SAE International

SURFACE VEHICLE RECOMMENDED PRACTICE

SAE J551-5

REV. JAN2004

Issued 1995-06
Revised 2004-01

Superseding J551-5 DEC1997

Performance Levels and Methods of Measurement of Magnetic and Electric Field Strength from Electric Vehicles, Broadband, 9 kHz To 30 MHz

Foreword

This part of SAE J551 was initially included as an appendix to the historical broadband radiated noise test. It was published separately in June 1995, and is now in use in the industry as the standard method for electromagnetic emission testing of electric vehicles. As with all SAE standards, users are invited to comment on this document to the EMR Standards Committee.

1. Scope

The test procedures and performance levels in this SAE Recommended Practice cover the measurement of magnetic and electric field strengths over the frequency range 9 kHz to 30 MHz and conducted emissions over the frequency range of 450 kHz to 30 MHz[1].

Conducted emission measurements in this document are applicable only to battery-charging systems which utilize a switching frequency above 9 KHz, are mounted on the vehicle, and whose power is transferred by metallic conductors. Conducted emission requirements apply only during charging of the batteries from AC power lines.

Conducted and radiated emissions measurements of battery-charging systems that use an induction power coupling device are not covered by this document.

The measurement of electromagnetic disturbances for frequencies from 30 MHz to 1000 MHz and narrowband electromagnetic disturbances for frequencies from 150 KHz to 30 MHz are covered in SAE J551-2.

[1] The levels and methods for the conducted emissions test are based on CFR Title 47 Part 15 Subpart B - Unintentional Radiators. CISPR 22, the IEC document comparable to CFR Title 47 Part 15 Subpart B, has a broader frequency range, different measuring requirements and limits.

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2. *References*

The following documents contain provisions which, through reference in this text, constitute provisions of this document. At the time of publication, the editions indicated were valid. All documents are subject to revision, and parties to agreements based on this document are encouraged to investigate the possibility of applying the most recent editions of the documents indicated as follows. Members of IEC and ISO maintain registers of currently valid International Standards.

2.1 Applicable Publications

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

2.1.1 SAE PUBLICATIONS

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

SAE J551-1—Performance Levels and Methods of Measurement of Electromagnetic Compatibility of Vehicles and Devices (60 Hz to 18 GHz)
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

2.1.2 CISPR PUBLICATIONS

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

CISPR 16-1—CISPR Specification for radio disturbance measuring apparatus and measurement methods; Part 1: Radio disturbance and immunity measuring apparatus
CISPR 22—Information Technology Equipment—Radio Disturbance Characteristics—Limits and Methods of Measurement

2.1.3 ANSI PUBLICATIONS

Available from ANSI, 25 West 43rd Street, New York, NY 10036-8002, or from IEEE, 445 Hoes Lane, PO Box 1331, Piscataway, NJ 08855-1331.

ANSI C63.4—American National Standard for Methods of Measurement of Radio-Noise Emissions from Low-Voltage Electrical and Electronic Equipment in the Range of 9 KHz to 40 GHz
ANSI C63.12—American National Standard for Electromagnetic Compatibility Limits— Recommended Practice

2.1.4 UNITED STATES GOVERNMENT OFFICE OF THE FEDERAL REGISTER PUBLICATIONS

Available from US Government Printing Office, P.O. Box 371954, Pittsburgh, PA 15250-7954.

Code of Federal Regulations Title 47—Telecommunications; Part 15—Radio Frequency Devices

2.2 Related Publication

The following publication is provided for information purposes only and is not a required part of this document.

2.2.1 IEEE PUBLICATION

Available from IEEE, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331.

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

3. Definitions

For general definitions see SAE J551-1.

4. Limits of Disturbance

4.1 Radiated Emissions

The recommended performance level for electric field strength is given in Figure 1 and for magnetic field strength in Figure 2. A derivation that re-establishes these limits from the original electric vehicle limits, based on a change of measurement distance, is included in Appendix A.

TABLE 1—ELECTRIC FIELD EMISSION LIMITS

Frequency	Level dB(μV/m/KHz)
9 KHz to 4.77 MHz	$99.9 - 20\log_{10}(\text{Freq(MHz)}/.009)$
4.77 MHz to 15.92 MHz	$154.4 - 40\log_{10}(\text{Freq(MHz)}/.009)$
15.92 MHz to 20 MHz	$89.4 - 20\log_{10}(\text{Freq(MHz)}/.009)$
20 MHz to 30 MHz	22.5

TABLE 2—MAGNETIC FIELD EMISSION LIMITS

Frequency	Level dB(μA/m/KHz)
9 KHz to 4.77 MHz	$48.4 - 20\log_{10}(\text{Freq(MHz)}/.009)$
4.77 MHz to 15.92 MHz	$102.9 - 40\log_{10}(\text{Freq(MHz)}/.009)$
15.92 MHz to 20 MHz	$37.9 - 20\log_{10}\text{Freq(MHz)}/.009)$
20 MHz to 30 MHz	-29.0

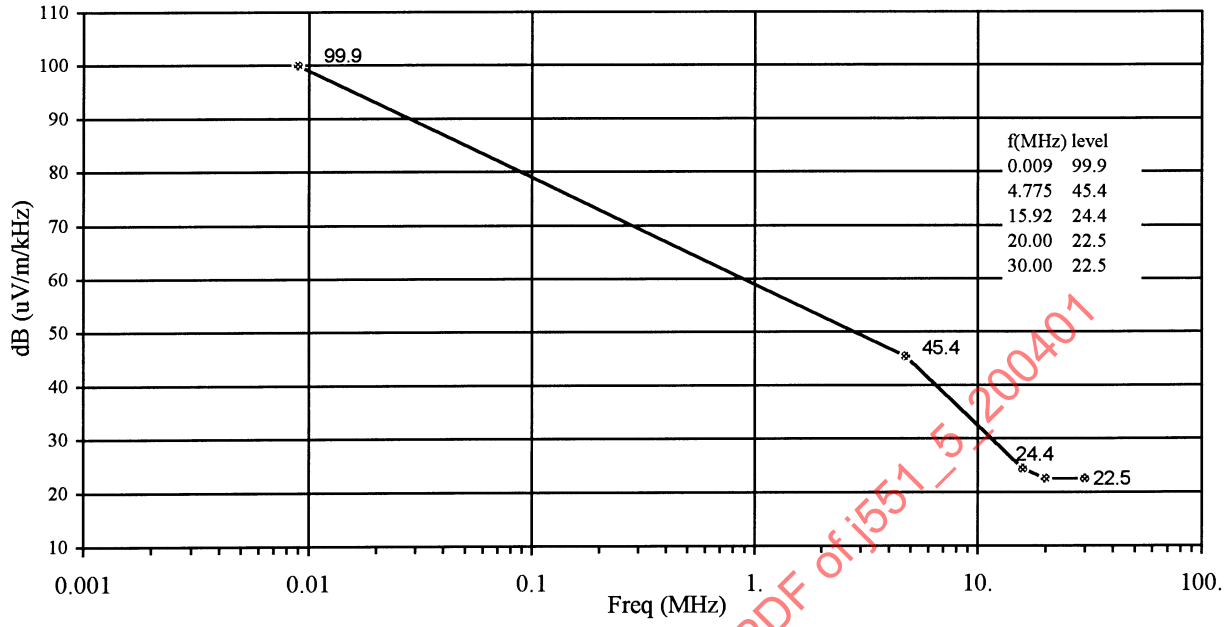

FIGURE 1—RECOMMENDED PERFORMANCE LEVEL FOR NORMALIZED PEAK IMPULSE ELECTRIC FIELD STRENGTH

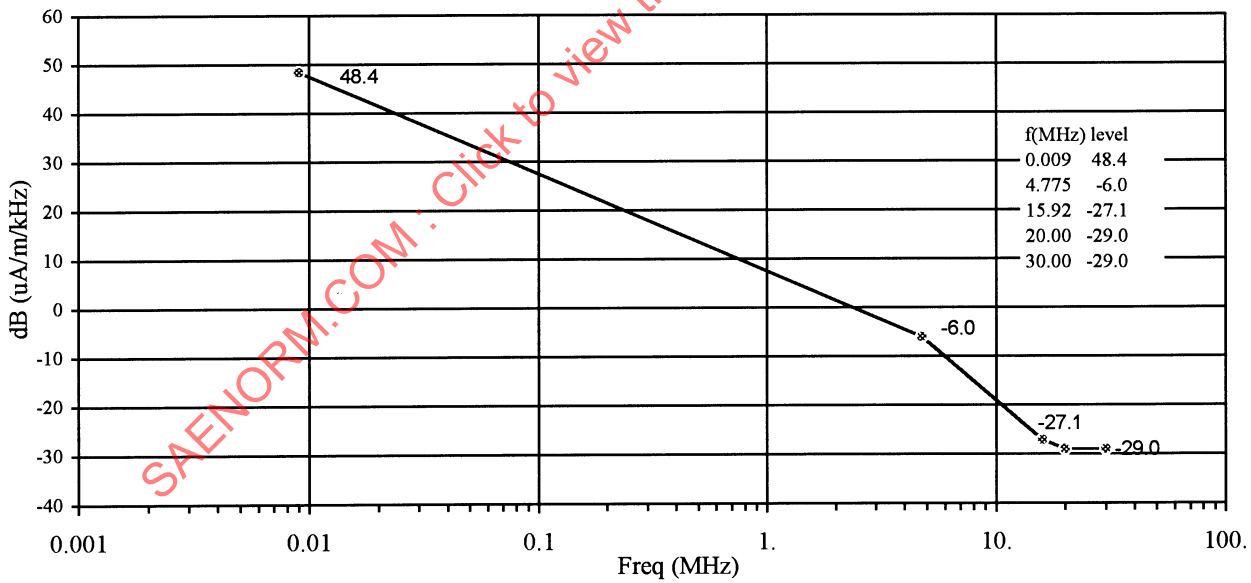

FIGURE 2—RECOMMENDED PERFORMANCE LEVEL FOR NORMALIZED PEAK IMPULSE MAGNETIC FIELD STRENGTH

4.2 Conducted Emissions

The level for road vehicles and other vehicles not exclusively used in a commercial environment shall be 250 μV. The level for vehicles recharged exclusively in a commercial environment are given in Table 3. The measurements are to be made with a quasi-peak detector. Measurements made with a peak detector (9 KHz bandwidth min.) that comply with the quasi-peak limits also satisfy the requirement.

TABLE 3—CONDUCTED EMISSION LIMITS

Frequency	Level
450 KHz to 1.705 MHz	1 mV
1.705 MHz to 30 MHz	3 mV

The following option may be employed if the conducted emissions exceed the limits defined previously when measured using instruments employing a quasi-peak detector: If the level of the emission measured using the quasi-peak instrumentation is 6 dB, or more, above the level measured with instrumentation having an average detector and a 9 KHz minimum bandwidth, that emission is considered broadband and the level obtained with the quasi-peak detector may be reduced by 13 dB for comparison to the limits. When employing this option, the following shall be observed:

a. The measuring instrumentation with the average detector shall employ a linear IF amplifier.
b. Care must be taken not to exceed the dynamic range of the measuring instrument when measuring an emission with low-duty cycle.
c. The test report shall contain all details supporting the use of this option.

5. Method of Measurement

5.1 Measuring Instrumentation Requirements

5.1.1 MEASURING INSTRUMENT

5.1.1.1 Type

The measuring instrument shall comply with the requirements of CISPR 16-1. Manual or automatic frequency scanning may be used. Spectrum analyzers and scanning receivers are particularly useful for interference measurements. Special consideration shall be given to overload, linearity, selectivity, and the normal response to pulses.

5.1.1.2 Minimum Scan Time

The scan rate of a spectrum analyzer or scanning receiver shall be adjusted according to Table 4.

TABLE 4—MINIMUM SCAN TIME

Band		Peak Detection
A	9 to 150 KHz	100 ms/KHz
B	0.15 to 30 MHz	100 ms/MHz

NOTE 1—Band definition from CISPR 16-1.
NOTE 2—Certain signals (e.g., low repetition rate or intermittent signals) may require slower scan rates or multiple scans to insure that the maximum amplitude has been measured.

5.1.1.3 Measuring Instrument Bandwidth

The bandwidth of the measuring instrument shall be chosen such that the noise floor is at least 6 dB lower than the limit curve. The bandwidths in Table 5 are recommended.

NOTE—When the bandwidth of the measuring instrument exceeds the bandwidth of a narrowband signal, the measured signal amplitude will not be affected. The indicated value of impulsive broadband noise will be lower when the measuring instrument bandwidth is reduced.

TABLE 5—MEASURING INSTRUMENT BANDWIDTH (6 dB)

Frequency Band	Instrument Bandwidth
9 to 150 KHz	200 Hz
0.15 to 30 MHz	9 KHz

If a spectrum analyzer is used for peak measurements, the video bandwidth shall be at least three times the resolution bandwidth.

5.1.2 ANTENNA SYSTEMS

The test limits shown in Figures 1 and 2 are listed in dB(μA/m/KHz) and dB(μV/m/KHz) and thus, theoretically, any antenna can be used, provided that it has adequate sensitivity, the antenna correction factor is applied, and the antenna provides a 50 Ω match to the measuring receiver. The following antennas shall be used for this test method:

a. 0.009 to 30 MHz—1 m vertical monopole with a suitable antenna matching unit. The counterpoise shall be as recommended by the antenna manufacturer.
b. 0.009 to 30 MHz—The 60 cm electrostatically shielded loop antenna of CISPR 16-1.

Commercially available rod and loop antennas with known antenna correction factors may be used. A calibration procedure for the 1 m monopole (rod) antenna and its associated matching unit is provided in CISPR 16-1. The cable loss factor can be determined in accordance with the SAE J551-2 Antenna and Transmission Line Calibration Appendix.

5.1.3 ANTENNA MATCHING UNIT

Correct impedance matching between the matching unit and the measuring receiver must be maintained at all frequencies. The maximum SWR shall be 2:1. Appropriate correction shall be made for any attenuation/gain of the antenna system from the antenna to the receiver.

NOTE—Care should be taken to ensure input voltages do not exceed the pulse input rating of the unit or overloading may occur. This is particularly important when active matching units are used.

5.1.4 LINE IMPEDANCE STABILIZATION NETWORK(S) (LISN) [ARTIFICIAL NETWORK(S)]

The 50 μH, 50 Ω LISN defined in ANSI C63.4 shall be used in each power lead. The current rating of the LISN's shall be greater than the peak current draw of the vehicle being charged. The voltage rating shall be compatible with the power line voltage and frequency being used. The LISN's shall meet the impedance requirement over the frequency range of 450 KHz to 30 MHz.

5.2 Radiated Emission Measuring Location Requirements

The site shall conform to the Open Area Test Site (OATS) Requirements, or the Absorber-Lined Shielded Enclosure (ALSE) Requirements, of SAE J551-2.

5.2.1 The base of the rod antenna shall be at ground level and 3 m ± 0.1 m away from the nearest part of the vehicle.

5.2.2 The center of the loop antenna shall be 1 m ± 0.05 m above the ground level and 3 m ± 0.2 m away from the nearest part of the vehicle.

NOTE—The loop antenna orientation for maximum sensitivity to a magnetic field is such that an axis perpendicular to the plane of the loop is also parallel to the direction of the magnetic field. The term polarization is sometimes applied to the direction of this axis in the case of loop antennas. Strictly speaking, the term polarization is used to denote the orientation of the electric field; for a loop antenna oriented for maximum coupling to the field, the direction of the electric field is parallel to the plane of the loop.]

5.3 Conducted Emission Measuring Location Requirements

The conducted emission test shall be conducted in accordance with ANSI C63.4.

NOTE—The test should be run in a shielded enclosure to preclude ambient emission from influencing the test results.

The length of cable between the LISN(s) and the connection to the vehicle shall be 1.5 m ± 0.05 m.

The LISN(s) shall be bonded to the ground plane under the vehicle with straps that are as short as possible and that have a maximum length to width ratio of 7.

When more than one LISN is used, each 50 Ω port shall be terminated with a measuring instrument or 50 Ω resistive load.

6. Preliminary Scan Procedure (not applicable to AC power line battery charger emissions measurement).

6.1 Elevate the drive wheels using insulated jack stands as supports.

NOTE—If operation of the vehicle in the unloaded state would cause damage to the propulsion system or result in lower radiated emissions levels, a dynamometer may be used.

6.2 Establish steadystate conditions of 40 km/h (25 mph) in high gear.

6.3 Record the data for the vertical electric field and all three orthogonal planes for the magnetic field.

6.4 Repeat for the other three sides of the vehicle.

6.5 Determine the direction of maximum emission based upon the results of 6.3 and 6.4. This determination should be based on the highest level obtained from the four sides of the vehicle. If the highest levels are approximately equal for two different sides of the vehicle, either of these sides may be selected as the direction of maximum radiation.

6.6 With the antenna positioned and oriented for maximum received signal, i.e., the side determined in 6.5, repeat 6.3 for steady-state conditions of 16 km/h (10 mph) and 64 km/h (40 mph) in order to determine the speed that produces maximum radiation.

7. Vehicle Measurement (except for power line battery-charging system)—9 KHz to 30 MHz

7.1 Frequency Range

Measurements shall be performed over the frequency range of 9 KHz to 30 MHz. This range shall be divided into a minimum of 11 bands with approximately one band per frequency octave. Each band shall be scanned either manually or automatically to determine the radiated field strength as a function of frequency. As an example, one possible set of bands would be:

9 to 30 KHz	0.5 to 1.1 MHz
30 to 60 KHz	1.1 to 2.4 MHz
60 to 150 KHz	2.4 to 5.0 MHz
150 to 250 KHz	5.0 to 10.0 MHz
250 to 500 KHz	10.0 to 20.0 MHz
	20.0 to 30.0 MHz

Spot frequency measurements, although not recommended, shall be considered sufficient provided that a minimum of two frequencies is measured per octave and the ratio of successive frequencies does not exceed 1.6.

7.2 Operating Conditions

The vehicle shall be driven on a dynamometer with no load, or on axle stands with a constant speed.

NOTE—If operation of the vehicle in the unloaded state would cause damage to the propulsion system, or result in lower radiated emissions levels, measurements may be made using a dynamometer to load the vehicles at the zero-grade road load for the particular speed determined in 6.6.

The vehicle shall be operated at the speed determined in 6.6 during all of the testing.

7.3 Vehicle Measurements

The data shall be normalized to dB(μA/m/KHz) or dB(μV/m/KHz) by incorporating the appropriate bandwidth and antenna factors. (See 4.5.3 of SAE J551-2 for bandwidth correction.)

8. On-Board Charger Measurements (Vehicle propulsion system de-energized)

Measurements shall be made at maximum and trickle charge rates. If the vehicle is designed for charging at more than one power line voltage, the emissions shall be measured at each line voltage. The required test frequency range shall be swept and the data recorded.

If a digital control or switching circuit utilizes a frequency that exceeds 1.705 MHz, then radiated emission tests of the charging system are also required. The measurements shall be made in accordance with SAE J551-2 using the narrowband radiated emissions limit in the frequency range of 30 to 1000 MHz.

9. Notes

9.1 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 EMR STANDARDS COMMITTEE

APPENDIX A

(INFORMATIVE)
RE-DERIVATION OF SAE J551-5 LIMIT SCALING FROM 10 m TO 3 m MEASUREMENT DISTANCE

A.1 Electric Field Limits

The original recommended performance levels for peak impulse electric field intensity, from the Georgia Institute of Technology technical report[2], are given in dBμV/m/kHz for a 10m. measurement distance:

$$L_{E_{10m}} = 75.1 - 20\log\frac{f}{14} \qquad \text{(Eq. A1)}$$

where:

f is in kHz

Re-normalizing to the current J551/5 lowest measurement frequency of 9 kHz:

$$L_{E_{10m}} = 78.94 - 20\log\left(\frac{f}{9}\right) \qquad \text{(Eq. A2)}$$

The ANSI C63.12 method for scaling field strength limits in the near field region[3] will be used. The near field boundary distance is:

$$d = \frac{\lambda}{2\pi} = \frac{150 \cdot 10^3}{\pi f} \qquad \text{(Eq. A3)}$$

where:

f is in kHz

Thus, the original (G.I.T.) and new (SAE) measurement positions are in the near field region for the following frequency ranges: (See Table A1.)

TABLE A1—NEAR FIELD CONDITIONS

Measurement Distance	Near Field Frequency Range
10 m (G.I.T.)	f≤4.77 MHz
3 m (SAE)	f≤15.92 MHz

[2] "Investigation of Electric Vehicle EMI/EMC and its Control", Georgia Institute of Technology Engineering Experiment Station technical report, 1983.

[3] ANSI C63.12-1987 American National Standard for Electromagnetic Compatibility Limits - Recommended Practice, Section 6.1.1 footnote.