

Performance Levels and Methods of Measurement of Magnetic and Electric Field Strength from Electric Vehicles, 150 kHz to 30 MHz

RATIONALE

This revision of SAE J551 includes numerous technical changes. The conducted limits are re-aligned with current FCC limits, and the radiated emission limits now begin at 150 kHz, corresponding to the CISPR/D decision regarding frequency coverage in CISPR 25. Limit scaling in the near field (Appendix A) now utilizes the 60dB/decade distance relationship due to measurement of both E and H fields, but the vertical H field measurement is deleted due to its typically low magnitude, poor far field radiation efficiency, and lack of receiving systems using this field component. In recognition of the changing nature of electric vehicles (which primarily utilized DC brush motors when the limits were proposed in 1983), the scope has been expanded and ANSI C63.12 limits with average detection are added, while the impulsive bandwidth normalization has been removed from the expression of fields and limits. The emission maximizing procedure has been updated based on experience acquired since the initial procedure was developed.

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 EMC Standards Committee.

1. SCOPE

This SAE Recommended Practice specifies measurement procedures and performance levels for magnetic and electric field emissions and conducted power mains emissions over the frequency range 150 kHz to 30 MHz, for vehicles incorporating electric propulsion systems, e.g., battery, hybrid, or plug-in hybrid electric vehicles.

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 is covered in CISPR 12.

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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 Documents

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 PUBLICATIONS

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

SAE J551-1 Performance Levels and Methods of Measurement of Electromagnetic Compatibility of Vehicles, Boats (up to 15 m), and Machines (16.6 Hz to 18 GHz)

SAE J1772 SAE Electric Vehicle and Plug in Hybrid Electric Vehicle Conductive Charge Coupler

2.1.2 CISPR PUBLICATIONS

Available from American National Standards Institute, 25 West 43rd Street, New York, NY 10036-8002, Tel: 212-642-4900, www.ansi.org.

CISPR 16-1-1 - CISPR Specification for radio disturbance and immunity measuring apparatus and methods – Part 1-1: Radio disturbance and immunity measuring apparatus

CISPR 16-1-4 - CISPR Specification for radio disturbance and immunity measuring apparatus and methods – Part 1-4: Radio disturbance and immunity measuring apparatus - Ancillary equipment - Radiated disturbances

2.1.3 IEEE PUBLICATIONS

Available from ANSI, 25 West 43rd Street, New York, NY 10036-8002, Tel: 212-642-4900, www.ansi.org, or from IEEE, 445 Hoes Lane, Piscataway, NJ 08854-1331, Tel: 732-981-0060, www.ieee.org.

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

3. DEFINITIONS

For general definitions see SAE J551-1.

4. LIMITS OF DISTURBANCE

4.1 Radiated Emissions

The recommended performance levels for peak detector electric and magnetic field strengths are given in Table 1 and Table 2. The derivation of these limits from original legacy limits is documented in Appendix A, based on distance scaling and removal of bandwidth normalization. Average detector electric field emission limits are given in Table 3.

TABLE 1 - PEAK ELECTRIC FIELD EMISSION LIMITS

Frequency f (MHz)	Level dB(μ V/m)
0.15 to 4.77	$88.89 - 20\log_{10}(f)$
4.77 to 15.92	$116.05 - 60\log_{10}(f)$
15.92 to 20	$67.98 - 20\log_{10}(f)$
20 to 30	41.96

TABLE 2 - PEAK MAGNETIC FIELD EMISSION LIMITS

Frequency f (MHz)	Level dB(μ A/m)
0.15 to 4.77	$37.36 - 20\log_{10}(f)$
4.77 to 15.92	$64.52 - 60\log_{10}(f)$
15.92 to 20	$16.45 - 20\log_{10}(f)$
20 to 30	-9.57

TABLE 3 - AVERAGE ELECTRIC FIELD EMISSION LIMITS

Frequency f (MHz)	Level dB(μ V/m)
0.15 to 0.8	$59.37 - 20\log_{10}(f)$
0.8 to 4.77	61.37
4.77 to 15.92	$88.53 - 40\log_{10}(f)$
15.92 to 30	40.46

NOTE: In Tables 1-3, the frequency variable f is in MHz.

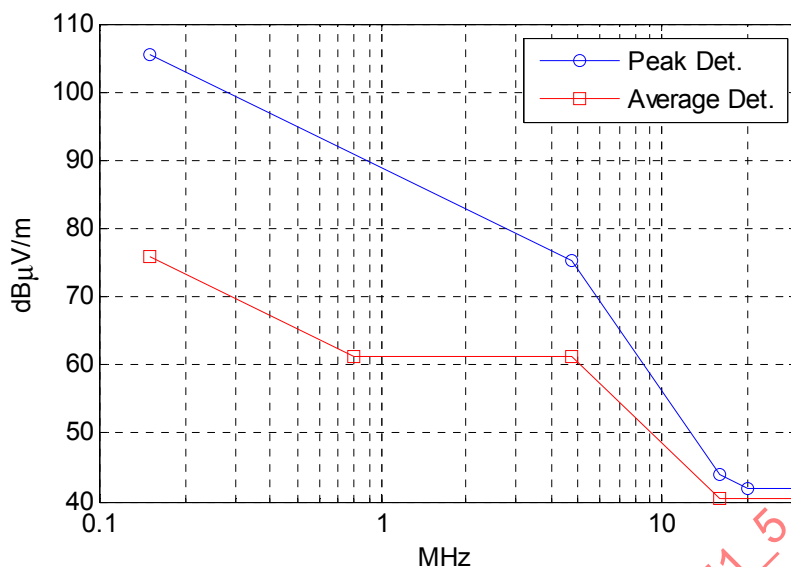


FIGURE 1 - RECOMMENDED PERFORMANCE LEVELS FOR ELECTRIC FIELD STRENGTH

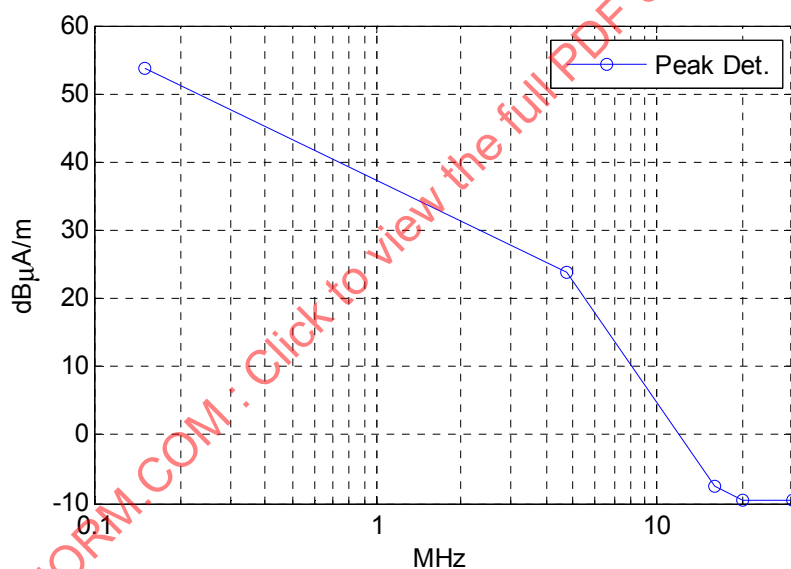


FIGURE 2 - RECOMMENDED PERFORMANCE LEVEL FOR MAGNETIC FIELD STRENGTH

4.2 Conducted Emissions

The FCC rules in the Code of Federal Regulations – Title 47, Part 15 include requirements for unintentional radiators and power line communication systems. Vehicle subsystems designed for connection to the AC supply (such as on-vehicle chargers), if employing an internal frequency source exceeding 9 kHz, shall comply with the powerline conducted emission requirements of FCC CFR 47, Title 47, Parts 15A, 15B, while charging. Verification may be performed by in-vehicle testing, or testing as a separate subsystem.

NOTES:

1. Charging or support equipment used exclusively in vehicles may be formally exempted from FCC specific technical standards per paragraph 15.103, but FCC strongly recommends compliance to the FCC limits. The applicability of the FCC paragraph 15.103 exemption to specific devices is outside the scope of this document. The FCC Office of Engineering and Technology Laboratory Division Knowledge Database website provides up-to-date published interpretations of FCC rules.
2. An on-board Power Line Communication system requires separate FCC Part 15 compliance testing in a representative configuration, if the vehicle is so equipped. See FCC rules for composite systems incorporating carrier current communication systems.
3. Additionally, some markets may regulate charging system EMC via the relevant sections of IEC 61851-21, "Electric Vehicle Charging Systems". For such devices, the FCC requires radiated emission measurements as well as the conducted emission measurements.

5. METHOD OF MEASUREMENT

5.1 Measuring Instrument

The measuring instrument shall comply with the requirements of CISPR 16-1-1. The measuring instrument noise floor shall be at least 6 dB lower than the limit curve.

NOTE: A preamplifier may be used between the antenna and the spectrum analyzer in order to achieve the 6 dB noise floor requirement, only in combination with a passive antenna and with careful consideration of preamp and receiver overload characteristics. The preferred approach is to utilize antennas having included active matching units, without additional preamplification.

5.1.1 Scanning Receiver Parameters

The scanning receiver bandwidth, step size, and dwell time are listed in Table 5.

TABLE 5 - STEPPING RECEIVER PARAMETERS

Detector	BW (kHz)	Max. Step Size (kHz)	Dwell Time
Peak	9 or 10	4.5	10 ms (min.)
Average	9 or 10	4.5	10 ms

NOTE: 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.

5.1.2 Antenna systems

The antennas shall comply with the requirements of CISPR 16-1-4. The following antennas shall be used for this test method:

- a. Electric Antenna - 1 m vertical ground mounted monopole with a suitable antenna matching unit.
- b. Magnetic Antenna - The 60 cm electrostatically shielded loop antenna of CISPR 16-1-4.

Commercially available rod and loop antennas with known antenna correction factors may be used. Appropriate correction shall be made for any attenuation/gain of the antenna system from the antenna to the receiver.

5.1.3 Antenna matching unit

The 1 m monopole antenna matching unit shall be calibrated in accordance with CISPR 16-1-4.

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.

5.2 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 CISPR 12.

5.2.1 Electric Antenna Grounding Requirements

The matching unit shall be mounted on the ground plane to achieve the minimum possible grounding inductance. If an Outdoor Test Site (OTS) is used (which is allowed for development testing only), the manufacturer's recommended counterpoise shall be placed on the ground, and connected with minimum inductance to a ground rod of 2 m minimum length. Use of a floating counterpoise, grounded at the receiver by the antenna cable, is not allowed.

5.2.2 Electric Antenna Position Requirements

The base of the rod antenna shall be at ground level and 3 ± 0.03 m away from the nearest part of the vehicle. Measurements are performed at four antenna positions:

- In front of vehicle and in back of vehicle, along vehicle centerline
- On left and right sides of vehicle, along a line passing midway between the front and rear wheels

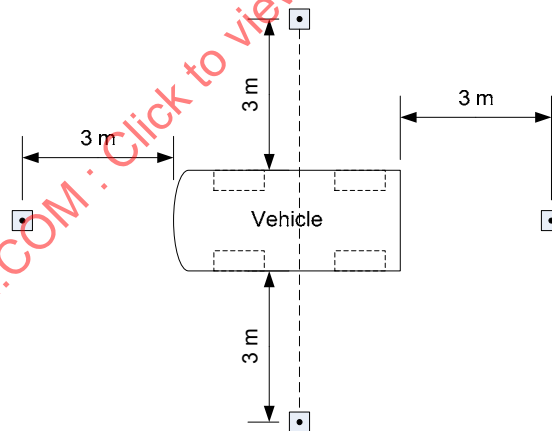


FIGURE 3 - ANTENNA POSITIONS WITH RESPECT TO VEHICLE

5.2.3 Magnetic Antenna Position Requirements

The center of the loop antenna shall be $1 \text{ m} \pm 0.05 \text{ m}$ above the ground level and $3 \pm 0.03 \text{ m}$ away from the nearest part of the vehicle. The loop support shall be capable of holding the loop in two polarizations. These orientations are denoted by the orientation of the magnetic field vector perpendicular to the plane of the loop (and therefore in the direction of maximum loop response):

Radial: The loop's direction of maximum magnetic response is pointed horizontally towards the vehicle.

Transverse: The loop's direction of maximum magnetic response is pointed horizontally and perpendicular to the radial direction.

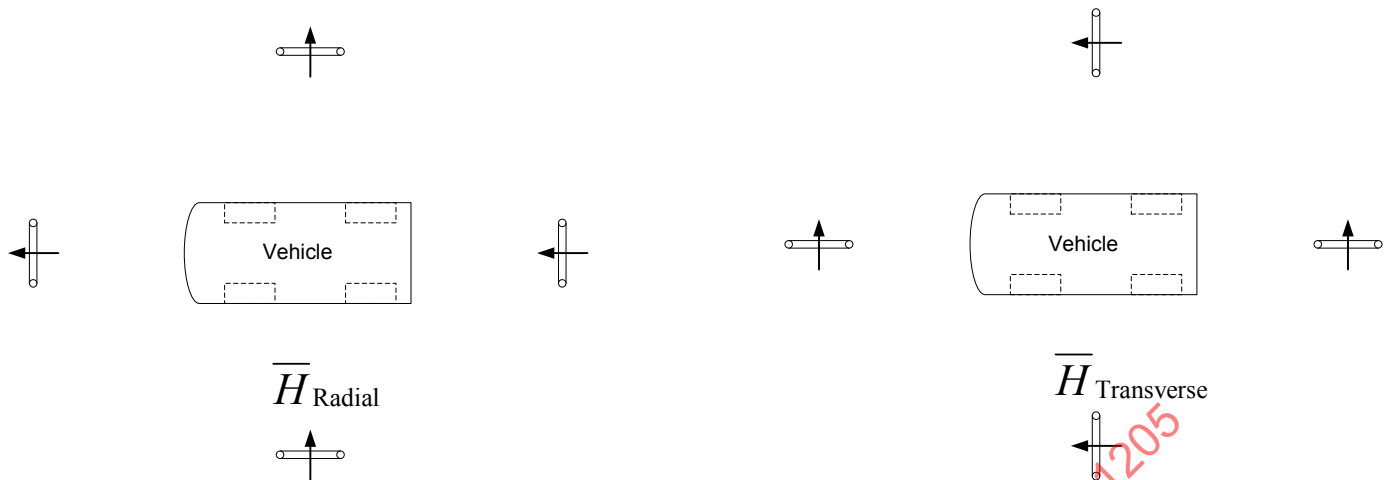


FIGURE 4 - RADIAL AND TRANSVERSE LOOP ORIENTATIONS AND POSITIONS

5.2.4 Dynamometer Requirements

The site shall be equipped with a dynamometer capable of maintaining equal rotational speed of all driven wheels, and providing a representative continuous road load torque, for speeds up to at least 95 km/h (60 MPH). The dynamometer rolls shall be metal and the bearing support structure shall be grounded to the chamber floor. Grounded metal dynamometer rolls with or without non-conductive coatings are acceptable.

CAUTION: The facility performing this test is strongly advised to develop specific procedures for operating this test safely. For example, relocating antennas near an operating dynamometer may create an unsafe condition.

NOTE: Below 30 MHz, electromagnetic resonances of a sub-floor dynamometer support structure can influence test results if no direct ground path exists from the dynamometer bearing housing(s) to the chamber floor. If a sub-floor pedestal provides the dynamometer ground, additional straps or other direct connections from the dynamometer housing upward to the chamber floor may be necessary to suppress resonances.

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 RF emissions from influencing the test results.

The length and layout of the cable between the LISN(s) and the connection to the vehicle shall be as shown in Figure 5.

The LISN(s) shall be bonded directly to the ground plane under the vehicle, or connected 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.

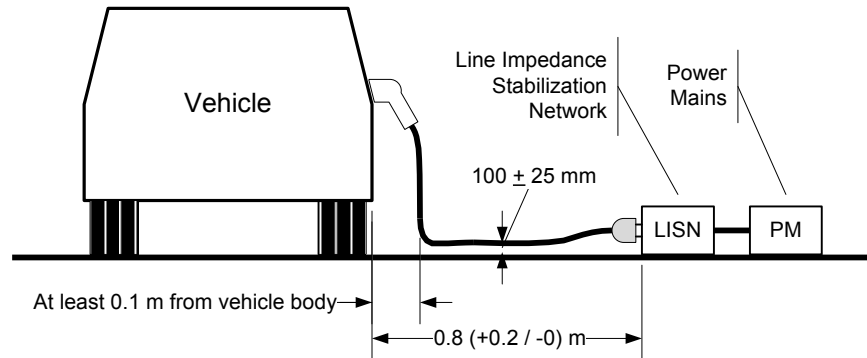


FIGURE 5 - CONDUCTED EMISSIONS CABLE LAYOUT

5.4 Vehicle Conditions (not applicable to charger conducted emissions measurement).

5.4.1 Preliminary Observations

Before measurement of emissions on the dynamometer, preliminary subjective observations of the vehicle electric emissions relationship to operating mode should be made by operating the vehicle on the road, while listening to weak mediumwave broadcast band signals (and longwave band signals, if applicable in the vehicle's markets). This can be performed using the vehicle's built-in antenna and radio, or with a temporary roof-mounted monopole and receiver. If a temporary receiving system is used, attention must be paid to antenna-to-body grounding, and operation of the receiver from an isolated battery is recommended. The observations should be made during the daytime on at least three weak signal channels spaced across the band(s).

5.4.2 Default Operating Conditions

Three default vehicle conditions are defined for emission measurements. The powertrain is in Drive (or equivalent) mode for all default conditions.

Brake Applied - The wheels are held motionless by pressure on the brake pedal.

Creep - There is no pressure on the brake or accelerator pedals, resulting in slow but normally non-zero wheel speed.

Cruise - The accelerator or cruise control is set to produce a nominal vehicle speed of 70 km/h (45 MPH). The dynamometer load is adjusted to provide the correct road load (torque) corresponding to the vehicle speed.

If engineering design information, component testing, the preliminary vehicle observations, or other observations (e.g., during subsequent emission maximization) indicate that additional steady state operating modes are required in order to measure maximum emissions, they shall be added to the list of vehicle conditions for testing.

5.4.3 Emission Maximization Procedure

Emission levels can be a function of vehicle operating parameters. Default parameter values for each operating condition are given in Table 6, but measurements are recommended to determine whether other parameter values produce significantly higher emissions.

TABLE 6 - PARAMETERS TO MAXIMIZE EMISSIONS

Operating Condition	Parameter to Vary	Default Parameter Value	Parameter Range
Brake Applied	Brake Pressure	Approx. 2 x pressure which reduces wheel speed to zero	Design normal operating range
Creep	Dyno Torque	road load torque	0 N-m up to torque which reduces wheel speed to zero
Cruise	Vehicle Speed	70 km/h (45 MPH)	Creep Speed up to 95 km/h (60 MPH)

The following recommended maximizing procedure is performed with the antenna at the drivers side measurement location, for each operating condition:

- Perform the electric peak scan with the default parameter value listed in Table 6.
- From the scan results, determine the frequency having the highest value of emission field strength minus emission limit.
- At the frequency from step b, vary the parameter within the Table 6 parameter range while observing emissions. If a significant and repeatable emissions increase (>2dB) is observed, replace the default parameter value with the maximized value. The new parameter value applies for this combination of operating condition, field component (electric or magnetic), and detector.
- Repeat steps a, b, and c for the other 3 combinations of field component (electric or magnetic) and detector.

The test report shall include documentation of parameter values used for each combination of operating condition, field component, and detector.

5.4.4 Transient Vehicle Conditions

Test procedures for transient vehicle conditions are under study.

6. VEHICLE MEASUREMENT (NOT APPLICABLE TO CHARGER CONDUCTED EMISSIONS MEASUREMENT)

For each of the four combinations of field component and detector shown in Table 7, vehicle measurements shall be performed at all four antenna positions and for each operating condition determined in paragraph 5.4.

TABLE 7 - FIELD COMPONENT AND DETECTOR COMBINATIONS

Field Component	Detector
Electric / Vertical	Peak
Electric / Vertical	Average
Magnetic / Radial	Peak
Magnetic / Transverse	Peak

6.1 Frequency Range

Measurements shall be performed over the frequency range of 150 kHz to 30 MHz.

6.2 Methods of verifying compliance

The user of standard is advised to consider the measures described in CISPR 12 for evaluation of prototype and production vehicles.

7. ON-BOARD CHARGER MEASUREMENTS (VEHICLE PROPULSION SYSTEM DE-ENERGIZED)

Measurements shall be made at a charge rate of at least 80% of maximum, and at minimum rate. 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 CISPR 12 using the average detector limit in the frequency range of 30 to 1000 MHz.

8. NOTES

8.1 Marginal Indicia

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