SAE INTERNATIONAL

SURFACE VEHICLE STANDARD

J2954™ AUG2024

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Superseding J2954 AUG2022

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

RATIONALE

Electrified powertrains including battery electric and plug-in electric vehicles (BEV/PHEV) are projected to become more prevalent in production internationally due to environmental factors (such as GHG, CO_2 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.

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 an additional advantage for automated vehicles by enabling autonomous parking with alignment assistance and automated charging (in all weather conditions, such as rain or snow).

This update to the standard is an evolution of SAE J2954 that includes a standardized method for alignment called DIPS (Differential Inductive Positioning System). The SAE J2954 Wireless Power Transfer Taskforce has documented lessons learned from the first stage of testing with real OEM systems in accompanying SAE technical data reports (see 2.1.1). Additionally, detailed requirements for EMF in Region 1 is also updated. Bidirectional, Vehicle to X (V2X) transfer will be a focus of a future standard revision, focused on product systems targeting home/fleet overnight charging.

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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 three charging levels up to 11 kVA and in future revisions up to 22 kVA. 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. This is meant to be used in conjunction with communications standard SAE J2847/6 and use cases J2836/6 and ground assembly WPT Certification UL 2750. 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.

This standard addresses stationary light-duty applications (charging while vehicle is not in motion); heavy-duty applications are considered in SAE J2954/2 and dynamic applications are to be specified in SAE J2954/3. In this version, only above-ground (surface-mounted) installations are covered; flush-mounted installations have been discussed and are planned to be specified in the next revision. 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 that are used to determine acceptable performance of products.

While this version of SAE J2954 explicitly specifies unidirectional WPT in the forward direction (from grid to vehicle), the next revision of this document is planned to also address testing and communication requirements for bidirectional transfer. V2G WPT may be integrated into future product applications for overnight fleet or home-based charging systems that aim to support regional smart grid interactions. That is, requirements for also transferring energy in the reverse direction using the vehicle high voltage energy storage to provide power to loads on the infrastructure side. The specific requirements for connecting back to the grid, to other vehicles, or to external devices are covered in other SAE standards. SAE J2954 will provide grid-equivalent voltage and current by sourcing it from the vehicle battery system.

Until the time SAE J2954 explicitly covers bidirectional energy transfer as a standard, some sections of this current version are directly applicable to evaluate certain aspects in the development of bidirectional systems. Bidirectional V2G, WPT is to be used in conjunction per standards SAE J3072 and SAE J2836/3 (and applicable IEEE and UL standards).

1.1 Wireless Power Transfer General System Description

WPT systems consist of a Ground Assembly (GA) Subsystem and a Vehicle Assembly (VA) Subsystem are 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.

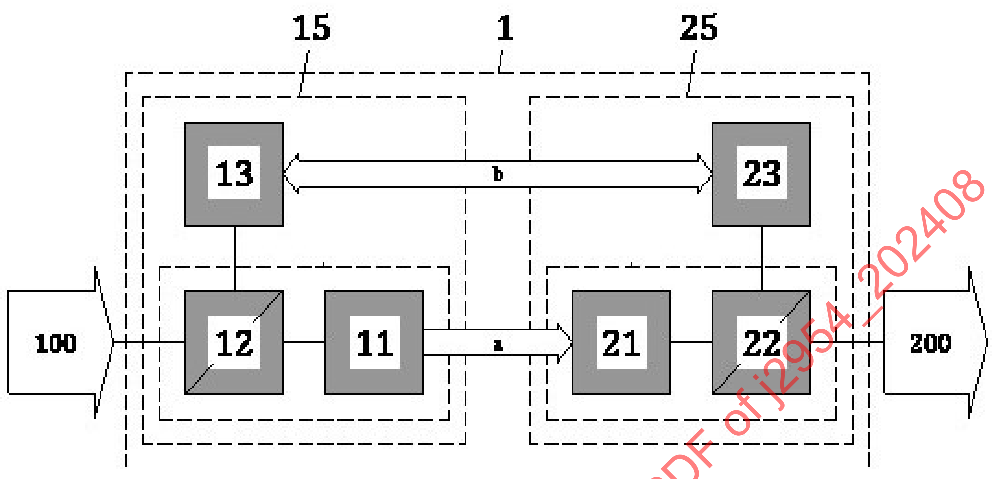
In order to ensure safety, a certain set of requirements are met by both the GA and the VA, including monitoring for safe operation (voltage, current, and temperature) and the ability to take corrective action in the event that a limit indicating unsafe operation is being approached.

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.



KEY			
1	WPT system	21	VA coil
11	GA coil	22	VA electronics
12	GA electronics	23	Vehicle communication controller
13	Base communication controller	25	VA - vehicle subsystem
15	GA - ground subsystem	200	Power to battery
100	Power from grid	b	Communication
a	Wireless power flow		

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

1.2 Bidirectional Energy Transfer

Just as wireless energy can be transferred from the GA to the VA, it is also possible to transfer energy from the VA to the GA if appropriate electronics are provided. Magnetically, the reference coils in SAE J2954 are reciprocal, meaning that wireless energy coupling can occur in either direction without changing the magnetics design. Bidirectional is also referred to as V2G (Vehicle to Grid) or V2X (Vehicle to Everything).

1.3 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:

- Appendix N is first divided into lists of sections that are applicable for verifying compliance of Interoperability Class I GAs, Interoperability Class II GAs, Interoperable VAs, and VAs that are part of an Interoperability Class II system.
- Each of the above lists is then grouped into applicable test categories.

The final determination of the applicable sections to be verified 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 indicating 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 Categories are 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 for Wireless Power Transfer Between Light-Duty Plug-in Electric Vehicles and Wireless EV Charging Stations

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., Sealy, K., Boettigheimer, M., Laemmle, T. et al., "Validation and Comparison of Alignment Methodologies for the SAE Wireless Power Transfer, J2954 Standard," SAE Technical Paper 2024-01-2027, 2024, https://doi.org/10.4271/2024-01-2027.

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.

Sirota, J., Kesler, M., Klerer, M., Mathar, S. et al., "Bench Testing Validation of Wireless Power Transfer up to 7.7kW 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.

Tachikawa, K., Kesler, M., Danilovic, M., Esteban, B. et al., "Bi-Directional Wireless Power Transfer for Vehicle-to-Grid: Demonstration and Performance Analysis," SAE Technical Paper 2019-01-0870, 2019, https://doi.org/10.4271/2019-01-0870.

2.1.2 ANSI Accredited Publications

Copies of these documents are available online at https://webstore.ansi.org/.

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

2.1.3 CISPR Publications

Available online at https://webstore.iec.ch/.

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 https://webstore.ansi.org/.

ISO 4130 Road Vehicles - Three-Dimensional Reference System and Fiducial Marks - Definitions

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 23374 Intelligent Transport Systems - Automated Valet Parking Systems (AVPS) - System Framework, Communication Interface, and Vehicle Operation

ISO 26262 Road Vehicles - Functional Safety

2.1.8 NFPA Publications

Available from National Fire Protection Association, 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

Available from International Telecommunication Union, Place des Nations, 1211 Geneva 20 Switzerland, https://www.itu.int/.

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 Wireless Power Transfer Equipment for Electric Vehicles

2.1.12 Code of Federal Regulations (CFR) Publications

Available from 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 Publications

Available from United Nations Economic Commission for Europe, Palais des Nations, CH-1211, Geneva 10, Switzerland, Tel: +41-0-22-917-12-34, www.unece.org.

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 sunlight.

3.3 CARDIAC IMPLANTABLE ELECTRONIC DEVICE (CIED)

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

3.4 CENTER POINT (of a GA coil or a VA coil)

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

3.5 CENTERED POSITION

The position of the VA coil relative to the GA coil when the VA is located in the middle of the defined alignment tolerance area as described in 6.4.3.

3.6 ELECTRIC VEHICLE (EV)

A three- or a four-wheel vehicle propelled by an electric motor drawing current from an externally rechargeable battery intended for public roadway use and rated at less than 4545-kg gross vehicle weight (GWV).

3.7 ESSENTIAL AUXILIARY LOAD

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

3.8 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 a 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.

3.9 GA COIL

The portion of the GA comprising litz wire, ferrite material, and any shielding material that impacts the magnetic field. See Figure 1, Item 11.

3.10 GA COIL PACKAGE

The ground-based device that is located below the vehicle to allow for 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.

3.11 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. See Figure 1, Items 12 and 13.

3.12 GUIDANCE

A process that assists vehicle navigation toward a WPT charging space.

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 GA coil and the coil in the VA coil that allows power to be transferred with galvanic isolation.

3.15 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.

3.16 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 the IEC 61980 series.

3.17 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).

3.18 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.

3.19 NATURAL OFFSET

The offset required between a GA coil and a VA coil 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 12.11).

3.20 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.

3.21 PRODUCT GA

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

3.22 PRODUCT VA

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

3.23 TEST STATION (VA/GA) COMMUNICATION MODULE

A device that meets the communication requirements of Section 12 and 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 VA COIL

The portion of the VA comprising litz wire and ferrite material. See Figure 1, Item 21.

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 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 consists of the VA coil, power electronics, control, and communication necessary to safely transfer power to the vehicle. See Figure 1, Item 25.

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 EV wireless power transfer and control between the GA and VA includes 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 between the AC supply network and the electric vehicle by contactless means. WPT is a charging system that transfers power across an airgap between a GA and a VA or in reverse to provide power to the vehicle electric system in one direction or to externally utilize energy stored in the vehicle battery in the reverse direction.

4. ABBREVIATIONS

ALSE	Absorber-Lined Shielded Enclosure
CAN	Controller Area Network
CFR	Code of Federal Regulations
CO_2	Carbon Dioxide
DIPS	Differential Inductive Positioning System
DRL	Dosimetric Reference Limit
EMC	Electromagnetic Compatibility
EMF	Electromagnetic Field
EMI	Electromagnetic Interference

EPA	Environmental Protection Agency
ERL	Exposure Reference Level
ESD	Electrostatic Discharge
EU	European Union
EVCC	Electric Vehicle Communication Controller
EVSE	Electric Vehicle Supply Equipment
FCC	Federal Communications Commission (U.S.)
FOD	Foreign Object Detection
GA	Ground Assembly
GHG	Greenhouse Gas
IEC	International Electrotechnical Commission
IMN	Impedance Matching Network
ISO	International Organization for Standardization
ITU	International Telecommunication Union
LIN	Local Interconnect Network
LOP	Live Object (Human) Protection
NIST	National Institute of Standards and Technology
OATS	Open Area Test Site
OBC	Onboard Charger
PE	Power Electronics
PTB	Physical-Technical Federal Institute (Germany)
SAC	Semi-Anechoic Chamber
SECC	Supply Equipment Communication Controller
SOC	State of Charge (in percent)
UFA	Uniform Field Area
UL	UL Solutions
VA	Vehicle Assembly
V2G	Vehicle to Grid
V2I	Vehicle-to-Infrastructure

V2V Vehicle-to-Vehicle

V2X Vehicle to Everything

WCS Wireless Charging System

WPT Wireless Power Transfer

ZEV Zero-Emission Vehicle

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 (see Figure 2).

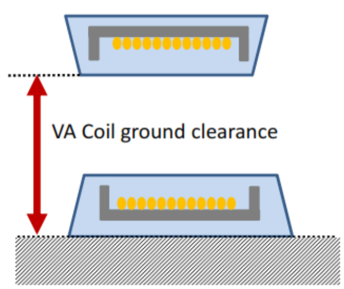


Figure 2 - VA coil ground clearance

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 vehicle test, it is tested with a Test Station GA that covers the range required by the Product VA.

5.2.3 Z-Class Related to Test Station and Product GAs

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

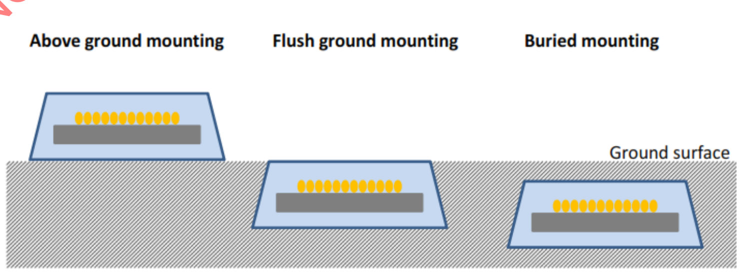


Figure 3 - GA mounting schemes

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

5.4 SAE J2954 Interoperability Classifications

Product GAs are classified by their application (public/private) and intended level of interoperability.

5.4.1 Interoperability Class I GA (Informational: Apply to Test 3A)

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.

An Interoperability Class I GA shall utilize the common Differential Inductive Positioning System (DIPS) as specified in Section 12.

5.4.2 Interoperability Class II GA

Interoperability Class II is the classification of a GA that 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 with SAE J2954, reference safety considerations in this standard, the IEC 61980 series, 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, which 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 WCS.

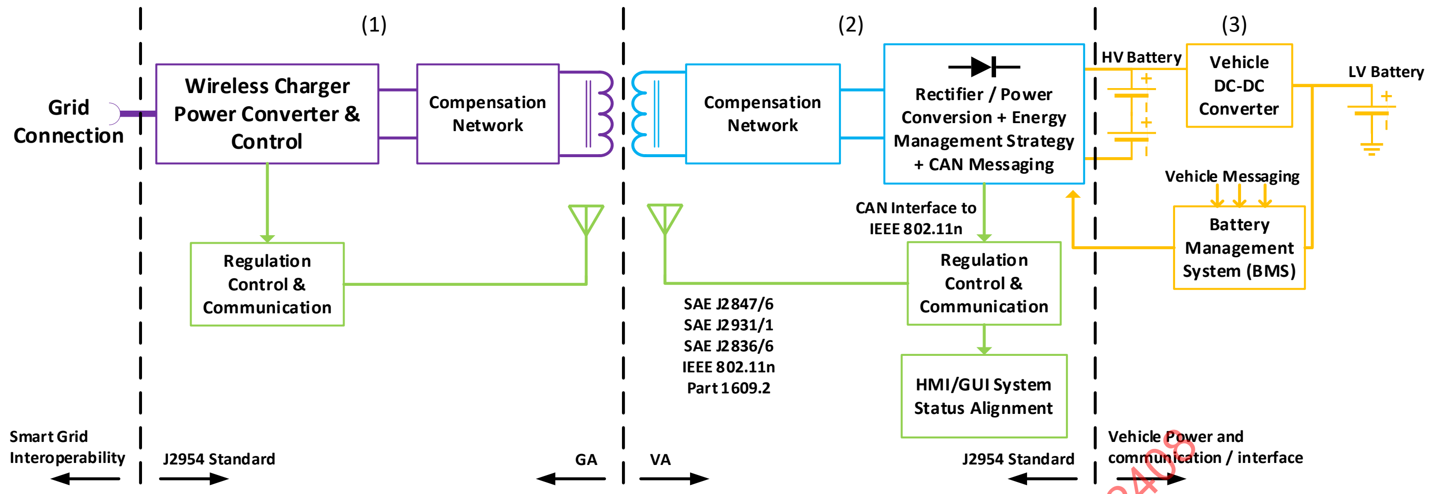


Figure 4 - Typical functional elements of a wireless charging system (WCS)

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 that might be heated to a dangerous temperature during power transfer. See 16.3 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 10.1 and its corresponding Appendix E 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)

While 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 a GA is specified by determining the position of the VA coil relative to the GA coil when the VA is located 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 center points 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,” a vector that describes the position of the VA center point when the VA is in the middle of the defined X and Y alignment tolerance range. This natural offset is determined for a GA and VA pair.

See 12.5.2 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; i.e., 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).

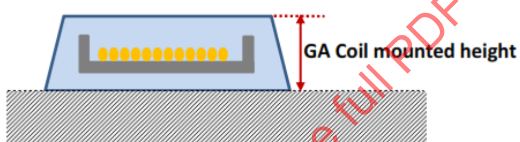


Figure 5 - Definition of GA coil mounted height

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 F.

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

The center point 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, and EMF and touch current requirements are covered in Section 10. Electrical safety requirements and tests are specified in UL 2750 (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 modules 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 ensure compliance with 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) over the ambient temperature range and within the exposed surface temperature limits as specified in UL2750 for the duration of the power transfer session and respond safely to any incidents (e.g., FOD/LOP detection).
- Compliance with EMC requirements.
- Compliance with EMF protection requirements.

An Interoperability Class I GA:

- Shall 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, control protocols, and alignment system requirements in Sections 12 and 13.
- Shall operate with the SAE J2954 Test Station VAs.
- Shall be certified by a nationally recognized testing lab to meet SAE J2954 requirements and shall also meet UL 2750 (or equivalent) requirements.
- Shall have an applicable “weights and measure” test and certification 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 nationally 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

The 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 the 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 (see 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

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 (Informational: Requirements apply to Tests 5C, 5D)

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 (Informational: Requirements apply to Tests 5A, 5B)

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

The measured power factor under all test conditions shall be ≥ 95%.

Local regulations at the installation location may require a higher power factor.

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 (see 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 ≥85% when operating at full output power with the VA at the middle of the relevant Z range at centered position and when the GA input voltage and VA output voltage are at the midpoint (nominal) of the range. The system efficiency shall be ≥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 ≥85% when operating at full output power with the VA in the middle of the relevant Z range at centered position and when the GA input voltage and VA output voltage are at the midpoint (nominal) of the range. The efficiency shall be ≥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 Appendix K. 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, power transfer shall not be initiated. If power transfer has already been initialized but the VA is moved beyond the alignment tolerance area, 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 subsections 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 for recommended exposure limits below 100 kHz. Additionally, IEEE has issued the IEEE C95.1 specifying more detailed exposure limits based on the type of tissue. For WPT operation below 100 kHz, these limits, based on a large safety margin, ensure no temporary causal effects due to 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 Live Object Protection (LOP) (Informational: Requirements Apply to Tests 2A, 2B, 5A, 5B)

For live object protection (LOP) in accessible areas of the vehicle, the electromagnetic fields shall be less than the applicable limits, 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 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 acceptable limits and cause immediate system shutdown. See Appendix E.

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 stand-alone 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 EMC for the Grid Connected Components (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 a 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)	Class A limits as defined in standard (2nd to 40th harmonics)
EMI	AC Power	Charging and Standby	Fluctuations and Flicker	IEC 61000-3-3 (<16 A) IEC 61000-3-11 (<75 A)	$P_{st} < 1.0$, $P_{lt} < 0.6$ $d_c < 3.3\%$, $d_{max} <$ 4 to 7% device dependent d(t) > 3.3% only <500 ms	$P_{st} < 1.0$, $P_{lt} < 0.6$ $d_c < 3.3\%$, $d_{max} <$ 4 to 7% device dependent d(t) > 3.3% only <500 ms
EMI	AC Power	Charging and Standby	Conducted Emissions	FCC 18/15	150 kHz to 30 MHz	150 kHz to 30 MHz
EMI	Comm Lines	Charging and Standby	Conducted Emissions	FCC 15	150 kHz to 30 MHz	150 kHz to 30 MHz
EMI	WPT System Level	Charging and Standby	Radiated Emissions	FCC 18	9 kHz to 30 MHz	9 kHz to 30 MHz
EMI	WPT System Level	Charging and Standby	Radiated Emissions	FCC 15	30 MHz to X GHz[2]	30 MHz to X GHz[2]
EMI	DIPS (Alignment System)	Alignment and Standby	Radiated Emissions	FCC 15	9 kHz to 30 MHz[2]	9 kHz to 30 MHz[2]
CW EMS	AC Power	Charging and Standby	Conducted Immunity	IEC 61000-4-6	150 kHz to 80 MHz: 30 Vrms	150 kHz to 80 MHz: 30 Vrms
CW EMS	WPT System Level	Charging and Standby	Radiated Immunity	IEC 61000-4-3	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	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
CW EMS	WPT System Level	Charging and Standby	Magnetic Field Immunity	IEC 61000-4-8	30 A/m	100 A/m
TRANSIENT EMS	WPT System Level	Charging and Standby	ESD	IEC 61000-4-2	8 kV/4 kV air/contact	8 kV/4 kV air/contact
TRANSIENT EMS	AC Power	Charging and Standby	EFT	IEC 61000-4-4	1 kV (5/50 ns, 100 kHz)	2 kV (5/50 ns, 100 kHz)
TRANSIENT EMS	AC Power	Charging	Surge	IEC 61000-6-2 (IEC 61000-4-5)	1 kV Line-to-Line 2 kV Line-to-Ground	1 kV Line-to-Line 2 kV Line-to-Ground
TRANSIENT EMS	Signal Line	Charging	Surge	IEC 61000-6-2 (IEC 61000-4-5)	1 kV Line-to-Ground	1 kV Line-to-Ground
TRANSIENT EMS	AC Power	Charging and Standby	Voltage Dips and Interrupts	IEC 61000-4-11 (<16 A) IEC 61000-4-34 (>16 A)	30% reduction for 25 cycles 60% reduction for 10 cycles >95% reduction for 1 cycle 100% reduction for 250 cycles	30% reduction for 25 cycles 60% reduction for 10 cycles >95% reduction for 1 cycle 100% reduction for 250 cycles
TRANSIENT EMS	AC Power	Charging and Standby	Harmonic Distortion	IEC 60204-1	Harmonic distortion <10% of the total rms voltage between live conductors for the sum of the 2nd to the 5th harmonic	Harmonic distortion <10% of the total rms voltage between live conductors for the sum of the 2nd to the 5th harmonic

(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. Note that Figures 6, 7, and 8 are examples; other setups that conform to IEC 61000-4-3 can be used. It is preferred to test one UFA that covers all components. If this is not possible as per IEC 61000-4-3, use partial illumination.

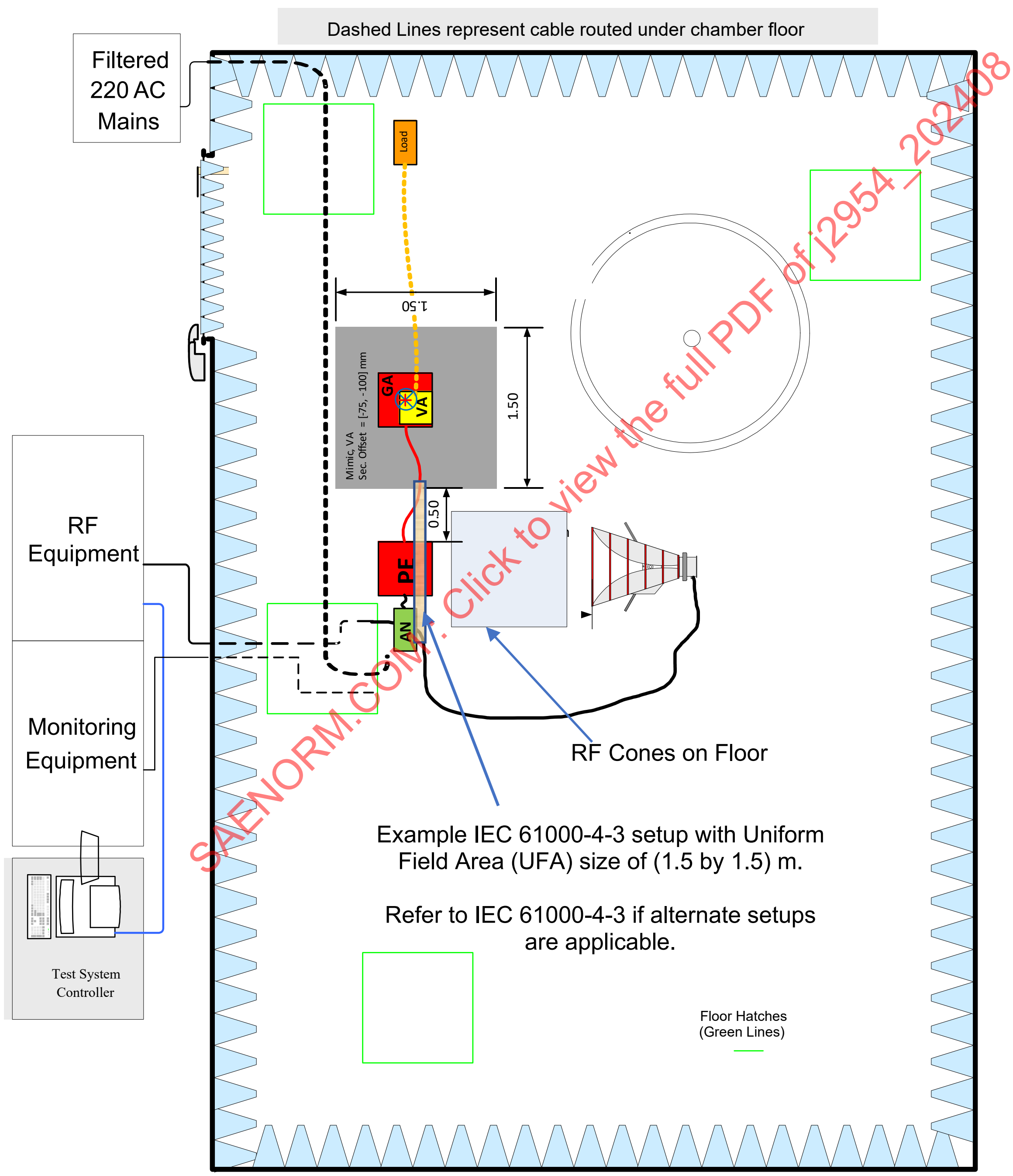


Figure 6 - Example of RI ALSE test setup for component-level wireless charging system (top view)

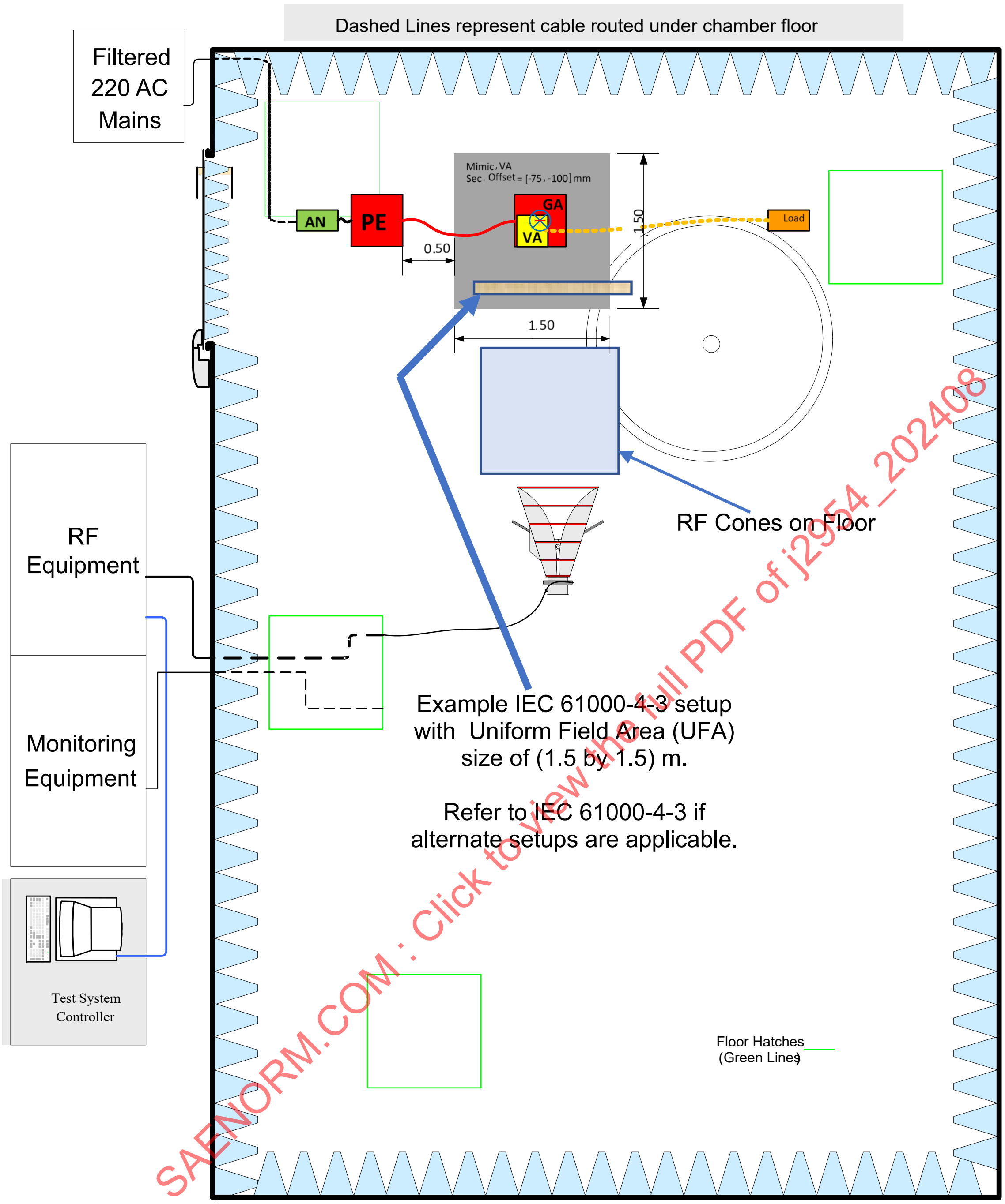


Figure 7 - Example of RI ALSE test setup for component-level wireless charging system (top view)

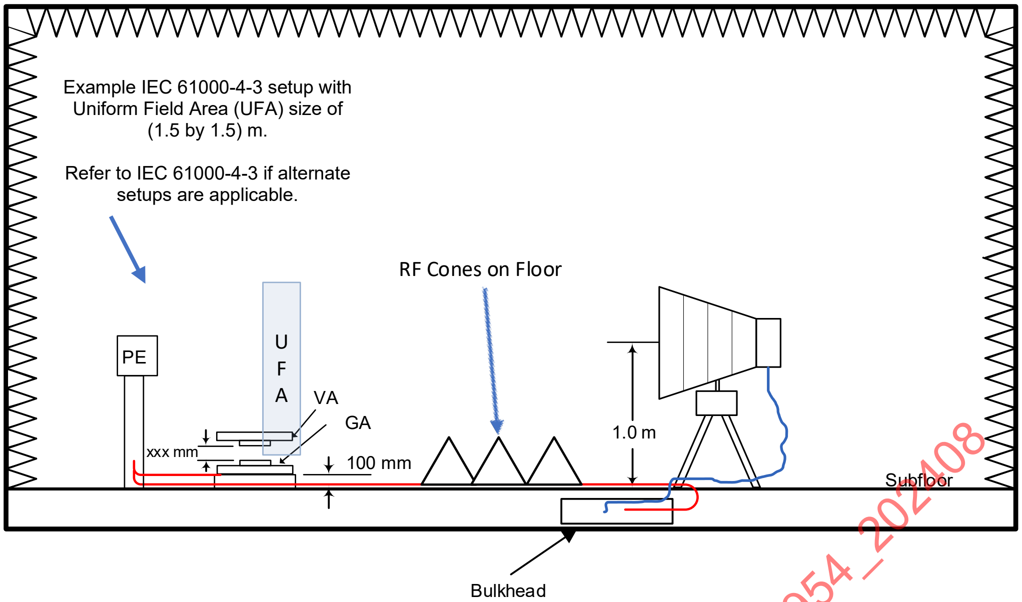


Figure 8 - Example of RI ALSE test setup for component-level wireless charging system (side view)

The component-level wireless charging system should be tested to the requirements of RF CDN (coupling/decoupling network) injection 150 kHz to 80 MHz (refer to 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; refer to 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 Figures 9A, 9B, and 9C, which illustrate 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, a 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 ongoing 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.

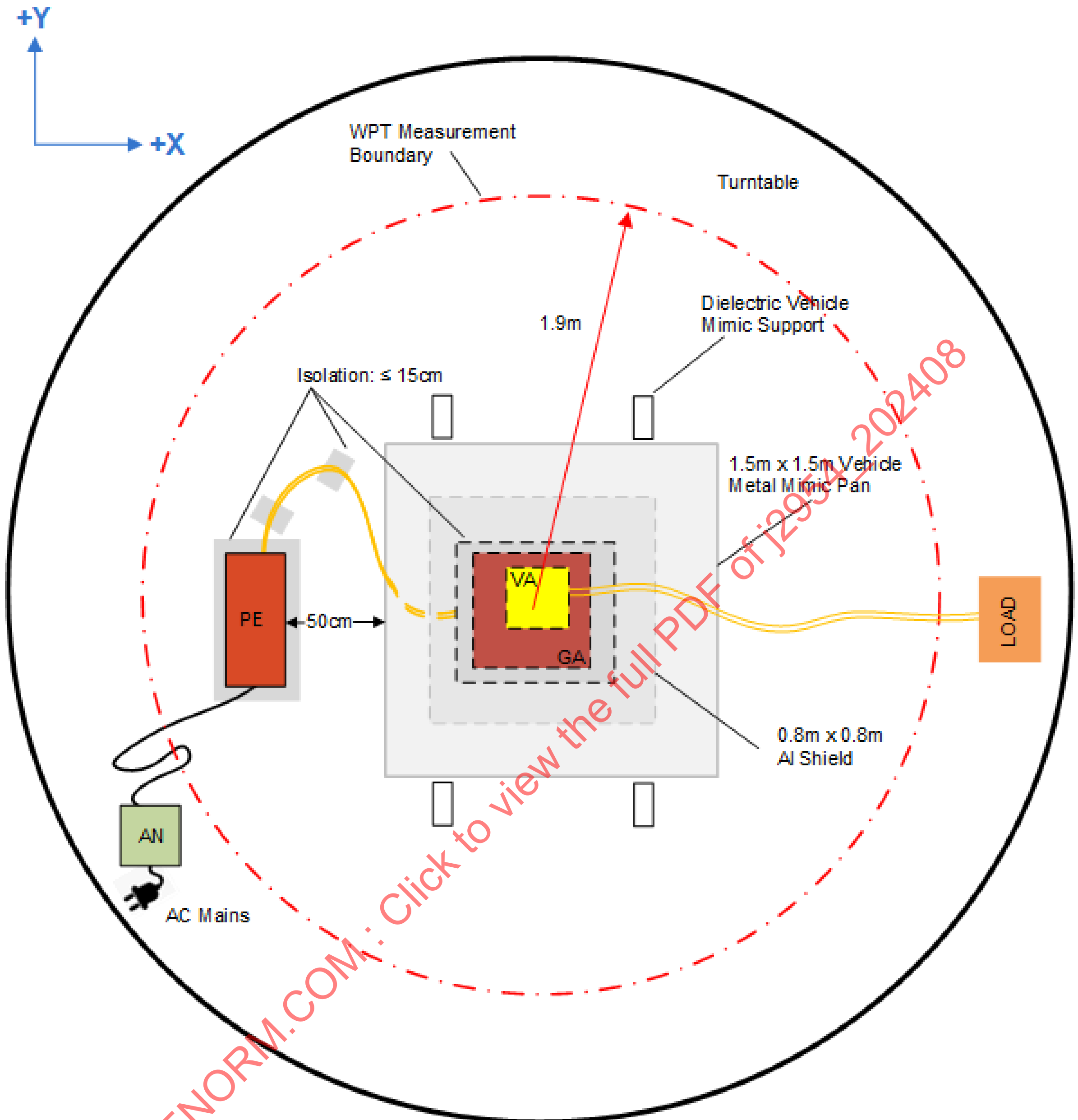


Figure 9A - Recommended test setup, top view, for radiated emissions testing of SAE J2954 Test Station system with power electronics in the front position

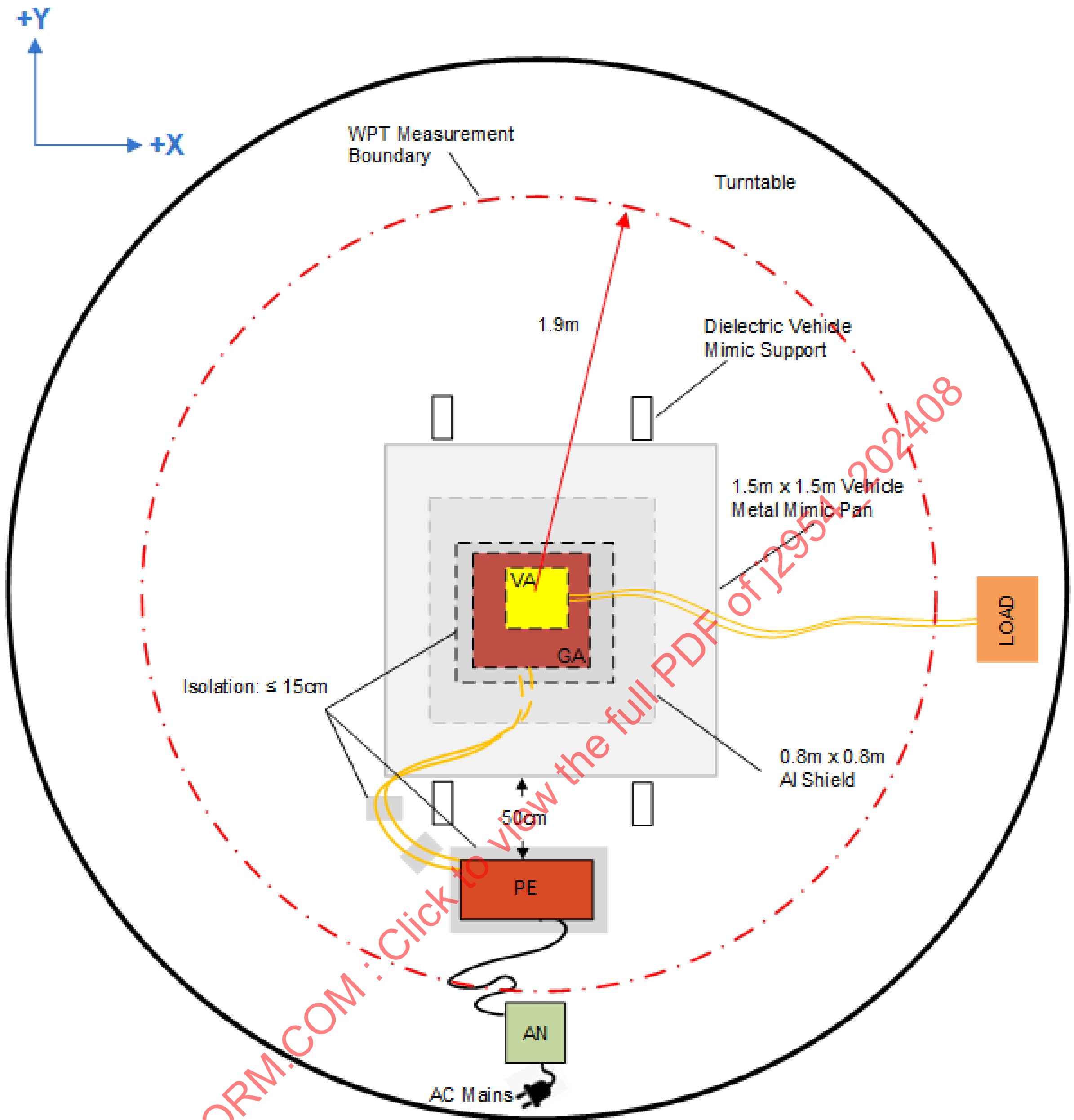


Figure 9B - Recommended test setup, top view, for radiated emissions testing of SAE J2954 Test Station system with power electronics in the side position

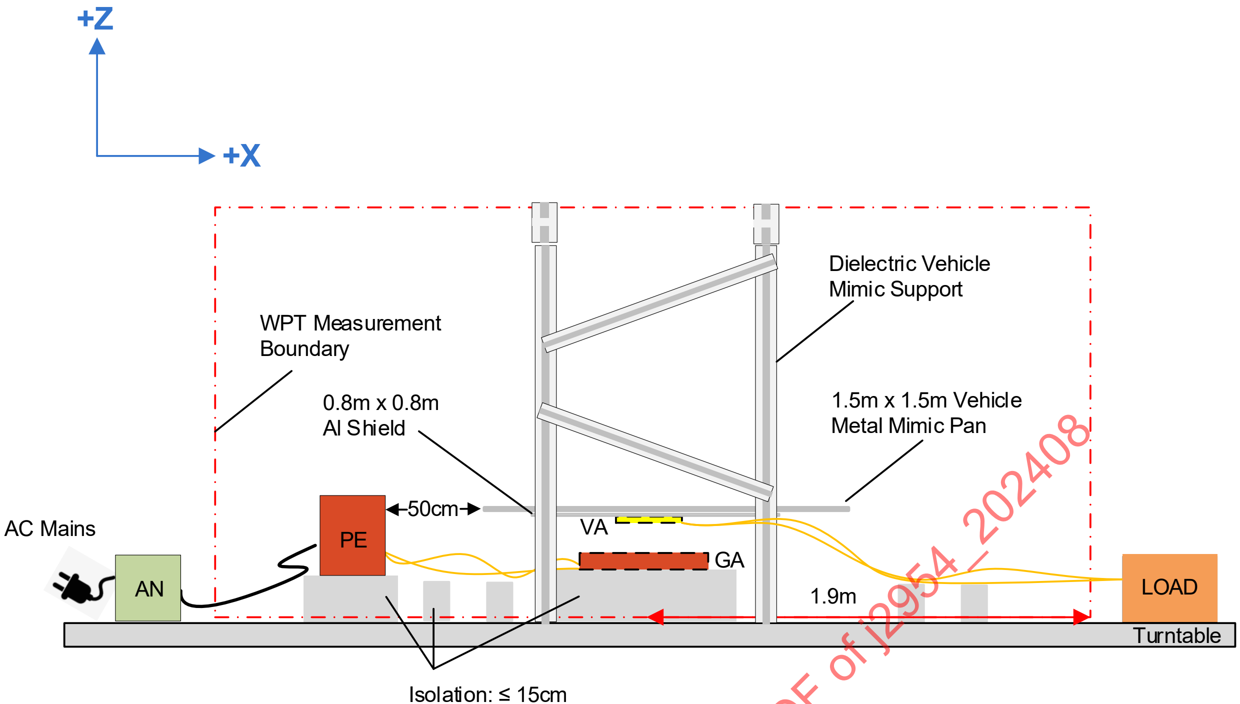


Figure 9C - Recommended test setup, side view, for radiated emissions testing of SAE J2954 Test Station system with power electronics in the front position

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 nonmagnetic and nonmetallic 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 U.S., 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 - Onboard 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 onboard electronics during normal operation of a vehicle (but not necessarily when the WPT system is active). The intention of this chapter is to ensure EMC of onboard 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 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). The recommended setup is shown in Figures 11A, 11B, and 11C. The figures illustrate the vehicle on the 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 the 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 refer 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 10.10.

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 U.S., 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 the 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.

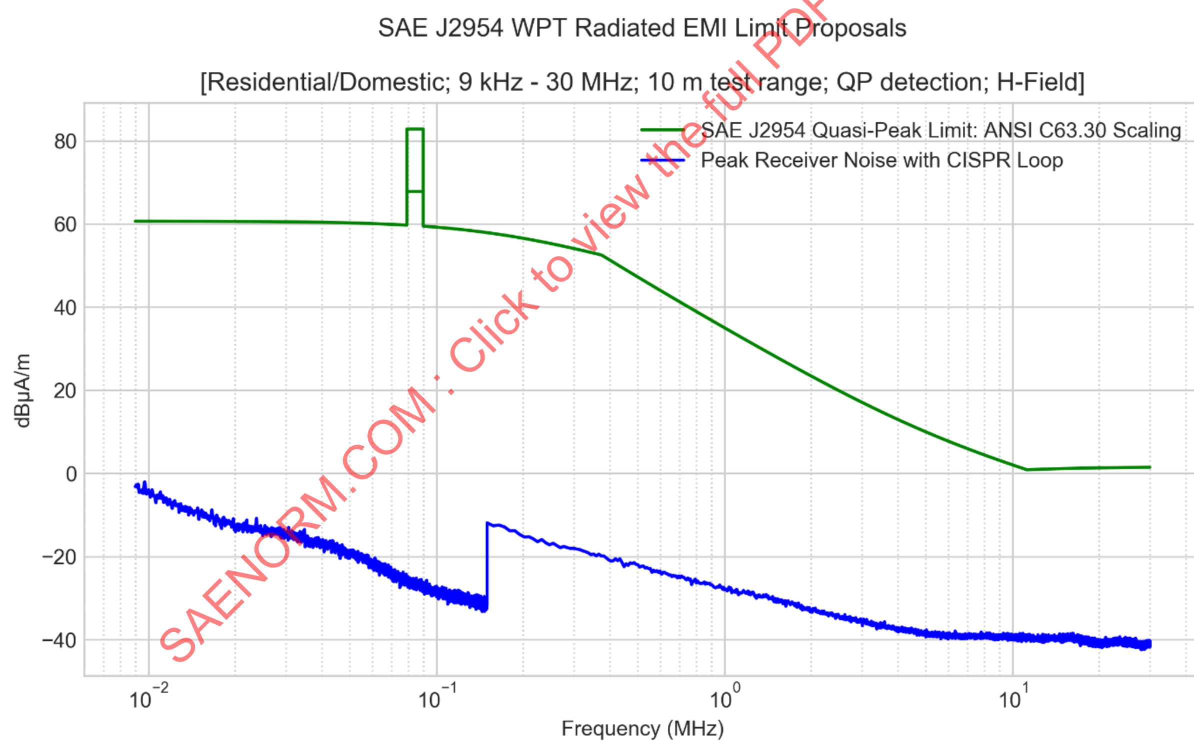


Figure 10 - Recommended limits

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 1: Limits may be reduced based on regional regulatory requirements. For example, limits may 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.

NOTE 2: Additional regulatory limits specific to applicable regions shall be met.

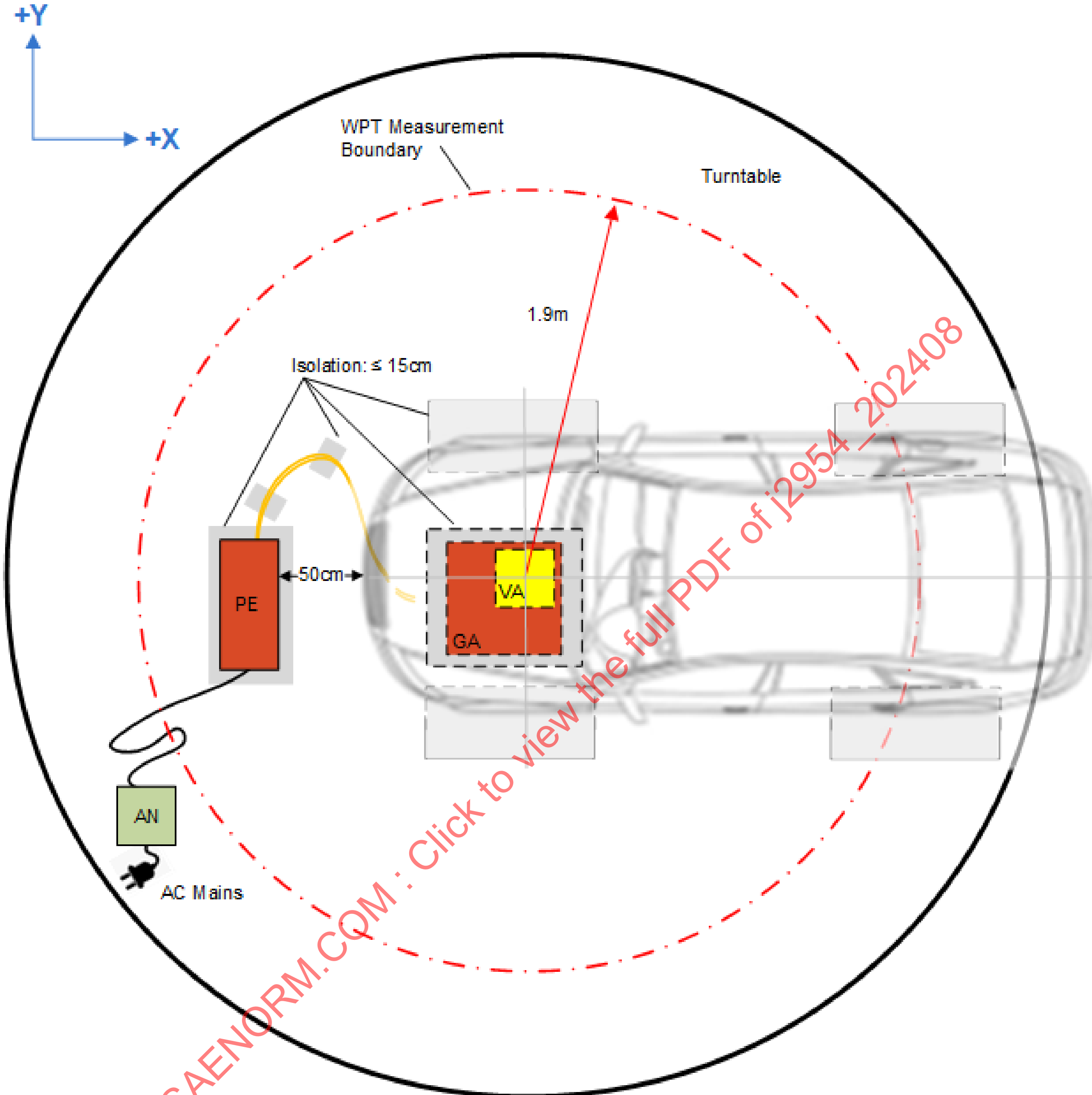


Figure 11A - Recommended setup, top view, for vehicle radiated emissions testing with power electronics in the front position

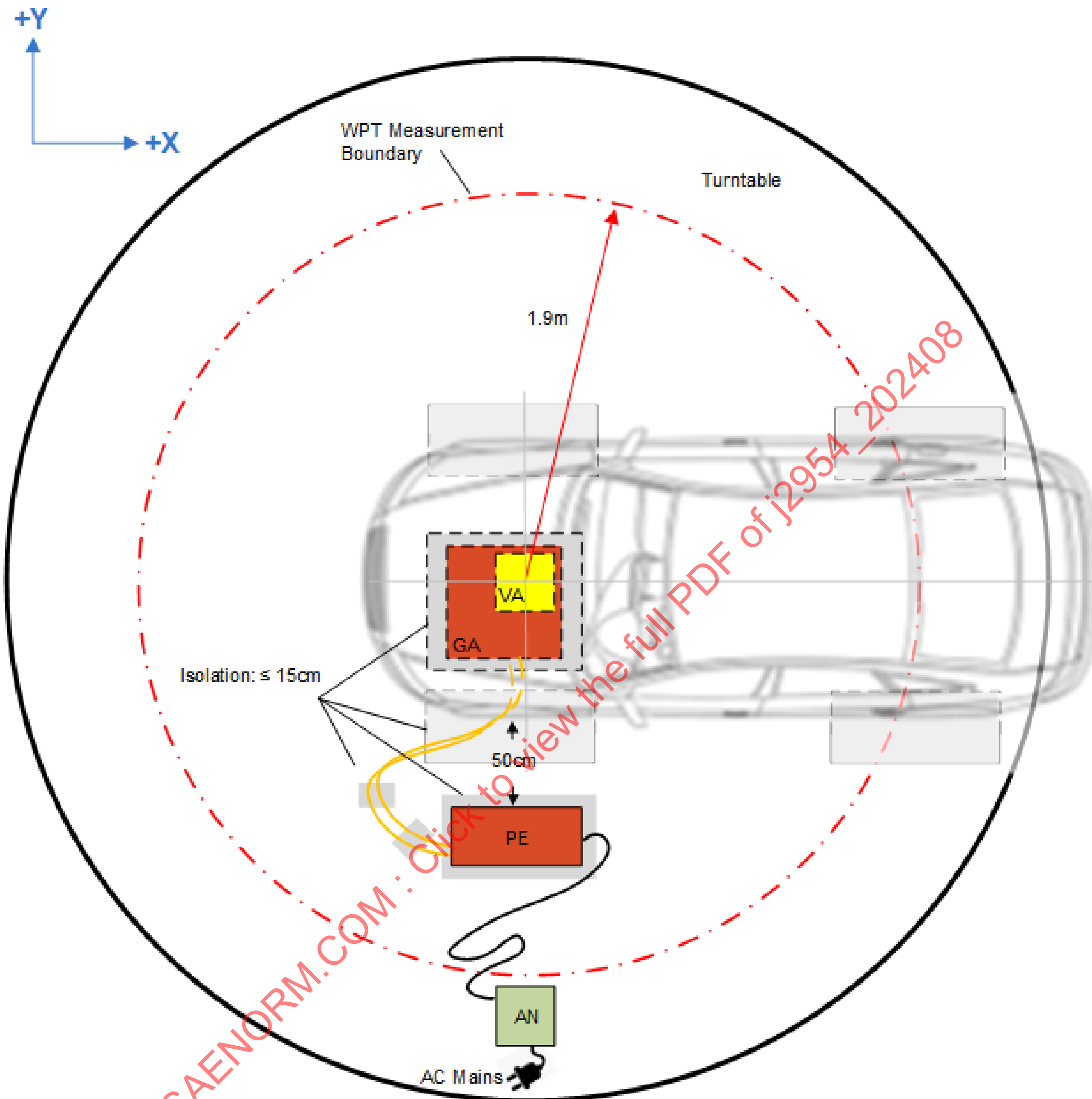


Figure 11B - Recommended setup, top view, for vehicle radiated emissions testing with power electronics in the side position

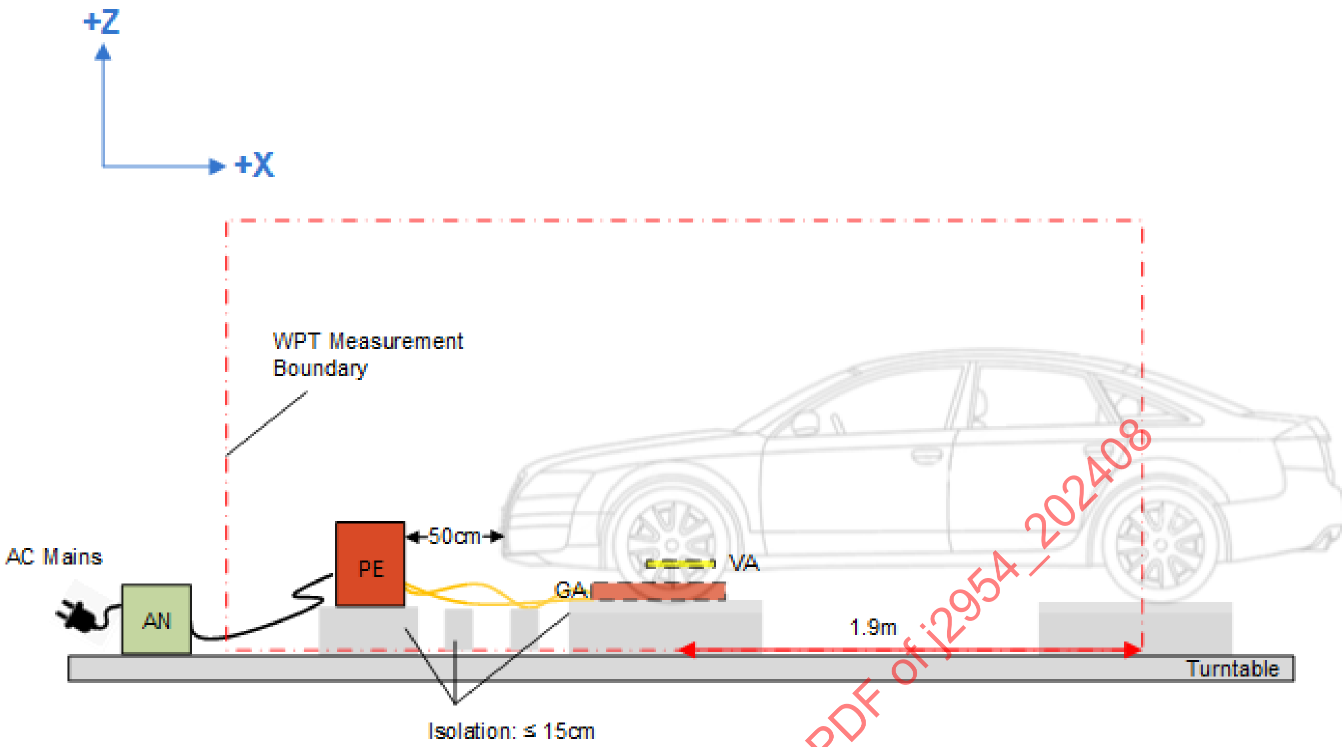


Figure 11C - Recommended setup, side view, for vehicle radiated emissions testing with power electronics in the front position

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 that 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 nonmagnetic and nonmetallic 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 and the IEEE C95.1-2019 standard, depending on the location near the vehicle. 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 and IEEE C95.1 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 Region 1 limits listed in Table 12. An alternate, yet more conservative, approach is to prevent exposure to magnetic fields above the Region 1 reference levels in Table 11. 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.

In cases where detection and shutdown is the method utilized, this is considered a live object protection (LOP) system. For LOP systems, the potential velocity of entry shall be considered based on the Z-class and encroachment method. For example, a reasonable assumption is that a head or torso would encroach a Z3 WPT system at a rate no greater than 10 cm/s, whereas a limb might encroach at a rate between 0.3 m/s for a child and up to 1 m/s for an adult in the worst case (e.g., swinging arm circumferential motion).

For a Z1 system, it is unlikely to have a head or torso encroach Region 1 appreciably. See Appendix E for more information on LOP testing.

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 16.

The EMF management strategy shall be applicable for all operational conditions; e.g., coupler offset or other system variations that 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.

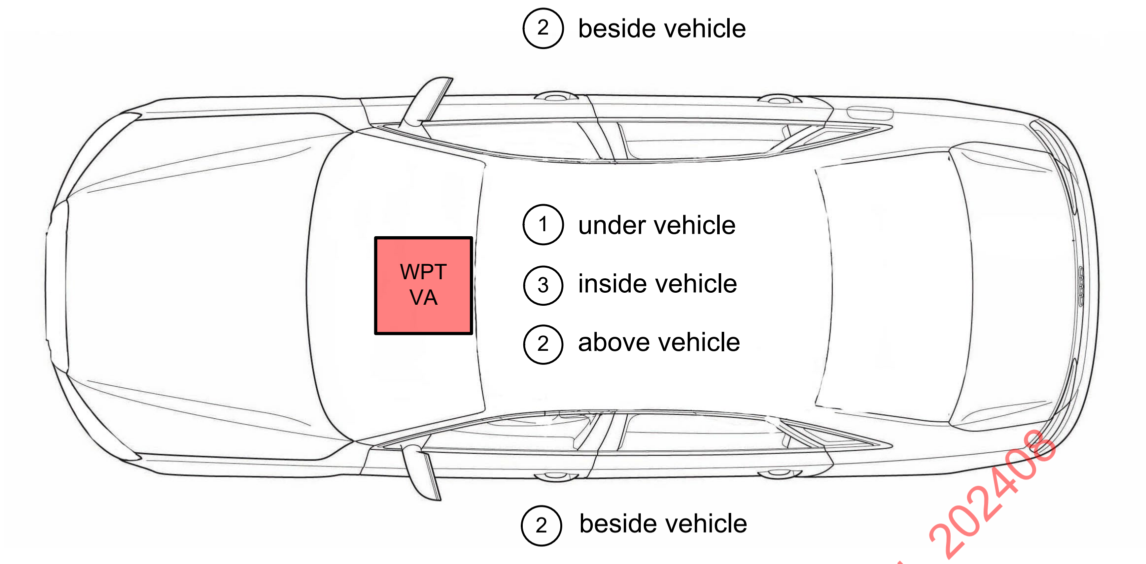


Figure 12 - EMF regions, top view

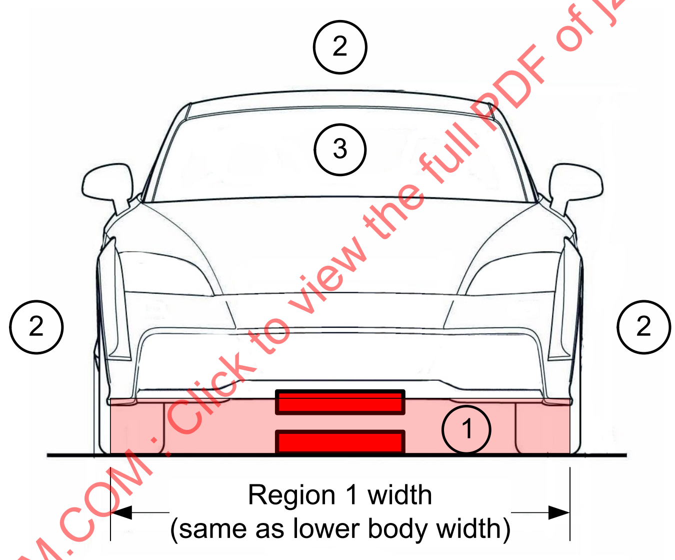


Figure 13 - EMF regions, front view

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

For any realistic location in Regions 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 L

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	**Region 1:** **IEEE C95.1-2019** **Exposure Reference Level (ERL)** **[Unrestricted Access / Restricted Access]** **(rms Field Strength for 79 to 90 kHz)**	**Regions 2 and 3:** **ICNIRP 2010** **General Public Reference Level** **(rms Field Strength for 79 to 90 kHz)**
Magnetic Field	**Head and Torso:** 205 µT (unrestricted) / 615 µT (restricted) **Limb:** 1.13 mT	27 µT or 21.5 A/m[(1)]
Electric Field	**Uniform whole body:** 614 V/m (unrestricted) / 1842 V/m (restricted)	83 V/m

(1) When using 100 cm^2 three-axis standard field probe for magnetic field measurements.

Table 12 - Human EMF exposure standard, basic restriction, and dosimetric reference limits

Quantity	**Region 1:** **IEEE C95.1-2019** **Dosimetric Reference Limit (DRL)** **[Unrestricted Access / Restricted Access]** **(rms Field Strength for 79 to 90 kHz)**	**Regions 2 and 3:** **ICNIRP 2010** **General Public Basic Restriction Level** **(rms Field Strength for 79 to 90 kHz)**
Internal Electric Field	**Brain:** $5.89 \times 10^{-3} \cdot \frac{f(Hz)}{20}$ = 25.03 V/m at 85 kHz **Heart:** $0.943 \cdot \frac{f(Hz)}{167}$ = 479.97 V/m at 85 kHz **Limb:** $2.10 \cdot \frac{f(Hz)}{3350}$ = 53.28 V/m at 85 kHz **Other tissues (Unrestricted):** $0.701 \cdot \frac{f(Hz)}{3350}$ = 17.79 V/m at 85 kHz **Other tissues (Restricted):** $2.10 \cdot \frac{f(Hz)}{3350}$ = 53.28 V/m at 85 kHz	1.35×10^{-4} * f(Hz) = 11.475 V/m at 85 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 that 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.

10.3 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 cm^2 loop area, are less than the levels defined as $V_{MAX\_INDUCED\_RMS} = \frac{3\sqrt{2}}{2}$ mV × 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 10.3, the Table 13 levels provide an alternative, but conservative, assessment of CIED WPT magnetic interoperability, utilizing the same 100 cm^2 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 1: 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 2: 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 cm^2 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.

10.4 Vehicle Human/CIED EMF Assessment - General Considerations (Informational: Requirements Apply to Tests 2A, 2B, 2C, 2D, 4A, 4B, 4C, 4D)

Procedures for EMF assessment of vehicles with wireless chargers should be based on standardized EMF measurement procedures to the degree they apply. Table 14 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 (see Table 11) ensures compliance with the basic restrictions (see Table 12).

- For CIED EMF reference level assessments, the minimum probe distance shall be chosen such that compliance with the CIED EMF reference levels (see Table 13) conveys compliance with the ISO 14117 lead voltage test limits for uninfluenced device operation (based on an assumed 225-cm^2 lead loop area). The reference field level of 15 µT using a 100-cm^2 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 nonmetallic 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 14 provides a recommended flowchart for combined human and CIED EMF assessments.

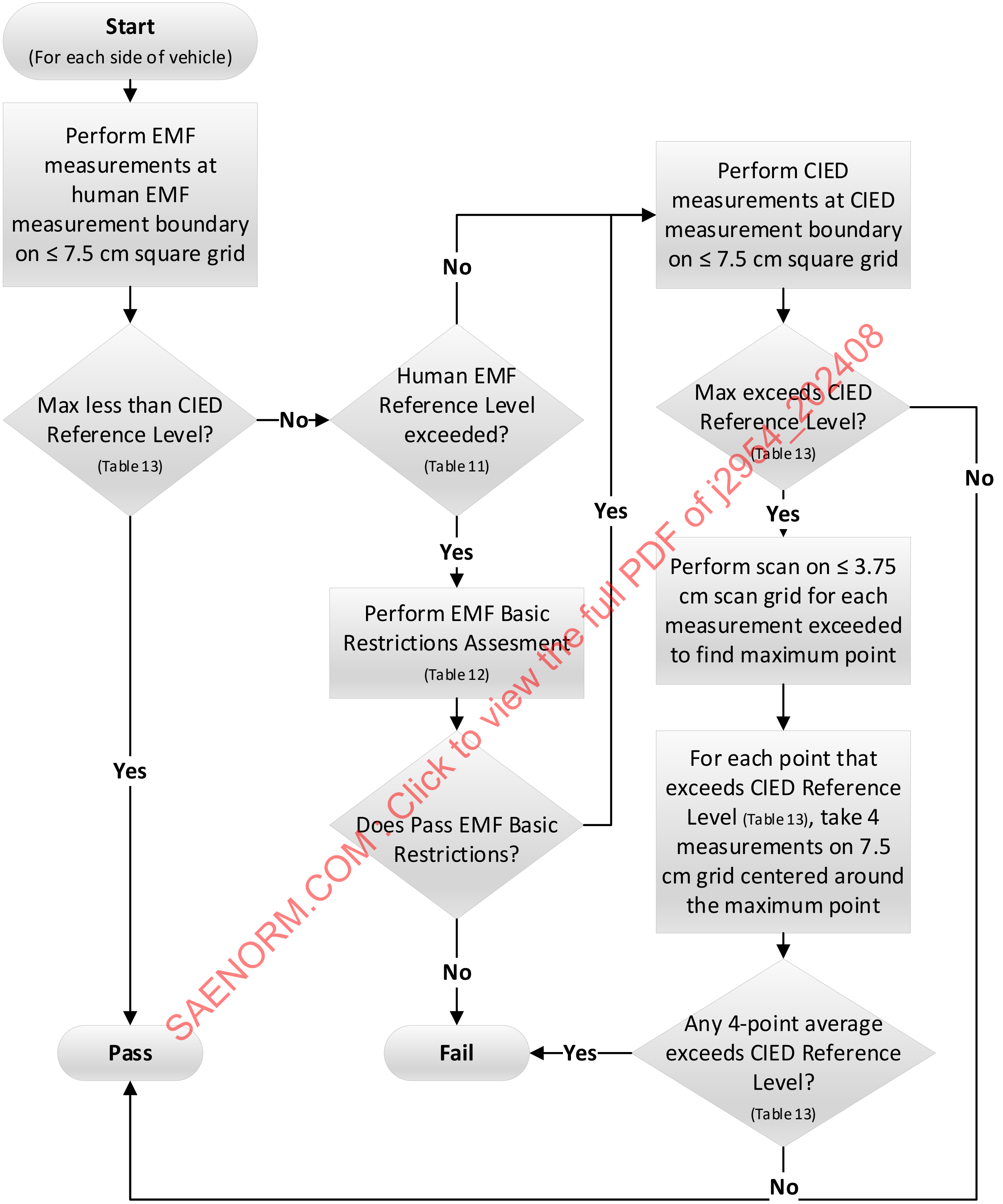


Figure 14 - Flowchart for combined EMF and CIED assessment

Table 14 - 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 cm^2.
- 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:

a. Using a maximum resolution of 3.75 cm, sweep each region where the CIED reference level (15 µT) is exceeded in Regions 2 or 3. Find and record (or mark) the location of the highest reading.

b. Designate an equally spaced 2 x 2 grid of four 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.

c. At each of the four grid points, record the field value (magnitude of all probe axes).

d. Average all four points. The average 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 in Figure 15. 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.

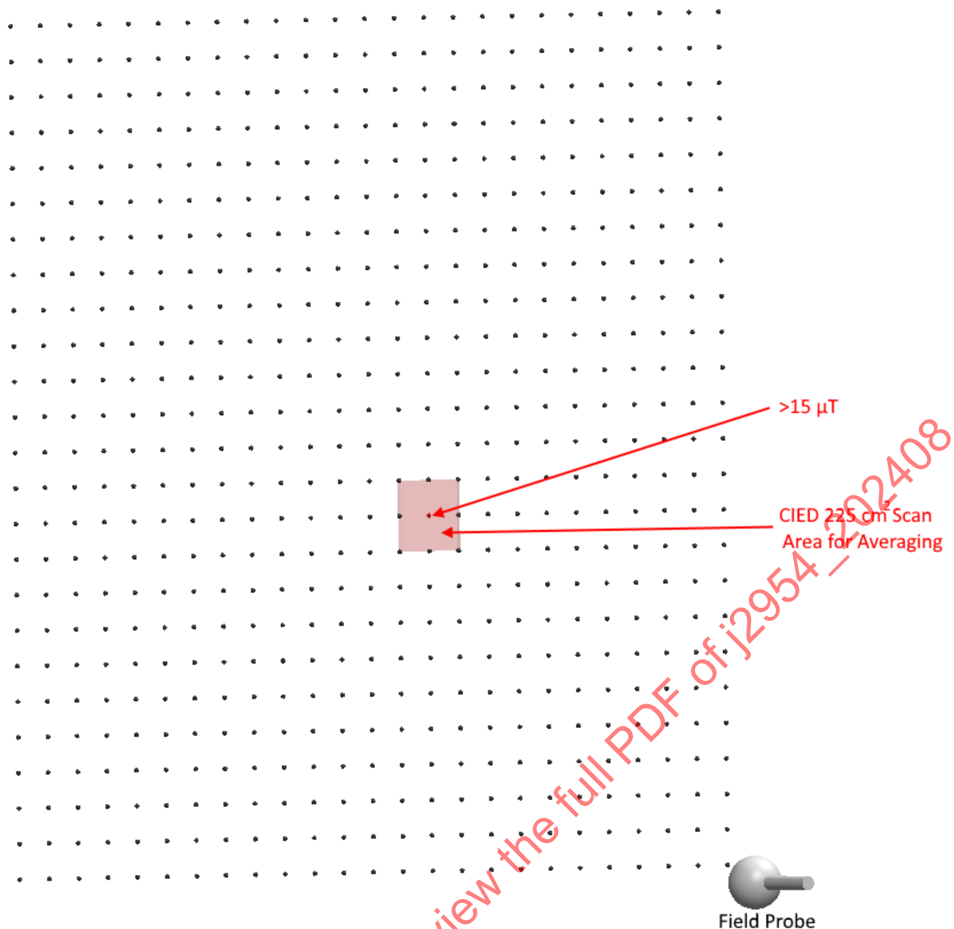


Figure 15 - Reference scan example with measurement above reference level

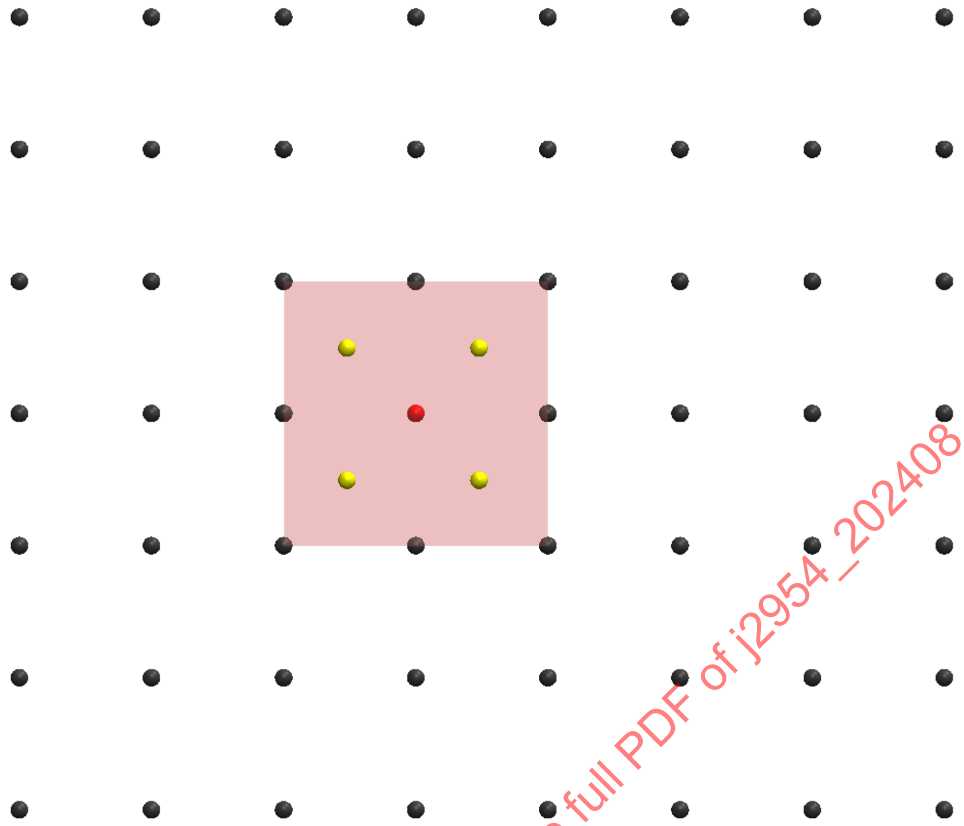


Figure 16 - Region for reference level average measurement - 2 x 2 grid with light color points indicate points of measurement centered around peak

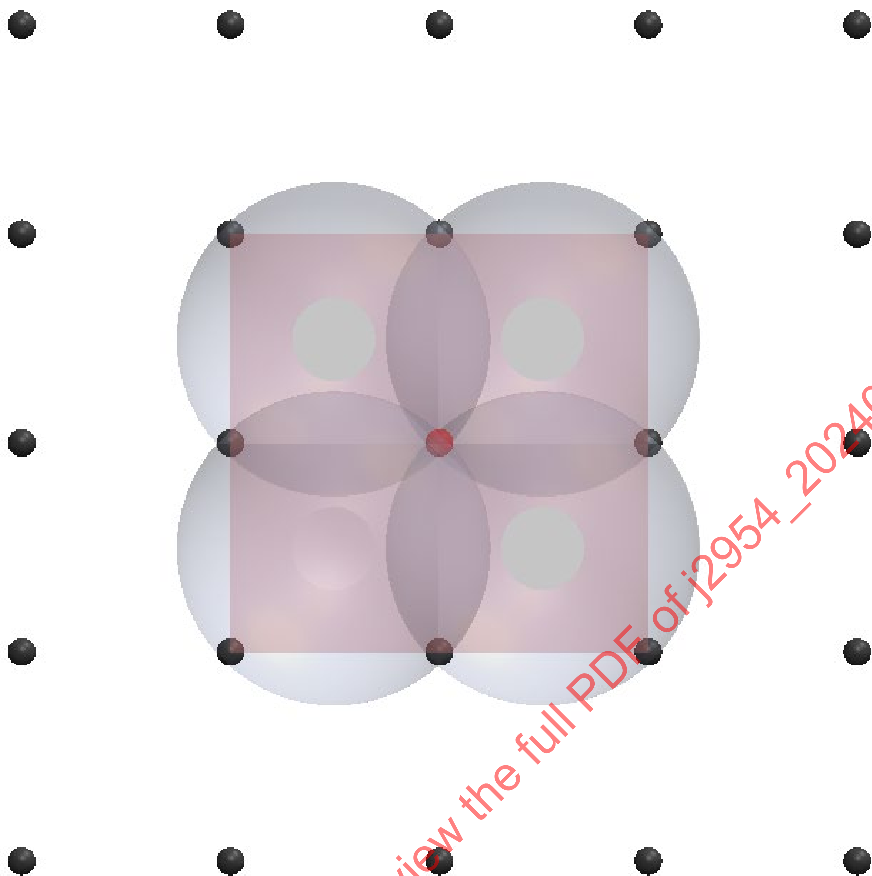


Figure 17 - Locations for standard field probe averages around peak - 2 x 2 grid separated equidistantly by 7.5 cm center-to-center

10.6 Facility for EMF/CIED Exposure Assessment (Informational: Requirements Apply to Tests 2A, 2B, 2C, 2D, 4A, 4B, 4C, 4D)

Vehicle WPT human and CIED EMF exposure measurements shall be performed over a ground surface that is representative of the actual system usage. Usually, this means that testing shall be performed on a concrete or asphalt paved surface.

10.7 Vehicle Regions 2 and 3 Exposure Assessment (Informational: Requirements Apply to Tests 2A, 2B, 2C, 2D, 4A, 4B, 4C, 4D)

The following experimental procedure for reference level assessment is recommended to find the maximum fields in Regions 2 and 3, among several combinations of misalignment and gap:

a. Set up the system offset and gap conditions.

b. Sweep the magnetic field probe horizontally around the Region 1/Region 2 boundary (e.g., at one-half of the height of the floor pan) to find the maximum boundary field. Maintain a sufficiently slow rate of motion to avoid motion-induced magnetic reading errors. Scan vertically and outward from the Region 1 boundary as necessary to determine the location of the spatial maximum field. Record the maximum Region 2 magnetic field location and value.

c. Repeat Step b. for the electric field EMF measurement.

d. At each seating position in Region 3, sweep the magnetic field probe throughout the occupant area to find the maximum field. Maintain a sufficiently slow rate of motion to avoid motion-induced magnetic reading errors. Record the maximum magnetic field location and value for each seating position. Additionally, at each seating position, record the fields measured at points A (head), B (chest), C (seat cushion), and D (foot), illustrated in Figure 18.

e. If the vehicle floor pan is nonmetallic, repeat Step d. for the electric field EMF measurement. For vehicles with metallic floor pans, an electric field assessment is not required in Region 3, except in the vicinity of floor openings.

f. Repeat for each combination of offset and gap conditions.

An example worksheet (see Table 15) is provided with a minimum set of offset and gap combinations to be tested. This is intended as a starting point because fields may vary rapidly with offset or gap, especially at large offsets and gaps. Additional offset and gap combinations should be considered as appropriate to determine the worst-case conditions for magnetic and electric fields if results obtained from the initial measurements exceed 50% of the exposure limit.

Table 15 - Example worksheet for worst-case operating condition search

Coupler Offset and Gap			Max Magnetic Field		Max Electric Field	
dX	**dY**	**dZ**	**Location**	**B(uT)**	**Location**	**E(V/m)**
+max	+max	Max				
+max	-max	Max				
-max	+max	Max				
-max	-max	Max				

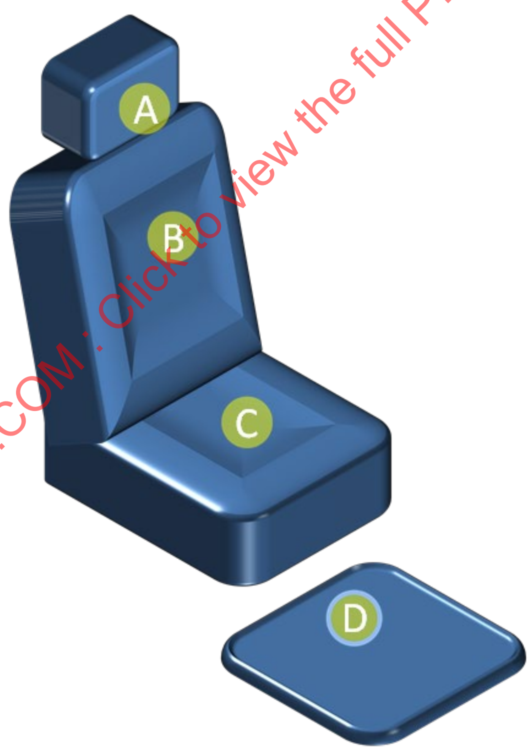


Figure 18 - Region 3 EMF data points

10.8 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 16. 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 that 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 16 - 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 U_2 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.

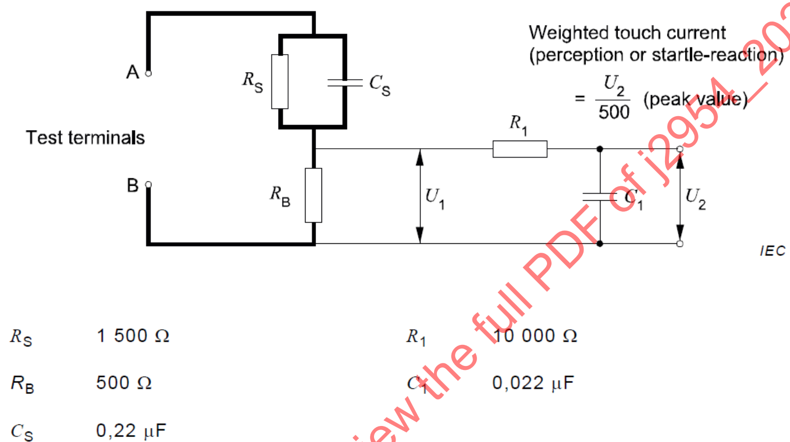


Figure 19 - IEC 60990 touch current measuring circuit

10.9 Touch Current Assessment Procedure (Informational: Requirements Apply to Tests 1A, 1B, 1C, 1D, 2A, 2B, 2C, 2D, 4A, 4B, 4C, 4D)

Measurements of touch current shall be performed in accordance with IEC 60990, utilizing the measurement network weighted for perception or startle-reaction. Measurements shall be performed over a metallic ground plane, with the charging system (and vehicle, if applicable) elevated by a nominal minimum amount necessary to reduce the effect of the ground plane on WPT operation and achieve normal operating conditions; e.g., 10 cm. Measurements shall be performed between the combinations of accessible parts listed in Table 17.

Table 17 - Touch current measurement points

Measurement	**IEC 60990 Figure 4 Touch Current Measurement Network Connection Points**	
	Test Terminal A	**Test Terminal B**
1	Vehicle body (e.g., door latch)	Ground plane directly under Terminal A
2	Metallic enclosure of charging system control/display	Ground plane directly under Terminal A
3	Vehicle body (e.g., door latch)	Metallic enclosure of charging system control/display
4	Additional exposed metallic charging system components	Additional metallic charging system components

All combinations of metallic charging system components, the vehicle body, and ground, which are simultaneously accessible and reachable by a person during charging, shall be added to the Table 17 list of measurements to be performed. For any measurements where Test Terminal B is not connected to the ground plane, it is necessary that the measuring instrument (connected to U_2 of the IEC 60990 Figure 4 measurement network) utilize a differential amplifier input.

Measurements should be performed for the coupler configurations listed in Table 18.

Table 18 - Coupler configurations for touch current measurement

Coupler Offset and Gap		
dX	dY	dZ
0	0	min
+max	+max	min
-max	+max	min

NOTE: Vehicle body (or mimic)-to-ground touch current will usually be dependent on the body or mimic capacitance to ground. Elevating the vehicle or using a mimic with less area than the vehicle underbody will tend to decrease capacitance and increase touch current. It may be necessary to add body or mimic capacitance to restore a value representative of the minimum capacitance which may occur in actual usage conditions (representing the smallest applicable vehicle on the ground).

10.10 Laboratory EMF and CIED Exposure Management

At the time of publication of this standard, the use of vehicle WPT systems will still be a new technology, and as such it is anticipated that many laboratories may initially lack policies addressing the operation of such systems. To aid in the creation or expansion of such policies, the following practices are suggested. The purpose of this section is not to impose requirements or to modify existing policies, but rather to educate.

During the testing process, steps should be taken to ensure that personnel are not exposed to hazardous RF electromagnetic fields or voltages. Special care should be taken when working with component-level systems that may have less shielding than their vehicle integrated counterparts and may not include automatic protection systems.

For the prevention of exposure to excessive electromagnetic fields, a marked safety perimeter should be established around the wireless power transfer system and personnel should not enter the safety perimeter when wireless power transfer fields are active. It is recommended that magnetic and electric field limits of Table 19 be used to provide combined protection for persons with CIEDs and for the general public.

Table 19 - Combined EMF limits for laboratory use

Quantity	Laboratory EMF Limit (rms)
Magnetic Field	15 μT or 11.9 A/m
Electric Field	83 V/m
Touch Current	15.8 mA

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

It is recommended that the perimeter be first established at a distance greater than 3.0 m around the system being tested and that initial power-up be done at the lowest power transfer level possible. Controls for operating the wireless charging system and any safety apparatus should be located outside the EMF perimeter. The power level will then be gradually increased to rated power, while the electrical and magnetic fields are carefully monitored by the laboratory field sensor(s) set up at the perimeter. If the sensor readings exceed the EMF threshold during the perimeter exercise, power transfer should be stopped immediately, and the perimeter should be increased to a safe distance. Misalignment also shall be considered when attempting to introduce the conditions of maximum field strength/intensity leakage. Once the worst-case EMF conditions are understood and established, the perimeter can be moved inward until fields at the perimeter are at the recommended limit levels.

Careful attention shall be paid to the grounding of equipment to prevent the possibility of RF shock or burn from touching equipment having RF potential. In some laboratory measurement setups, it may be necessary to operate the VA (possibly including the rectifier and load) in a “floating” or ungrounded condition (e.g., to mimic vehicle conditions). In such cases, it is important to consider whether inadvertent grounding through a human could occur.

If metallic WPT equipment is isolated from ground and accessible to personnel, the maximum human body grounding current should not exceed 15.8 mA. Particular attention should be paid to ungrounded objects that are in close proximity to the WPT couplers (e.g., a floor pan mimic plate) and are directly accessible from the perimeter or have attached conducting elements extending to or beyond the perimeter (e.g., instrumentation leads).

As component level systems may not have sufficient shielding, precautions should be made to protect any equipment sensitive to high intensity magnetic and electric fields so long as the countermeasures do not alter the performance of the wireless power transfer system.

10.10.1 ICNIRP Safety Compliance

Measure the magnetic and electric field levels at the perimeter of the boundary surrounding charging coils (0.8 m from the center point of VA coil; vehicle: 0 mm from vehicle edges) for ICNIRP compliance for safety of the test operator.

Evaluate the EM field at nominal Z-gap (manufacturer recommended) for both the aligned condition and maximum (worst case) misalignment in X and Y at full rated power. From these results, set a perimeter boundary around the test setup to ensure the test operator safety.

Repeat this evaluation of the EM field at the maximum Z-gap and the worst-case X and Y misalignment and roll and yaw to verify that the worst-case EM field conditions have been identified. Set the perimeter boundary in accordance with the maximum measured EM field of any test condition.

Table 20 - Measurements of fields

		Performance Metrics	Safety Notes
ICNIRP	ICNIRP Gen.Pub. Distance X-Axis		
	ICNIRP Gen.Pub. Distance Y-Axis		

11. ADDITIONAL SAFETY REQUIREMENTS (INFORMATIONAL: REQUIREMENTS APPLY TO TESTS 1A, 1B)

UL has published a standard, UL 2750, to specifically cover the safety aspects of the off-vehicle components and operation of WPT. The NFPA National Electric Code (NEC), Article 625, has provisions covering the installation of wireless charging systems. The NEC is used by most U.S. local electrical inspection services to determine approval of electrical installations.

12. COMMUNICATIONS AND ALIGNMENT

12.1 Introduction (Informational: Requirements Apply to Tests 3A, 6A, 6B, 6C, 6D)

Wireless charging of EVs adds a number of communication requirements to those required to support conductive charging. Foremost among these is the need to be able to communicate between the VA and the GA over a wireless physical medium.

This results in the need to ensure the communication connection between the VA and GA are verified before charging is initiated by the WPT system. SAE J2954 Product GAs and Product VAs utilize the communication protocol and messages defined in SAE J2836/6, SAE J2847/6, and SAE J2931/6 to support communications needed for WPT.

Wireless charging is convenient due to its contactless nature. One of the benefits of wireless charging is the flexibility allowed in alignment between the charging infrastructure and a vehicle. While fairly large tolerances may be allowed, some level of vehicle alignment is required to ensure safe and efficient charging. It is primarily the responsibility of the vehicle’s onboard capability to guide or otherwise assist the driver in aligning the VA to the GA. There is a need, however, for a standardized method to allow for any vehicle with a SAE J2954 Product VA to align with any SAE J2954 Interoperability Class I GA.

The SAE J2954 alignment sub-team has surveyed vehicle OEMs and wireless charging suppliers to determine the minimum common method for light-duty alignment (fine alignment, pairing, and alignment check) to be standardized. The minimum common alignment method that shall be supported by a light-duty Class I GA is the “Differential Inductive Positioning System” (DIPS) described in this section. The alignment methodology for medium-duty and heavy-duty vehicles is to be specified in SAE J2954/2.

The basic approach to DIPS interoperability is as follows:

- A prescribed set of alignment magnetic fields are created by five auxiliary coils added to a compliant J2954 Class I GA; each coil operating at a unique frequency.

- Receive alignment coils can be added to a Product VA to capture the alignment fields, and the VA can use the resulting received signals to calculate navigation instructions for positioning.

- No requirements are given for the VAs to use DIPS. However, the vehicle system must ensure alignment tolerance requirements are met for wireless charging.

- The DIPS transmitter and receiver definition is such that they can be fully integrated into the GA and VA.

- All necessary pairing information is modulated onto the magnetic field of the auxiliary coils.

- All alignment and wireless charging functions indicated in this section can be fully automated.

As described in other parts of this standard, communications are used to support a variety of functions, along with alignment, that are of utility to the user as well as necessary to ensure efficient and safe transfer of power while complying with applicable regulations. The sections below give a high-level description of the functions supported; details can be found in the above referenced communications standards.

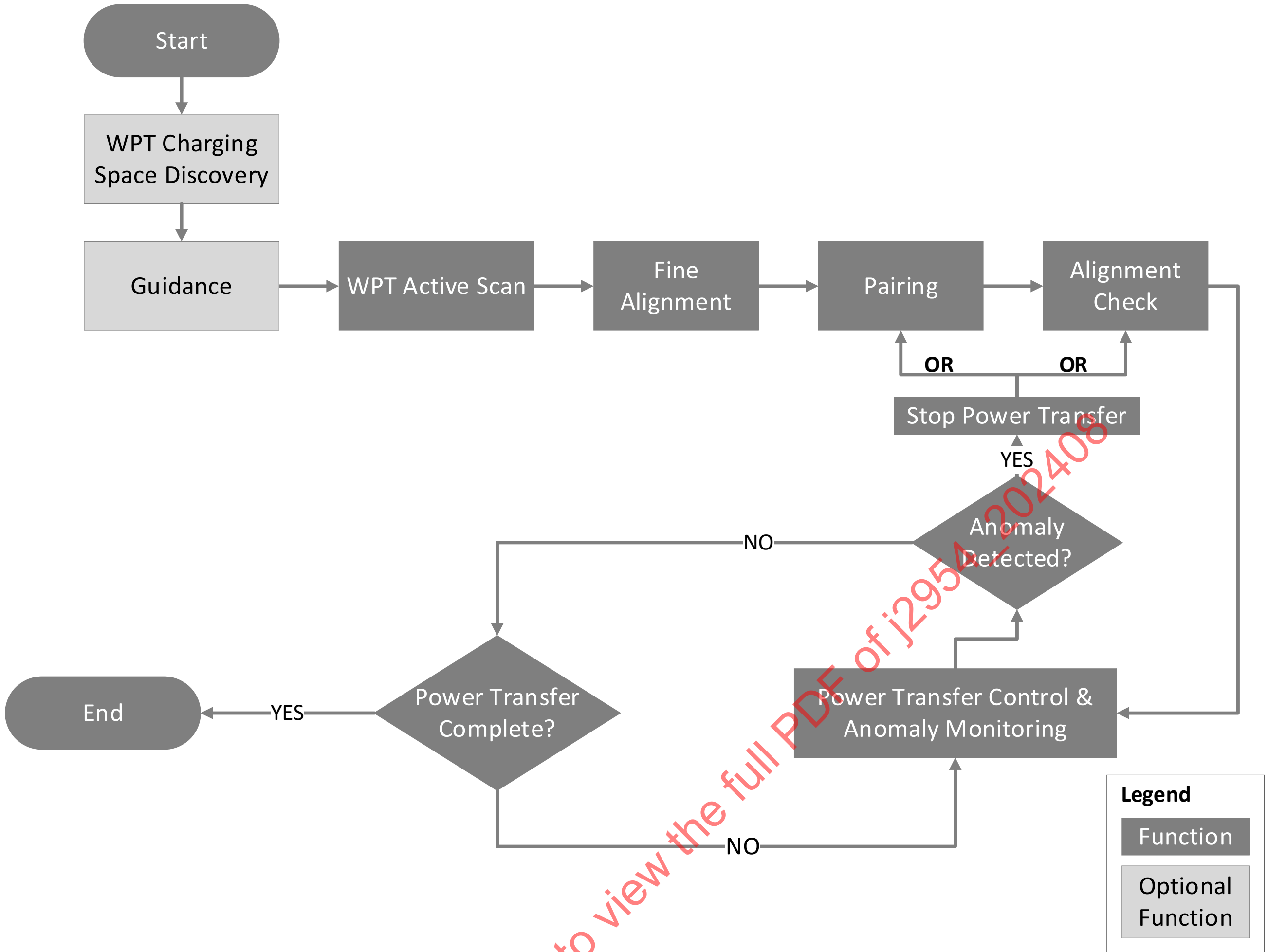


Figure 20 - Wireless charging process flow diagram

12.2 WPT Charging Space Discovery

WPT charging space discovery allows a user to locate a WPT space, its capabilities, compatibilities, and availability. Communication supporting this functionality is independent of the charging technology and may reuse general internet technologies and capabilities. It is not covered by this specification.

12.3 Guidance

Guidance is an optional and proprietary function that may be used to assist the vehicle's navigation (e.g., global positioning system) toward a WPT charging space once WPT charging space discovery has occurred. Guidance is not covered by this specification.

12.4 WPT Active Scan (Informational: Requirements Apply to Tests 5A, 5C, 6A, 6C)

WPT Active Scan is initiated by the VA to notify nearby GAs of its presence prior to parking. The WPT Active Scan shall be performed according to the Wi-Fi standard 802.11 active Wi-Fi scan in the 2.4-GHz frequency band and contains vendor-specific elements defined in SAE J2847/6.

When an unoccupied GA receives a matched WPT Active Scan, it can turn on its systems required for the alignment process.

12.4.1 Generalized WPT Active Scan Process

a. VA transmits (broadcasts) a probe request to all access points in Wi-Fi range.

b. GAs that receive a probe request can turn on systems required for alignment and pairing (horizontal and vertical field coils).

c. GAs send a probe response back to the VA to confirm the request (optional).

12.5 Fine Alignment (Informational: Requirements Apply to Tests 3A, 5A, 5C)

Supporting communication capabilities are defined in SAE J2847/6 to facilitate manual or automated positioning of an EV for optimal power transfer.

Fine alignment provides assistance to the vehicle or driver when approaching a parking space to facilitate centered alignment between the VA coil and the GA coil. When aligned, the VA coil shall be within the defined allowed offsets for the WPT system as defined in 8.2.2.

The following are the minimum requirements for fine alignment:

- Interoperability Class I GAs shall support the common DIPS fine alignment method.
- The GA and VA shall begin the fine alignment process at a minimum distance of 1.5 m from the centered position of the VA coil and GA coil or when the VA and GA have initiated communication.
- The final alignment position check shall ensure the VA is within the positioning tolerance area (see 8.2.2).

It is possible that the VA may choose to utilize one or more fine alignment methods in conjunction with or instead of the common alignment method. It is not the intention of SAE J2954 to limit vehicle fine alignment methods but rather provide a minimum means for interoperability.

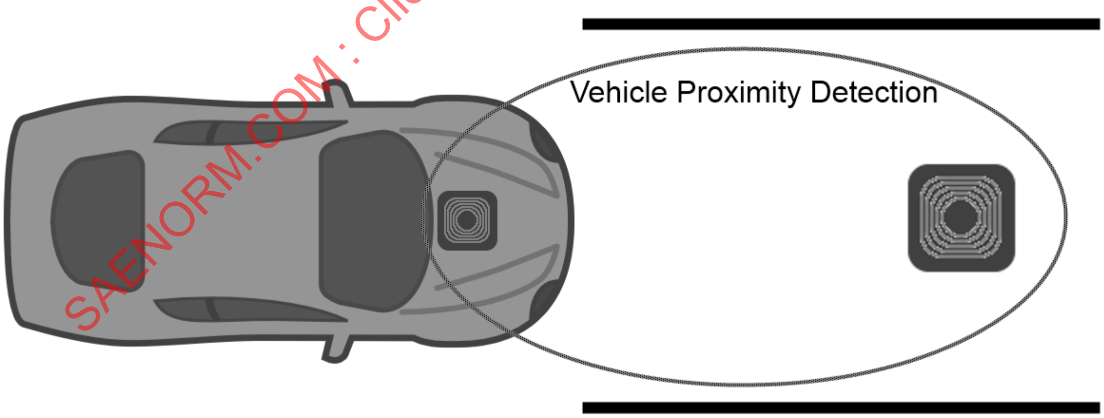


Figure 21 - SAE J2954 vehicle alignment concept

12.5.1 Details of Interoperability for Fine Alignment Method

Prior to fine alignment of the GA and VA coils, vehicle guidance may have optionally been used to assist the driver in finding the appropriate SAE J2954 parking space. By this time, appropriate communication information has been exchanged between the VA and GA (including vectors for calculating the natural offset described in 12.5.2).

12.5.1.1 Generalized Fine Alignment Process

- The VA requests the fine alignment method from the GA.
- The driver (or vehicle, if automated) positions the vehicle in the parking space while the VA provides positioning information.
- The driver puts the vehicle into park. If this position is not within the alignment tolerance area (see 8.2.2 for position tolerance requirements), the driver is notified to reposition the vehicle before power transfer can begin.
- After determining that the vehicle is within the alignment tolerance area, the VA requests the GA to terminate the fine alignment process.

12.5.1.2 Common Fine Alignment Method “Differential Inductive Positioning System” (DIPS) (Informational: Requirements Apply to Test 3A)

The DIPS-Enabled GA can be based on any compliant Interoperability Class I GA.

Figure 22 shows an exploded view of an example of a DIPS-Enabled GA including the litz wire, ferrite tiles, and aluminum plate using concepts from the Universal GA in Appendix B. Mechanical design specifications of this example DIPS-Enabled GA is provided in Appendix C.4.1.

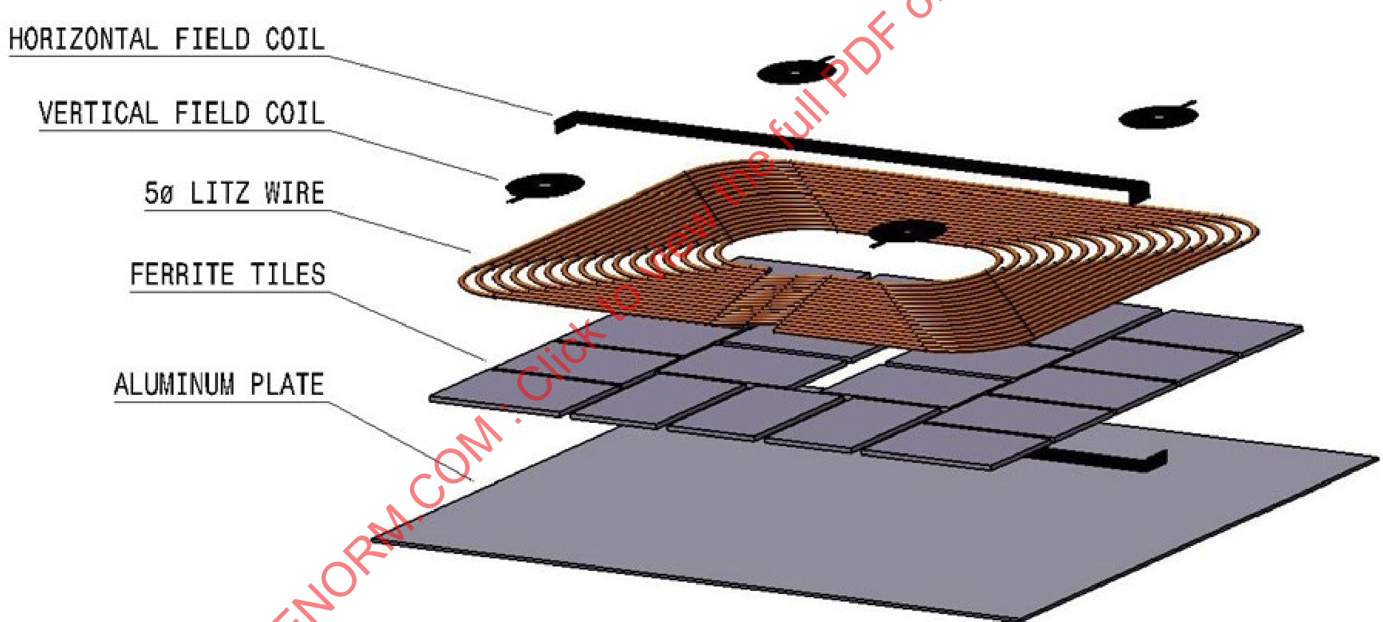


Figure 22 - Exploded view of an example of a DIPS-Enabled GA

The five coils are named according to their functionality regarding the provided magnetic field main flux direction:

- Vertical field coils: Four small planar circular coils shall be placed upon the GA ferrite and the litz wire to generate a vertical magnetic field above the GA to provide distinguishable alignment fields with different frequencies for the VA when it is near the GA.
- Horizontal field coil: A solenoid coil shall be placed around the ferrite and litz wire of the GA power transfer coil to generate a horizontal magnetic field predominantly in the X-direction (driving direction) to provide an alignment field for the VA at a farther distance from the GA.

The requirements for an Interoperability Class I GA to provide the alignment magnetic fields for DIPS are as follows:

- The frequencies of the horizontal and vertical field coils shall be as defined in Table 21 and Table 22 with an accuracy of ± 25 ppm.

- In a parking area with more than one GA, the GA being installed shall not use the same frequency for the horizontal field coils as any of the neighboring parking spaces (left, right, driving direction, or diagonally).

- The operating frequency used for the horizontal field coil of the GA shall be documented (digitally or visually).

- The DIPS-Enabled Interoperability Class I Product GA shall pass the DIPS Conformance Test for Fine Alignment described in Appendix C, Section C.2.

- The alignment magnetic field shall be provided by the GA within 0.5 seconds of receiving the VA's Active Scan probe request or if triggered by an external sensor when a vehicle enters the parking space.

Table 21 - Frequency/position definition for DIPS GA vertical coils

Frequency #	Position (See Figure C11)	Vertical Field Coils
f1	+X, -Y	142.00 kHz
f2	+X, +Y	143.00 kHz
f3	-X, +Y	145.00 kHz
f4	-X, -Y	146.00 kHz

Table 22 - Horizontal field coil frequencies

Horizontal Field Coils
111.50 kHz
113.50 kHz
115.50 kHz
117.50 kHz

12.5.2 Alignment Natural Offset Between Circular- and DD-Topologies (Informational: Requirements Apply to Tests 5A, 5B, 5C, 5D, 6A, 6B, 6C, 6D)

When a DD-topology VA as described in Appendix H is used over a circular-topology GA as described in Appendix B, a "natural offset" (x_0) has to be set between the VA and GA, as shown in Figure 23. This offset between circular- and DD-topology is needed for correct coupling and power transfer. It is unrealistic to have a table of every possible natural offset for every VA and GA; therefore, appropriate vector information is required for the VA to determine the "natural offset" during the guidance and fine alignment processes. To facilitate this, the VA and GA will exchange vector information prior to guidance or fine alignment to determine the natural offset.

The GA shall define one vector (X, Y, Distance) that gives the distance and direction from the GA coil geometric center to the designated axis in which the centered position is achieved with a circular reference VA coil's center point. If the GA coil has multiple possible vectors (such as is the case for the DD-topology), then a single axis is chosen for the designated vector to achieve centered position with a circular reference VA coil. Note that if the GA coil has no natural offset with a reference circular VA coil, then the vector will have zero direction and distance.

The VA shall define two vectors (X, Y, Distance) that gives the distance and direction from the VA coil geometric center to the designated axis in which the centered position is achieved with a circular reference GA coil's center point. One vector is defined for forward movement of the VA and one vector is defined for backward movement of the VA (and they could be the same). Only one of the VA's vectors is transmitted depending on the direction of movement determined by the VA. Note that if the VA coil has no natural offset with a reference circular GA coil, then the vector will have zero direction and distance.

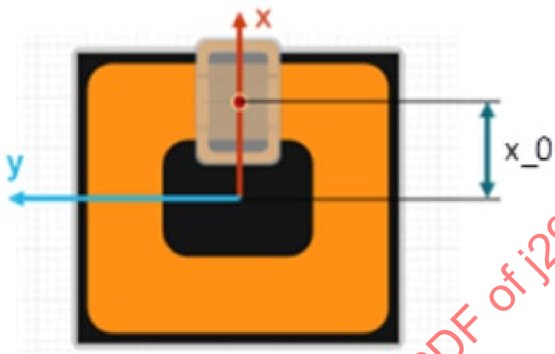


Figure 23 - Example for the "natural offset" definition x_0 for a DD-topology VA over a circular-topology GA

The values shown in Tables 23 and 24 are examples of offset vectors and natural offsets for configurations using the coils described in Appendix B and Appendix H.

Table 23 - Examples of "natural offset" (x_0) for VA/GA pairs from Appendix H and Appendix B

Circular GA	GA Offset Vector		DD VA	VA Offset Vector		Natural Offset
Appendix	**GA_{x_0}**		**Appendix/WPT/Z**	**VA_{x_0}**		**$GA_{x\_0} + VA_{x\_0}$**
B	0 mm		H.1 WPT2 Z1	+190 mm		+190 mm
			H.1 WPT2 Z1	-190 mm		-190 mm
B	0 mm		H.2 WPT2 Z2	+190 mm		+190 mm
			H.2 WPT2 Z2	-190 mm		-190 mm

Table 24 - Examples of "natural offset" (x_0) for VA/GA pairs from Appendix H and Appendix B

Circular GA	GA Offset Vector		DD VA	VA Offset Vector		Natural Offset
Appendix	**GA_{x_0}**		**Appendix/WPT/Z**	**VA_{x_0}**		**$GA_{x\_0} + VA_{x\_0}$**
B	0 mm		H.1 WPT2 Z1	+190 mm		+190 mm
			H.1 WPT2 Z1	-190 mm		-190 mm
B	0 mm		H.2 WPT2 Z2	+190 mm		+190 mm
			H.2 WPT2 Z2	-190 mm		-190 mm

The values given in Tables 23 and 24 are examples based on magnetics only. The "natural offset" that needs to be used in practice may be different because of further consideration of variable frequency and tuning circuit aspects. That means the values as shown in Tables 23 and 24 may need further fine-tuning to achieve power and/or efficiency maximum.

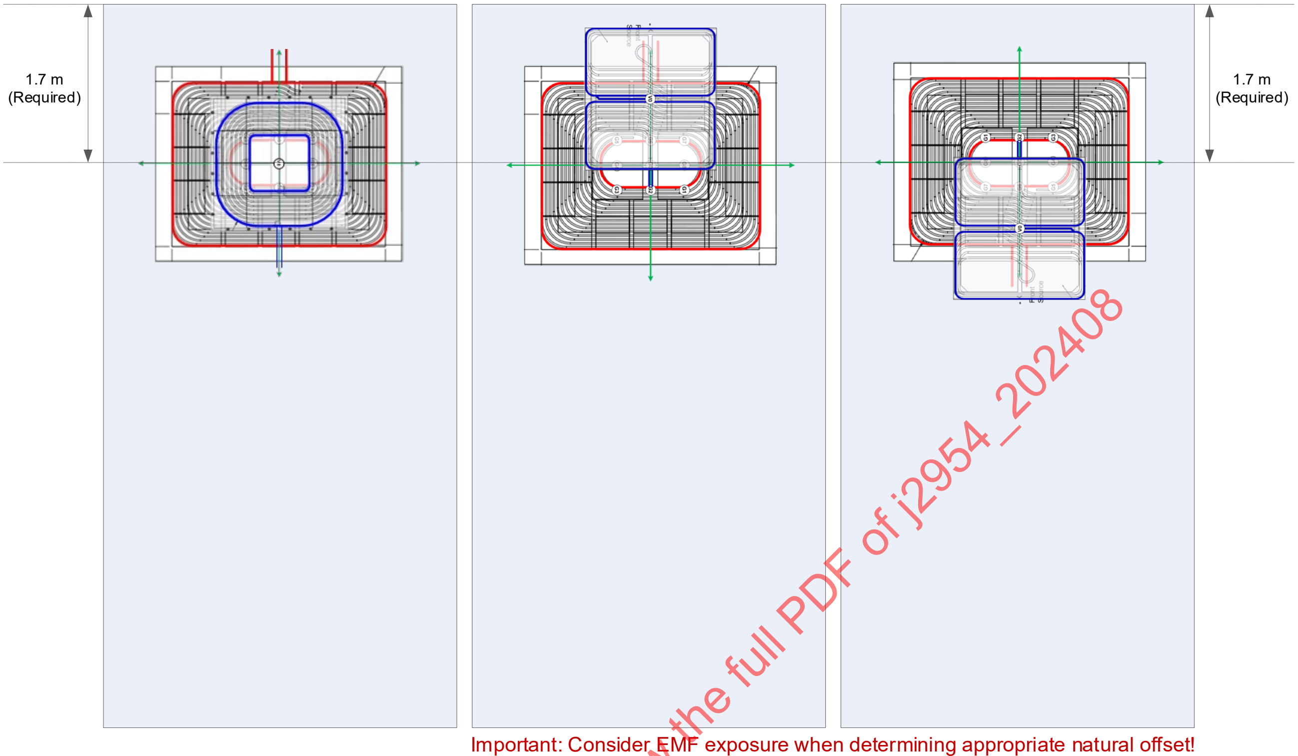


Figure 24 - Examples of DD and circular coil natural offset conditions

12.5.3 WPT Alignment and Vehicle Automated Driving Systems

SAE J3016 includes taxonomy and definitions for terms related to on-road motor vehicle automated driving systems and refers to levels of automation 1 through 5. The DIPS alignment method specified is recommended for use in assisting with automation of parking, alignment, and charging of on-road automated driving systems.

12.6 Pairing (Informational: Requirements Apply to Tests 5A, 5B, 5C, 5D, 6A, 6B, 6C, 6D)

Pairing verifies that the VA WPT coil is positioned above the GA WPT coil intended for power transfer and confirms that the VA is communicating with the same GA it is parked over. If no automated pairing method is available between the GA and the VA, then the VA shall perform one of two actions:

a. If the VA or GA is capable of automatically identifying the physical pairing uniquely on its own (e.g., DIPS method, unique SSID, automated optical recognition in parking space or vehicle, etc.), then the pairing confirmation shall occur automatically.

b. If no other option is available, at a minimum, the VA (by means of a user interface) shall request "external confirmation." External confirmation is provided when the driver is capable of uniquely identifying the GA over which the vehicle is parked (e.g., by means of signage, SSID, or other unique aspects such as a single parking space).

12.6.1 Generalized Pairing Process

- The VA requests pairing to begin and waits for the modulated signal from the GA.
- The VA and GA perform whatever measurements are deemed necessary during the transmission of the modulated signal to determine correct pairing.
- Based on the measurements during the transmission of the pairing signal, the VA reports the pairing code to the GA and the GA determines if they are appropriately paired. If so, the alignment check process begins.
- If an automated pairing method is unavailable, the VA requests external confirmation from the operator in order to correctly pair the VA with the GA over which the vehicle is parked.

12.6.2 Pairing using DIPS (Informational: Requirements Apply to Tests 5A, 5C)

An Interoperability Class I GA shall support the DIPS pairing method as follows:

a. The GA provides a one-way data transmission from the GA to the VA by transmitting necessary pairing information.

b. The data transmission includes a DIPS Data Package (see Appendix C for details). This data package is modulated on the horizontal and vertical field coils by Binary-Amplitude-Shift-Keying.

c. For the physical layer signal, the DIPS Conformance Test for Pairing is mandatory.

d. All requirements for DIPS pairing are defined in Appendix C, Section C.3.

e. A DIPS-Enabled VA can receive pairing data through appropriate signal processing and correctly decode the pairing information.

12.7 Alignment Check (Informational: Requirements Apply to Tests 5A, 5B, 5C, 5D, 6A, 6B, 6C, 6D)

Alignment check verifies that alignment between the VA coil and the GA coil meets the alignment requirement of 8.2.2 and that the VA and GA are ready for power transfer.

In case the GA and the VA do not have another compatible means for alignment check by using external signaling and sensors, the GA and VA shall perform a power check. The power check method requires that appropriate compatibility parameters have already been exchanged through the SAE J2847/6 communication channel, including the VA coil ground clearance range.

The process for power check is as follows and applies to all systems:

a. The VA requests the minimum power/current that the GA is capable of delivering (using the previously exchanged compatibility parameters). The VA load (battery) is available to transfer power.

b. The GA ramps its GA coil current to its minimum capable level.

c. The GA and VA perform measurements to ensure the power level is appropriate based on the compatibility parameters (including VA coil ground clearance).

d. The GA and VA perform anomaly monitoring to ensure no anomalous behavior that would indicate misalignment.

e. If all initial measurements are within the bounds expected by the GA and the VA, then the VA continues to make appropriate power/current requests for the GA to ramp up power. When the VA is satisfied that the GA is appropriately coupled, alignment check is confirmed, and power transfer begins from that point.

f. If at any point during power ramp up the GA or the VA determines there are anomalous measurements, then the alignment check is reported as a failure.

13. CONTROL STABILITY AND MONITORING

13.1 Control States of Operation

The following states are considered separately for control stability:

- Pre-negotiation
- Power start-up
- Power shutdown
- Power transfer and optimization
- Error conditions

13.2 Power Transfer Cycle Control

If the alignment is satisfactory, the VA requests power transfer, at which point the GA may optionally ramp the current down first or may start from present state of current to reach currents required for power transfer. A key functionality required for efficient power transfer is the capability for the EV to control the power transfer process. To support this, SAE J2847/6 defines messages that provide the following capabilities:

- Verification of compatibility
- Initiation of a charging cycle
- Control of the GA current/voltage/energy to match the vehicle's requests
- Modification of the power transfer process in response to external and internal events
- Termination of the charging cycle

13.2.1 Anomaly Monitoring During Power Transfer (Informational: Requirements Apply to Tests 5A, 5B, 5C, 5D, 6A, 6B)

During power transfer, the delivered power is coordinated and not expected to change sharply except in the case where the VA or vehicle removes the load for safety reasons. Unexpected changes in power, current, voltage, efficiency, or other measurements within the GA or VA are considered "anomalies". An anomaly during power transfer is an asynchronous and unexpected condition that is determined by the VA or GA when an unexpected measurement or set of measurements, conditions, or states occurs. The VA and the GA shall be characterized for normal operating conditions across interoperable conditions so that an anomaly for a given VA or GA is detectable. The VA and GA shall continuously monitor for anomalies during power transfer; this is referred to as "anomaly monitoring." As part of anomaly monitoring, the GA shall monitor its input power. One possible cause for anomalies is the sudden change in coupling between the GA coil and VA coil; this change in coupling can be caused by unexpected movement of the vehicle. One of the purposes of anomaly monitoring is to ensure that power transfer only occurs in conditions that meet EMF exposure requirements as provided in Section 10.

The VA and GA may independently determine their own definition of a measurement anomaly based upon expected system operation. If the GA or the VA detects an anomaly or a series of anomalies, the GA shall shut down power transfer immediately and proceed to either the alignment check or pairing states to verify appropriate alignment and/or pairing. If the anomaly is a large and sharp drop in input power detected by the GA, then the GA shall consider that the VA has removed the load for safety reasons and shall immediately terminate power transfer and negotiate next steps over out-of-band SAE J2847/6-compliant communications.

13.2.2 Monitoring of the Charging Process (Informational: Requirements Apply to Tests 3A, 3B, 6A, 6B)

To ensure that power transfer operates within specified operation and regulatory limits, the EV may be equipped with various sensors and detectors for critical events. SAE J2847/6 defines messages that allow for the communication of these events so that appropriate action can be taken.

The GA shall have a means to prevent power transmission continuing when the power control program has malfunctioned. This may be accomplished by using a watchdog timer or having a supervisor program for the power control program.

13.2.3 Control Bandwidth/Update Rates and Stability (Informational: Requirements Apply to Tests 2A, 2B, 3A, 3B, 3C, 3D, 5A, 5B, 5C, 5D, 6A, 6B, 6C, 6D)

The GA shall have the means to increase and decrease the delivered power to the VA during power transfer. The GA makes these adjustments by changing the GA coil current to meet the needs of the system. The VA may have its own mechanism of control to optimize power delivery to the vehicle battery system. In case the VA has the ability to make changes that affect the power delivery or impedance seen at the GA coil, special considerations shall be made to ensure the control loop on the GA and the control loop on the VA operate in a way that guarantees control criteria for stability.

The GA and VA together form a closed-loop control system. In addition, separate but interacting closed-loop or open-loop control systems may exist on the GA and VA.

To ensure stability during pre-negotiation, the following criteria shall be met:

- The GA and VA shall follow the pre-negotiation protocol defined in J2847/6 to ensure operational compatibility of the GA and VA, as well as to negotiate power transfer parameters.

The VA sets the power ramp conditions by communicating the desired power from the GA. To ensure stability during power start-up, the following criteria shall be met:

- The power shall ramp at a rate no less than 0.25 kW/s and no greater than 2 kW/s.

- If the VA is capable of making adjustments on its own that affect power delivery or the impedance seen at the GA coil, the changes shall not result in power delivery changes that exceed the above ramp-up and ramp-down rates. The VA shall only request changes in power delivery during start-up once its own control adjustments are complete.

To ensure stability during power transfer, the following criteria shall be met:

- The GA shall ramp power at a rate no less than 0.25 kW/s and no greater than 2 kW/s when a change in power or coil current is requested by the VA.

- The GA shall update its power control parameters that are capable of changing the GA coil current at a rate of at least 500 Hz or greater to ensure power delivery is constant when the impedance at the GA coil changes due to changes caused by the VA electronics.

- If the VA is capable of adjusting power or impedance seen at the GA coil, the VA shall update its power control or impedance control parameters at a rate less than or equal to 50 Hz to ensure the GA can appropriately compensate for the resultant impedance changes before further VA impedance changes occur.

- All changes in GA coil current shall result in a condition that guarantees no more than 10% overshoot. Whenever possible, the GA coil current changes should result in an overdamped condition.

- Under constant loading conditions, all changes by the VA shall result in a condition that guarantees no more than 10% overshoot of power delivery to the vehicle battery system.

During power shutdown, the following criteria shall be met:

- The power shall ramp down at a rate of 2.5 kW/s or more during power shutdown (i.e., power request to 0 kW).

During Error Conditions, the following criteria shall be met:

- The VA shall protect itself from damage and may operate at any update rate necessary to do so.
- The GA shall be capable of decreasing its GA coil current to stop power transfer and shall meet the criteria of 13.2.1.
- In the event that the VA communication is lost for more than 2 seconds, the GA shall ramp down its GA coil current to stop power transfer within 4 seconds from the loss of communication.
- An emergency shutdown shall occur when a system anomaly is detected or a critical system malfunction has occurred. The GA shall ramp down its GA coil current and stop power transfer within 1 second of an emergency shutdown.
- In all error cases, the GA coil current shall remain low enough to meet EMF limits specified in Section 10, directly above the GA coil (as if no VA were present) when no power transfer is occurring.

13.2.4 Frequency Modification During Charge Cycle/Power Transfer

See 6.4.2 for frequency adjustment requirements.

14. SAE J2954 PARKING SPACE

14.1 Location of GA Coil Center Point in SAE J2954 Parking Space

Section 14 applies specifically for Interoperability Class I GAs and may be used as a reference for the location of Class II GAs as well. SAE J2954 specifies a single position for the center point of the GA coil in a parking space; however, it is recognized that these recommendations cannot be enforced. See Figure 25.

The reference datum point (0,0) used for measurements is at the inner edge of the parking lot line in the front of the parking space on the Y-axis center line.

The center point of the GA coil is shown in Figure 25. There shall be visible marks on the GA to indicate the X and Y axis of the center point of the coil for installation. The X and Y position GA markings shall be located on each edge.

The center point of the GA coil shall be 1.7 m from the datum point (front of parking space) and shall be located on the centerline in the parking space.

The center point of the GA coil shall have an installation tolerance of ±0.01 m in the X axis.

The center point of the GA coil shall have an installation tolerance of ±0.01 m in the Y axis.

The recommended length of an SAE J2954 parking space is 6 m.

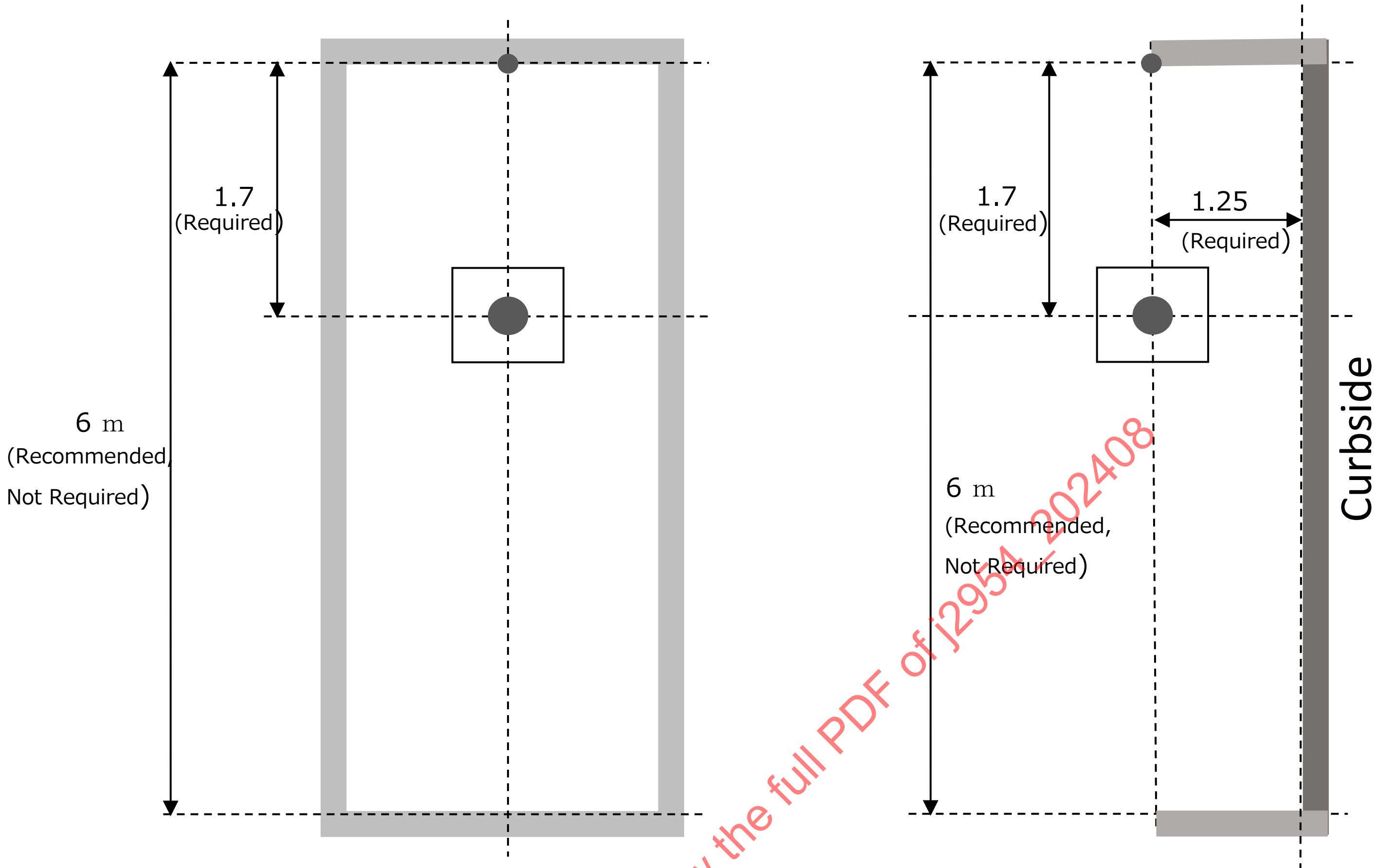


Figure 25 - SAE J2954 GA center point location diagram

NOTE: The centerline for handicapped parking spaces is based on the actual parking stall and not the extra space available for entry/exit around the vehicle.

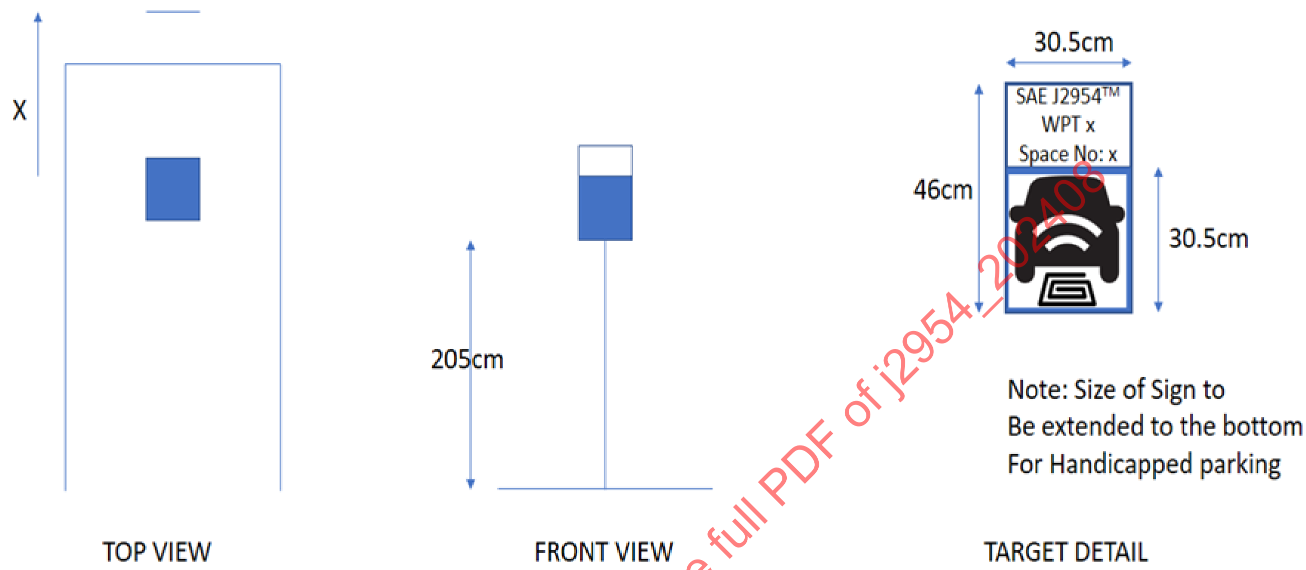
14.2 SAE J2954 Parking Space Parking Direction and Visual Cues

The SAE J2954 parking space shall allow a vehicle to drive forward into the space unless the requirements of the parking space dictate otherwise. The SAE J2954 parking space shall also facilitate additional visual alignment cues where possible.

14.3 SAE J2954 Parking Space Markings

It is helpful to designate SAE J2954 parking spaces for interoperable charging. The following figures show the recommended signage to be used for designating an SAE J2954 parking space. See Figure 26.

- Optional SAE J2954 ™ Sign* located at front of parking stall
    - Centered in Parking Spot
    - Reference Height for bottom of sign is 205 cm from ground (to correspond to the max. 80" required for handicapped)
    - Standard US parking sign is 30.5 cm x 46 cm
    - Painted SAE J2954 Logo on Sign (size regional)



*SAE J2954 and the SAE J2954 Wireless Power Transfer and Alignment Symbol are Trademark and Copyright of SAE International

Figure 26 - SAE J2954 wireless charging identification markers

15. PERFORMANCE TESTING

Performance testing appears in various sections of this standard:

- Requirements for specific performance related to power transfer are given in Section 8.
- EMC testing appears in Section 9.
- EMF testing appears in Section 10.
- Communication and alignment test requirements appear in Section 12.
- Control stability and monitoring requirements appear in Section 13.
- Power transfer testing is covered in 15.1.
- Performance relative to safety is covered in Section 16.

As listed in 8.2, testing for Product GAs and Product VAs is performed against SAE J2954 Test Station devices. Because of the need to change relative positions of the GA and VA and to change other test conditions during these tests, they are most conveniently done at a component level on a Test Station.

Testing of other functions, such as some aspects of communication and alignment (see Section 12) and live object protection (see Section 16), are performed at a vehicle/system level.

15.1 Power Transfer Testing (Informational: Requirements Apply to Tests 5A, 5B, 5C, 5D)

The procedures in 15.1 are intended to support the requirement that the vehicle side components of any SAE J2954-compliant system be interoperable with the infrastructure side components of any SAE J2954-compliant system. This section addresses both component-level testing for power transfer and vehicle-level testing with regards to power transfer.

SAE J2954 has established normative Test Station VAs for WPT1, WPT2, and WPT3 (see Appendix A) and a normative Test Station GA (see Appendix B) against which Product GAs and Product VAs shall meet the power transfer performance requirements established in Section 8. All such Product VAs and GAs shall be tested for performance and safety with Test Station devices as described in Section 8, even if they are presented as a system from the same manufacturer.

During testing, whether at the component or vehicle level, consideration should be given to electromagnetic safety, as described in 10.10.

15.1.1 SAE J2954 WPT Test Station (Informational: Requirements Apply to Tests 4A, 4B, 4C, 4D)

The SAE J2954 Test Station enables X and Y offsets and Z-gap variations for power transfer performance testing. It can also be used for EMC, EMF, and alignment testing. The ideal Test Station has an X, Y, and Z positioning mechanism that is capable of 1 mm precision, as well as provision for testing roll, pitch, and yaw. Any of the above offset positions may be achieved by moving the GA or the VA. Since process efficiency during test is important, the positioning mechanism should be automated, but that is not required.

The materials for the Test Station frame, including any supporting mechanisms, shall be nonmetallic except for the devices being tested and the shield and vehicle mimic. All other metallic materials should be kept below the plane of the base of the GA coil or above the mimic plate.

If the Test Station is being used for EMC testing, it should be on a metal turntable.

Figure 27 shows an example of an SAE J2954 WPT Test Station.

The WPT Test Station GA consists of GA electronics driving a GA coil and a GA Communications Module. The GA electronics and the GA coil are represented as the power transfer functions within boxes 11 and 12 of Figure 1; the GA communications module is represented by the communication functions within boxes 12 and 13.

The WPT Test Station VA consists of a VA coil connected to VA electronics and a VA communication module. The VA coil and the VA electronics are represented as the power transfer functions within boxes 21 and 22 of Figure 1; the VA communication module is represented by the communication functions within boxes 22 and 23 along with a vehicle CAN bus simulator.

A Product GA or a Product VA would comprise these same elements, including the communication function.

The shield is used to protect ferrous materials (such as a steel underbody) from the heating effects of the magnetic fields that are not captured by the VA resonator. Since the fields are generated by the GA resonator, the design and size of the GA resonator is a principal determining factor in the optimal shield size. However, the vehicle may not be able to accommodate the optimal shield size, and a specific vehicle application may require a shield that is smaller.

For GA testing using the normative Test Station VAs, the aluminum shield to be used is specified in the appendix for that specific VA. The shield to be used when using the Test Station with a Product VA shall be specified by the manufacturer and should be the size and contour (if possible) of the shield that will be used when mounting the VA to the vehicle.

Because it is possible that the shield size may not capture the stray fields from the GA, either because of the GA size or shape or because the shield size possible for a given Product VA is small, heating of the steel mimic plate might occur. Therefore, when testing, the mimic plate in the Test Station shall be monitored for excess heating while testing.

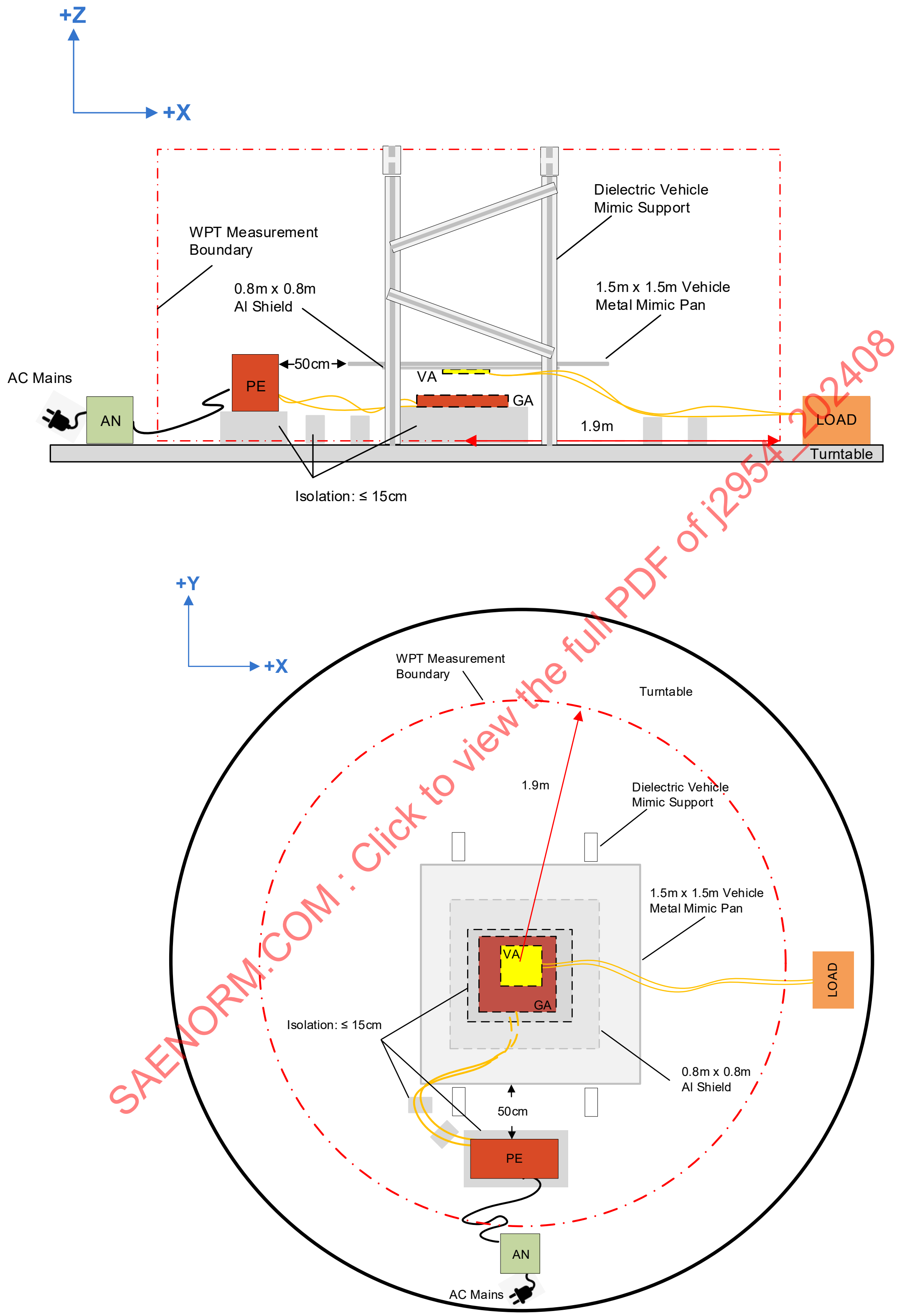


Figure 27 - SAE J2954 WPT Test Station

15.1.2 Component Power Transfer Test for Product VA (Informational: Requirements Apply to Tests 4A, 4B, 4C, 4D)

As described in 8.2.1.1, the Product VA is tested against the normative GA from Appendix B in conjunction with the GA communication module. The manufacturer of the Product VA specifies the aluminum shield size and shape; for most accurate results, the shield specified should be as close to the size and shape of the actual shield to be used when installed on the vehicle.

The VA output goes to a DC load as a replacement for the battery system of the actual vehicle. Communication shall be active, and enablement of the conditions that would otherwise be available from the vehicle (CAN signals, for example) shall be possible. Testing that simulates the various critical steps in the control sequence described in Figure 20, including charging control, shall occur to ensure safe and proper operation and to confirm non-operation in those cases when the compatibility check is not valid.

On the GA side, communication shall be active and able to simulate the handshake and the various critical steps in the control sequence described in Figure 20, including charging control, to ensure safe and proper operation/non-operation. Power transfer system efficiency tests shall be made at nominal input voltage as described in 8.2.8.1.

15.1.3 Vehicle Test for Product VA (Informational: Requirements Apply to Tests 4C, 4D)

While component testing is more convenient, a vehicle test can instead be performed to determine conformance of a Product VA. A vehicle test would give more accurate power transfer results, but control of the test conditions will be more difficult. The state of charge (SOC) of the battery will be constantly changing, and while the actual CAN signals will be available, they might not be easily controllable to simulate the necessary test conditions. A mechanism for rapid restoration of the SOC to a low level (low output voltage) should be provided for test efficiency.

The Product VA being tested should be installed as intended as a product using the intended shield. Temperature monitoring of the vehicle underbody should be considered by the manufacturer.

The positioning offsets in X, Y, and Z can be accomplished with movement of the GA for X and Y and spacers under the wheels and/or the GA for Z adjustments.

15.1.4 Test for Product GA

As described in 8.2.2.1 and 8.2.2.2.

An Interoperability Class I GA is tested against each of the normative VAs in Appendix A using the VA communication module for control.

An Interoperability Class II GA is tested against normative VAs within the specified GA ground clearance range in Appendix A along with the VA communication module, as well as the specific VAs it is meant to work with.

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

Testing a Product GA is to be done using a Test Station. Communication shall be active, and enablement of the conditions that would otherwise be available from the vehicle (CAN signals, for example) shall be possible. Testing that simulates the various critical steps in the control sequence described in Figure 20, including charging control, shall occur to ensure safe and proper operation and non-operation.

Power transfer system efficiency tests shall be made at nominal, low, and high input voltage, as described in 8.2.8.2.

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

Testing a Product GA is to be done using a Test Station. Communication shall be active, and enablement of the conditions that would otherwise be available from the vehicle (CAN signals, for example) shall be possible. Testing that simulates the various critical steps in the control sequence described in Figure 20, including charging control, shall occur to ensure safe and proper operation or non-operation.

Power transfer system efficiency tests shall be made at nominal, low, and high input voltage, as described in 8.2.8.3.

15.1.5 Coordinate System

The coordinate system used for definition and testing should utilize the three-dimensional reference system as defined by ISO 4130.

where:

X = positive in the reverse direction

Y = positive to the right side

Z = positive in the upward direction

X, Y = 0,0 is defined by the centered position of the GA coil

Z = 0 is defined by the surface of the ground

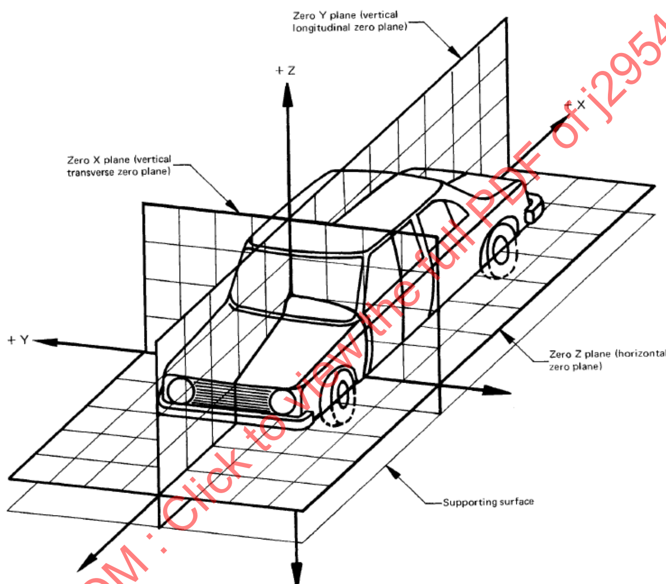


Figure 28 - ISO 4130 three-dimensional reference system vehicle coordinate system

15.1.6 Test Environment (Informational: Requirements Apply to Tests 4A, 4B, 4C, 4D)

Test Station and vehicle-level testing shall, for the purpose of 15.1, be conducted at an ambient temperature of 20 °C ± 5 °C throughout the setup and testing process (environmental tests are not covered in this section at this time). Tests shall be performed in a draft-free environment and no additional cooling or ventilation shall be provided for the test sample unless specified by the manufacturer or required for safety.

The grounding of equipment shall be set up to prevent the possibility of RF shock or burn caused by touching equipment having RF potential. If metallic WPT equipment is isolated from ground and accessible to personnel, the maximum human body grounding current shall be assessed. The line frequency shall be 50 HZ or 60 Hz. The RF currents shall be verified as being within the limits specified in Section 21, Leakage Current Test, in UL 2231-2.

15.1.7 System Efficiency Test Procedure (Informational: Requirements Apply to Tests 4A, 4B, 4C, 4D)

System efficiency shall be determined by measuring the power from the AC grid into the GA electronics and measuring the DC power out of the VA electronics, which feeds the battery system and essential auxiliary loads. Non-essential auxiliary loads should not be considered. System efficiency is the ratio of output power to input power, expressed as a percentage.

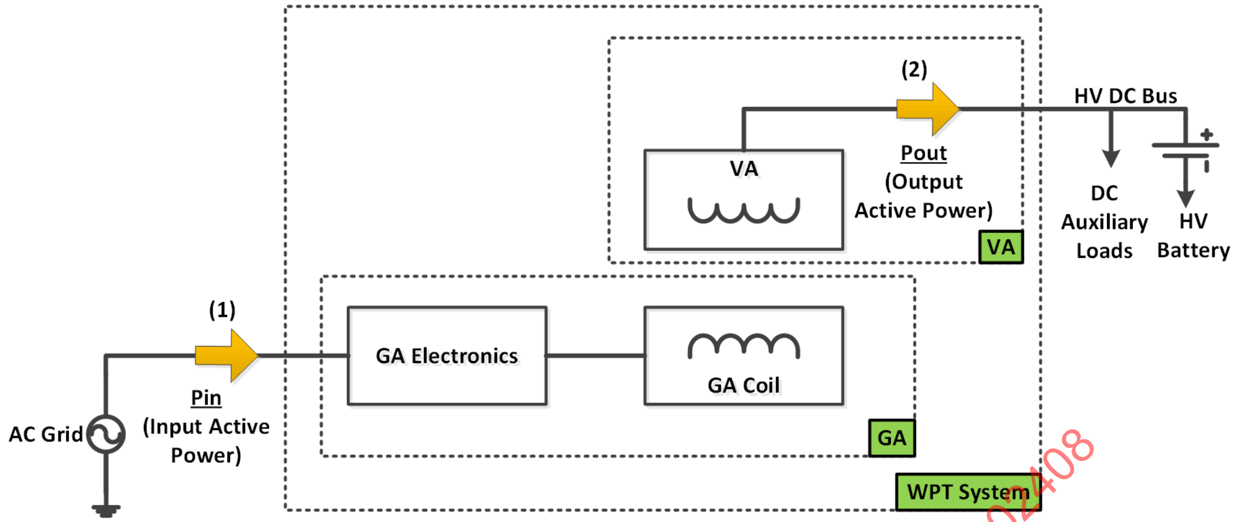


Figure 29 - Block diagram of a WPT system (including VA and GA) illustrating the efficiency points (1) and (2)

15.1.7.1 SAE J2954 System Efficiency Test Conditions (Informational: Requirements Apply to Tests 4A, 4B, 4C, 4D)

The specific test requirements are dependent on the device being tested and, in the case of a Product VA, on manufacturer specifications. AC grid power shall be provided as listed by the GA specification. The GA might be either a Product GA or a Test Station GA.

Input power shall be measured at the input to the GA electronics with appropriate test equipment. Refer to IEC 61000-3-7.

Output load voltage and power shall be specified as appropriate for the specific test configuration.

An Interoperability Class I GA shall be tested with all of the VAs from Appendix A (SAE WPT Test Station VAs) over the full Z range as specified in Table 2 and the three reference battery voltages of 280 V, 350 V, and 420 V, with an equivalent series load resistance of 0.15 Ω.

An Interoperability Class II GA shall be tested over the specified Z range of that GA with the VAs from Appendix A (SAE WPT Test Station VAs), which cover that Z range at the three reference battery voltages of 280 V, 350 V, and 420 V, with an equivalent series load resistance of 0.15 Ω.

When testing Product VAs, the Z range and the output voltage range shall be specified by the VA manufacturer.

Coil alignment shall include all required offsets in X and Y, in increments of no more than 50% of the maximum offset in that direction. Z offsets shall be at the minimum, the maximum, and the midpoint, as specified by the manufacturer if a Product VA is being tested or as specified in Table 2 for the Z class of the Appendix A VA being used.

In addition to the offset limits in X, Y, and Z, system efficiency tests shall include testing for rotational misalignment. Roll is the rotation of the vehicle around the X axis, pitch is the rotation of the vehicle around the Y axis, and yaw is the rotation of the vehicle around the Z axis. Testing of roll, pitch, and yaw shall be performed at the centered alignment position (X and Y) at maximum roll, pitch, and yaw as specified. If the test is a Test Station test, Z should be at the mid-range position; if the test is a vehicle test, Z should be as the vehicle presents.

Position tolerance is ±1.0 mm for linear dimensions and less than ±0.5 degree for angular dimensions.

System efficiency tests shall be run only after the system has warmed up (a minimum of 5 minutes at full power) and the system temperature is stable. Ambient temperature shall be 20 °C ± 5 °C. Temperature stability should be determined by measuring the surface temperature of the GA using a thermocouple or another contact method or by an IR camera; the accuracy of the thermal camera should be confirmed using a thermocouple or other contact method.

15.1.7.2 System Efficiency Requirement

For all conditions of X, Y, Z, and rotational offsets:

- For Product VAs, the requirements in 8.2.8.1 apply.
- For Class I Product GAs, the requirements in Table 8 apply.
- For Class II Product GAs, the requirements in Table 9 apply.

Table 25 - Sample system efficiency test form

Test No.	Z POS	X POS	Y POS	Roll/Pitch/Yaw	PWR Factor	P In	P Out	EFF	Mimic Temp

15.1.7.3 Surface Temperature (Informational: Requirements Apply to Tests 2A, 2B, 2C, 2D, 4A, 4B, 4C, 4D)

During all the Test Station and vehicle tests, the temperature of accessible surfaces of the functional units shall be monitored to ensure that they are compliant with UL 2750 maximum surface temperature levels.

16. SAFETY VERIFICATION

Performance testing is designed to measure how well units work. Safety testing is meant to ensure units do not transfer power if it is unsafe to do so. Safety verification must occur prior to the start of power transfer and also during power transfer.

16.1 Safety Verification Prior to Power Transfer (Informational: Requirements Apply to Tests 6A, 6B, 6C, 6D)

Communication, as described in Section 12, shall be verified to work, and those systems that are not designed to be compatible or fail the compatibility check state cannot move to the next state or eventually to power transfer.

After compatibility has been confirmed, the system must also pass the alignment check to ensure that alignment between the VA coil and the GA coil is sufficient for wireless power transfer.

Resultant behavior of the WPT system shall be checked to ensure that actions, including safety verification, are consistent with SAE J2847/6 messages.

16.2 Safety Verification During Power Transfer (Informational: Requirements Apply to Tests 5A, 5B, 5C, 5D, 6A, 6B, 6C, 6D)

In the event that power transfer is interrupted, the system shall not automatically restart unless it is manually restarted or the safety systems associated with WPT verify that it is safe to restart automatically.

16.3 Safe Operation with Respect to Metallic Foreign Objects

Safe operation with respect to metallic foreign objects is primarily the responsibility of the infrastructure side components of the system. Therefore, this testing is done using a candidate Product GA and either a Test Station VA or an SAE J2954 Product VA.

The potential hazards with metallic foreign objects fall into three areas:

- Metallic object becomes hot enough to damage the surface with which it is in contact and, as a result, creates an electrical thermal issue. For example, an object on the GA surface might get hot enough to damage the surface and expose components that could be dangerous.

- Metallic object is heated to a temperature that is dangerous to touch at the time that the object becomes accessible. Accessibility could happen after the vehicle leaves the charging spot or if someone reaches under the vehicle. The maximum temperature that an object reaches is not a sufficient test criteria; if the heat capacity of the object is small enough, by the time the object becomes accessible it may have cooled to a temperature below the touch threshold.

- Metallic object in contact with a flammable item becomes hot enough and contains enough thermal energy to cause ignition of the flammable item.

One approach is to control the characteristics of the magnetic fields through the GA coil design such that dangerous temperatures cannot occur.

Another approach is to use an FOD system to detect objects and cause the system to take action, such as shutting down power transfer if already running or preventing the system from starting power transfer if detection occurs before power transfer has started.

16.3.1 Test Requirements and Considerations (Informational: Requirements Apply to Tests 5A, 5B, 5C, 5D)

Whether GA coil design or an FOD system is used, the following are the requirements:

- Objects shall not be above touch hazard temperature when a person is able to touch that object.

- Any damage to the GA surface shall not create a safety hazard.

- Objects shall not cause ignition.

16.3.2 Test Objects (Informational: Requirements Apply to Tests 4A, 4B, 4C, 4D, 5A, 5B, 5C, 5D)

Table 26 lists the required objects that shall be used to verify the safety of the system against heating of foreign objects.

Due to the fact that a list of possible objects is infinite in length, a set of test objects is provided that will ensure a minimum FOD capability. Additional test objects can be tested but are not required in order to certify the Product GA as safe under this standard. These test objects have been selected because they are appropriate to prevent the hazards mentioned above, are readily available, and allow repeatability of results independent of what facility is performing the tests while keeping the number of objects at a reasonable level.

This list was developed through an SAE risk analysis, which considered the likelihood of occurrence and severity of failure to detect.

Table 26 - Table of test objects

Item	Sample Objects	Temp Rise	Ignition Test	Alignment of test object at H_{max}	Notes
1	Paper stack with paper clip		X	Largest parallel field	Five sheets of 20-pound paper at least 2 inches square attached to a steel wire paper clip approximately 1.25 inches long. Location and orientation should refer to the paper clip. Stack is assumed to be lying flat on the surface.
2	Foil with paper backing		X	Largest perpendicular field	2 x 4 inches, similar to chocolate bar wrapper or cigarette foil material. Lying flat on the surface.
3	Coins	X		Largest perpendicular field	U.S. 5-cent piece (nickel).
4	Nail	X		Largest parallel field	10d common steel, uncoated.
5	Aluminum foil	X		Largest perpendicular field	2- to 3-inch square or circular piece 0.002 to 0.010 inch thick.
6	Steel bar	X		Largest perpendicular field and largest parallel field	4 x 2.75 x 0.4 inches lying flat on the surface.

16.3.3 Test Procedure Without an FOD System (Informational: Requirements Apply to Tests 4A, 4B, 4C, 4D)

The actual procedure for a given implementation is highly dependent on the specific implementation of the GA coil. The manufacturer of the GA coil must specify and mark the location and orientation of the strongest magnetic field component parallel to the surface of the GA coil package or perpendicular to the GA coil package with a VA that produces that largest magnetic field component. This location and orientation are to be noted as "H_{Max}."

The GA and the VA shall be arranged such that the Z height and the X/Y offset are those that create H_{Max}. If there are multiple positions that create H_{Max}, choose the position which gives the greatest accessibility to the GA coil package surface so that test objects may be placed most easily and accurately.

16.3.3.1 Test Object in Place Before Power Transfer (Informational: Requirements Apply to Tests 4A, 4B, 5A, 5B)

Place the first ignition test object on the GA coil package surface at the H_{Max} location with the longest dimension of the metallic portion of the test object along the H_{Max} orientation. Turn on power transfer to full power and maintain that level for 10 minutes. Repeat with the other ignition test object. If ignition does not occur, this test is passed.

16.3.3.2 Test Object Introduced During Power Transfer (Informational: Requirements Apply to Tests 4A, 4B, 5A, 5B)

This test will use the four temperature rise test objects.

a. Turn on power transfer to full power and maintain that level during each of the tests. With full power being transferred, place the test object in the H_{Max} position and orientation (longest dimension of the test object aligned with H_{Max}). Let power transfer continue for 5 minutes, at which time quickly remove the test object and measure its temperature.

    1. If less than 80 °C, that object at that position has passed. If greater than 80 °C, measure the temperature at 30 seconds after removal and 60 seconds after removal. If the temperature of the test object 60 seconds after removal is less than 80 °C, the test is passed.

    2. If the test object is more than 80 °C at 60 seconds or if there was damage to the GA surface, the test is failed.

b. Rotate through test objects to give the heated object time to cool back to ambient before using it again. Repeat with the test object placed at a random position.

16.3.4 Test Procedure with an FOD System (Informational: Requirements Apply to Tests 4A, 4B, 4C, 4D)

The actual procedure for a given implementation is highly dependent on the specific implementation of the GA coil and the FOD system. The manufacturer of the GA coil must specify and mark the location and orientation of the strongest magnetic field parallel to or perpendicular to the surface of the GA coil package with a VA that produces that largest magnetic field component. This location and orientation are to be noted as "H_{Max}."

The manufacturer shall specify the location on the surface of the GA coil package where the probability of non-detection of the test object is the greatest. If there is more than one such location, the three with the highest probability of non-detection shall be specified and notated as D_{Min1}, D_{Min2}, and D_{Min3}. If there is a directional component to the detection sensitivity, that shall also be specified.

The GA and the VA shall be arranged such that the Z height and the X/Y offset are those that create H_{Max}. If there are multiple positions that create H_{Max}, choose the position which gives the greatest accessibility to the GA coil package surface so that test objects can be placed most easily and accurately.

16.3.4.1 Test Object in Place Before Power Transfer (Informational: Requirements Apply to Tests 4A, 4B, 4C, 4D, 5A, 5B, 5C, 5D)

a. Place the first ignition test object on the GA coil package surface object at the H_{Max} location with the longest dimension of the metallic portion of the test along the H_{Max} orientation. If power does turn on, increase to full power and maintain that level for 10 minutes unless object is detected. Repeat with the other ignition test object. If the test object was detected or if ignition does not occur, this test is passed.

b. Place the first temperature rise test object at D_{Min1}; if an orientation sensitivity was specified, align the test object's longest dimension in the orientation that will be most difficult to detect.

c. Turn on power. If the FOD system is activated and prevents the start of power transfer, this test with this object is passed. Repeat with the next test object.

d. If power does turn on, increase it to full power. Let it run at full power for 5 minutes or until the FOD system is activated and turns off power. Remove the test object and measure its temperature; if less than 80 °C, that object at that position has passed.

e. If greater than 80 °C, measure the temperature at 30 seconds after removal and 60 seconds after removal. If the temperature of the test object 60 seconds after removal is less than 80 °C, the test is passed

f. Repeat with the other temperature rise test objects.

16.3.4.2 Test Object Introduced During Power Transfer (Informational: Requirements Apply to Tests 4A, 4B, 4C, 4D, 5A, 5B, 5C, 5D)

If there is a test mode which indicates a foreign object has been detected without actually initiating power shutdown, that mode may be used to make testing more efficient. However, at least one of the foreign object detection tests must be performed in the normal operating mode to show that shutdown does actually occur in normal operation upon detection of a foreign object.

This test will use the four temperature rise test objects.

a. Turn on power transfer to full power and maintain that level during each of the tests. With full power being transferred, place the test object in the H_{Max} position and orientation (longest dimension of the test object aligned with H_{Max}). Let power transfer continue for 5 minutes or until the FOD system is activated, at which time quickly remove the test object and measure its temperature.

   1. If less than 80 °C, that object at that position has passed. If greater than 80 °C, measure the temperature at 30 seconds after removal and 60 seconds after removal. If the temperature of the test object 60 seconds after removal is less than 80 °C, the test is passed.

   2. If the test object is more than 80 °C at 60 seconds or if there is damage to the GA coil package surface, the test is failed.

b. Rotate through test objects to give the heated object time to cool back to ambient before using it again.

c. With full power being transferred, place the first test object in a random position and orientation. Let power transfer continue for 5 minutes or until the FOD system is activated, at which time quickly remove the test object and measure its temperature.

   1. If less than 80 °C, that object at that position has passed. If greater than 80 °C, measure the temperature at 30 seconds after removal and 60 seconds after removal. If the temperature of the test object 60 seconds after removal is less than 80 °C, the test is passed.

   2. If the test object is more than 80 °C at 60 seconds or if there is damage to the GA coil package surface, the test is failed.

d. Rotate through test objects to give the heated object time to cool back to ambient before using it again.

e. With full power being transferred, place the first test object at D_{Min1} with orientation for highest probability of non-detection. Let power transfer continue for 5 minutes or until the FOD system is activated, at which time quickly remove the test object and measure its temperature.

   1. If less than 80°C, that object at that position has passed. If greater than 80 °C, measure the temperature at 30 seconds after removal and 60 seconds after removal. If the temperature of the test object 60 seconds after removal is less than 80 °C, the test is passed.

   2. If the test object is more than 80 °C at 60 seconds or if there is damage to the GA coil package surface, the test is failed.

f. Rotate through test objects to give the heated object time to cool back to ambient before using it again.

g. With full power being transferred, place the first test object at D_{Min2} with orientation for highest probability of non-detection. Let power transfer continue for 5 minutes or until the FOD system is activated, at which time quickly remove the test object and measure its temperature.

   1. If less than 80 °C, that object at that position has passed. If greater than 80 °C, measure the temperature at 30 seconds after removal and 60 seconds after removal. If the temperature of the test object 60 seconds after removal is less than 80 °C, the test is passed.

   2. If the test object is more than 80 °C at 60 seconds or if there is damage to the GA coil package surface, the test is failed.

17. DURABILITY (INFORMATIONAL: REQUIREMENTS APPLY TO TESTS 1A, 1B, 1C, 1D)

Labeling of the ground assembly packages shall meet the required content, size, and durability requirements of UL2750 and applicable local regulations.

Vehicle side components shall meet the requirements of SAE J1211.

18. NOTES

18.1 Revision Indicator

A change bar (l) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of this document. An (R) symbol to the left of the document title indicates a complete revision of the document, including technical revisions. Change bars and (R) are not used in original publications, nor in documents that contain editorial changes only.

PREPARED BY SAE HYBRID - EV COMMITTEE

NOTE: One or more patents may apply to one or more aspects of the standards or the entire standard. By publication of this standard, no position is taken with respect to the validity of this claim or of any patent rights in connection therewith. The patent holder(s) has, however, filed a statement of willingness to grant a license under these rights on reasonable and nondiscriminatory terms and conditions to applicants desiring to obtain such a license for the purpose of complying with the standard. Details may be obtained from SAE International at: http://www.sae.org/standardsdev/patents.htm.

APPENDIX A - TEST STATION VA SPECIFICATIONS (NORMATIVE)

A.1 TEST STATION VA WPT1/Z1

This appendix provides the mechanical and electrical design specifications of the Test Station VA for power class WPT1 and gap class Z1 (VA WPT1/Z1).

NOTE: Specifications are designed for optimal operation with the Test Station GA WPT1 specified in Appendix F.

A.1.1 Mechanical Specification

Figures A1, A2, A3, and A4 show the mechanical dimensions of the Test Station VA WPT1/Z1.

The ferrite tiles are made using PC95 (TDK).

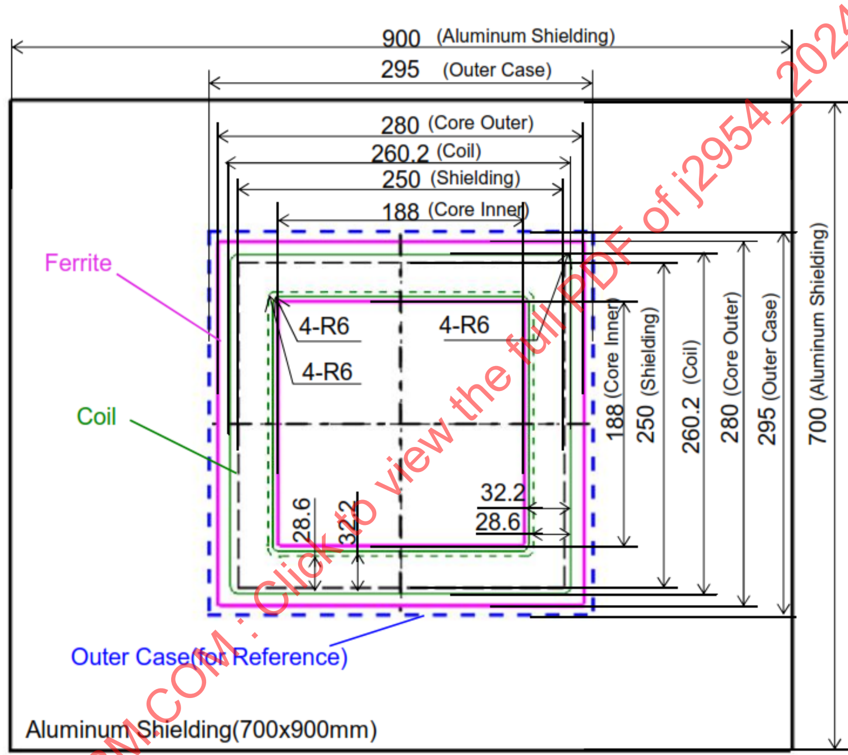


Figure A1 - Mechanical dimensions of the Test Station VA WPT1/Z1

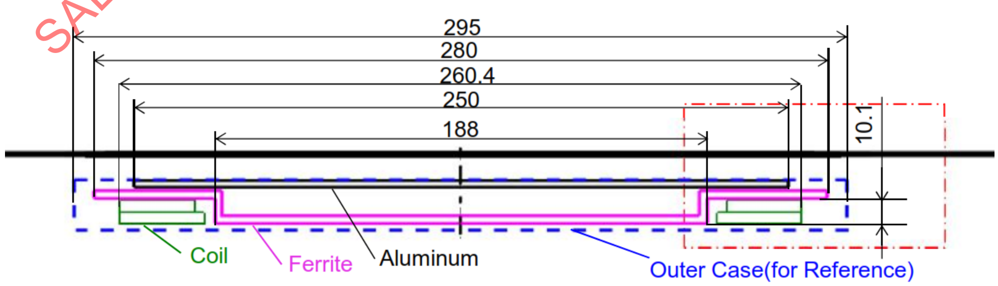


Figure A2 - Mechanical dimensions of the Test Station VA WPT1/Z1

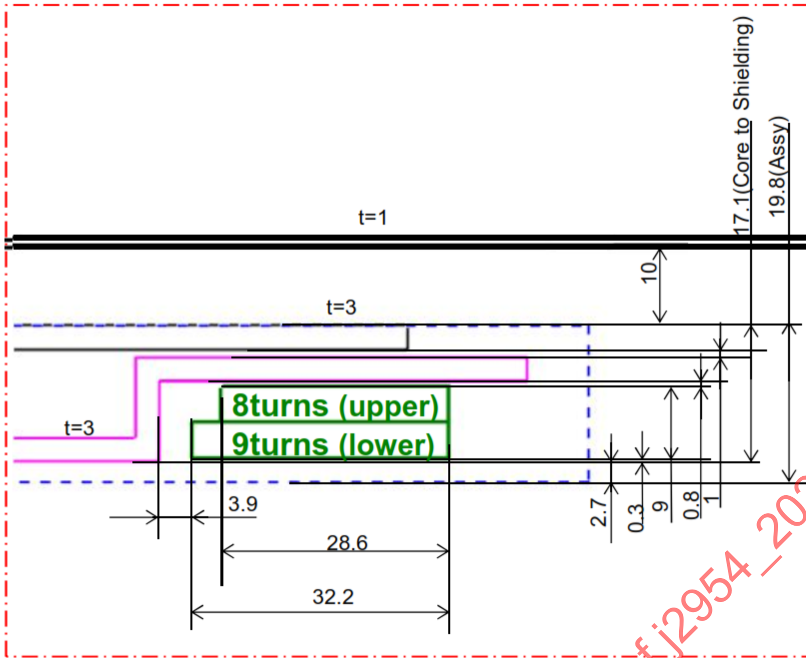


Figure A3 - Detailed cross-section view

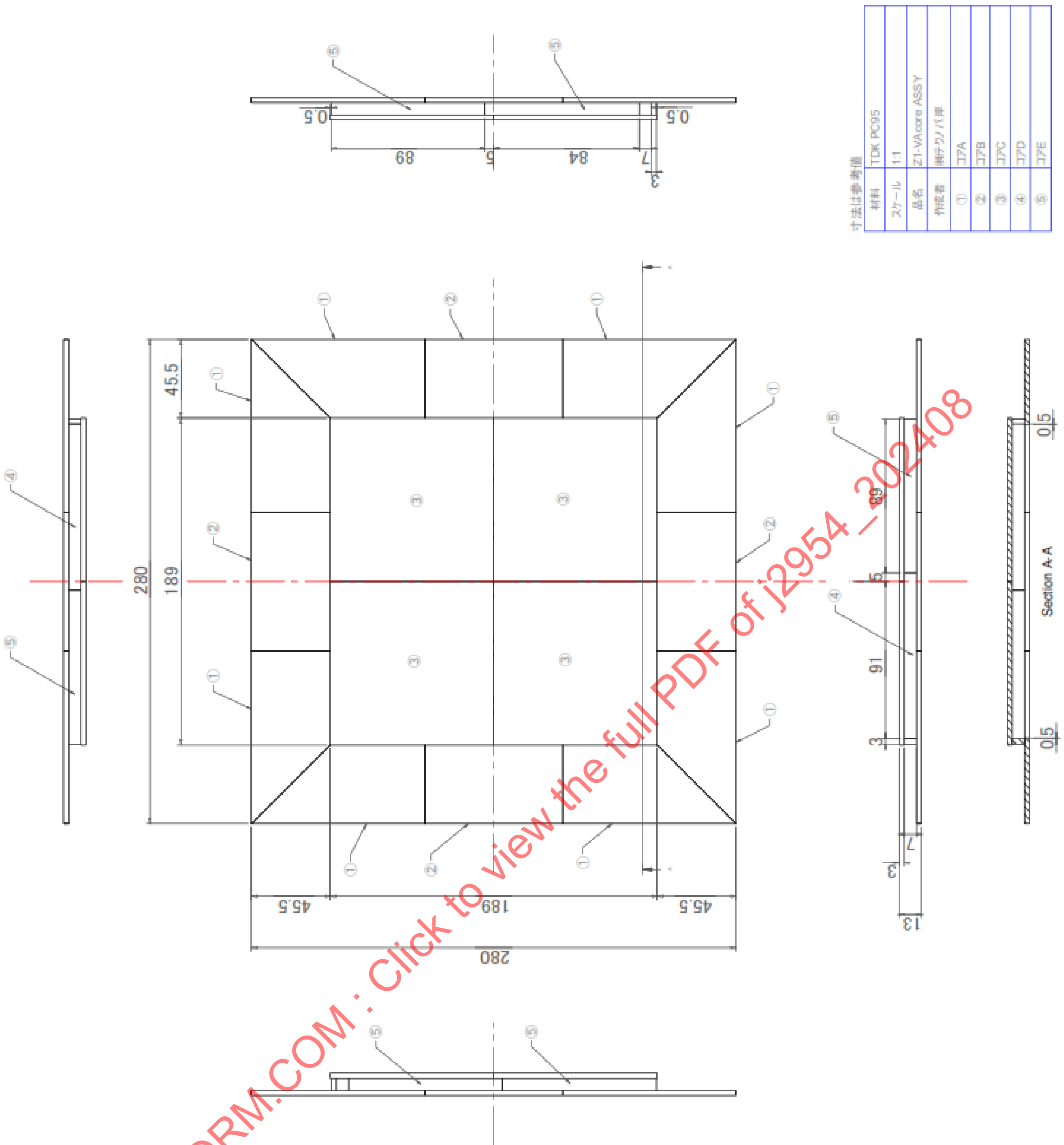


Figure A4 - Detail of the ferrite core construction

A.1.2 Electrical Specification

Figure A5 shows the electrical specification of the of the Test Station VA WPT1/Z1.

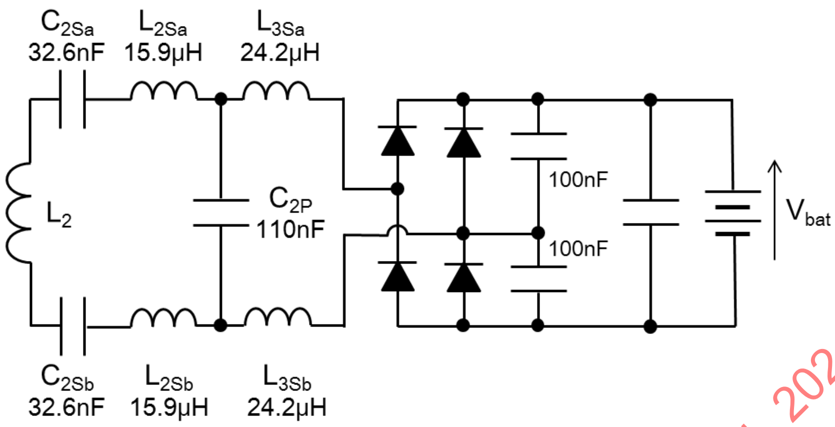


Figure A5 - Electrical specification of the Test Station VA WPT1/Z1

The minimum and maximum inductance are given in Table A1.

Table A1 - Inductance

L_2 min	214 µH
L_2 max	232 µH

A.2 TEST STATION VA WPT1/Z2

This appendix provides the mechanical and electrical design specifications of the VA for power class WPT1 and gap class Z2 (VA WPT1/Z2).

NOTE: Specifications are designed for optimal operation with the Test Station GA WPT1 specified in Appendix F.

A.2.1 Mechanical Specification

Figures A6, A7, A8, and A9 show the mechanical dimensions of the Test Station VA WPT1/Z2.

The ferrite tiles are made using PC95 (TDK).

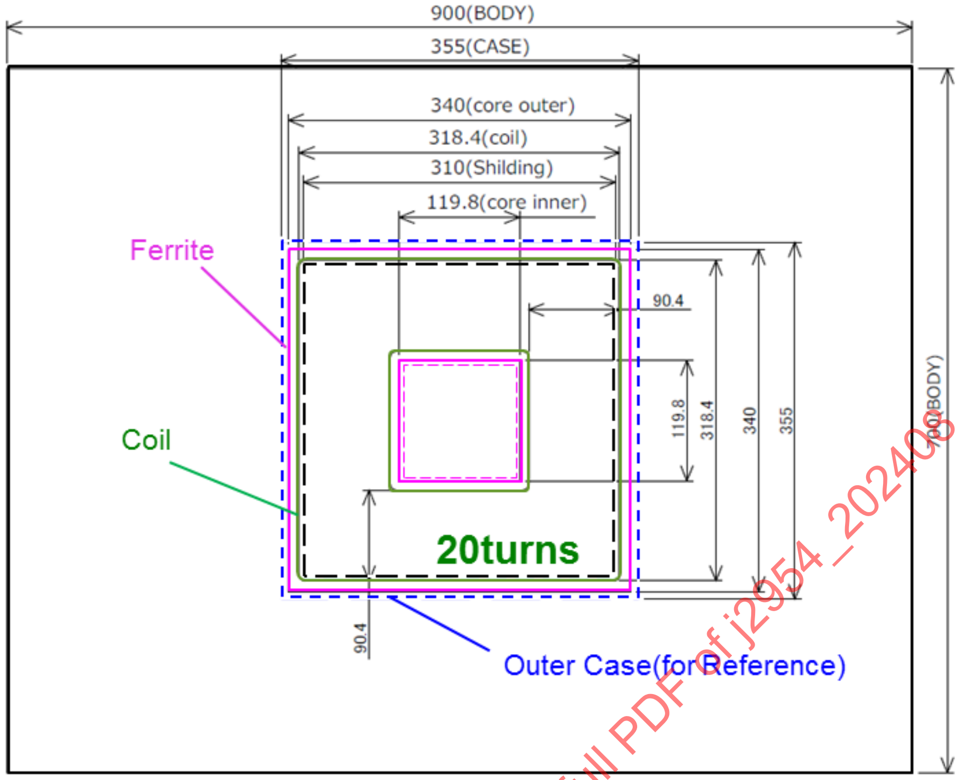


Figure A6 - Mechanical dimensions of the Test Station VA WPT1/Z2

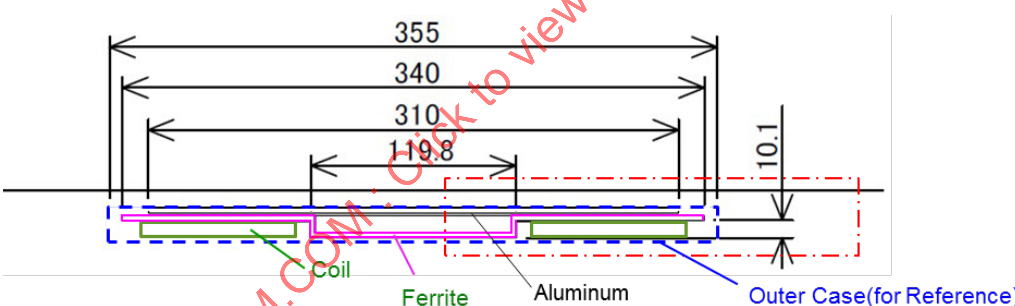


Figure A7 - Mechanical dimensions of the Test Station VA WPT1/Z2

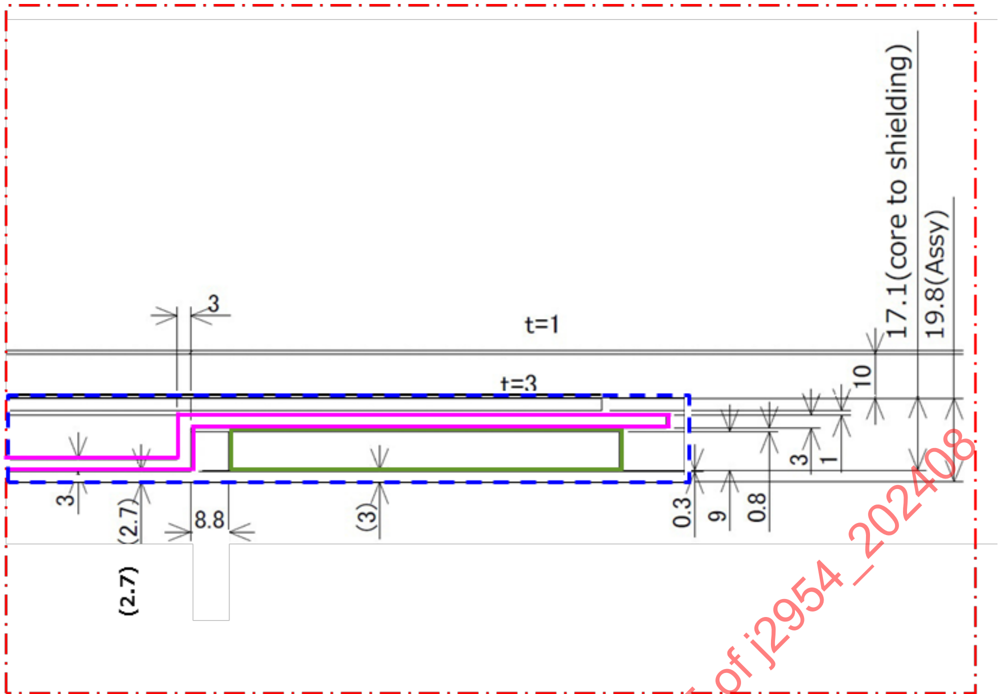


Figure A8 - Detailed cross-section view

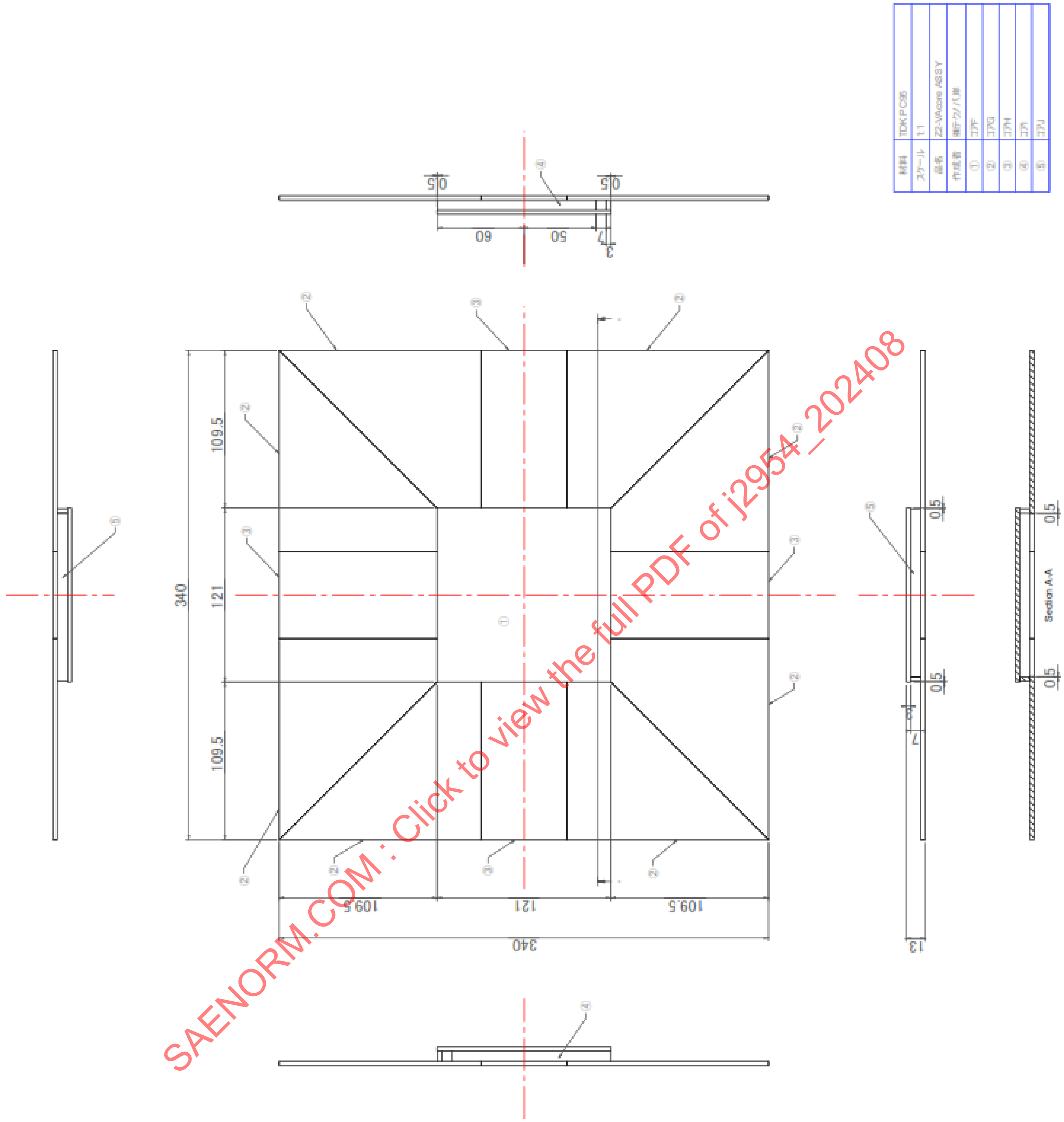


Figure A9 - Detail of the ferrite core construction

A.2.2 Electrical Specification

Figure A10 shows the electrical specification of the Test Station VA WPT1/Z2.

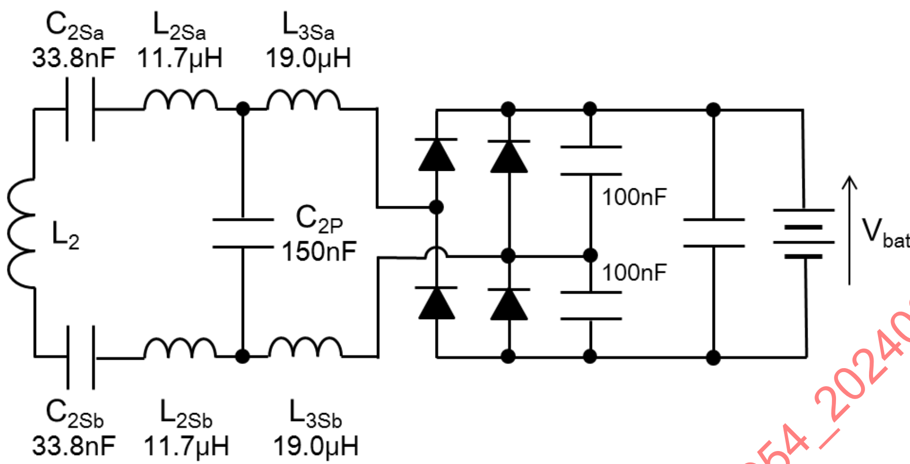


Figure A10 - Electrical specification of the Test Station VA WPT1/Z2

The minimum and maximum inductance are given in Table A2.

Table A2 - Inductance

L_2 min	207 µH
L_2 max	214 µH

A.3 TEST STATION VA WPT1/Z3

This appendix provides the mechanical and electrical design specifications of the VA for power class WPT1 and gap class Z3 (VA WPT1/Z3).

NOTE: Specifications are designed for optimal operation with the Test Station GA WPT1 specified in Appendix F.

A.3.1 Mechanical Specification

Figures A11, A12, A13, and A14 show the mechanical dimensions of the Test Station VA WPT1/Z3.

The ferrite tiles are made using N96 (TDK).

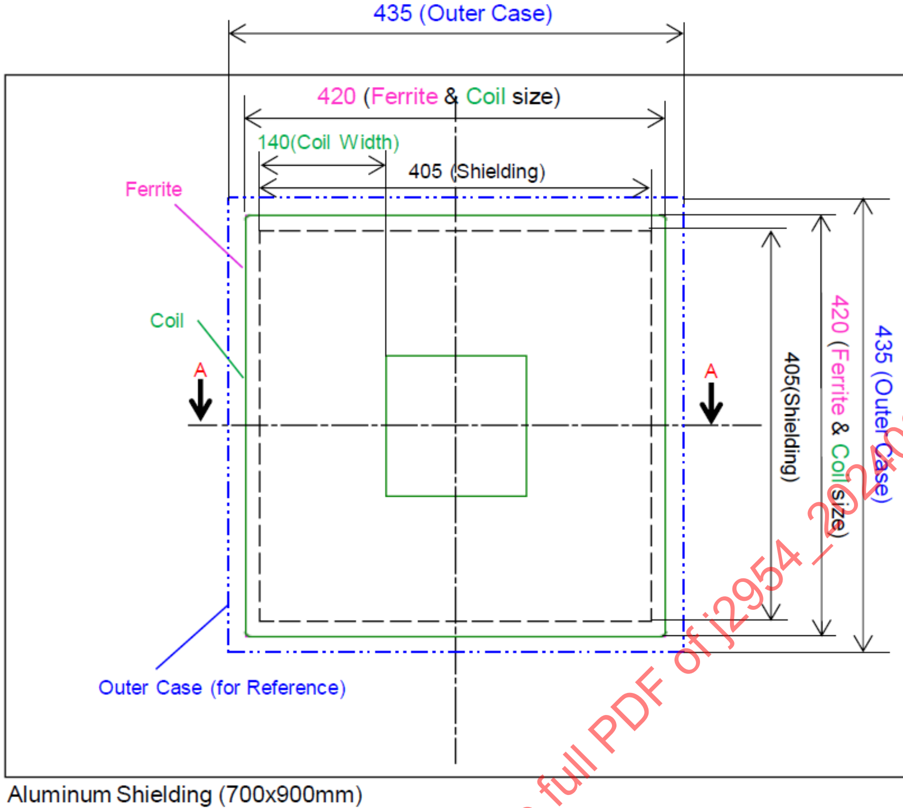


Figure A11 - Mechanical dimensions of the Test Station VA WPT1/Z3

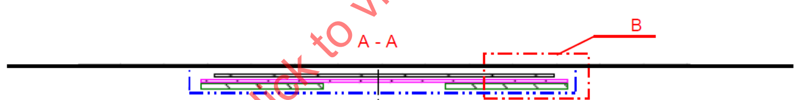


Figure A12 - Mechanical dimensions of the Test Station VA WPT1/Z3

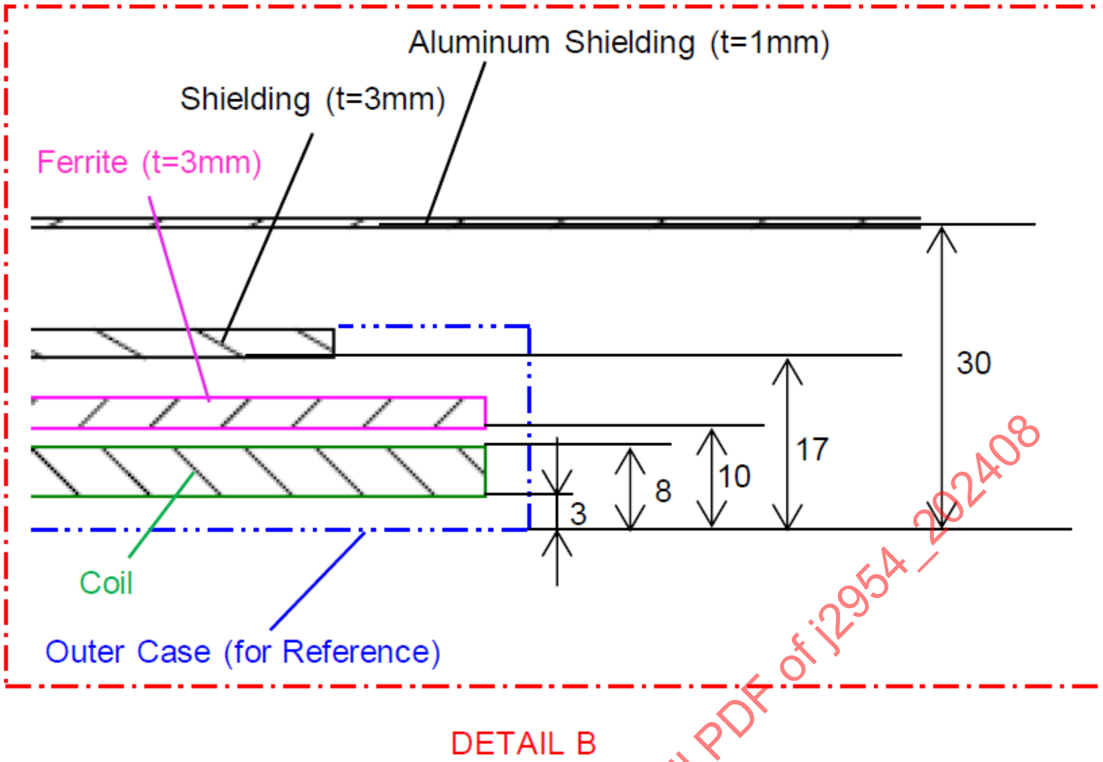


Figure A13 - Detailed cross-section view

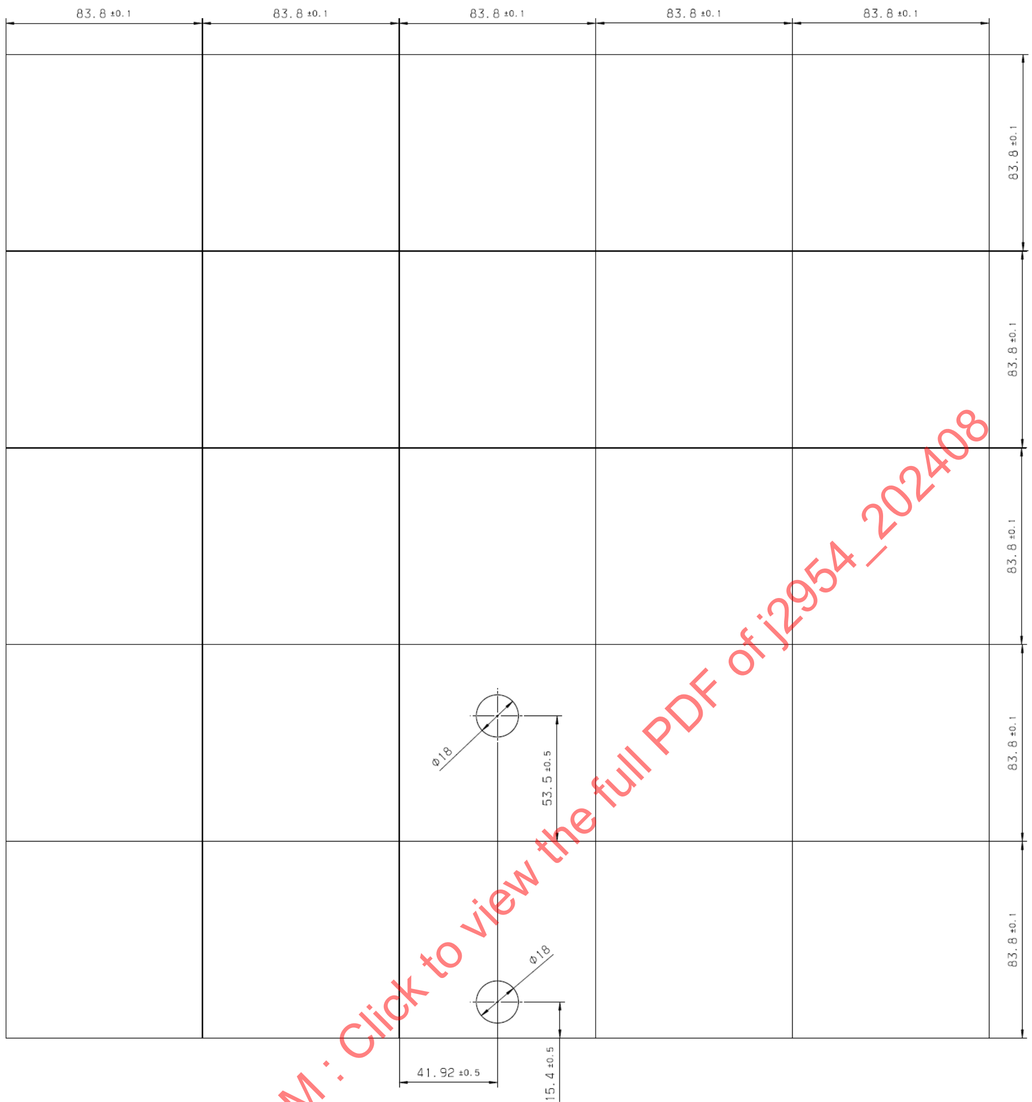


Figure A14 - Detail of the ferrite core construction

A.3.2 Electrical Specification

Figure A15 shows the electrical specification of the Test Station VA WPT1/Z3.

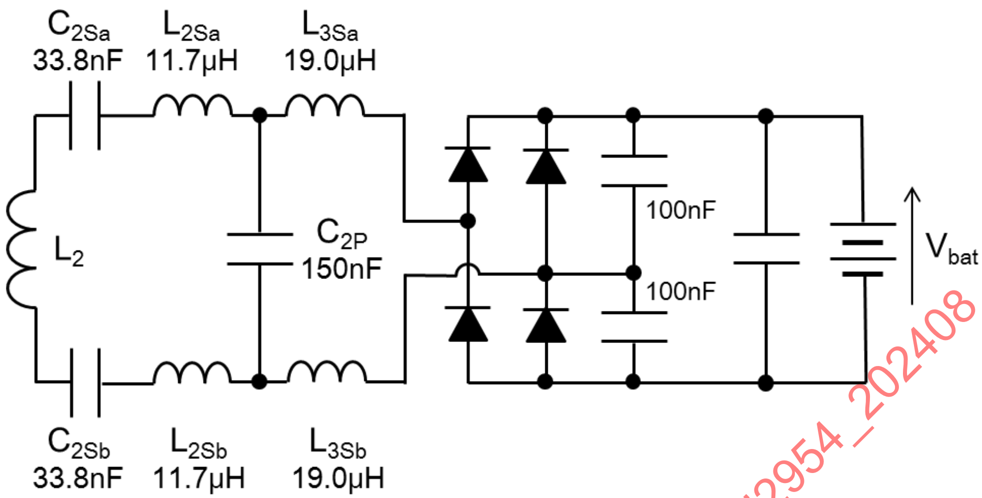


Figure A15 - Electrical specification of the Test Station VA WPT1/Z3

The minimum and maximum inductance are given in Table A3.

Table A3 - Inductance

L_2 min	198 µH
L_2 max	203 µH

A.4 TEST STATION VA WPT2/Z1

This appendix provides the mechanical and electrical design specifications of the VA for power class WPT2 and gap class Z1 (VA WPT2/Z1).

NOTE: Specifications are designed for optimal operation with the Test Station Universal GA specified in Appendix B.

A.4.1 Mechanical Specification

Figures A16 and A17 show the mechanical dimensions of the Test Station VA WPT2/Z1.

Typical properties of the ferrite material used in the VA are shown in Table A4.

Table A4 - Typical ferrite properties

Material	MnZn
Initial Permeability (25 °C)	>1000
Flux Density, B_S (100 °C) (H = 1200 A/m, 10 kHz)	>400 mT
Core Loss, P_V (100 kHz, 200 mT, 100 °C)	<350 kW/m^3

The lateral dimensions of the aluminum shield shown in Figure A17 are 800 x 800 mm, and the thickness should be 0.7 mm or larger.

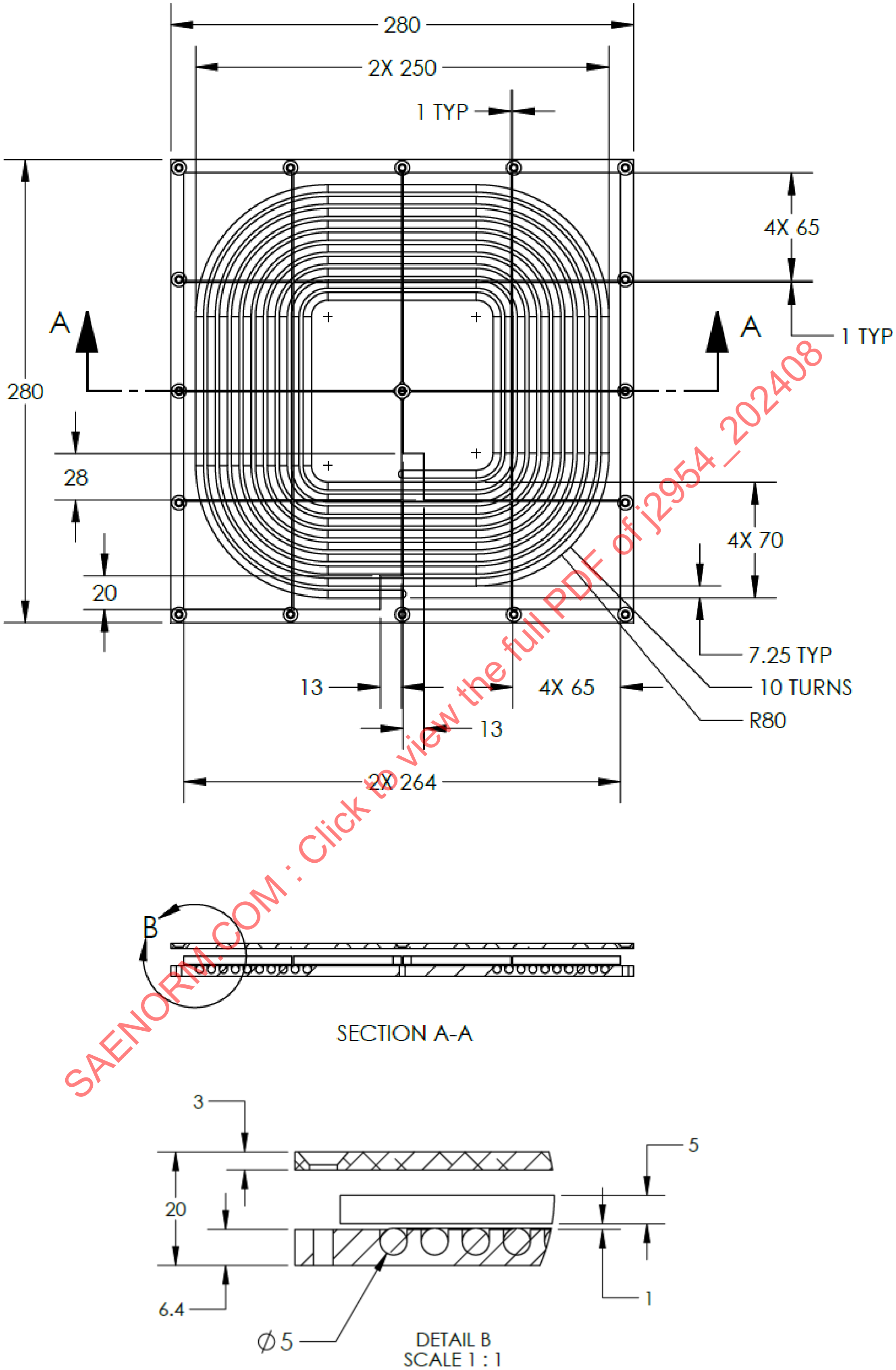


Figure A16 - Mechanical dimensions of the Test Station VA WPT2/Z1

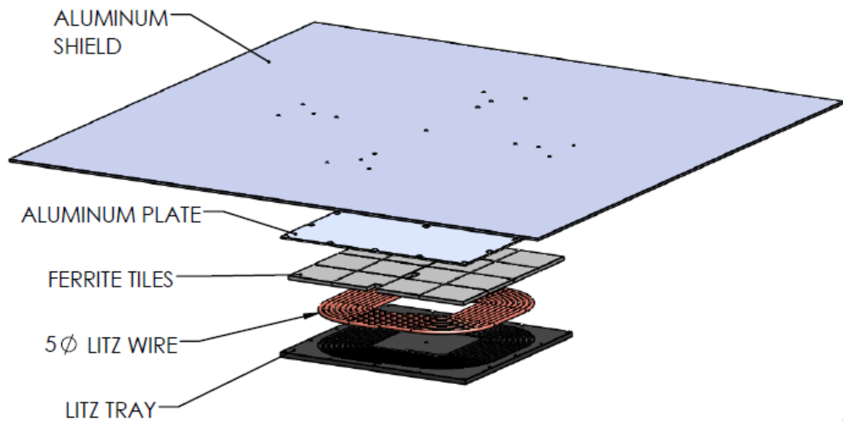


Figure A17 - Exploded view of the Test Station VA WPT2/Z1

A.4.2 Electrical Specification

Figure A18 shows the electrical specification of the Test Station VA WPT2/Z1.

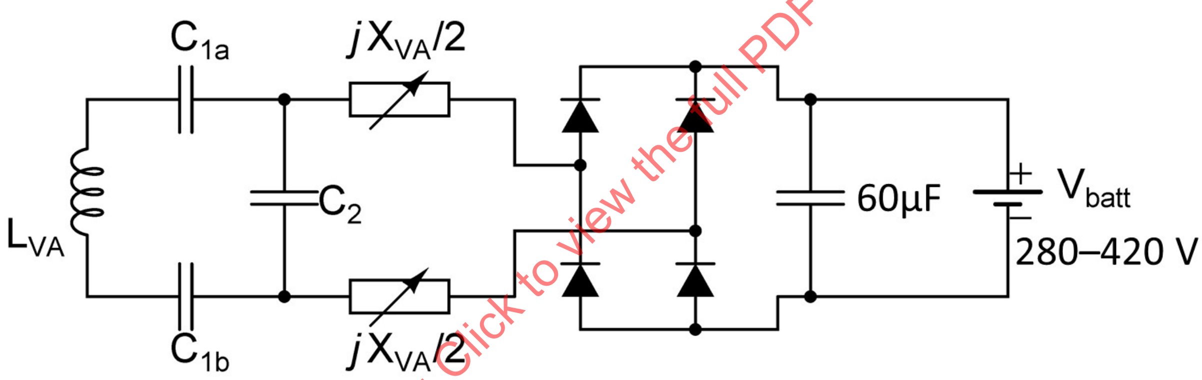


Figure A18 - Electrical specification of the Test Station VA WPT2/Z1

Minimum and maximum values of secondary coil inductance L_{VA} and the impedance matching values are given in Table A5.

Table A5 - Secondary coil inductance L_{VA} and impedance matching values

L_{VA}_min [µH]	37.2
L_{VA}_max [µH]	38.7
C1a [nF]	290
C1b [nF]	290
C2 [nF]	170
X_{VA}/2 min [Ω]	-8
X_{VA}/2 max [Ω]	5

A.5 TEST STATION VA WPT2/Z2

This appendix provides the mechanical and electrical design specifications of the VA for power class WPT2 and gap class Z2 (VA WPT2/Z2).

NOTE: Specifications are designed for optimal operation with the Test Station Universal GA specified in Appendix B.

A.5.1 Mechanical Specification

Figures A19 and A20 show the mechanical dimensions of the Test Station VA WPT2/Z2.

Typical properties of the ferrite material used in the VA are shown in Table A6.

Table A6 - Typical ferrite properties

Material	MnZn
Initial Permeability (25 °C)	>1000
Flux Density, B_S (100 °C) (H = 1200 A/m, 10 kHz)	>400 mT
Core Loss, P_V (100 kHz, 200 mT, 100 °C)	<350 kW/m^3

The lateral dimensions of the aluminum shield shown in Figure A20 are 800 x 800 mm, and the thickness should be 0.7 mm or larger.

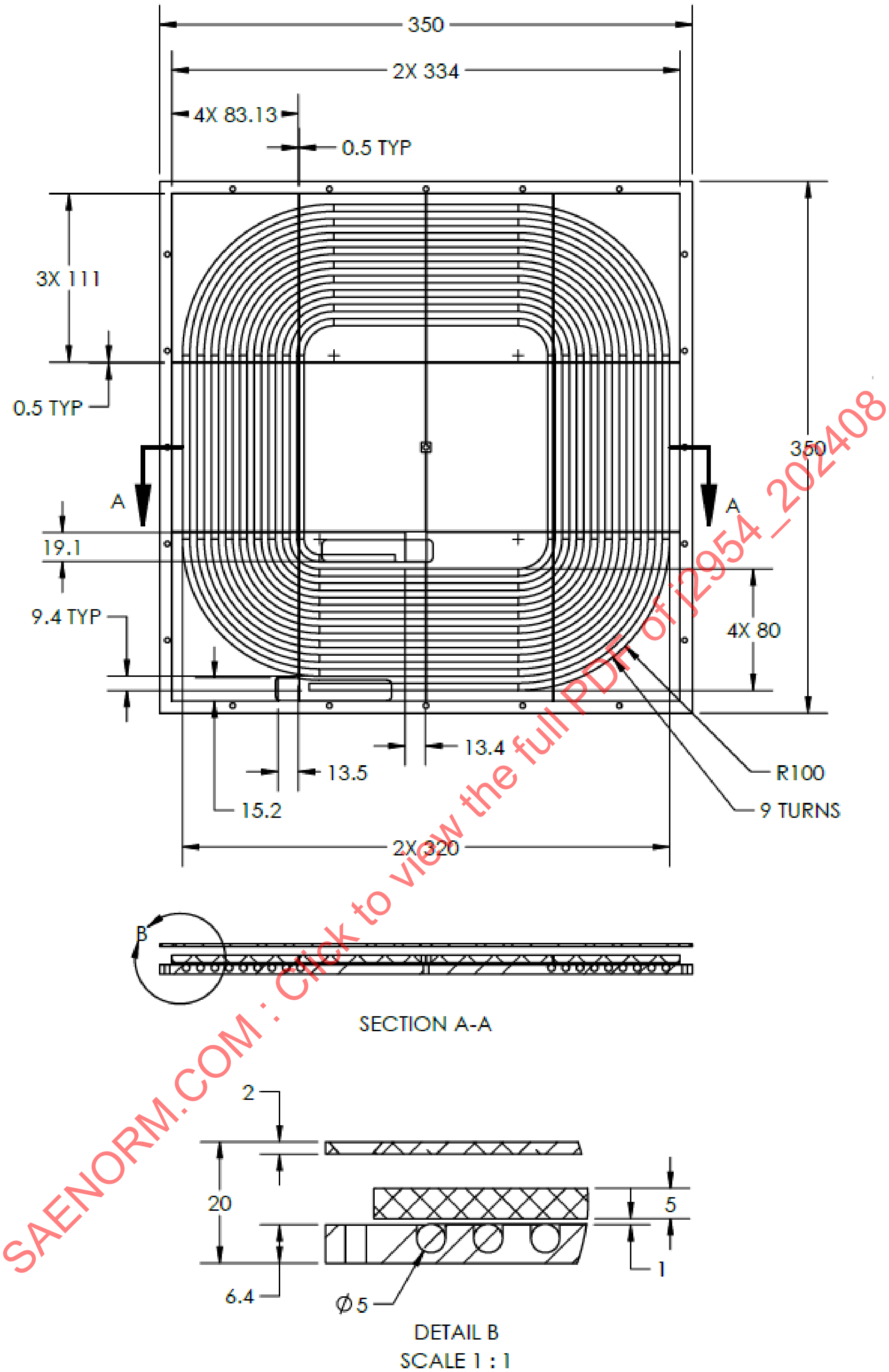


Figure A19 - Mechanical dimensions of the Test Station VA WPT2/Z2

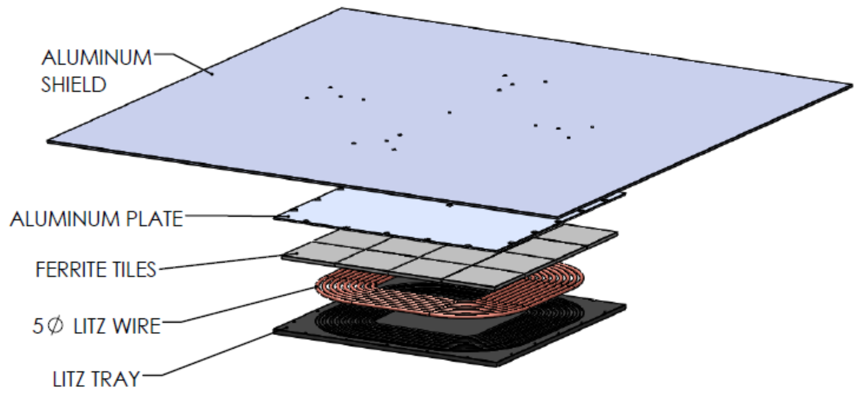


Figure A20 - Exploded view of the Test Station VA WPT2/Z2

A.5.2 Electrical Specification

Figure A21 shows the electrical specification of the Test Station VA WPT2/Z2.

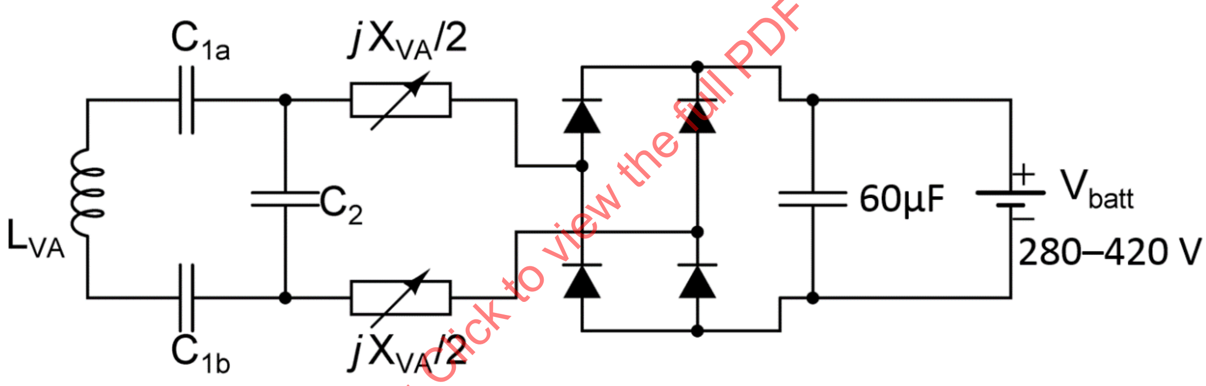


Figure A21 - Electrical specification of the Test Station VA WPT2/Z2

Minimum and maximum values of secondary coil inductance L_{VA} and impedance matching values are given in Table A7.

Table A7 - Secondary coil inductance L_{VA} and impedance matching values

L_{VA}_min [μH]	43.1
L_{VA}_max [μH]	44.0
C1a [nF]	250
C1b [nF]	250
C2 [nF]	170
X_{VA}/2 min [Ω]	-6
X_{VA}/2 max [Ω]	7

A.6 TEST STATION VA WPT2/Z3

This appendix provides the mechanical and electrical design specifications of the VA for power class WPT2 and gap class Z3 (VA WPT2/Z3).

NOTE: Specifications are designed for optimal operation with the Test Station Universal GA specified in Appendix B.

A.6.1 Mechanical Specification

Figures A22 and A23 show the mechanical dimensions of the Test Station VA WPT2/Z3.

Typical properties of the ferrite material used in the VA are shown in Table A8.

Table A8 - Typical ferrite properties

Material	MnZn
Initial Permeability (25 °C)	>1000
Flux Density, B_S (100 °C) (H = 1200 A/m, 10 kHz)	>400 mT
Core Loss, P_V (100 kHz, 200 mT, 100 °C)	<350 kW/m^3

The lateral dimensions of the aluminum shield shown in Figure A23 are 800 x 800 mm, and the thickness should be 0.7 mm or larger.

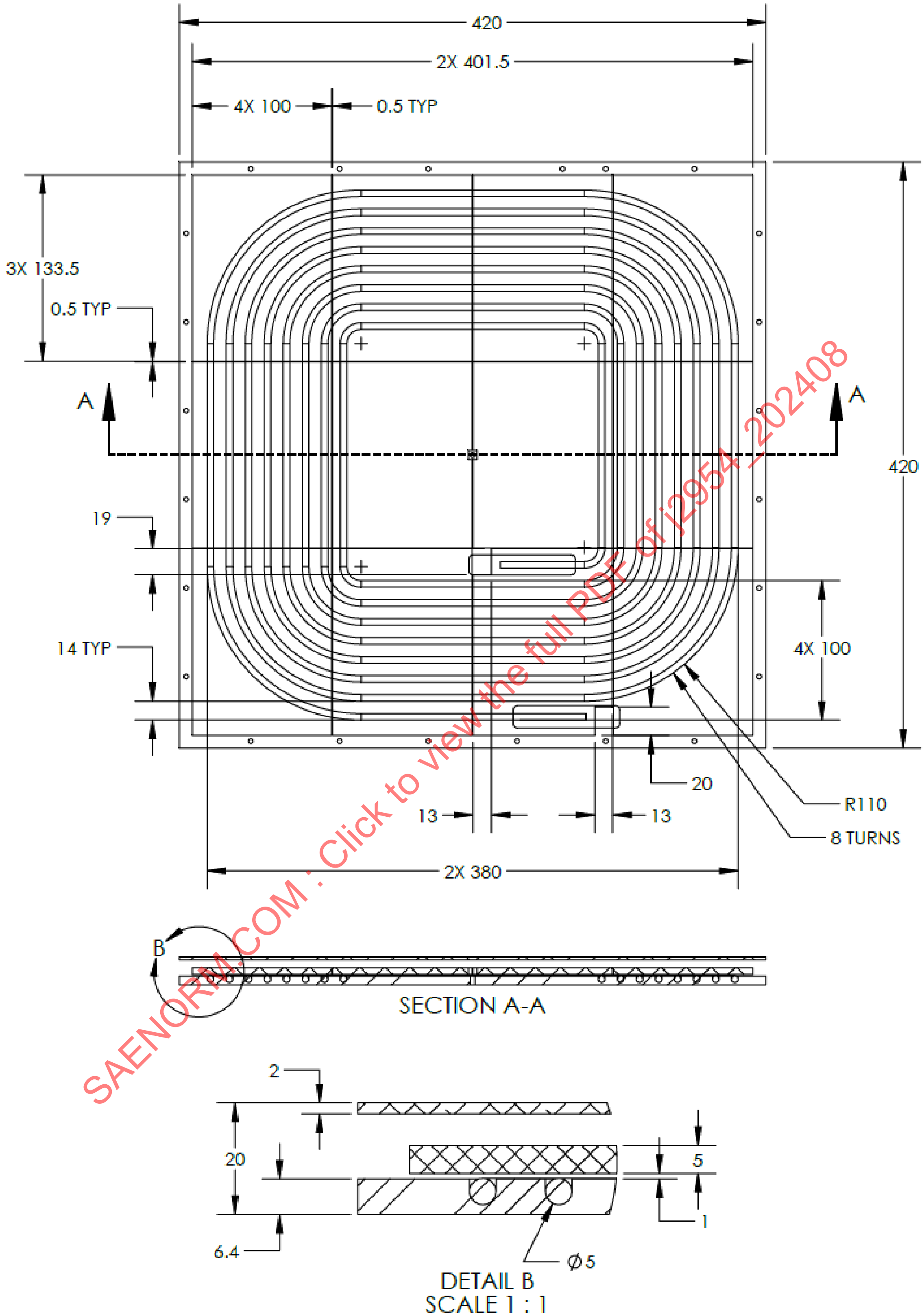


Figure A22 - Mechanical dimensions of the Test Station VA WPT2/Z3

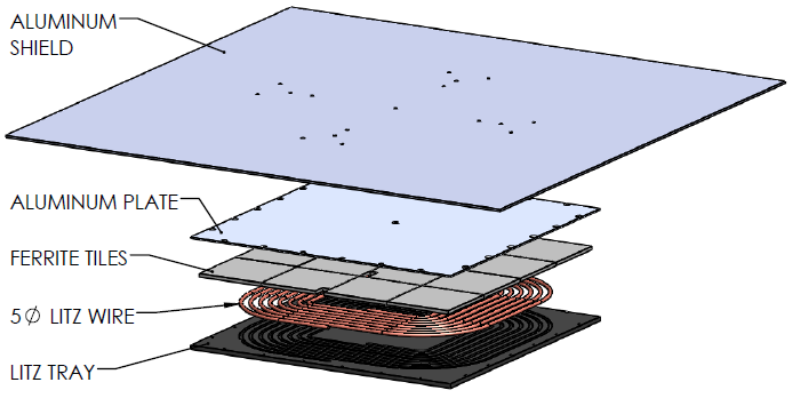


Figure A23 - Exploded view of the Test Station VA WPT2/Z3

A.6.2 Electrical Specification

Figure A24 shows the electrical specification of the Test Station VA WPT2/Z3.

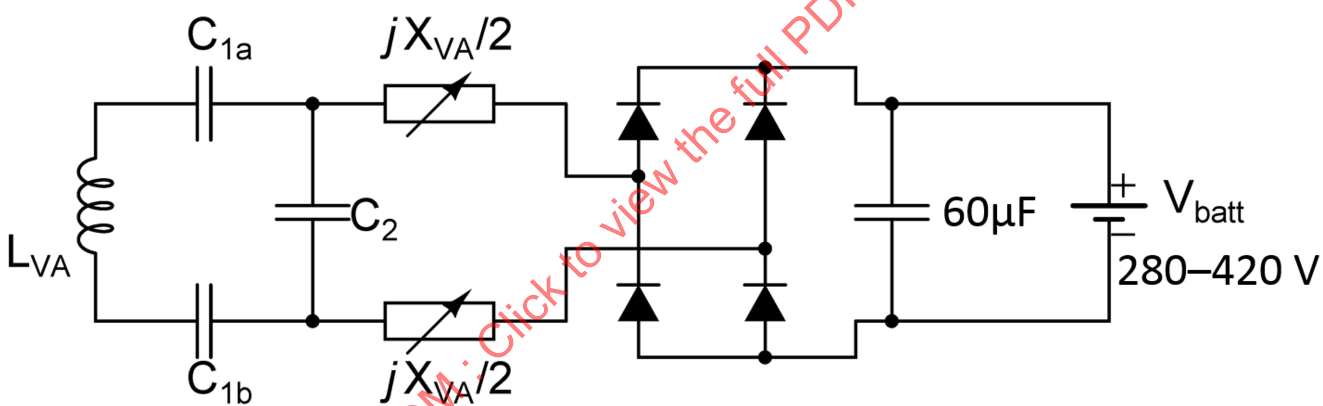


Figure A24 - Electrical specification of the Test Station VA WPT2/Z3

Minimum and maximum values of secondary coil inductance L_{VA} and impedance matching values are given in Table A9.

Table A9 - Secondary coil inductance L_{VA} and impedance matching values

L_{VA}_min [µH]	39.3
L_{VA}_max [µH]	40.0
C1a [nF]	310
C1b [nF]	310
C2 [nF]	170
X_{VA}/2 min [Ω]	-8
X_{VA}/2 max [Ω]	5

A.7 TEST STATION VA WPT3/Z1

This appendix provides the mechanical and electrical design specifications of the VA for power class WPT3 and gap class Z1 (VA WPT3/Z1).

NOTE: Specifications are designed for optimal operation with the Test Station GA specified in Appendix B.

A.7.1 Mechanical Specification

Figures A25 and A26 show the mechanical dimensions of the ferrite and the coil of the VA WPT3/Z1.

Typical properties of the ferrite material used in the VA are shown in Table A10.

Table A10 - Typical ferrite properties

Material	MnZn
Initial Permeability (25 °C)	>1000
Flux Density, B_S (100 °C) (H = 1200 A/m, 10 kHz)	>400 mT
Core Loss, P_V (100 kHz, 200 mT, 100 °C)	<350 kW/m^3

The lateral dimensions of the aluminum shield shown in Figure A26 are 800 x 800 mm, and the thickness should be 0.7 mm or larger.

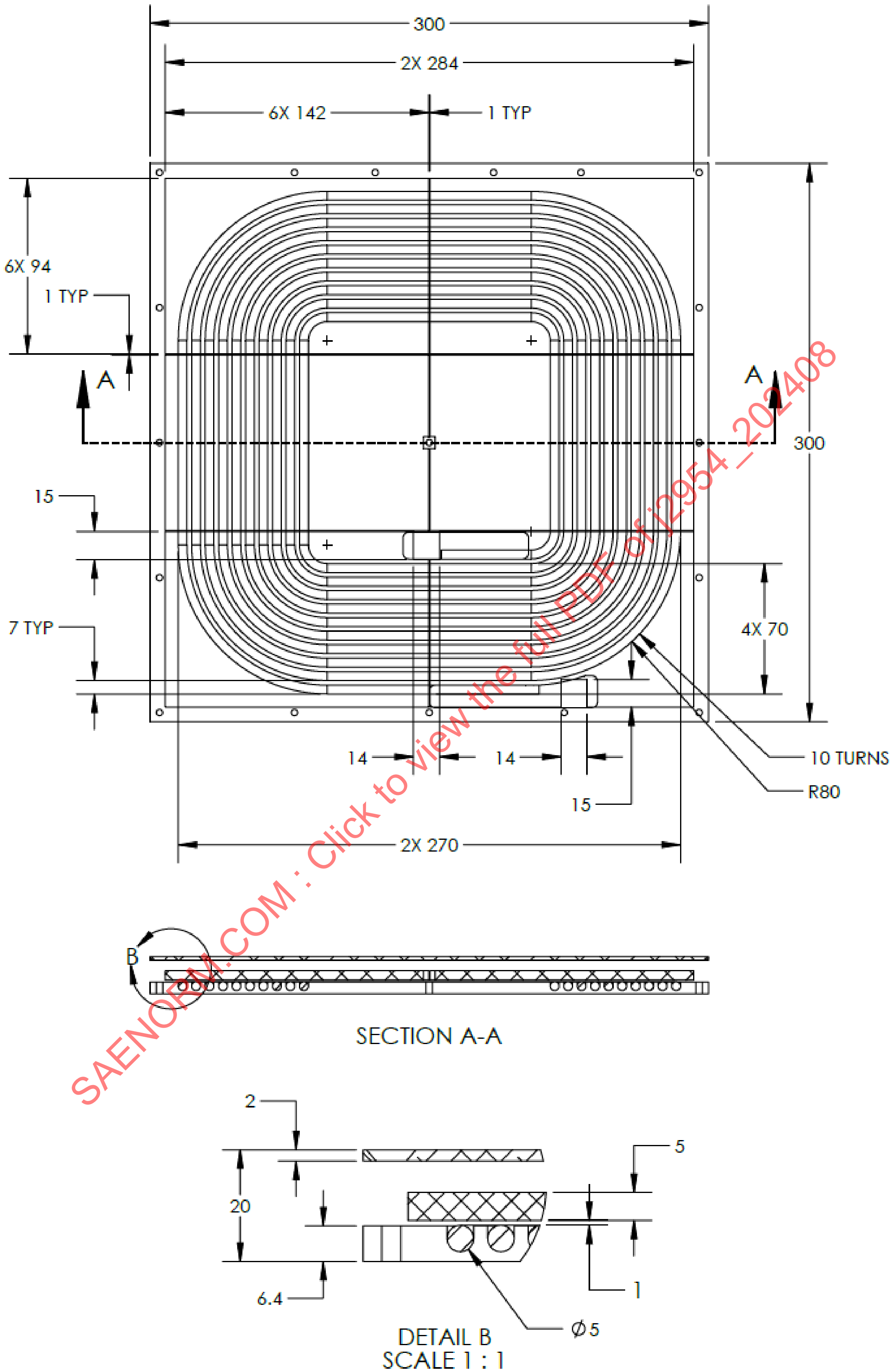


Figure A25 - Mechanical dimensions of the Test Station VA WPT3/Z1

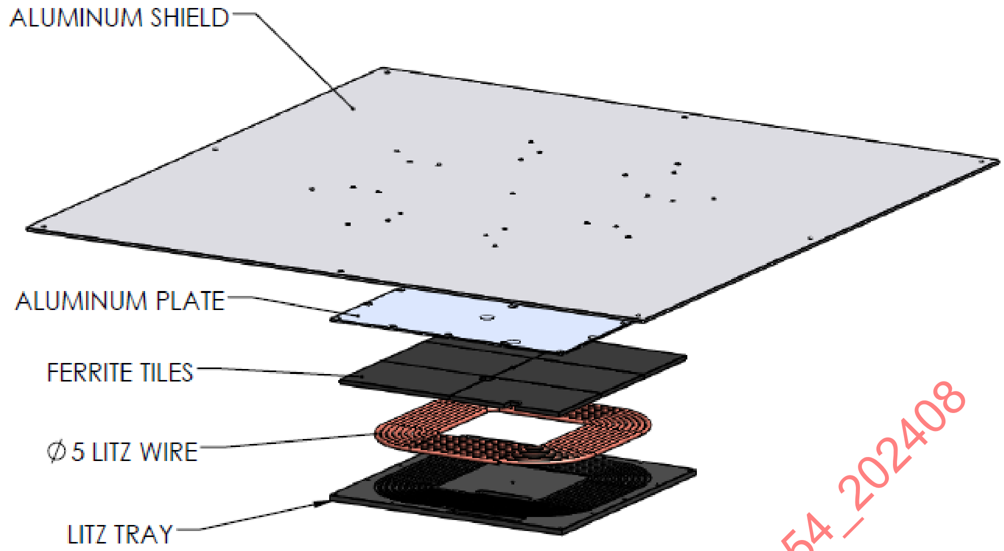


Figure A26 - Exploded view of the Test Station VA WPT3/Z1

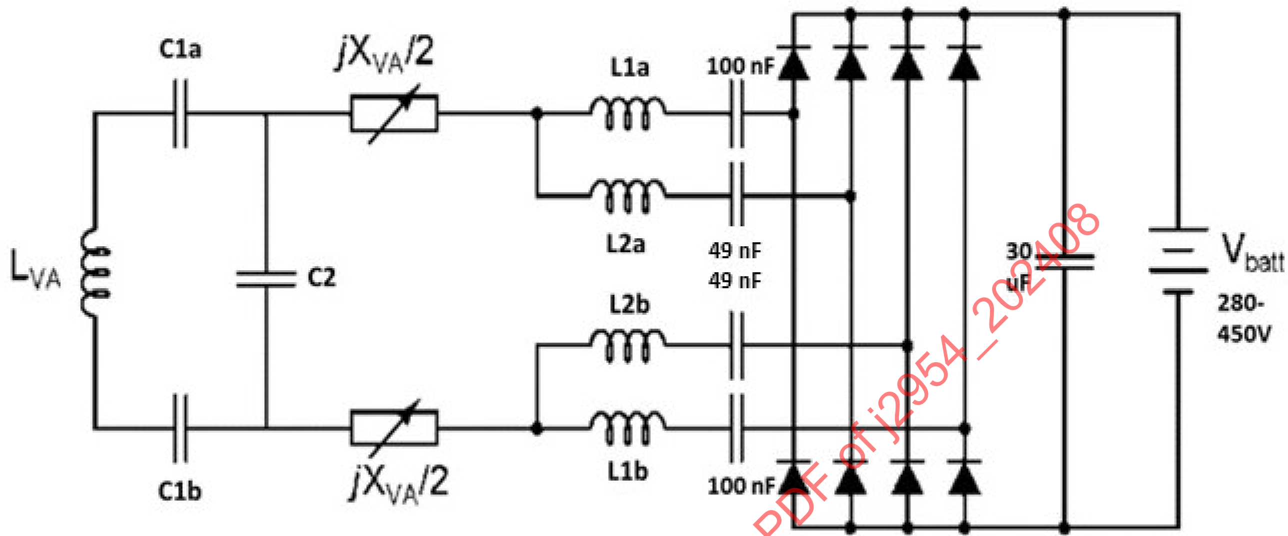
Table A11 shows the mechanical dimensions of the VA WPT3/Z1 and nominal vehicle shield.

Table A11 - Mechanical dimensions of the Test Station VA WPT3/Z1

	Coil + Ferrite Only	Housing	Vehicle Shield Size
L x W x H [mm]	284 x 284 x 12.6	300 x 300 x 20	800 x 800 x 1

A.7.2 Electrical Specification

Figure A27 shows the electrical specification of the VA WPT3/Z1.



C1a, C1b [nF]	223
C2 [nF]	143
$jX_{VA}/2$ [ohms]	-15 to 0
L1a, L1b [uH]	54
L2a, L2b [uH]	54

Figure A27 - Electrical specification of the Test Station VA WPT3/Z1

Minimum and maximum values of secondary coil inductance L_{VA} are given in Table A12.

Table A12 - Secondary coil inductance L_{VA}

L_Min [µH]	45.0
L_Max [µH]	47.0

A.8 TEST STATION VA WPT3/Z2

This appendix provides the mechanical and electrical design specifications of the VA for power class WPT3 and gap class Z2 (VA WPT3/Z2).

NOTE: Specifications are designed for optimal operation with the Test Station GA specified in Appendix B.

A.8.1 Mechanical Specification

Figures A28 and A29 show the mechanical dimensions of the ferrite and the coil of the VA WPT3/Z2.

Typical properties of the ferrite material used in the VA are shown in Table A13.

Table A13 - Typical ferrite properties

Material	MnZn
Initial Permeability (25 °C)	>1000
Flux Density, B_S (100 °C) (H = 1200 A/m, 10 kHz)	>400 mT
Core Loss, P_V (100 kHz, 200 mT, 100 °C)	<350 kW/m^3

The lateral dimensions of the aluminum shield shown in Figure A29 are 800 x 800 mm, and the thickness should be 0.7 mm or larger.

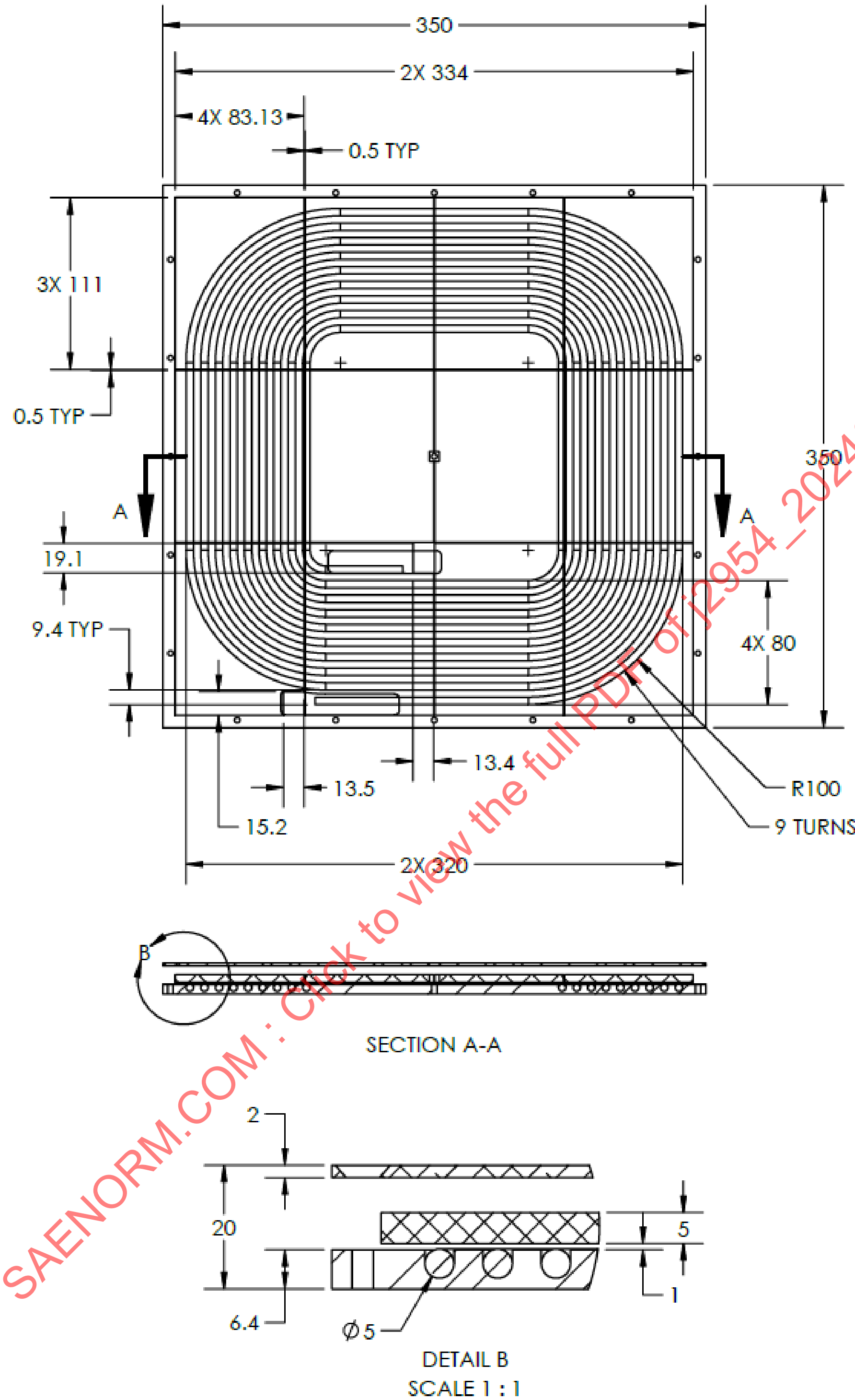


Figure A28 - Mechanical dimensions of the Test Station VA WPT3/Z2

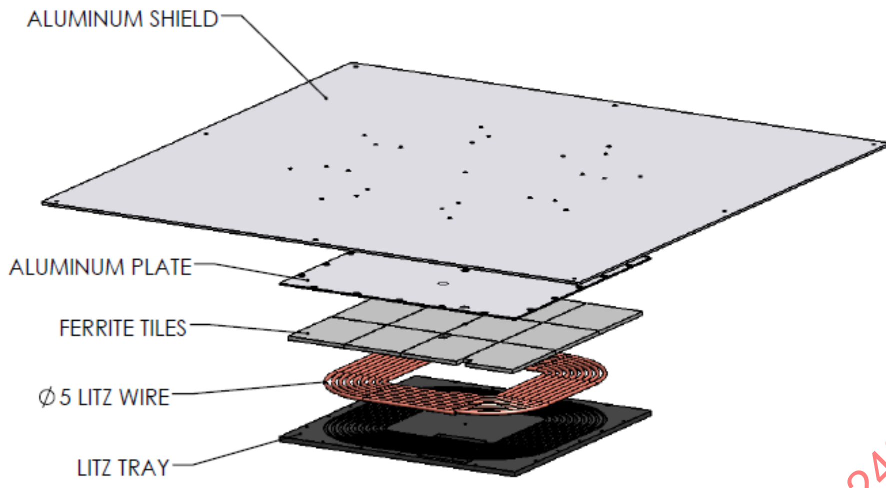


Figure A29 - Exploded view of the Test Station VA WPT3/Z2

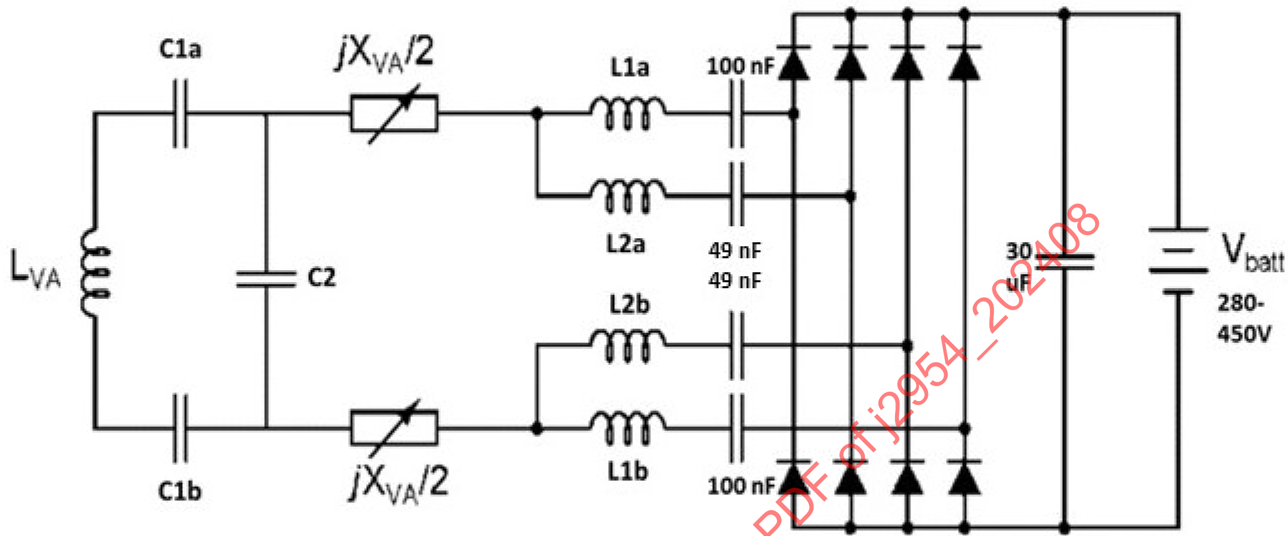
Table A14 shows the mechanical dimensions of the VA WPT3/Z2 and nominal vehicle shield.

Table A14 - Mechanical dimensions of the Test Station VA WPT3/Z2

	Coil + Ferrite Only	Housing	Vehicle Shield Size
L x W x H [mm]	334 x 334 x 12.6	350 x 350 x 20	800 x 800 x 1

A.8.2 Electrical Specification

Figure A30 shows the electrical specification of the VA WPT3/Z2.



C1a, C1b [nF]	270
C2 [nF]	145
$jX_{VA}/2$ [ohms]	-15 to 0
L1a, L1b [uH]	54
L2a, L2b [uH]	54

Figure A30 - Electrical specification of the Test Station VA WPT3/Z2

Minimum and maximum values of secondary coil inductance L_{VA} are given in Table A15.

Table A15 - Secondary coil inductance L_{VA}

L_Min [µH]	43.1
L_Max [µH]	44.0

A.9 TEST STATION VA WPT3/Z3

This appendix provides the mechanical and electrical design specifications of the VA for power class WPT3 and gap class Z3 (VA WPT3/Z3).

NOTE: Specifications are designed for optimal operation with the Test Station GA specified in Appendix B.

A.9.1 Mechanical Specification

Figures A31 and A32 show the mechanical dimensions of the ferrite and the coil of the VA WPT3/Z3.

Typical properties of the ferrite material used in the VA are shown in Table A16.

Table A16 - Typical ferrite properties

Material	MnZn
Initial Permeability (25 °C)	>1000
Flux Density, B_S (100 °C) (H = 1200 A/m, 10 kHz)	>400 mT
Core Loss, P_V (100 kHz, 200 mT, 100 °C)	<350 kW/m^3

The lateral dimensions of the aluminum shield shown in Figure A32 are 800 x 800 mm, and the thickness should be 0.7 mm or larger.

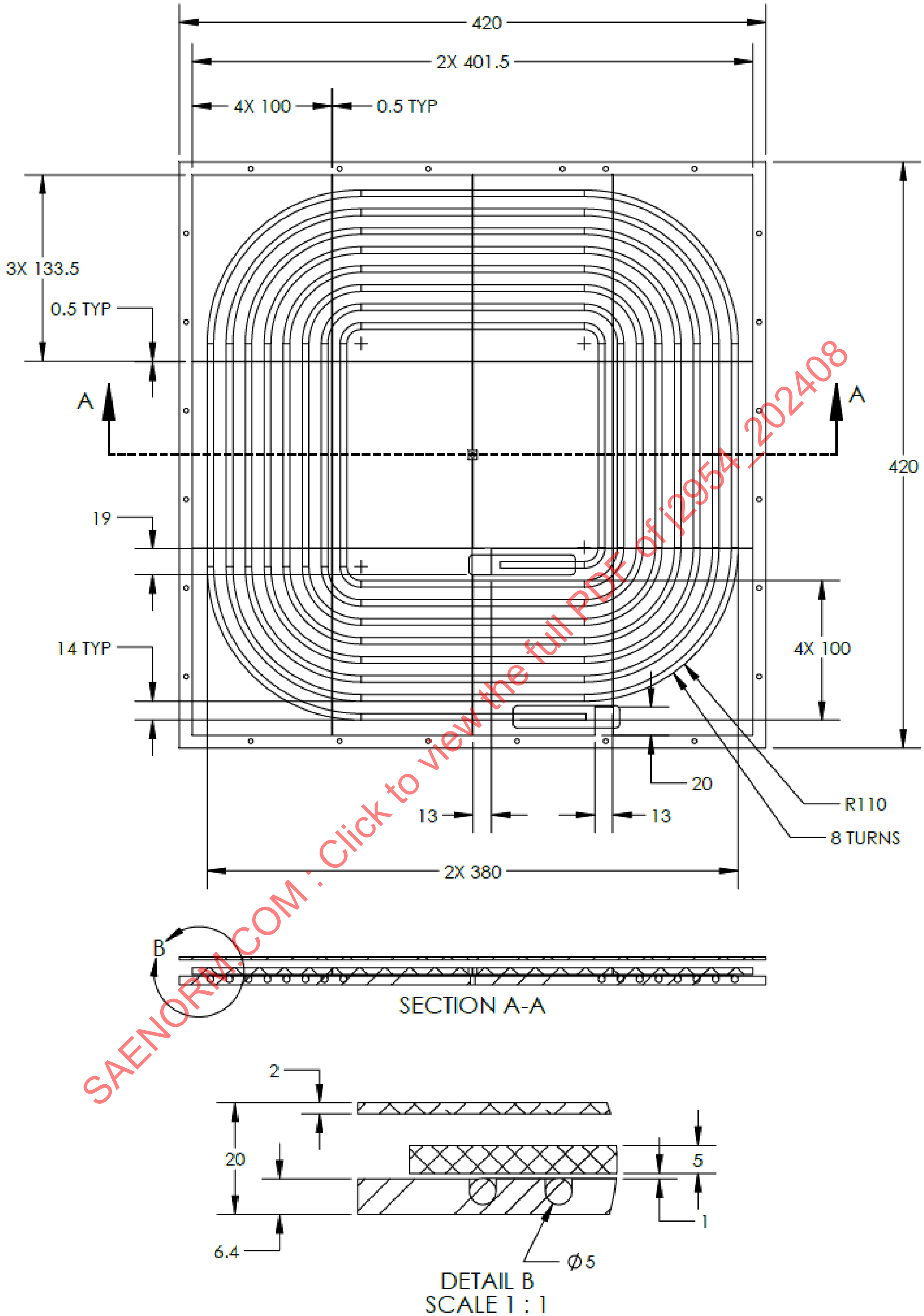


Figure A31 - Mechanical dimensions of the Test Station VA WPT3/Z3

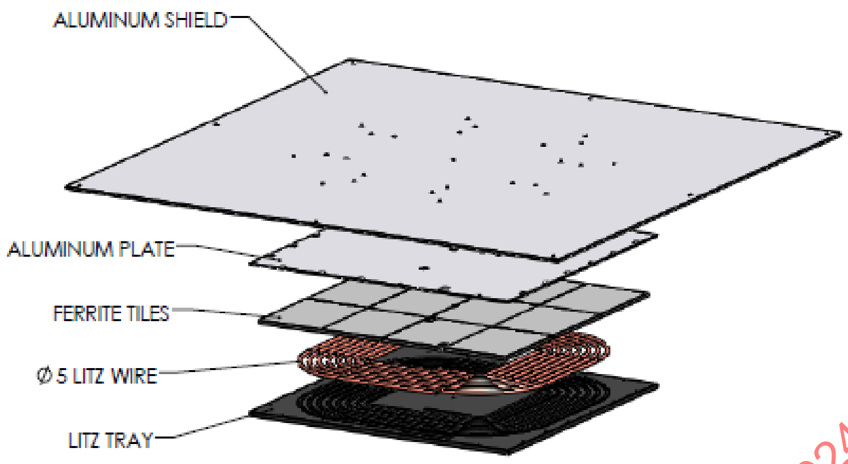


Figure A32 - Exploded view of the Test Station VA WPT3/Z3

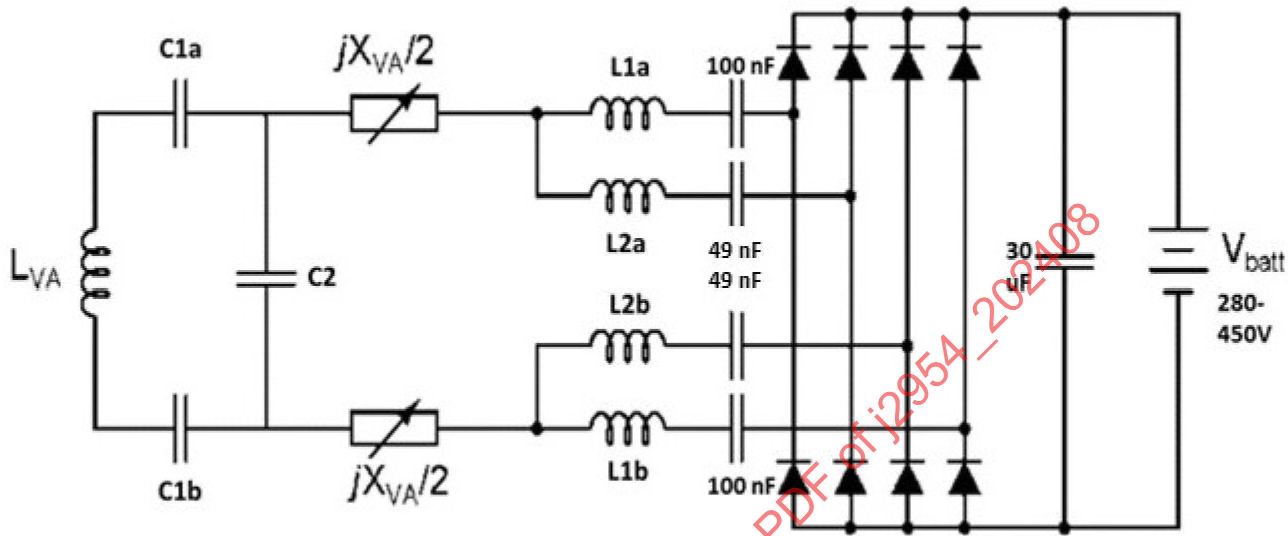
Table A17 shows the mechanical dimensions of the VA WPT3/Z3 and nominal vehicle shield.

Table A17 - Mechanical dimensions of the Test Station VA WPT3/Z3

	Coil + Ferrite Only	Housing	Vehicle Shield Size
L x W x H [mm]	401.5 x 401.5 x 12.6	420x 420 x 20	800 x 800 x 1

A.9.2 Electrical Specification

Figure A33 shows the electrical specification of the VA WPT3/Z3.



C1a, C1b [nF]	325
C2 [nF]	150
$jX_{VA}/2$ [ohms]	-15 to 0
L1a, L1b [uH]	54
L2a, L2b [uH]	54

Figure A33 - Electrical specification of the Test Station VA WPT3/Z3

Minimum and maximum values of secondary coil inductance L_{VA} are given in Table A18.

Table A18 - Secondary coil inductance L_{VA}

L_Min [μH]	39.3
L_Max [μH]	40.0

APPENDIX B - TEST STATION UNIVERSAL GA (WPT1, WPT2, WPT3) (NORMATIVE)

This appendix provides the mechanical and electrical design specifications of the Test Station Universal GA.

NOTE: Specifications are designed for optimal operation with the Test Station VA WPT2/Z1 (see Appendix A, Section A.4), the Test Station VA WPT2/Z2 (see Appendix A, Section A.5), the Test Station VA WPT2/Z3 (see Appendix A, Section A.6), the Test Station VA WPT3/Z1 (see Appendix A, Section A.7), the Test Station VA WPT3/Z2 (see Appendix A, Section A.8), and the Test Station VA WPT3/Z3 (see Appendix A, Section A.9).

B.1 MECHANICAL SPECIFICATION

Figures B1 and B2 show the mechanical dimensions of the Test Station Universal GA. Figure B3 shows an exploded view of the mechanical construction of the GA with the aluminum plate toward the ground. The ferrite layers in the GA are constructed of ferrite tiles of dimensions 100 x 150 x 5 mm and 100 x 100 x 5 mm. Typical properties of the ferrite material used in the GA are shown in Table B1.

Table B1 - Typical ferrite properties

Material	MnZn
Initial Permeability (25 °C)	>1000
Flux Density, B_S (100 °C) (H = 1200 A/m, 10 kHz)	>400 mT
Core Loss, P_V (100 kHz, 200 mT, 100 °C)	<350 kW/m^3

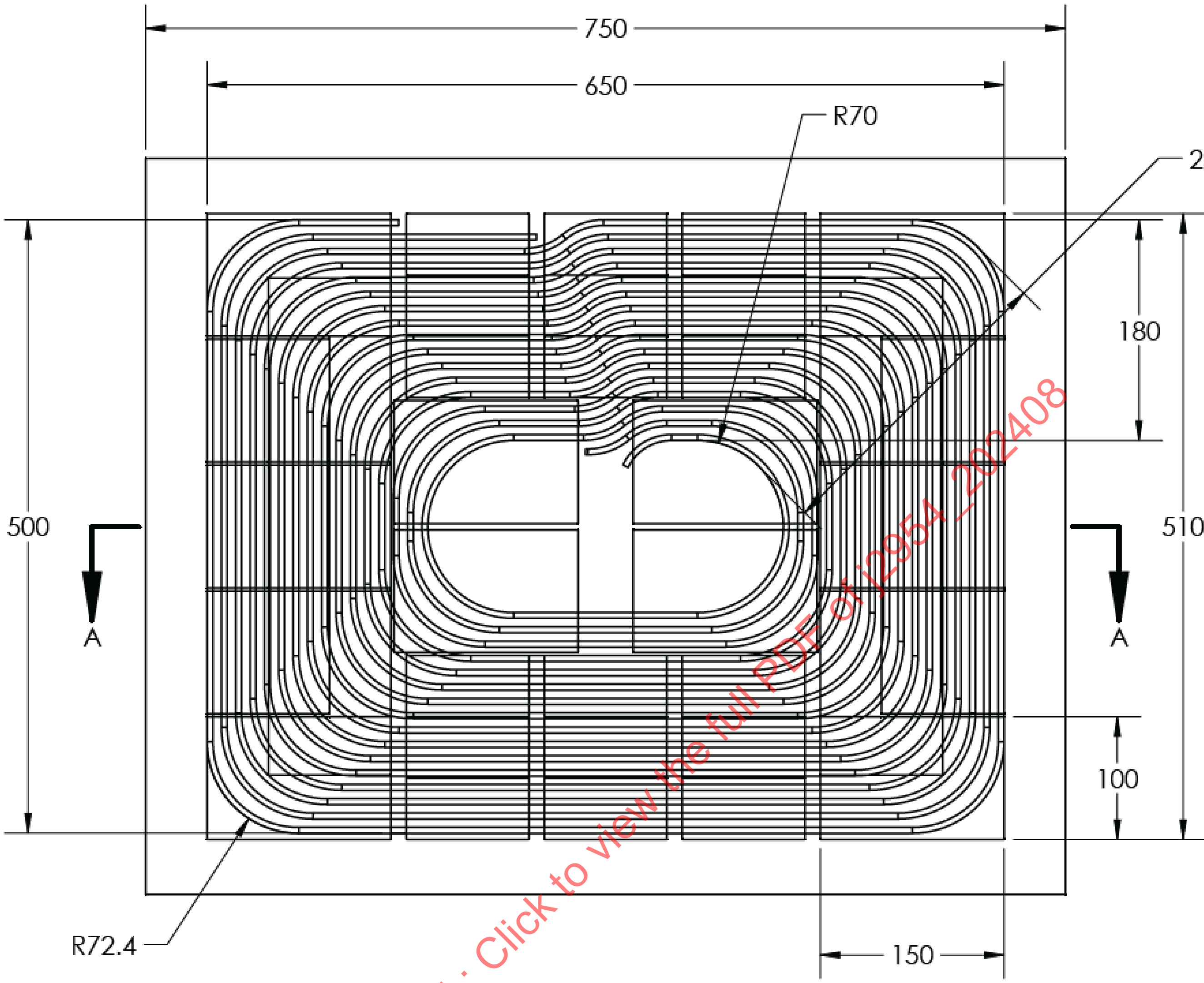


Figure B1 - Mechanical dimensions of the Test Station Universal GA

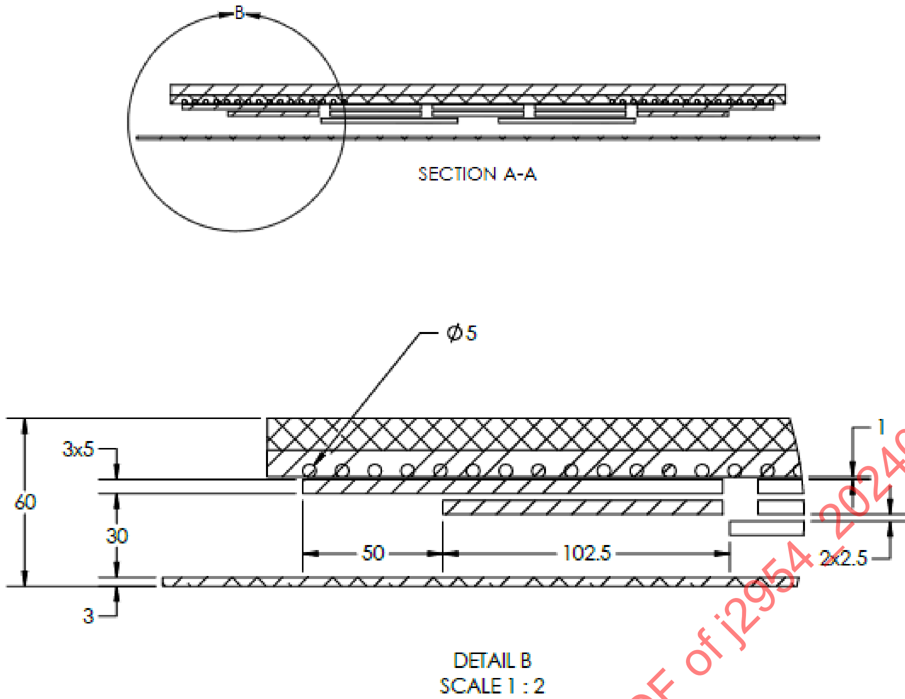


Figure B2 - Detailed cross-section view of the Test Station Universal GA

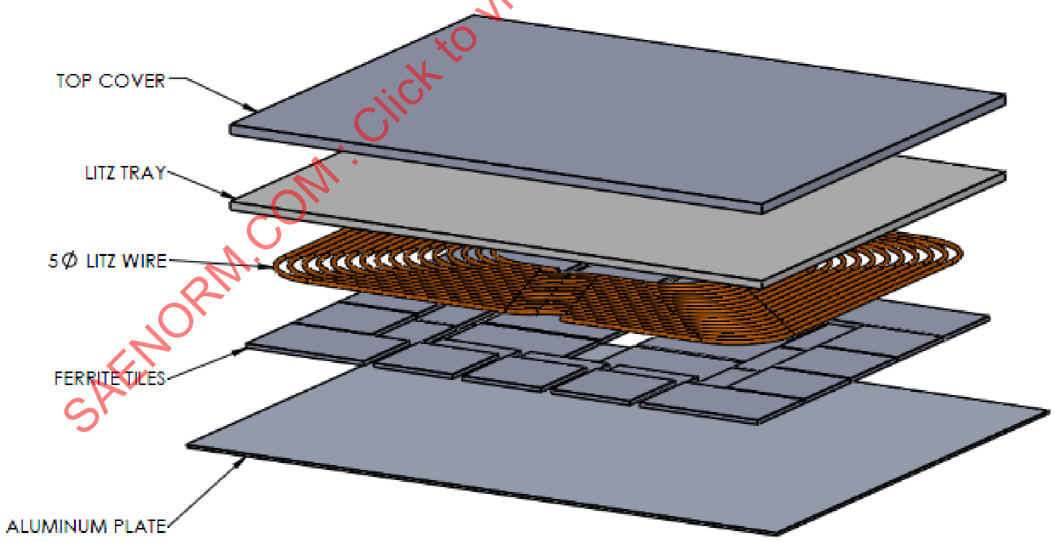


Figure B3 - Exploded view of the Test Station Universal GA

NOTE: Ferrite placed on a single plane rather than at three levels can also be used but will result in a slight change of inductance and coupling values.

B.2 ELECTRICAL SPECIFICATION

Figure B4 and the values in Table B2 show the electrical specification of the Test Station Universal GA.

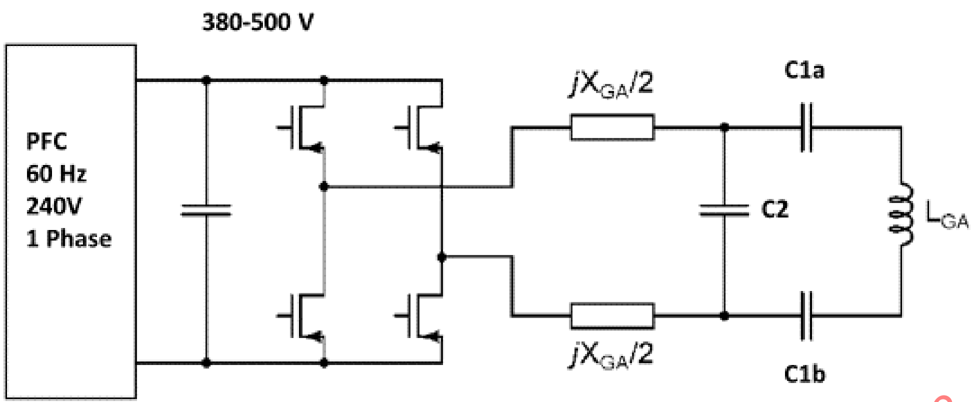


Figure B4 - Electrical schematic of the Test Station Universal GA

Table B2 - Table of values

C1a, C1b [nF]	320
C2 [nF]	270
$jX_{GA}/2$ [ohms]	4 to 16

Minimum and maximum values of L_{GA} when simulated with an 800 x 800 mm aluminum shield are given in Table B3.

Table B3 - Primary coil inductance L_{GA} depending on the Z-class

Z-Class	VA	L_{GA}_Min [µH]	L_{GA}_Max [µH]
WPT2/Z1	Appendix A.4	29.6	35.8
WPT2/Z2	Appendix A.5	35.1	38.1
WPT2/Z3	Appendix A.6	37.4	38.7
WPT3/Z1	Appendix A.7	30.0	36.2
WPT3/Z2	Appendix A.8	35.1	38.1
WPT3/Z3	Appendix A.9	37.4	38.7

Table B4 - Maximum currents in the Test Station Universal GA

Maximum PFC Output Current	29 ADC
Maximum GA Inverter Output Current	40 A rms
Maximum GA Coil Current	75 A rms

Minimum and maximum values of k when simulated with an 800 x 800 mm aluminum shield are given in Table B5.

Table B5 - Coupling k between primary and secondary coil depending on the Z-class

Z-Class	VA	k_Min	k_Max
WPT2/Z1	Appendix A.4	0.109	0.238
WPT2/Z2	Appendix A.5	0.090	0.221
WPT2/Z3	Appendix A.6	0.087	0.229
WPT3/Z1	Appendix A.7	0.119	0.246
WPT3/Z2	Appendix A.8	0.090	0.221
WPT3/Z3	Appendix A.9	0.087	0.229

APPENDIX C - DIFFERENTIAL INDUCTIVE POSITIONING SYSTEM (DIPS) - ALIGNMENT PROCEDURE AND PAIRING COMMUNICATIONS DETAILS (NORMATIVE) (INFORMATIONAL: REQUIREMENTS APPLY TO TEST 5A)

This appendix provides information for the GA producer for adding the DIPS hardware to an Interoperability Class I GA candidate and verifying that the DIPS feature on that GA is able to provide specified test fields used in the alignment process. It also provides requirements for pairing using the DIPS implementation.

Final compliance with the power transfer requirements shall be verified per 8.2.8.2 with the DIPS hardware installed and in a state ready for power transfer.

C.1 DIPS HARDWARE COMPONENTS AND GENERAL DESCRIPTION OF DIPS OPERATION (INFORMATIONAL: REQUIREMENTS APPLY TO TEST 3A)

The hardware components shall include four vertical field coils and one horizontal field coil. The vertical field coils are located symmetrically around the magnetic center of the GA but beyond the alignment tolerance area. Each vertical field coil shall operate at the frequency specified for that vertical field coil position as specified in Table 21 in 12.5.1.

The horizontal field coil is wrapped around the ferrite and the litz wire of the power transfer coil in the Y direction. The field coil shall operate at one of the frequencies specified in Table 22 in 12.5.1. At the discretion of the manufacturer, the horizontal field coil can be capable of operating at more than one of the listed frequencies in order to avoid conflict with installed GA neighbors.

See the example of a DIPS-Enabled GA in Section C.4.

During the alignment operation, the vertical and horizontal coils of the selected GA are energized. Additional coils in the VA receive the signals, which are then processed in the VA electronics, and determine what action is required to align the VA with the GA within the alignment tolerance area (see Appendix D). The required action is sent to the driver through an appropriate human interface, or instructions are sent to an automatic driving system. Once the voltage matrix generated meets the criteria for being within the alignment tolerance area of that GA, alignment is stopped and pairing commences, followed by alignment check. When all of these activities are successfully complete, power transfer can start.

C.2 TESTING THE DIPS-ENABLED GA AGAINST FINE ALIGNMENT REQUIREMENTS

C.2.1 DIPS-Enabled GA Test Device (Informational: Requirements Apply to Test 3A)

The DIPS-Enabled GA Test Device (Test Device) is used to determine the compliance of the DIPS implementation of the GA under test. This is a bench test, not a system test. It is recommended that the test be performed using the Test Station described in 15.1.1, adapted for these tests. The GA under test is on the Test Station base, and this Test Device is used instead of a reference VA.

Because this Test Device is critical to the measurement for compliance of the generated fields at specific positions, the fabrication and construction of the Test Device shall follow the requirements and descriptions stated.

Figure C1 shows an exploded view and Figure C2 shows the mechanical dimensions of the ferrite and the coil of the Test Device. The material of the ferrites shall meet the typical ferrite properties in Table C1.

Table C1 - Typical ferrite properties

Material	MnZn
Initial Permeability (25 °C)	>2000
Flux Density, B_S (100 °C) (H = 1200 A/m, 10 kHz)	>400 mT
Core Loss, P_V (100 kHz, 200 mT, 100 °C)	<350 kW/m^3

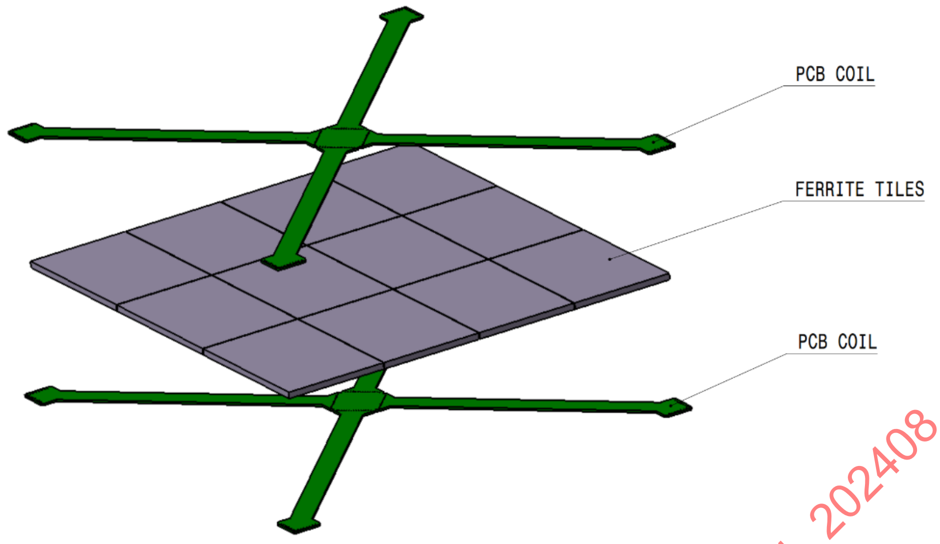


Figure C1 - Exploded view of the Test Device

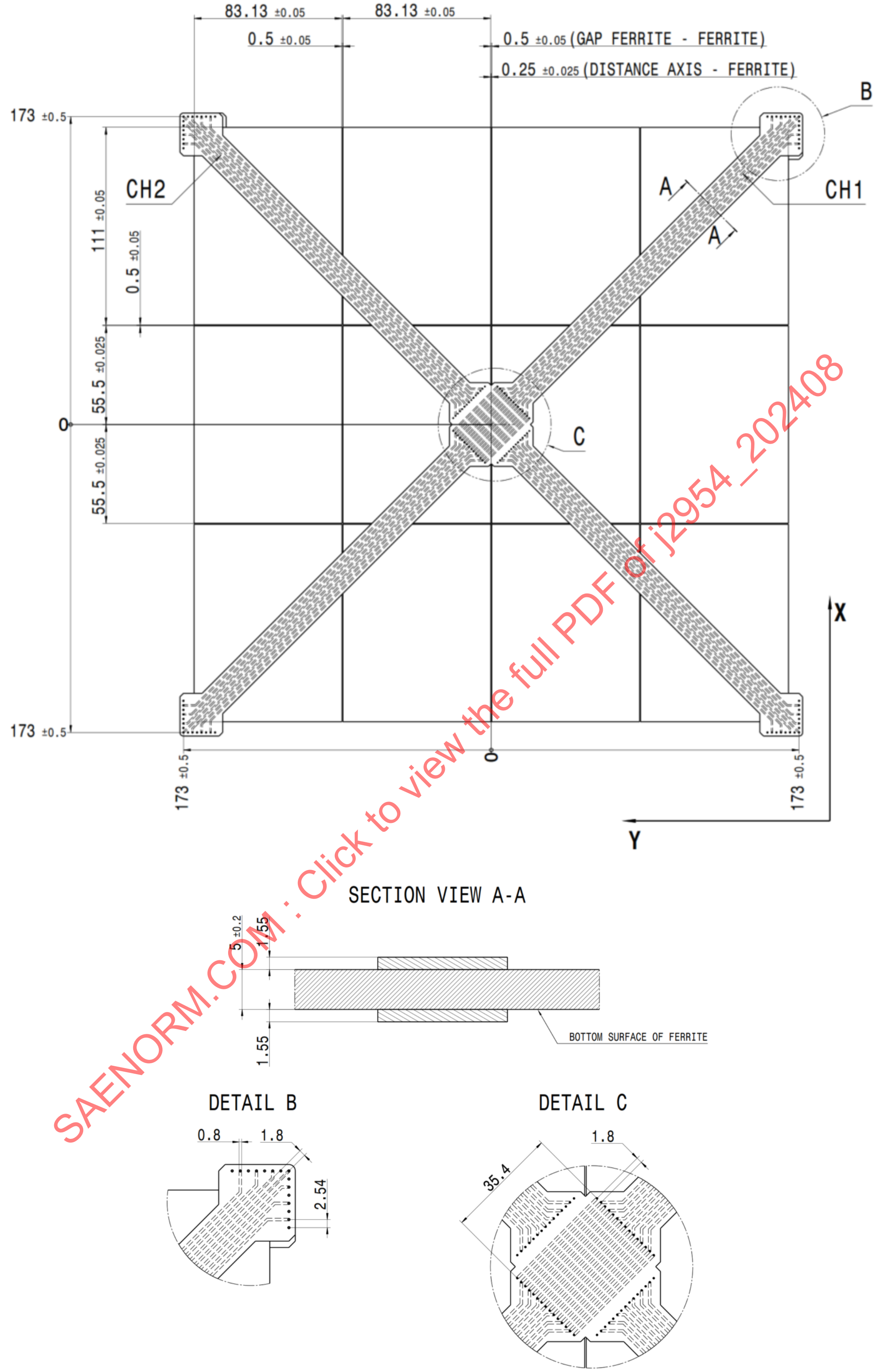


Figure C2 - Mechanical dimensions of the Test Device

PCB coil segments, indicated in Figures C1 and C2, are placed on both sides of the ferrite layer. The end points of the PCB coil segments are connected together with inter-board pin connectors to make two 15-turn coils, orthogonal to each other, wrapped around the ferrite layer. While it is not otherwise shown, a thin ferrite tray to maintain the ferrite positions and spacing is expected.

Each of the two coil windings indicated in Figure C2 are a measurement channel. The terminals of the two measurement channels are indicated in Figure C3.

C.2.2 Test Station Setup (Informational: Requirements Apply to Tests 3A, 4A)

Because the field results are influenced by the GA power transfer magnetics and DIPS is meant to be installed and interoperate on any GA that meets the requirements for a Interoperability Class I GA, there will not be a single DIPS implementation that will meet the requirements of the DIPS Conformance Tests. It is recommended that the designer use modeling as a tool to determine a set of locations, the size and shape of the coils, and coil currents for a specific GA. The final determination of compliance with the fields required for alignment will be determined by using the DIPS Test Device using the Test Station.

Because the presence of metals near the fields being measured can distort the measurements, no metals, except the coax cables being used for connecting the DIPS Test Device coils to the measuring equipment, shall be present in the volume defined by an area in the XY plane of 1.5 m x 1.5 m, centered on the GA center point at a Z height from 0.0 m to 100 mm above the upper surface of the DIPS Test Device (the keep-out zone). There should be no large metal surfaces above the DIPS Test Device for at least 1 m.

For the alignment fields testing, the DIPS Test Device shall be able to maintain a stable fixed position in X, Y, and Z with rotations per the requirements of Figure C3; that is, 0 degrees, 90 degrees, 180 degrees, and 270 degrees. Metal components to facilitate these requirements shall be located above the keep-out zone described above.

The GA center point and the DIPS Test Device center point become the (X,Y) = (0,0) position. The Z height is the ground clearance, which in this case is the distance between the ground surface and the bottom surface of the ferrite as shown in Section View AA of Figure C2.

To measure the voltages induced in the two measurement channels by the horizontal and vertical fields, it is recommended that an oscilloscope is used as the measurement equipment. The AC induced voltages of the two channels of the DIPS Test Device shall be measured separately. The two channels of the DIPS Test Device are connected to the oscilloscope through coaxial cables. The input impedance of the oscilloscope shall be set to high impedance (1MΩ).

The measurement results from the oscilloscope are used as raw data for subsequent frequency analysis. It is recommended to measure each vertical and horizontal coil separately so that the vertical resolution of the oscilloscope can be set appropriately for each measurement point. The recommended sampling rate is not less than 6 MHz and the number of samples shall not be less than 60000.

Measurement techniques with equivalent or higher accuracy are equally acceptable.

C.2.3 Test Conditions for DIPS Fine Alignment Tests (Informational: Requirements Apply to Tests 4A, 5A)

Coil alignment tests shall include all required offsets in X, Y, and Z per Tables C3 to C5 and C6 to C8. The values in the tables shall be measured with roll = pitch = yaw = 0 degrees.

Position tolerance is ±1.0 mm for linear dimensions and less than ±0.5 degree for angular dimensions. Ambient temperature shall be 20 °C ± 5 °C.

C.2.4 DIPS Conformance Test of the Vertical Field Coils (Informational: Requirements Apply to Test 4A)

During this test, the DIPS-Enabled GA shall be tested as it will be configured during alignment operation including the IMN. The horizontal field coil shall not be energized and the DIPS-pairing modulation shall be disabled. The vertical field coils, each with different frequencies, can be measured individually or simultaneously. The DIPS Test Device shall be placed at the measurement points defined in Tables C3 to Table C5. The induced voltages in the two measurement channels of the DIPS Test Device are analyzed within the frequency domain separately. The peak values at each frequency of the vertical field coils are recorded. At each measurement point, the DIPS Test Device shall be placed in four different orientations (0 degrees, 90 degrees, 180 degrees, and 270 degrees) as shown in Figure C3, and the above measurements shall be conducted in each orientation. The X and Y directions in Figure C3 are defined the same as in Figure 28.

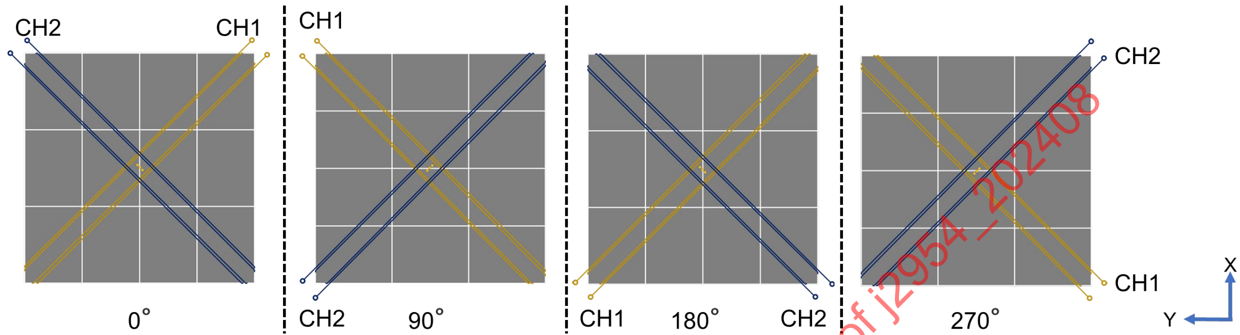


Figure C3 - Definition of the orientation of the DIPS Test Device

The test result of a measurement point shall be calculated as

$$u_{\text{result\_}fn} = (|u_{\text{peak\_}fn\text{\_CH1\_0}}| + |u_{\text{peak\_}fn\text{\_CH2\_0}}| + |u_{\text{peak\_}fn\text{\_CH1\_90}}| + |u_{\text{peak\_}fn\text{\_CH2\_90}}| + |u_{\text{peak\_}fn\text{\_CH1\_180}}| + |u_{\text{peak\_}fn\text{\_CH2\_180}}| + |u_{\text{peak\_}fn\text{\_CH1\_270}}| + |u_{\text{peak\_}fn\text{\_CH2\_270}}|)/4$$

where: n is in [1,4] and the CH1 and CH2 in the subscripts denote, respectively, both measurement channels.

An example worksheet for one measurement point is provided in Table C2.

Table C2 - DIPS Conformance Test form for one measurement point

X (mm) =		*Y (mm)* =		*Z (mm)* =
	f_1 (n=1)	f_2 (n=2)	f_3 (n=3)	f_4 (n=4)
$\lvert u_{\text{peak\_}fn\text{\_CH1\_0}}\rvert$				
$\lvert u_{\text{peak\_}fn\text{\_CH2\_0}}\rvert$				
$\lvert u_{\text{peak\_}fn\text{\_CH1\_90}}\rvert$				
$\lvert u_{\text{peak\_}fn\text{\_CH2\_90}}\rvert$				
$\lvert u_{\text{peak\_}fn\text{\_CH1\_180}}\rvert$				
$\lvert u_{\text{peak\_}fn\text{\_CH2\_180}}\rvert$				
$\lvert u_{\text{peak\_}fn\text{\_CH1\_270}}\rvert$				
$\lvert u_{\text{peak\_}fn\text{\_CH2\_270}}\rvert$				
Sum/4 (Measurement result)				
Deviation from rated value				

The deviation of the measurement value from rated measurement value shall be calculated as:

$$\text{Deviation} = \frac{\text{Measurement result in V} - \text{Rated measurement value inV}}{\text{Rated measurement value in V}}.$$

The rated measurement values for the vertical field coil at f1 are shown in Tables C3 to C5. These rated measurement values in the tables are also valid for f2, f3, and f4. For each table (each height), the rated measurement values for the f1 and f2 are symmetric with Y=0, and the rated measurement values for the f1 and f4 and for the f2 and f3 are symmetric with X=0.

For all measurement points, the tolerance allowed is ± 20% (equivalent to +1.58 dB and -1.94 dB) compared to the rated measurement values. In addition, within each height (Z=100, 175 mm and 250 mm), the difference between the highest and the lowest value of the deviation of all measurement points shall not exceed 20%.

Table C3 - Rated measurement values for uresult_f1 in dBV with Z=100mm

Y(mm) / X(mm)	-175	-100	0	100	175
-175			-31.19		
-75		-22.28	-25.65	-31.23	
0	-8.15	-7.69	-18.54	-28.73	-33.44
75		-2.47	-11.63	-27.35	
175			-7.41		

Table C4 - Rated measurement values for uresult_f1 in dBV with Z=175mm

Y(mm) / X(mm)	-175	-100	0	100	175
-175			-34.08		
-75		-20.76	-24.94	-30.88	
0	-12.80	-14.07	-20.91	-28.90	-33.83
75		-12.19	-18.53	-25.18	
175			-13.21		

Table C5 - Rated measurement values for uresult_f1 in dBV with Z=250mm

Y(mm) / X(mm)	-175	-100	0	100	175
-175			-33.17		
-75		-23.61	-26.91	-31.81	
0	-18.64	-19.78	-24.36	-30.43	-34.75
75		-18.96	-24.32	-27.59	
175			-19.94		

C.2.5 DIPS Conformance Test of the Horizontal Field Coil (Informational: Requirements Apply to Test 4A)

During this test, the DIPS-Enabled GA shall be tested as it will be configured during alignment operation including the IMN. The vertical field coils shall not be energized, and the DIPS pairing modulation should be disabled. For this test, the Test Station shall still be used to vary the Y and Z of the DIPS Test Device, but the GA should be moved to reach the X offset test positions (350 to 1000 mm) with Y (of the GA) = 0 and Z (of the GA) = 0.

The DIPS Test Device should be arranged in 0 degrees (see Figure C3) and placed at the measurement points defined in Tables C6 to Table C8. The induced voltages in the two measurement channels of the DIPS Test Device are analyzed within the frequency domain separately. The peak values of both induced voltages at the frequency of the horizontal field are recorded. The rated measurement values are shown in Tables C6 to C8. For all measurement points, the tolerance allowed for the voltage is ±10% (equivalent to +0.83 dB and -0.92 dB).

Table C6 - Rated measurement values for the induced voltages in DIPS Test Device of the horizontal field in dBV with Z=100mm

Y(mm) \ X(mm)		350	380	410	600	1000
-100	CH1	-18.08	-18.38	-19.11	-28.56	-41.56
	CH2	-16.01	-16.46	-17.28	-26.45	-39.64
0	CH1=CH2	-17.02	-17.31	-18.00	-27.21	-40.35
100	CH1	-16.01	-16.46	-17.28	-26.45	-39.64
	CH2	-18.08	-18.38	-19.11	-28.56	-41.56

Table C7 - Rated measurement values for the induced voltages in DIPS Test Device of the horizontal field dBV with Z=175mm

Y(mm) \ X(mm)		350	380	410	600	1000
-100	CH1	-24.43	-24.03	-24.16	-29.78	-41.75
	CH2	-21.18	-21.13	-21.46	-27.49	-39.83
0	CH1=CH2	-22.63	-22.34	-22.57	-28.23	-40.53
100	CH1	-21.18	-21.13	-21.46	-27.49	-39.83
	CH2	-24.43	-24.03	-24.16	-29.78	-41.75

Table C8 - Rated measurement values for the induced voltages in DIPS Test Device of the horizontal field in dBV with Z=250mm

Y(mm) \ X(mm)		350	380	410	600	1000
-100	CH1	-32.34	-30.64	-29.87	-32.00	-42.27
	CH2	-26.92	-26.25	-26.05	-29.41	-40.31
0	CH1=CH2	-29.11	-28.04	-27.53	-30.37	-41.03
100	CH1	-26.92	-26.25	-26.05	-29.41	-40.31
	CH2	-32.34	-30.64	-29.87	-32.00	-42.27

In addition to the tests in Table C6, the DIPS Test Device should be arranged in 0 degrees (see Figure C3) and placed at the measurement point (X=0, Y=0, Z=100). The induced voltages in the two measurement channels of the DIPS Test Device are analyzed within the frequency domain separately. The peak values of both induced voltages at the frequency of the horizontal field shall not be larger than -4.40 dBV.

If the GA under test can implement multiple horizontal field frequencies, all of them shall pass the conformance test.

C.3 SPECIFICATIONS AND TESTING OF DIPS PAIRING (INFORMATIONAL: REQUIREMENTS APPLY TO TESTS 4A, 5A, 6A)

An Interoperability Class I Product GA shall support the DIPS Pairing method:

- The Product GA synchronously modulates the DIPS data package on the horizontal field coil current and the vertical field coil currents.
- Binary-Amplitude-Shift-Keying, specifically ON-OFF keying, is used for modulation.
- As shown in Figure C4, the ON-OFF keying modulation is the interface between the logical layer and the physical layer.

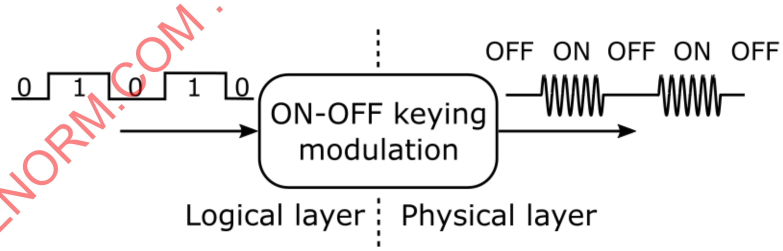


Figure C4 - Relationship between the physical and logical layers of DIPS Pairing

The following requirements must be fulfilled for the logical layer:

- The DIPS data package shall be sent repeatedly without interrupt (see Figure C5).
- The DIPS data package shall be implemented as described in C.3.1
- The DIPS data package shall be encoded as described in C.3.2

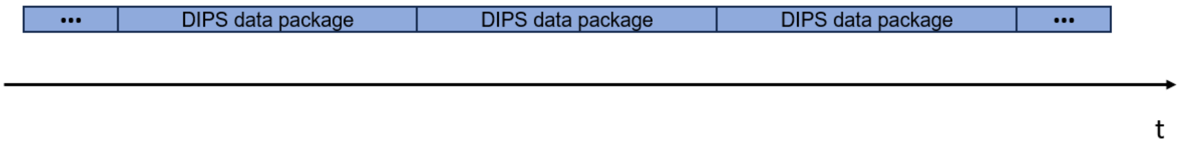


Figure C5 - DIPS signaling frame of DIPS data package

C.3.1 DIPS Data Package (Informational: Requirements Apply to Test 6A)

The data package is defined as follows:

Preamble 8 Bytes	**GA-Type ID** 2 Bytes	**BSSID** 4 Bytes	**Pairing ID** 6 Bytes	**CRC -16** 2 Bytes

Figure C6 - Format of the DIPS data package

- Preamble: The DIPS data package starts with an 8-byte pseudo random sequence (see Table C9). The preamble serves the VA to determine the start of a data package, to establish bit synchronization, to set an appropriate threshold for decoding subsequent data, and to distinguish future evolutions of DIPS. The VA shall be capable of detecting and discriminating all preambles specified in Table C9.

- GA-Type ID: as needed by the VA to apply GA-type specific measures and parameters for determining alignment (see Table C9).

- BSSID: Basic Service Set ID of the Wi-Fi Access Point associated to the GA as needed for establishing the Wi-Fi connection between VA and GA (see Table C9).

- PairingID: to identify the GA as needed for pairing (see Table C9).

- CRC-16: Cyclic redundancy check code for error detection. Applies to GA-TYPE-ID, BSSID, Pairing ID (excluding Preamble) (see Table C9).

Table C9 - Data description

Data field	Description	Semantics
Preamble	Preamble 1 (default): Preamble 2: Preamble 3: Preamble 4: (Preambles 2, 3, 4 may be used to distinguish future evolutions of DIPS)	HEX: C96ECD5F8218A7A2 HEX: 83C953422DFAE33A HEX: FD4C12F1B1A8DE88 HEX: 7E8541B39C523DB2 MSB of HEX is the first bit
GA-Type ID	2-byte code Default for Class I GA: Codes for other GA-Types (e.g., flush mount or buried) may be added in future	HEX: “0000” MSB of HEX is the first bit
BSSID	6-byte ID code containing Basic Service Set ID of the Wi-Fi of the SECC (MAC address of the Access Point)	e.g., HEX: "12-34-56-78-9A-BC" transmitted in canonical format with LSB of each Byte first as "01001000 00101100 01101010 00011110 01011001 00111101"
Pairing ID	4-byte random number assigned to GA on a non-coordinated basis	Any number in range from 1 to 4294967295 in binary format with MSB transmitted first.
CRC-16	2-byte code	Generator polynomial: $x^{16} + x^{12} + x^5 + 1$

NOTE: The preambles were selected from Gold code sets of length 63 adding a fill bit.

C.3.2 DIPS-Pairing Modulation (Informational: Requirements Apply to Test 6A)

Requirements of the logical signal modulation are:

- The current in each of the horizontal and vertical fields shall be encoded via Manchester Encoding according to the IEEE 802.3 convention, where a positive transition (OFF to ON) signifies a logical “1” and a negative transition (ON to OFF) signifies a logical “0.”
- Logical bit rate of DIPS data package is 500 bit/s.
- The period of one Manchester coding element shall be 2000 μs ± 0.2 μs (nominally 500 Hz).
- The minimum pulse width shall be 1000 μs ± 0.1 μs in relation to 50% of the horizontal and vertical field peak value.

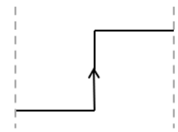
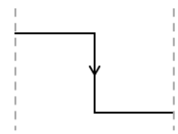
Bit Setting	Transition	Encoded Waveform
1	0 to 1	
0	1 to 0	

Figure C7 - Manchester coding convention

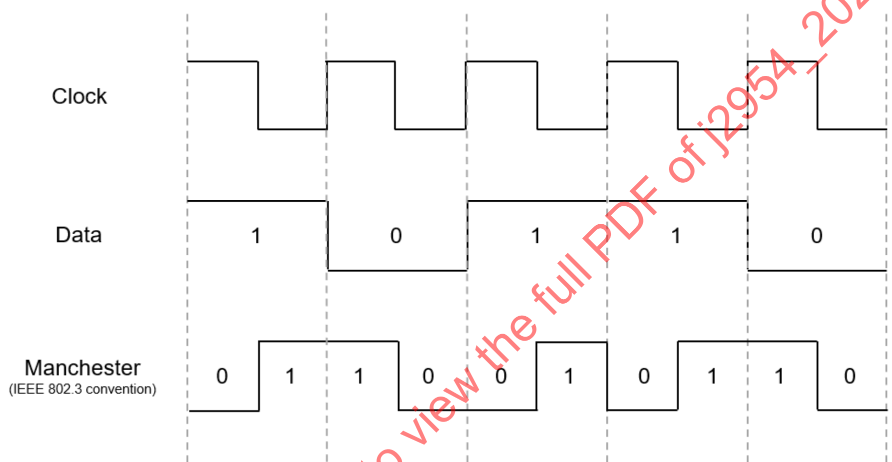


Figure C8 - Example for Manchester coding pattern

C.3.3 DIPS Conformance Test for Pairing (Informational: Requirements Apply to Tests 4A, 5A, 6A)

An Interoperability Class I Product GA shall pass DIPS Conformance Test for Pairing. During this test, the DIPS-Enabled GA shall be tested as it will be configured during alignment operation, including the IMN. The vertical field coils and the horizontal field coil should be energized.

This test verifies the conformity of the physical layer signals generated by the DIPS-Pairing modulation described in C.3.2. The logical layer signal of the DIPS data package shall meet the requirements in C.3.1. Precondition for this test is that the GA under test has passed the DIPS Conformance Test of the vertical field coils and the DIPS Conformance Test of the horizontal field coil in Appendix C, Section C.2.

First, the DIPS-Pairing modulation of the GA under test shall be disabled. The peak-to-peak values of the currents of the four vertical field coils and the horizontal field coil are measured. The measurement results of all five currents are recorded as $i_{\mathrm{pp\_1}}$ to $i_{\mathrm{pp\_5}}$, which are sorted form the lowest to the highest current frequency. $i_{\mathrm{pp\_1}}$ to $\mathrm{i}_{\mathrm{pp\_5}}$ are the reference values for the DIPS conformance test for Pairing.

After that, the DIPS-Pairing modulation of the GA under test shall be enabled. The DIPS data package shall be modulated on the currents of the four vertical field coils and the horizontal field coil according to the timing specified in C.3.1. In this test, all the 22 bytes of the DIPS data package are filled with “1.” The currents in the four vertical field coils and the horizontal field coil are measured simultaneously under the same conditions as before.

For each current, the sample rate f_s should not be lower than 10 MHz, and the sampling time is 5 ms. The measurement results of all five currents are noted as $i_{\text{pairing\_1}}$ to $i_{\text{pairing\_5}}$ in the same order as the peak-to-peak measurements. $i_{\text{pairing\_1}}$ to $i_{\text{pairing\_5}}$ should contain two complete ON-OFF keying modulation cycles. The difference between the upper and lower envelope of $i_{\text{pairing\_1}}$ to $i_{\text{pairing\_5}}$ is calculated separately and noted in the same order as $\Delta i_{\text{envelope\_1}}$ to $\Delta i_{\text{envelope\_5}}$. The $\Delta i_{\text{envelope\_}m}$ can be calculated as:

$$\Delta i_{\text{envelope\_}m}[n] = \max\{i_{\text{pairing\_}m}[n], \ldots, i_{\text{pairing\_}m}[n + n_{\text{p}} - 1]\} - \min\{i_{\text{pairing\_}m}[n], \ldots, i_{\text{pairing\_}m}[n + n_{\text{p}} - 1]\}$$

where: m is in [1,5] and n is in [0, (sample size of measurement - n_{p} -1)]. n_{p} can be calculated as:

$$n_{\text{p}} = \lceil f_s / 110\text{kHz} \rceil.$$

The conditions in Table C10 can determine the ON-OFF states of $\Delta i_{\text{envelope\_1}}$ to $\Delta i_{\text{envelope\_5}}$.

Table C10 - ON-OFF characteristic of single coil current

Parameter	Notation	Value	
		Max (mA)	Min (mA)
OFF state of a single coil	$\Delta i_{\text{envelope\_}m}$	0.2* $i_{\text{pp\_}m}$	-0.2* $i_{\text{pp\_}m}$
ON state of a single coil	$\Delta i_{\text{envelope\_}m}$	1.2* $i_{\text{pp\_}m}$	0.8* $i_{\text{pp\_}m}$

NOTE: m is from 1 to 5.

The example of the ON-OFF determination of single coil current is given in Figure C9.

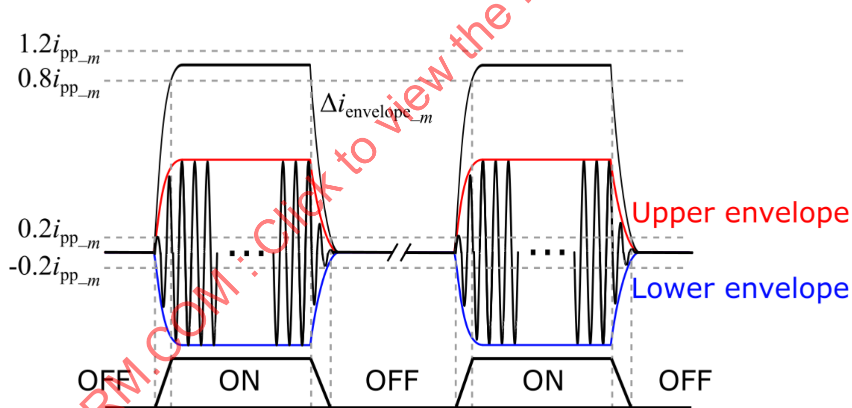


Figure C9 - Example of ON-OFF determination of single coil current

The result of the DIPS Conformance Test for Pairing is i_{pairing}, which is generated based on $\Delta i_{\text{envelope\_1}}$ to $\Delta i_{\text{envelope\_5}}$. The i_{pairing} signal is considered as OFF when all $\Delta i_{\text{envelope\_1}}$ to $\Delta i_{\text{envelope\_5}}$ are simultaneously determined to be OFF. The i_{pairing} is considered as ON when all $\Delta i_{\text{envelope\_1}}$ to $\Delta i_{\text{envelope\_5}}$ are simultaneously determined as ON. The example of the ON-OFF determination of i_{pairing} is given in Figure C10.

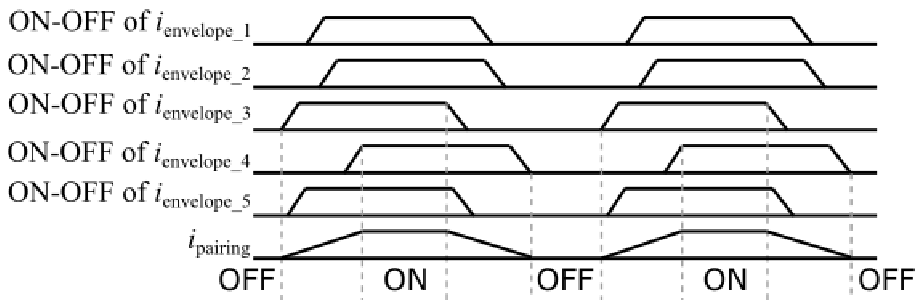


Figure C10 - Example of ON-OFF determination of $i_{pairing}$

The GA under test passes the DIPS Conformance Test for Pairing when i_{pairing} meets the conditions in Table C11 within all complete ON-OFF keying modulation cycles in the sampling time.

Table C11 - Requirements for the $i_{pairing}$

Parameter	Notation	Value	
		Max	Min
Duration of each ON and OFF state of i_{pairing}	$t_{\mathrm{pairing\_ON}}$ and $t_{\mathrm{pairing\_OFF}}$	-	700.00 µs
Ratio between the duration of ON and OFF state of i_{pairing}	$\frac{t_{\mathrm{pairing\_OFF}}}{t_{\mathrm{pairing\_ON}}}$	1.1	0.9

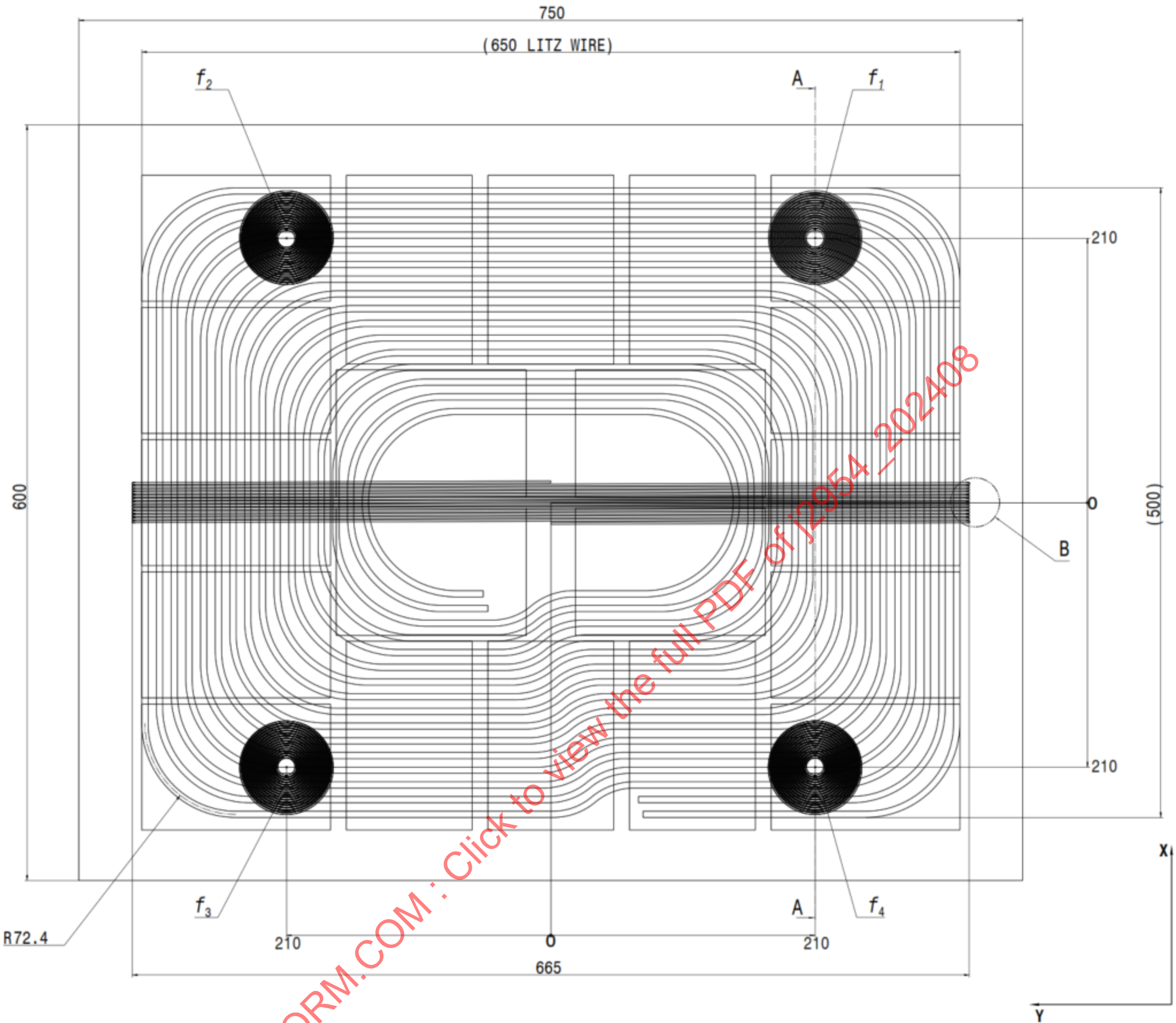
C.4 EXAMPLE OF A DIPS-ENABLED GA

The purpose of this section is to provide an example of a DIPS-Enabled GA.

C.4.1 Mechanical Specifications

Figure C11 shows the mechanical dimensions of the example DIPS-Enabled GA. The purpose is to provide an example of the coils and their placement.

The horizontal field coil is wound around the litz wire and the ferrite layer of the power transfer coil (see Detail C in Figure C12). The vertical field coils are placed above the litz wire of the power transfer coil. The PCB thickness of the vertical field coils is 1.55 mm.


750
(650 LITZ WIRE)
f2
A
f1
600
210
0
(500)
B
210
X
f3
A
f4
R72.4
210
0
210
665
Y

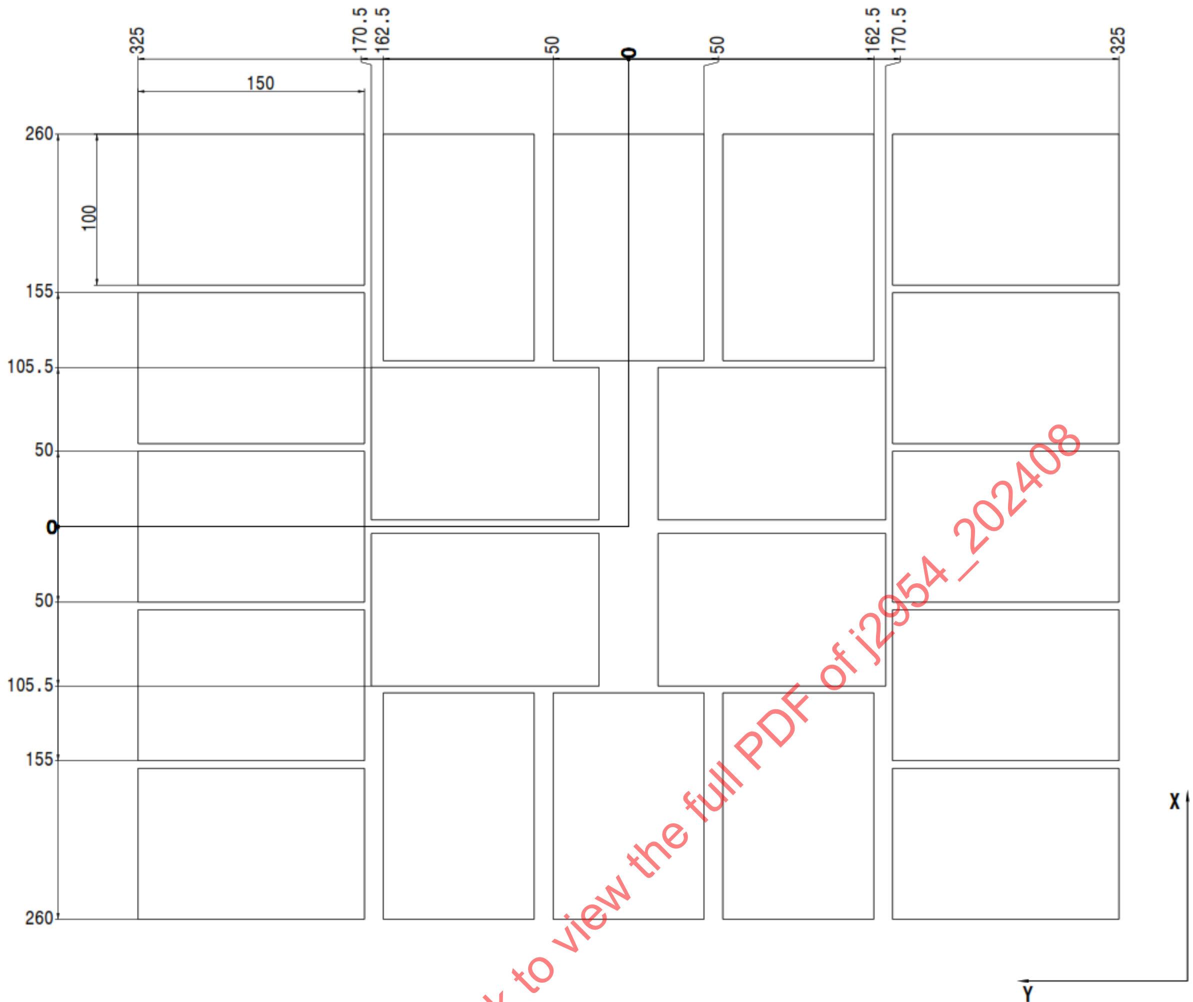


Figure C11 - Mechanical dimensions of the example DIPS-Enabled GA

Figure C12 shows a cross section and detailed view with mechanical dimensions.

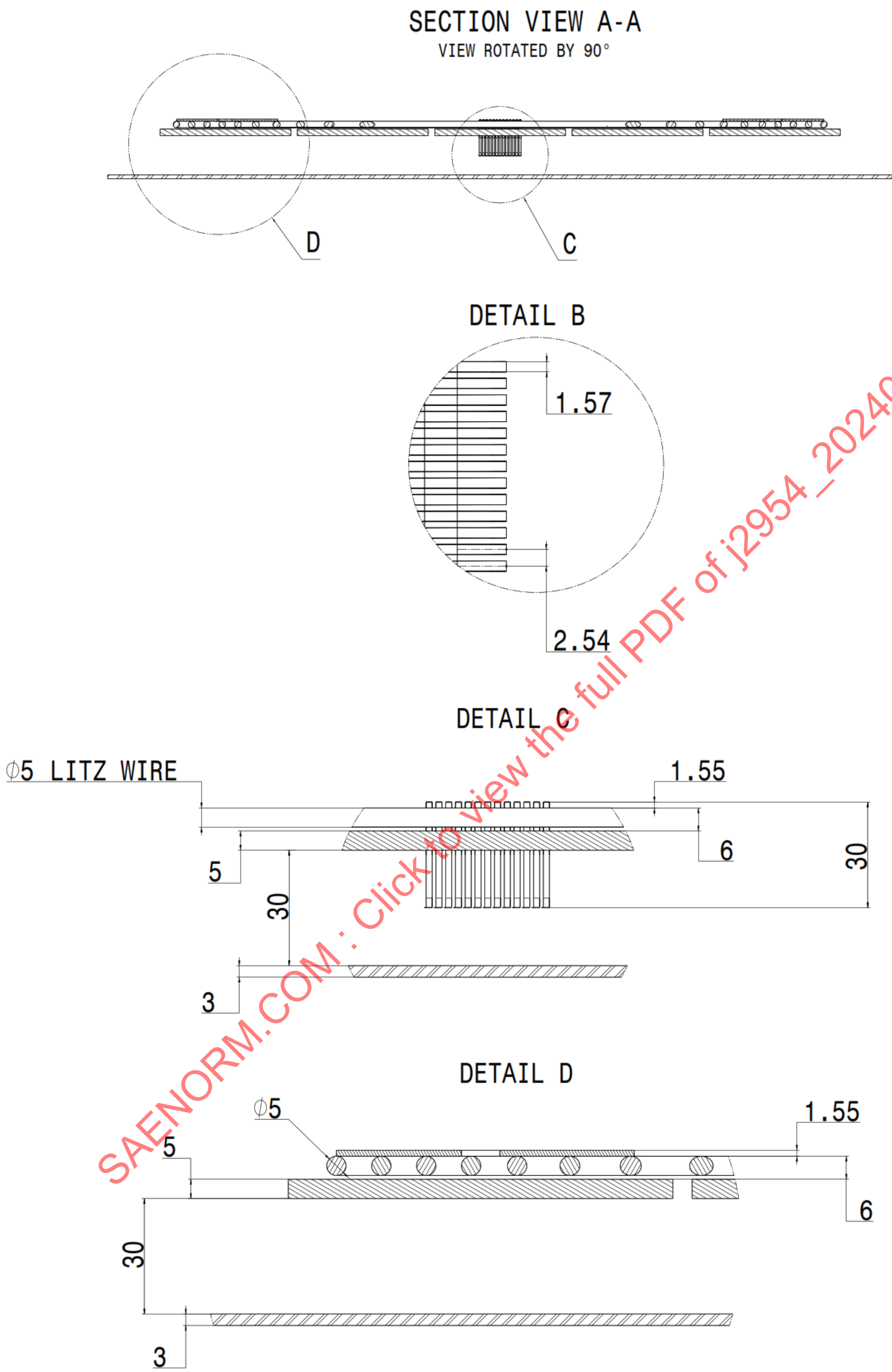


Figure C12 - Detailed cross section of the example DIPS-Enabled GA in Figure C11

Figure C13 shows the mechanical dimensions of a vertical field coil used in the example GA with the layout of the top and bottom layers. The tracks of the two layers are mirror images of each other and are connected in series through a via.

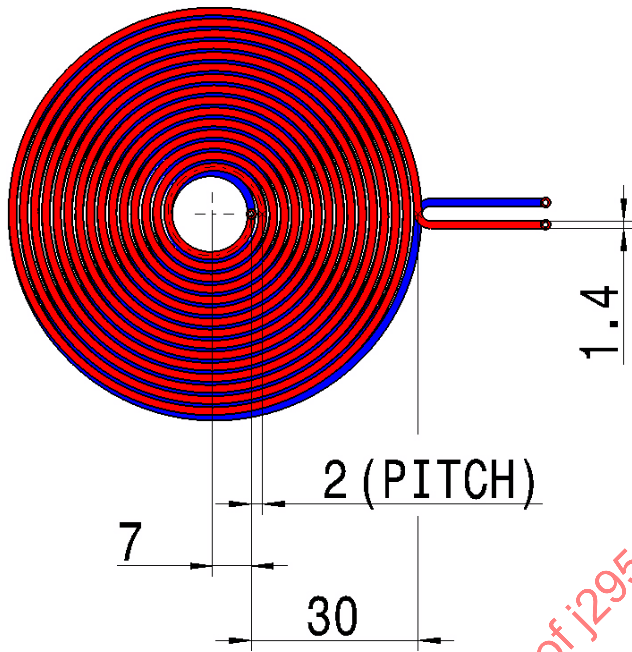


Figure C13 - Mechanical dimensions of a vertical field coil in the example GA

C.4.2 Electrical Specifications

Figure C14 shows the electrical specification of the example GA.

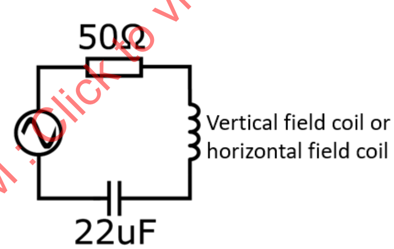


Figure C14 - Electrical specification of field coils

The reference value of fundamental current RMS for vertical field coils from Figure C13 is 100 mA at the corresponding frequency specified in Table 21. The reference value of fundamental current RMS for horizontal field coils from Figure C11 is 20 mA at one of the frequencies from Table 22. Taking into account the tolerances in the system built up, the current can be adjusted accordingly to pass the conformance tests defined in Section C.2. The voltage source in Figure C14 can be realized by a voltage source type amplifier. The Binary-Amplitude-Shift-Keying for transmitting of DIPS data packages can be realized by modulating its control signal. The example DIPS-Enabled GA is defined with the power transfer coil(s) open circuited.

APPENDIX D - DIFFERENTIAL INDUCTIVE POSITIONING SYSTEM - EXAMPLE PRODUCT VA (INFORMATIVE)

This appendix provides information about an example of a DIPS-Enabled Product VA whose performance has been demonstrated. This implementation is usable for Fine Alignment and Pairing with any Interoperability Class I GA.

D.1 DESCRIPTION OF DIPS OPERATION

The general goal for Fine Alignment is a straight-line approach to the GA. DIPS allows a design that makes it easy for the driver to accomplish that. The idea is to provide steering and braking information early and then a stop signal when alignment is within the alignment tolerance zone.

If the driver does not follow the navigation instructions from the system, correction arrows will show that the vehicle is outside the alignment tolerance zone, and the driver can follow these instructions to align the vehicle in the alignment tolerance zone.

This example of a DIPS-Enabled Product VA has two single turn solenoid coils wound around the ferrite of the power transfer coil. The windings are orthogonal to each other and are at a 45-degree angle to the vehicle X axis (the driving direction). These coils detect the magnetic field generated by the horizontal and vertical field coils of the DIPS-Enabled product GA installed in the parking space.

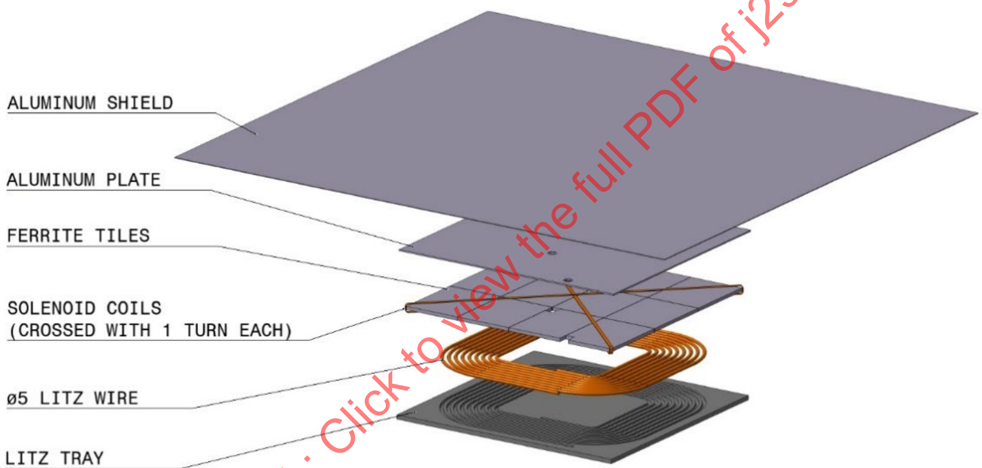


Figure D1 - Exploded view of DIPS Product VA example

D.2 CONVERSION OF RECEIVED SIGNALS TO ACTIVITY

For this example, the general principle for the evaluation of the magnetic field is as follows:

- Steering information: The VA performs a differential signal processing as shown in Figure D2. When the induced voltage at the horizontal field coil frequency from Coil A is greater than from Coil B it means that the user should steer left. When the induced voltage from Coil B is greater than from Coil A it means that the user needs to steer right. If the induced voltages from both coils are the same, the steering should be straight ahead.

- Braking information: Because the fields generated by the GA are known, the strength of the horizontal field coil can be used to determine the distance to the GA by evaluating the magnitude of the induced voltages. With a linearized bar, the approach to the target location could be displayed while the reduction of that bar indicates where the vehicle is on that approach.

- Stop signal: When the vehicle is close to the GA, the VA DIPS coils can detect the signals from the four vertical field coils. Because the frequency of the coil at each position on the GA is different and known to the VA, the VA can calculate its position in relation to the GA center and display it relative to the alignment tolerance zone and, when appropriate, generate a stop signal.

- DIPS-Pairing package: The VA detects data modulated over vertical and horizontal fields by DIPS-Pairing modulation and decodes to obtain DIPS-Pairing package.

- For the case where there is more than one GA installed on adjacent parking spaces, a signal strength threshold for the different horizontal field coil frequencies can be used in order to unambiguously identify the GA chosen by the user.

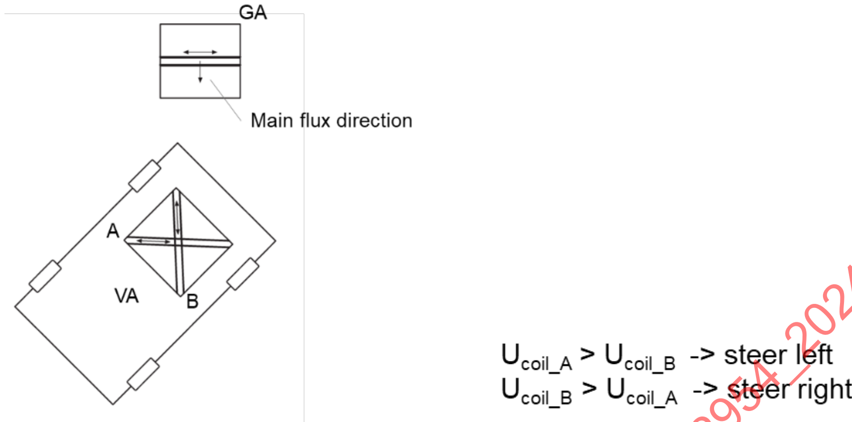


Figure D2 - Differential evaluation of the magnetic field

A solution for the signal processing could be as follows:

- Bandpass filter: The induced voltages from the horizontal and vertical fields from the GA are passed through a bandpass filter. The frequency ranges below and above the frequencies of Table 21 are thereby blocked or significantly attenuated.

- Amplifier: To adjust the induced voltages to the ADC of the digital signal processor, it is recommended to use an amplifier.

- Digital signal processor: Sampling of the measured values and calculation of the output information to the vehicle or driver.

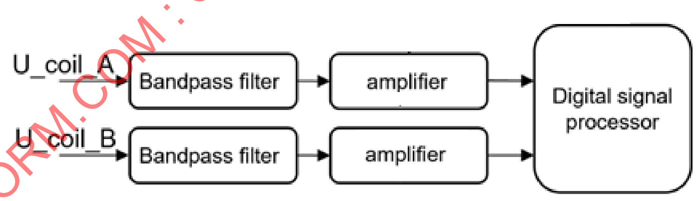


Figure D3 - Example of VA signal processing

APPENDIX E - LIVE OBJECT PROTECTION (NORMATIVE) (INFORMATIONAL: REQUIREMENTS APPLY TO TEST 4A)

This appendix gives suggested guidelines for the test procedure that should be undertaken to ensure humans are protected from being exposed to EMF in excess of the IEEE C95.1-2019 Dosimetric Reference Limits (DRLs) in Region 1 when utilizing a Live Object Protection (LOP) system. The test procedure is intended for validating LOP systems integrated in Product GAs. First, the borderline where the Region 1 DRLs are met when transferring power under worst-case field conditions needs to be determined. Alternatively, if the more conservative ERLs can be met, then this boundary may be used as a determination in place of the DRL boundary. Second, the speed of decay from turn-off of the system (detection) down to the level where the DRLs (or alternatively ERLs) are satisfied is determined. Note that the borderline depends on the part of the human body that is encroaching (i.e., a limb will have a different borderline from a head/torso).

Based on informal investigations, the LOP testing shall use a maximum encroachment speed of 1000 mm/s for an adult hand (limb) moving in a circumferential motion under the vehicle with a radius of 700 mm from the edge of the vehicle and an average encroachment speed of 300 mm/s for a child's hand (limb) moving in a reaching motion toward the GA surface. For Z2 and Z3 WPT systems, the LOP testing shall also consider an average encroachment speed of 100 mm/s for a head or torso in a crawling motion toward the GA surface. Therefore, the LOP safety line is the above borderline, extended by the product of the decay time in seconds and the encroachment speed with consideration for the body part and the direction of motion.

This LOP safety line is the line where detection of the appropriate body part mimic should occur.

Note the DRLs are the basic requirement for LOP testing; however, the use of DRLs in this test procedure requires detailed and validated human exposure modeling on various body parts to be performed to determine the borderlines as described. The use of the more conservative ERLs is a simpler alternative when possible since these can be measured using standard field probe equipment.

E.1 SPEED OF SHUTDOWN TEST (INFORMATIONAL: REQUIREMENTS APPLY TO TEST 4A)

This part of the test measures the system shutdown speed from trigger to the Region 1 limit (i.e., DRL or more conservative ERL).

The test is undertaken under worst-case conditions; i.e., it shall take place with the system delivering full rated power to the VA on the vehicle, when the VA is under worst-case alignment as described below.

The test is undertaken with an integrated VA coil (or VA coil and vehicle mimic) positioned over the Product GA, which incorporates the LOP system as submitted for validation. The vehicle or vehicle mimic is parked over the Product GA's base-pad (or "pad") while the vehicle is located at the maximum X and Y offset as shown in Figure E1.

A magnetic field probe is placed over the base pad resting on the surface in a location that is expected to be a strong magnetic field.

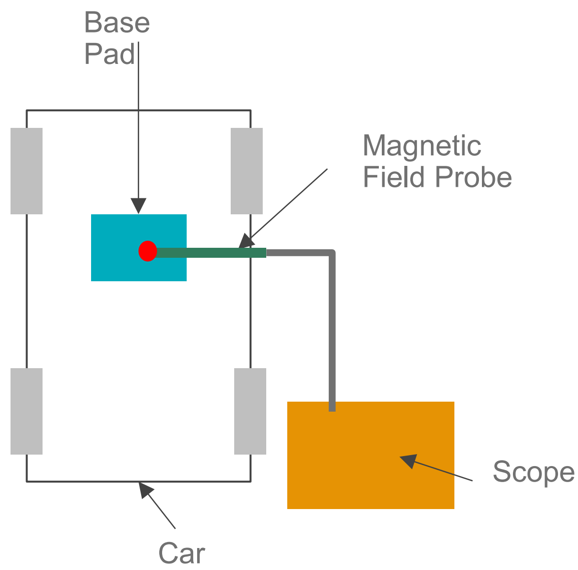


Figure E1 - Test measurement setup for LOP

The probe is connected to a scope, which is triggered by the shutdown event and records the field decay over time. The shutdown shall be initiated without the risk of human exposure, therefore requiring a repeatable manual trigger that initiates this timing. The time signal at which the LOP system triggers is captured on the same scope as the magnetic field strength, allowing the decay of the field to be plotted and evaluated with time.

The time it takes for the field to be less than the Region 1 limit (i.e., in consideration of either the DRL or more conservative ERL) is the decay time, used later in the process.

This test may be run several times at different GA surface locations to ensure that the decay time determined is the longest that is expected.

E.2 DETERMINING THE LOP BORDERS (INFORMATIONAL: REQUIREMENTS APPLY TO TEST 4A)

Using the same setup, with the GA transferring maximum power, determine the borderline around the periphery of the GA where the fields, while transferring maximum power, are at the Region 1 limit for each type of body part analyzed. This line is the LOP border.

Once the above tests are completed, using an encroachment speed appropriate for the body part being represented, determine the product of the decay time and the encroachment speed along with the direction of motion to arrive at the distance outside the LOP border, determined above, that a live object shall be detected. This is the detection line.

Note that when a vehicle is parked over a GA, the accessibility may not be equal for all directions, and this should be considered when selecting the test approach conditions.

E.3 HUMAN MIMIC (INFORMATIONAL: REQUIREMENTS APPLY TO TESTS 3A, 4A)

Rather than using a human to trigger the system for these tests, a representative body part mimic shall be used. The mimic should reasonably represent the appropriate body part considering the size of a small child. In the case of the limb, a not-so-easy-to-detect human hand/arm should be utilized.

In some cases, human body mimics for limbs and heads can be purchased and are used for similar human exposure testing (e.g., https://speag.swiss/components/phantoms/proximity/). Alternatively, for representing a child's hand and arm, a 5-cm diameter sphere, filled with water, may be used as a reasonable mimic, based on size and ease of replication. For more realism, the sphere should be attached to a 4-cm diameter cylinder with length of 15 cm. For an adult's hand and arm, a 10-cm diameter sphere, filled with water, may be used as a reasonable mimic. The sphere should be attached to an 8-cm diameter cylinder with a length of 30 cm. Since a person reaching under the vehicle would be effectively grounded, the sphere/cylinder should also be grounded for these tests.

E.4 LOP TEST (INFORMATIONAL: REQUIREMENTS APPLY TO TEST 5A)

The purpose of this test is to verify, based on the above determinations, that the mimic is detected at or outside the LOP safety line. This test can be done without power being transferred.

Using the appropriate mimic, verify that the LOP system triggers before the test object goes over the detection line at several locations around the periphery of the GA. If LOP detection triggering occurs for each of these cases reliably, the LOP system shall be considered as having passed.

APPENDIX F - PARKING SPACE DEFINITION GUIDELINE (INFORMATIVE)

F.1 SAE J2954 PARKING SPACE GLOBAL SURVEY

The following diagram shows the results of the SAE J2954 parking space global survey.

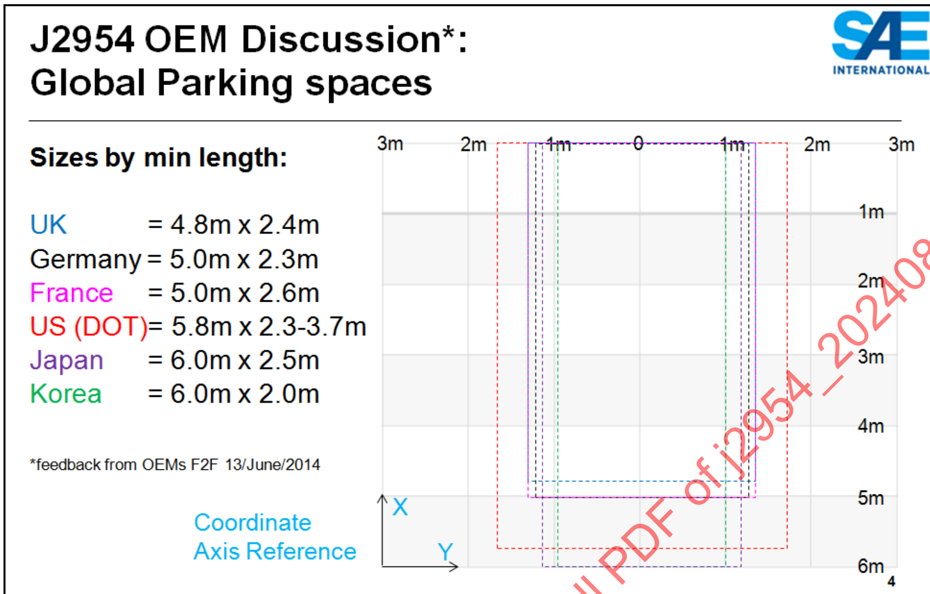


Figure F1 - SAE J2954 OEM survey for GA location in parking space

The following diagram shows the effects of the GA center point in the X-axis.

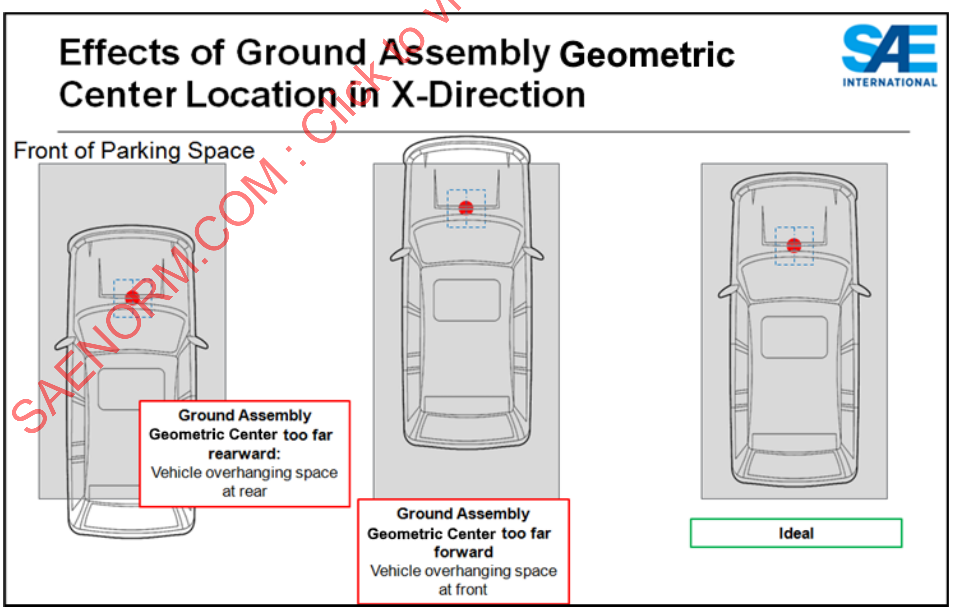


Figure F2 - Effect of incorrect GA location in parking space

APPENDIX G - WPT1 INTEROPERABILITY CLASS II TEST STATION GA (INFORMATIVE)

G.1 EXAMPLE GA WPT1 (INFORMATIVE)

This appendix provides the mechanical and electrical design specifications of the GA WPT1.

NOTE: Specifications are designed for optimal operation with the Test Station VA WPT1/Z1 (see Appendix A, Section A.1), the Test Station VA WPT1/Z2 (see Appendix A, Section A.2), and the Test Station VA WPT1/Z3 (see Appendix A, Section A.3).

G.1.1 Mechanical Specification

Figures G1, G2, G3, G4, and G5 show the mechanical dimensions of the GA WPT1.

The ferrite tiles are made using N96 (TDK).

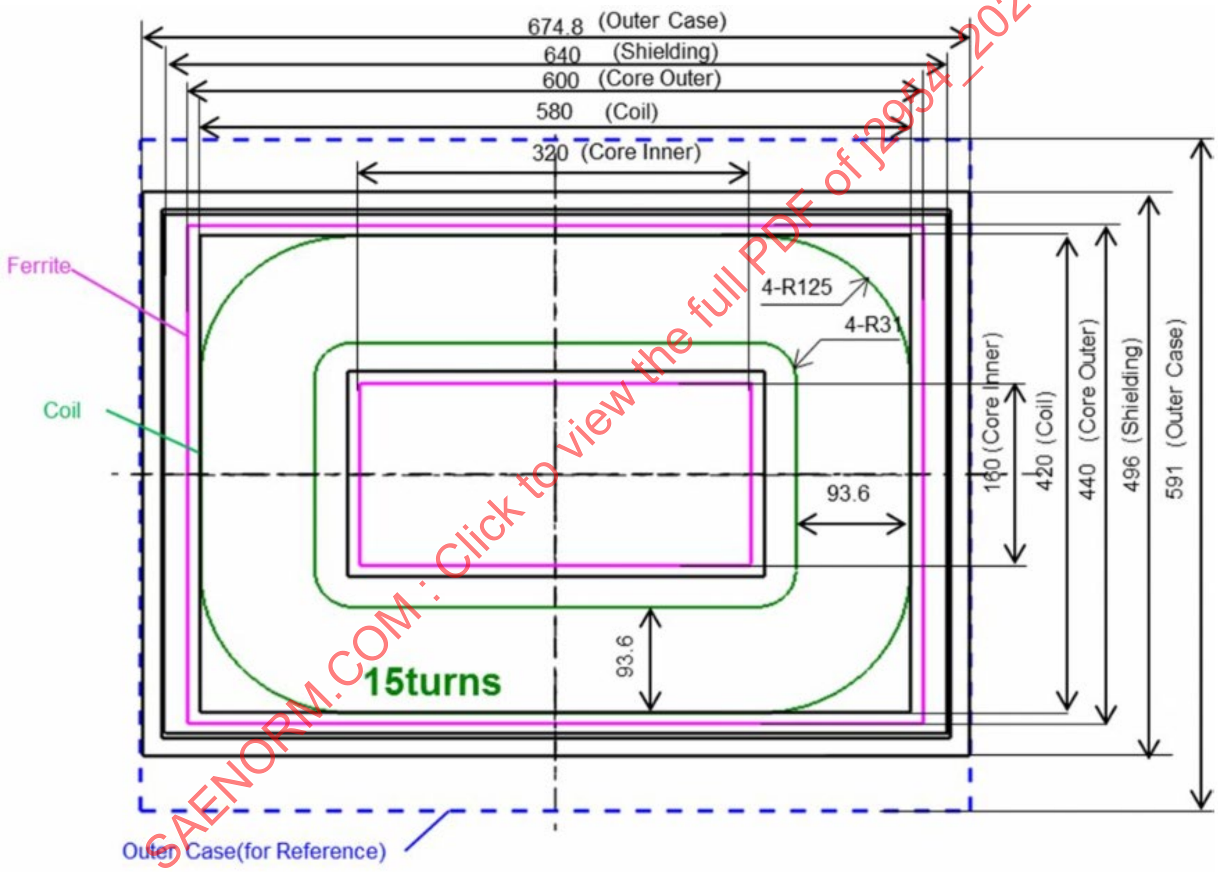


Figure G1 - Mechanical dimensions of the GA WPT1

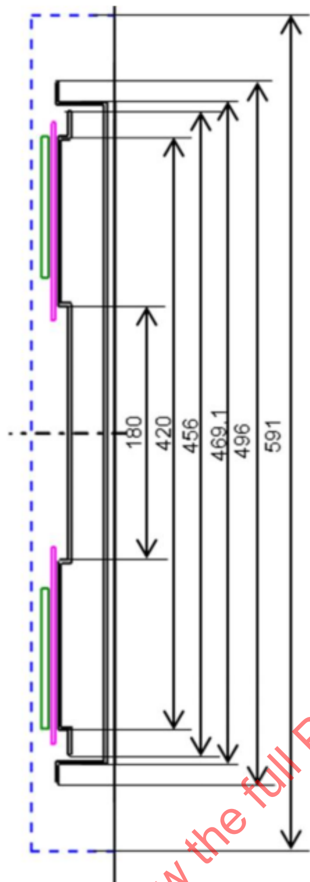


Figure G2 - Mechanical dimensions of the GA WPT1

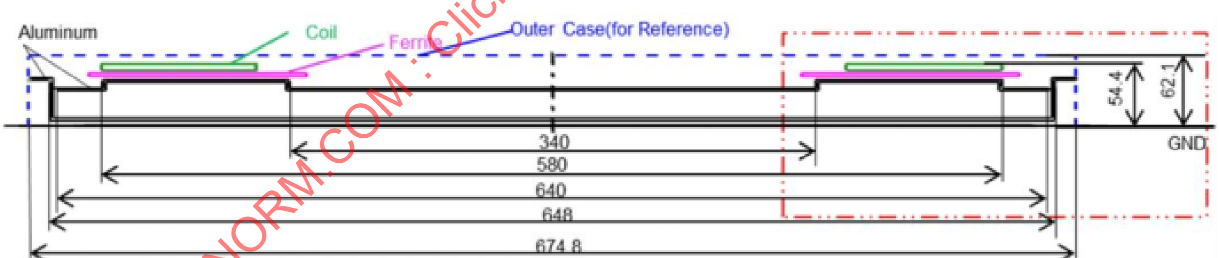


Figure G3 - Mechanical dimensions of the GA WPT1

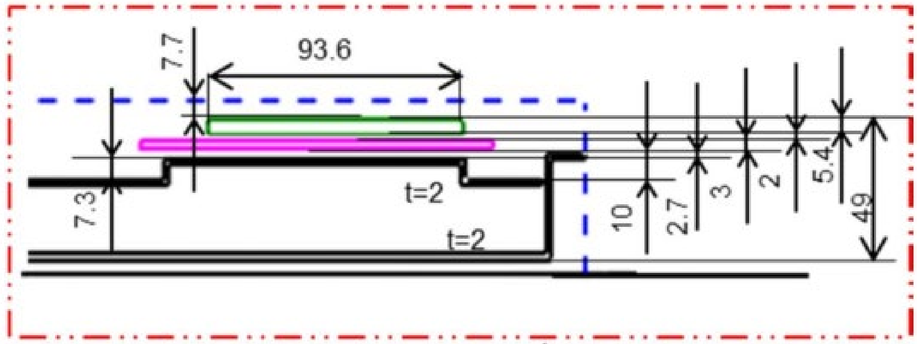


Figure G4 - Detailed cross-section view

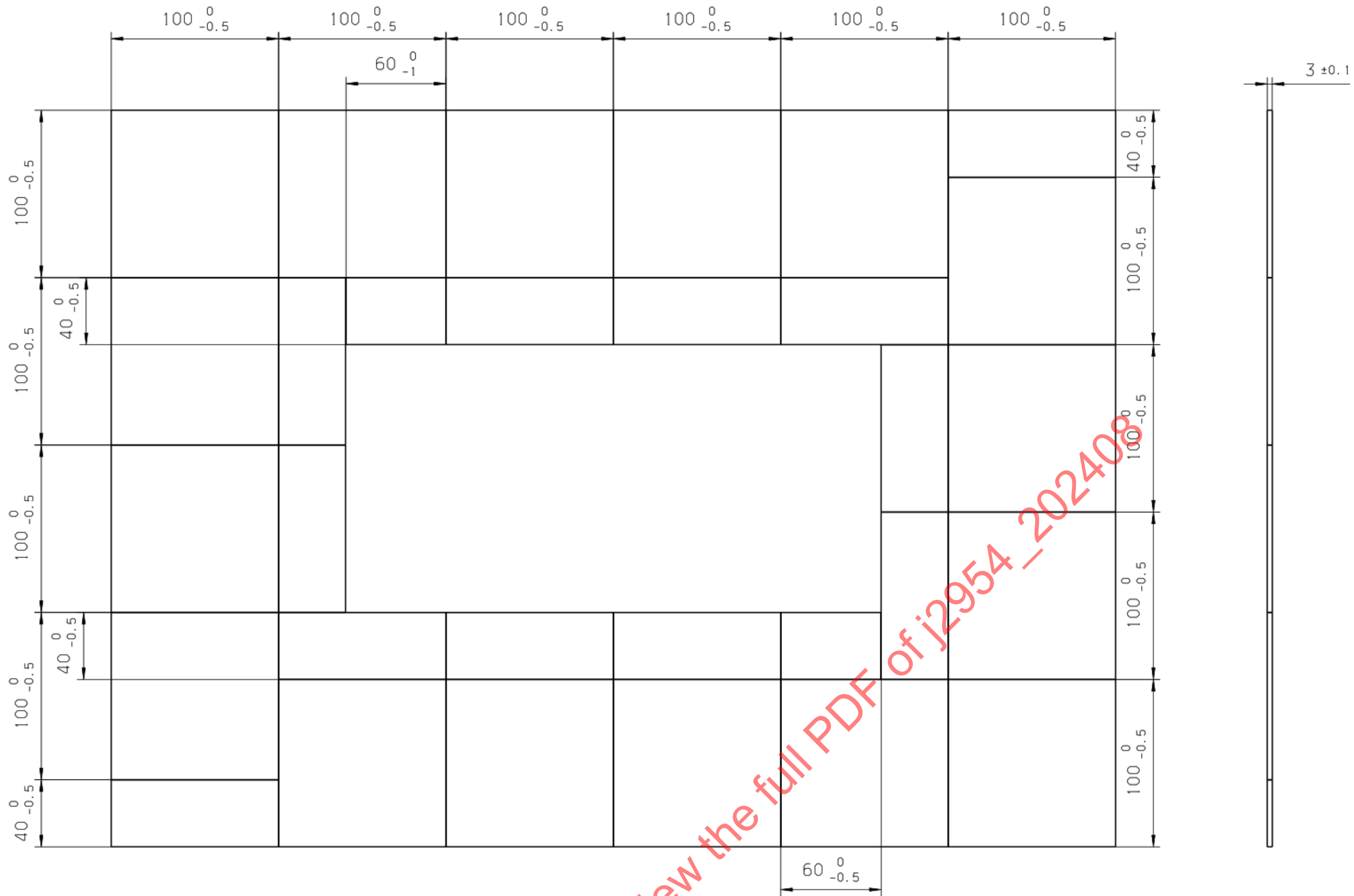


Figure G5 - Detail of the ferrite core construction

G.1.2 Electrical Specification

Figure G6 shows the electrical specification of the GA WPT1.

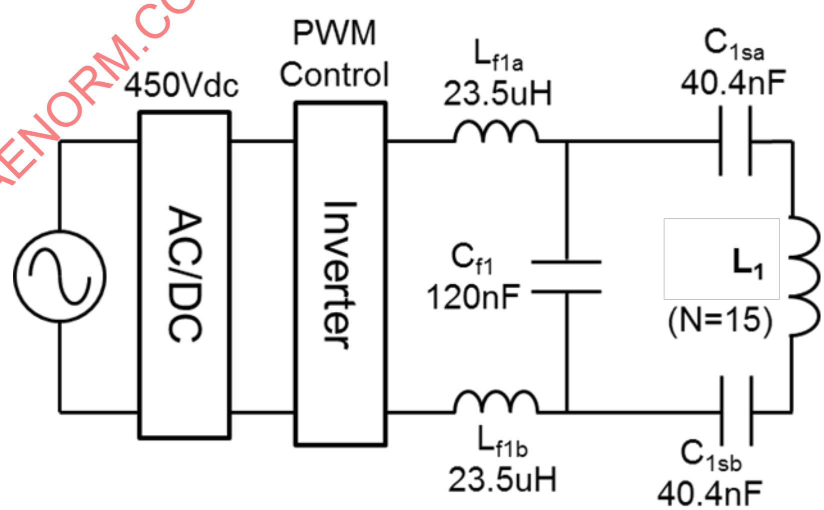


Figure G6 - Electrical specification of the GA WPT1

Table G1 - Maximum values of currents

Maximum PFC Output Current	9 ADC
Maximum GA Inverter Output Current	30 A rms
Maximum GA Coil Current	30 A rms

Minimum and maximum values of L_1 are given in Table G2.

Table G2 - Primary coil inductance L_1 depending on the Z-class

Z-Class	VA	L_1 Min [μH]	L_1 Max [μH]
Z1	Appendix A.1	185	217
Z2	Appendix A.2	212	223
Z3	Appendix A.3	224	227

Minimum and maximum values of k are given in Table G3.

Table G3 - Coupling k between primary and secondary coil depending on the Z-class

Z-Class	VA	k Min	k Max
Z1	Appendix A.1	0.100	0.249
Z2	Appendix A.2	0.085	0.221
Z3	Appendix A.3	0.084	0.243

APPENDIX H - EXAMPLE PRODUCT VA SPECIFICATIONS (INFORMATIVE)

H.1 PRODUCT VA WPT2/Z1

This appendix provides the mechanical and electrical design specifications of a Product VA for power class WPT2 and gap class Z1 (VA WPT2/Z1).

NOTE: The specifications are designed for optimal operation with the example Product GA WPT2 specified in Appendix I, Section I.1.

H.1.1 Mechanical Specification

Figure H1 shows the mechanical dimensions of the Product VA WPT2/Z1. For clarity, the housing is not shown. The VA orientation on the vehicle is indicated by the icon on the left.

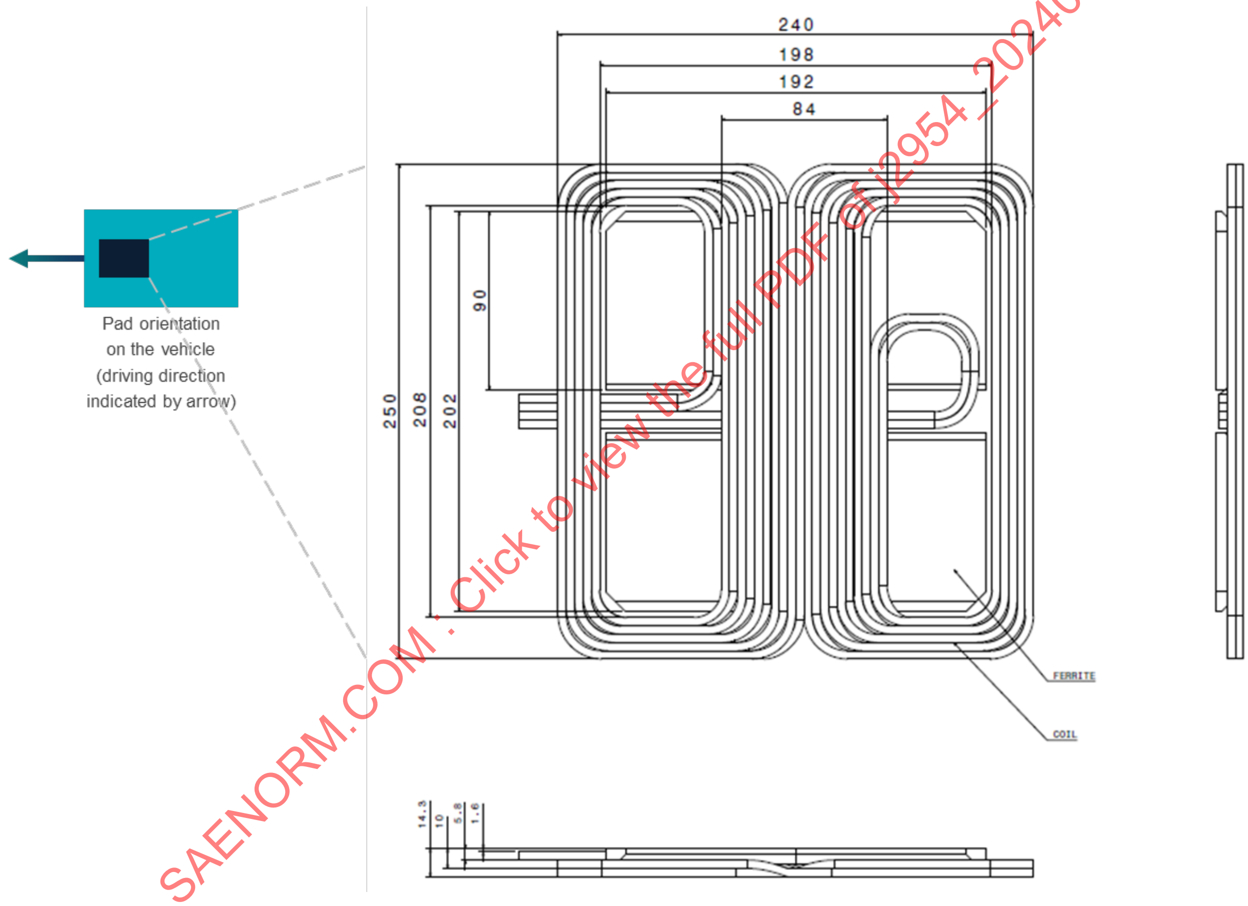


Figure H1 - Mechanical dimensions of the Product VA WPT2/Z1

Figure H2 shows a detailed cross-section view (including housing and an assumed vehicle shield thickness of 2 mm).

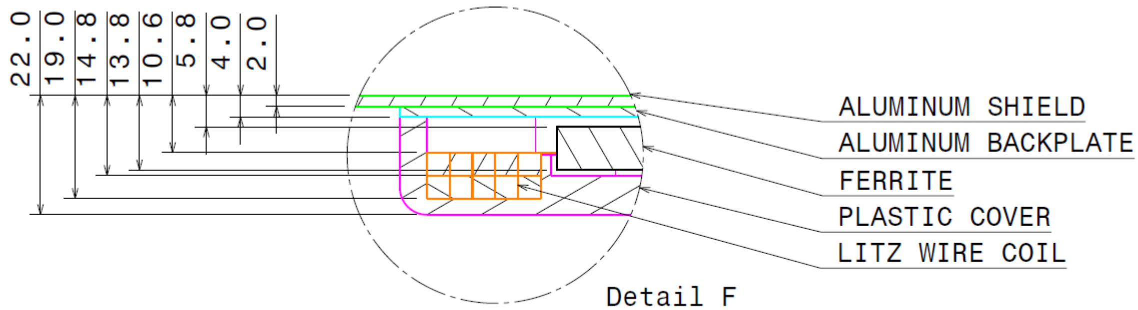


Figure H2 - Detailed cross-section view of the Product VA WPT2/Z1

Table H1 shows the mechanical dimensions of the Product VA WPT2/Z1.

Table H1 - Mechanical dimensions of the Product VA WPT2/Z1

	Coil + Ferrite Only	**Housing (w/o Vehicle Shield)**
L x W x H [mm]	240 x 250 x 13.3	250 x 260 x 20

H.1.2 Electrical Specification

The VA is made using ferrite tiles of N96 or similar. Coupling and inductances listed are achieved when an aluminum shield of 1.1 m x 1.1 m x 0.76 mm to 1-mm thick is used per the drawing.

The system is tuned for a fixed frequency operation at f = 85 kHz. Frequency tuning to compensate, e.g., for height and alignment variation, is not required.

Figure H3 shows the electrical specification of this VA. Typical currents and voltages for the WPT2 power class are indicated in the block diagram.

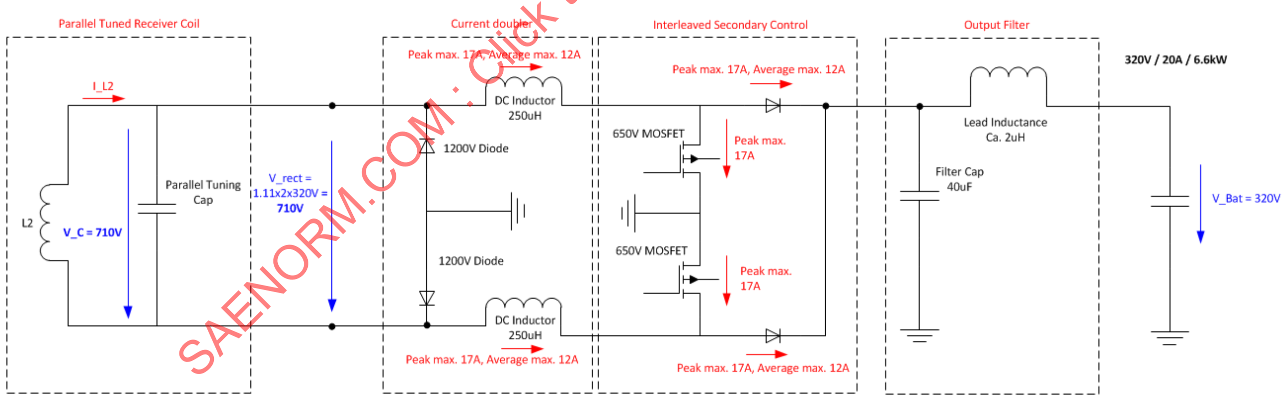


Figure H3 - Electrical specification of the Product VA WPT2/Z1

Values of secondary tuning capacitor C and minimum and maximum values of secondary coil inductance L2 are given in Table H2.

Table H2 - Secondary coil inductance L2 and secondary tuning capacitor C

L_Min [µH]	24.2
L_Max [µH]	26.2
C [nF]	145

H.2 PRODUCT VA WPT2/Z2

This appendix provides the mechanical and electrical design specifications of a Product VA for power class WPT2 and gap class Z2 (VA WPT2/Z2).

NOTE: The specifications are designed for optimal operation with the example Product GA WPT2 specified in Appendix I, Section I.1.

H.2.1 Mechanical Specification

Figure H4 shows the mechanical dimensions of the Product VA WPT2/Z2. For clarity, the housing is not shown. The VA orientation on the vehicle is indicated by the icon on the left.

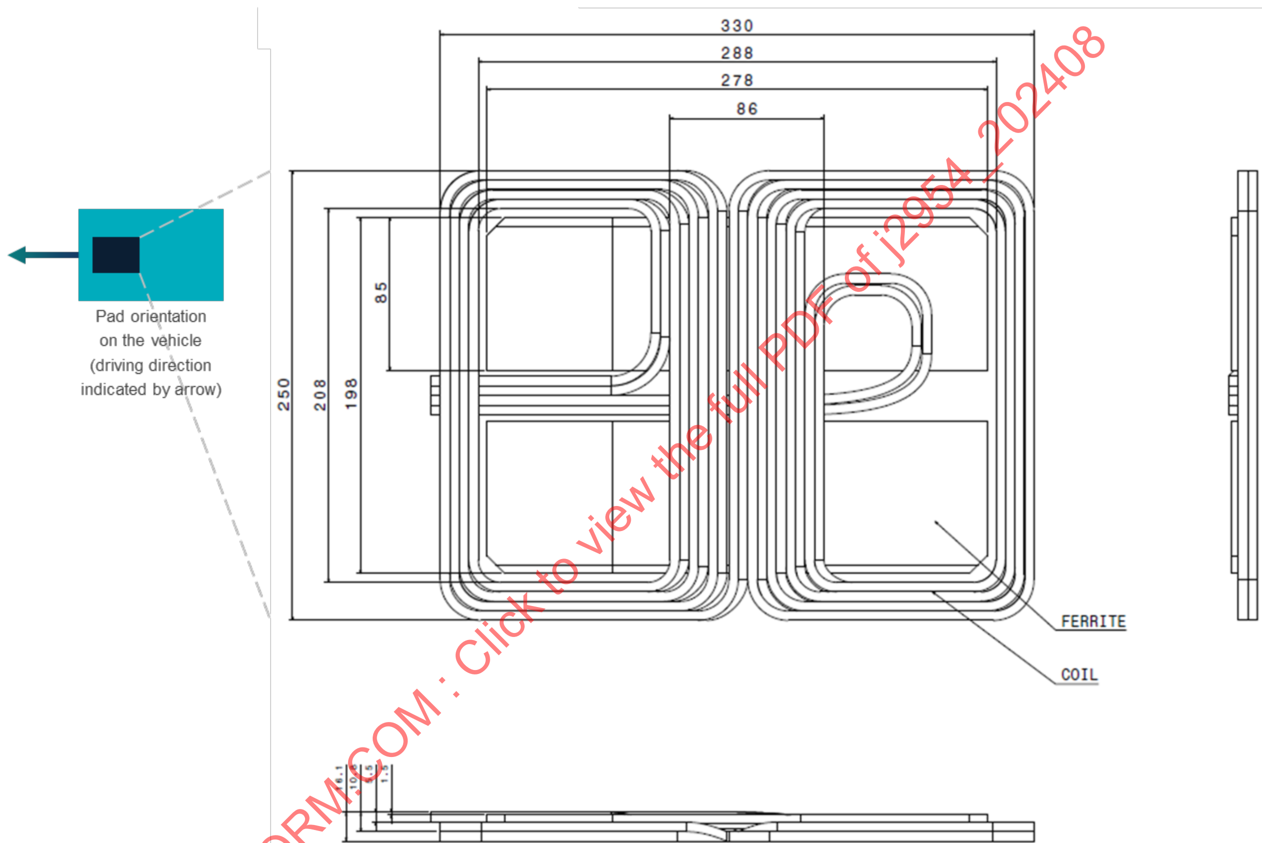


Figure H4 - Mechanical dimensions of the Product VA WPT2/Z2

Figure H5 shows a detailed cross-section view of the Product VA WPT2/Z2 (including housing and an assumed vehicle shield thickness of 2 mm).

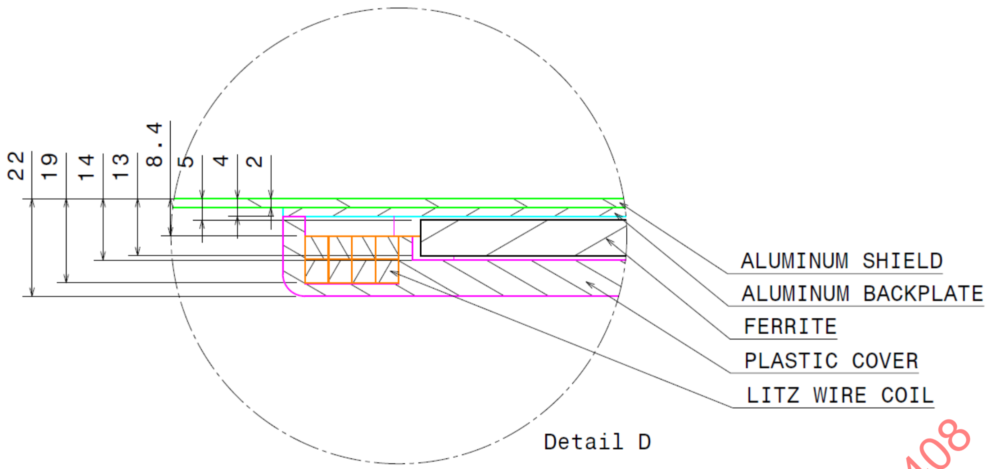


Figure H5 - Detailed cross-section view of the Product VA WPT2/Z2

Table H3 shows the mechanical dimensions of the Product VA WPT2/Z2.

Table H3 - Mechanical dimensions of the Product VA WPT2/Z2

	Coil + Ferrite Only	Housing (w/o Vehicle Shield)
L x W x H [mm]	330 x 250 x 16	340 x 260 x 20

H.2.2 Electrical Specification

The VA is made using ferrite tiles of N96 or similar. Coupling and inductances listed are achieved when an aluminum shield of 1.1 m x 1.1 m x 0.76 mm to 1-mm thick is used per the drawing.

The system is tuned for a fixed frequency operation at f = 85 kHz. Frequency tuning to compensate, e.g., for height and alignment variation, is not required.

Figure H6 shows the electrical specification of the Product VA WPT2/Z2. Typical currents and voltages for the WPT2 power class are indicated in the block diagram.

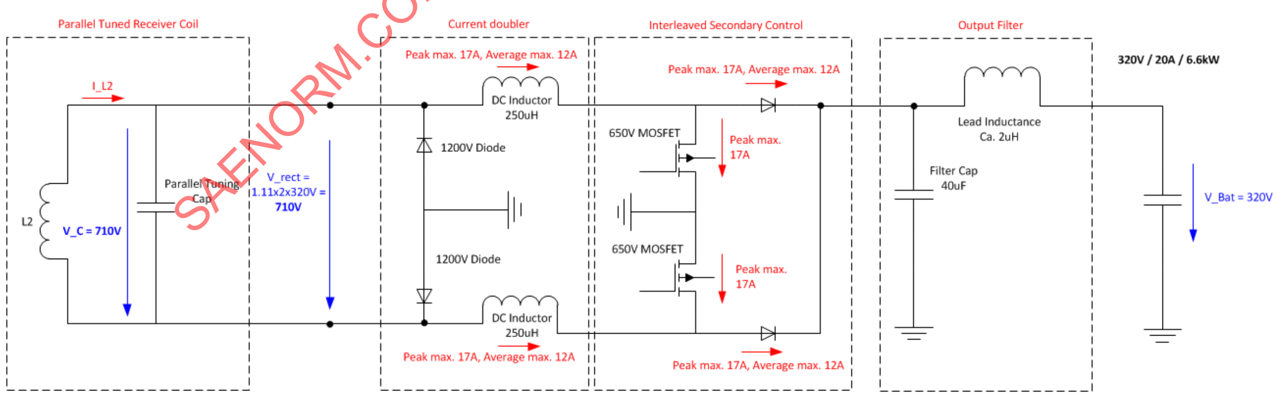


Figure H6 - Electrical specification of the Product VA WPT2/Z2

Values of secondary tuning capacitor C and minimum and maximum values of secondary coil inductance L2 are given in Table H4.

Table H4 - Secondary coil inductance L2 and secondary tuning capacitor C

L_Min [µH]	19.5
L_Max [µH]	20.5
C [nF]	181

H.3 PRODUCT VA WPT2/Z3

This appendix provides the mechanical and electrical design specifications of a Product VA for power class WPT2 and gap class Z3 (VA WPT2/Z3).

NOTE: The specifications are designed for optimal operation with the example Product GA WPT2 specified in Appendix I, Section I.1.

H.3.1 Mechanical Specification

Figure H7 shows the mechanical dimensions of the Product VA WPT2/Z3. For clarity, the housing is not shown. The VA orientation on the vehicle is indicated by the icon on the left.

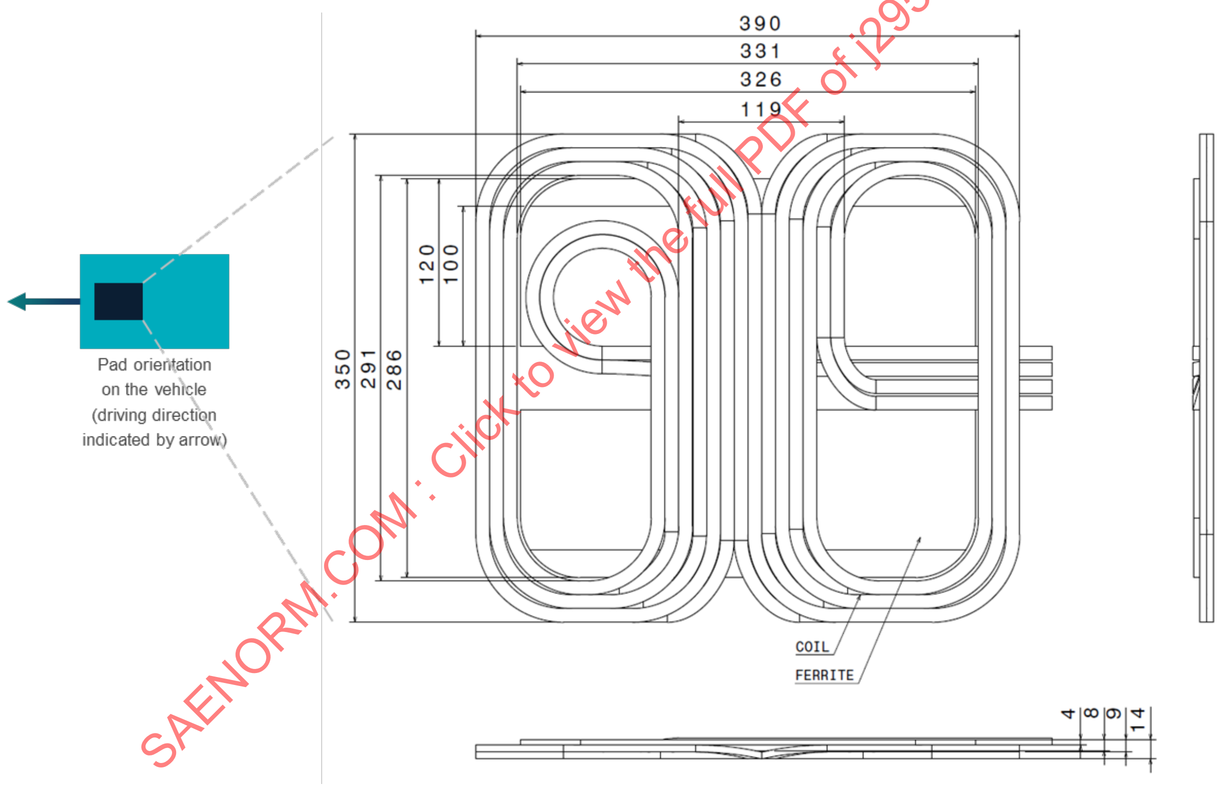


Figure H7 - Mechanical dimensions of the Product VA WPT2/Z3

Figure H8 shows a detailed cross-section view of the Product VA WPT2/Z3 (including housing and an assumed vehicle shield thickness of 2 mm).

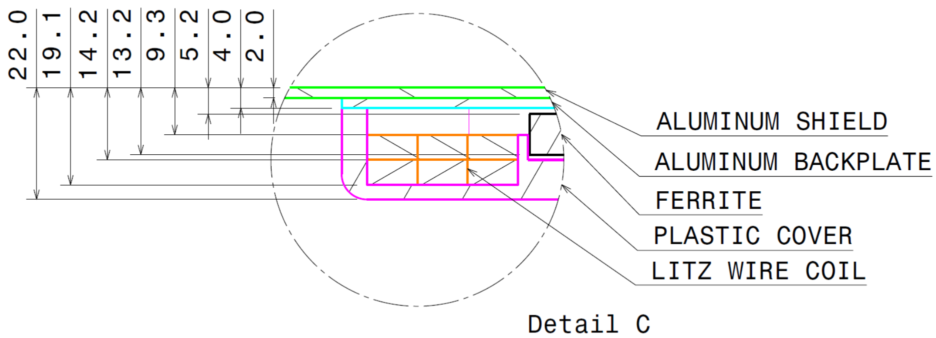


Figure H8 - Detailed cross-section view of the Product VA WPT2/Z3

Table G5 shows the mechanical dimensions of the Product VA WPT2/Z3.

Table H5 - Mechanical dimensions of the Product VA WPT2/Z3

	Coil + Ferrite Only	Housing (w/o Vehicle Shield)
L x W x H [mm]	390 x 350 x 14	400 x 360 x 20

H.3.2 Electrical Specification

The VA is made using ferrite tiles of N96 or similar. Coupling and inductances listed are achieved when an aluminum shield of 1.1 m x 1.1 m x 0.76 mm to 1-mm thick is used per the drawing.

The system is tuned for a fixed frequency operation at f = 85 kHz. Frequency tuning to compensate, e.g., for height and alignment variation, is not required.

Figure H9 shows the electrical specification of the Product VA WPT2/Z3. Typical currents and voltages for the WPT2 power class are indicated in the block diagram.

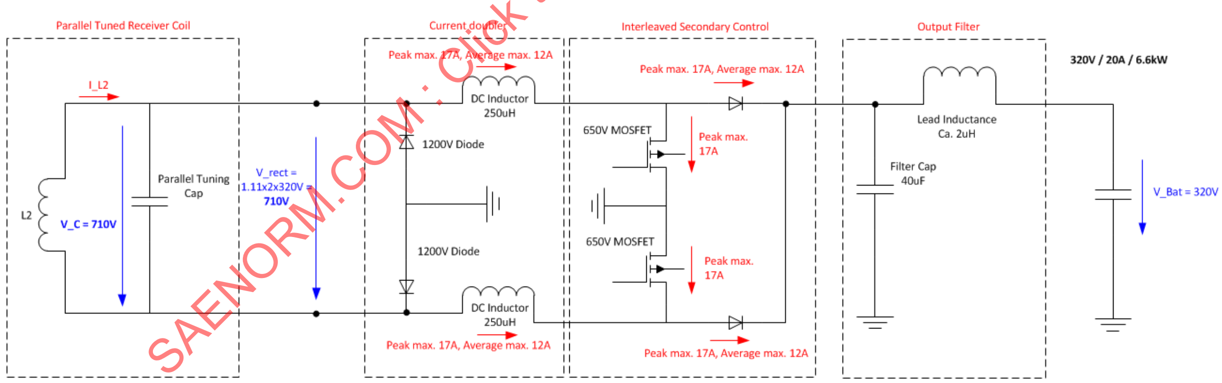


Figure H9 - Electrical specification of the Product VA WPT2/Z3

Values of the secondary tuning capacitor C and minimum and maximum values of secondary coil inductance L2 are given in Table H6.

Table H6 - Secondary coil inductance L2 and secondary tuning capacitor C

L_Min [µH]	13.5
L_Max [µH]	14.2
C [nF]	250

H.4 PRODUCT VA WPT3/Z1

This appendix provides the mechanical and electrical design specifications of a Product VA for power class WPT3 and gap class Z1 (VA WPT3/Z1).

NOTE: The specifications are designed for optimal operation with the example Product GA WPT3 specified in Appendix I, Section I.2.

H.4.1 Mechanical Specification

Figure H10 shows the mechanical dimensions of the ferrite and the coil for the VA WPT3/Z1. For clarity, the housing is not shown. The VA orientation on the vehicle is indicated by the icon on the left.

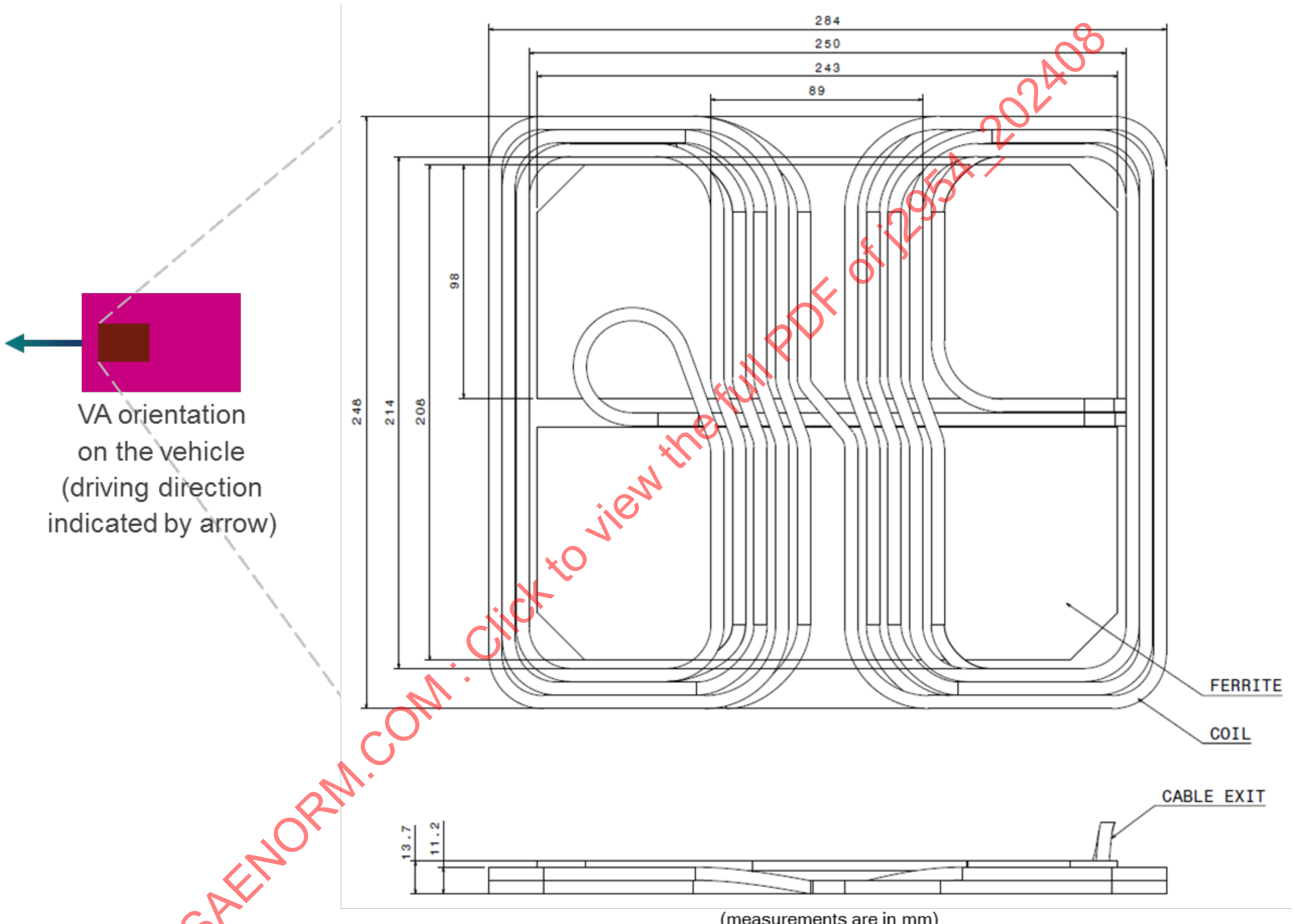


Figure H10 - Mechanical dimensions of the Product VA WPT3/Z1

Figure H11 shows a detailed cross-section view of the Product VA WPT3/Z1 (including housing and an assumed vehicle shield thickness of 2 mm). The Product VA WPT3/Z1 has four turns (bifilar).

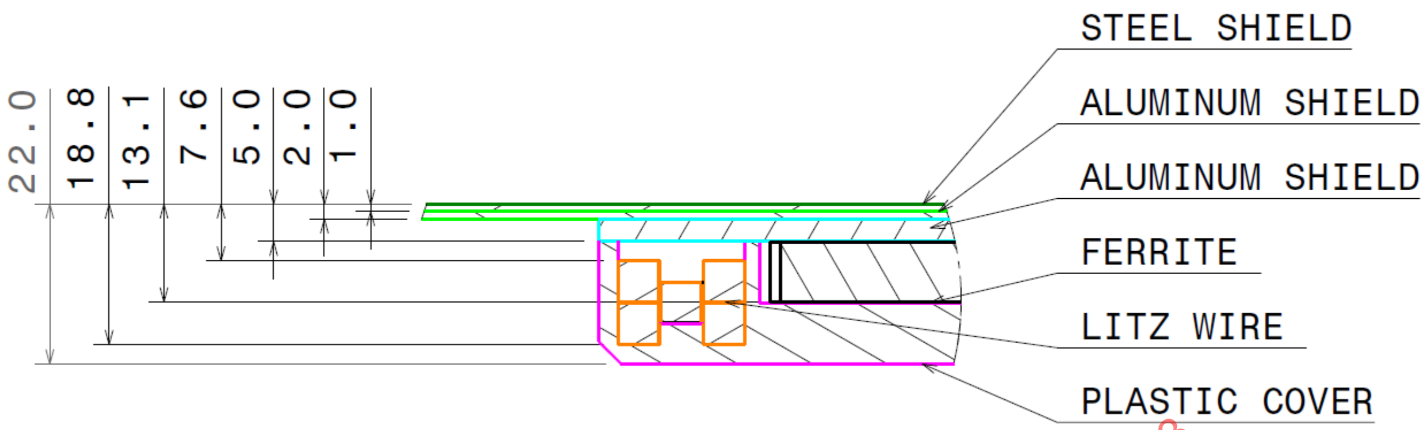


Figure H11 - Detailed cross-section view of the Product VA WPT3/Z1

Table H7 shows the mechanical dimensions of the VA WPT3/Z1.

Table H7 - Mechanical dimensions of the VA WPT3/Z1

	Coil + Ferrite Only	Housing (w/o Vehicle Shield)
L x W x H [mm]	284 x 248 x 13.7	302 x 302 x 20

H.4.2 Electrical Specification

The VA is made using ferrite tiles of N96 or similar. Coupling and inductances listed are achieved when an aluminum shield of 1.1 m x 1.1 m x 0.76 mm to 1-mm thick is used per the drawing.

The system is tuned for a fixed frequency operation at f = 85 kHz. Frequency tuning to compensate, e.g., for height and alignment variation, is not required.

Figure H12 shows the electrical specification of this VA. Typical currents and voltages for the WPT3 power class are indicated in the block diagram.

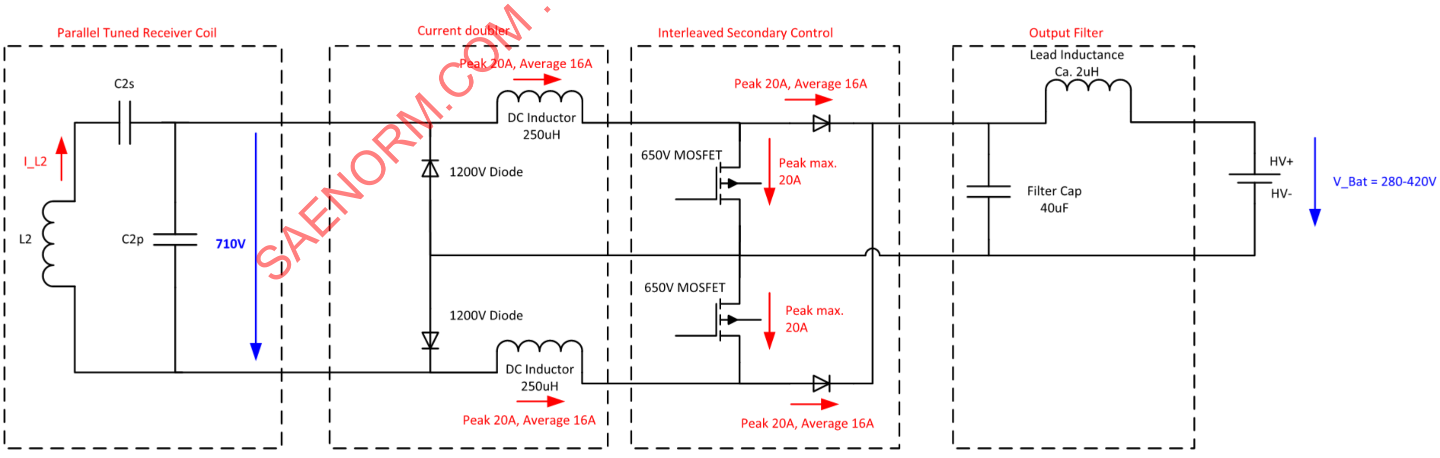


Figure H12 - Electrical specification of the Product VA WPT3/Z1

Values of secondary tuning capacitor C and minimum and maximum values of secondary coil inductance L2 are given in Table H8.

Table H8 - Secondary coil inductance L2 and secondary tuning capacitor C

L_Min [µH]	27.1
L_Max [µH]	29.4
C2s/C2p [nF]	517/169

H.5 PRODUCT VA WPT3/Z2

This appendix provides the mechanical and electrical design specifications of a Product VA for power class WPT3 and gap class Z2 (VA WPT3/Z2).

NOTE: The specifications are designed for optimal operation with the example Product GA WPT3 specified in Appendix I, Section I.2.

H.5.1 Mechanical Specification

Figure H13 shows the mechanical dimensions of the ferrite and the coil for the Product VA WPT3/Z2. For clarity, the housing is not shown. The VA orientation on the vehicle is indicated by the icon on the left.

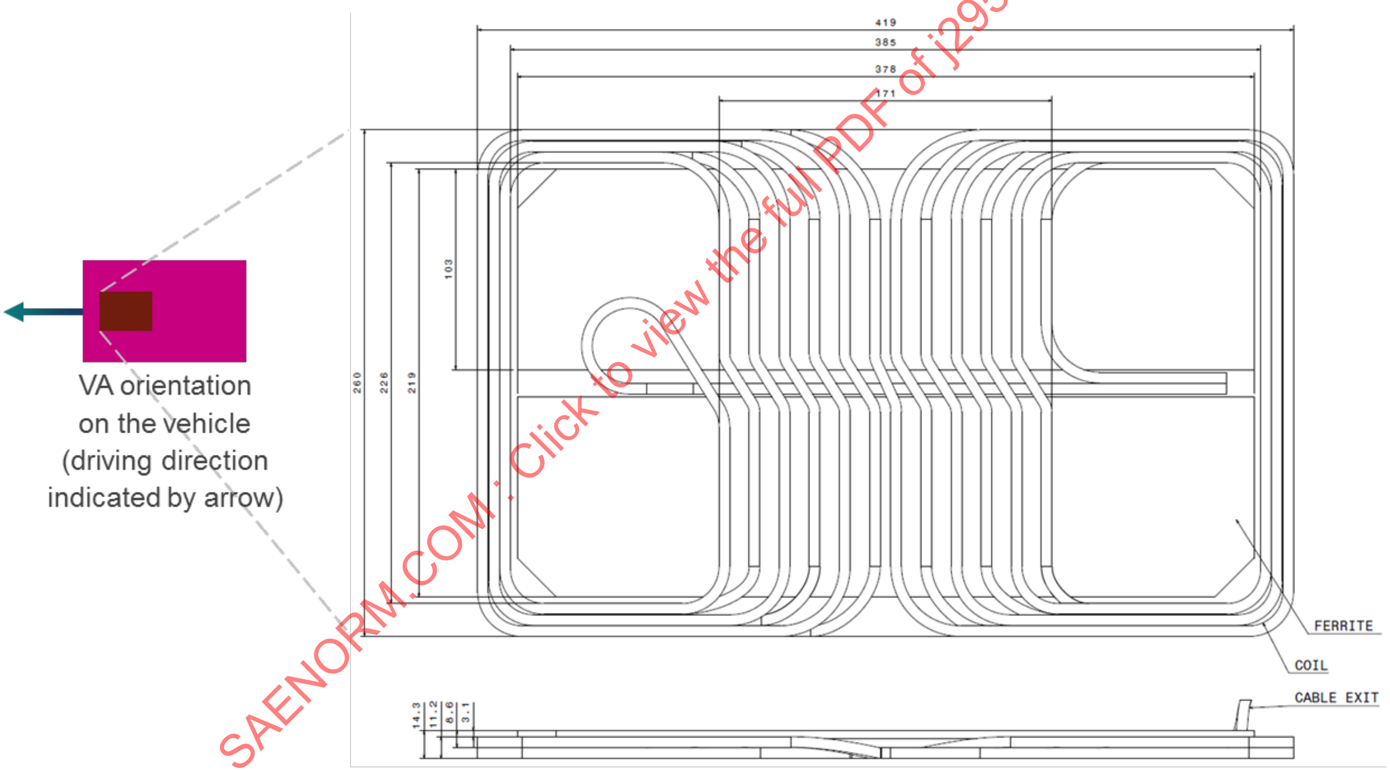


Figure H13 - Mechanical dimensions of the Product VA WPT3/Z2

Figure H14 shows a detailed cross-section view of the Product VA WPT3/Z2 (including housing and an assumed vehicle shield thickness of 2 mm). The Product VA WPT3/Z2 has three turns (bifilar).

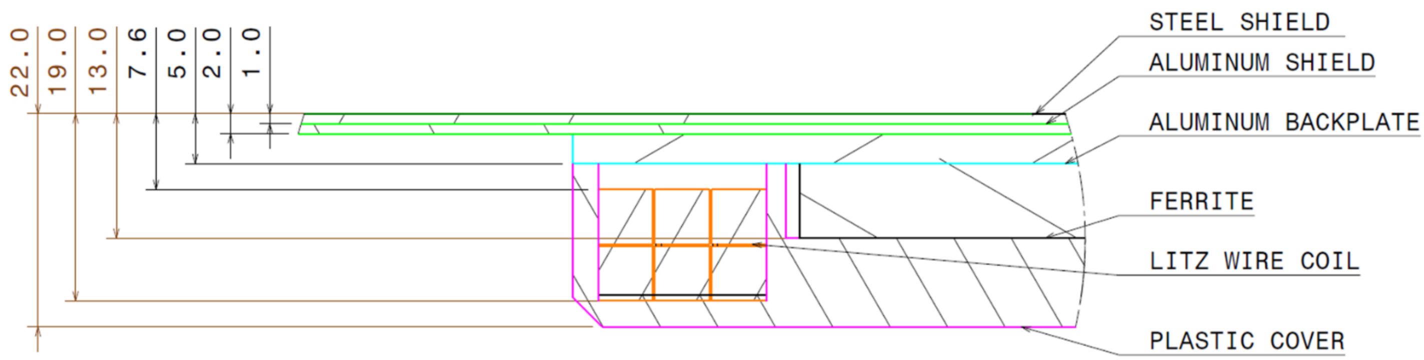


Figure H14 - Detailed cross-section view of the Product VA WPT3/Z2

Table H9 shows the mechanical dimensions of the Product VA WPT3/Z2.

Table H9 - Mechanical dimensions of the Product VA WPT3/Z2

	Coil + Ferrite Only	Housing (w/o Vehicle Shield)
L x W x H [mm]	419 x 260 x 14.3	438 x 302 x 20

H.5.2 Electrical Specification

The VA is made using ferrite tiles of N96 or similar. Coupling and inductances listed are achieved when an aluminum shield of 1.1 m x 1.1 m x 0.76 mm to 1-mm thick is used per the drawing.

The system is tuned for a fixed frequency operation at f = 85 kHz. Frequency tuning to compensate, e.g., for height and alignment variation, is not required.

Figure H15 shows the electrical specification of the Product VA WPT3/Z2. Typical currents and voltages for the WPT3 power class are indicated in the block diagram.

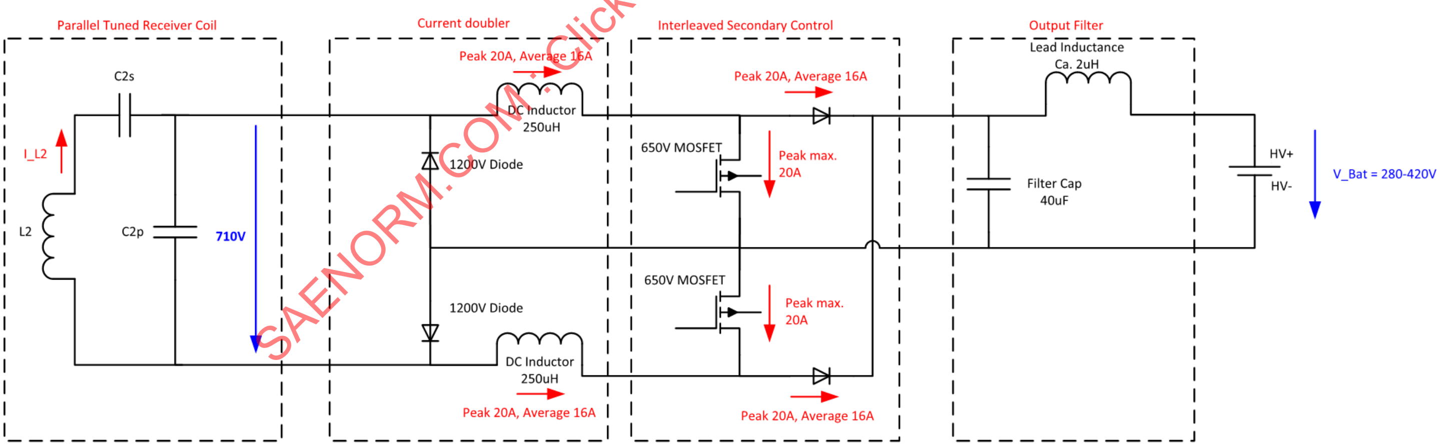


Figure H15 - Electrical specification of the Product VA WPT3/Z2.

Values of secondary tuning capacitor C and minimum and maximum values of secondary coil inductance L2 are given in Table H10.

Table H10 - Secondary coil inductance L2 and secondary tuning capacitor C

L_Min [µH]	44.7
L_Max [µH]	48.2
C2s/C2p [nF]	165/146

H.6 PRODUCT VA WPT3/Z3

This appendix provides the mechanical and electrical design specifications of a Product VA for power class WPT3 and gap class Z3 (VA WPT3/Z3).

NOTE: The specifications are designed for optimal operation with the example Product GA WPT3 specified in Appendix I, Section I.2.

H.6.1 Mechanical Specification

Figure H16 shows the mechanical dimensions of the ferrite and the coil for the Product VA WPT3/Z3. For clarity, the housing is not shown. The VA orientation on the vehicle is indicated by the icon on the left.

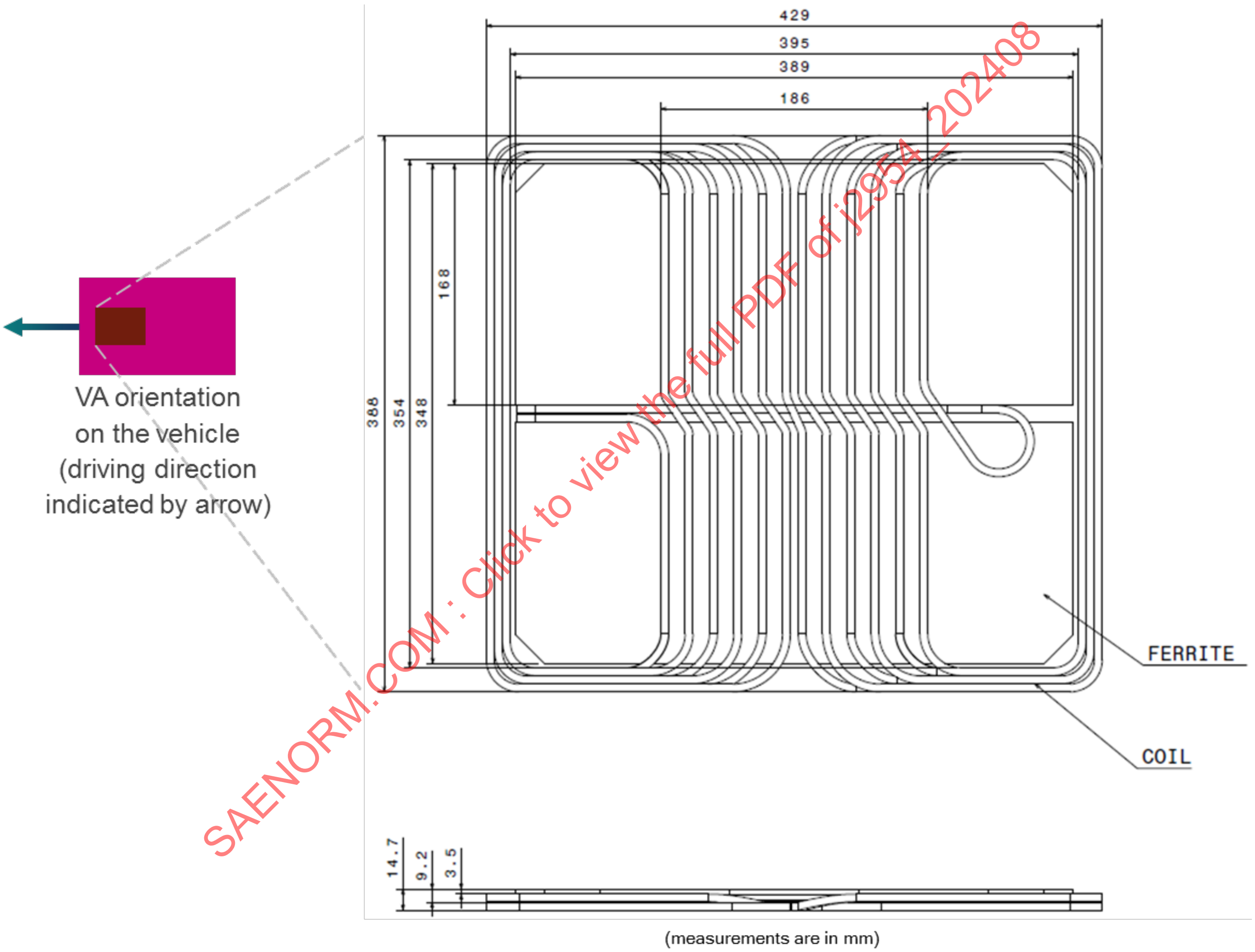


Figure H16 - Mechanical dimensions of the Product VA WPT3/Z3

Figure H17 shows a detailed cross-section view of the Product VA WPT3/Z3 (including housing and an assumed vehicle shield thickness of 2 mm). The Product VA WPT3/Z3 has three turns (bifilar).

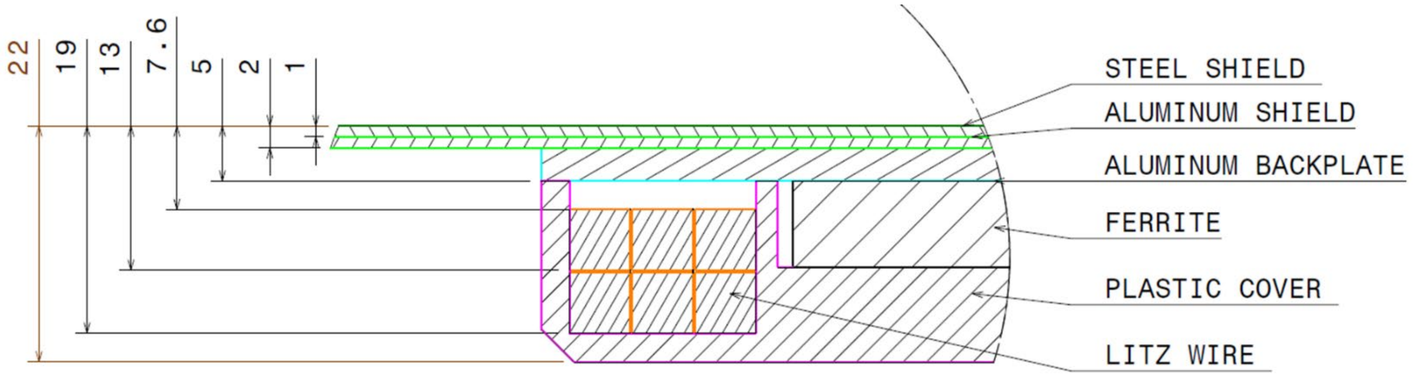


Figure H17 - Detailed cross-section view of the Product VA WPT3/Z3

Table H11 shows the mechanical dimensions of the VA WPT3/Z3.

Table H11 - Mechanical dimensions of the Product VA WPT3/Z3

	Coil + Ferrite Only	Housing (w/o Vehicle Shield)
L x W x H [mm]	429 x 388 x 14.7	449 x 442 x 20

H.6.2 Electrical Specification

The VA is made using ferrite tiles of N96 or similar. Coupling and inductances listed are achieved when an aluminum shield of 1.1 m x 1.1 m x 0.76 mm to 1-mm thick is used per the drawing.

The system is tuned for a fixed frequency operation at f = 85 kHz. Frequency tuning to compensate, e.g., for height and alignment variation, is not required.

Figure H18 shows the electrical specification of the Product VA WPT3/Z3. Typical currents and voltages for the WPT3 power class are indicated in the block diagram.

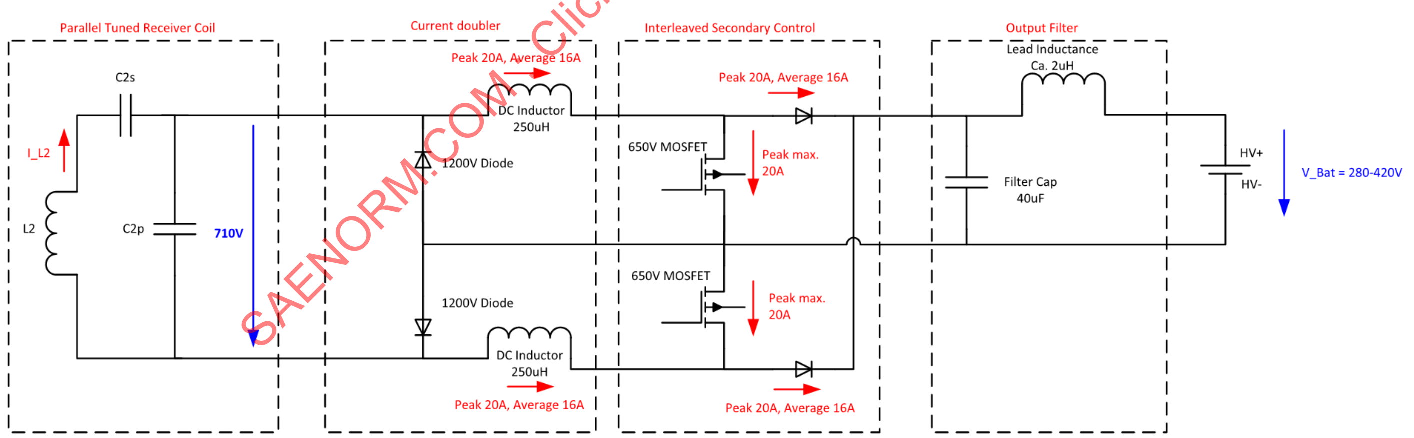


Figure H18 - Electrical specification of the Product VA WPT3/Z3

Values of the secondary tuning capacitor C and minimum and maximum values of secondary coil inductance L2 are given in Table H12.

Table H12 - Secondary coil inductance L2 and secondary tuning capacitor C

L_Min [µH]	61.1
L_Max [µH]	64.7
C2s/C2p [nF]	94/142

APPENDIX I - EXAMPLE OF AN ABOVE-GROUND PRODUCT GA SPECIFICATION (INFORMATIVE)

In the case of the GA of a DD topology, the GA shall define vectors giving the distance and direction from the GA coil center point to the center point of the single D coil that is most forward in the parking space. The GA will have two possible offset vectors, one positive and one negative, and a circular VA will have an offset vector of 0. If the VA is also of DD technology, it will have two offset vectors, one positive and one negative. Since the natural offset is the vector sum of the GA offset vector and the VA offset vector, there could be four results. Only the two with the smallest magnitude natural offset should be considered as possible.

I.1 EXAMPLE PRODUCT GA WPT2

This appendix provides the mechanical and electrical design specifications of an example Product GA for power class WPT2.

NOTE: The specifications are designed for optimal operation with the Product VAs specified in Appendix H, Sections H.1, H.2, and H.3.

I.1.1 Mechanical Specification

Figure I1 shows the mechanical dimensions of the Product GA WPT2. For clarity, the housing is not shown. The GA orientation in the parking space is indicated by the icon on the left.

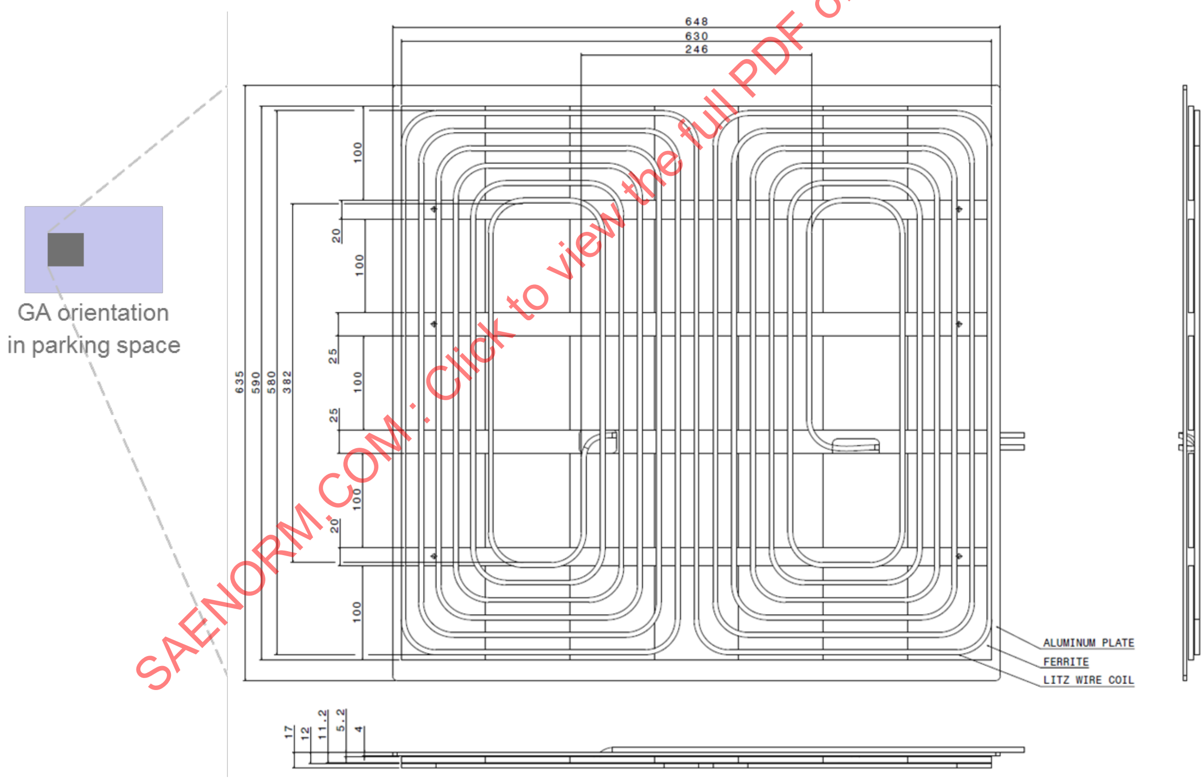


Figure I1 - Mechanical dimensions of the Product GA WPT2

Figure I2 shows a detailed cross-section view of the Product GA WPT2 (including housing).

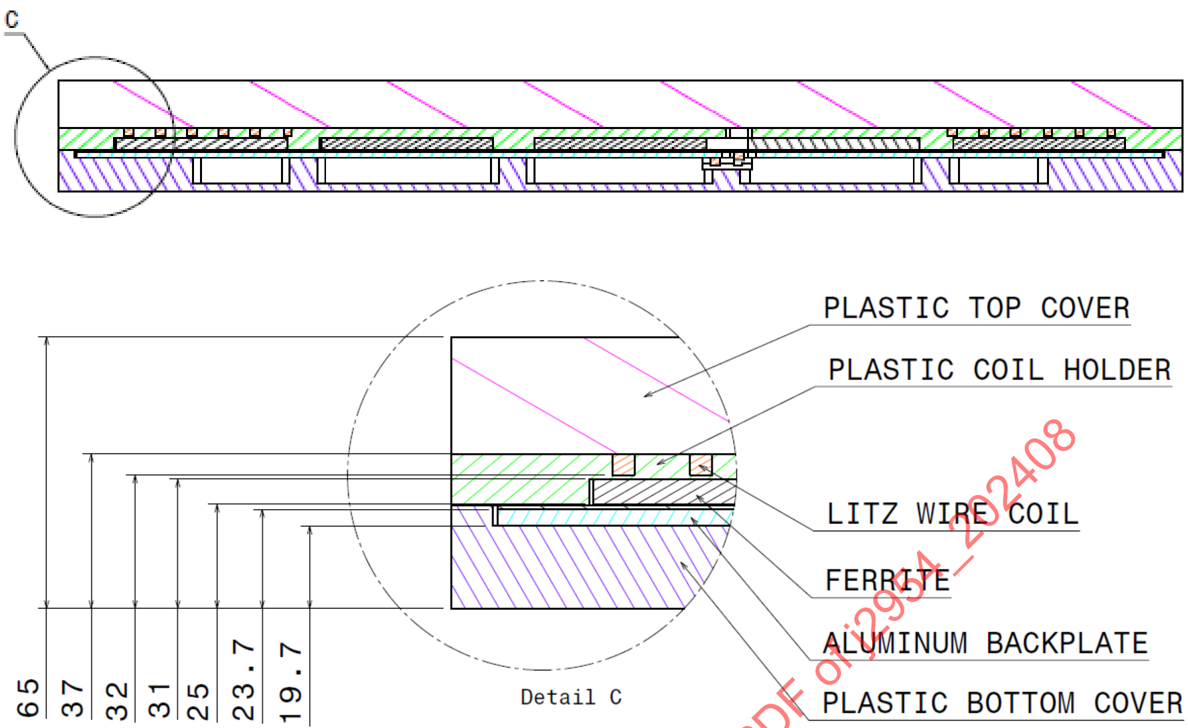


Figure I2 - Detailed cross-section view of the Product GA WPT2

Table I1 shows the mechanical dimensions of the of the Product GA WPT2.

Table I1 - Mechanical dimensions of the Product GA WPT2

	Coil + Ferrite Only	Housing
L x W x H [mm]	630 x 590 x 22	657 x 670 x 65

I.1.2 Electrical Specification

The system is tuned for a fixed frequency operation at f = 85 kHz. Frequency tuning to compensate, e.g., for height and alignment variation, is not required.

Figure I3 shows the electrical specification of the Product GA WPT2. Typical currents and voltages for the WPT2 power class are indicated in the block diagram.

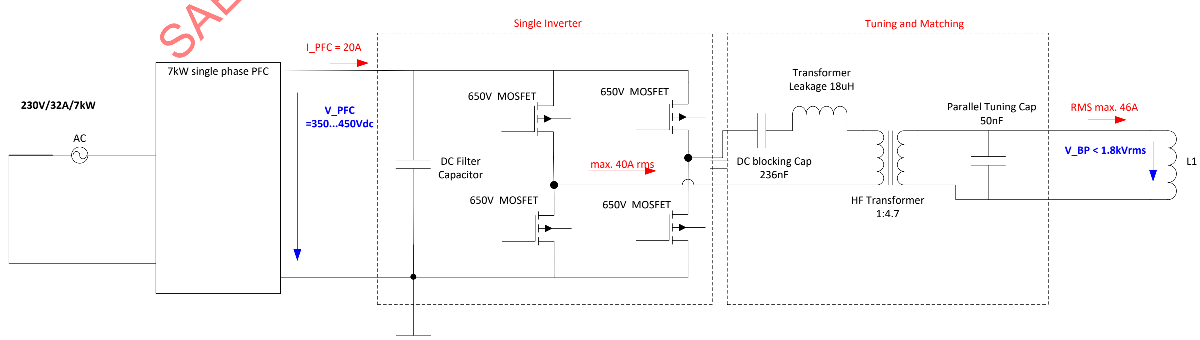


Figure I3 - Electrical specification of the Product GA WPT2

The value of the primary coil inductance L1 varies depending on the air gap class. Minimum and maximum values of L1 are given in Table I2.

Table I2 - Primary coil inductance L1 depending on the Z-class

Z-Class	VA	L_Min [μH]	L_Max [μH]
Z1	Appendix G.1	54.9	62.5
Z2	Appendix G.2	62.5	65.8
Z3	Appendix G.3	65.6	68.5

The coupling k between the primary and the secondary coil also varies depending on the air gap class. Minimum and maximum values of k are given in Table I3.

Table I3 - Coupling k between primary and secondary coil depending on the Z-class

Z-Class	VA	k_Min	k_Max
Z1	Appendix G.1	0.162	0.344
Z2	Appendix G.2	0.134	0.318
Z3	Appendix G.3	0.126	0.314

I.2 EXAMPLE PRODUCT GA WPT3

This appendix provides the mechanical and electrical design specifications of an example Product GA for power class WPT3.

NOTE: The specifications are designed for optimal operation with the Product VAs specified in Appendix H, Sections H.4, H.5, and H.6.

I.2.1 Mechanical Specification

Figure I4 shows the mechanical dimensions of the ferrite and the coil for the Product GA WPT3. For clarity, the housing is not shown. The GA orientation in the parking space is indicated by the icon on the left.

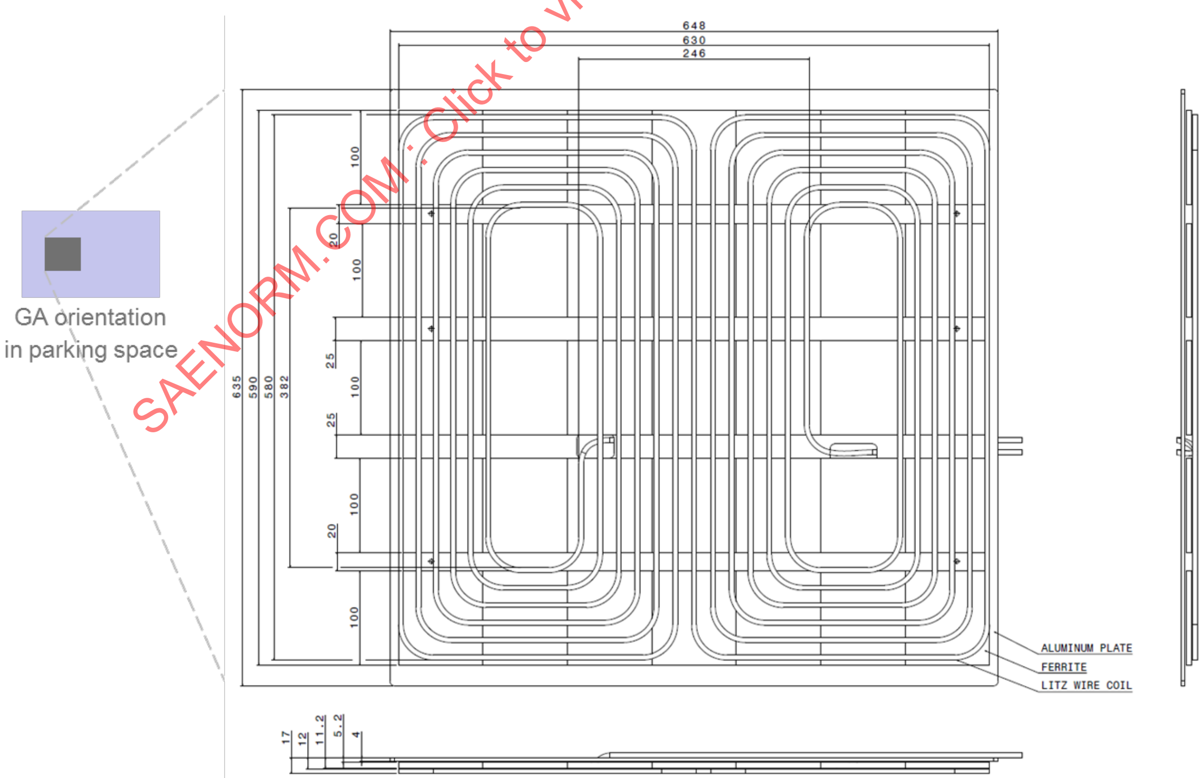


Figure I4 - Mechanical dimensions of the Product GA WPT3

Figure I5 shows a detailed cross-section view of the Product GA WPT3 (including housing).