SAE The Engineering Society For Advancing Mobility Land Sea Air and Space® INTERNATIONAL

400 Commonwealth Drive, Warrendale, PA 15096-0001

SURFACE VEHICLE STANDARD

SAE J1113-1

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(R) Electromagnetic Compatibility Measurement Procedures and Limits for Components of Vehicles, Boats (up to 15 m), and Machines (Except Aircraft) (50 Hz to 18 GHz)

Foreword—This SAE Standard brings together methodology for testing the electromagnetic emissions and immunity characteristics of vehicular modules and components. The writers of this document have participated extensively in the drafting of ISO TC 22 Subcommittee 3 and CISPR Subcommittee D documents.

By intent, the methods and limits of this document closely resemble the counterpart international standards.

SAE J1113–1 General and Definitions
SAE J1113–2 Conducted Immunity, 30 Hz to 250 kHz, Power Leads
SAE J1113–3 Conducted Immunity, 250 kHz to 500 MHz, Direct Radio Frequency (RF) Power Injection
SAE J1113–4 Conducted Immunity-Bulk Current Injection (BCI) Method
[Parts 5 through 10 reserved for future use]
SAE J1113–11 Immunity to Conducted Transients on Power Leads
SAE J1113–12 Electrical Interference by Conduction and Coupling—Coupling Clamp
SAE J1113–13 Immunity to Electrostatic Discharge
[Parts 14 through 20 reserved for future use]
SAEJ1113–21 Road Vehicles—Electrical Disturbances by Narrowband Radiated Electromagnetic Energy—Component Test Method—Absorber Lined Chamber
SAE J1113–22 Immunity to Radiated Magnetic Fields from Power Lines
SAE J1113–23 Immunity to Radiated Electromagnetic Fields, 10 kHz to 200 MHz, Strip Line Method
SAE J1113–24 Immunity to Radiated Electromagnetic Fields, 10 kHz to 200 MHz, TEM Cell Method
SAE J1113–25 Immunity to Radiated Electromagnetic Fields, 10 kHz to 1000 MHz, Tri-Plate Line Method
SAE J1113–26 Immunity to AC Power Line Electric Fields
SAE J1113–27 Immunity to Radiated Electromagnetic Field—Reverberation Chamber Method
[Parts 28 through 40 reserved for future use]
SAE J1113–41 Limits and Methods of Measurement of Radio Disturbance Characteristics of Components and Modules for the Protection of Receivers Used On-Board Vehicles, Narrowband, 150 kHz to 1000 MHz
SAE J1113–42 Conducted Transient Emissions

1. ***Scope***—This SAE Standard covers the measurement of voltage transient immunity and within the applicable frequency ranges, audio (AF) and radio frequency (RF) immunity, and conducted and radiated emissions.

Emissions from intentional radiators are not controlled by this document. (See applicable appropriate regulatory documents.) The immunity of commercial mains powered equipment to over voltages and line transients is not covered by this document.

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2. *References*

2.1 Applicable Publications—The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

2.1.1 SAE PUBLICATION—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE J551-2—Test Limits and Methods of Measurement of Radio Disturbance Characteristics of Vehicles, Motorboats, and Spark-Ignited Engine-Driven Devices
SAE J1113–1—General and Definitions
SAE J1113–2—Conducted Immunity, 30 Hz to 250 kHz, Power Leads
SAE J1113–3—Conducted Immunity, 250 kHz to 500 MHz, Direct Radio Frequency (RF) Power Injection
SAE J1113–4—Conducted Immunity-Bulk Current Injection (BCI) Method
SAE J1113–11—Immunity to Conducted Transients on Power Leads
SAE J1113–12—Electrical Interference by Conduction and Coupling—Coupling Clamp
SAE J1113–13—Immunity to Electrostatic Discharge
SAEJ1113–21—Road Vehicles—Electrical Disturbances by Narrowband Radiated Electromagnetic Energy—Component Test Method—Absorber Lined Chamber
SAE J1113–22—Immunity to Radiated Magnetic Fields from Power Lines
SAE J1113–23—Immunity to Radiated Electromagnetic Fields, 10 kHz to 200 MHz, Strip Line Method
SAE J1113–24—Immunity to Radiated Electromagnetic Fields, 10 kHz to 200 MHz, TEM Cell Method
SAE J1113–25—Immunity to Radiated Electromagnetic Fields, 10 kHz to 1000 MHz, Tri-Plate Line Method
SAE J1113–26—Immunity to AC Power Line Electric Fields
SAE J1113–27—Immunity to Radiated Electromagnetic Field—Reverberation Chamber Method
SAE J1113–41—Limits and Methods of Measurement of Radio Disturbance Characteristics of Components and Modules for the Protection of Receivers Used On-Board Vehicles, Narrowband, 150 kHz to 1000 MHz
SAE J1113–42—Conducted Transient Emissions
SAE J1812—Function Performance Status Classification for EMC Immunity

2.1.2 ANSI PUBLICATIONS—Available from ANSI, 25 West 43rd Street, New York, NY 10036-8002.

ANSI C63.2–1996—American National Standard for Instrumentation–Electromagnetic Noise and Field Strength, 10 kHz to 40 GHz–Specifications
ANSI C63.4–1992—Emissions from Low–Voltage Electrical and Electronic Equipment in the range of 9 kHz to 40 GHz
ANSI C95.1–1999—American National Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz
ANSI/IEEE STD 100–1993—Standard Dictionary of Electrical and Electronic Terms

2.1.3 CISPR PUBLICATIONS—Available from ANSI, 25 West 43rd Street, New York, NY 10036-8002.

CISPR 12 Fifth edition: Limits and Methods of Measurement of Radio Interference Characteristics of Vehicles, Motor Boats, and Spark-Ignited Engine-Driven Devices
CISPR 16-1: Edition 1.1 1998 Specification for radio disturbance and immunity measuring apparatus and methods–Part 1: Radio disturbance and immunity measuring apparatus
CISPR 25–1st edition: 1995 Limits and Methods of Measurement of Radio Disturbance Characteristics for the Protection of Receivers used On-board Vehicles

2.1.4 IEC PUBLICATIONS—Available from ANSI, 25 West 43rd Street, New York, NY 10036-8002.

IEC Publication 60050(161)—International Electrotechnical Vocabulary–Electromagnetic Compatibility
IEC Publication 60050(726)—International Electrotechnical Vocabulary–Transmission Lines and Waveguides

2.1.5 ISO PUBLICATIONS—Available from ANSI, 25 West 43rd Street, New York, NY 10036-8002.

ISO 7637-1:2002—Road vehicle Electrical interference by conduction and coupling: Part I—General
ISO 7637-2:1990—Road vehicles—Electrical disturbance by conduction and coupling: Part 2—Commercial vehicles with nominal 24 V supply voltage—Electrical transient conduction along supply lines only
ISO 7637-3:1995—Road vehicles—Electrical disturbance by conduction and coupling: Part 3—Vehicles with nominal 12 V or 24 V supply voltage—Electrical transient transmission by capacitive and inductive coupling via lines other than supply lines.
ISO 11452-1:2001—Road vehicles—Component test methods for electrical disturbances from narrowband radiated electromagnetic energy—Part 1: General and definitions
ISO 11452-2:1995—Road vehicles—Electrical disturbances by narrowband radiated electromagnetic energy—Component test methods—Part 2: Absorber-lined chamber
ISO 11452-3:2001—Road vehicles—Component test methods for electrical disturbances from narrowband radiated electromagnetic energy—Part 3: Transverse electromagnetic mode (TEM) cell
ISO 11452-4:2001—Road vehicles—Component test methods for electrical disturbances from narrowband radiated electromagnetic energy—Part 4: Bulk current injection (BCI)
ISO 11452-5:1995—Road vehicles—Electrical disturbances by narrowband radiated electromagnetic energy—Component test methods—Part 5: Stripline
ISO 11452-7:1995—Road vehicles—Electrical disturbances by narrowband radiated electromagnetic energy—Component test methods—Part 7: Direct radio frequency (RF) power injection

2.2 Related Publications—The following publications are provided for information purposes only and are not a required part of this specification.

2.2.1 SAE PUBLICATION—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

HS–3600 –1999 Edition SAE Surface Vehicle Electromagnetic Compatibility (EMC) Standards Manual

2.2.2 ANSI PUBLICATIONS—Available from ANSI, 25 West 43rd Street, New York, NY 10036-8002.

ANSI C63.5–1998—American National Standard for Electromagnetic Compatibility-Radiated Emissions Measurements in Electromagnetic Interference (EMI) Control- Calibration of Antennas (9 kHz to 40 GHz)
ANSI C63.14–1998 (EMC)—Electromagnetic Pulse (EMP), and Electrostatic Discharge (ESD)
ANSI C63.16–1993—Methodologies and Criteria for Electronic Equipment

2.2.3 CISPR PUBLICATIONS—Available from ANSI, 25 West 43rd Street, New York, NY 10036-8002.

CISPR 16–2: First Edition 1996—Specification for radio disturbance and immunity measuring apparatus and methods–Part 2: Methods of Measurement of Disturbances and Immunity
CISPR 22—Limits and methods of measurement of radio interference characteristics of information technology equipment

2.2.4 ISO PUBLICATIONS—Available from ANSI, 25 West 43rd Street, New York, NY 10036-8002.

ISO TR 10305:1992 Generation of standard em fields for calibration of power density meters—20 kHz to 1000 MHz
ISO TR 10605:1992—Road vehicles—Electrical disturbances from electrostatic discharges

2.2.5 IEEE PUBLICATIONS—Available from IEEE, Inc., 445 Hoes Lane, PO Box 1331, Piscataway NJ 08855-1331.

IEEE STD 211–1997—IEEE Standard Definition of Terms for Radio Wave Propagation
IEEE STD 291–1991—IEEE Standard Methods for Measuring Electromagnetic Field Strength of Sinusoidal Continuous Waves, 30 Hz to 30 GHz.

2.2.6 OTHER PUBLICATIONS

SAE paper 810333, “Implementation of EMC Testing of Automotive Vehicles,” Kinderman, J.C., et al., February 1981

SAE paper 831011, “An Indoor 60 Hz to 40 GHz Facility for Total Vehicle EMC Testing,” Vrooman, June 1983

Adams, J.W., Taggart, H.E., Kanda, M., and Shafer, J., “Electromagnetic Interference (EMI) Radiative Measurements for Automotive Applications,” NBS Tech. Note 1014, June 1979

Tippet, J.C., Chang, D.C., and Crawford, M.L., “An Analytical and Experimental Determination of the Cutoff Frequencies of Higher-Order TE Modes in a TEM cell,” NBSIR 76-841, June 1976

Tippet, J.C., Modal Characteristics of Rectangular Coaxial Transmission Line, Thesis submitted June 1978 for degree of Doctor of Philosophy to University of Colorado, Electrical Engineering Dept., Boulder, CO

Nichols, F.J., and Hemming, L.H., “Recommendations and Design Guides for the Selection and Use of RF Shielded Anechoic Chamber in the 30-1000 MHz Frequency Range,” IEEE Inter. Symposium on EMC., Boulder, CO, August 18-20,1981, pp 457-464

3. Definitions—The definitions listed below apply to certain terms used in the various parts of SAE J1113 and are not intended to be an exhaustive list. For more information, check other resources such as IEC publications 60050(161) and 60050(726) and the latest editions of ANSI/IEEE Dictionaries of Technological terms. Definitions without a source reference were defined within the SAE committee activities.

3.1 Absorber-Lined Shielded Enclosure ALSE (abbreviation)—A shielded room with absorbing material on its internal ceiling and walls. Note: The common practice is to have the metallic floor of the ALSE exposed (semi-anechoic condition), or absorbing material may be placed over the entire floor area (fully anechoic condition). (Adapted from ISO 11452–1.)

3.2 Amplitude Modulation AM (abbreviation)—The process by which the amplitude of a carrier wave is varied following a specified law. The result of the process is an AM signal. (Adapted from ISO 11452–1.)

3.3 Antenna Correction Factor—A factor, comprised of the antenna factor and the cable factor, applied to the voltage measured at the input connector of the measuring instrument to give the field strength at the antenna. (Adapted from CISPR 25 1st Edition.)

3.4 Antenna Factor—The ratio, at a specific frequency, of the field level present at an antenna and the resultant voltage at the antenna terminals (1/m). A factor when multiplied by the antenna terminal voltage results in the field at the antenna in V/m or dBV/m.

3.5 Antenna Matching Unit—A unit for matching the impedance of an antenna to that of the 50 Ω measuring receiver over the antenna measuring frequency range. (CISPR 25 1st Edition.)

3.6 Artificial Network AN (abbreviation); Line Impedance Stabilization Network LISN (abbreviation USA)—A network inserted in the supply leads of apparatus to be tested which provides, in a given frequency range, a specified load impedance for the measurement of disturbance voltages and which isolates the apparatus from the power supply in that frequency range. (Adapted from IEC 60050(161)–04–05.)

3.7 Bandwidth—The width of a frequency band over which a given characteristic of an equipment or transmission channel does not differ from its reference value by more than a specified amount or ratio. (Adapted from IEC 60050(161)–06–09)

3.8 Bench Testing—Bench testing is component testing performed in a laboratory or test facility.

3.9 Bond—A connection between conductive parts or surfaces that assures that the required electrical conductivity will be achieved.

3.10 Broadband Artificial Network BAN (abbreviation)—A network that presents a controlled impedance to the device under test over a specified frequency range while allowing the device under test to be interfaced to its support system. It is used in power, signal, and control lines. (Adapted from ISO 11452–1.)

3.11 Broadband Emission—An emission which has a bandwidth greater than that of a particular measuring apparatus or receiver. (IEC 60050(161)–06–11.)

3.12 Broadband Emission (Short Duration)—An emission that possesses a spectrum broad in width as compared to the nominal bandwidth of the measuring instrument, and whose spectral components are sufficiently close together and uniform so that the measuring instrument cannot resolve them and the duration is less than six seconds. (Adapted from ANSI C-63.4.)

3.13 Bulk Current—Total amount of common mode current in a harness. (ISO 11452–1.)

3.14 Bulk Current Injection Probe—A device for injecting current in a conductor without interrupting the conductor and without introducing significant impedance into the associated circuits

3.15 Burst—A burst is a transient with multiple spikes.

3.16 Characteristic Level—The controlling (or dominant) emission level experienced in each frequency sub-band. The characteristic level is the maximum measurement obtained for both antenna polarizations and for all the specified measurement positions of the vehicle or device. Known ambient signals shall not be considered part of the characteristic level. (CISPR 12, 5th Edition.)

3.17 Class—A performance level agreed upon by the purchaser and the supplier and documented in the test plan. (CISPR 25 1st Edition.)

3.18 Component Conducted Emissions—The noise voltages/currents of a nature existing on the supply or other wires of a component/module. (Adapted from CISPR 25 1st Edition.)

3.19 Compression Point—The input signal level at which the gain of the measuring system becomes nonlinear such that the indicated output deviates from an ideal linear receiving system's output by the specified increment in dB. (CISPR 25 1st Edition.)

3.20 Conducted Emissions—Conducted emissions are transients and/or other disturbances observed on the external terminals of a device during its normal operation.

3.21 Conducted Emissions Level—Conducted emissions level is the amplitude of the emissions from the DUT as measured according to the test procedure.

3.22 Conducted Susceptibility Threshold—Conducted susceptibility threshold is defined as the level of conducted interference at which the Device Under Test responds undesirably or experiences performance degradation. For conducted susceptibility bench testing, a representative number of conducted interference waveforms are artificially generated and injected into the DUT to determine the threshold level of susceptibility.

3.23 Coupling—A means or a device for transferring power between systems. (Adapted from IEC 60050(726)–14–01.)

3.24 Current Probe (Measuring or Monitoring)—A device for measuring the current in a conductor without interrupting the conductor and without introducing significant impedance into the associated circuits. (Adapted from IEC 60050(161)–04–35.)

3.25 Damped Sinusoid—A waveform composed of a sine wave having a decaying amplitude envelope. The waveform occurs when a pulse excites a circuit having a condition of resonance.

3.26 Degradation (of performance)—An undesired departure in the operational performance of any device, equipment or system from its intended performance.

NOTE— The term “degradation” can apply to temporary or permanent failure. (IEC 60050(161)–01–19.)

3.27 Device—An electrical or electronic component, module, subassembly or system. Each could include a wiring harness(s).

3.28 Device Under Test DUT (abbreviation)—The device, equipment or system being evaluated.

3.29 Directional Coupler—A three- or four-port device consisting of two transmission lines coupled together in such a manner that a single traveling wave in any one transmission line will induce a single traveling wave in the other; the direction of propagation of the latter wave being dependent upon that of the former. (Adapted from IEC 60050(726)–14–02.)

3.30 Disturbance Suppression—Action which reduces or eliminates an electromagnetic disturbance. (IEC 60050(161)–03–22.)

3.31 Disturbance Voltage/Interference Voltage—Voltage produced between two points on separate conductors by an electromagnetic disturbance, measured under specified conditions. (Adapted from IEC 60050(161)–04–01.)

3.32 Electromagnetic Compatibility EMC (abbreviation)—The ability of an equipment or system to function satisfactory in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment. (IEC 60050(161)–01–07.)

3.33 Electromagnetic Disturbance—Any electromagnetic phenomenon which may degrade the performance of a device, equipment or system, or adversely affect living or inert matter.

NOTE— An electromagnetic disturbance may be an electromagnetic noise, an unwanted signal or a change in the propagation medium itself.
(IEC 60050(161)–01–05.)

3.34 Electromagnetic Immunity (to a disturbance)—The ability of a device, equipment, or system to perform without degradation in the presence of an electromagnetic disturbance. (Adapted from IEC 60050(161)–01–20.)

3.35 Electromagnetic Interference EMI (abbreviation)—Degradation of the performance of an equipment, transmission channel, or system caused by an electromagnetic disturbance.

NOTE— The English words “interference” and “disturbance” are often used indiscriminately.
(IEC 60050(161)–01–06.)

3.36 (Electromagnetic) Radiation

1. The phenomena by which energy in the form of electromagnetic waves emanates from a source into space.
2. Energy transferred through space in the form of electromagnetic waves.

NOTE— By extension, the term “electromagnetic radiation” sometimes also covers induction phenomena. (IEC 60050(161)–01–10.)

3.37 Electromagnetic Susceptibility—The inability of a device, equipment, or system to perform without degradation in the presence of an electromagnetic disturbance. Note: Susceptibility is the lack of immunity. (Adapted from IEC 60050(161)–01–21.)

3.38 Electrostatic Discharge ESD (Abbreviation)—A transfer of electric charge between bodies of different electrostatic potential in proximity or through direct contact. (IEC 60050(161)–01–22.)

3.39 Forward Power—That power supplied by the output of an amplifier (or generator) traveling towards the load. (Adapted from ISO 11452–1.)

3.40 Frequency Sub-Bands—Frequency bands that contain approximately three bands in each octave (2:1 frequency ratio). Where the limit is not constant (i.e., slopes), the ratio of the highest frequency to lowest frequency in each band shall be no greater than 1.34. For example, the frequency range of 30 MHz to 1000 MHz is divided into 14 sub-bands. (CISPR 12, 5th Edition.)

3.41 Function Performance Status Classifications—See Appendix A for definitions of Functional Performance Status Classifications, the associated Regions of Performance, and Performance Objectives.

3.42 Glow Discharge—A portion of the transient waveform characterized by a short fall time preceded by a relatively longer rise time. The waveform occurs at the end of the initial switch arc of the on-to-off switching operation of inductive loads. There may be a single or multiple occurrences of this waveform.

3.43 Ground (Reference) Plane—A flat conductive surface whose potential is used as a common reference. (IEC 60050(161)–04–36.)

3.44 Ignition Noise Suppressor—That portion of a high-voltage ignition circuit intended to limit the emission of impulsive ignition noise. (CISPR 12 5th Edition.)

3.45 Immunity Level—The maximum level of a given electromagnetic disturbance incident on a particular device, equipment or system for which it remains capable of operating at a required degree of performance. (IEC 60050(161)–03–14.)

3.46 Impulse Electric Field Strength—The root-mean-square value of the sinusoidal varying radiated electric field producing the same peak response in a bandpass system, antenna, and bandpass filter, produced by the unknown impulse electric field.

3.47 Impulse Noise—Noise characterized by transient disturbances separated in time by quiescent intervals.

NOTE— The typical frequency spectrum of these disturbances will be substantially uniform over the pass band of the transmission system.
(Adapted from ANSI/IEEE Std 100.)

3.48 Impulsive Ignition Noise—The unwanted emission of electromagnetic energy, predominantly impulsive in content, arising from the ignition system within a vehicle or device. (CISPR 12 5th Edition.)

3.49 Inductive Kick—A portion of the transient waveform which occurs during the on-to-off switching operation of inductive loads at the end of the initial switch arc. It is characterized by an exponential wave shape with negative voltage amplitude.

3.50 Informative Appendix—Applies here to classify an appendix that contains information that is advisory or explanatory in nature, as opposed to being mandatory.

3.51 Interference Suppression—Action which reduces or eliminates electromagnetic interference. (IEC 60050(161)–03–23.)

3.52 Load Dump—An exponentially decaying positive transient produced by the alternator when the load presented by the battery or any other large current load is suddenly removed.

3.53 Machine—An implement equipped with an internal combustion engine or electric motor but not self-propelled. Includes, but are not limited to, chain saws, irrigation pumps, and air compressors. [This definition applies only to SAE J551–2.] (Adapted from CISPR 12, 5th edition.)

3.54 Measuring Instrument Impulse Bandwidth—The maximum value of the output response envelope divided by the spectrum amplitude of an applied impulse.

3.55 Modulation Factor (m)—The ratio of the peak variation of the envelope to the reference value. The reference value is usually taken to be the amplitude of the un-modulated wave. The value of m varies between 0 and 1.

3.56 Narrowband Emission—An emission which has a bandwidth less than that of a particular measuring apparatus or receiver. (IEC 60050(161)–06–13.)

3.57 Net Power—Forward power minus reflected power at the same location on the transmission line. (Adapted from ISO 11452–1.)

3.58 Normative Appendix—An appendix containing information whose use is mandatory when applying this document.

3.59 Parallel Plate Antenna—An electric field generating antenna with a set of parallel arms. (ISO 11452–1.)

3.60 Peak Detector—A detector, the output voltage of which is the peak value of an applied signal. (IEC 60050(161)–04–24)

3.61 Polarization (of a wave or field vector)—The property of a sinusoidal electromagnetic wave or field vector defined at a fixed point in space by the direction of the electric field strength vector or of any specified field vector; when this direction varies with time, The property may be characterized by the locus described by the extremity of the considered field vector. (IEC 60050(726)–04–01.)

3.62 Quality Factor "Q"—If a DUT has a frequency response with a center frequency fDUT and a –3 dB bandwidth (BW), Q is defined as the ratio of f_{DUT}/BW.

3.63 Quasi-peak Detector—A detector having specified electrical time constants which, when regularly repeated identical pulses are applied to it, delivers an output voltage which is a fraction of the peak value of the pulses, the fraction increasing towards unity as the pulse repetition rate is increased. (IEC 60050(161)–04–21.)

3.64 Receiver Terminal Voltage—The external voltage measured in dB (V) at the input of a radio interference measuring instrument conforming to the requirements of CISPR Publication 16–1: Edition 1.1 1998 or ANSI C63.2. (Adapted from CISPR 25 1st Edition.)

3.65 Reflected Power—That power traveling toward the amplifier (or generator) reflected by the load caused by impedance mismatch between the transmission line and the load. (Adapted from ISO 11452–1.)

3.66 Representative Frequency—A selected frequency from a sub-band that is used to determine the maximum emission level for that sub-band. For example, the representative frequency for the 30 to 34 MHz sub-band is 32 MHz. (CISPR 12, 5th Edition.)

3.67 RF Ambient (electromagnetic environment)—The totality of electromagnetic phenomena existing at a given location. (Adapted from IEC 60050(161)–01–01)

3.68 RF Boundary—An element of an EMC test set-up that separates that part of the harness and/or peripherals that is included in the RF environment and that part that is excluded. It may consist of, for example, ANs, BANs, filter feed-through pins, RF absorber coated wire, and/or shielding.

3.69 RF Disturbance Power—It is the amount of RF power measured (difference remaining) between two measurements the first being made without suppression and the second made when suppression is present.

3.70 Ripple—Regular or irregular variations in voltage around the nominal DC voltage level during steady state operation of the system.

3.71 Ripple Peak—The greatest variations due to ripple above and below the nominal DC level are called the Upper Peak and Lower Peak, respectively. Peak-to-Peak Ripple is the difference between the Upper Peak and Lower Peak voltages.

3.72 Shall—Used to express a command; i.e., conformance with the specific recommendation is mandatory and deviation is not permitted. The use of the word “shall” is not qualified by the fact that compliance with the document is considered voluntary.

3.73 Shielded Enclosure / Screened Room—A mesh or sheet metallic housing designed expressly for the purpose of separating electromagnetically the internal and external environment. (IEC 60050(161)–04–37.)

3.74 Source Resistance—The output resistance of the source.

3.75 Spike—A transient that exceeds peak ripple for a period less than 150 µs. Spikes are sometimes high frequency oscillations resulting from sudden load variations.

3.76 Standing Wave Ratio (in a transmission line); SWR (abbreviation); Voltage Standing Wave Ratios VSWR (abbreviation)—The ratio, along a transmission line, of a maximum to an adjacent minimum magnitude of a particular field component of a standing wave. (Adapted from IEC 60050(726)– 07–09.)

NOTE— SWR or VSWR is usually measured in terms of line voltage or line current.

3.77 Surge—A non-oscillatory transient that exceeds peak ripple, is infrequent, and has a duration equal to or greater than 150 µs.

3.78 Test Plan—The test plan is a document provided by the test requester to define the tests to be done, the object of the testing, the device under test (DUT) operating status, the conditions for the test and performance objectives. It completely guides the implementation of the test, by reference to the standard test procedure, or by detailing revisions or additions for the specific DUT.

3.79 Tracking Generator—A test signal oscillator (CW) that is frequency locked to the receive frequency of a measuring instrument. (CISPR 12, 5th Edition.)

3.80 Transient—A temporary increase or decrease of voltage or current. Transients may take the form of spikes or surges. Specific transient parameters include:

3.80.1 AMPLITUDE—The maximum voltage excursion beyond ripple peak.

3.80.2 WIDTH (T)—The time from the instant the transient reaches 10% of its maximum amplitude to the instant it falls below that value (ISO 7637–1).

3.80.3 INTERVAL BETWEEN TRANSIENTS—The time between the end of one transient and the beginning of the next (both measured at 10% of the maximum amplitude).

3.80.4 REPETITION RATE—The number of surges, spikes, or pulses per unit time.

3.80.5 RISE TIME (T_R), FALL TIME (T_F)—The time required for the instantaneous transient amplitude to increase from 1 0 to 90% (T_R), or decrease from 90 to 10% (T_F) of the maximum amplitude, respectively (ISO 7637–1.)

3.81 Transmission Line System TLS (abbreviation)—TLS is a stripline or parallel plate or similar device used to generate an E-field. (Adapted from ISO 11452–1.)

3.82 TEM Mode; Transverse Electromagnetic Mode—A mode in which both the longitudinal components of the electric and magnetic field strength vectors are everywhere zero. (Adapted from IEC 60050(726)–03–08.)

3.83 Transverse Electromagnetic TEM (abbreviation) Cell—An enclosed system, often a rectangular coaxial line, in which a wave is propagated in the transverse electromagnetic mode to produce a specified field for testing purposes.

3.84 Vehicle; Ground-Vehicle—A self-propelled machine (excluding aircraft and rail vehicles and boats over 10 m in length). Vehicles may be propelled by an internal combustion engine, electrical means, or both. Vehicles include but are not limited to automobiles, trucks, agricultural tractors, motorcycles, mopeds, snowmobiles, and small motorboats.

4. Overview of Test Methods

4.1 The attributes of the immunity tests are shown in Table 1.

TABLE 1—IMMUNITY TEST ATTRIBUTES

Part	Test Type	Frequency Range	Standard
SAE J1113–1	Introduction	NA	ISO 11452–1
SAE J1113–2	Conducted Immunity	30 Hz to 250 kHz	NA
SAE J1113–3	Conducted Immunity	250 kHz to 500 MHz	ISO 11452–7
SAE J1113–4	Bulk Current Immunity	1 to 400 MHz	ISO 11452–4
SAE J1113–11	Power Lead Immunity	NA	ISO 7637–2
SAE J1113–12	Coupled Immunity	NA	ISO 7637–3
SAE J1113–13	Electrostatic Discharge	NA	ISO 10605
SAE J1113–21	Radiated Immunity	30 MHz to 18 GHz	ISO 11452–2
SAE J1113–22	AC Power Line-Magnetic Field	60 Hz	NA
SAE J1113–23	Radiated Immunity-Strip-Line	10 kHz to 200 MHz	ISO 11452–5
SAE J1113–24	Radiated Immunity-TEM Cell	10 kHz to 200 MHz	ISO 11452–3
SAE J1113–25	Radiated Immunity-Tri-Plate	10 kHz to 500 MHz	NA
SAE J1113–26	AC Power Line-Electric Fields	60 Hz	NA
SAE J1113–27	Radiated Immunity-Reverberation	500 MHz to 2 GHz	NA

NOTE-Future systems may require new tests.

4.2 The attributes of the emissions tests are shown in Table 2.

TABLE 2—EMISSIONS TEST ATTRIBUTES

Part	Test Type	Frequency Range	Comparable Standard
SAE J1113–41	RF Emissions	150 kHz to 1 GHz	IEC CISPR 25
SAE J1113–42	Conducted transients	NA	NA

NOTE— Future systems may require new tests.

5. Standard Emissions Test Requirements and Conditions—Test conditions for the emissions tests of Part 41 are defined in that document.

6. Standard Immunity Test Procedure—The common characteristics for all of the immunity test parts of this document are described in this section.

6.1 Test Conditions

6.1.1 TEST TEMPERATURE AND SUPPLY VOLTAGE—The ambient temperature during the test shall be 23 °C ± 5 ° C. The supply voltage during the test shall be 13.5 V ± 0.5 V for 12 V electrical systems and 27 V ± 1 V for 24 V electrical systems. If other values are agreed upon those values shall be documented in the test report.

6.1.2 MODULATION—The characteristics of the system determines the type and frequency of modulation. If no values are agreed upon between the users of this document, the following shall be used:

a. No modulation (CW)
b. 1 kHz sinewave amplitude modulation (AM) 80% (See Appendix C, Constant Peak Test Method)

6.1.3 DWELL TIME—At each frequency, the DUT shall be exposed to the test level for, at least, the minimum response time needed to control the DUT and monitor response. In all cases, this minimum time of exposure shall be 2 seconds minimum.

6.1.4 FREQUENCY STEPS—Two methods are presented. The logarithmic steps are based on the Q of the DUT and is therefore the preferred method. The linear method is based on a fixed maximum frequency step size.

6.1.4.1 Logarithmic Method (Preferred)—Setting the immunity test frequencies using a logarithmic relationship is a technique that produces equally spaced frequency steps on a logarithmic scale. The number of steps per octave or decade, are based on the expected Q of the DUT. The values agreed upon by the users of this standard shall be documented in the test report. The method of generating this frequency list is developed in Appendix E. Sample frequency lists are included. Typical values of Q have been included in Appendix E, Figure E3.

6.1.4.2 Linear Method (Alternate)—Table D1 in Appendix D illustrates the maximum frequency step size applicable to SAE J1113 immunity tests using the linear step technique. Apply the steps according to the applicable frequency range of each SAE J1113 part (-2, -3, -4, -23, -24, -25, and -27). Smaller step sizes are encouraged.

6.1.5 TEST SIGNAL QUALITY—The intent of narrowband immunity test is to expose the DUT to a single frequency. Often, certain test frequencies will produce significant harmonics of the fundamental. To ensure that harmonics do not skew the results, either do not test at any frequency that produces harmonics above –12 dBc or carefully document the condition in the test report. If a frequency is skipped due to harmonics, enter it in the test report.

6.1.6 THRESHOLD OF RESPONSE—If a response or event is observed when applying or approaching the required test level, reduce the power 10 dB. Start incrementing the net power at a slow rate (typically 0.1 dB per 2 seconds) until the event is observed. Record this power level as the threshold value. The dwell time at each power increment should be determined by the response time of the DUT or 2 seconds which ever is longer.

6.2 Test Methods—Immunity testing is commonly done using either one of two different techniques, (a) substitution and (b) closed loop leveling. This paragraph explains the control parameters of each.

a. The Substitution Method—The substitution method uses NET POWER as the reference parameter that sets the test level during the characterization and the immunity test. The specific test level (E-field, current, voltage or power) is characterized at each frequency per 6.1.4, by adjusting the net power to produce the desired test level. This number is recorded and used as the reference parameter for the immunity test. This is done in an empty chamber (absorber lined shielded enclosure, TEM cell, tri-plate etc.) for immunity testing and with a characterization test fixture for bulk current injection. The DUT test is conducted by subjecting the DUT to the test levels at each frequency as determined in terms of net power in the characterization phase.

Measurements using the substitution method can be affected by coupling between the antenna and the DUT as well as by reflected energy. During the test, the net power shall be set to the characterization net power level with a limit of –0 to a +2 dB increase in forward power.

NOTE 1—If the forward power has to be increased by 2 dB or more, this shall be indicated in the test report.

NOTE 2—If the SWR in the test system can be demonstrated to be less than 1.2:1, then forward power may be used as the reference parameter to establish the test level.

b. The Closed-loop Leveling Method—This method does not require a characterization prior to the test, however a pre-characterized sensor must be used to monitor the control parameter throughout the duration of the test. The signal generator level is adjusted based upon input from the control parameter until the desired test level is obtained.

6.2.1 CHARACTERIZATION—Verification of test item parameters shall be performed in accordance with individual test method's requirements. The test level versus frequency data shall be established using a CW signal. The method and results for each characterization point shall also be documented.

6.2.2 TESTS WITH A DUT

CAUTION—Hazardous radio frequency voltages and fields may exist within the test area. Care should be taken to ensure that the requirements for limiting the exposure of humans to RF energy are met. ANSI C95.1 is the US National Standard addressing exposure of humans to electromagnetic fields. [The National Council on Radiation Protection (NCRP) has a similar standard which is more stringent in the microwave region.]

The test shall employ the following process:

a. At each frequency, increase the level, linearly or logarithmically, up to the chosen test level. The rate of increase of the test level shall be controlled to ensure that excessive overshoot does not occur. The test level parameter is (see Appendix A for guidance to set test level parameters:

1. The NET POWER, related to the test signal severity level, for the substitution method (see Equation 1.

$$\text{NET PWR (Test Signal)} = \text{NET POWER (Char)}\frac{[\text{Test Signal Severity Level}]^k}{\text{Char Level}} \qquad \text{(Eq. 1)}$$

where:

k = l for power test levels and
k = 2 for field, current, or voltage test levels.

2. The TEST SIGNAL SEVERITY LEVEL, Set to the desired field, current, voltage, or power for the closed-loop leveling method.

Table 3 gives the CW and AM test levels for the substitution method and for the closed-loop leveling method.

TABLE 3—CW AND AM TEST LEVELS

	CW	AM
SUBSTITUTION METHOD	Net Power	$\frac{(2+m^2)}{2(1+m)^2} \times$ (Net Power) (1)
CLOSED-LOOP LEVELING METHOD	Test signal severity level	Test signal severity level

1. where m is the modulation factor ($0 \leq m \leq 1$)

Both methods use a constant peak test level for CW and AM tests. The relationship between AM net power and CW characterized net power results from this principle (see Appendix C).

b. Maintain the test level for the minimum response time needed to exercise the DUT (this minimum time of exposure shall be greater or equal to 2 seconds).
c. As necessary, decrease the test level by at least 20 dB before moving to the next frequency. The rate of decrease of the level shall be controlled to avoid unreproducible susceptibilities.

NOTE— Turning off the signal generator may cause unreproducible susceptibilities of the DUT.

d. Step to the next frequency.

6.3 Test Severity Levels—For both substitution and closed-loop leveling methods and for CW and AM tests, the test severity levels of this document are expressed in terms of equivalent RMS (root-mean-square) value of an unmodulated wave.

EXAMPLE—Test severity level of 20 V/m means that CW and AM test will be conducted for a 28 V/m peak value.

CAUTION—Field Strength Measurement of AM Modulated Wave—When using devices such as oscilloscopes, non–frequency selective voltmeters, or broadband field strength sensors to measure a modulated immunity test signal; correction factors shall be applied to adjust the reading to represent the equivalent RMS value for the peak of the modulation envelop. Modulation correction is determined by dividing the reading of a continuous wave (CW) signal by the reading for a modulated signal (AM) of the same peak amplitude. The modulation correction might vary with frequency, amplitude, waveshape, and the modulation frequency.

6.4 Artificial Loads—For module level testing, it is desirable that the module be connected to the sensors and loads used in its production application. However, some loads and sensors are not convenient to use because of size, cooling requirements, duty cycle, etc. It is therefore acceptable to use an electrical equivalent load for these devices provided the artificial loads have the same impedance characteristics as the actual devices over the frequency band under test. For example, a motor can be replaced with a network of two resistors, an inductor and a capacitor.

6.5 Grounding and Shielding—Establishing uniform measurement conditions at radio frequencies requires that consistent grounding practices be followed. Unless otherwise called out in the test procedure or plan, the following grounding practice shall be applied. The DUT, artificial networks and terminating loads shall:

a. Be placed on a metallic ground plane having the following minimum dimensions:

   1. Thickness 0.5 mm copper, brass or galvanized steel sheet.
   2. Length 1000 mm or underneath the entire equipment plus 500 mm, whichever is larger.
   3. Width Width of the equipment plus 200 mm on each side.

b. Be bonded to the ground plane as in its intended installation.
c. Not otherwise be grounded, unless required in the DUT installation instructions. The artificial networks shall be bonded to the ground plane unless otherwise specified in the test procedure or plan. No shielding is to be used other than that called out in the installation instructions.

6.6 Power Supply—The continuous supply source shall have an internal resistance Rs less than 0.01 Ω DC and an internal impedance $Z_S = R_S$ for frequencies less than 400 Hz. The output voltage shall not deviate more than 1 V from 0 to maximum load (including inrush current) and shall recover 63% of its maximum excursion within 100 ms. The superimposed ripple voltage, V_r, shall not exceed 0.2 V peak-to-peak and have a maximum frequency of 400 Hz.

If a standard power supply (with sufficient current capacity) is used in bench testing to simulate the battery, it is important that the low internal impedance of the battery also be simulated. When a battery is used, a charging source is needed to achieve the specified reference levels.

NOTE— Ensure that the charging source does not affect the test.

7. Notes

7.1 Marginal Indicia—The change bar (l) located in the left margin is for the convenience of the user in locating areas where technical revisions have been made to the previous issue of the report. An (R) symbol to the left of the document title indicates a complete revision of the report.

PREPARED BY THE SAE EMI AND EMR STANDARDS COMMITTEE

APPENDIX A

FUNCTION PERFORMANCE STATUS CLASSIFICATION
(BASED ON SAE J1812)
(INFORMATIVE)

***A.1 Scope and Field of Application*—**This appendix provides a general method for defining function performance status classification for automotive electronic devices. This criteria is used to set limits for tests specified in this series of documents.

***A.2 General*—**Components or systems shall only be tested with the conditions, as described in the main part of the document, representing the simulated automotive electromagnetic environments to which the devices would actually be subjected. This will help to assure a technically and economically optimized design for potentially susceptible components and systems.

It should also be noted that this appendix is not intended to be a product specification and cannot function as one. Nevertheless, using the concepts described in this appendix and by careful application and agreement between manufacturer and supplier, this document could be used to describe the functional status requirements for a specific device. This could then, in fact, be a statement of how a particular device could be expected to perform under the influence of the specified interference signals.

***A.3 Essential Elements of Function Performance Status Classification*—**Four elements are required to describe a function performance status classification. They can be generically applied to all immunity testing for electromagnetic disturbances (both conducted and radiated). These elements are:

A.3.1 Test Method and Test Signal—This element refers to the respective test signal(s) applied to the device under test and the method of test. This information is contained in the appropriate section of each part of this document.

A.3.2 Functional Status Classifications—This element classifies the operational status of the function for an electrical/electronic device within the vehicle. Three classes have been established as follows:

Class A—Any function that provides a convenience (e.g., entertainment, comfort).
Class B—Any function that enhances, but is not essential to the operation or control of the vehicle (e.g., speed display).
Class C—Any function that is essential to the operation or control of the vehicle (e.g., braking, engine management).

A.3.3 Region of Performance—This element describes the region, bounded by two test signal levels, that defines the expected performance objectives of the device under test.

a. Region I—The function shall operate as designed during and after exposure to a disturbance.
b. Region II—The function may deviate from design during exposure but will return to normal after the disturbance is removed.
c. Region III—The function may deviate from designed performance during exposure to a disturbance but simple operator action may be required to return the function to normal, once the disturbance is removed.
d. Region IV—The device/function may deviate, but shall not exhibit any damage after the disturbance is removed.

A.3.4 Test Signal Level—This element defines the specification of test signal level and essential parameters. The test signal severity level is the stress level (voltage, volts per meter, etc.) applied to the device under test.

A.4 Application of Function Performance Status Classification—Figure A1 illustrates the relationship of Function Status Classifications, Region of Performance, and Test Severity Level of a given test method.

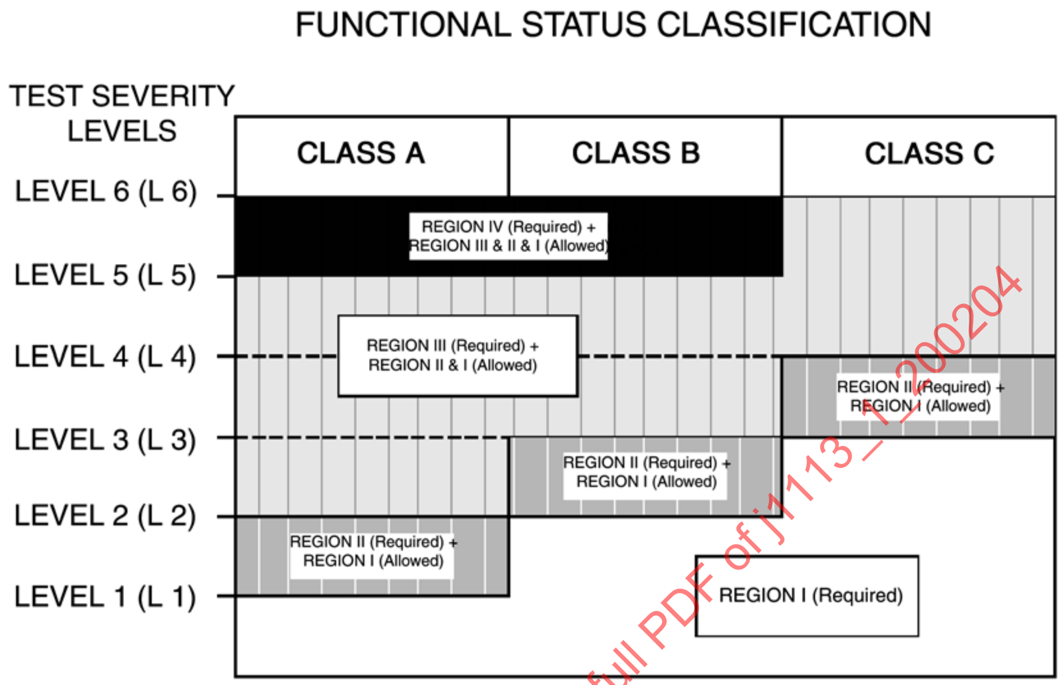


FIGURE A1—FUNCTIONAL STATUS CLASSIFICATIONS

A.5 Examples of Test Pulse Severity Selection Tables—The following two examples illustrate the selection table of test pulse severity levels for Conducted Immunity Testing and Radiated Immunity Testing as described in the main part of the document (table only partially completed to demonstrate concept):

TABLE A1—EXAMPLE OF TEST PULSE SEVERITY SELECTION TABLE

Test Pulse Severity Level	Pulse 1	Pulse 2	Pulse 3a	Pulse 3b	Pulse 4	Pulse 5
L6	V					
L5	0.8 V					
L4	0.6 V					
L3	0.4 V					
L2	0.2 V					
L1						

TABLE A2—EXAMPLE OF TEST SIGNAL SEVERITY LEVEL SELECTION TABLE

Test Signal Severity Levels	E-Field Strength (volts/meter)
L6	E
L5	0.8 E
L4	0.6 E
L3	0.4 E
L2	0.2 E
L1	

NOTE— Refer to SAE J1812 for additional information.

APPENDIX B

CONSTANT PEAK TEST LEVEL
(BASED ON ISO 11452-1)
(INFORMATIVE)

This appendix explains the principle of constant peak test level and subsequent implications of power levels.

B.1 Unmodulated Signal—The electric field strength of an unmodulated sine wave signal ECW, can be written in the form;

$$E_{CW} = E\cos(\omega t) \qquad \text{(Eq. B1)}$$

where:

E is the peak value of ECW
ω is the frequency of the unmodulated signal (CW) (e.g., RF carrier).

The mean power of the unmodulated signal is calculated:

$$P_{CW} = kE^2 \qquad \text{(Eq. B2)}$$

where:

P_{CW} is the power for the unmodulated signal
k is a proportionality factor which is constant for a specific test setup

B.2 Modulated Signal—The electric field strength of an amplitude modulated signal, EAM, can be written in the form as shown in Equation B3:

$$E_{AM} = E'[1 + m\cos(\theta t)]\cos(\omega t) \qquad \text{(Eq. B3)}$$

where:

E'	The peak amplitude of the unmodulated signal
E'(1+m)= E_{Ampeak}	The peak amplitude of the modulated signal EAM
M	The modulation factor ($0 \le m \le 1$)
θ	The frequency of modulating signal (i.e., voice, baseband, 1 kHz CW, etc)
ω	The frequency of the unmodulated signal (CW) (e.g., RF carrier)

The total mean power in an amplitude modulated signal is the sum of the power in the carrier component [kE'^2] and the total power in the sidebands component. It may be calculated as follows:

$$\left(\frac{k}{2}E'^2m^2\right) \qquad \text{(Eq. B4)}$$

$$P_{AM} = k\left(1 + \frac{m^2}{2}\right)E'^2$$

B.3 Peak Conservation—For peak test level conservation, the peak amplitude of the unmodulated and modulated signals are defined to be identical.

$$E_{CW\ peak} = E_{AM\ peak} \qquad \text{(Eq. B5)}$$

There are two ways to adjust the signal to maintain peak conservation.

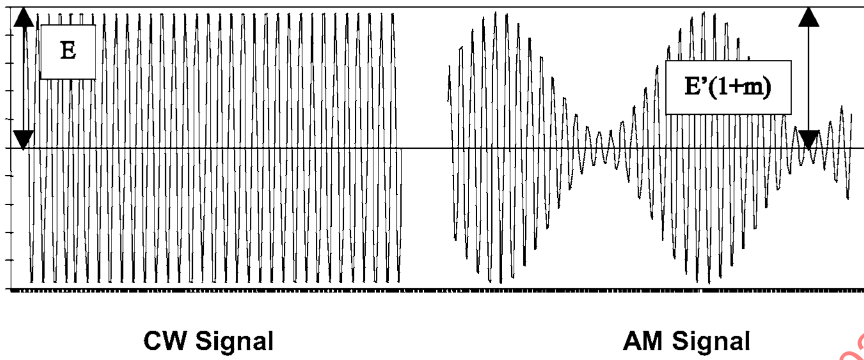


FIGURE B1—CONSTANT PEAK TEST LEVEL COMPARISON

B.3.1 Measure the Ratio of Modulated Power to CW Power—The relationship between CW power and AM power (using peak test level conservation) is given by Equation B6:

$$\frac{P_{AM}}{P_{CW}} = \frac{k\left[\left(1+\frac{m^2}{2}\right)E'^2\right]}{kE^2} = \left(1+\frac{m^2}{2}\right)\left(\frac{E'}{E}\right)^2 = \frac{\left(1+\frac{m^2}{2}\right)}{(1+m)^2} \quad \text{(Eq. B6)}$$

Therefore:

$$P_{AM} = P_{CW}\left[\frac{2+m^2}{2(1+m)^2}\right] \quad \text{(Eq. B7)}$$

For m=0.8 (AM 1 kHz 80%), this relationship gives:

$$P_{AM} = 0.407\ P_{CW} \quad \text{(Eq. B8)}$$

B.3.2 Measure the Ratio of Power in the Unmodulated Peak Test Level Conservation Signal to the CW Power—The power of the peak test level conservation signal before modulation is applied can be compared to the power of the CW signal used for certification.

The relationship is:

$$\frac{P_{CWBeforeModulation}}{P_{CW}} = \left(\frac{1}{1+m}\right)^2 \quad \text{(Eq. B9)}$$

Therefore:

$$P_{CWbeforemodulation} = P_{CW}\left(\frac{1}{1+m}\right)^2 \quad \text{(Eq. B10)}$$

for m=0.8 (AM 1kHz 80%), this relationship gives:

$$P_{CWbeforemodulation} = 0.309P_{CW} \quad \text{(Eq. B11)}$$

APPENDIX C

ROD ANTENNA (MONOPOLE)/MATCHING NETWORK—PERFORMANCE EQUATIONS AND CHARACTERIZATION THE EOUIVALENT CAPACITANCE SUBSTITUTION METHOD (NORMATIVE)

C.1 Rod (Monopole) Performance Equations—The following equations are used to determine the effective height, self-capacitance and height correction factor of rod or monopole antennas of unusual dimensions. They are valid only for rod antennas shorter than Î/4.

$$h_e = \frac{\lambda}{2\pi}\tan\left(\frac{\pi h}{\lambda}\right) \qquad \text{(Eq. C1)}$$

$$C_a = \frac{55.6h}{1n\left(\frac{h}{a}\right) - 1}\left(\frac{\tan\frac{2\pi h}{\lambda}}{\frac{2\pi h}{\lambda}}\right) \qquad \text{(Eq. C2)}$$

$$c_h = 20\log(h_e) \qquad \text{(Eq. C3)}$$

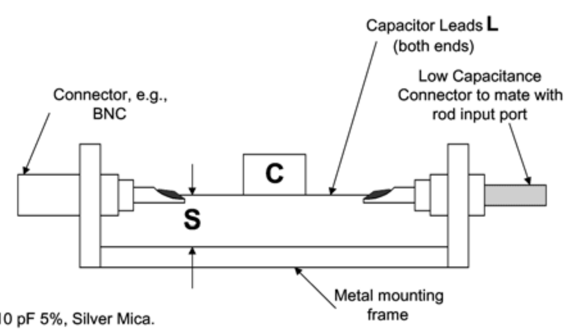
where:

h_e is the effective height of the antenna in meters
h is the actual height (length) of the rod element in meters
λ is the wavelength in meters
C_a is the self-capacitance of the rod antenna in pF
a is the radius at the base of the rod element in meters
C_h is the height correction factor in dB(m)

C.2 Dummy Antenna Considerations

NOTE— The capacitor used as the dummy antenna should be mounted in a small metal box or on a small metal frame. The leads must be kept as short as possible and kept close to the surface of the metal box or frame. A spacing of 5 to 10 mm is recommended. See Figure C1.

The T-connector used in the antenna factor measurement setup may be built into the dummy antenna box. The resistor pad to provide matching to the generator may also be built into the dummy antenna box.



C: 10 pF 5%, Silver Mica.

S: Lead Spacing, 5 to 10 mm (10 mm from all surfaces if enclosed in box).

L: Lead length, as short as possible but not greater than 12 mm. (Total lead length not greater than 40 mm including both capacitor leads and length of rod port connector.)

FIGURE C1—EXAMPLE OF CAPACITOR MOUNTING IN DUMMY ANTENNA

C.3 Characterization Method—The equivalent capacitance substitution method uses a dummy antenna in place of the actual rod element and is based on IEEE Std 291–1991. The primary component of the dummy antenna is a capacitor equal to the self-capacitance of the rod or monopole. This dummy antenna is fed by a signal source and the output from the coupler or base unit of the antenna is measured using the test configuration shown in Figure C2. The antenna factor in dB(1/m) is given by Equation C4, where the input impedance of the matching unit or receiver is much greater than the resistive component of source impedance of the antenna.

$$AF = V_D - V_L - C_h \quad \text{(Eq. C4)}$$

where:

V_D is the measured output of the signal generator in dB(μV)
V_L is the measured output of the coupler in dB(μV)
C_h is the correction factor for the effective height in dB(m)

For the 1 meter rod commonly used in EMC measurements, the effective height (h_e) is 0.5 m, the height correction factor (C_h) is –6 dB(m) and the self-capacitance (C_a) is 10 pF.

NOTE— See Section C.1 to calculate the effective height, height correction factor and selfcapacitance of rod antennas of unusual dimensions.

Either of two procedures shall be used: (a) the network analyzer, or (b) the signal generator and radionoise meter method. The same dummy antenna is used in both procedures. See Section C.2 for guidance in making a dummy antenna. Measurements shall be made at a sufficient number of frequencies to obtain a smooth curve of antenna factor versus frequency over the operating range of the antenna or 9 kHz to 30 MHz, whichever is smaller.

a. Network Analyzer Procedure.

1. Calibrate the network analyzer with the cables to be used in the measurements.
2. Setup the antenna to be characterized and the test equipment as shown in Figure C1(a).
3. Subtract the signal level (in dB) in the reference channel from the signal level (in dB) in the test channel and subtract C_h (–6 dB for the 1 m rod) to obtain the antenna factor (in dB) of the antenna.

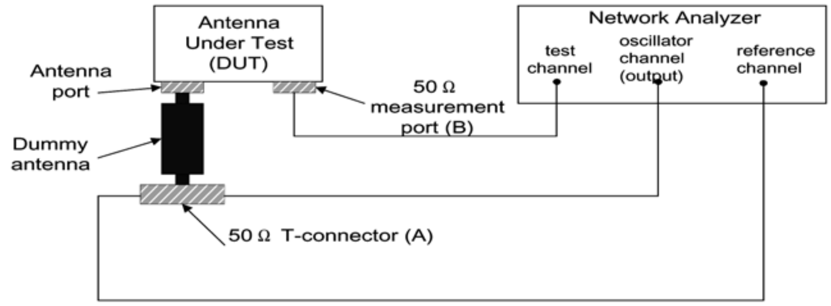
NOTE— Attenuator pads are not needed with the network analyzer because the impedances of the channels in the network analyzer are very nearly 50 Ω and any errors are corrected during network analyzer characterization. Attenuator pads may be used, if desired, but including them complicates the network analyzer characterization.

b. Radio-Noise Meter and Signal Generator Procedure

1. Setup the antenna to be characterized and the test equipment as shown in Figure C1(b).
2. With the equipment connected as shown and a 50 Ω termination on the T-connector (A), measure the received signal voltage V_L in dB(μV) at the RF port (B).
3. Leaving the RF output of the signal generator unchanged, transfer the 50 Ω termination to the RF port (B) and transfer the receiver input cable to the T-connector (A). Measure the drive signal voltage V_D in dB(μV).
4. Subtract V_L from V_D and subtract C_h (–6 dB for the 1 m rod) to obtain the antenna factor (in dB) of the antenna.

The 50 Ω termination shall have very low VSWR (less than 1.05:1). The radio-noise meter shall be characterized and have low VSWR (less than 2:1). The output of the signal generator shall be frequency and amplitude stable.

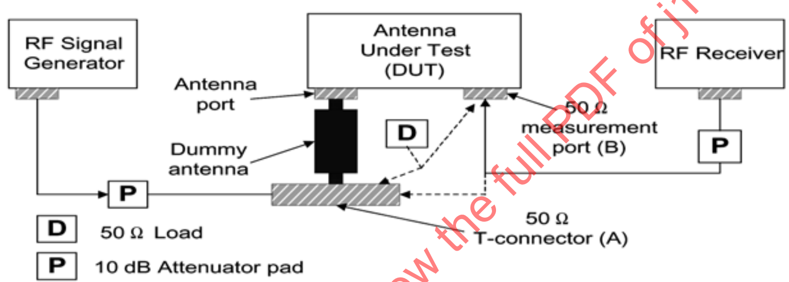
NOTE— The signal generator need not be characterized, since it is used as a transfer standard.



NOTES:
1. Place the dummy antenna as close to the DUT port as possible. Place the T-connector as close to the dummy antenna as possible. Use the same length and type of cables between the T-connector and the reference channel input, and the T-connector and the 50 Ω measurement port test channel.

2. Attenuator pads are not needed with the network analyzer and are not recommended.

(a) Method Using the Network Analyzer



NOTES:
1. Place the dummy antenna as close to the DUT port as possible. Place the T-connector as close to the dummy antenna as possible.

2. If VSWR of receiver and signal generator is low, pads may not be needed or may be reduced to 6 dB or 3 dB

3. The dummy antenna may incorporate other matching components to control VSWR at its input and signal generator level measuring ports.

(b) Method using the Radio-Noise Meter and Signal Generator

FIGURE C2—MEASUREMENT OF ROD (MONOPOLE) ANTENNA FACTOR

APPENDIX D

SETTING IMMUNITY TEST FREQUENCIES IN A LOGARITHMIC SEQUENCE (INFORMATIVE)

D.1 Relationship between Q and the Number of Test Point Frequencies—For a **decade** progression

Test frequency steps are calculated as follows:

$$f_{injection} = f_{initial} \times 10^{(k/n)} \quad \text{(Eq. D1)}$$

where:

$f_{injection}$ is the frequency to inject
$f_{initial}$ is the start frequency
k is the index number of the injection frequency (i.e., 0, 1,2, ...)
n is the number of test frequency steps per decade

Then:

$$f_{(j+1)} = f_j \times 10^{(1/n)} \quad \text{(Eq. D2)}$$

Let the frequency of the maximum DUT response be midway between two adjacent test frequencies such that:

$$f_{DUT} = \frac{f_{(j+1)} + f_i}{2} \quad \text{(Eq. D3)}$$

For the case of a DUT response described by a linear second order system, if $f_{(j+1)}+f_j$ define the –3 dB bandwidth of the DUT, then the Q of the system is given by:

$$Q = \left(\frac{f_{DUT}}{f_{(j+1)} - f_j}\right) = \left(\frac{1}{2}\right) \times \left(\frac{f_j \times 10^{\left(\frac{1}{n}\right)} + f_j}{f_j \times 10^{\left(\frac{1}{n}\right)} - f_j}\right) = \left(\frac{1}{2}\right)\left(\frac{10^{\left(\frac{1}{n}\right)} + 1}{10^{\left(\frac{1}{n}\right)} - 1}\right) \quad \text{(Eq. D4)}$$

Therefore:

$$Q = \left(\frac{1}{2}\right) \times \left(\frac{10^{\left(\frac{1}{n}\right)} + 1}{10^{\left(\frac{1}{n}\right)} - 1}\right) \quad \text{(Eq. D5)}$$

Solving for n:

$$n = \frac{1}{\log_{10}\left(\frac{2Q+1}{2Q-1}\right)} \quad \text{(Eq. D6)}$$

Similarly, for an **octave** progression, the corresponding equations used for calculating the frequency steps, Q and n are:

$$f_{injection} = f_{initial} \times 2^{\left(\frac{k}{n}\right)} \quad \text{(Eq. D7)}$$

where:

$f_{injection}$ is the frequency to inject
$f_{initial}$ is the start frequency
k is the index number of the injection frequency (i.e., 0, 1,2, ...)
n is the number of test frequency steps per octave

Therefore:

$$Q = \frac{1}{2} \times \left(\frac{2^{\left(\frac{1}{n}\right)} + 1}{2^{\left(\frac{1}{n}\right)} - 1} \right) \quad \text{(Eq. D8)}$$

and:

$$n = \frac{1}{\log_2\left(\frac{2Q+1}{2Q-1}\right)} \quad \text{(Eq. D9)}$$

D.2 Determination of Soak Time—The soak time τ in terms of a stated total time T spent **per decade** is then:

$$\tau = \frac{T}{n} = (T)\log_{10}\left(\frac{2Q+1}{2Q-1}\right) \quad \text{(Eq. D10)}$$

The soak time τ in terms of a stated total time T spent **per octave** is then:

$$\tau = \frac{T}{n} = (T)\log_2\left(\frac{2Q+1}{2Q-1}\right) \quad \text{(Eq. D11)}$$

D.3 Calculation of Test Frequencies using a Logarithmic Progression—Figures D1 and D2 illustrate a list of frequencies related in a logarithmic progression for two (2) values of Q. The values of this figure can be calculated using the equations of this appendix.

Example 1

Figure D1 shows the list of frequencies over a decade for a Q of 36 starting at 30 MHz. (Q of 36 corresponds to 25 steps per octave or 83 steps per decade)

30.0	30.8	31.7	32.6	33.5	34.5	35.4	36.4
37.4	38.5	39.6	40.7	41.8	43.0	44.2	45.5
46.7	48.1	49.4	50.8	52.2	53.7	55.2	56.8
58.4	60.0	61.7	63.4	65.2	67.0	68.9	70.9
72.9	74.9	77.0	79.2	81.4	83.7	86.0	88.5
90.9	93.5	96.1	98.8	102	104	107	110
114	117	120	123	127	130	134	138
142	146	150	154	158	163	167	172
177	182	187	192	198	203	209	215
221	227	233	240	247	254	261	268
276	283	291	300				

FIGURE D1—LIST OF FREQUENCIES OVER A DECADE FOR A Q OF 36

Example 2

Figure D2 shows the list of frequencies over a decade for a Q of 22 starting at 30 MHz. (Q of 22 corresponds to 15 steps per octave or 50 steps per decade)

30.0	31.4	32.9	34.4	36.1	37.8	39.5	41.1
43.4	45.4	47.5	49.8	52.1	54.6	57.2	59.8
62.7	65.6	68.7	72.0	75.3	78.9	82.6	86.5
90.6	94.9	99.3	104	109	114	119	125
131	137	144	150	157	165	173	181
189	198	207	217	228	238	250	261
274	286	300					

FIGURE D2—LIST OF FREQUENCIES OVER A DECADE FOR A Q OF 22

TABLE D1—FREQUENCY STEPS AND ASSOCIATED VALUES OF Q FOR THE LINEAR STEP METHOD

Frequency band	Maximum frequency step size	Range of Expected values of Q
10 kHz to 100 kHz	10 kHz	0.6–6
100 kHz to 1 MHz	100 kHz	0.6–6
1 MHz to 10 MHz	1 MHz	0.6–6
10 MHz to 200 MHz	2 MHz	3–60 (9 at 30 MHz)
200 MHz to 1 GHz	20 MHz	6–30
1 GHz to 18 GHz	200 MHz	3–90

NOTE— If, at the specified test level, the vehicle exhibits a condition bordering on a response, the frequency steps in Table D1 should be reduced to identify the most critical frequencies and minimum threshold of susceptibility.

D.4 Example of Calculating n and τ—If the user specifies a Q of 30, and the average sweep time **per decade** T=20 sec., the number of test frequency points per decade (n) and the corresponding soak time per test point (τ) are determined as follows:

$$n = \frac{1}{\log_{10}\left(\frac{2Q+1}{2Q-1}\right)} = \frac{1}{\log_{10}\left(\frac{2 \times 30 + 1}{2 \times 30 - 1}\right)} = 69 \text{ Points/decade} \quad \text{(Eq. D12)}$$

$$\tau = \frac{20\text{ s}}{69\text{ points/decade}} = 290\text{ ms} \quad \text{(Eq. D13)}$$

APPENDIX E

COMPONENT EMC TEST PLAN
(INFORMATIVE)

E.1 Overview—The EMC Test Plan shall be prepared and submitted to the approving activity (Note: 1)days prior to commencement of EMC testing. The purpose for this test plan is to develop and document a well thought out procedure to verify that DUTs are robust to the anticipated electromagnetic environment that they must operate within. The test plan also provides a mechanism for ongoing enhancements and improvements to the test setup which better correlates with vehicle level testing.

E.2 Preparation of Test Plan—The DUT EMC Test Plan shall be prepared in accordance to the outline shown in Part E.3.1. The Test Plan requires collaborations between the Design Engineer, EMC Applications and Test Engineers.

E.3 Test Plan

E.3.1 Test Plan Outline—See Figures E1 to E12.

Title Page

1.0 Introduction

1.1 Product Family Description
1.2 Theory of Operation
1.3 Physical Construction
1.4 EMC Specification Release
1.5 Approved Test Facility
1.6 DUT Part Number(s)
1.7 DUT Manufacturer(s)
1.8 DUT Usage

2.0 EMC Requirements Analysis

2.1 Critical Interface Signals
2.2 Potential Sources of Emissions
2.3 DUT Surrogate selection

3.0 Test Design and Requirements

3.1 DUT Operating Modes/Functional Classifications
3.2 Test Requirements
3.3 Input Requirements
3.4 Output Requirements
3.5 Load Box/Test Support Requirement

4.0 Test Setup, Procedures

5.0 Test Report Requirements

5.1 DUT Design level (PWB number(s), Software version, DV/PV)
5.2 General

Note: 1—A period of 60 days is recommended.

FIGURE E1—TEST PLAN OUTLINE

E.3.2 Test Plan Template

Test Description:		**Approved Test Plan Number:**	**Date:**
Prepared by: **Product Design Engineer:** **EMC Applications Engineer:** **EMC Test Engineer:**	**Approved by:**		
Approved by:	**Approved by:**		
Revision History			
Date	Description		
	Initial Test Plan Release		

This Test Plan is approved with the following corrections and/or added conditions:

FIGURE E2—TEST PLAN TEMPLATE

1.0 Introduction

1.1 Product Family Description

Provide DUT product family description including any similarities and differences. Provide diagrams showing typical system configuration including power and control signal connections to ignition switch, power relay etc.

1.2 Theory of Operation

Describe functional theory of operation for the DUT(s) including system interfaces. Use wording that describes the system to those not familiar with the product (define acronyms).

1.3 Physical Construction

Describe physical construction including number of connectors and PCB construction (i.e. board material, number of layers). Also describe the external housing construction. Include table listing external interface connector pin out descriptions.

1.4 Specification Release Date

Indicated Specification release and date used for this plan.

1.5 Indicate Test House(s) That Can be Used

Indicate test house used

1.6 DUT Part Number(s)

1.7 DUT Manufacturer(s)

1.8 DUT Usage:

Model Year   Vehicle Application(s)

FIGURE E3—TEST PLAN TEMPLATE (CONTINUED)

2.0 EMC Requirements Analysis

2.1 Critical Interface Signals

List all DUT interface signals. From that list, identify those signals whose EMC immunity is critical (potentially more susceptible). For those critical signals, include electrical characteristics (e.g. Voltage/Current Level, Frequency, Duty Cycle).

Signal Description	Pin #	Critical	Input	Output	Voltage/Current Level	Frequency, Duty Cycle	Other

2.2 Potential Sources of Emissions

List all DUT internal microprocessor clocks, sub-clock, local oscillators, etc. in addition to all periodic interface signals that may act as potential sources of radiated or conducted emissions. Signal characteristics including frequency, duty cycle, and signal voltage/current level should also be included.

Signal Source Description	Voltage/Current Level	Frequency	% Duty Cycle (range)	Other

2.3 DUT Surrogate Selection

Justify selection of surrogate sample(s) to represent entire DUT family if applicable.

FIGURE E4—TEST PLAN TEMPLATE (CONTINUED)

3.0 Test Design and Requirements

3.1 DUT Operating Modes/Functional Classifications

List all DUT operating mode(s) that are active for each of the vehicle operating mode (i.e. ACC, OFF, START, RUN). For each DUT operating mode, list all major functions under their appropriate Functional Class. Use the table below for presentation of this information. Names may be used in the table to reference DUT operating modes and functions as long as a subsequent description of the mode/function is included. Use an X to indicate the applicable vehicle operating modes.

DUT Mode	DUT Functions			Vehicle Operating Modes			
	Class A	Class B	Class C	Accessory	Off	Start	Run

3.1.1 DUT Mode Description(s):

(e.g. AM, FM, IDLE, CRUISE)

3.1.2 Function Description(s):

(e.g. Stable Audio Volume, Stable Fuel)

FIGURE E5—TEST PLAN TEMPLATE (CONTINUED)

3.2 Test Requirements

Select the required tests for DUT. For each test selected, indicate the appropriate DUT operating mode and functions to be used based on those listed in the table in section 3.1 above. indicate if tests will apply to only one of the two required test samples. Provide justification if both samples are not subjected to the same test conditions. Also provide justification for any omissions in testing for any of the operating modes listed in section 3.1.

Example:

Test (Ref SAE J1113-XX)	***Test Applies***	***Functional Class & Functional Status***			***DUT I/O, Note 1***	***DUT Operating Mode/Function to be used for indicated test***
		A	***B***	***C***		
RADIATED IMMUNITY						
Tri-Plate SAE-25 Level 1		I	I	I		
Level 2		II	I	I		
Level 3		III	II	I		
Magnetic Field SAE-22		I	I	I		
CONDUCTED IMMUNITY - SINEWAVE						
Sine wave SAE-2 Level 1		I	I	I		
Level 2		II	II	II		
CONDUCTED IMMUNITY - TRANSIENTS, INDUCTIVE SWITCHING						
Pulse 1 SAE-11		II	II	II		
Pulse 2 SAE-11		II	II	II		
Pulse 3a SAE-11		I	I	I		
Pulse 3b SAE-11		I	I	I		
CONDUCTED IMMUNITY - POWER CYCLE						
Pulse 4 SAE-11		II	II	II		
CONDUCTED IMMUNITY - ALTERNATOR LOAD DUMP						
Pulse 5 SAE-11		III	III	II		

FIGURE E6—TEST PLAN TEMPLATE (CONTINUED)

Test (Ref SAE J1113-XX)	***Test Applies***	***Functional Class & Functional Status*** ***A***	***B***	***C***	***DUT I/O, Note 1***	***DUT Operating Mode/Function to be used for indicated test***
CONDUCTED IMMUNITY–ESD						
Unpowered SAE-13		III	III	III		
Powered - Cust Access SAE-13		II	II	II		
RADIATED EMISSIONS						
Electric Field - Narrowband SAE-41		I	I	I		
Electric Field - Broadband, SAE-41		I	I	I		
CONDUCTED EMISSIONS						
Time Domain SAE-42		I	I	I		
Frequency Domain SAE-41		I	I	I		

Note 1: Indicate specific DUT circuits that test applies to. C (Combined) = Circuits are to be tested simultaneously, S (Separate) = Circuits are to tested separately.

FIGURE E7—TEST PLAN TEMLATE (CONTINUED)

3.3 Input Requirements

Select input conditions that will place the DUT in the desired operating mode(s) required for each test listed in section 3.2. List all modes required and the signal names used in them. Duplicate entries for signal names may exist but under different modes. Include any additional information that is needed to support operation of the DUT during testing including data bus messages, special test software, and/or any non-electrical interfaces. The format below should be used to provide this information.

3.3.1 Electrical Input Signals/Characteristics To Make DUT Functional

DUT Mode	Signal Name	Test	Pin #	Waveform	Amplitude	Freq/PW/DC%	Other

3.3.2 Non-electrical input signals/characteristics to make DUT functional

(Include mode information for each signal)

FIGURE E8—TEST PLAN TEMPLATE (CONTINUED)