



SURFACE VEHICLE STANDARD

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(R) Wireless Power Transfer for Light-Duty Plug-in/Electric Vehicles and Alignment Methodology

RATIONALE

Electrified powertrains, specifically battery electric and plug-in electric (BEV/PHEV) vehicles, are projected to become more prevalent in production internationally due to environmental factors (such as GHG, CO₂ emissions), regulations (such as the EU, China, U.S. EPA regulations, and the California ZEV mandates), as well as the increasing price of fossil fuels. The main benefits of electrified powertrains are eliminating or significantly reducing local emissions while increasing the overall well-to-wheels efficiency. In addition, automated are soon to be more commonplace to allow more convenient and safer transportation, especially in traffic settings and long-distance driving.

Standardized wireless power transfer (WPT, also called wireless charging) allows the BEV/PHEV customer an automated, seamless, and more convenient alternative to plug-in (conductive) charging. Essentially, the customer simply needs to park in an SAE J2954-compatible parking space in order to charge the vehicle. WPT offers the additional advantage to automated enabling autonomous parking with alignment assistance and automated charging (in all weather conditions, such as rain or snow).

This standard is an evolution of SAE J2954, which is based on actual bench testing and vehicle interoperable data taken around the world. SAE J2954 is meant to harmonize with standards developing organizations in order to make a world-wide WPT standard to 11.1 kVA, useful for commercial applications. The SAE Task Force (TF) harmonized with numerous standard organizations (AAMI, ANSI, CISPR, GB, ISO, IEC, UL, VDA) towards these goals and specifically the documents produced in ISO and IEC. The SAE J2954 TF has worked directly with government agencies to gain feedback (U.S. DOE, U.S. FCC, U.S. FDA) and testing actual systems both in government laboratories and private. The SAE J2954 TF has documented the lessons learned from the first stage of testing with real OEM systems in accompanying SAE technical data reports (see Section 2). It is essential that data-based standards are used as a basis for commercialization of this technology.

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Documents

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1. SCOPE

The SAE J2954 standard establishes an industry-wide specification that defines acceptable criteria for interoperability, electromagnetic compatibility, EMF, minimum performance, safety, and testing for wireless power transfer (WPT) of light-duty plug-in electric vehicles. The specification defines various charging levels that are based on the levels defined for SAE J1772 conductive AC charge levels 1, 2, and 3, with some variations. A standard for WPT based on these charge levels enables selection of a charging rate based on vehicle requirements, thus allowing for better vehicle packaging and ease of customer use. The specification supports home (private) charging and public wireless charging.

In the near term, vehicles that are able to be charged wirelessly under SAE J2954 should also be able to be charged conductively by SAE J1772 plug-in chargers.

SAE J2954 addresses unidirectional charging, from grid to vehicle; bidirectional energy transfer may be evaluated for a future standard. This standard is intended to be used in stationary applications (charging while vehicle is not in motion); dynamic applications may be considered in the future. In this version, only above-ground (surface mounted) installations are covered; flush mounted installations have been discussed but are not yet ready for inclusion.

SAE J2954 contains requirements for safety, performance, and interoperability. It also contains recommended methods for evaluating electromagnetic emissions, but the requirements and test procedures are controlled by regulatory bodies. Development of the interoperability requirements in this standard employed a performance-based evaluation of candidate designs using a standardized Test Station and procedures, resulting in defining reference devices which are used to determine acceptable performance of products.

1.1 Wireless Power Transfer General System Description

WPT systems consist of a Ground Assembly (GA) Subsystem and a Vehicle Assembly (VA) Subsystem as depicted in Figure 1. The GA broadly consists of a mains-connected Power Factor Correction (PFC) converter, followed by a DC-AC inverter, a filter, and Impedance Matching Network (IMN) that is connected to the GA coil. The magnetic energy created by the GA coil is coupled to the VA coil. The VA consists of the VA coil connected to an IMN and filter, a rectifier, and an optional impedance converter that produces suitable voltages and currents to the connected battery.

In order to ensure safety, a certain set of requirements are met by both the GA and the VA, including monitoring for safe operation (voltage, current, and temperature) and the ability to take corrective action in the event that a limit indicating unsafe operation is being approached.

The GA and the VA share a communication system that allows the GA to know the state of the VA and for the GA to receive and respond to messages from the VA. It is critical that power transfer is not initiated until the GA determines that a vehicle with a compatible VA is in place and properly aligned.

The following steps describe the high-level operation of the closed loop charging system with respect to the sub-system blocks in the diagram in Figure 1, after necessary safety and compatibility checks have been performed and passed.

- Within the VA (25), the power desired to charge the battery is determined.
- The request for power is communicated over the wireless communication channel (b) from the VA to the GA (15).
- The GA recognizes the request, draws power from the grid, converts it to high frequency AC, and sends it to the GA coil (11).
- The high frequency AC couples (a) to the VA coil (21), is rectified and processed in the VA, and charges the batteries.
- This process continues until the VA signals a different power level requirement, including no power required, as would be the case when the batteries are adequately charged.

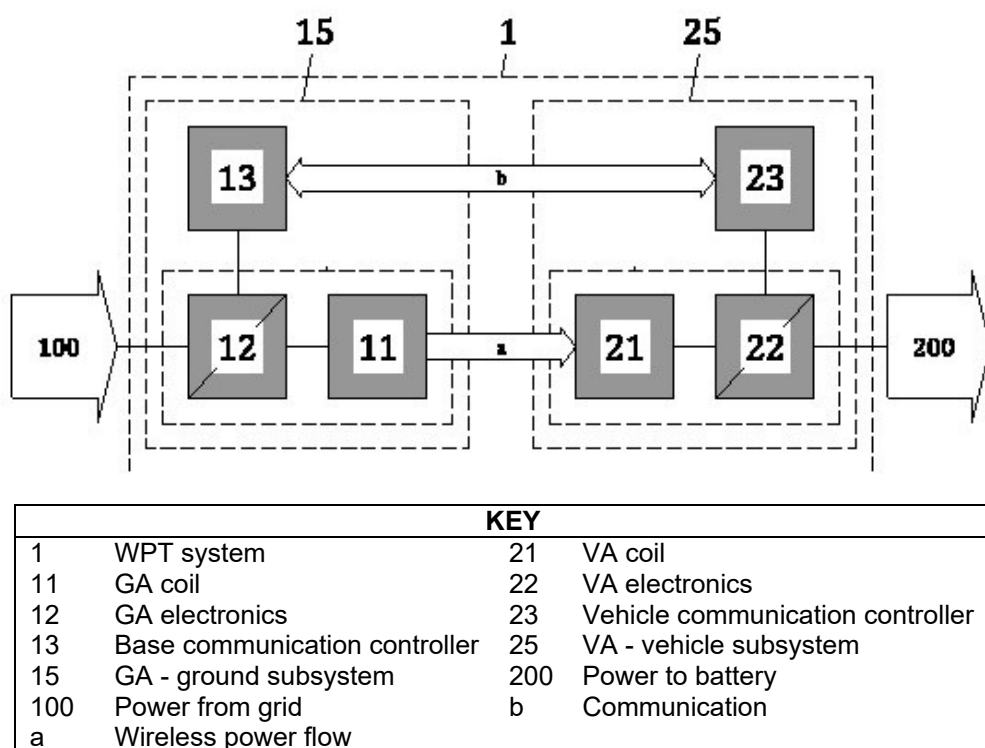


Figure 1 - SAE J2954 WPT flow diagram (harmonized with ISO 19363)

1.2 SAE J2954 WPT Compliance Test Guidance Information

There are numerous requirements stated in many sections of this document. They apply to a range of purposes, including test setup, electrical safety verification, human safety verification, physical design, performance tests, and regulatory tests). Two methods are used to provide guidance to the user of this standard when performing compliance evaluations:

- Informative APPENDIX Q lists applicable paragraphs for testing compliance of Interoperability Class I GAs, Interoperability Class II GAs, Interoperable VAs and VAs that are part of an Interoperability Class II system.
- At the beginning of each of the sections listed in Appendix Q guidance is presented regarding which test category and which system component the requirements in the section applies to when performing compliance evaluations..

In both of the above, the final determination of the applicable sections for any product under test is made by the parties involved in the test.

The related test category and product category is a combination of a letter and a number. The numbers indicate the Test Categories are as follows:

- 1 Electrical Safety
- 2 Human Safety
- 3 Physical Design
- 4 Test Setup
- 5 Performance
- 6 Communication
- 7 Regulatory

The Product Category is as follows:

- A Interoperability Class I GA
- B Interoperability Class II GA, System
- C Interoperable VA
- D VA as part of a Class II System

2. REFERENCES

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 +1 724-776-4970 (outside USA), www.sae.org.

SAE J1772	SAE Electric Vehicle and Plug-in Hybrid Electric Vehicle Conductive Charge Coupler
SAE J2836/6	Use Cases for Wireless Charging Communication for Plug-in Electric Vehicles
SAE J2847/6	Communication between Wireless Charged Vehicles and Wireless EV Chargers
SAE J2931/6	Signaling Communication for Wirelessly Charged Electric Vehicles
SAE J3016	Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles

Schneider, J., Carlson, R., Sirota, J., Sutton, R. et al., "Validation of Wireless Power Transfer up to 11kW Based on SAE J2954 with Bench and Vehicle Testing," SAE Technical Paper 2019-01-0868, 2019, <https://doi.org/10.4271/2019-01-0868>.

Schneider, J., Kamichi, K., Mikat, D., Sutton, R. et al., "Bench Testing Validation of Wireless Power Transfer up to 7.7 kW Based on SAE J2954," SAE Int. J. Passeng. Cars - Electron. Electr. Syst. 11(2):89-108, 2018, <https://doi.org/10.4271/07-11-02-0009>.

2.1.2 ANSI Accredited Publications

Copies of these documents are available online at <http://webstore.ansi.org/>.

ANSI C63.30	American National Standard for Methods of Measurement of Radio Noise Emissions from Wireless Power Transfer Equipment
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2.1.3 CISPR Publications

Available online at https://www.iec.ch/dyn/www/f?p=103:30:27264173884763:::FSP_ORG_ID,FSP_LANG_ID:1412,25.

CISPR 11	Industrial, Scientific and Medical Equipment - Radio-Frequency Disturbance Characteristics - Limits and Methods of Measurement
CISPR 12	Vehicles, Boats and Internal Combustion Engines - Radio Disturbance Characteristics - Limits and Methods of Measurement for the Protection of Off-Board Receivers
CISPR 25	Vehicles, Boats and Internal Combustion Engines - Radio Disturbance Characteristics - Limits and Methods of Measurement for the Protection of On-Board Receivers

2.1.4 IEC Publications

Available from IEC Central Office, 3, rue de Varembe, P.O. Box 131, CH-1211 Geneva 20, Switzerland, Tel: +41 22 919 02 11, www.iec.ch.

IEC 60204-1	Safety of Machinery - Electrical Equipment of Machines - General Requirements
IEC 60990	Methods of Measurement of Touch Current and Protective Conductor Current
IEC 61000-3-2	Electromagnetic Compatibility (EMC) - Part 3-2: Limits for Harmonic Current Emissions (Equipment Input Current = 16 A per Phase)
IEC 61000-3-3	Electromagnetic Compatibility (EMC) - Part 3-3: Limits - Limitation of Voltage Changes, Voltage Fluctuations and Flicker in Public Low-Voltage Supply Systems, for Equipment with Rated Current ≤ 16 A per Phase and not Subject to Conditional Connection
IEC 61000-3-7	Electromagnetic Compatibility (EMC) - Part 3-7: Limits - Assessment of Emission Limits for the Connection of Fluctuating Installations to MV, HV and EHV Power Systems
IEC 61000-3-11	Electromagnetic Compatibility (EMC) - Part 3-11: Limits - Limitation of Voltage Changes, Voltage Fluctuations and Flicker in Public Low-Voltage Supply Systems - Equipment with Rated Current ≤ 75 A and Subject to Conditional Connection
IEC 61000-3-12	Electromagnetic Compatibility (EMC) - Part 3-12: Limits - Limits for Harmonic Currents Produced by Equipment Connected to Public Low-Voltage Systems with Input Current > 16 A and ≤ 75 A per Phase
IEC 61000-4-2	Electromagnetic Immunity - Testing and Measurement - Electrostatic Discharge
IEC 61000-4-3	Electromagnetic Immunity - Testing and Measurement - Radiated EM Immunity
IEC 61000-4-4	Electromagnetic Compatibility (EMC) - Part 4-4: Testing and Measurement Techniques - Electrical Fast Transient/Burst Immunity Test
IEC 61000-4-5	Electromagnetic Compatibility (EMC) - Part 4-5: Testing and Measurement Techniques - Surge Immunity Test
IEC 61000-4-6	Electromagnetic Compatibility (EMC) - Part 4-6: Testing and Measurement Techniques - Immunity to Conducted Disturbances, Induced by Radio-Frequency Fields
IEC 61000-4-8	Electromagnetic Compatibility (EMC) - Part 4-8: Testing and Measurement Techniques - Power Frequency Magnetic Field Immunity Test
IEC 61000-4-11	Electromagnetic Compatibility (EMC) - Part 4-11: Testing and Measurement Techniques - Voltage Dips, Short Interruptions and Voltage Variations Immunity Tests
IEC 61000-4-34	Electromagnetic Compatibility (EMC) - Part 4-34: Testing and Measurement Techniques - Voltage Dips, Short Interruptions and Voltage Variations Immunity Tests for Equipment with Mains Current More Than 16 A per Phase
IEC 61000-6-2	Electromagnetic Compatibility (EMC) - Part 6-2: Generic Standards - Immunity for Industrial Environments
IEC 61786-2	Measurement of DC Magnetic Fields, AC Magnetic and Electric Fields from 1 Hz to 100 kHz with Regard to Exposure of Human Beings - Part 2: Basic Standard for Measurements
IEC 61980-1	Electric Vehicle Wireless Power (WPT) Systems - Part 1: General requirements

IEC 61980-2	Electric Vehicle Wireless Power (WPT) Systems - Part 2: Specific requirements for MF-WPT system communication and activities
IEC 61980-3	Electric Vehicle Wireless Power (WPT) Systems - Part 3: Specific requirements for magnetic field wireless power transfer (MFWPT) systems
IEC 62764-1	Measurement Procedures of Magnetic Field Levels Generated by Electronic and Electrical Equipment in the Automotive Environment with Respect to Human Exposure

2.1.5 International Commission on Non-Ionizing Radiation Protection (ICNIRP) Publications

Copies of these documents are available at <https://www.icnirp.org/>.

ICNIRP 1998	Guidelines for Limiting Exposure to Time-Varying Electric, Magnetic and ElectroMagnetic Fields (up to 300 GHz)
ICNIRP 2010	ICNIRP Guidelines for Limiting Exposure to Time-Varying Electric and Magnetic Fields (1 Hz to 100 kHz)
ICNIRP 2020	ICNIRP Guidelines for Limiting Exposure to Electromagnetic Fields (100 kHz to 300 GHz)

2.1.6 IEEE Publications

Available from IEEE Operations Center, 445 and 501 Hoes Lane, Piscataway, NJ 08854-4141, Tel: 732-981-0060, www.ieee.org.

IEEE C95.1	IEEE Standard for Safety Levels with Respect to Human Exposure to Electric, Magnetic, and Electromagnetic Fields, 0 Hz to 300 GHz
IEEE C95.3	Recommended Practice for Measurements and Computations of Electric, Magnetic and Electromagnetic Fields with Respect to Human Exposure to Such Fields, 0 Hz to 100 kHz

2.1.7 ISO Publications

Copies of these documents are available online at <http://webstore.ansi.org/>.

ISO 4130	Road Vehicles - Three-Dimensional Reference System and Fiducial Marks - Definitions
ISO 23374	Intelligent Transport Systems - Automated Valet Parking Systems (AVPS) - System Framework, Communication Interface, and Vehicle Operation
ISO 7637-2	Road Vehicles - Electrical Disturbances from Conduction and Coupling - Part 2: Electrical Transient Conduction Along Supply Lines Only
ISO 7637-3	Road Vehicles - Electrical Disturbances from Conduction and Coupling - Part 3: Electrical Transient Transmission by Capacitive and Inductive Coupling via Lines other Than Supply Lines
ISO 10605	Road Vehicles - Test Methods for Electrical Disturbances from Electrostatic Discharge
ISO 11452-2	Road Vehicles - Component Test Methods for Electrical Disturbances from Narrowband Radiated Electromagnetic Energy - Part 2: Absorber-Lined Shielded Enclosure
ISO 11452-4	Road Vehicles - Component Test Methods for Electrical Disturbances from Narrowband Radiated Electromagnetic Energy - Part 4: Harness Excitation Methods
ISO 14117	Active Implantable Medical Devices - Electromagnetic Compatibility - EMC Test Protocols for Implantable Cardiac Pacemakers, Implantable Cardioverter Defibrillators, and Cardiac Resynchronization Devices

ISO 19363 Electrically Propelled Vehicles - Magnetic Field Wireless Power Transfer - Safety and Interoperability Requirements

ISO 26262 Road Vehicles - Functional Safety

2.1.8 National Fire Protection Agency Publications

Available from NFPA, 1 Batterymarch Park, Quincy, MA 02169-7471, Tel: 617-770-3000, www.nfpa.org.

NFPA 70 National Electric Code (NEC)

NOTE: The applicable edition of NFPA 70 may be called out by the local code and may not be the latest revision.

2.1.9 ITU Publications

ITU-R Rec. SM.2110 Guidance on frequency ranges for operation of non-beam wireless power transmission for electric vehicles

ITU-R Report SM.2303 Wireless power transmission using technologies other than radio frequency beam

ITU-R Report SM.2451 Assessment of impact of wireless power transmission for electric vehicle charging on radio communication services

2.1.10 NIST Publications

Available from NIST, 100 Bureau Drive, Stop 1070, Gaithersburg, MD 20899-1070, Tel: 301-975-6478, www.nist.gov.

NIST Handbook 44 Specifications, Tolerances, and Other Technical Requirements for Weighing and Measuring Devices

2.1.11 UL Publications

Available from UL, 333 Pfingsten Road, Northbrook, IL 60062-2096, Tel: 847-272-8800, www.ul.com.

UL 2202 Standard for Electric Vehicle (EV) Charging System Equipment

UL 2231-2 Personnel Protection Systems for Electric Vehicle (EV) Supply Circuits: Particular Requirements for Protection Devices for Use in Charging Systems

UL 2594 Standard for Electric Vehicle Supply Equipment

UL 2750 Investigation for Wireless Charging Equipment for Electric Vehicles (under development)

2.1.12 Code of Federal Regulations (CFR) Publications

Available from the United States Government Printing Office, 732 North Capitol Street, NW, Washington, DC 20401, Tel: 202-512-1800, www.gpo.gov.

CFR Title 47 Telecommunication

CFR Title 49 Transportation

2.1.13 United Nations Regulations

Available from the following website. <http://www.unece.org/trans/main/wp29/wp29regs1-20.html>.

ECE REG 10 Uniform Provisions Concerning the Approval of Vehicles with Regard to Electromagnetic Compatibility

3. DEFINITIONS

3.1 ALIGNMENT

The relative position of the VA coil and the GA coil.

NOTE: When aligned, the VA coil is within the defined allowed offsets for the WPT system, as described in 8.2.2.

3.2 AMBIENT TEMPERATURE

The ground-level temperature of the air measured at the subsystem under consideration and not in direct sun light.

3.3 CARDIAC IMPLANTABLE ELECTRONIC DEVICE (CIED)

A classification of implanted medical devices comprising pacemakers and other implanted cardiac devices.

3.4 CENTERED POSITION

The position of the VA coil relative to the GA coil when the VA is placed in the middle of the defined X and Y offsets, as described in 6.4.3.

3.5 ELECTRIC VEHICLE

An automobile, as defined in 49 CFR 523.3, intended for highway use, powered by an electric motor that draws current from an on-vehicle energy storage device, such as a battery, which is rechargeable from an off-vehicle source, such as residential or public electric service, or an on-vehicle fuel-powered generator.

3.6 ESSENTIAL AUXILIARY LOAD

An auxiliary load which is essential to the proper functioning of the WPT system, such as low voltage power supplies, communication, foreign object detection, or live object protection systems.

3.7 GROUND ASSEMBLY (GA)

An assembly on the infrastructure side consisting of the GA coil, a power/frequency conversion unit and controller, as well as the wiring from the grid and between each unit, filtering circuits, housing(s) etc., necessary to function as the power source of wireless power charging system. The GA includes communication elements necessary for communication between the GA and the VA and any auxiliary systems contained on the infrastructure side of the WPT system.

3.8 GA COIL

The portion of the GA comprising the litz wire and ferrite material.

3.9 GA COIL PACKAGE

The ground-based device that is located below the vehicle to allow wireless power transfer. It contains the GA coil and any other components, including housings, fasteners, electronic assemblies, and auxiliary systems, as specified by the manufacturer.

3.10 GA ELECTRONICS

The portion of the GA that is NOT the GA coil. This may include items that are packaged in the GA coil package.

3.11 GEOMETRIC CENTER (of the GA coil or VA coil)

The spatial X, Y center of the GA or VA coil.

NOTE: The GA coil is defined in 3.8, and the VA coil is defined in 3.25.

3.12 GUIDANCE

The method that provides assistance to the vehicle or driver to navigate into the parking bay/slot. See Section 12.

3.13 IMPEDANCE MATCHING NETWORK (IMN) or COMPENSATION NETWORK

An electrical network that transforms an input impedance to an output impedance.

3.14 INDUCTIVE COUPLER

The coupled system formed by the coil in the GA coil and the coil in the VA coil that allows power to be transferred with galvanic isolation.

3.15 INDUCTIVE COUPLING

The coupled system formed by the coil in the GA coil and the coil in the VA coil that allows power to be transferred with galvanic isolation.

3.16 LIGHT DUTY (LD) PLUG-IN ELECTRIC VEHICLE

A three- or four-wheeled vehicle propelled by an electric motor drawing current from a rechargeable storage battery or other energy devices for use primarily on public streets, roads, and highways, and rated at less than 4545 kg gross vehicle weight (GVW).

3.17 MAGNETIC RESONANCE

Inductive wireless power transfer (WPT) that occurs when operating one or more high quality factor coils with their IMN (or compensation network) at or near resonance.

3.18 NATURAL OFFSET

The offset required between the GA coil and VA coil geometric center points when the VA and GA coil topologies are different (e.g., circular and DD) to achieve the centered position for power transfer (see 6.4.3 and 12.4.2).

3.19 POWER ELECTRONICS (PE)

Power electronics is the use of electronic devices to control and convert electric power. PE acts as an interface between the electrical source and the electrical load.

3.20 PLUG-IN ELECTRIC VEHICLE (PEV)

An electric vehicle that recharges the on-vehicle primary battery by connecting to the power grid, such as an SAE J1772 connection.

3.21 PRODUCT GA

An SAE J2954 GA for commercialization which has been verified to meet both operational and safety requirements in this standard.

3.21.1 INTEROPERABILITY CLASS I GA

A Product GA which has been verified to meet the interoperability, performance, and safety requirements for an Interoperability Class I GA as described in 5.4.1.

3.21.2 INTEROPERABILITY CLASS II GA

A Product GA for deployment in a home garage or locations for a captive fleet and not intended to be generally available to the public. It has been verified to meet the interoperability, performance, and safety requirements for an Interoperability Class II GA, as described in 5.4.2.

NOTE: For proprietary WPT systems not compliant to SAE J2954, refer to safety considerations in this standard, UL 2750, and IEC 61980.

3.22 PRODUCT VA

A Product VA is a VA that has been developed for series commercialization that has been verified with SAE J2954 to meet the performance and safety requirements in this standard.

3.23 TEST STATION (VA/GA) COMMUNICATION MODULE

A device which meets the communication requirements of Section 12 and which adds communication capability to Test Station devices to enable validation testing.

NOTE: There is one version used with the Test Station GAs and another version used with the Test Station VAs.

3.24 TEST STATION GA

The GA used to verify the performance of candidate Product VAs. The Test Station GA is listed in Appendix B.

3.25 TEST STATION VA

The Test Station VA is used to verify the performance of candidate Product GAs. The Test Station VAs are listed in Appendix A.

3.26 VEHICLE ASSEMBLY (VA) COIL

The portion of the VA comprising the litz wire and ferrite material.

3.27 VA COIL GROUND CLEARANCE

The VA coil ground clearance is the vertical distance between the ground surface and the lower surface of the VA coil package. See Figure 2.

3.28 VA COIL PACKAGE

The physical device located on the vehicle which allows wireless power transfer. It contains the VA coil and any other components, including housings, fasteners, electronic assemblies, and auxiliary systems as specified by the manufacturer.

3.29 VEHICLE ASSEMBLY (VA)

The equipment on the vehicle consisting of the VA coil, power electronics, control, and communication necessary to safely transfer power to the vehicle.

3.30 VEHICLE GROUND CLEARANCE

The vertical distance between the ground surface and the lowest part of the vehicle underbody.

3.31 WATCHDOG TIMER

A special purpose timer that will reset the system if it has not been periodically serviced by normal activity.

3.32 WIRELESS CHARGING SYSTEM (WCS)

The system for wireless power transfer and control between the GA and VA including alignment and communications. In the forward direction, this system transfers energy from the electric supply network to the electric vehicle electromagnetically (see Figure 1).

3.33 WIRELESS POWER TRANSFER (WPT)

The transfer of electrical power from the AC supply network to the electric vehicle by contactless means. WPT is a charging system that transfers power across an airgap from a GA to a VA and then rectifies that power into DC voltage to charge the batteries.

4. ABBREVIATIONS

ALSE	Absorber-Lined Shielded Enclosure
CAN	Controller Area Network
CFR	United States Code of Federal Regulations
EMC	Electromagnetic Compatibility
EMF	Electromagnetic Field
EMI	Electromagnetic Interference
ESD	Electrostatic Discharge
EVCC	Electric Vehicle Communication Controller
EVSE	Electric Vehicle Supply Equipment
FOD	Foreign Object Detection
FCC	Federal Communications Commission (U.S.)
IEC	International Electrotechnical Commission
IMN	Impedance Matching Network
LIN	Local Interconnect Network
LOP	Live Object (Human) Protection
OBC	On-Board Charger
PE	Power Electronics
SECC	Supply Equipment Communication Controller
SOC	State of Charge (in percent)
UL	Underwriters Laboratories
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
WPT	Wireless Power Transfer

5. WPT CLASSIFICATIONS

5.1 WPT Power Classes

WPT power classes are defined by the maximum input volt-amps drawn from the grid connection. Power class WPT1 and WPT2 have been defined to align with SAE J1772 for AC levels 1 and 2 charging, respectively. SAE J2954 set WPT3 as 11.1 kVA to align with European three-phase outlet rating.

Additional WPT power classes, with maximum input volt-amps of 22 kVA (WPT4) and 60 kVA (WPT5) are under consideration for the next version of this standard.

Table 1 - SAE J2954 WPT power classifications

	WPT1	WPT2	WPT3
Range of Input Volt-Amps	0 to 3.7 kVA	0 to 7.7 kVA	0 to 11.1 kVA

5.2 WPT Z-Classes

The vertical distance over which the power must be transferred is an important parameter for the WPT system specification. Three Z-classes are defined to classify the range of ground clearances over which systems operate and are specified as VA coil ground clearance.

The VA coil ground clearance is the vertical distance between the ground surface and the lower surface of the VA coil package (Figure 2).

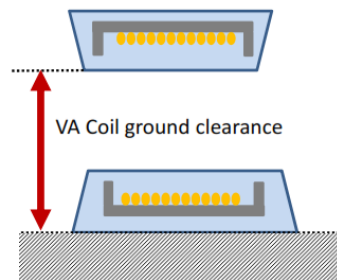


Figure 2 - VA coil ground clearance

The VA coil ground clearance range for each SAE J2954 Z-class is specified in Table 2.

Table 2 - Specification of the SAE J2954 VA Z-classes

Z-Class	VA Coil Ground Clearance Range (mm)
Z1	100 to 150
Z2	140 to 210
Z3	170 to 250

5.2.1 Z-Class Related to Test Station VAs

The SAE J2954 Test Station VAs are characterized by Z-Class, since they are used to validate the performance of Product GAs over a range of VA coil ground clearances.

5.2.2 Z-Class Related to Product VAs

A Product VA does not need to be classified by Z-Class, but rather by the range of VA coil ground clearances over which it operates. The ground clearance for a Product VA is dependent on the vehicle, and it will vary depending on factors such as tire pressure, vehicle loading and mounting location. When testing a Product VA, whether as a component test or a system test, it is tested with a Test Station GA which covers the range required by the Product VA.

5.2.3 Z-Class Related to Test Station and Product GAs

The operating range for a SAE J2954 Test Station GA is specified in terms of the minimum and maximum VA coil ground clearance over which it operates.

The operating range for a Product GA is specified in terms of the minimum and maximum VA coil ground clearance over which it has been tested to operate.

See Table 3 for the specification of the SAE J2954 Z-class for a GA.

Table 3 - Specification of the SAE J2954 GA Z-classes

GA Z-Class	Range of VA Ground Clearances (mm)
Z1	100 to 150
Z2	100 to 210
Z3	100 to 250

5.3 Ground Assembly Installation Categories

Ground Assemblies could be installed differently relative to the ground surface:

- Above ground mounting of the Ground Assembly (e.g., private garage or covered parking structure). The GA is mounted on top of a ground surface.
- Flush mounting of the Ground Assembly (e.g., public parking lot). The outer casing of the GA is flush mounted with the ground surface.
- Buried mounting of the Ground Assembly. The outer casing of the GA is buried at a distance under the ground surface.

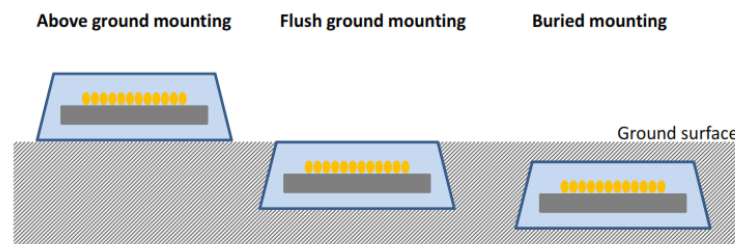


Figure 3 - GA mounting schemes

NOTE: SAE J2954 currently only specifies above ground mounting. Proposed specifications for flush ground mounted and buried mounted assemblies will be considered in a future version of this standard.

5.4 SAE J2954 Interoperability Classifications

Product GAs are classified by their intended application interoperability.

5.4.1 Interoperability Class I GA

Interoperability Class I is the classification of a GA that is intended for public usage. An Interoperability Class I GA will work over the full VA coil ground clearance range and input power range.

Full performance is expected by a VA system when charging over an Interoperability Class I GA. The performance requirements and the test configurations for an Interoperability Class I GA are covered in Section 8.

5.4.2 Interoperability Class II GA

Interoperability Class II is the classification of a GA which is intended to be primarily for a specific application, such as a fleet operation or a home system for a specific vehicle or vehicle family. An Interoperability Class II GA may operate over less than the full VA coil ground clearance range and input power range.

Full performance is expected from a specific set of VAs for which this GA was optimized to work with while limited performance is expected from other SAE J2954-compliant Product VAs that are within the VA coil ground clearance range of the Interoperability Class II GA. There is an expectation of prevention of operation with a VA outside of these ranges. The performance requirements and the test configurations for an Interoperability Class II GA are covered in Section 8.

NOTE: For proprietary WPT systems not compliant to SAE J2954, reference safety considerations in this standard, IEC 61980, and UL 2750.

6. WIRELESS CHARGING SYSTEM FUNCTIONS AND OPERATION

A wireless charging system consists of several functional elements:

- A power transfer function
- A communication function
- Safety related functions are required to:
 - Protect against damage from heating of metal foreign objects
 - Protect humans from exposure to electromagnetic fields

6.1 Power Transfer Functional Description

The WCS consists of a grid interface, high frequency power inverter, filter, compensation network, power transfer coils, compensation network, filter, rectifier, optional regulator, and communications between the vehicle energy charging/storage system and the grid connected power inverter. The grid interface is similar to an existing EVSE connection for single or three-phase AC power. Figure 4 illustrates the major functional components of an example wireless charging system.

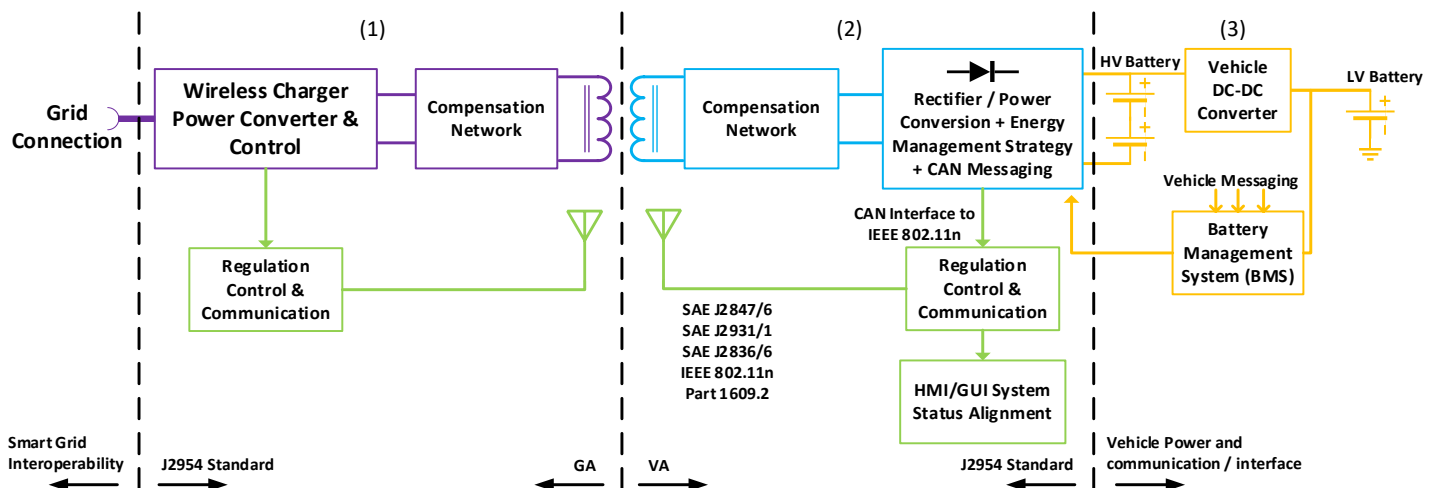


Figure 4 - Typical functional elements of a wireless charging system

6.1.1 Physical Partitions of the Power Transfer Function

Wireless charging technology for electric vehicles consists of three major partitions: (1) the grid-connected converter with its attendant GA coil for power coupling, with a communication link to the vehicle system (the GA); (2) the vehicle-mounted VA coil with rectification, filtering components, and charging control power electronics necessary for regulation/safety/shutdown when required, with a communications link to the infrastructure side (the VA); and (3) the secondary energy storage system, battery management system components, and associated modules necessary for in-vehicle communications (CAN, LIN) required for battery SOC, charge rate, and other necessary information (the vehicle energy storage system). See Figure 4.

6.1.2 Main Functional Elements of the Power Transfer Function

Proceeding from left to right in Figure 4, the grid connected converter should be situated at a parking space. The function of this converter is to process grid supplied and metered electricity into a nominal 85 kHz frequency current suitable for magnetic coupling under resonance. This converter includes active front-end power electronics to control the power factor. The converter is matched to one (or more) GA coils located on or embedded in the residential garage floor or public parking space.

The vehicle system functional elements consist of a VA coil operating under magnetic resonance with the GA coil and adhering to the requirements of this standard, power conversion electronics to process the received energy or to shut down the system under a fault condition, and the interface to the vehicle energy storage system.

6.2 Communication Function

The communication system transfers information between the VA and the GA for the purpose of regulating the level of transmitted power and to communicate enable and inhibit signals depending on vehicle energy storage system status.

In addition to the communication that is mentioned above in support of safe power transfer, bidirectional communication between the GA and VA is utilized for guidance, alignment, positioning, position verification, compatibility verification and other purposes prior to the start of power transfer. See Section 12 for additional details.

6.3 Safety Functions (Informational: Requirements Apply to Tests 1A, 1B, 1C, 1D)

Prior to and during power transfer, it is important to detect any objects which might be heated to a dangerous temperature during power transfer. See 16.2.1 for description and requirements regarding detection of foreign objects.

During power transfer, it is important to prevent humans from exposure to harmful electromagnetic fields. While general exposure is covered in Section 10 for accessible regions, exposure in the case of unusual circumstances, such as crawling under the vehicle while charging, need to be protected against. See 16.2.2 for live object protection (LOP) requirements.

Vehicle components in a WPT system shall be designed according to functional safety in ISO 26262 related to possible hazards caused by malfunctioning behavior of safety-related electrical systems, including interaction of these systems. WPT system designs should avoid a single point failure wherever possible.

6.4 Description of Wireless Charging Operation

6.4.1 General (Informational: Requirements Apply to Tests 2A, 2B, 2C, 2D, 5A, 5B, 5C, 5D, 6A, 6B, 6C, 6D)

During parking in a parking space that is equipped with an SAE J2954-compliant GA, the driver begins the guidance and alignment process. The GA and the VA exchange information to ascertain compatibility. If compatible, positioning information is exchanged. When the vehicle is within the charging tolerance area and stopped, information is exchanged to confirm that it is allowable to start charging.

Unless the vehicle has confirmed that it is compatible with the GA and that it is within the allowable position tolerance area, the VA shall not request power transfer, and the GA shall not initiate power transfer.

Following confirmation that the VA coil is properly aligned with the GA coil, the VA shall exchange information with the GA to activate and initiate power transfer according to the requests from the vehicle energy storage system. This information is relayed to the GA to set the power level for proper charging. Control over the charging process can be performed through the vehicle's dedicated charger or directly from the VA using messages provided over the wireless communication path between the GA and VA.

The GA and the VA shall ensure their own safe operation with regards to parameters such as temperature, current and voltage. Should an unsafe condition develop, the system shall take corrective action, including—if necessary—causing system shutdown and the safe cessation of power transfer.

6.4.2 Power Transfer Frequency (Informational: Requirements Apply to Tests 4A, 4B, 5A, 5B, 5C, 5D)

Since the power transfer systems in this standard are based on principles of magnetic resonance, a common power transfer frequency between the GA and the VA shall exist.

The SAE J2954 frequency range of 79 to 90 kHz shall be used for wireless power transfer. Frequency is controlled by the GA.

The nominal power transfer frequency of the SAE J2954 frequency range is 85 kHz. In order to optimize performance, if it is necessary to use a different power transfer frequency, determination of that frequency shall be done at the start of a charge session and shall be accomplished at no more than 25% of the full power of the charging system (the lower of the GA input power rating and the VA output power rating). The power transfer frequency shall remain constant (within a ± 50 Hz range) for the duration of the charge session.

6.4.3 Centered Position and Natural Offset

In order to be able to compare performance and determine interoperability, a centered position of the VA coil relative to the GA coil is described.

The centered position in the XY-plane of a VA with respect to any GA is specified by determining the position of the VA coil relative to the GA coil when the VA is placed in the middle of the defined X and Y alignment tolerance offsets.

In the case where the VA coil topology is the same as the GA coil topology, the centered position is typically the position where the geometric centers of the GA and the VA are aligned.

In the case where the VA coil topology is NOT the same as the GA coil topology, the centered position may require the use of a "natural offset," relative to the position that aligns the geometric centers of the VA and the GA.

See 12.4.2 for additional information about the natural offset.

7. PHYSICAL DIMENSIONS AND PARAMETERS

7.1 GA Coil Dimensions

The length of the GA coil is specified along the direction of travel of the vehicle; i.e., the X direction. The width of the GA coil is specified in the transverse direction of the vehicle, the Y direction.

The actual size of the assembly is determined by system requirements for interoperability and safety. Assembly sizes of the SAE J2954 Test Station devices for interoperability evaluations are specified in their respective appendices.

7.2 GA Coil Mounted Height (Informational: Requirement Applies to Tests 3A, 3B)

The GA coil mounted height is the distance from the ground surface to the top surface of the GA coil package outer case (see Figure 5).

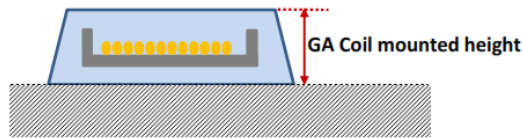


Figure 5 - Definition of GA coil mounted height

The maximum recommended allowable protrusion above the ground surface is 70 mm. This maximum protrusion height may be subject to local installation rules and may be more or less than the value recommended here.

7.3 GA Coil Location

The recommended location of the GA coil within a parking space is given in Section 14 and Appendix D.

7.4 VA Coil Size

The size of a Product VA coil is dependent on OEM considerations.

Sizes of the Test Station VA coils used for interoperability testing are specified in Appendix A.

7.5 VA Coil Ground Clearance

The installed Product VA coil ground clearance is dependent on the specific vehicle and conditions such as the loading condition and tire pressure.

7.6 VA Coil Mounting Location

The mounting location of the VA coil on the vehicle is determined by the OEM.

The geometric center of the VA coil is recommended to be installed on the centerline of the vehicle in the Y direction.

The geometric center of the VA coil in the driving direction (X) is determined by the OEM and could be near the front of the vehicle for forward parking locations or near the rear for reverse parking locations.

8. PERFORMANCE, INTEROPERABILITY, AND SAFETY REQUIREMENTS

8.1 General (Informational: Requirements Apply to Tests 1A, 1B, 2A, 2B, 5A, 5B, 6A, 6B, 7A, 7B)

The requirements, test configurations, and tests described in this standard ensure that the systems meet the interoperability and performance requirements and are safe to operate under normal conditions.

EMC requirements and recommended procedures are covered in Section 9, EMF and touch current requirements are covered in Section 10. Electrical safety requirements and tests are specified in UL 2750 (under development) (see Section 11). Communication and alignment requirements are referenced in Section 12.

The tests to verify conformance with the listed power transfer performance requirements are in Section 16; they ensure the correct degree of interoperability. Unless otherwise specified, they are intended to be Test Station tests, with one side being Test Station devices/communication module and the other side being product device candidates. Some tests are intended to be vehicle level tests and are so noted.

NOTE: Vehicle tests are applicable only to that specific vehicle configuration and are important to assure compliance to certain requirements, such as EMC and EMF.

All systems, at the system level, require:

- Compatible communication method/sequence/messages.
- The necessary output power to be delivered within the expected operating conditions of the system (e.g., with a GA/VA pair at its centered position and at the specified offsets) while operating within thermal limits over the power transfer duration, and responding safely to any incidents (e.g., FOD/LOP detection).
- Compliance with EMC requirements.
- Compliance with EMF protection requirements.

An Interoperability Class I GA:

- Shall (for the first version of this standard) use a circular coil topology, and it is recommended that it follows the normative GA in Appendix B.
- Shall have equivalent functionality as the GA in Appendix B and meet all safety and EMC limits in SAE J2954.
- Shall follow the communications and the control protocols detailed in Sections 12 and 13.
- Shall operate with the SAE J2954 Test Station VAs.
- Shall be certified by a national recognized testing lab to meet SAE J2954 requirements and shall also meet UL 2750 (or equivalent) requirements.
- Shall have an applicable “weights and measure” certification and test according to local and/or national regulations (e.g., NIST Handbook 44, PTB, etc.) or equivalent for deployment in a commercial environment.

An Interoperability Class II GA:

- Shall meet all performance, safety and EMC requirements with all Product VAs it is intended to work with and the normative SAE J2954 Test Station VAs within the specified GA ground clearance range.
- Shall follow the communication, control, and alignment requirements detailed in Sections 12 and 13 and shall use these protocols when operating with all SAE J2954-compliant VAs, including the Test Station VAs.
- Shall be certified by a national recognized testing lab as meeting UL2750 (or equivalent) requirements.

NOTE: A GA can use proprietary alignment, communications and controls with a specific Product VA it is intended to work with, in addition to the requirements listed above.

8.2 Power Transfer Performance Requirements

8.2.1 Test Configurations

Testing procedure is given in Section 15.

8.2.1.1 Product VA

A Product VA is tested with the SAE J2954 Normative Test Station GA described in Appendix B using the Test Station GA communication module.

8.2.1.2 Interoperability Class I Product GA (Informational: Requirements Apply to Tests 4A, 5A, 6A)

An Interoperability Class I GA is tested with each of the Normative Test Station VAs described in Appendix A along with Test Station VA communication module. As a result, the performance of the Interoperability Class I GA will be verified over all three Z classes, at a full range of power levels, output voltages, and alignment tolerances.

8.2.1.3 Interoperability Class II Product GA (Informational: Requirements Apply to Tests 4B, 4D, 5B, 5D, 6B, 6D)

An Interoperability Class II GA is tested with the specific VAs it is intended to work with and with Normative Test Station VAs described in Appendix A.

The Interoperability Class II GA is tested with only the Normative Test Station VAs which are specified to operate at the same VA coil ground clearance as the GA. Communication (Section 12) provides information to the GA about the VA coil ground clearance. The GA shall not begin power transfer (for Interoperability Class II) if the VA is outside the GA's specified and tested VA coil ground clearance range.

8.2.2 Alignment Tolerance (Informational: Requirements Apply to Tests 5A, 5B, 5C, 5D)

The SAE J2954 WPT system (for any interoperability class) shall operate safely over a range in X, Y, and Z to allow for parking misalignment and variations in vehicle height. The worst-case misalignment in the XY plane occurs when both X and Y are at a maximum distance from the centered position.

8.2.2.1 SAE J2954 Alignment Tolerance for Product VAs

Table 4 - X, Y, Z operating range requirements for Product VAs

Offset Direction	Value (mm)
ΔX	± 75
ΔY	± 100
Z range	Specified by manufacturer

8.2.2.2 SAE J2954 Alignment Tolerance for Product GAs

Table 5 - Ground clearance operating range requirements for Product GAs

Offset Direction	Value (mm) Interop Class I GA	Value (mm) Interop Class II GA
ΔX	± 75	± 75
ΔY	± 100	± 100
Z range	All Z-Classes	Manufacturer specification

8.2.3 Roll Pitch and Yaw (Informational: Requirements Apply to Tests 5C, 5D)

Product VAs are required to operate over a range of roll, pitch, and yaw.

Table 6 - SAE J2954 roll, pitch, and yaw operating range requirements for Product VAs

Type	VA Offset
Roll	2 degrees
Pitch	2 degrees
Yaw	3 degrees

8.2.4 Output Voltage and Power

8.2.4.1 Output Voltage and Power from Product VA (Informational: Requirements Apply to Tests 5C, 5D)

The manufacturer shall specify the range of voltages and power that the VA provides.

NOTE: Some vehicle architectures have voltages up to 900 V.

8.2.4.2 Output Voltage and Power with a Product GA

8.2.4.2.1 Output Voltage and Power for an Interoperability Class I Product GA (Informational: Requirements Apply to Test 5A)

The output voltage from the normative SAE J2954 Test Station VA shall cover the range of 280 to 420 V at full output power over the full ground clearance range and alignment tolerance area.

8.2.4.2.2 Output Voltage and Power for an Interoperability Class II Product GA (Informational: Requirements Apply to Tests 5B, 5D)

For the manufacturer-specified VAs, the output voltage range and power output level shall be specified by the manufacturer over the full ground clearance range at the centered position. The power level delivered over the alignment tolerance area shall be at least 50% of the power delivered at the centered position.

The output voltage from these specified VAs shall cover the voltage range specified by the manufacturer at the power levels specified by the manufacturer.

For the normative reference VAs:

- If the VA WPT class is less than the maximum power rating of the GA, the output voltage shall cover the range of 280 to 420 V at full output power from the VA.
- If the VA WPT class is greater than the maximum power rating of the GA, the output voltage shall cover the range of 280 to 420 V at the rated input kVA to the GA.
- If the VA WPT class covers the maximum power rating of the GA, the output voltage shall cover the range of 280 to 420 V at the lower of the rated input kVA to the GA or full output power from the VA.
- For any of the above cases, the power level delivered over the alignment tolerance area shall be at least 50% of the power delivered at the centered position.

8.2.5 Input Power (Informational: Requirements Apply to Test 5A, 5B)

An Interoperability Class I Product GA shall cover the input kVA range up to 11.1 kVA, the entire range of input kVA covered by this standard.

An Interoperability Class II Product GA may be specified to any input kVA maximum limit up to 11.1 kVA; it does not need to accept the full input kVA of any WPT Power Class

See Table 7 for the required ranges.

Table 7 - Range of input kVA by class of Product GA

Interoperability GA Class	Minimum Input kVA Rating	Maximum Input kVA Rating
Class I	1 kVA	11.1 kVA
Class II	1 kVA	Specified by manufacturer

The manufacturer of a Product GA shall specify the input voltage range over which the GA is specified to meet the performance requirements.

8.2.6 Power Factor

Power factor is an important parameter to ensure that the system operates safely and efficiently. Although power factor is not a criterion for compliance with this standard, it should be greater than 99% during normal charging operations and always greater than 95%. Power factor requirements may be subject to local regulation.

8.2.7 Frequency

See 6.4.2.

8.2.8 System Efficiency

System efficiency is measured from the AC grid connection to the HV battery connection (Figure 4).

8.2.8.1 Product VA System Efficiency (Informational: Requirements Apply to Test 5C)

For each Product VA being tested, the system efficiency at full output power shall be $\geq 85\%$ when operating at full output power with the VA at the middle of the relevant Z range at center position, and when the GA input voltage and VA output voltage are at the mid-point (nominal) of the range. The system efficiency shall be $\geq 80\%$ over the full range of variations specified in 8.2.2 to 8.2.4. For this purpose, full power is the lower of the rated input kVA to the GA or the rated output power of the VA, when increasing the power levels.

8.2.8.2 SAE J2954 Interoperability Class I GA System Efficiency (Informational: Requirements Apply to Test 5A)

For each Interoperability Class I Product GA, under all the variations in the requirements in 8.2.2 to 8.2.4, the system efficiency shall meet or exceed the system efficiency requirement listed in Table 8 while operating at full power. For this purpose, full power is the lower of the rated maximum input kVA to the GA or the rated output power of the VA.

Table 8 - Class I minimum system efficiency requirements

WPT Class of Test VA	At Centered Position	In Alignment Tolerance Area
WPT1	80%	75%
WPT2	82%	77%
WPT3	85%	80%

8.2.8.3 SAE J2954 Interoperability Class II GA System Efficiency (Informational: Requirements Apply to Tests 5B, 5D)

For the manufacturer-specified VAs, the system efficiency shall be $\geq 85\%$ when operating at full output power with the VA in the middle of the relevant Z range at center position, and when the GA input voltage and VA output voltage are at the mid-point (nominal) of the range. The efficiency shall be $\geq 80\%$ over the full range of variations specified in 8.2.2 to 8.2.4.

For operation with the applicable normative VAs, the system efficiency shall be per Table 9 when operating at the lower of the input kVA rating of the GA and the maximum output power of the VA, within the Z range specified in 8.2.2.2 and at the range of variations in the requirements in 8.2.2 to 8.2.4. Outside of the Z range specified for this Interoperability Class II GA, power transfer shall not be initiated.

Table 9 - Class II minimum system efficiency requirements

WPT Class Difference of Test VA	At Centered Position and Over Alignment Tolerance Area
Same Power Class	80%
One Power Class Difference	77%
Two Power Class Difference	75%

SAE J2954 WPT shall be tested for efficiency according to 15.1.7 and shall not exceed the acceptable heat generation.

8.3 Ramp Rates and Control Loop Bandwidth (Informational: Requirements Apply to Tests 5A, 5B, 5C, 5D)

The GA and VA together form a closed-loop control system, with possible separate but interacting closed or open-loop control systems on the GA and VA.

In all interoperable testing scenarios, the criteria in 13.2.3 shall be met.

8.4 Interoperability Across Power Classes (Informational: Requirements Apply to Tests 5A, 5B, 5D)

Interoperability Class I GAs, which are required to meet the WPT3 input level, shall also be able to meet the requirements for WPT2 and WPT1 GAs.

Interoperability Class II GAs shall meet the requirements for input kVA range from minimum WPT1 level to the maximum input power specified by the manufacturer.

8.5 Interoperability Regarding Z Class (Informational: Requirements Apply to Tests 5A, 5B, 5D, 6A, 6B, 6D)

Interoperability Class I GAs shall work with VAs of any Z class.

Interoperability Class II GAs are designed to work at a specific VA ground clearance range. VAs outside of this range are not compatible and as a result, power transfer shall not be initiated.

8.6 Allowance for Reactance Variation (in the GA) (Informational: Requirements Apply to Tests 5A, 5B)

The GA coil reactance will vary due to changes in VA height or alignment, or variations in the values of the electronic components. The system shall be able to operate with and/or compensate for this variation. Compensation can reduce stress on the GA electronics, and reduce loss associated with higher inverter currents and the presence of harmonics.

An alternative approach to determining the suitability of a GA that includes new Product GA coils and/or Product GA electronics is presented in Informative Appendix J. This approach has yet to be fully evaluated, agreed to, and validated. The intention is to remove critical dependence during design phases on the Test Station GAs and Test Station VAs.

8.7 Safety Requirements

8.7.1 Safe Operation/Non-Operation (Informational: Requirements Apply to Tests 5A, 5B, 5C, 5D, 6A, 6B, 6C, 6D)

If the exchange of information between the VA and GA does not confirm compatibility, power transfer shall not be initiated. If the vehicle is not aligned within the alignment tolerance specified in 8.2.2, the VA and GA shall be able to guarantee that all EMF requirements are met; otherwise, power transfer shall not be initiated. If power transfer has already been initialized but the VA is moved outside the alignment tolerance, then EMF requirements shall be guaranteed to be met; otherwise, power transfer shall be immediately terminated.

8.7.2 Heating of Foreign Object (Informational: Requirements Apply to Tests 5A, 5B)

The magnetic fields used in wireless power transfer can cause heating of metallic objects. As a result, a hazard could exist if the object causes ignition of flammable material; if the object is hot when it becomes accessible; or the object could become so hot, even while not accessible, to cause damage to the GA coil package surface.

Section 16.2 and sub-sections specify tests for minimum requirements to prevent damage from these hazards. A manufacturer might specify additional requirements based on the specifics of the coil design and detection system.

8.7.3 Exposure to Electromagnetic Fields

High levels of time-varying electromagnetic fields may be a hazard to humans. ICNIRP has issued guidelines in 1998, 2010, and 2020 specifying recommended exposure limits for given frequencies. These limits are based on a large safety margin to ensure no adverse health effects due to heating or nerve stimulation.

Guidelines for exposure to electromagnetic fields have also been developed for users of implanted medical devices, such as cardiac implantable electronic devices (CIED).

8.7.3.1 Cardiac Implantable Electronic Devices (Informational: Requirements Apply to Tests 2A, 2B, 2C, 2D)

For the safety of CIEDs, requirements and testing methods are specified in Section 10.

8.7.3.2 Living Object Protection (LOP) (Informational: Requirements Apply to Tests 2A, 2B, 5A, 5B)

For living object protection (LOP) in accessible areas of the vehicle, the electromagnetic fields shall be less than the applicable ICNIRP recommended limits, measured as specified in Section 10.

In order to transfer power at levels called for in this standard, the field strength under the vehicle is likely to be much higher than the ICNIRP recommended limits. This area is generally considered to be inaccessible under normal circumstances. However, if a person does attempt to reach under the vehicle while power is being transferred, the system shall detect such an intrusion into the area where the fields are above ICNIRP levels and cause immediate system shutdown. See 16.2.2.

9. ELECTROMAGNETIC COMPATIBILITY/ELECTROMAGNETIC EMISSIONS (Informational: Requirements Apply to Tests 4A, 4B, 4C, 4D, 7A, 7B, 7C, 7D)

This section addresses electromagnetic compatibility (EMC); electromagnetic safety (EMF) is covered in Section 10. This section applies to all Product GAs and Product VAs.

This section is informative; it contains suggestions for process, but normative requirements are based on the geographic region of use. Systems should be tested for EMC compliance using a reference device in Appendices A or B.

EMC testing is separated into two parts: component testing and vehicle testing. While component testing can provide valuable data, vehicle-level EMC testing should be used to determine compliance with applicable regulatory requirements of the complete system for specific standalone systems as supplied by the vehicle OEM for private use.

If the WPT system is to be sold as aftermarket or for public use (as in the case of a charge station with GA), then an appropriate vehicle mimic shall be used and shall meet all regulations for the region of intended use.

9.1 Component EMC (Informational: Requirements Apply to Tests 4A, 4B, 4C, 4D, 7A, 7B, 7C, 7D)

Component-level tests should be performed before integration into a vehicle system. The component-level EMC testing is for evaluation purposes only. Table 10 is to be used as guide to determine which tests may need to be completed on the components.

Table 10 - Component-level EMC - off-board components

Test Parameters		Test Documentation		Test Limits per Use Environment ¹	
Interface	Mode	Description	Standard	Residential	Occupational
EMI	AC Power	Charging and Standby	Harmonics	IEC 61000-3-2 (<16 A) IEC 61000-3-12 (<75 A)	Class A limits as defined in standard (2nd to 40th harmonics)
	AC Power	Charging and Standby	Fluctuations and Flicker	IEC 61000-3-3 (<16 A) IEC 61000-3-11 (<75 A)	Class A limits as defined in standard (2nd to 40th harmonics)
	AC Power	Charging and Standby	Conducted Emissions	FCC 18/15	$P_{st} < 1.0$, $P_{lt} < 0.6$ $d_c < 3.3\%$, $d_{max} < 4$ to 7% device dependent $d(t) > 3.3\%$ only <500 ms
	Comm Lines	Charging and Standby	Conducted Emissions	FCC 15	$P_{st} < 1.0$, $P_{lt} < 0.6$ $d_c < 3.3\%$, $d_{max} < 4$ to 7% device dependent $d(t) > 3.3\%$ only <500 ms
	WPT System Level	Charging and Standby	Radiated Emissions	FCC 18	150 kHz to 30 MHz
	WPT System Level	Charging and Standby	Radiated Emissions	FCC 15	150 kHz to 30 MHz
CW EMS	AC Power	Charging and Standby	Conducted Immunity	IEC 61000-4-6	150 kHz to 30 MHz
	WPT System Level	Charging and Standby	Radiated Immunity	IEC 61000-4-3	150 kHz to 80 MHz: 30 Vrms 80 MHz to 1 GHz: 30 V/m 1 GHz to 4.2 GHz: 3 V/m 2 GHz to 2.7 GHz: 3 V/m
	WPT System Level	Charging and Standby	Magnetic Field Immunity	IEC 61000-4-8	30 A/m
TRANSIENT EMS	WPT System Level	Charging and Standby	ESD	IEC 61000-4-2	8 kV/4 kV air/contact
	AC Power	Charging and Standby	EFT	IEC 61000-4-4	1 kV (5/50 ns, 100 kHz)
	AC Power	Charging	Surge	IEC 61000-6-2 (IEC 61000-4-5)	2 kV (5/50 ns, 100 kHz)
	Signal Line	Charging	Surge	IEC 61000-6-2 (IEC 61000-4-5)	1 kV Line-to-Line 2 kV Line-to-Ground
	AC Power	Charging and Standby	Voltage Dips and Interrupts	IEC 61000-4-11 (<16 A) IEC 61000-4-34 (>16 A)	1 kV Line-to-Line 2 kV Line-to-Ground
	AC Power	Charging and Standby	Harmonic Distortion	IEC 60204-1	1 kV Line-to-Ground

¹ Please refer to the referenced standard for complete test limits and conditions.

² FCC Part 15 states that the 10th harmonic of the highest fundamental be captured for intentional radiators.

For all component-level testing, the default vehicle mimic pan is accomplished by the use of a metal plate (e.g., high strength steel) with minimum dimensions of 1.5 x 1.5 m, with a thickness of 0.7 to 1 mm. These minimum dimensions of the plate have been shown to reasonably simulate the smallest actual electric vehicle.

9.1.1 Electromagnetic Immunity (Informational: Requirements Apply to Tests 7A, 7B, 7C, 7D)

The component-level wireless charging system should be tested to the requirements for electromagnetic field immunity, refer to IEC61000-4-3; 80 to 1000 MHz, 30 V/m carrier test severity level; 1000 to 2000 MHz, 3 V/m carrier test severity level. See Figure 6 for setup for testing the charge station and Figures 7 and 8 for testing of charging to vehicle components.

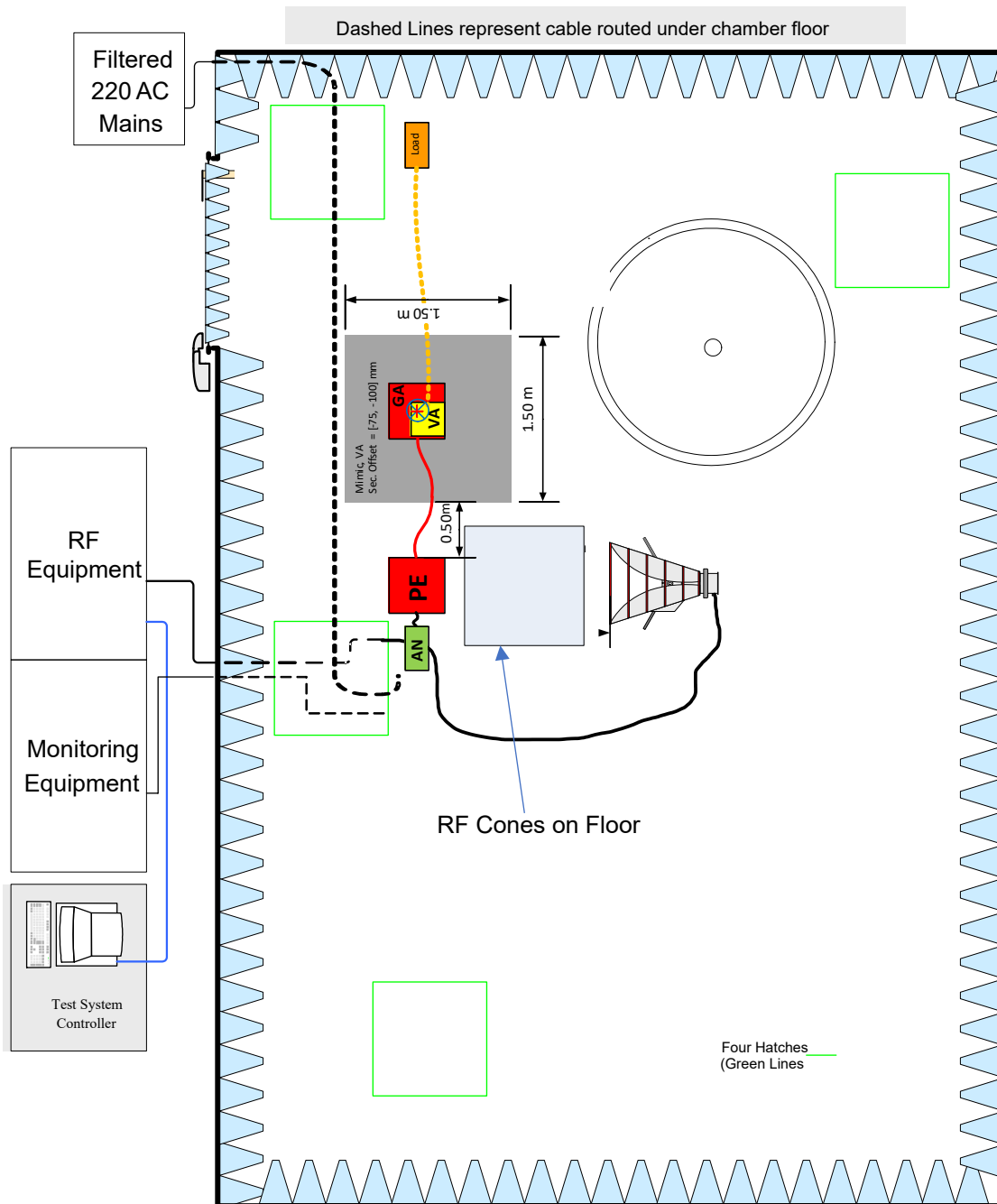


Figure 6 - RI ALSE test setup for component-level wireless charging system for base station top view

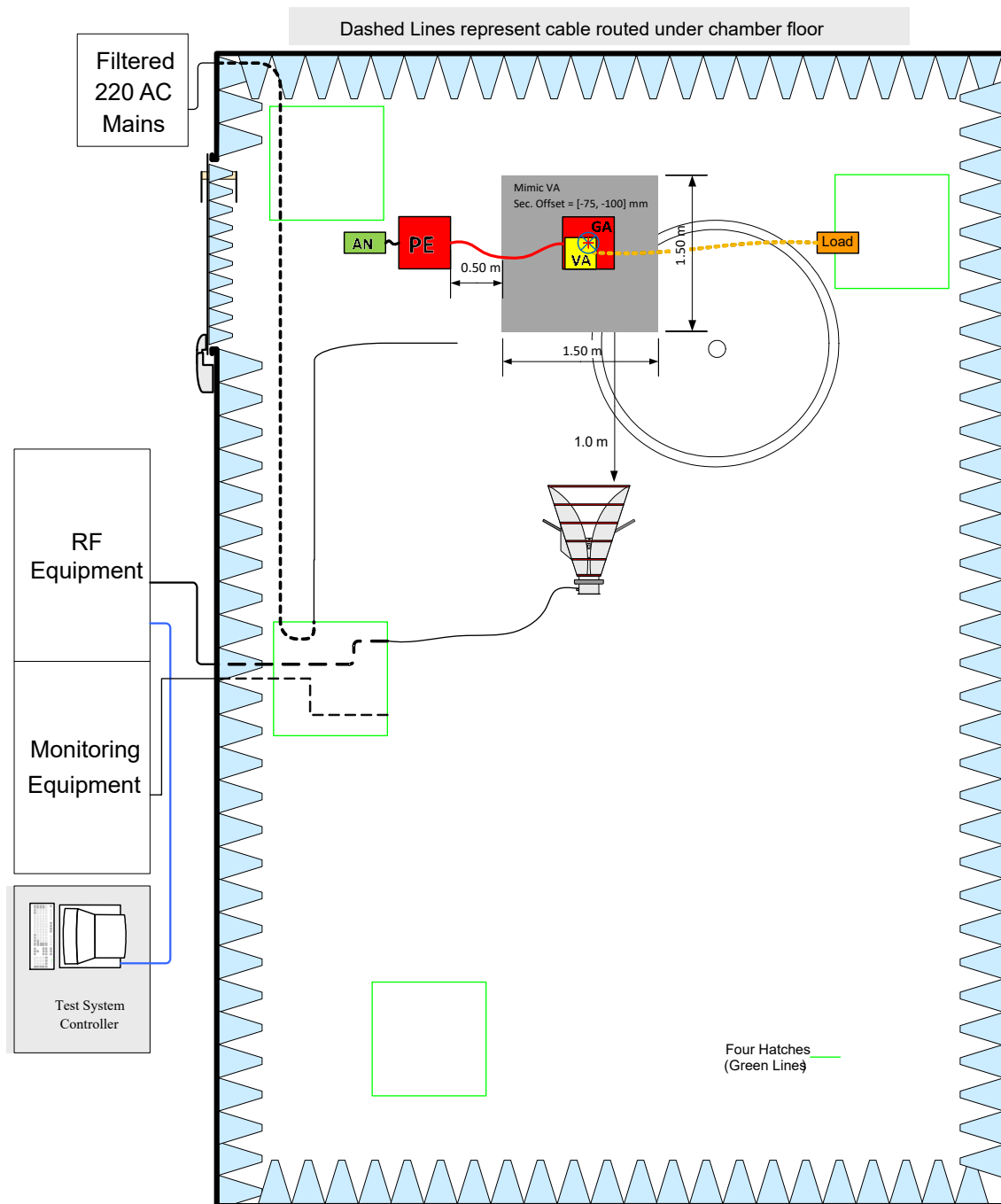


Figure 7 - RI ALSE test setup for component-level wireless charging system for vehicle components top view

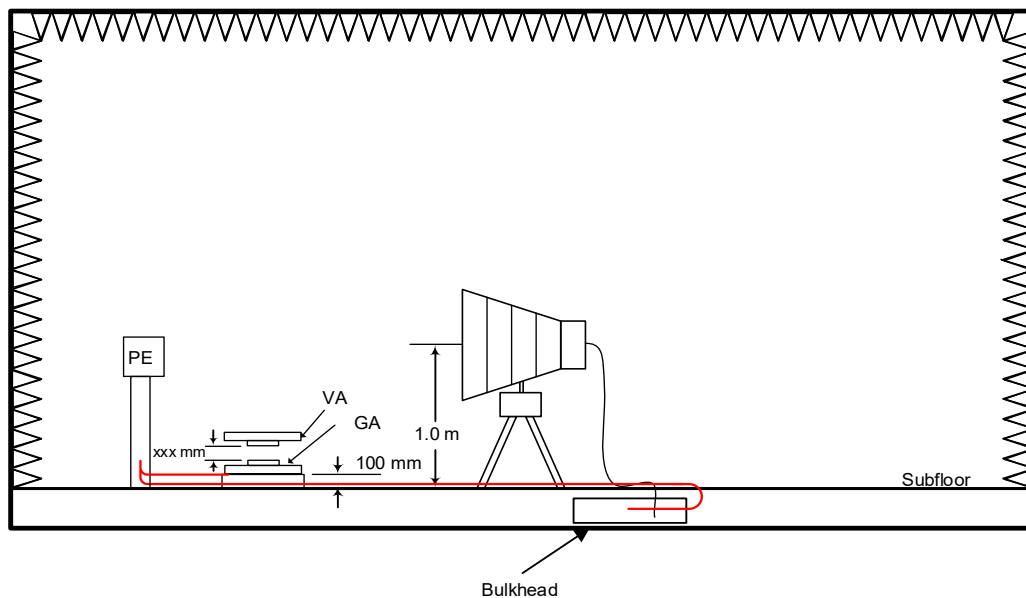


Figure 8 - RI ALSE test setup for component-level wireless charging system for vehicle components side view

The component-level wireless charging system should be tested to the requirements of RF CDN (coupling/decoupling network) injection 150 kHz to 80 MHz IEC 61000-4-6, using a 30 Vrms EMF test severity level.

9.1.2 Radiated Emissions (Informational: Requirements Apply to Tests 4A, 4B, 4C, 4D, 7A, 7B, 7C, 7D)

The wireless charging system shall be tested to the requirements for radiated emissions; refer to FCC Part 18. Measurement at antenna distances of either 3 m or 10 m is allowed. It is recommended to use an antenna distance of 10 m. Measurement at other antenna distances is allowed; reference ANSI C63.30 for the proper scaling factors. The recommended limit for the frequency range of 79.00 to 90.00 kHz is 82.8 dBμA/m (limits shall be reduced by 15 dB to 67.8 dBμA/m for EV WPT installations within a distance of 10 m from known sensitive equipment in public spaces), as indicated in Figure 10. The recommended setup is shown in Figure 9, which illustrates an SAE J2954 Test Station system on a turntable.

The emission of the fundamental is to be scanned at a maximum turntable angle step size of 22.5 degrees. Once the maximum emission is found using a maximum step size of 22.5 degrees, more precise measurement of the maximum emission may be determined by reducing the turntable angle increment.

Testing shall be done over a metal ground plane at an open area test site (OATS). Testing in an absorber-lined shielded enclosure (ALSE) may be utilized if it can be shown to have correlation to OATS. If testing over an outdoor test site (OTS), the limits should be adjusted accordingly based on the correlation to the OATS.

Limits and test methods for EV WPT are presently under review globally by various regulatory bodies. Presently, there are efforts on-going to develop this assessment, showing that ALSE results correlate with results from OATS. These are only recommended limits based on classifying the WPT function as FCC part 18 below 30 MHz. The Test Station system measurement setup and limits are presently under development with CISPR 11, CISPR 25, and ANSI C63.30.

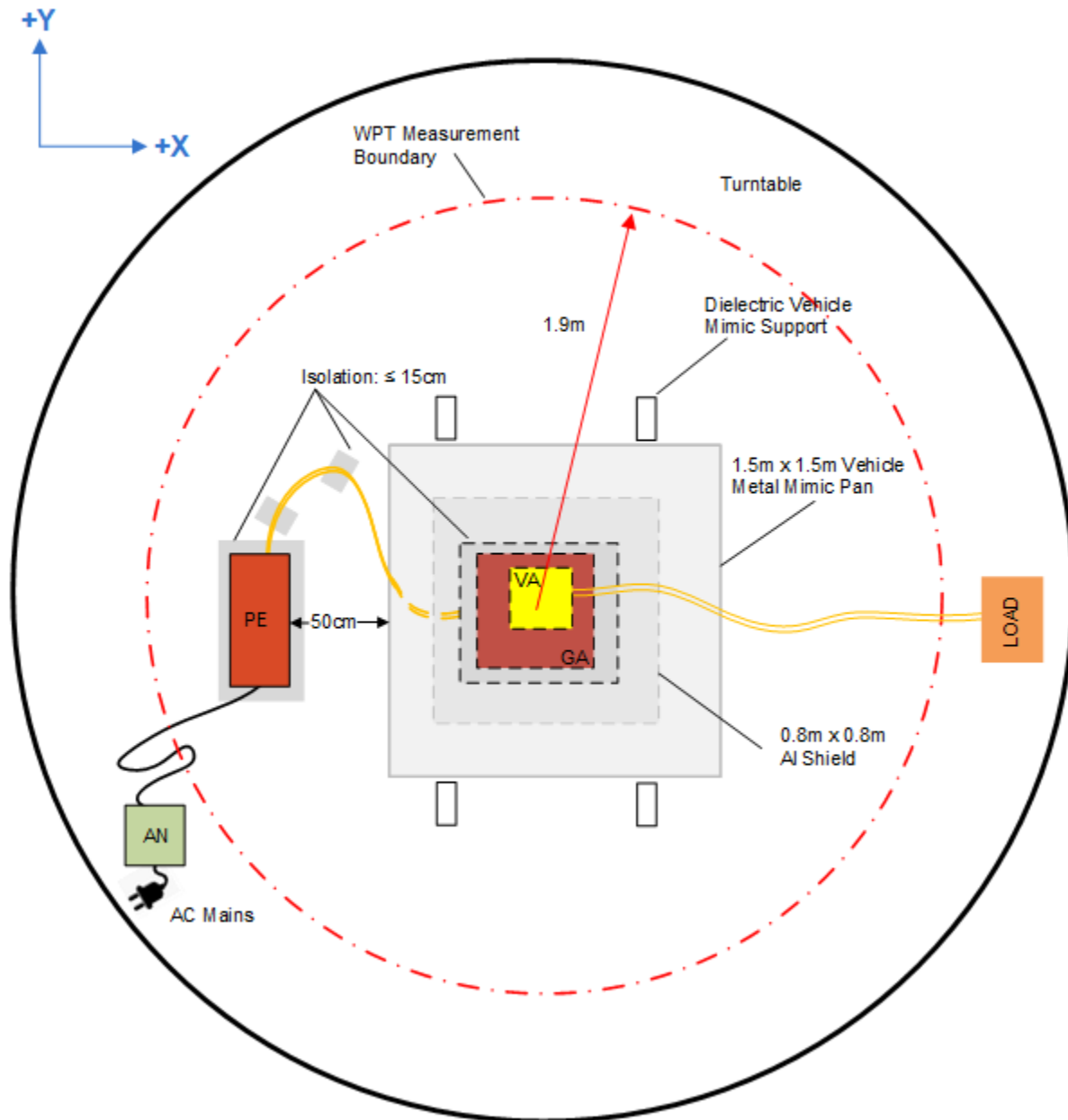


Figure 9A - Recommended test setup, top view, for radiated emissions testing of SAE J2954 Test Station system with power electronics in the front position

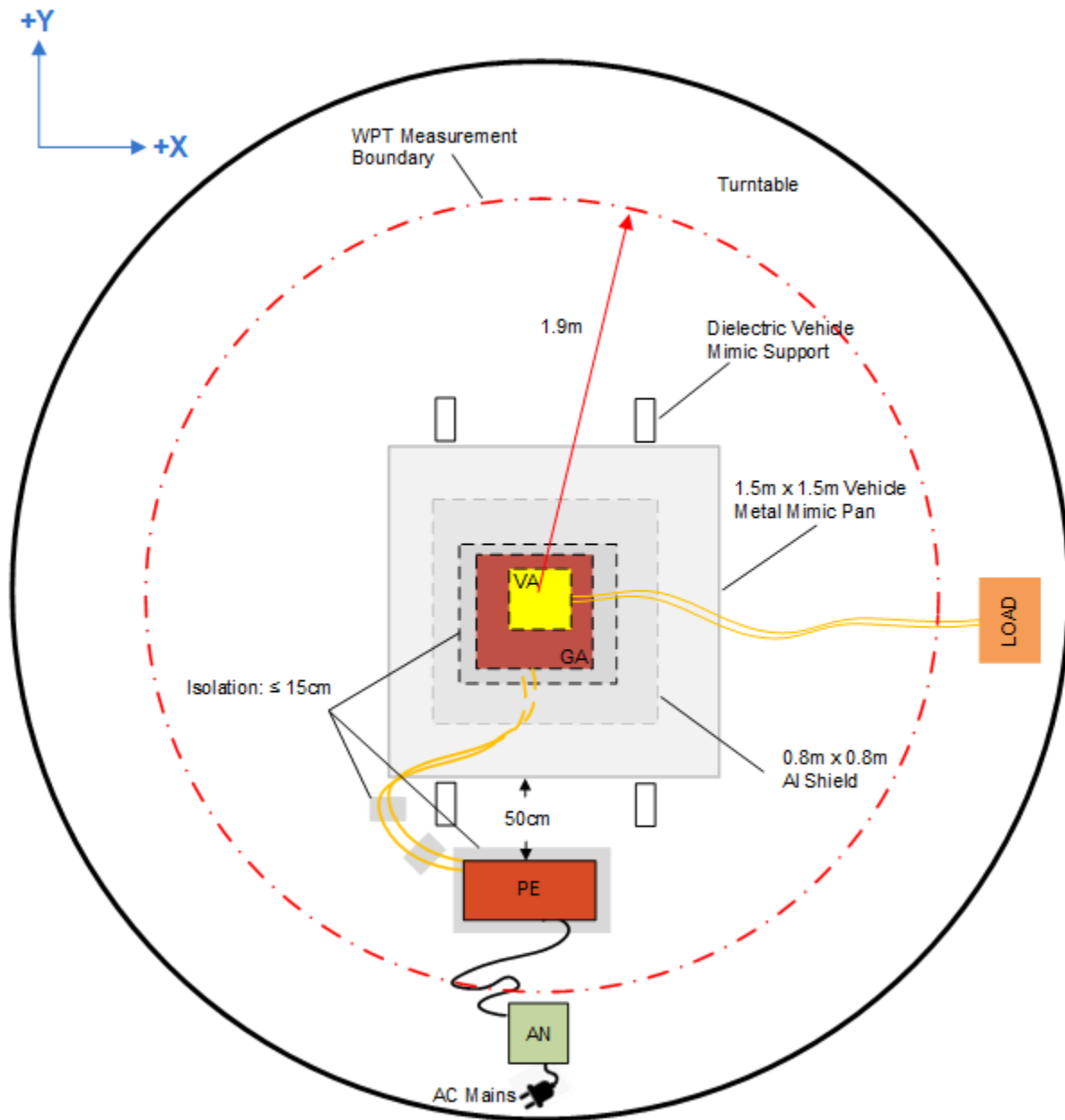


Figure 9B - Recommended test setup, top view, for radiated emissions testing of SAE J2954 Test Station system with power electronics in the side position

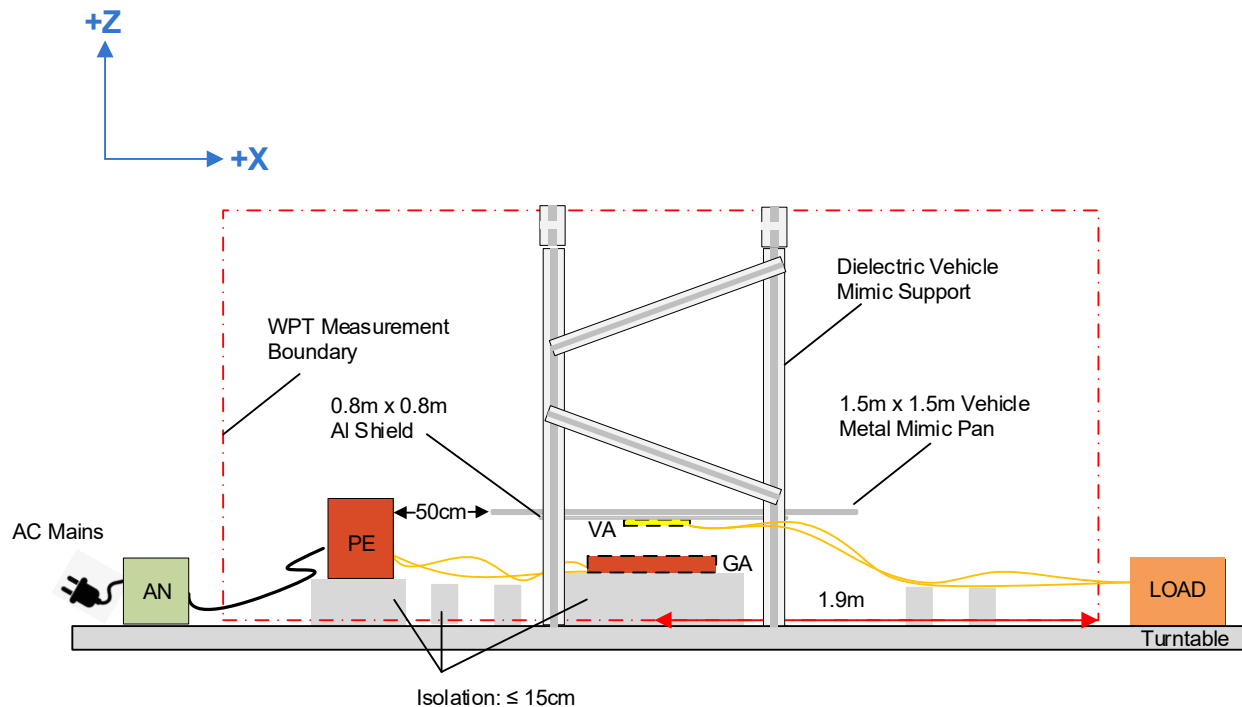


Figure 9C - Recommended test setup, side view, for radiated emissions testing of SAE J2954 Test Station system with power electronics in the front position

Notes for recommended test setup of radiated emissions testing of SAE J2954 Test Station system:

- Distance is measured from antenna to 1.9 m fixed radius ring centered on the GA.
- VA and vehicle mimic assembly are shifted by [dX, dY] relative to the GA to achieve offset conditions.
- The GA and the VA are raised above the ground plane using a spacer up to 15 cm. The GA coil package can have a large area which can inadvertently be capacitively coupled with the ground plane. Given this, the GA coil package needs to be raised up near 15 cm. All spacers need to be non-magnetic and non-metallic materials. The vehicle spacer cannot have direct metallic contact with the ground plane.
- Figures 9A to 9C show the typical position of the PE relative to the WPT system. For testing of the specific system, placement of PE is as specified by the manufacturer of the WPT system.
- Use of Artificial Mains Network (AN) and/or a Common Mode Absorption Device (CMAD) is recommended on the AC mains feed to the GA for radiated emissions testing only.
- Note that the z-height is to be measured from the surface of the VA facing down to the bottom side of the GA. This is known as the VA coil ground clearance.

Unintentional Radiators: The emissions from electronic devices within the vehicle-level wireless charging system not related to the power transfer frequency shall meet FCC Part 15, Subpart B, radiated limits for unintentional radiators. In countries outside the USA, other radiated emission limits may apply. The emissions from electronic devices within the component-level wireless charging system not related to the power transfer function should meet FCC Part 15, Subpart B, radiated limits for unintentional radiators. In countries outside the USA, other radiated emission limits may apply.

Intentional Radiators: The emissions from RF communications devices within the vehicle-level wireless charging system shall meet FCC Part 15, Subpart C, requirements for intentional radiators. The emissions from RF communications devices within the component-level wireless charging system should meet FCC Part 15, Subpart C, requirements for intentional radiators (e.g., Wi-Fi, Bluetooth, LTE, etc.).

9.1.3 Conducted Emissions (Informational: Requirements Apply to Tests 7A, 7B)

The conducted emissions for the WPT function (not wireless communication devices) within the system should meet FCC Part 18 requirements on a vehicle level.

The emissions from electronic devices (not related to the power transfer frequency) within the component-level wireless charging system should meet FCC Part 15, Subpart B, conducted limits for unintentional radiators.

Conducted emissions from intentional radiators (i.e., communication devices) shall meet the requirements of FCC Part 15, Subpart C.

9.1.4 Electrostatic Discharge (ESD)

The component-level wireless charging system should be tested to the requirements for ESD; refer to IEC 61000-4-2.

9.1.5 Harmonic Distortion Immunity

The component-level wireless charging system should be tested to the requirements for harmonic distortion immunity; refer to IEC 60204-1.

9.1.6 Electrical Fast Transients

The component-level wireless charging system should be tested to the requirements for electrical fast transient immunity; refer to IEC 61000-6-2.

9.1.7 Voltage Dips, Short Interruptions, and Voltage Variations Immunity

The component-level wireless charging system should be tested to the voltage dips, short interruptions, and voltage variations immunity; refer to IEC 61000-4-11.

9.1.8 Magnetic Field Immunity

The component-level wireless charging system should be tested for magnetic field immunity; refer to IEC 61000-4-8.

9.1.9 EMC Tests - On-Board Vehicle Electronic Components (Informational: Requirements Apply to Tests 7C, 7D)

On-vehicle electronic modules intended for sale to a vehicle Original Equipment Manufacturer (OEM) shall be validated per OEM-specific EMC requirements. If the vehicle OEM is not known, at a minimum, the following automotive component EMC tests are required for on-board electronics during normal operation of vehicle (but not necessarily when the WPT system is active). The intention of this chapter is to ensure EMC of on-board electronics under normal vehicle operation.

The following standards apply to the above-mentioned measurements: CISPR 25 Chapters 6.2 and 6.4, ISO 11452-2, ISO 11452-4, ISO 7637-2, ISO 7637-3, and ISO 10605.

9.2 Vehicle-Level EMC Tests

9.2.1 Radiated Emissions Due to Wireless Power Transfer (Informational: Requirements Apply to Tests 7A, 7B, 7C, 7D)

The fundamental frequency for WPT is the operating frequency within the tuning band (79.00 to 90 kHz). The compliance of the product is dependent on testing the system installed on the intended vehicle and having radiated emissions below regulatory limits set by the specific country of intended use. The vehicle measurement procedure is presently under development with CISPR 11, CISPR 12, and ANSI C63.30.

The SAE J2954 recommended limits are shown in Figure 10. The recommended limit for the operating frequency range of 79.00 to 90.00 kHz is 82.8 dB μ A/m (limits shall be reduced by 15 dB to 67.8 dB μ A/m for EV WPT installations within a distance of 10 m from known sensitive equipment in public spaces). The recommended setup is shown in Figure 11. The figure illustrates the vehicle on turntable.

The measurement method and test environment are according to the test described in 9.1.2. When the system is not in WPT mode and vehicle is not present, systems not on vehicle shall meet all applicable regulations and systems on vehicle shall meet the requirements set forth by the specific vehicle OEM. Please note that the ANSI C63.30 standard includes procedures for compliance testing of several different types of WPT products with applicable electromagnetic compatibility (EMC) and radio regulatory requirements. The test procedures in ANSI C63.30 focus on radiated field and conducted measurements and refers to established standards. Consideration is also given to appropriate testing distances and test locations (such as semi-anechoic chambers, OATs, ground plane, and earth sites). Related national and international standards (e.g., CISPR, SAE, etc.) are used to the extent possible. Laboratory EMF and CIED management guidelines are given in 10.9.

9.2.1.1 Unintentional Radiation (Informational: Requirements Apply to Tests 7A, 7B, 7C, 7D)

The emissions from electronic devices not related to the wireless power transfer frequency shall meet FCC Title 47, Part 15, Subpart B, radiated limits for unintentional radiators. In countries outside the USA, other radiated emission limits may apply.

9.2.1.2 Intentional Radiation (Informational: Requirements Apply to Tests 7A, 7B, 7C, 7D)

The emissions from all RF communications devices that are classified as intentional radiators according to FCC within WPT systems shall meet FCC Part 15, Subpart C, requirements for intentional radiators (e.g., Wi-Fi, Bluetooth, LTE, etc.).

The emissions from the WPT system are classified as Industrial Scientific and Medical (ISM) and shall meet FCC Title 47, Part 18 requirements with modifications for the fundamental frequency in the range of 79 to 90 kHz as shown in Figure 10.

SAE J2954 WPT Radiated EMI Limit Proposals

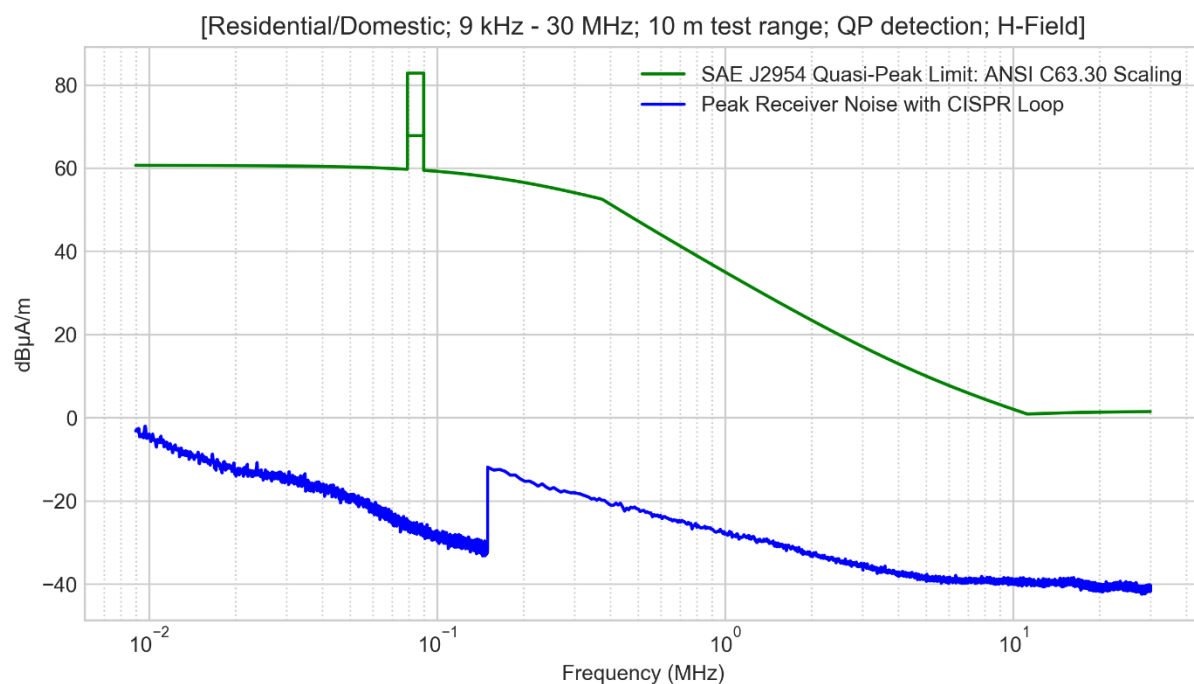


Figure 10 - Recommended limits

The recommended limit for the frequency range of 79.00 to 90.00 kHz for WPT is 82.8 dBuA/m. The recommended limits are for a 10 m antenna distance.

NOTE: Limits may be reduced based on regional regulatory requirements. For example, limits may be reduced by 15 dB to 67.8 dBuA/m for EV WPT installations within a distance of 10m from known sensitive equipment in public spaces.

NOTE: Additional regulatory limits specific to applicable regions shall be met.

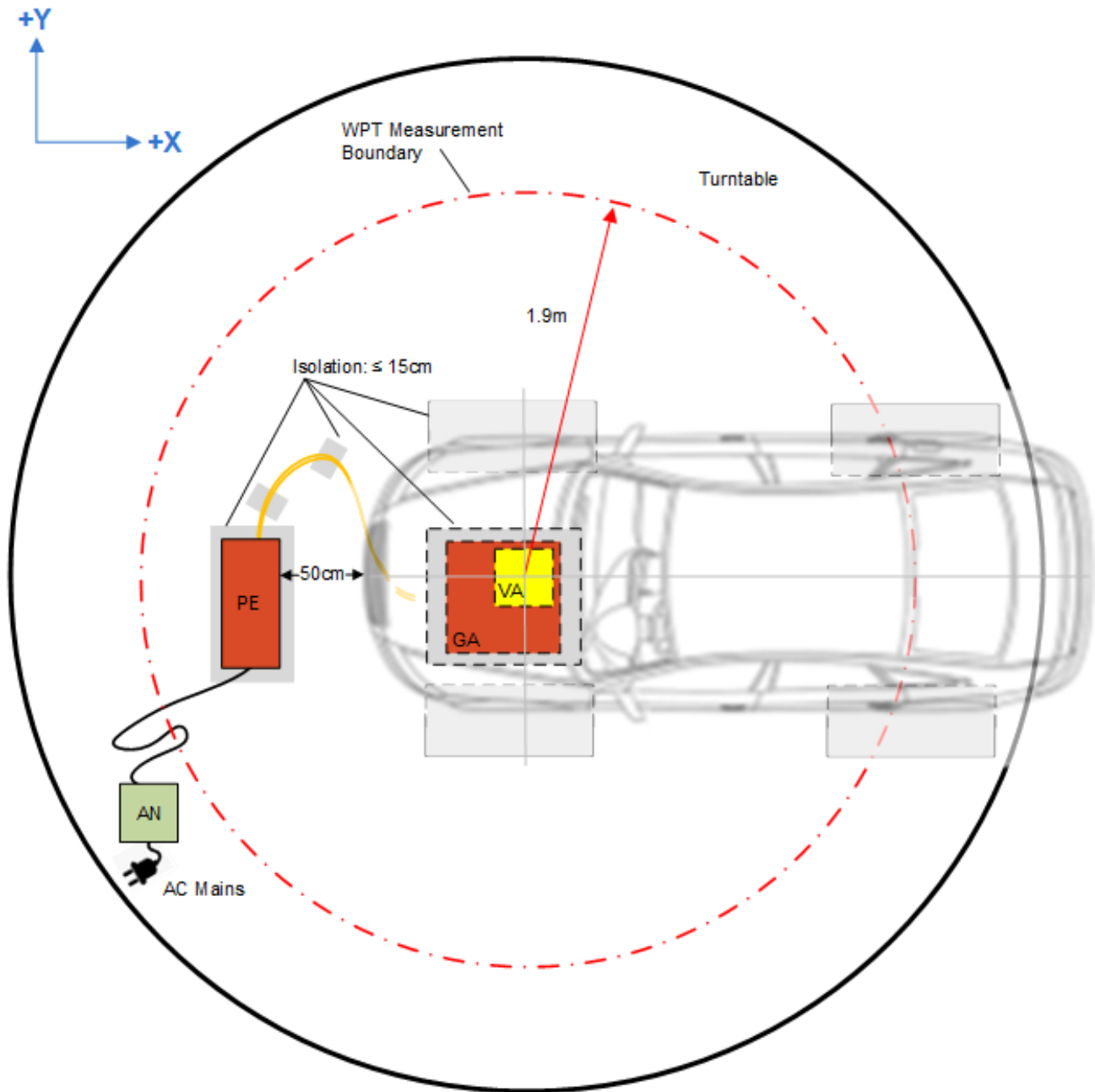


Figure 11A - Recommended setup, top view, for vehicle radiated emissions testing with power electronics in the front position

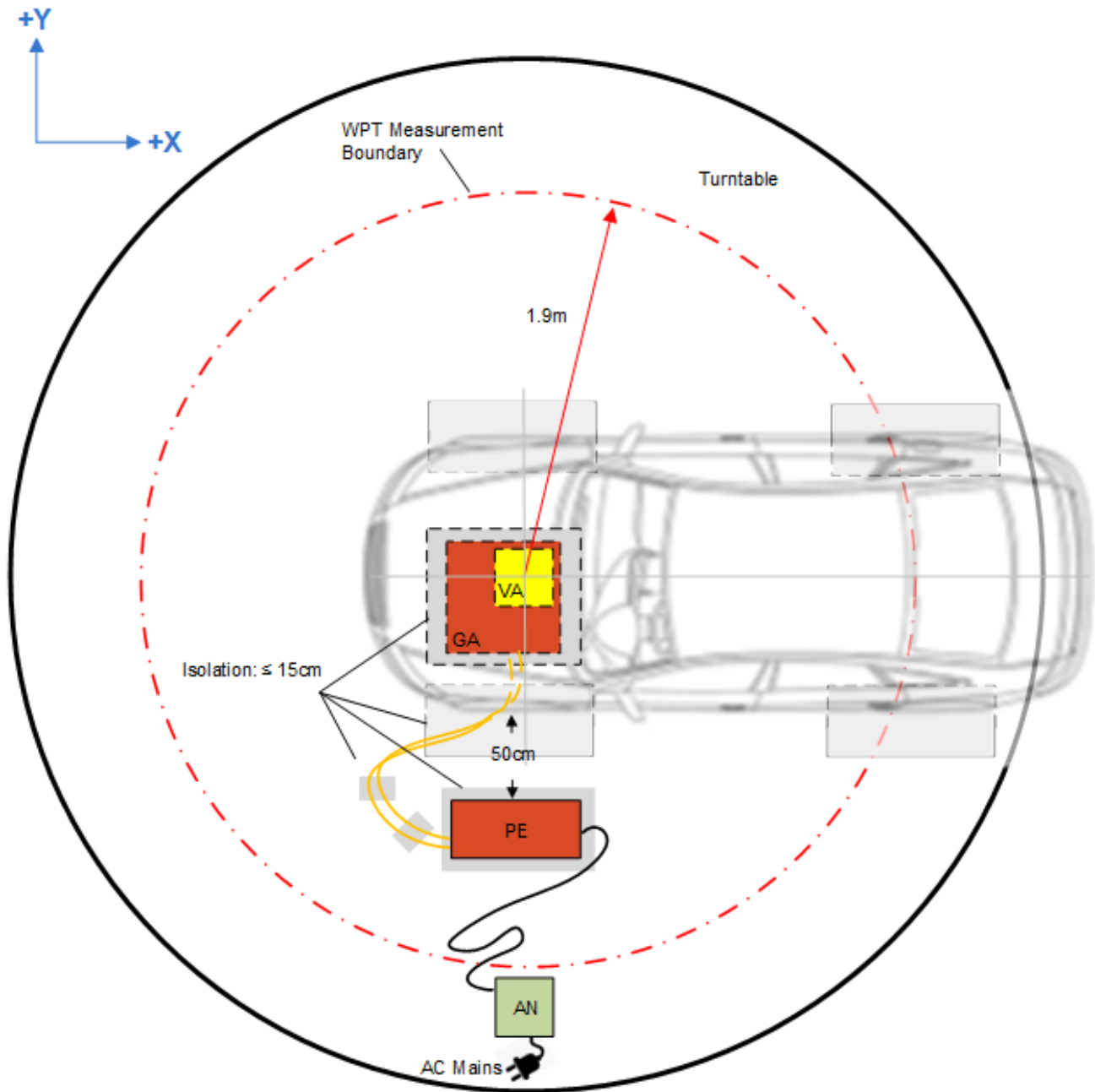


Figure 11B - Recommended setup, top view, for vehicle radiated emissions testing with power electronics in the side position

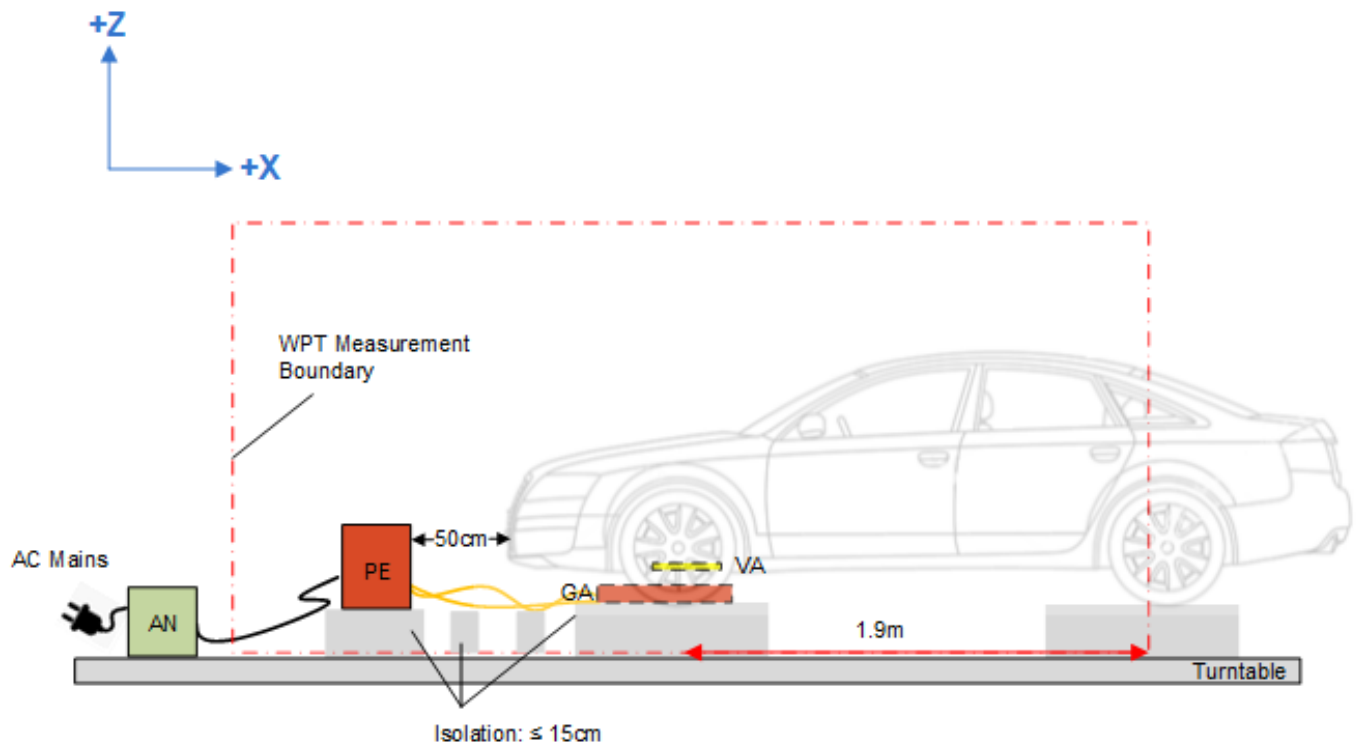


Figure 11C - Recommended setup, side view, for vehicle radiated emissions testing with power electronics in the front position

Notes for recommended setup of vehicle radiated emissions testing:

- Distance is measured from antenna to 1.9 m fixed radius ring centered on the VA.
- GA is shifted by $[-dX, -dY]$ to achieve same relative offset conditions as in mimic testing.
- Clearance between vehicle and power electronics is recommended to be 50 cm.
- In case of vehicle testing on a turntable, etc., the VA should be the center of the rotation due to weight, etc.
- The GA and the vehicle are raised above the ground plane using a spacer up to 15 cm. The GA coil package can have a large area which can inadvertently be capacitively coupled with the ground plane. Given this, the GA coil package needs to be raised up near 15 cm. All spacers need to be non-magnetic and non-metallic materials. The vehicle spacer cannot have direct metallic contact with the ground plane.
- Figures 11A to 11C show the typical position of the PE relative to the WPT system. For testing of the specific system, the PE is placed as specified by the manufacturer.
- Use of an Artificial Mains Network (AN) and/or a Common Mode Absorption Device (CMAD) on the AC mains feed to the GA is recommended for radiated emissions testing only.
- Note that the z-height is to be measured from the surface of the VA facing down to the bottom side of the GA. This is known as the VA coil ground clearance.

9.2.2 Conducted Emissions, System Level (Informational: Requirements Apply to Tests 7A, 7B, 7C, 7D)

The conducted emissions for the WPT function (not wireless communication devices) within the system shall meet FCC Part 18 requirements.

The emissions from electronic devices not related to the wireless power transfer frequency shall meet FCC Title 47, Part 15, Subpart B, conducted limits for unintentional radiators.

Conducted emissions from intentional radiators (i.e., communication devices) shall meet the requirements of FCC Part 15, Subpart C.

The system shall meet all applicable in-country requirements for each country in which it is planned to be used; e.g., in certain countries, CISPR 11 requirements apply.

9.2.3 Radiated Immunity (Informational: Requirements Apply to Tests 7A, 7B, 7C, 7D)

Vehicle-level radiated immunity testing is to be conducted by the vehicle OEM according to their internal requirements and test methods.

The system shall meet all applicable in-country requirements for each country in which it is planned to be used; e.g., ECE REG 10 EMC requirements may apply in EC.

9.2.4 Conducted Immunity (Informational: Requirements Apply to Tests 7A, 7B, 7C, 7D)

Vehicle-level conducted immunity testing is to be conducted by the vehicle OEM according to their internal requirements and test methods.

The system shall meet all applicable in-country requirements for each country in which it is planned to be used; e.g., ECE REG 10 EMC requirements may apply in EC.

9.2.5 Electrostatic Discharge (ESD) (Informational: Requirements Apply to Tests 1A, 1B, 1C, 1D)

Vehicle-level ESD testing is to be conducted by the vehicle OEM according to their internal requirements and test methods.

The system shall meet all applicable in-country requirements for each country in which it is planned to be used; e.g., ECE REG 10 EMC requirements may apply in EC.

10. EMF EXPOSURE TO HUMANS AND CARDIAC IMPLANTABLE ELECTRONIC DEVICES (CIED)

10.1 General (Informational: Requirements Apply to Tests 2A, 2B, 2C, 2D)

Section 10 applies to all Product GAs and Product VAs. Human EMF exposure limits are based upon ICNIRP 2010 guidelines. Limits for implanted medical devices (IMD) other than cardiac implantable electronic devices (CIED) are under consideration, but CIEDs are considered worst case in terms of combined criticality, prevalence, and susceptibility potential. CIEDs are therefore the basis for CIED EMF limits in this standard. CIED WPT magnetic interoperability assessment limits are defined herein by setting CIED EMF reference levels in a manner analogous to ICNIRP limits.

EMF and related measurements in this Section 10 should NOT be made over a metallic ground plane, unless otherwise stated.

Three physical regions are defined to facilitate EMF safety management of the wireless charging system:

- Region 1 is the entire area underneath the vehicle, including and surrounding the wireless power assemblies. Region 1 shall not extend beyond lower body structure edges (e.g., rocker panels or lower edge of bumpers).
- Region 2 is the region outside the periphery of the vehicle. The boundary between Regions 1 and 2 extends downward from the lower periphery of the vehicle body sides. When the vehicle is not covering the GA, Region 2 includes the entire area over and around the GA.
- Region 3 is the vehicle interior.

The EMF management regions are illustrated in Figures 12 and 13. The following EMF safety management principles shall be adhered to for each respective region:

Region 1: The manufacturer shall take reasonable measures to prevent exposure of human beings in Region 1 to EMF levels exceeding the limits listed in Tables 11 or 12. Such exposures may be prevented in Region 1 by any of various means, including any of the following:

- a. Active or passive access control; i.e., preventing or barring a human being from entering that area when WPT is active.
- b. Detection and shutdown before ingress into areas where such exposure could occur.
- c. By meeting the human EMF exposure limits specified in Tables 11 or 12.

Regions 2 and 3: Magnetic fields shall meet the CIED EMF reference levels listed in Table 13 for any realistic CIED lead loop position associated with a reasonably foreseeable human body torso position in Regions 2 or 3. For all locations in Regions 2 and 3, the EMF shall also meet the EMF reference levels listed in Table 11, or the induced internal electric field basic restrictions listed in Table 12.

Regions 2 and 3: Touch currents shall meet the limits listed in Table 14.

The EMF management strategy shall be applicable for all operational conditions; e.g., coupler offset or other system variations which may affect the worst-case exposure.

In addition to the CIED and human EMF requirements, touch current requirements are given to prevent the possibility of startle-reaction for a person touching the vehicle and/or charging system during operation.

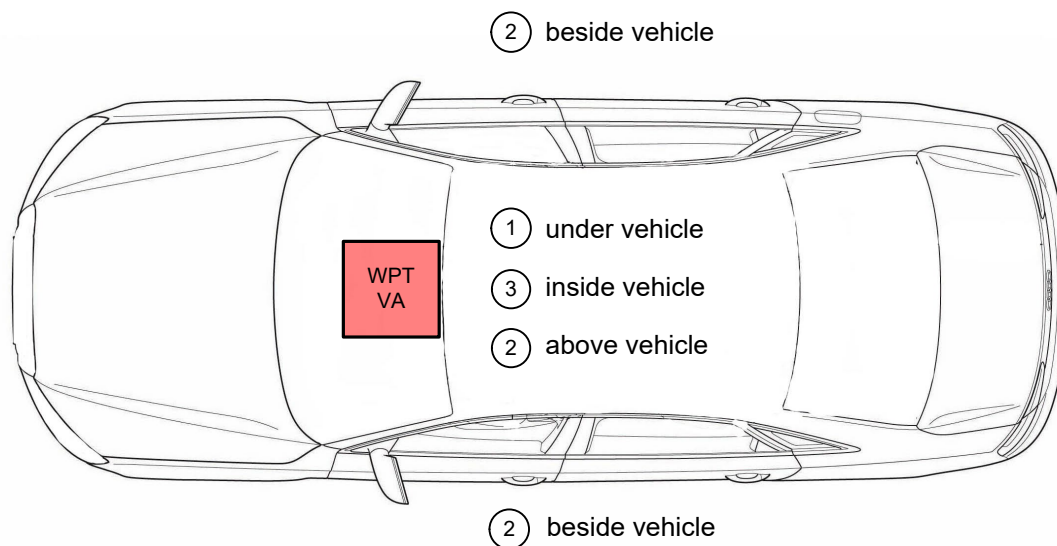


Figure 12 - EMF regions, top view

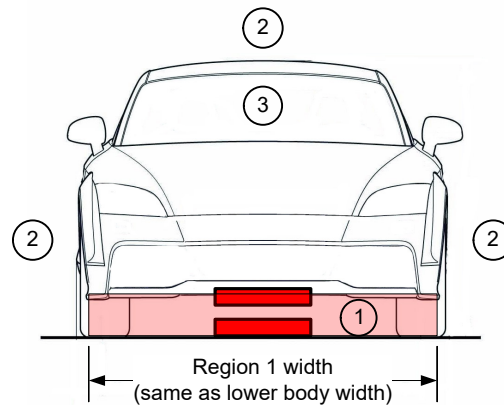


Figure 13 - EMF regions, front view

10.2 Vehicle-Level EMF Requirements (Informational: Requirements Apply to Tests 2A, 2B, 2C, 2D)

For any realistic location in Region 2 and 3, the CIED EMF Reference Limits are typically the most stringent. Measurements for CIED EMF reference levels in Region 2 shall be based on reasonable human body torso positions and so shall be made at most 20 cm from the vehicle. In Region 3, CIED EMF reference level measurements shall be based on reasonable human body torso positions.

For all locations in Regions 2 and 3, electric and magnetic fields shall comply with the guidelines for general public EMF exposure referenced in ICNIRP 2010. Compliance with the reference levels listed in Table 11 ensures compliance with the basic restrictions of the guideline, which are listed in Table 12. Recommended procedures for performing an EMF assessment using the basic restrictions are given in Appendix K.

NOTE: Additional regulatory restrictions on EMF may exist in some markets or regions.

The general public human EMF reference levels given in Table 11 are applicable from 3 kHz to 10 MHz, including the standard operating frequency of band of 79 to 90 kHz, and significant harmonics thereof.

Table 11 - Human EMF exposure standard, reference levels

Quantity	ICNIRP 2010 General Public Reference Level (rms Field Strength for 79-90 kHz)
Magnetic Field	27 μ T or 21.5 A/m ¹
Electric Field	83 V/m

¹ When using 100 cm² three-axis standard field probe for magnetic field measurements.

Table 12 - Human EMF exposure standard, basic restriction levels

Quantity	ICNIRP 2010 General Public Basic Restriction Level (rms Field Strength for 79-90 kHz)
Internal Electric Field	$1.35 \times 10^{-4} * f(\text{Hz}) = 11.475 \text{ V/m at } 85 \text{ kHz}$

NOTE: It is recognized that the ICNIRP 2010 guidelines recommend that the restrictions on internal electric fields induced by electric or magnetic fields, including transient or very short-term peak fields, be regarded as instantaneous values which should not be time averaged. The use of rms measurements and limits for EMF exposure assessment is predicated on the assumption that the WPT fields are continuous and sinusoidal during the rms averaging period, and do not contain transient overshoot. If the WPT fields are modulated, substantially non-sinusoidal, or include overshoot during amplitude transitions, the EMF assessments should be performed using peak limits equal to the rms limits times 1.41.

The use of spatial averaging (of multiple field probe positions) for human EMF exposure is not recommended until guidance is provided by EMF exposure standardization bodies, based on correlation analysis of wireless charger spatially averaged reference level versus spatial peak Basic Restriction dosimetry.

The CIED and human EMF exposure limits shall be met in Regions 2 and 3 under all normal (non-faulted) operating conditions of the wireless charging system, including coupler offset.

10.2.1 Cardiac Implantable Electronic Device (CIED) EMF Requirements (Informational: Requirements Apply to Tests 2A, 2B, 2C, 2D)

CIED WPT magnetic interoperability assessment limits are defined herein by setting CIED EMF reference levels in a manner analogous to ICNIRP limits. Based on the ISO 14117 Appendix M, it is expected that CIEDs operate as designed when 79 to 90 kHz magnetically induced lead voltages, in a 225 cm² loop area, are less than the levels defined as $V_{MAX\_INDUCED\_RMS} = \frac{3\sqrt{2}}{2} \text{ mV} \times \text{Frequency (kHz)}$ (e.g., 180.31 mVrms at 85 kHz). These voltages are the basis for the field limits in the SAE J2954 CIED EMF reference levels shown in Table 13, which shall not be exceeded for any realistic CIED lead loop position associated with a reasonably foreseeable human body torso position in Regions 2 or 3. Under the CIED EMF reference level measurement distance constraints described in 10.4, the Table 13 levels provide an alternative, but conservative, assessment of CIED WPT magnetic interoperability, utilizing the same 100 cm² field probe used for human EMF assessment. All field measurement limits are conservatively expressed as the magnitude (root sum squared) of the X, Y, and Z components of the magnetic field (e.g., $|B_{FIELD}| = \sqrt{B_X^2 + B_Y^2 + B_Z^2}$).

NOTE: If the WPT fields are modulated, substantially non-sinusoidal, or include overshoot during amplitude transitions, the CIED EMF assessments should be performed using peak limits equal to the rms limits times 1.41.

NOTE: The limits and precautionary measures for CIEDs may be revisited in the future based on data as per the ISO 14117 Committee. Additional limits for other IMDs are under consideration.

Table 13 - CIED EMF reference level

Quantity	Magnetic Field Limit Regions 2 and 3 (rms)
Magnetic Field Strength	15.0 μT or 11.9 A/m ¹ (for 79 to 90 kHz)

¹ These limits apply when using 100 cm² standard field probe, perform four measurements in a 2 x 2 grid and spaced at 7.5 cm (probe centered at each point) centered around the location of each reading above 15.0 μT . Average these four measurements.

10.3 Touch Current Requirements (Informational: Requirements Apply to Tests 1A, 1B, 1C, 1D, 2A, 2B, 2C, 2D)

Equipment shall meet the requirement for touch currents given in Table 14. The requirement is specified in terms of the output voltage U_2 of the IEC 60990 touch current measuring circuit weighted for perception or startle-reaction. This requirement level is chosen to correspond to the ICNIRP general public touch current reference level in the frequency range of 2.5 to 100 kHz.

The touch current limit applies to the current which can occur when a person comes in simultaneous contact with any two accessible conductive portions of the vehicle or charging system, or an accessible conductive portion of the vehicle or charging system, and ground. The magnitude of the touch current will depend on situational factors.

Table 14 - Touch current limits

Touch Current Limit	
Touch Current (ICNIRP units) (mA, rms) (Information Only)	IEC 60990 Measuring Circuit Output U ₂ (mV, rms) (Normative)
0.2 * f(kHz) (e.g., 15.8 mA at 79 kHz)	75

NOTE: If the WPT touch current measuring circuit output voltage U₂ is modulated, substantially non-sinusoidal, or includes overshoot during amplitude transitions, the touch current assessment should be performed using peak limits equal to the rms limits times 1.41.

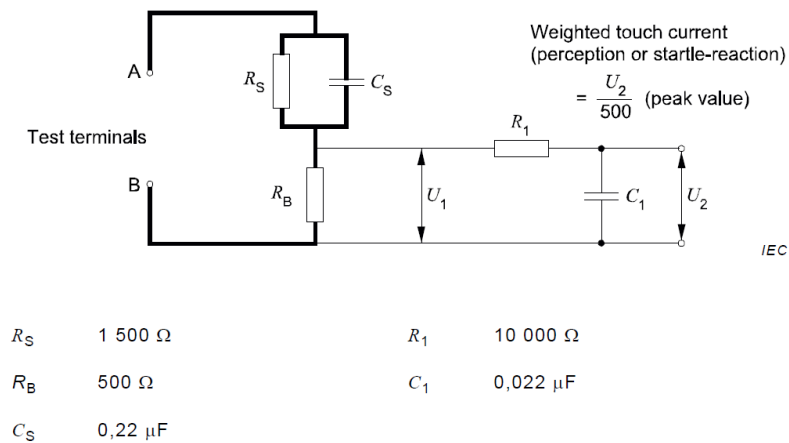


Figure 14 - IEC 60990 touch current measuring circuit

10.4 Vehicle Human/CIED EMF Assessment - General Considerations (Informational: Requirements Apply to Tests 2A, 2B, 2C, 2D)

Procedures for EMF assessment of vehicles with wireless chargers should be based on standardized EMF measurement procedures, to the degree they apply. Table 15 lists several applicable or related EMF measurement standards.

The objective of the following procedure is to determine compliance of the maximum magnetic and electric fields in Regions 2 and 3, for their respective worst-case gap and alignment (maximum offset) operating conditions and power levels. Although system controls may reduce power under misaligned or large gap conditions, maximum EMF may still occur under such conditions. Worst-case EMF may be associated with conditions producing maximum GA and/or VA coil current.

Probe movement during EMF measurements may be subject to an appropriate minimum distance(s) between the probe and nearby metallic surfaces or the Region 1 boundary or the GA when the vehicle is not present. The purpose of such probe distance restrictions is to improve reproducibility and avoid excessive overestimation of exposure, while maintaining correlation to the fundamental exposure metrics:

- For human EMF reference level assessments, the minimum probe distance shall be chosen such that compliance with the reference levels (Table 11) ensures compliance with the basic restrictions (Table 12).
- For CIED EMF reference level assessments, the minimum probe distance shall be chosen such that compliance with the CIED EMF reference levels (Table 13) conveys compliance with the ISO 14117 lead voltage test limits for uninfluenced device operation (based on an assumed 225 cm² lead loop area). The reference field level of 15 μT using a 100 cm² probe and averaging four points is conservatively chosen to ensure this limit is met.

For human EMF assessment, the probe tip shall be placed as close to the vehicle body as possible (e.g., less than 1 cm) in Region 2, and in the designated locations of Region 3. At the bottom edge of the vehicle, the plane of measurement (boundary of Region 1) shall extend directly downward from the lower edge of the vehicle as shown in Figure 13. For CIED EMF assessment, it is recommended that the minimum probe distance (to sensor perimeter) should be less than or equal to the minimum expected effective distance from a patient's implanted lead loop to the metallic surface or boundary in question. A conservative approach for human EMF assessment is to use no minimum distance; i.e., to allow the probe to touch all objects and boundaries. For human EMF assessment near non-metallic objects (e.g., seat cushions), no minimum distance shall be applied.

Depending on the relative values of minimum probe distances for human and CIED EMF measurements, and whether the basic restrictions are used for human EMF assessment, the human and CIED EMF assessments may be combined for efficiency. Figure 15 provides a recommended flowchart for combined human and CIED EMF assessments.

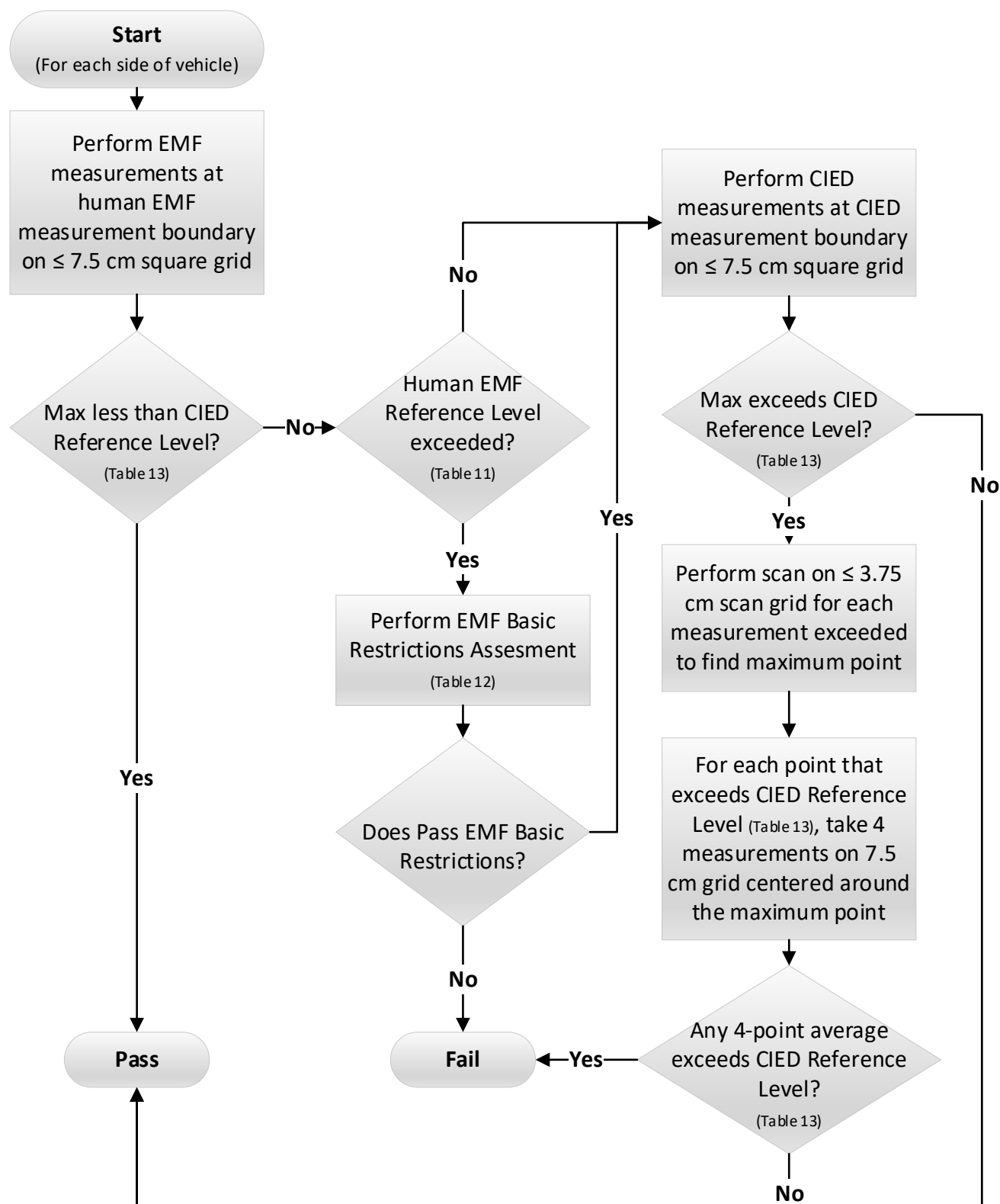


Figure 15 - Flowchart for combined EMF and CIED assessment

Table 15 - Reference EMF exposure measurement standards

Related Exposure Measurement Procedures (Informative)
IEC 60990: Methods of measurement of touch current and protective conductor current.
IEC 61786-2: Measurement of DC magnetic fields, AC magnetic and electric fields from 1 Hz to 100 kHz with regard to exposure of human beings. Part 2: Basic standard for measurements.
IEC TS 62764-1: Measurement procedures of magnetic field levels generated by electronic and electrical equipment in the automotive environment with respect to human exposure.
IEEE Std. C95.3: Recommended practice for measurements and computations of electric, magnetic, and electromagnetic fields with respect to human exposure to such fields, 0 Hz to 100 kHz.

10.5 Instrumentation (Informational: Requirements Apply to Tests 2A, 2B, 2C, 2D, 4A, 4B, 4C, 4D)

For magnetic and electric field EMF measurement using reference levels, and for CIED EMF reference level measurement, the following specifications apply:

- The instrument should utilize rms or peak detection, based on the considerations described in 10.2.
- An isotropic three-axis sensor should be used.
- The three sensors should be centered at the same point.
- The sensor shell should be spherical in shape, with a maximum external diameter of 12.5 cm.
- For magnetic field measurement, the three sensors should be circular with an area of 100 cm².
- A coarse resolution of 7.5 cm or less should be used when sweeping for peak values.

If the CIED reference level is exceeded during measurement, then an average at four designated points may be applied. The following method for determining a field average for the CIED reference level applies:

- Using a maximum resolution of 3.75 cm, sweep each region where the CIED reference level (15 μ T) is exceeded in Regions 2 or 3. Find and record (or mark) the location of highest reading.
- Designate an equally spaced 2 x 2 grid of 4 measurement points centered around the highest recorded point. The resolution of the grid should be 7.5 cm. The plane of the grid should be chosen to maximize the average reading in Regions 2 or 3.
- At each of the four grid points, record the field value (magnitude of all probe axes).
- Average all four points. The averaged result shall be less than the CIED reference level.

NOTE 1: If the field probe interferes with the ground (due to the peak occurring at or near the ground) then the 2 x 2 grid of four measurements can be moved up so that the field probe is touching the ground for the lower two measurements.

NOTE 2: If the spatial maximum falls on the border of the sampled data (not interfering with the ground) then additional data needs to be collected on that border to ensure sufficient data for performing the 4-point average.

In general, to facilitate the search for the spatial maximum fields within Region 2, it is recommended that appropriate means be devised and constructed to constrain the range of probe movement so that it does not enter Region 1 during testing. For example, a short vertical plastic barrier "wall" under the edge of the vehicle, enclosing Region 1, is suggested. The height of the wall should be at least equal to the vehicle ground clearance minus the radius of the probe.

A graphical representation of an example CIED reference scan is shown below. Note that it is possible the maximum point be off the original 7.5 cm grid so care should be taken to find the actual maximum before performing the averaging.

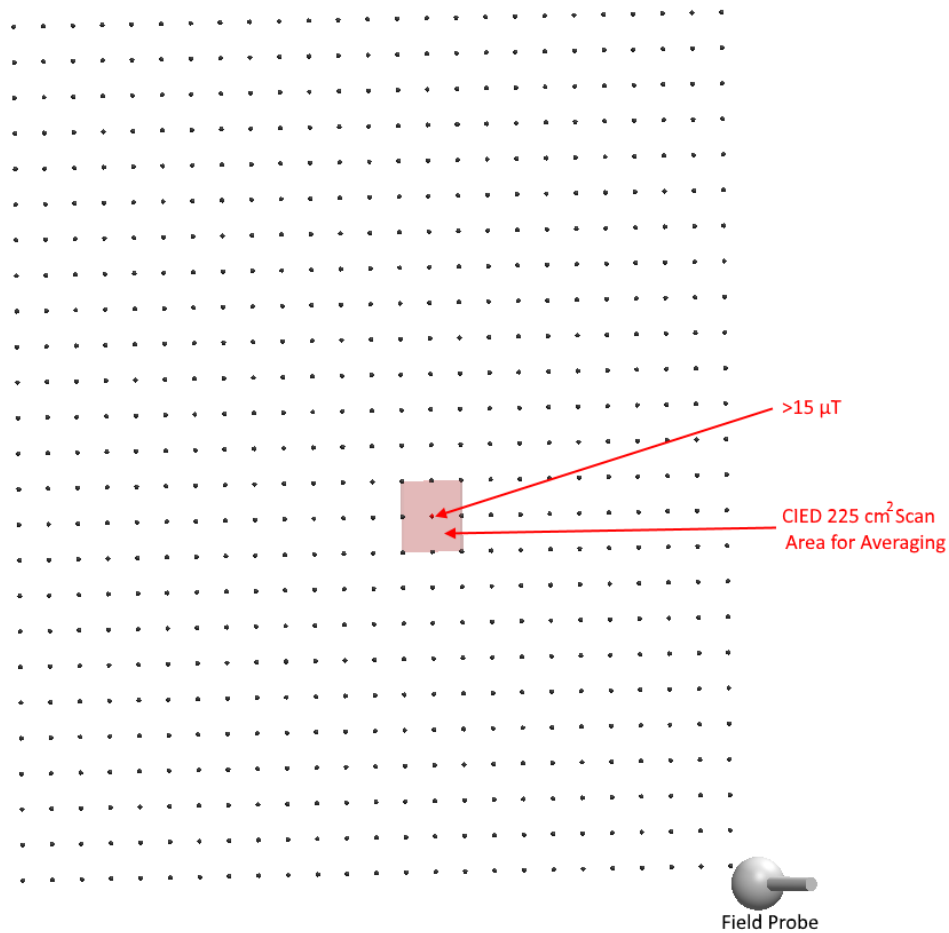


Figure 16 - Reference scan example with measurement above reference level

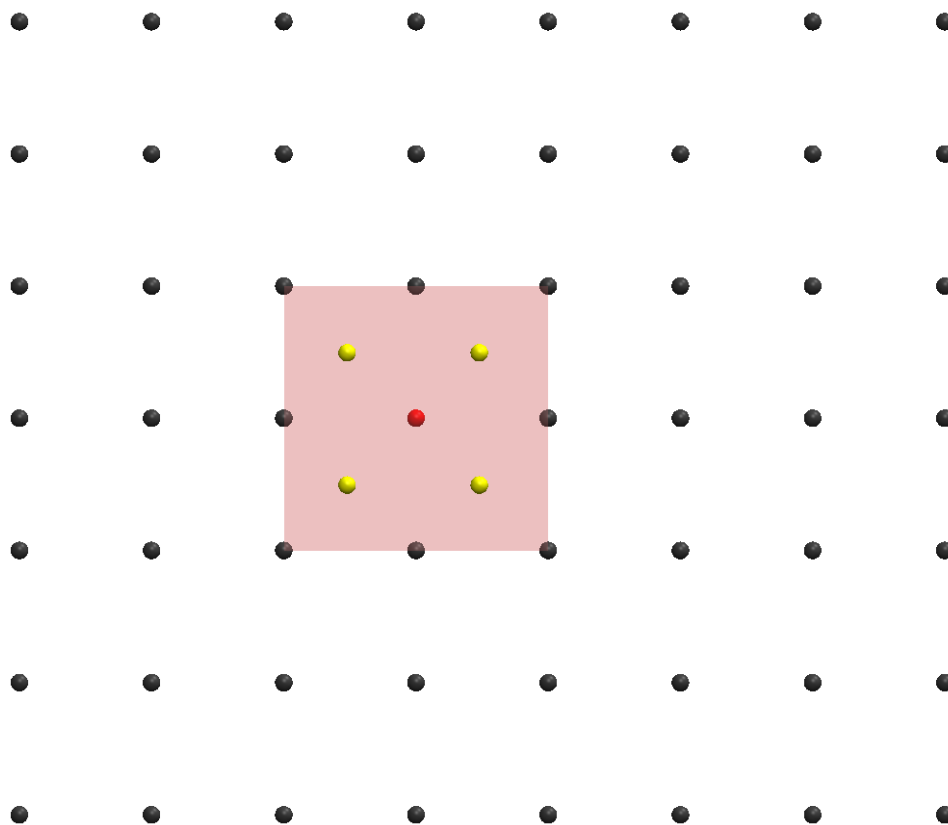


**Figure 17 - Region for reference level average measurement - 2 x 2 grid
with light color points indicate points of measurement centered around peak**