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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Submitted for recognition as an American National Standard

ELECTROMAGNETIC COMPATIBILITY MEASUREMENT PROCEDURES AND LIMITS FOR VEHICLE COMPONENTS (EXCEPT AIRCRAFT) (60 HZ TO 18 GHZ)

Foreword—This Document has not changed other than to put it into the new SAE Technical Standards Board Format.

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]
SAE J1113-21—Road Vehicles—Electrical Disturbances by Narrowband Radiated Electromagnetic Energy—Component Test Methods—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 500 MHz, Tri-plate Line Method
SAE J1113-26—Immunity to AC Power Line Electric Fields
SAE J1113-27—Immunity to Radiated Electromagnetic Fields—Reverberation Chamber Method [Parts 28 through 40 reserved for future use]
SAE J1113-41—Test Limits and Methods of Measurement of Radio Disturbance Characteristics from Vehicle Components and Modules, Narrowband, 150 kHz to 1000 MHz
SAE J1113-42—Conducted Transient Emissions

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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. (See applicable UL or other appropriate agency documents.)

2. *References*

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

2.1.1 SAE PUBLICATIONS—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, Broadband, 30 to 1000 MHz
SAE J551-3—Test Limits and Methods of Measurement of Radio Disturbance Characteristics of Vehicles and Devices, Narrowband, 10 kHz to 1000 MHz
SAE J1812—Function Performance Status Classification for EMC Immunity

2.1.2 ANSI PUBLICATIONS—Available from ANSI, 11 West 42nd Street, New York, NY 10036-8002.

ANSI C63.14-1992—Standard Dictionary for Technologies of Electromagnetic Compatibility (EMC), Electromagnetic Pulse (EMP), and Electrostatic Discharge (ESD)
ANSI C95.1-1991—American National Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz
ANSI/IEEE STD 100-1988—Standard Dictionary of Electrical and Electronic Terms

2.1.3 CISPR PUBLICATIONS—Available from ANSI, 11 West 42nd Street, New York, NY 10036-8002.

CISPR 12—Third edition: 1990-01—Limits and Methods of Measurement of Radio Interference Characteristics of Vehicles, Motor Boats, and Spark-Ignited Engine-Driven Devices
CISPR 16-1 First edition: 1993-08—Specification for radio disturbance and immunity measuring apparatus and methods; Part 1: Radio disturbance and immunity measuring apparatus
CISPR 25—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, 11 West 42nd Street, New York, NY 10036-8002.

IEC Publication 50(161):1990—International Electrotechnical Vocabulary - Electromagnetic Compatibility
IEC Publication 50(726):1982—International Electrotechnical Vocabulary—Transmission Lines and Waveguides

2.1.5 ISO PUBLICATIONS—Available from ANSI, 11 West 42nd Street, New York, NY 10036-8002.

ISO TR 10305:1992—Generation of standard em fields for calibration of power density meters—200 kHz to 1000 MHz
ISO TR 10605:1992—Road vehicles—electrical disturbances from electrostatic discharges
ISO 11452:1993—Road vehicles—electrical disturbances by narrowband radiated electromagnetic energy Component test methods (under development)
ISO 7637—Road vehicles—Electrical interference by conduction and coupling: Part 1—General, and Part 2—Vehicles with nominal 12 V supply voltage—Electrical transient conduction along supply lines only

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

IEEE Std 291-1991—IEEE Standard Methods for Measuring Electromagnetic Field Strength of Sinusoidal Continuous Waves, 30 Hz to 30 GHz.

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

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

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

2.2.2 Other Publications

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*—**All definitions used in any part of this series of documents are included in this part. For the purpose of this document, the definitions contained in IEC Publications 50(161) and 50(726) are applicable. For additional definitions refer to ANSI/IEEE STD 100.

The following definitions are specific to this document:

3.1 Absorber-Lined Chamber—A shielded room with absorbing material on its internal reflective surfaces (floor absorber material optional). (Adapted from ISO 11452-1.)

3.2 Amplitude Modulation (AM)—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. (ISO 11452-1)

3.3 Antenna Correction Factor—The factor which is 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 Matching Unit—A unit for matching the impedance of an antenna to that of the 50 Ω measuring instrument over the antenna measuring frequency range. (CISPR 25 1st Edition.)

3.5 Artificial Network (AN) [Line Impedance Stabilization Network (LISN)]—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 50:1990-161-04-05.)

3.6 Bandwidth—The width of the frequency band over which a given characteristic of an equipment does not differ from its reference value by more than a specified amount or ratio. (IEC 50:1990-161-06-09)

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

3.8 **Broadband Artificial Network (BAN)**—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.

3.9 **Broadband Emission**—An emission which has a bandwidth greater than that of a particular measuring apparatus or receiver. (IEC 50:1990-161-06-13)

3.10 **Bulk Current**—Total amount of common mode current in a harness. (ISO 11452-1)

3.11 **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.

3.12 **Burst**—A burst is a transient with multiple spikes.

3.13 **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 draft 4th Edition)

3.14 **Class**—An arbitrary performance level agreed upon by the purchaser and the supplier and documented in the test plan. (CISPR 25 first edition.)

3.15 **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.)

3.16 **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 receiving system's output by the specified increment in dB. (CISPR 25 1st Edition)

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

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

3.19 **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.

3.20 **Coupling**—A means or a device for transferring power between systems. (IEC 50:1982-762-14-01)

3.21 **Current (Measuring or Monitoring) Probe**—A device for measuring the current in a conductor without interrupting the conductor and without introducing significant impedance into the associated circuits. (IEC 50:1990-161-04-35)

3.22 **Damped Sinusoid**—A waveform composed of a sinewave having a decaying amplitude envelope. The waveform occurs when a pulse excites a circuit which has a condition of resonance.

3.23 **Degradation (of performance)**—An undesired departure in the operational performance of any device, equipment, or system from its intended performance. (IEC 50:1990-161-01-19)

3.24 Device—A machine equipped with an internal combustion engine but not self-propelled. Devices include, but are not limited to, chain saws, irrigation pumps, and air compressors. [This definition applies only to SAE J551/2 and /3.] (Adapted from draft CISPR 12, 4th edition.)

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

3.26 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. (IEC 50:1982-726-14-02)

3.27 Disturbance Suppression—Action which reduces or eliminates electrical disturbance. (IEC 50:1990-161-03-22)

3.28 Disturbance Voltage; Interference Voltage—Voltage produced between two points on separate conductors by an electromagnetic disturbance, measured under specified conditions. (IEC 50:1990-161-04-01)

3.29 Electromagnetic Compatibility (EMC)—The ability of an equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbance to anything in that environment. (IEC 50:1990-161-01-07)

3.30 Electromagnetic Disturbance—Any electromagnetic phenomenon which may degrade the performance of a device, equipment or system, or adversely affect living or inert matter. (IEC 50:1990-161-01-05)

3.31 (Electromagnetic) Immunity (to a disturbance)—The ability of a device, equipment, or system to perform without degradation in the presence of an electromagnetic disturbance. (IEC 50:1990-161-01-20)

3.32 Electromagnetic Interference (EMI)—Degradation of the performance of equipment, transmission channel, or system caused by an electromagnetic disturbance. (IEC 50:1990-161-01-06)

3.33 (Electromagnetic) Radiation

a. The phenomenon by which energy in the form of electromagnetic waves emanates from a source into space.
b. Energy transferred through space in the form of electromagnetic waves. (IEC 50:1990-161-01-10)

3.34 (Electromagnetic) Susceptibility—The inability of a device, equipment, or system to perform without degradation in the presence of an electromagnetic disturbance. (IEC 50:1990-161-01-21)

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

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

3.37 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.

3.38 Ground (reference) Plane—A flat conductive surface whose potential is used as a common reference. (IEC 50:1990-161-04-36)

3.39 Ignition Noise Suppressor—That part of a high-voltage ignition circuit intended to limit the emission of impulsive ignition noise. (CISPR 12 3rd Edition 1990-01)

3.40 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 50:1990-161-03-14)

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

3.42 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.)

3.43 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 3rd Edition 1990-01)

3.44 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 waveshape with negative voltage amplitude.

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

3.46 Interference Suppression—Action which reduces or eliminates electrical interference. (IEC 50:1990-161-03-23)

3.47 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.

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

3.49 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 unmodulated wave. The value of m varies between 0 and 1.

3.50 Narrowband Emission—An emission which has a bandwidth less than that of a particular measuring apparatus or receiver. (IEC 50:1990-161-06-13)

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

3.52 Normative—Applies here to classify an appendix that contains information whose use is mandatory in the use of this standard.

3.53 Peak Detector—A detector, the output voltage of which is the peak value of the applied signal. (IEC 59:1990-161-04-24)

3.54 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 field vector; when the direction varies with time, the property may be characterized by the locus described by the extremity of the considered field vector. (IEC 50:1982-726-04-01)

3.55 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 50:1990-161-04-21)

3.56 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 or ANSI C63.2. (Adapted from CISPR 25 1st Edition.)

3.57 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.)

3.58 RF Ambient (Electromagnetic Environment)—The totality of electromagnetic phenomena existing at a given location. (IEC 50:1990-161-01-01)

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

3.60 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.

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

3.62 Shielded Enclosure—A mesh or sheet metallic housing designed expressly for the purpose of separating electromagnetically the internal and external environment. (IEC 50:1990-161-04-37)

3.63 Source Resistance—The output resistance of the source.

3.64 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.

3.65 Standing Wave Ratio (SWR); Voltage Standing Wave Ratio (VSWR)—The ratio, along a transmission line, of a maximum to an adjacent minimum magnitude of a particular field component of a standing wave. (IEC 50:1982-726-07-09)

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

3.67 Test Plan—The test plan is a document provided by the test requestor to define the tests to be done, the object of the testing, the 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.

3.68 Tracking Generator—A narrowband radio frequency source synchronized to the instantaneous receive frequency of the measuring instrument. (Draft CISPR 12, 4th Edition)

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

3.69.1 AMPLITUDE—The maximum voltage excursion beyond ripple peak.

3.69.2 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).

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

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

3.69.5 RISE TIME (TR), FALL TIME (TF)—The time required for the instantaneous transient amplitude to increase from 10 to 90% (Tr), or decrease from 90 to 10% (Tf) of the maximum amplitude, respectively (ISO 7637-1).

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

3.71 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, 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	Comparable Standard
J1113/1	Introduction	NA	ISO 11452-1
J1113/2	Conducted Immunity	30 Hz to 250 kHz	NA
J1113/3	Conducted Immunity	250 kHz to 500 MHz	ISO 11452-7
J1113/4	Bulk Current Immunity	1 to 400 MHz	ISO 11452-4
J1113/11	Power Lead Immunity	NA	ISO 7637-2
J1113/12	Coupled Immunity	NA	ISO 7637-3
J1113/13	Electrostatic Discharge	NA	ISO 10605
J1113/21	Radiated Immunity	30 MHz to 18 GHz	ISO 11452-2
J1113/22	AC Power Line - Magnetic Field	60 Hz	NA
J1113/23	Radiated Immunity - Strip-Line	10 kHz to 200 MHz	ISO 11452-5
J1113/24	Radiated Immunity - TEM Cell	10 kHz to 200 MHz	ISO 11452-3
J1113/25	Radiated Immunity - Tri-Plate	10 kHz to 500 MHz	NA
J1113/26	AC Power Line - Electric Fields	60 Hz	NA
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
J1113/41	On-board antenna	150 kHz to 1 GHz	IEC CISPR 25
J1113/42	Conducted transients	NA	NA

NOTE—Future systems may require new tests.

5. Standard Emissions Test Conditions

a. Ambient Level—6 dB below test level
b. Temperature—not controlled
c. Humidity—noncondensing
d. Separation from Absorber Material—1 m minimum
e. Clear Area—see individual test requirements
f. DUT Operating Voltage—within designed operating range
g. Engine Temperature—within designed operating range
h. Vehicle Equipment—operating at worst case noise producing condition

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

a. Test temperature and supply voltage
b. Modulation
c. Dwell time
d. Frequency steps

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 by the users of this document, the 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 the minimum response time needed to control the DUT and monitor response. In all cases, this minimum time of exposure shall be 2 s.

6.1.4 FREQUENCY STEPS—All of the RF immunity tests in this document shall be conducted with the linear frequency step sizes no greater than those given in Table 3 or in logarithmic steps with the same minimum number of steps in each frequency band. The step sizes agreed upon by the users of this document shall be documented in the test report.

TABLE 3—FREQUENCY STEPS

Frequency Band	Maximum Frequency Step Size
10 kHz to 100 kHz	10 kHz
100 kHz to 1 MHz	100 kHz
1 MHz to 10 MHz	1 MHz
10 MHz to 200 MHz	2 MHz
200 MHz to 1 GHz	20 MHz
1 GHz to 18 GHz	200 MHz

NOTE—If it appears that the susceptibility thresholds of the DUT are very close to the chosen test level, these frequency steps should be reduced in the concerned frequency range in order to find the minimum susceptibility thresholds.

6.2 Test Methods—Some parts of this document present two test methodologies:

a. The Substitution Method

The substitution method is based upon the use of NET POWER as the reference parameter used for calibration and test.

In this method the specific test level (E-field, current, voltage, or power) shall be calibrated prior to actual testing.

The test with the DUT is then conducted by subjecting the DUT to the test plan signals based on the calibrated values as predetermined in the test plan.

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 need only be maintained relative to the calibration point up to a limit of 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

During the actual test, the test level (E-field, voltage, current, or power) is measured by a calibrated device and fed back to the signal generator to either increase or decrease the test level until the predetermined value is achieved.

6.2.1 CALIBRATION—Calibration 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 calibration 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 test procedure shall apply the following specifications:

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 so that excessive overshoot does not occur. The test level parameter is (see Appendix A regarding test level specification):

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

$$\text{NET PWR (Test Signal)} = \text{NET PWR (Calib)}\left(\frac{\text{Test sig severity level}}{\text{Calibration level}}\right)^{k} \quad \text{(Eq. 1)}$$

   with k=1 for power test levels and k=2 for field, current, or voltage test levels.

   2. The TEST SIGNAL SEVERITY LEVEL for the closed-loop leveling method.

   Table 4 gives the CW and AM test levels for the substitution method and for the closed-loop leveling method.

TABLE 4—CW AND AM TEST LEVELS

	CW	AM
SUBSTITUTION METHOD	Net Power	$\frac{2+m^2}{2(1+m)^2} \times \text{Net power}$
CLOSED-LOOP LEVELING METHOD	Test signal severity level	Test signal severity level
where m is the modulation factor ($0 \leq m \leq 1$)		

   Both of these methods use a constant peak test level for CW and AM tests. The relationship between AM net power and CW calibrated 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 s).
c. 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 unrepeatable 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.

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 specific grounding practices be followed. Ground requirements are that the DUT, artificial networks and terminating loads:

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

    1. Thickness—1.5 mm (min) copper, brass or galvanized steel sheet
    2. Length—1000 mm or underneath the entire equipment plus 500 mm, whichever is larger (min)
    3. Width—width of the equipment plus 200 mm on each side (min)

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. 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 R_S 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 µs. The superimposed ripple voltage, U_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.

PREPARED BY THE SAE EMR AND EMI STANDARDS COMMITTEES

APPENDIX A

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

A.1 Scope and Field of Application—The purpose of this appendix is to provide a general method for defining function performance status classification for the functions of automotive electronic devices upon application of the test conditions specified as described in this series of documents.

A.2 General—It must be emphasized that components or systems shall only be tested with the conditions, as described in the main part of the document, that represent 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—There are four elements required to describe a function performance status classification:

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:

a. Class A—Any function that provides a convenience (e.g., entertainment, comfort).
b. Class B—Any function that enhances, but is not essential to the operation or control of the vehicle (e.g., speed display).
c. 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 must not sustain 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 Pulse Severity Level of a given test method.

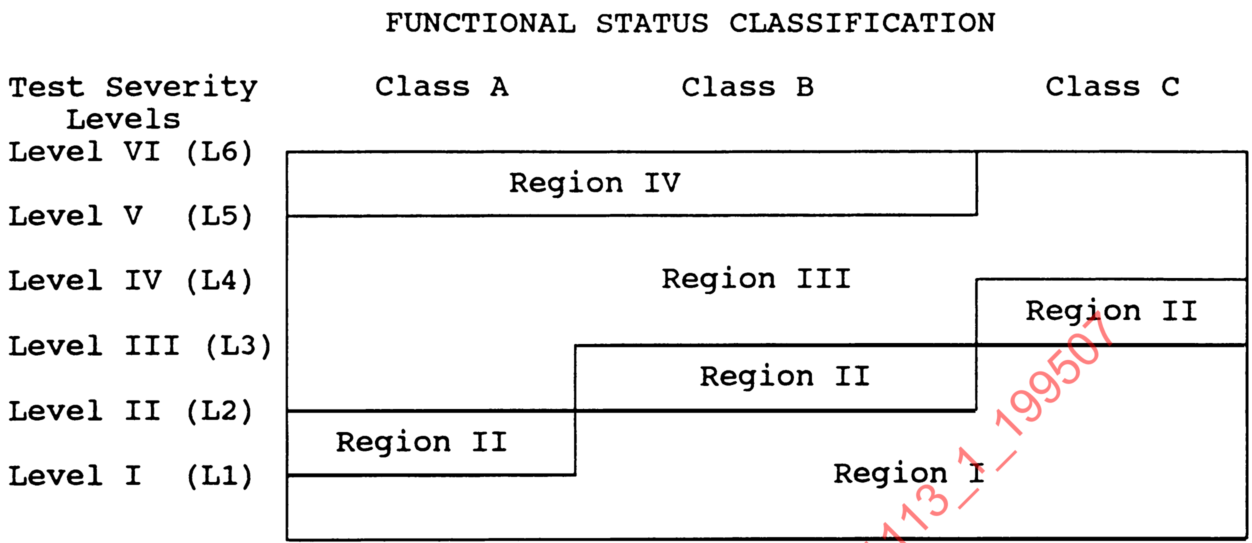

FIGURE A1—FUNCTIONAL STATUS CLASSIFICATIONS

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):

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						

FIGURE A2—EXAMPLE OF TEST PULSE SEVERITY 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	

FIGURE A3—EXAMPLE OF TEST SIGNAL SEVERITY LEVEL SELECTION TABLE

NOTE—Refer to SAE J1812 for additional information.

APPENDIX B

ROD ANTENNA CALIBRATION
THE EQUIVALENT CAPACITANCE SUBSTITUTION METHOD
(NORMATIVE)

B.1 Calibration 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 B1. The antenna factor in dB(1/m) is given by Equation B1, where the input impedance of the matching unit or receiver is much greater than the resistive component of source impedance of the antenna.

$$AF = V_D - V_L - C_h \qquad \text{(Eq. B1)}$$

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 m 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 B.3) to calculate the effective height, height correction factor and self-capacitance of rod antennas of unusual dimensions.

Either of two procedures shall be used: (a) the network analyzer, or (b) the signal generator and radio-noise meter method. The same dummy antenna is used in both procedures. (See section B.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. Set up the antenna to be calibrated and the test equipment as shown in Figure B1a.
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 calibration. Attenuator pads may be used, if desired, but including them complicates the network analyzer calibration.

b. Radio-Noise Meter and Signal Generator Procedure

1. Set up the antenna to be calibrated and the test equipment as shown in Figure B1b.
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 calibrated 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 calibrated, since it is used as a transfer standard.

B.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.

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.

B.3 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 λ/4.

$$h_e = \frac{\lambda}{2\pi}\tan\frac{\pi h}{\lambda} \quad \text{(Eq. B2)}$$

$$C_a = \frac{55.6h}{\ln\left(\frac{2h}{a}\right) - 1} \frac{\tan\frac{2\pi h}{\lambda}}{\frac{2\pi h}{\lambda}} \quad \text{(Eq. B3)}$$

$$C_h = 20\log h_e \quad \text{(Eq. B4)}$$

where:

h_e is the effective height of the antenna in meters
h is the actual height 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 average radius of the rod element in meters
C_h is the height correction factor in dB(m)