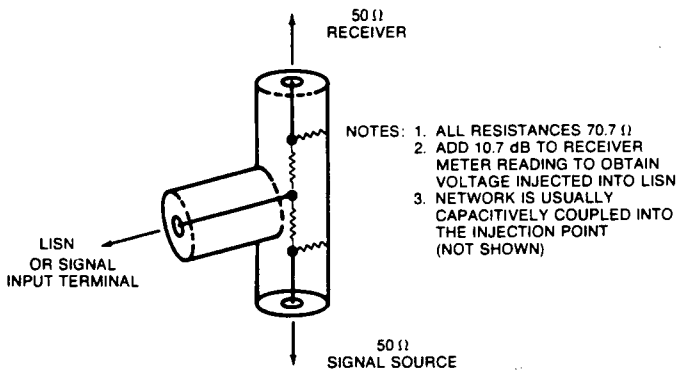
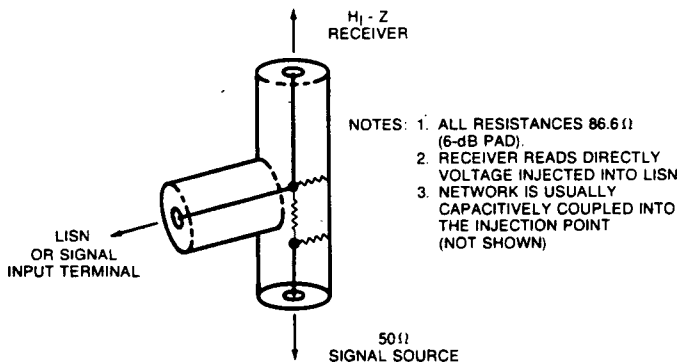
FIG. 5(A) - $Z_G = Z_R = 50 \Omega$ FIG. 5(B) - $Z_G = 50 \Omega$, $Z_R \gg 50 \Omega$

FIG. 5—TEST SOURCE INJECTION NETWORK

(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 measure 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 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 LISN's 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 or associated with other known external pulse sources that may be operating in close proximity.

4. Non-Tuned Equipment—Amplitude modulate 30% with 1000 Hz tone or as otherwise specified in the test plan.

4. Conducted Susceptibility, Transients, Power Leads 12 V Systems

4.1 Purpose—This section describes methods and apparatus to determine the capability of various electrical devices to withstand transients which normally occur in motor vehicles.

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, caused by the release

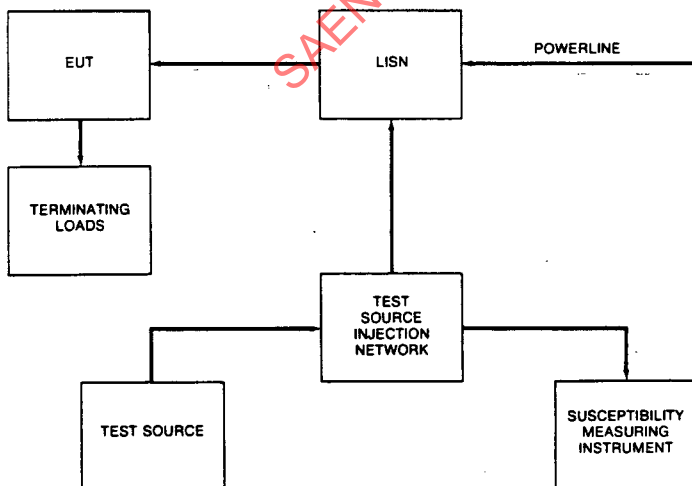


FIG. 6—EQUIPMENT BLOCK DIAGRAM FOR MEASURING CONDUCTED SUSCEPTIBILITY 50 kHz–100 MHz, POWERLINE ONLY

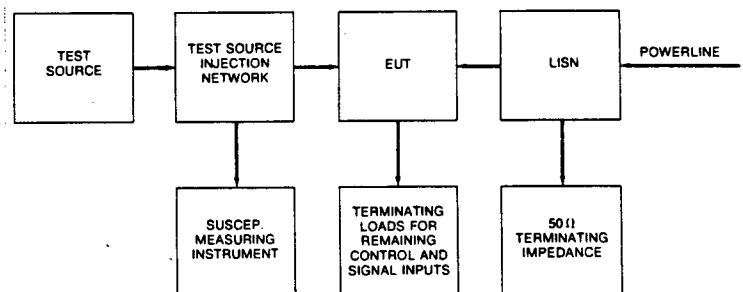


FIG. 7—EQUIPMENT BLOCK DIAGRAM FOR MEASURING CONDUCTED SUSCEPTIBILITY 50 kHz–100 MHz, CONTROL AND SIGNAL INPUTS

of stored energy during the operation of relay and other loads connected to the source and during start and turn off of vehicles. This test is designed to determine the capability of equipment to withstand such transients.

4.3 Apparatus—Test apparatus shall be as follows:

(a) Pulse generators capable of generating the transient waveforms shown in Figs. 9A and 9B and be adjustable up to the amplitudes indicated. The specification of rise time (T_r), duration (T), and internal resistance (R_i) represent fixed requirements unless otherwise specified.

(b) Oscilloscope for monitoring the pulse generator.

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

4.4 Test Setup and Procedure

(a) Connect a known functional EUT as shown in Fig. 8.

(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.

4.5 Notes

(a) In determining the susceptibility level, care must be exercised 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.

(c) Rise time requirements as specified in Fig. 9I represent a design objective. For short duration, high voltage pulse, some rise times may not be practical.

5. Static Discharge

5.1 Purpose—This section covers the requirement for determining the susceptibility of automotive electronic equipment, sub-systems, and systems to electrostatic discharge.

5.2 Measurement Philosophy—Occupants in a vehicle can generate considerable electrostatic potentials. Devices in the vehicle may fail when an electrostatic discharge occurs.

5.3 Apparatus—Test apparatus is as follows¹:

(a) High Voltage Power Supply.

(b) Two Vacuum Relays.

(c) High Voltage Measurement System.

(d) Metal Plate ($\frac{1}{2}$ meter square)

5.4 Test Set-Up and Procedure

(a) Connect the equipment as shown in Fig. 10.

(b) With the EUT properly grounded to the high voltage power supply, the test voltage shall be applied to the interfacing component through the use of the probe. The 300 pF capacitor is charged from 15 to 20 kV by using the normally closed vacuum relay and then this energy is discharged to the EUT by utilizing the normally open vacuum relay and the static discharge probe.

(c) This electro-static discharge shall be applied to all surfaces of the EUT that are normally accessible and could conduct the static discharge into the electronic components such as the faceplate, buttons, switches, knobs, and bulbs.

(d) This static discharge energy voltage shall also be applied to the metal plate placed next to the EUT.

(e) Perform the appropriate functional test to determine whether a failure has occurred. Consideration should be given to cumulative effects and effects which may be apparent only after life cycle tests.

6. Radiated Susceptibility, Magnetic Field 30 Hz—30 kHz

6.1 Purpose—This section covers the recommended testing technique for determining the magnetic field susceptibility of automotive electronic modules, subsystems, and systems.

6.2 Measurement Philosophy—In low frequency range, magnetic field susceptibility testing for certain devices may be necessary since these devices may not necessarily be susceptible to free space electric field radiation or to real radiated electromagnetic power.

6.3 Test Specification

(a) Lower frequency—30 Hz.

(b) Upper frequency—30 kHz.

(c) Magnetic flux density of Helmholtz coil—see Fig. 11A.

6.4 Test Apparatus—The following section describes a typical test setup that could be used to generate a uniform magnetic field for the testing as illustrated in Fig. 11B. Triangular wave that can generate a

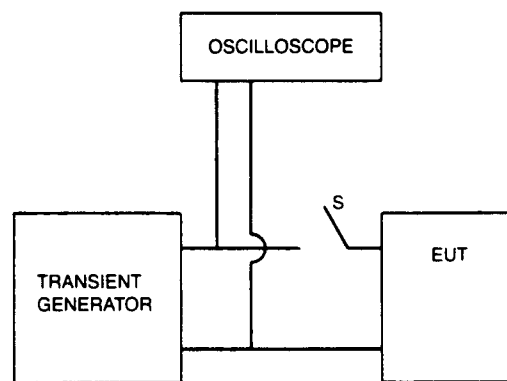


FIG. 8—TEST SETUP FOR CONDUCTED TRANSIENT SUSCEPTIBILITY

magnetic field inversely proportional to frequency which varies at a 12 dB/octave rate should be used to simulate the effect of power lines.

(a) Helmholtz Coil—The radius of the coil will be determined by the size of the EUT. In order to obtain a uniform magnetic field ($\pm 10\%$), the relationship between the EUT and the coil is illustrated in Fig. 11C. The coil should be capable of producing frequency dependent magnetic flux density of 200 dB (BT) at 30 Hz and a decreasing rate of 12 dB/octave.

The current carrying capability and turn ratio should be selected such that the test specification can be met.

The coil should not have a self resonant frequency at or lower than the upper test frequency.

(b) Function generator capable of producing 30 Hz—30 kHz.

(c) Audio Power Amplifier—30 Hz—30 kHz (approx. 200 W). Should be capable of delivering power to the coil to generate the specified magnetic field intensity at various frequencies as shown in Fig. 11A.

(d) Current Monitor—30 Hz—30 kHz.

(e) Magnetic Field Intensity Monitor—30 Hz—30 kHz. Should be capable of measuring the specified magnetic field intensity.

6.5 Test Setup and Procedure

(a) Place the operating EUT in the central region of the Helmholtz coil. (NOTE: The Helmholtz coil criteria should be met.)

(b) Connect the test setup according to Fig. 11B.

(c) Select the desirable waveform from the function generator.

(d) Increase the output of the function generator while monitoring the magnetic field intensity in the close vicinity of the EUT through the required frequency range in X steps.

Monitor the EUT and record the respective magnetic field intensity for: (1) malfunction, (2) degradation of performance, or (3) deviation of parameters beyond tolerances indicated in the EUT specifications and approved test plan.

6.6 Notes:—Care should be exercised not to operate the coil near large metal objects or in a shielded enclosure.

7. Radiated Susceptibility, 14 kHz—200 MHz, Electric Field Using a TEM Cell

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

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.

This technique is intended primarily for use in diagnostic testing to determine, for example, frequencies of EUT susceptibility, some indication of how interference is coupled into the EUT, and the relative improvement in EUT immunity resulting from efforts to reduce EUT susceptibility. It cannot be used to determine EUT susceptibility to absolute test field levels if the EUT includes long wired harnesses that must be exposed, polarization matched, to the test field. Alternately, open field tests as outlined in the SAE Information Report, J1338 (7), may be used at discrete frequencies.

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

¹ Equivalent apparatus is available from commercial equipment manufacturers.

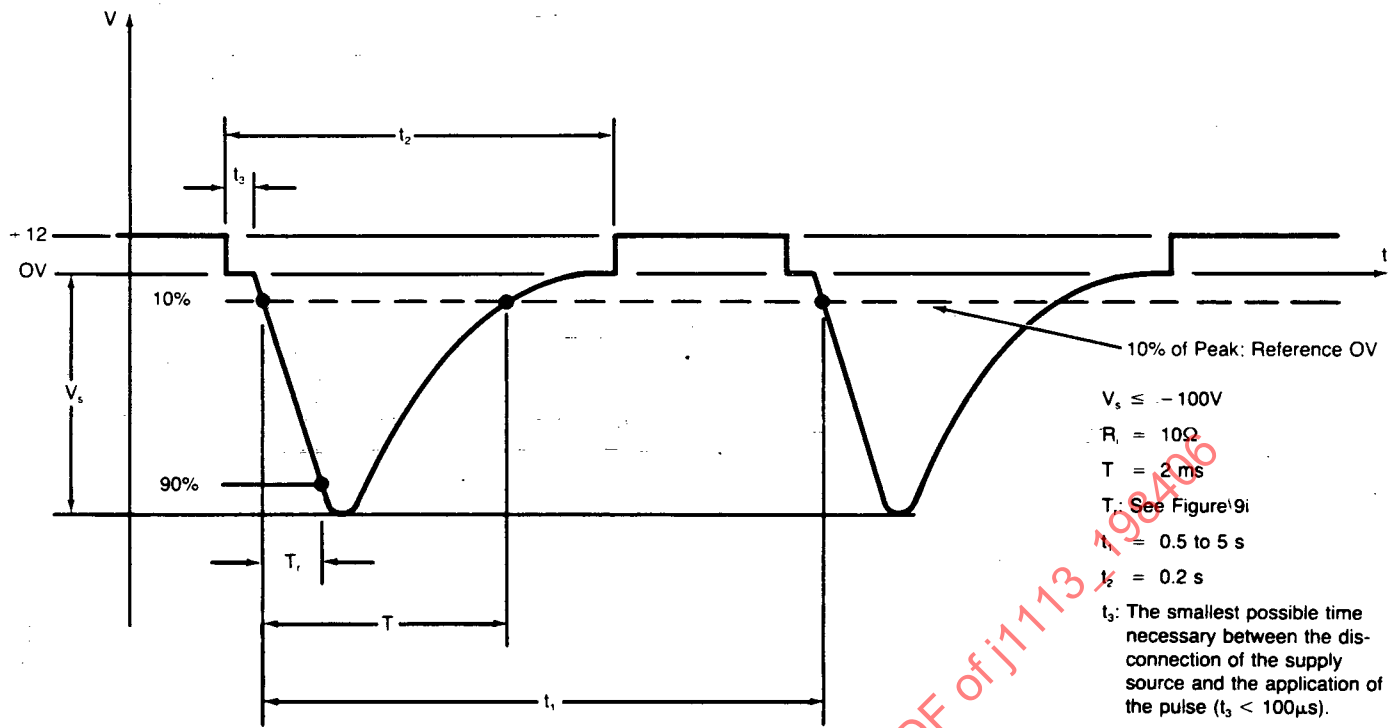


FIG. 9A—TEST PULSE 1 (DISCONNECTION FROM INDUCTIVE LOADS WITH DEVICE UNDER TEST REMAINING CONNECTED DIRECTLY IN PARALLEL WITH THIS INDUCTIVE LOAD)

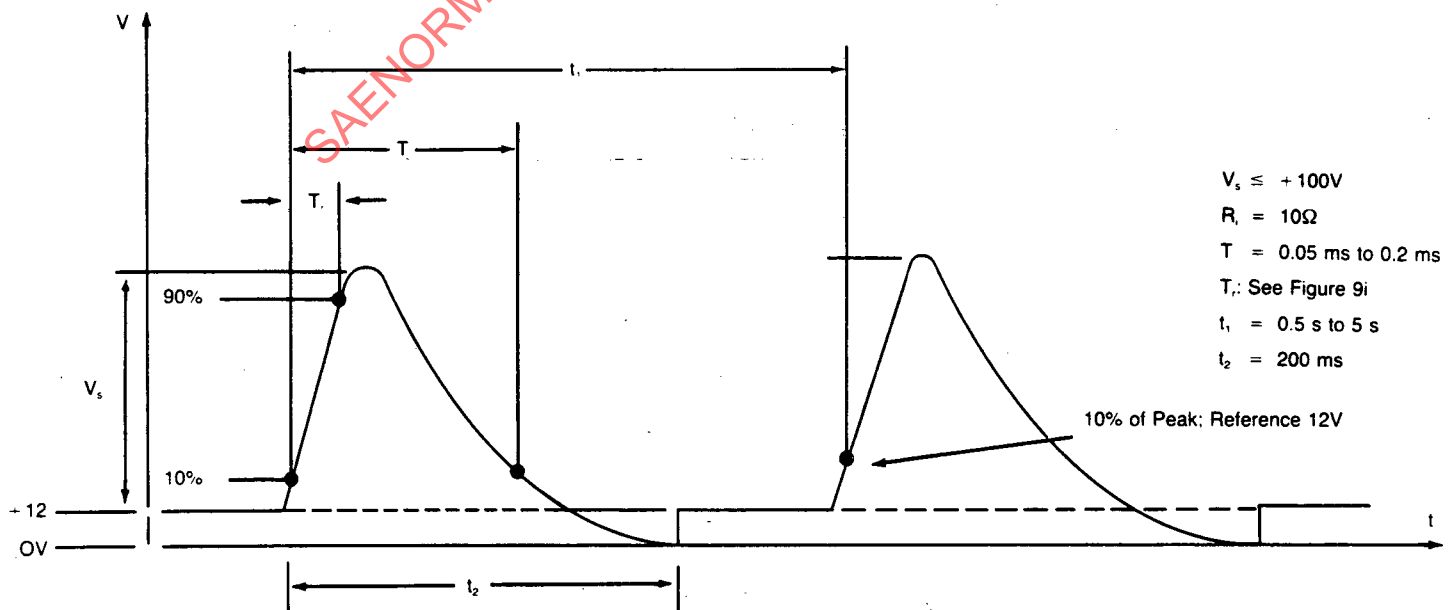
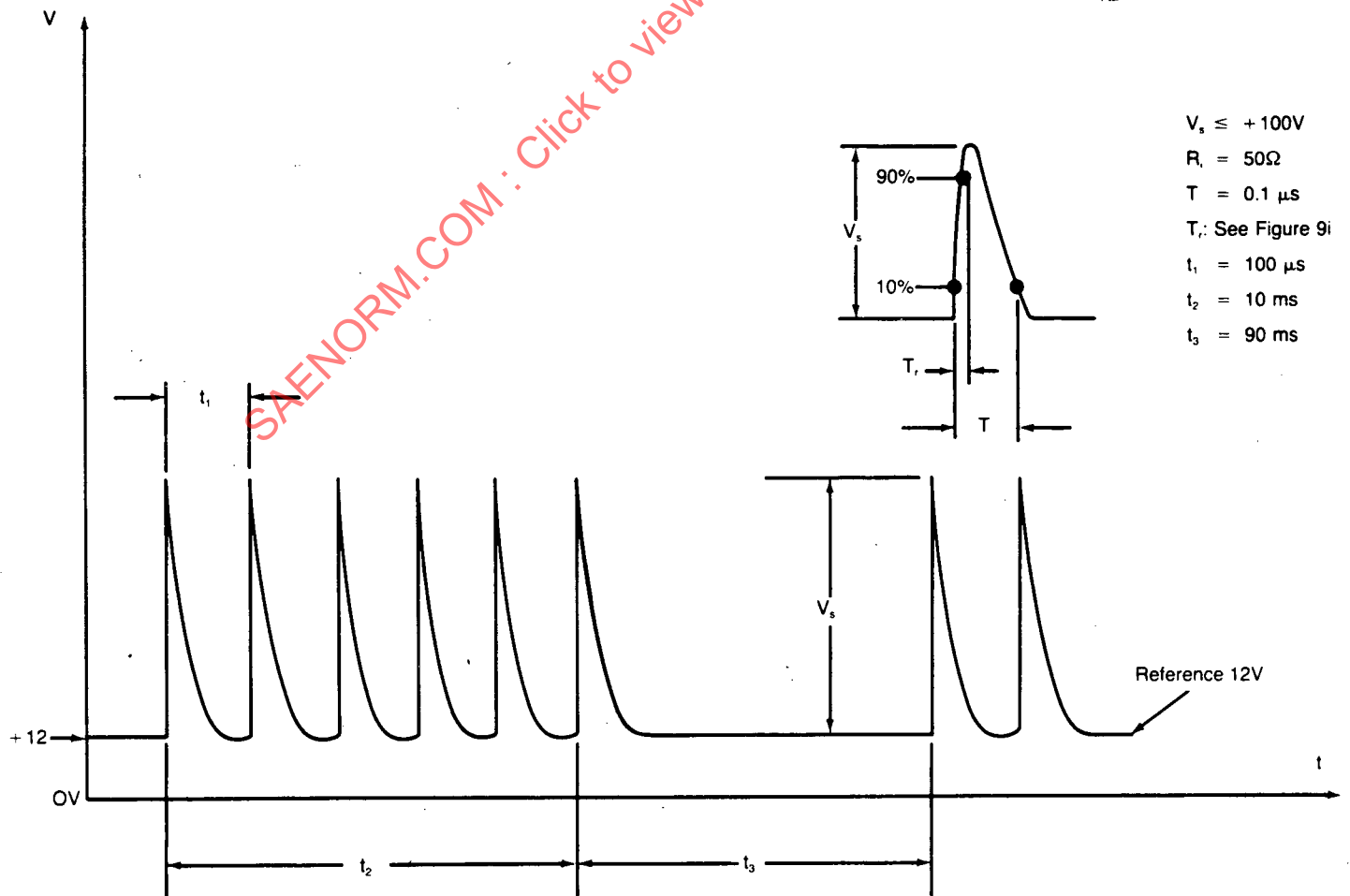
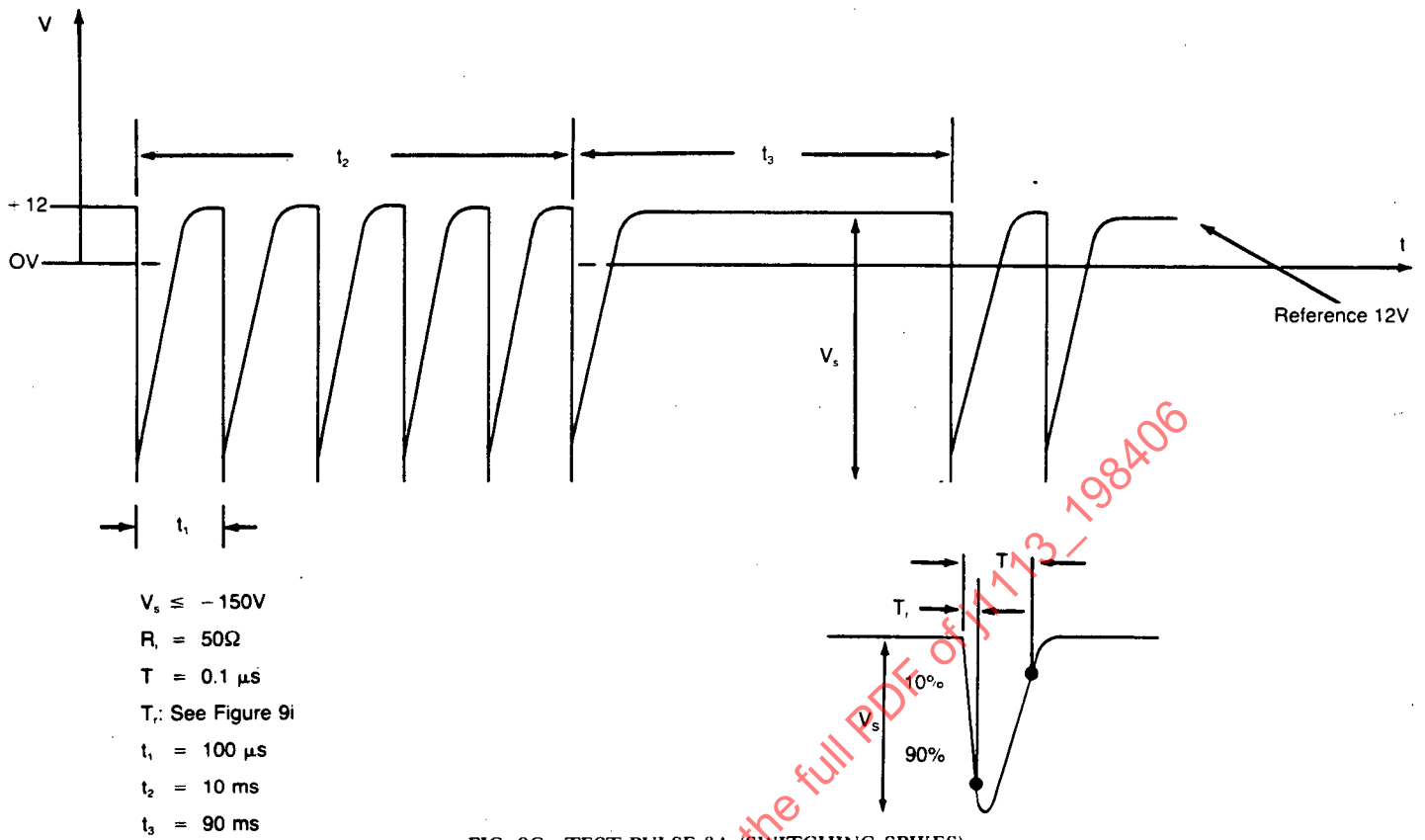


FIG. 9B—TEST PULSE 2 (SUDDEN INTERRUPTION OF A SERIES CURRENT)



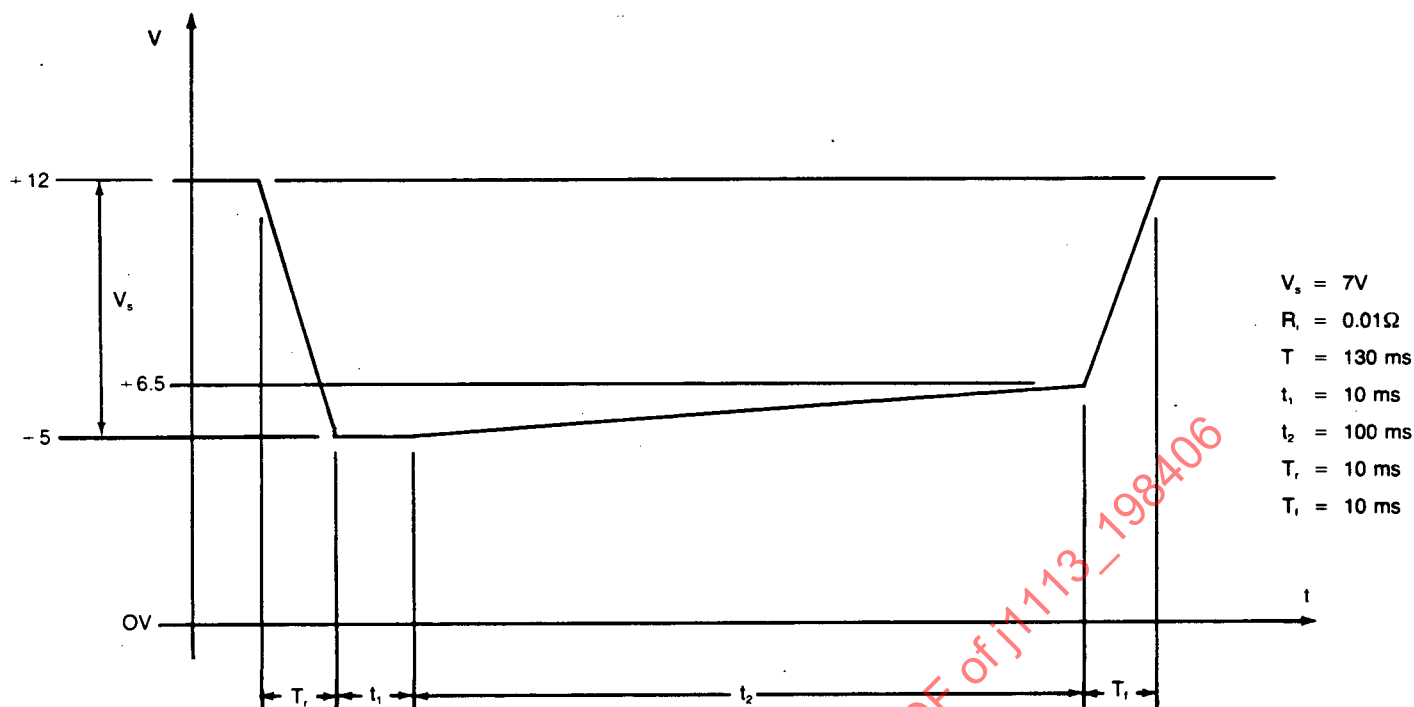


FIG. 9E—TEST PULSE 4 (SINGLE PULSE, E.G. STARTER MOTOR ENGAGEMENT DISTURBANCE)

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 $\pm 2\%$. 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, 50 Ω 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 Fig. 12.

(f) Low-Pass Filter—Cutoff at 200 MHz, with the signal down 60 dB at frequencies greater than 300 MHz.

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

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

(i) Dual Directional Coupler(s)— -30 dB or greater coupling ratio, 10—200 MHz.

(j) RF Power Meters With Sensors—Capable of measuring RF power levels up to 100 mW at frequencies of 10—200 MHz.

(k) Dual Channel XY Recorder.

7.4 Test Setup and Procedure—A detailed, step-by-step measurement procedure, suggested as a systematic approach for evaluating the EM radiated susceptibility of EUT is contained in SAE Information Report, J1448 (6). Briefly, this includes:

(a) Place the EUT inside the cell as shown, for example, in Fig. 12.
 (b) Access the EUT as required for operation and performance monitoring using appropriate shielded and fiber optic lines routed to filtered feed-through connectors mounted on the bottom outer shield as shown in Fig. 12. Care must be taken in routing the leads to obtain the most meaningful, repeatable results. Record lead positions for future reference.

(c) Connect up the measurement system as shown in Fig. 13A or 13B. Fig. 13A is used for frequencies below 10 MHz and Fig. 13B is used for frequencies above 10 MHz.

(d) Generate the test field as required. The field strength, E_v , is determined by:

$$E_v = \frac{V_{\pi}}{b}$$

where V_{π} is the input voltage to the cell in volts and b is the cell floor-to-septum separation in meters. At frequencies above 10 MHz, V_{π} is determined from the expression:

$$V_{\pi} = \sqrt{P_n / G_c}$$

where P_n is the net power flowing through the cell as measured by the power meters on the sidearms of the calibrated bi-directional coupler, and G_c is the real part of the cell's characteristic admittance (approximately $= 0.02\text{ mhos}$).

(e) Operate the EUT as required while monitoring its response to the RF test fields. Scan the entire frequency range from 14 kHz to 200 MHz with particular emphasis made at the EUT's critical frequencies (local oscillator frequencies, intermediate frequencies, etc.) as specified in the test plan. Orient the EUT in each orthogonal plane within the cell to determine maximum susceptibility. Record the threshold of susceptibility as determined by increasing the amplitude of the test field until degradation in performance is observed or the maximum level specified in the test plan is achieved.

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.

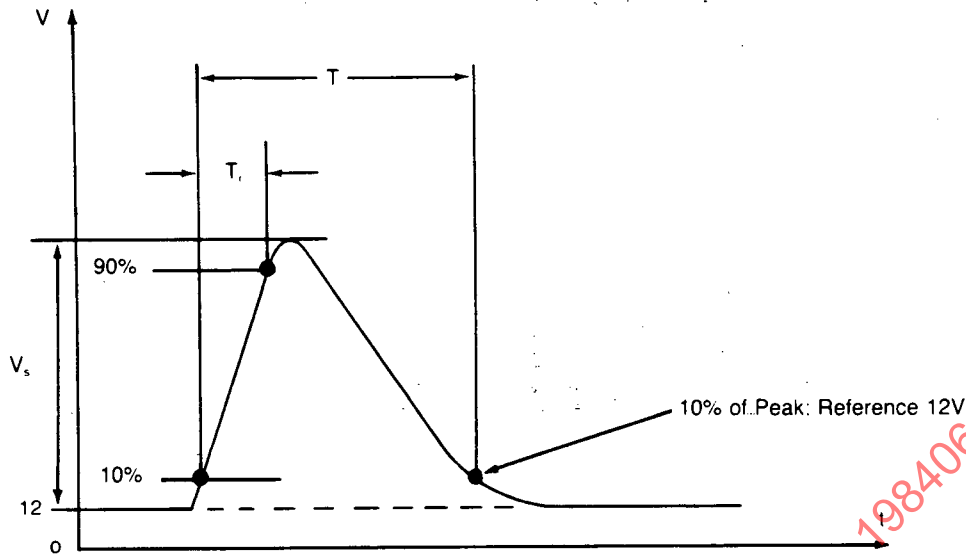
3. Digital Equipment—Use pulse modulation with pulse duration(s) and repetition(s) equal to those used in the EUT.

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) Detailed considerations concerning EUT size, frequency limitations, and construction specifications can be found in SAE Information Report, J1448. In general, the device should be less than $1/3$ the length, width, and separation distance between cell septum and floor.

(d) Not all the tests outlined in this measurement procedure may be required, and only those required by the test plan should be performed. For example, if the objective of the measurement program is to reduce the vulnerability (susceptibility) of the EUT, one EUT orientation with one input/output lead configuration could be tested in one particular operational mode to a preselected susceptibility test-field waveform and amplitude. Then, if corrective measures were made to the EUT and placement of the EUT and its leads inside the cell were carefully duplicated,



$V_s = 10$ to $120V$

$T = 40$ to 400 ms

$T_r = 5$ to 10 ms

$R_i = .5$ to 4Ω

1) The internal impedance of an alternator is a function of the following parameters:

- Speed
- Excitation Current
- Load Current.

The internal resistance of the load dump simulator shall be obtained from the following relationship:

$$R_i = \frac{V_{\text{open circuit}} - V_{\text{at 70 to 75\% of } I_{\text{short circuit}}}}{70 \text{ to } 75\% \text{ of } I_{\text{short circuit}}}$$

R_i shall represent a value corresponding to specified values of excitation current and speed.

- 2) Based on the inherent relationship between V_{∞} and R_i there exists a correspondence between the voltage range and the resistance range given above: the lower resistance value corresponds roughly to the lower voltage values and vice versa.
- 3) The open circuit waveform time constant shall be adjusted to the RL time constant of the excitation circuit.
- 4) Remarks: depending on the characteristics of the EUT (possibly including Zener diodes and varistors) the observed voltage waveform across the EUT may be quite different from the open circuit waveform.

FIG. 9F—TEST PULSE 5 (LOAD DUMP, SINGLE PULSE)

repeat measurements could be made. These measurements could then be compared to determine degree of improvement.

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.

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 to make it anechoic. Open field tests as outlined in SAE J1338 may also be used in this frequency range.

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 $\pm 2\%$. Harmonics

and spurious outputs shall not be more than 30 dB referred to the fundamental power.

- (b) EMI Meter or Spectrum Analyzer.
- (c) Antennas—Linear antennas such as the log periodic and the ridged-guide horn are recommended.
- (d) Output Monitor—Appropriate instrumentation to monitor the performance of the EUT shall be used.

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 beam width of the transmitted field. If this is not feasible, the sample may be tested in segments, each segment being

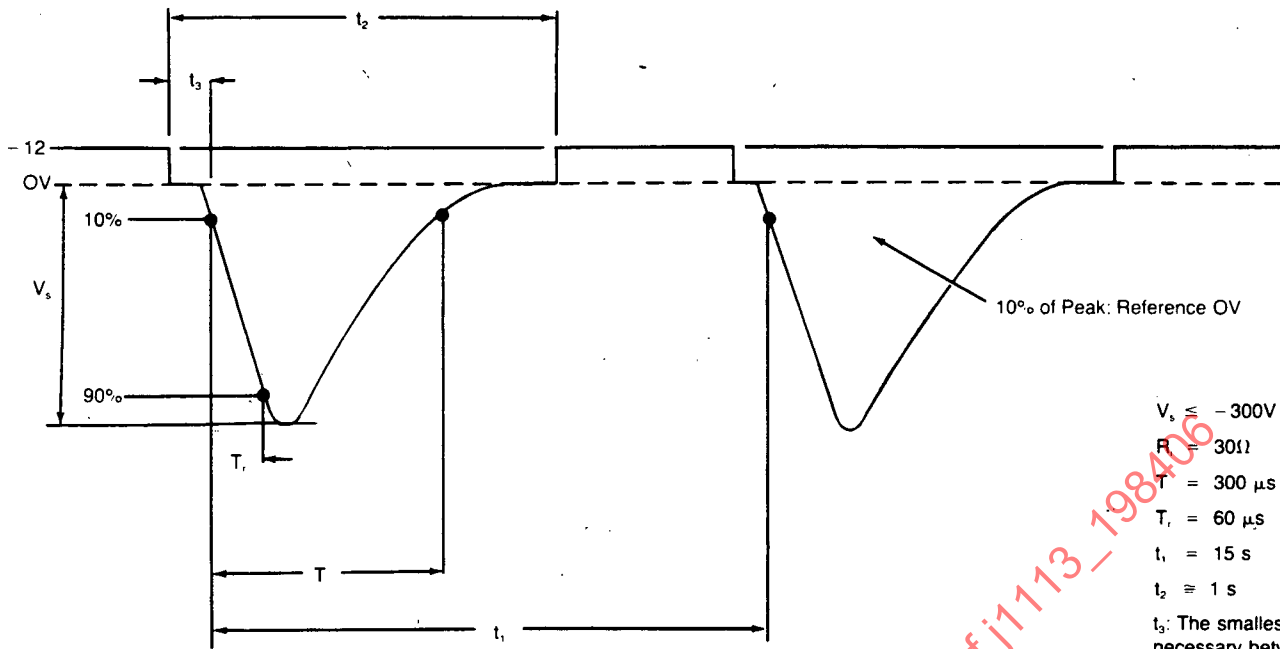


FIG. 9G—TEST PULSE 6 (IGNITION COIL CURRENT INTERRUPTION)

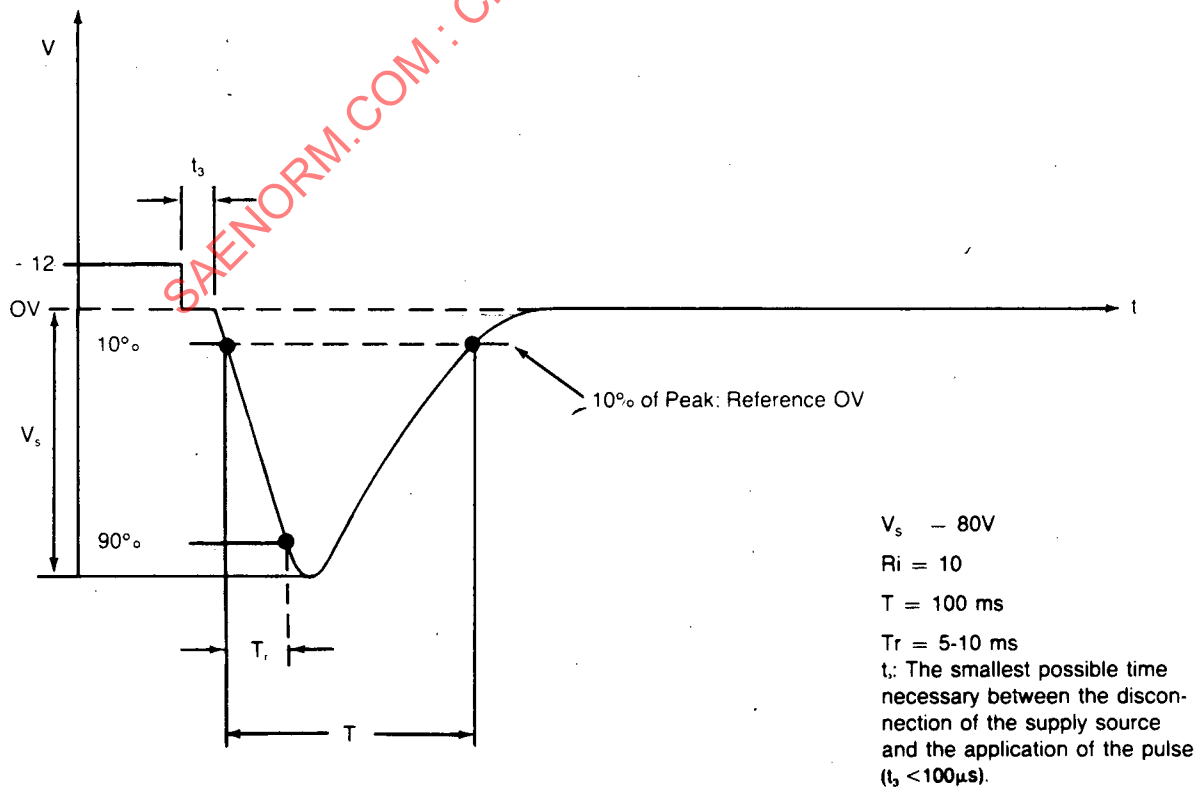


FIG. 9H—TEST PULSE 7 (SINGLE PULSE, E.G. ALTERNATOR FIELD TRANSIENT AT ENGINE TURN-OFF)

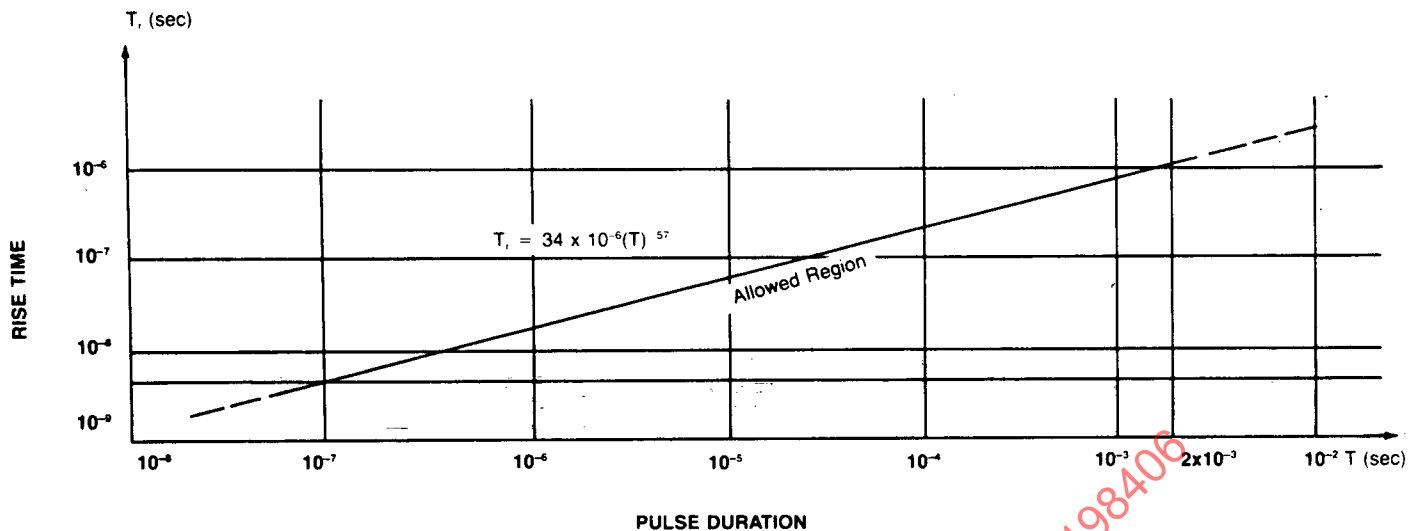


FIG. 9I—DESIGN OBJECTIVE FOR RISE TIME OF TEST PULSES 9A THROUGH 9D. NOTE THAT DESIGN DIFFICULTY CAN BE ENCOUNTERED FOR SHORT DURATION HIGH VOLTAGE PULSES

equal in dimension to the 3 dB beam width 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 1, the walls should be covered with a microwave absorber material which provides at least 20 dB attenuation of reflected power at 200 MHz. The setup is shown in Fig. 14.

(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 used.) The volume surrounding the EUT should be probed with the field measuring antenna to verify that a uniform field exists within the test area. For a more detailed discussion and recommendation to avoid problems inherent in probing the fields around an EUT, see SAE Paper No. 830606 (8).

(f) The EUT shall be oriented in each orthogonal plane within the shielded enclosure to determine maximum susceptibility.

(g) The entire frequency range from 200—1000 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 EUT critical frequencies (local oscillator frequency, intermediate frequency, and others) as specified in the test plan. Determine the threshold of susceptibility by increasing the test signal until degradation of performance is observed.

8.5 Notes

(a) Unless otherwise required in the equipment specification or approved 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: 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 a pulse of duration $2/BW$ 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 equipment.

4. Non-Tuned Equipment—Amplitude modulate 30% with 1000 Hz tone or as otherwise required in the test plan.

(b) At frequencies approaching 200 MHz and a separation distance of 1 m, the EUT approaches the reactive near field of the antenna. Use of these distances is standard practice despite possible errors caused by them.

(c) The EUT configuration shall be as close to the actual operating

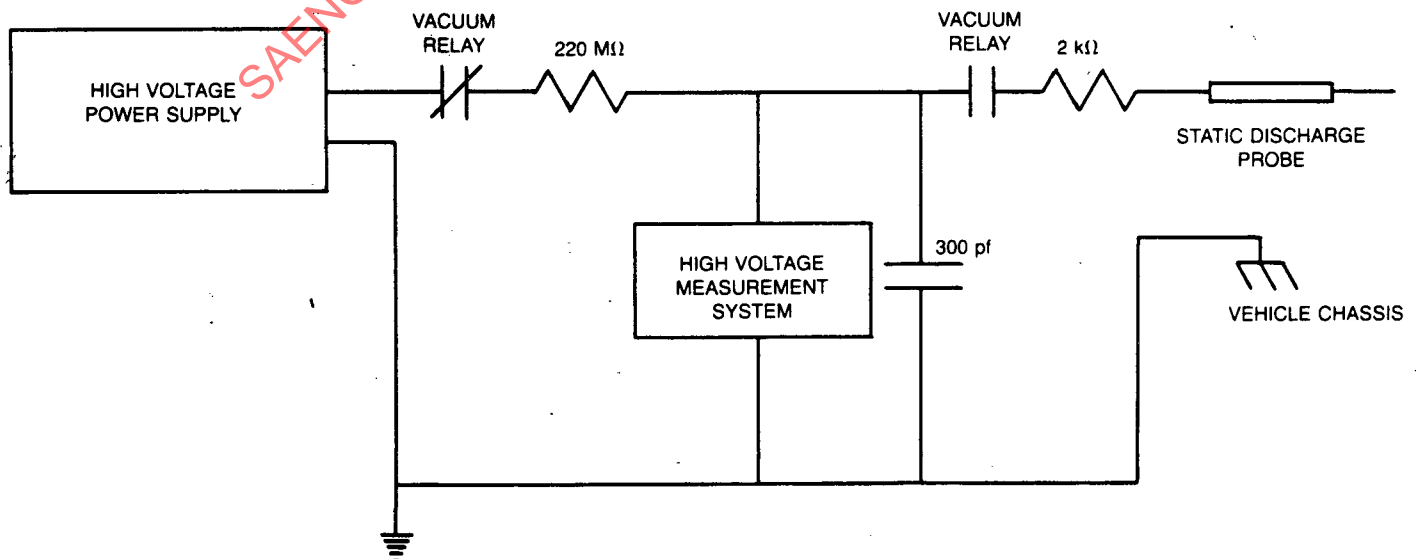


FIG. 10—ELECTROSTATIC DISCHARGE TEST CONFIGURATION

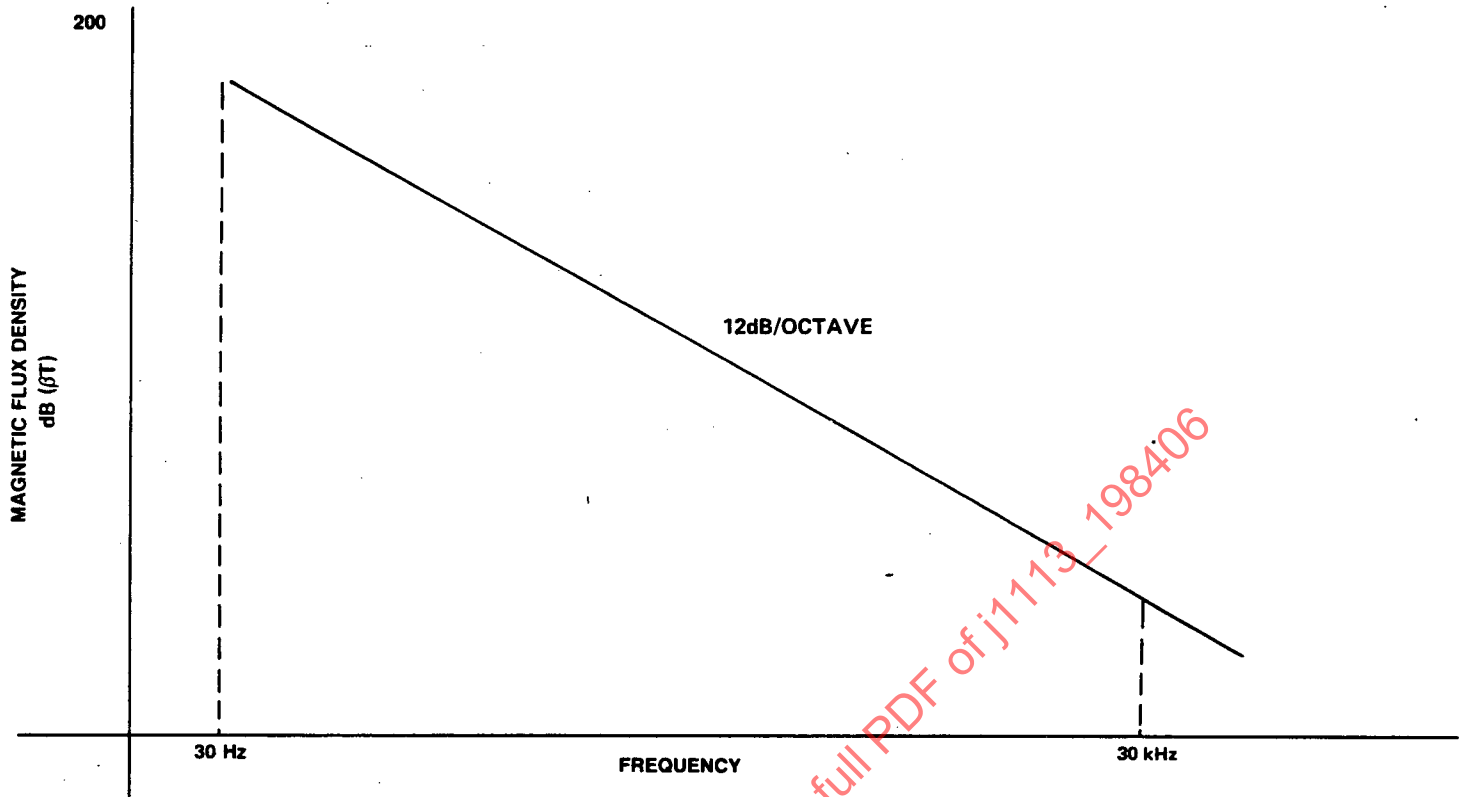


FIG. 11A—MAGNETIC FLUX DENSITY VERSUS FREQUENCY

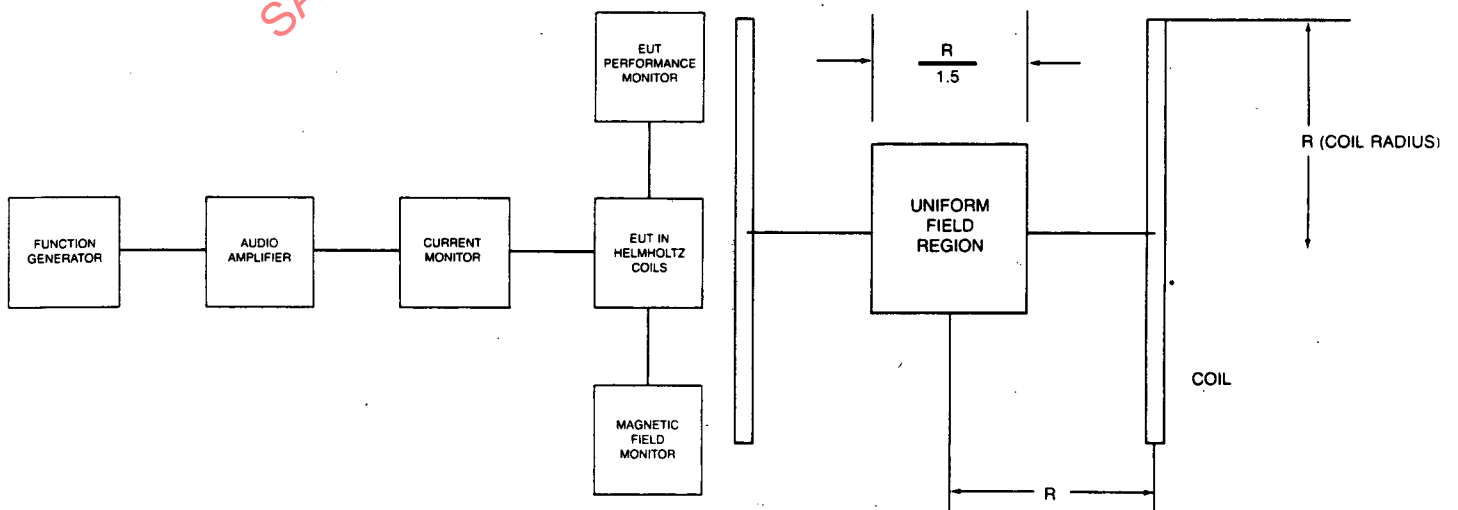


FIG. 11B—BLOCK DIAGRAM FOR MAGNETIC FIELD SUSCEPTIBILITY TESTING

FIG. 11C—HELMHOLTZ COIL CONFIGURATION

EM SUSCEPTIBILITY TESTING

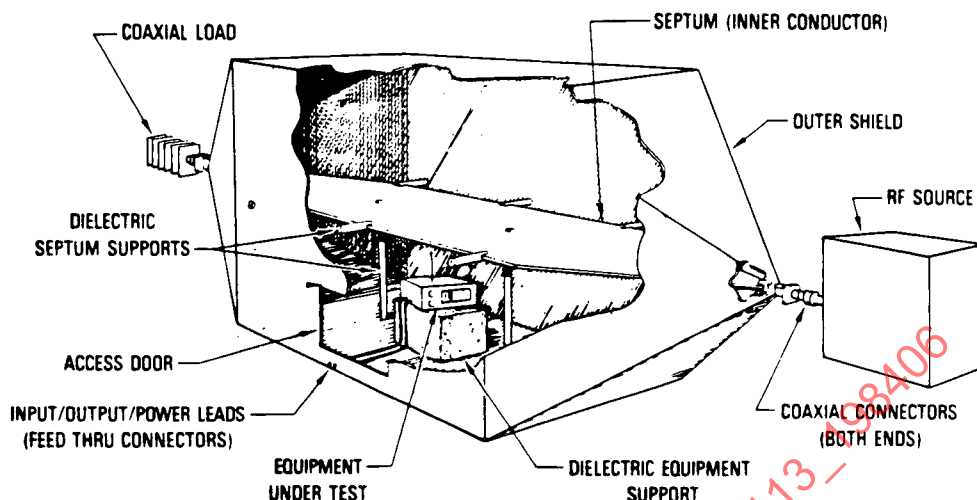


FIG. 12—CUT-AWAY VIEW OF TEM CELL BEING USED FOR EM SUSCEPTIBILITY TESTING. FIGURE SHOWS PLACEMENT OF EUT AND ASSOCIATED INPUT, OUTPUT, AND MONITORING LEADS INSIDE THE CELL

situation as possible in terms of surrounding metal structure, lead length, and terminating impedances.

(d) RF power handling capability of absorber shall be adequate to insure safe operation.

(e) When required, a copper or brass ground plane (solid plate) shall be used that has a minimum thickness of 0.25 mm for copper or 0.63 mm for brass and is 2.25 m² or larger in area with the smaller side no less than 76 cm. The ground plane shall be bonded to the shielded room such that the DC bonding resistance shall not exceed 2.5 milliohms. In addition, the bonds shall be placed at distances no greater than 90 cm apart. For large equipment mounted on a metal test stand, the test stand shall be considered a part of the ground plane for testing purposes and shall be bonded accordingly. The faces of the test sample shall be located 10 ± 2 cm from the edge of the ground plane. All leads and cables shall be within 10 ± 2 cm from the edge of the ground plane and shall be approximately 5 cm above the ground plane.

9. Radiated Susceptibility 14 kHz—1 GHz, Electric Field Using a Strip Line

9.1 Purpose—This section covers requirements for the determination of electric field susceptibility of equipment, subsystems, and systems typically (whose maximum height is less than 10 cm and maximum length is less than 2 m) in the frequency range 14 kHz—1 GHz.

9.2 Measurement Philosophy—A strip line is a shieldless, unbalanced version of a TEM transmission line which sets up a region of uniform electric and magnetic fields. The primary usage of the strip line is to expose at least 1 m of the wire harness feeding the EUT to RF fields. If desired, the EUT may also be tested using the strip line.

This technique is intended primarily for use in diagnostic testing to determine, for example, frequencies of EUT susceptibility, some indication of how interference is coupled into the EUT, and the relative improvement in EUT immunity resulting from efforts to reduce EUT susceptibility. It cannot be used to determine EUT susceptibility to absolute test field levels if the EUT includes long wired harnesses that must be exposed, polarization matched, to the test field.

9.3 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) **In-Line Wattmeter**—A commercially available wattmeter capable of measuring 200 W over the frequency range 20 MHz—1 GHz.

(c) **RF Voltmeter**—A commercially available RF voltmeter capable of measuring 100 V over the frequency range 14 kHz—10 MHz.

(d) **Frequency Counter**—A frequency counter capable of measuring frequencies up to 1 GHz.

(e) **Strip Line**—A strip line is shown in Figs. 15A and 15B. The L

dimension should be at least 2 m. The ratio of W to H determines the characteristic impedance according to the following equation:

$$Z_0 = \frac{120 \pi}{W/H + 2.42 - 0.44 H/W + (1 - H/W)^6}, W/H > 1$$

Typical strip line is generally constructed to be either 50 or 96 Ω with W/H equal to 5 and 1.75 respectively. The resistive load can be constructed of carbon resistors, conductive strips, etc. such that it matches the characteristic impedance of the strip line minimizing the standing waves.

9.4 Test Setup and Procedure

(a) Test setup should be as shown in Fig. 15C.

(b) The EUT wire harness should be placed in a non-conductive fixture and placed in the center of the line supported 2 cm off the ground plane.

(c) The EUT must not be grounded to the strip line, but may be placed on a non-conductive pad located on the strip line ground plane.

(d) Field should be generated as required. For frequencies below λ ≥ 10 L, the field strength, E_v, can be measured by using an RF voltmeter where:

$$E_v = \frac{V_r}{H} \text{ volts/meter}$$

For higher frequencies, a commercially available small field probe should be used to establish a calibration curve.

E_v can be monitored after establishing the calibration curve by:

$$E_v = \frac{\sqrt{PZ}}{H} \text{ volts/meter}$$

where P is the measurement forward power into the strip line in watts, Z is the strip line impedance in ohms, and H is the strip line spacing in meters.

(e) The EUT shall be operated by its normal inputs, where possible, and by simulators external to the strip line, filtered as required.

9.5 Notes

(a) Unless otherwise required in the equipment specification or approved 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: 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. EUT's with video channels other than receivers. Modulate 90—100% with a pulse of duration 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 equipment.