IEC TS 61980-3

Edition 1.0 2019-06

TECHNICAL SPECIFICATION

colour inside

Electric vehicle wireless power transfer (WPT) systems – Part 3: Specific requirements for the magnetic field wireless power transfer systems

IEC TS 61980-3:2019-06(en)

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Electric vehicle wireless power transfer (WPT) systems –
Part 3: Specific requirements for the magnetic field wireless power transfer systems

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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ELECTRIC VEHICLE WIRELESS POWER TRANSFER (WPT) SYSTEMS –

Part 3: Specific requirements for the magnetic field wireless power transfer systems

FOREWORD

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- the required support cannot be obtained for the publication of an International Standard, despite repeated efforts, or
- the subject is still under technical development or where, for any other reason, there is the future but no immediate possibility of an agreement on an International Standard.

Technical specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC TS 61980-3, which is a Technical Specification, has been prepared by IEC technical committee 69: Electric road vehicles and electric industrial trucks.

The text of this Technical Specification is based on the following documents:

Draft TS	Report on voting
69/554A/DTS	69/616B/RVDTS

Full information on the voting for the approval of this Technical Specification can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts of the IEC 61980 series, published under the general title *Electric vehicle wireless power transfer (WPT) systems*, can be found on the IEC website.

This part is to be used in conjunction with IEC 61980-1:2015.

The clauses of the particular requirements in this document supplement or modify the corresponding clauses in IEC 61980-1:2015. Where the text indicates an "addition" to or a "replacement" of the relevant requirement, test specification or explanation of IEC 61980-1:2015, these changes are made to the relevant text of IEC 61980-1:2015, which then becomes part of the standard. Where no change is necessary, the words "Clause xx of IEC 61980-1:2015 is applicable" are used. Additional items to those of IEC 61980-1:2015 are numbered starting 101. Additional annexes are lettered from AA onwards.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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INTRODUCTION

The IEC 61980 series is published in separate parts according to the following structure:

– IEC 61980-1 covers general requirements for electric road vehicle (EV) wireless power transfer (WPT) systems including general background and definitions. (e.g. efficiency, electrical safety, EMC);
– IEC TS 61980-2 covers specific requirements for communication between electric road vehicle (EV) and wireless power transfer (WPT) systems including general background and definitions.
– IEC TS 61980-3 covers specific requirements for electric road vehicle (EV) magnetic field wireless power transfer (MF-WPT) systems including general background and definitions (e.g. efficiency, electrical safety, EMC).

The requirements described in IEC 61980-1 are general. The technical requirements for the various wireless power transfer (WPT) technologies are very different; they are specified in the technology specific parts of the IEC 61980 series. A list of possible WPT technologies is listed in IEC 61980-1. The requirements for magnetic field wireless power transfer systems (MF-WPT) are described in this document. Further parts of the IEC 61980 series will describe other technologies such as power transfer via electric field (EF-WPT) or via electromagnetic field wireless power transfer systems (EF-WPT) or electromagnetic field-WPT systems, also named microwave-WPT systems (MW-WPT).

Reference to "technology specific parts" always refers to each parts of the IEC 61980 series. The structure of the "technology specific parts" follows the structure of IEC 61980-1.

WPT systems are still under development. For this reason, there is the future but not immediate possibility of an agreement to publish an International Standard. The committee has decided, by following the procedure set out in ISO/IEC Directives part 1:2018, 2.3, that the publication of a Technical Specification is appropriate. The reason for publishing the Technical Specification is a high market need for a first basic technical description.

IEC TS 61980-2, also published as a Technical Specification for the same reason as IEC TS 61980-3, deals with communication and for this reason has an independent structure. The numbering of the clauses does not follow the numbering of the other parts of the IEC 61980 series.

The electric road vehicles (EV) requirements of the MF-WPT system are covered by ISO PAS 19363.

ELECTRIC VEHICLE WIRELESS POWER TRANSFER (WPT) SYSTEMS –

Part 3: Specific requirements for the magnetic field wireless power transfer systems

1 Scope

This part of IEC 61980, which is a Technical Specification, applies to the equipment for the magnetic field wireless power transfer (MF-WPT) of electric power from the supply network to electric road vehicles for purposes of supplying electric energy to the RESS (rechargeable energy storage system) and/or other on-board electrical systems. The MF-WPT system operates at standard supply voltages ratings per IEC 60038 up to 1 000 V AC and up to 1 500 V DC The power transfer takes place while the electric vehicle (EV) is stationary.

This document also applies to MF-WPT equipment supplied from on-site storage systems (e.g. buffer batteries) at standard supply voltages ratings per IEC 60038 up to 1 000 V AC and up to 1 500 V DC.

The aspects covered in this document include

– the characteristics and operating conditions,
– the required level of electrical safety,
– requirements for basic communication for safety and process matters if required by a MF-WPT system,
– requirements for positioning to assure efficient and safe MF-WPT power transfer, and
– specific EMC requirements for MF-WPT systems.

The following aspects are under consideration for future documents:

– requirements for two- and three-wheel vehicles,
– requirements for MF-WPT systems supplying power to EVs in motion, and
– requirements for bidirectional power transfer.

This standard does not apply to

– safety aspects related to maintenance, and
– trolley buses, rail vehicles and vehicles designed primarily for use off-road.

NOTE The teRMS used in this document are specifically for MF-WPT.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60529, *Degrees of protection provided by enclosures (IP Code)*

IEC 60947-2, *Low-voltage switchgear and controlgear – Part 2: Circuit-breakers*

IEC 61008-1, *Residual current operated circuit-breakers without integral overcurrent protection for household and similar uses (RCCBs) – Part 1: General rules*

IEC 61009-1, *Residual current operated circuit-breakers with integral overcurrent protection for household and similar uses (RCBOs) – Part 1: General rules*

IEC TS 61980-2:2019, *Electric vehicle wireless power transfer (WPT) systems – Part 2: Specific requirements for communication between electric road vehicle (EV) and infrastructure with respect to wireless power transfer (WPT) systems*

IEC 62423, *Type F and type B residual current operated circuit-breakers with and without integral overcurrent protection for household and similar uses*

DIN 7405:1963, *Wire staple 24/6 for office-staplers*

EN 10130, *Cold rolled low carbon steel flat products for cold forming – Technical delivery conditions*

ICNIRP Guidelines 1998, *ICNIRP guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic fields (up to 300 GHz)*, International commission on non-ionizing radiation protection, published in: Health Physics 74(4):494-522; 1998

ICNIRP Guidelines 2010, *ICNIRP guidelines for limiting exposure to time-varying electric and magnetic fields (1 Hz – 100 kHz)*, International commission on non-ionizing radiation protection, published in: Health Physics 99(6):818-836; 2010

UL 2251, Standard for plugs, receptacles, and couplers for electric vehicles

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 61980-1 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

Additional terms and definitions:

3.101
primary coil
component of the primary device according IEC 61980-1 comprising one or more electrical windings generating a magnetic field for wireless power transfer (MF-WPT)

3.102
secondary coil
component of the secondary device according IEC 61980-1 comprising one or more electrical windings generating a magnetic field for wireless power transfer (MF-WPT)

3.103
system frequency
frequency range over which the system is designed to transfer power

Note 1 to entry: The bandwidth is a frequency range above and below the nominal frequency, and need not be centred at the nominal frequency. Spurious harmonics are not included in the bandwidth.

3.104
EV device
on-board component assembly, comprising the secondary device, the EV power electronics and the on-board communication controller, as well as the mechanical connections between the assemblies

3.105
complete power
power level which is the lower of the declared primary device input power according to the specifications listed in 6.3, or of the output power limit specified by the manufacturer for the EV device

3.106
primary device
off-board component that generates and shapes the magnetic field for power transfer

3.107
secondary device
on-board component that captures the magnetic field

3.108
secondary device ground clearance
vertical distance between the ground surface and the lowest point of the secondary device

Note 1 to entry: The lower surface may not be planar and may not be parallel to the ground surface..

3.109
plug and cable connected supply device
supply device that can be connected to, or disconnected from, the socket-outlet of AC or DC supply network by the use of a plug

3.110
MF-WPT input power class
power class of a supply device of MF-WPT systems defined from the perspective of the maximum power drawn from the supply network in order to drive the supply device

3.111
reference supply power circuit
supply power circuit that serves for conformance testing purposes

3.112
reference EVPC
on-board component which implements the communication with the SECC

3.113
EV communication controller
electrical vehicle communication controller
on-board component which implements the communication with the SECC

3.114
EV power circuit
EVPC
on-board component assembly that includes the secondary device and EV power electronics, as well as the mechanical connections between the components

3.115
EV power electronics
on-board component, that converts the power and frequency needed for the output from the EVPC

EXAMPLE Impedance matching network (IMN), filter, rectifier, impedance converter..

3.116
supply device
off-board component assembly comprising the primary device, the supply power electronics and the supply device communication controller, as well as the mechanical connections between the components necessary for wireless power transfer

3.117
supply power circuit
off-board component assembly comprising the supply power electronics and primary device, as well as the mechanical connections between the components

3.118
supply equipment communication controller
SECC
off-board component that implements the communication with the EVCC(s)

3.119
supply power electronics
off-board electronics, including all housings and covers, that supply the electric power to the primary device

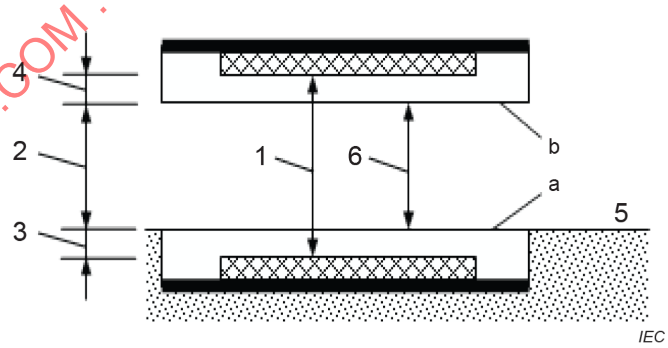
EXAMPLE PFC converter, DC-AC inverter, filter, impedance matching network..

3.120
MF-WPT system
system comprising the supply device and the EV device to perform MF-WPT

Note 1 to entry: See also Figure 303.

3.121
flush mounted
mounting of a primary device in such a manner that the top of the covering primary device is flush with the road surface

SEE Figure 101.



Key

a primary device

b secondary device

1 operational air gap

2 mechanical air gap

3 covering primary device

4 covering secondary device

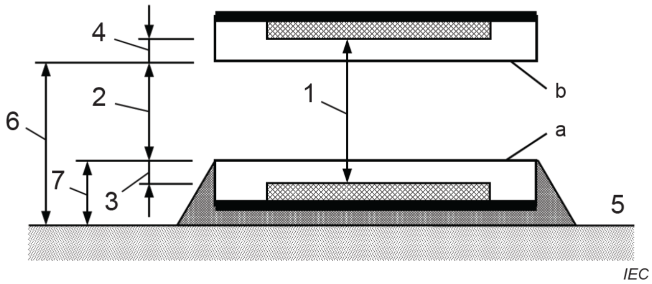
5 top of road surface

6 secondary device ground clearance

Figure 101 – Flush mounted

3.122
surface mounted
mounting of a primary device in such a manner it protrudes above ground up to certain mounting height

SEE Figure 102.



Key

a primary device
b secondary device
1 operational air gap
2 mechanical air gap
3 covering primary device
4 covering secondary device
5 top of road surface
6 secondary device ground clearance
7 mounting height

Figure 102 – Surface mounted

3.123
fundamental mutual inductance
M_0
mutual inductance M divided by the primary number of coil turns and divided by the secondary number of coil turns

Note 1 to entry: The mutual inductance M describes the magnetic interaction and characteristic between the primary and the secondary coil system.

Note 2 to entry: The value for the fundamental mutual inductance is defined by the geometric coil and ferrite design and the positioning parameters x, y, z describing the position from the secondary coil system against the primary coil system. A specific value of the fundamental mutual inductance is valid for a specific position x, y, z.

3.124
gauge device
test device which is intended to verify that a reference primary coils is functioning as designed, but may be used for testing and development of product devices

3.125
product primary device
primary device intending to prove standard conformance

Note 1 to entry: In symbols, the product primary device is identified by the subscript "P", whereas the reference primary device is identified by the subscript "R".

3.126
product secondary device
secondary device intending to prove standard conformance

4 Abbreviations

Clause 4 of IEC 61980-1:2015 is applicable except as follows.

Replacement of the title of Clause 4 of IEC 61980-1:2015:

4 Symbols and abbreviated terms

Addition:

Re	real of the reflected impedance
Im	real and imaginary part of the reflected impedance
C_{TD}	calibration factor of the gauge device as provided by the gauge device manufacturer
U_{i2}	induced voltage in gauge device, generated by the primary excitation $I_1 \times w_1$
ω	$2\pi f$; f = 85 kHz (nominal frequency)
w_2	number of turns of the gauge device
$\Phi_{1\rightarrow 2}$	magnetic flux the gauge device is exposed to, excited primary coil
M_0	fundamental mutual inductance with w_1 = 1, w_2 = 1
I_1	primary coil current
$I_1 \times w_1$	primary coil specific ampere turns
Z_2	impedance presented to the secondary device coil by the secondary device electronics and load
$P_{\mathrm{b,out}}$	output power of secondary device measured at the RESS (traction battery or adjustable load)
$U_{\mathrm{b,out}}$	output voltage of secondary device measured at the RESS (traction battery or adjustable load)

5 General

Clause 5 of IEC 61980-1:2015 is applicable except as follows.

Addition:

Unless otherwise specified, all tests shall be carried out in a draft-free location and at an ambient temperature of 20 °C ± 5 °C.

IEC TS 61980-3 applies to equipment that is designed to be used at an altitude up to 2 000 m.

For equipment designed to be used at altitudes above 2 000 m, it is necessary to take into account the reduction of the dielectric strength and the cooling effect of the air. Electrical equipment intended to operate under these conditions is not covered by IEC TS 61980-3 and should be designed or used in accordance with an agreement between manufacturer and user.

6 Classification

Clause 6 of IEC 61980-1:2015 is applicable except as follows;

6.2 Transfer technologies

Addition:

Wireless power transfer between a supply network (mains) and an EV as described in IEC TS 61980-3 is based on the principle of power transfer via magnetic field between a primary device and a secondary device and is further referred to as magnetic field wireless power transfer (MF-WPT).

6.3 Transfer power classes

Replacement:

The manufacturer shall specify the rated input power of the supply device.

A supply device shall be classified according to MF-WPT classes in Table 101.

Table 101 – WPT classes

MF-WPT class	MF-WPT rated input power kW
MF-WPT1	≤ 3,7
MF-WPT2	> 3,7 and ≤ 7,7
MF-WPT3	> 7,7 and ≤ 11,1
MF-WPT4	> 11,1 and ≤ 22
MF-WPT5	> 22

NOTE 1 Supply device with MF-WPT input power higher than 11,1 kW are under consideration for further editions of this document.

NOTE 2 Rated input power can be chosen at any value in the range, for example below 3,7 kW for MF-WPT1, or in between 3,7 and 7,7 kW for MF-WPT2.

6.5 Installation

Replacement:

The supply device shall be classified according to the type of mounting of the primary device.

– Stationary equipment:
  - surface mounting: the primary device is mounted on top of a ground surface;
  - flush mounting: the outer casing of the primary device is flush mounted with the ground surface.
– Non-stationary equipment.

For stationary equipment, see Annex DD for position within the parking spot.

Additional subclauses:

6.101 Z-gap classes

The supply device shall be classified according to their supported secondary device ground clearances as specified in Table 102.

Table 102 – Supply device Z classes

Supply device Z-class	Secondary device ground clearance range mm
Z1	100 to 150
Z2	100 to 210
Z3	100 to 250

The secondary device ground clearance is shown as item 6 in Figure 101 and Figure 102, which is identical to the "mechanical air gap" specified in IEC 61980-1:2015, Figure 6, for flush mounted systems and as the sum of the "mechanical air gap" and "mounting height" in IEC 61980-1:2015, Figure 7, for surface mounted systems.

7 Interoperability

Clause 7 of IEC 61980-1:2015 is applicable, except as follows.

Replacement of the title of Clause 7 of IEC 61980-1:2015:

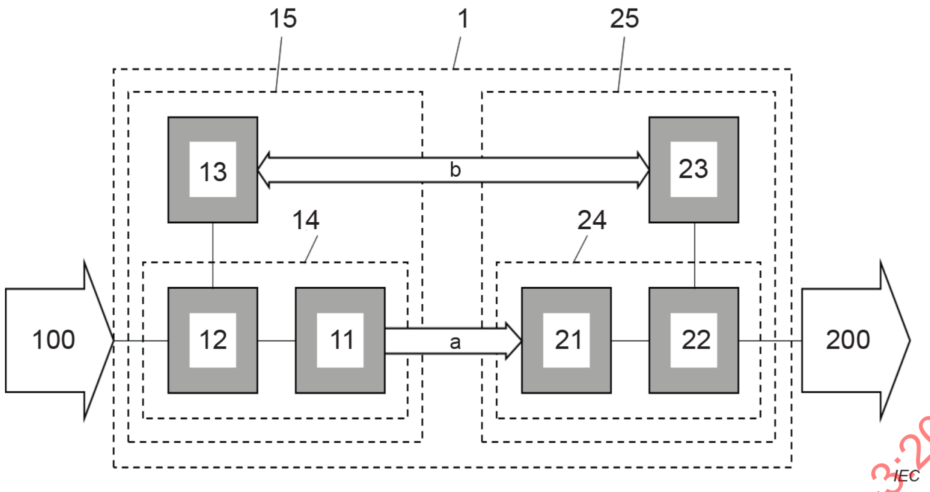
7 System infrastructure requirements

Additional subclauses:

7.101 General

MF-WPT is the transfer of electrical energy from a power source to an electrical load via magnetic field between a primary and a secondary device without current flow over a galvanic connection. Figure 103 shows the structure of the functional elements as applied throughout this document.

NOTE 1 The functional elements may be integrated into one enclosure or split up into several enclosures.



Key

1 MF-WPT system

11 primary device

12 supply power electronics

13 supply equipment communication controller (SECC)

14 supply power circuit

15 supply device

100 supply network

21 secondary device

22 EV power electronics

23 EV communication controller (EVCC)

24 EV power circuit (EVPC)

25 EV device

200 RESS

a wireless power flow

b communication

NOTE The numbering convention adopted is based on system blocks being assigned a number with the supply device blocks having numbers of the form "1X" and the EV device blocks of the form "2X". The second digit identifies equivalent functionality in the supply and EV sub-systems.

Figure 103 – Components of an MF-WPT system

Interoperability of both sides of the MF-WPT system is achieved when the power transfer mechanism (i.e. magnetic coupling), related functions and the communications can interoperate efficiently and safely. Therefore, 7.102 to 7.109 specify the requirements for the interoperability of the power transfer mechanism and related activities.

The requirements for interoperability of the communications are given in IEC 61980-2.

In order to determine power transfer interoperability, this document specifies reference EVPCs (R-EVPCs) for each power class and Z class in Annexes AA to BB.

A supply power circuit shall be tested according to Clause 101 with the R-EVPCs of the power and Z classes with which it is designed to operate. One R-EVPC is specified for each power class and Z class.

NOTE 2 An approach based on testing with gauges is currently being studied and can be found in Informative Annex EE.

7.102 Interoperability of power classes

For all MF-WPT classes, the supply power circuits shall be able to deliver complete power to EVPCs of MF-WPT1, MF-WPT2 and MF-WPT3.

NOTE 1 Complete power is defined as the power level which is the lower of the declared primary device input power according to the specifications listed in 6.3, or of the output power limit specified by the manufacturer for the EV device.

NOTE 2 Power transfer and efficiency requirements in case of unmatched power class configurations between EV device and supply devices are under investigation.

7.103 Z-gap classes

To assure interoperability with product secondary devices, the primary device shall operate across the whole range of Z-values from the minimum secondary coil ground clearance value to the maximum value of the Z-Class to which it claims compliance.

Universal interoperability for light duty vehicles is assured by having the primary device rated as being Z3 capable. This universal class is recommended for deployments where general access to EVs of random Z-gap heights is desired.

Interoperability is required as follows:

- Z1 primary device shall be able to deliver power to Z1 reference EVPC specified in this document;
- Z2 primary device shall be able to deliver power to Z1 and Z2 reference EVPCs specified in this document;
- Z3 primary device shall be able to deliver power to Z1, Z2 and Z3 reference EVPCs specified in this document.

7.104 MF-WPT system efficiency

Power transfer efficiency is determined as the ratio of the output power of the EVPC divided by the input power of the supply power circuit.

The minimum system efficiency for configurations using R-EVPC's of WPT1, WPT2 and WPT3 capacity shall be at least 85 % at optimal alignment and at least 80 % over the full alignment tolerance range specified in 7.107.

The measurement of the efficiency shall be done at rated input power.

7.105 Primary device construction

The primary device construction shall meet the requirements specified in IEC 61980-1 and as specified elsewhere in this document.

The specific requirements for reference devices are specified in the system specific annexes of this document. Actual MF-WPT products may have different dimensions.

7.106 Power transfer performance

The primary device input current overshoot shall remain within 10% of its target value during ramp up in normal operation.

Compliance is checked in accordance with Clause 101.

7.107 Alignment

The supply power circuit shall meet the efficiency requirements according to 7.104 over its entire secondary device ground clearance range within the alignment tolerance area specified in Table 103.

Power transfer is not required at maximum rated power for all alignments.

Table 103 – x and y alignment tolerance area requirements

Axis	Alignment tolerance area mm
x	±75
y	±100

The measurement positions concerning ground clearance and alignment conditions are specified in 101.1.3

NOTE The alignment tolerance area is defined with respect to the optimal alignment.

Compliance is checked in accordance with Clause 101.

7.108 Frequency

To ensure interoperability, the power transfer shall be operated within the system frequency range and at the nominal frequency, according to Table 104.

Table 104 – Frequency

Description	Frequency kHz
System frequency	81,38 to 90 79,0 to 90,0[a]
Nominal frequency	85 ± 0,05
[a] The lower border of the frequency range needs to be confirmed by ITU-R.	

A fixed-frequency system shall transfer the power at the nominal frequency. In order to optimize performance, frequencies in the allowable range may be used to optimize system level performance. For frequency-tuneable systems, the nominal frequency is typically observed under optimal alignment and while the system is in a steady-state. Frequency-tuneable systems may transfer power at any frequency within the system frequency range.

For coexistence with over the air synchronized clocks, operating in adjacent frequency bands, an interruption of energy transfer of 3 min every day at 02:00 h and 04:00 h shall occur. This measure need only be implemented in a region where these clock services operate within 15 kHz of the operating frequency of the WPT system. Measures need to be considered to assure no adverse impact on the grid.

7.109 Activities provided by MF-WPT system

7.109.1 MF-WPT mandatory activities

The following activities shall be provided or supported by the supply device (see also Clause 6 of IEC TS 61980-2:2019):

– communications setup;
– service selection;
– fine positioning;
– pairing;
– final compatibility check;

– initial alignment check (actual technology under consideration; further analysis is required to determine if this can be done without support from the EVPC);
– prepare power transfer;
– perform power transfer;
– stop power transfer;
– foreign object detection to prevent overheating and/or ignition of debris (this function shall be provided by the supply device);
– intrusion into protection zones (to be provided by the supply device);
– in the event that local regulations require ventilation of space containing this equipment while operating, controlling and monitoring the status of ventilation (to be provided by EVSE);
– safety monitoring and diagnostics:
  • communication link monitoring;
  • continuous alignment check (actual technology under consideration);
  • failure conditions monitoring;
  • power transfer monitoring.

NOTE Activities described in IEC 61980-2 which are purely related to communication are not listed here.

7.109.2 Optional supply device features

Additional features may be provided by the supply device. Examples include, but are not limited to

– power transfer operating frequency tuning,
– sleep mode,
– user initiated stop power transfer,
– ventilation during power transfer, and

  NOTE Required for the following countries: US, CA and MX.

– billing.

The activities, if provided, shall be according to IEC 61980-2 unless otherwise specified.

Other additional activities may be provided.

7.109.3 Details of the mandatory MF-WPT activities

7.109.3.1 Communications setup and service selection

Communication setup is initiated by the vehicle and allows for negotiation of WPT system service parameters, including available alignment and pairing services.

Communication setup and service selection shall be performed in accordance with IEC 61980-2.

7.109.3.2 Fine positioning

Fine positioning begins with the EV approaching the designated WPT spot, and some form of guidance shall be provided to the EV with the goal of having the secondary device and the primary device positioned within the alignment tolerance.

The fine positioning activity may have the following characteristics:

– fine positioning with non-communication support;

– fine positioning with communication support in accordance with IEC 61980-2.

7.109.3.3 Pairing

The pairing activity enables the SECC and the EVCC to uniquely identify the primary device over which the EV is placed.

The pairing activity shall be performed in accordance with IEC 61980-2.

Pre-programmed recognition and association may be provided for private/dedicated use.

7.109.3.4 Final compatibility check

Compatibility of the primary and the secondary devices shall be checked with the information exchanged after pairing in accordance with IEC 61980-2.

7.109.3.5 Initial alignment check

The MF-WPT system shall be able to determine that the primary and secondary devices are positioned relative to each other within the alignment tolerance specified in Clause 7.107.

7.109.3.6 Prepare power transfer

The MF-WPT system shall not perform power transfer until

– communication is properly established,
– successful initial alignment check,
– successful pairing confirmation,
– successful final compatibility check, and
– activation of the safety monitoring system and clearance of all potential fault conditions.

7.109.3.7 Perform power transfer

7.109.3.7.1 General aspects of power transfer

The SECC shall be able to accept requests from the EVCC to transfer a specific amount of power, with the power to be specified in watts.

The supply device shall transfer the power from the primary device to the secondary device upon the request from the EV.

NOTE 1 Power from the supply device will be measured at the input from the supply network.

If the EVCC requests more than the maximum available power, the SECC shall indicate that it is unable to service the request and shall not change the transfer power.

NOTE 2 Maximum available power is the maximum power that the supply device is capable of drawing from the grid at the time the power request is received from the EVCC.

If the EVCC requests a change in transferred power, the supply device shall cause an observable change in the direction requested within 1 s after receiving the request from EVCC.

The ramp-up and ramp-down rate shall be on the following range in normal operation.

– ramp up rate:
  - minimum of 0,5 kW/s;
  - maximum of 2 kW/s;
– ramp down rate: 5 kW/s or more.

In the case of emergency, the ramp down rate shall be 10 kW/s or more.

7.109.3.7.2 Power transfer control loop

The WPT system consists of the supply device and EV device. Each device includes a control mechanism (controller) to manage the process. Clause 7.109.3.7.2 defines the roles and relative time constraints for the EV controller and the supply device controller (SD controller).

Figure 104 shows the control loop of the WPT system. The control loop consists of two loops. One is a minor loop which controls the output power of the supply device. The other is a major loop which controls the input power to the secondary device.

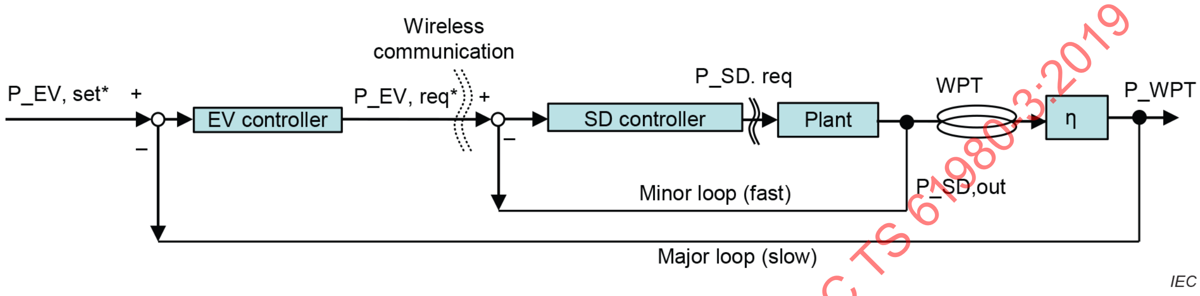


Figure 104 – Control loop of WPT system

The roles of the supply device and EV are shown in Table 105.

Table 105 – Roles of supply device and EV

Controller	Control variable	Input variable	Symbol
EV controller	Desired charging power		P_EV, set
	EV requested charging power to SD		P_EV, req
		Actual transferred power	P_WPT
SD controller		EV requested charging power to SD	P_EV, req
	SD requested output power		P_SD, req
		SD regulated output power	P_SD,out

Tables 106 describes the control variables and control inputs for the supply device controller and EV controller.

Table 106 – Supply device and EV controller of WPT system

Controller	Control variable	Control input
SD controller	Output power from supply device	Under consideration
EV controller	Input power to EV	Output power reference from supply device

These controllers have original feedback loops each other. In this case, response time of an inner loop controller should be faster than that of an outer loop controller. The definition of target response time of each loop is shown in Table 107.

Table 107 – Definition of response time of inner loop and outer one

Side	Loop	Response time
SD controller	Inner loop	Ti (Ti << Tv)
EV controller	Outer loop	Tv

If these two times are set appropriately, stable WPT power transfer control can be realized.

7.109.3.8 Stop power transfer

The supply device shall stop power transfer in the cases

– the EV requests stop power transfer,
– there is a failure in communication between the SECC and the EVCC, and
– fault condition is detected.

7.109.3.9 User initiated stop power transfer

The supply device may have a means to allow the user to terminate the transfer of power by the supply device, for example pushing a stop button.

7.109.3.10 Safety monitoring and diagnostics

7.109.3.10.1 General

MF-WPT systems safety monitoring and diagnostics activities may use, but are not limited to, the following safety measures:

– thermal monitoring;
– protection from electromagnetic fields;
– failure conditions monitoring;
– power transfer monitoring;
– determination of ventilation requirements of the area.

7.109.3.10.2 Thermal monitoring

Thermal monitoring means the MF-WPT system, when in operation, shall comply with 11.6 of IEC 61980-1:2015; if not, a means to detect foreign objects shall be implemented.

Compliance shall be tested according to 101.5.

7.109.3.10.3 Protection from electromagnetic fields

MF-WPT systems shall ensure that humans are not exposed to hazardous magnetic fields as a result of the MF-WPT system operation.

Compliance may be tested according to Annex C (informative) of IEC 61980-1:2015.

MF-WPT systems may either

– provide living object protection by design (for example by limiting access or by large coil geometries), or
– may provide means to detect living objects and to stop power transfer, or
– provide means to detect living objects and reduce power transfer below ICNIRP limits.

ICNIRP levels are required to be considered for area 1, 2 and 3.

Requirements for compliance with live object protection shall be given in the system specific annexes of this document, if needed.

7.109.3.10.4 Failure conditions monitoring

The supply device shall stop the transfer of power in the case of failure in the supply device, such as

- short-circuit,
- earth leakage,
- excessive operational temperature (overheating),
- overcurrent, and
- overload..

7.109.3.10.5 Power transfer monitoring

If, under steady state conditions, the input power to the supply power circuit is unusually larger than the output power of the EVPC (i.e. anomaly), then the supply device shall shut down power transfer.

What is "unusual" may be device specific and will then need to be specified by the manufacturer for the purpose of testing.

7.109.3.10.6 Foreign object detection

The supply device may, if required to prevent overheating of foreign objects, provide the means to detect such objects between the primary coil and the secondary coil, followed by, if necessary, corrective action (e.g. shuts off or reduces power transfer).

7.109.3.10.7 Living object detection

The supply device may provide the means to detect the incursion of living objects in areas where ICNIRP basic restrictions, or alternatively ICNIRP reference levels, would be exceeded, followed by, if necessary, corrective action (e.g. shuts off or reduces power transfer).

7.109.3.10.8 Ventilation during energy transfer

If additional ventilation is required during power transfer, power transfer shall only be allowed if such ventilation is available and actively running. The status of the ventilation system shall be monitored by the supply device during the whole energy transfer process.

The supply device shall be able to exchange information with installation environment regarding the status of the ventilation system.

NOTE 1 Ventilation requirements might be subject to local or national regulation or standard.

NOTE 2 In the following countries, national regulations may require ventilation for some situations for indoor charging under certain conditions: CA.

7.109.3.10.9 Sleep

The supply device may provide the means to perform the power transfer according to pre-set time schedule.

7.109.3.10.10 Operating frequency tuning

The supply device may use frequency tuning to achieve required performance. Power transfer will be within the allowable frequency range as specified in 7.108.

7.109.3.10.11 Communications link monitoring

The supply device shall monitor the communication between the SECC and EVCC. In case that the loss of communication is recognized, the supply device shall terminate the power transfer according to IEC 61980-2.

7.109.3.10.12 Continuous alignment check

The supply device shall monitor if the secondary device and primary device stay within the alignment tolerance area (see 7.107) during the power transfer. In case that the secondary device is determined to be out of the tolerance area, the supply device shall terminate the power transfer and shall inform the EVCC of this power termination.

7.109.4 Power transfer state

Power transfer control process and states are shown in figures and tables in Clause 7 of IEC 61980-2:2019. The supply device and the EV device shall exchange their control process state through communications.

8 General systems requirements

Clause 8 of IEC 61980-1:2015 is applicable, except as follows.

8.3.9 On-ground-mounting

Addition:

The "mounting height" of an on-ground mounted system shall not exceed 70 mm.

9 Communication

Clause 9 of IEC 61980-1:2015 is applicable.

10 Protection against electric shock

Clause 10 of IEC 61980-1:2015 is applicable except as follows.

10.1 General requirements

Replacement:

Hazardous live parts shall not be accessible.

Protection measures against electric shock under single fault conditions shall be implemented.

It is recommended to use independent protection means (overcurrent and fault current) for each primary device that can be used simultaneously in order to ensure a better availability of power.

NOTE For systems or equipment on board the vehicle, the requirements are specified in ISO PAS 19363.

10.3 Stored energy – discharge of capacitors

Replacement:

For plug and cable connected supply device, where the connection pins are accessible after unplugging, one second after disconnecting the standard plug from the standard socket-outlet, the voltage between any combination of accessible contacts of the standard plug shall be less than or equal to 60 V DC or the stored charge available shall be less than 50 µC.

For a supply device that consists of more than two parts connected by power cable and connector(s), where the connector can be disconnected without the use of a tool and the connection pins are not accessible with IPXXB after disconnecting, the voltage between any combination of accessible contacts of the connector shall be less than or equal to 60 V DC or the stored energy available shall be less than 0,2 J one second after disconnecting.

10.6.1 Additional protection

Replacement of 10.6.1 of IEC 61980-1:2015, including its title:

10.6.1 Protection against indirect contact by automatic disconnection of supply

Except for circuits using the protective measure of electrical separation, each AC input of supply power electronics shall be protected by its own RCD of at least of type A, having a rated residual operating current not exceeding 30 mA.

In case of multi-phase supply, if the characteristics of the load regarding possible DC fault currents above 6 mA are not known, protective measures against DC fault current shall be taken, except where provided by the fixed installation. The appropriate measures shall be as follows:

– RCD type B; or
– RCD type A and appropriate equipment that ensures disconnection of the supply in case of DC fault current above 6 mA.

RCD shall comply with IEC 60947-2, IEC 61009-1, IEC 61008-1 or IEC 62423.

RCD shall be used in conjunction with an over-current protection device.

Compliance is checked by inspection.

NOTE 1 In the following countries, RCDs of type AC may be used: JP.

NOTE 2 10.3.1 deals with indirect contact at grid frequency; the effect of indirect current from WPT at the system frequency can be required in the future.

Additional subclause:

10.101 Installation category

There are two categories of installation to which different protection requirements may apply:

– permanently connected;
– plug and cable connected.

NOTE Subclause 10.101 will be moved to IEC 61980-1 in a future edition.

11 Specific requirements for WPT systems

Clause 11 of IEC 61980-1:2015 is applicable, except as follows.

11.6.4 Protection against burns from heating of foreign objects

Replacement:

NOTE 1 Since the danger caused by heating of foreign object is independent of the means by which the object has been heated, 11.6.4 will potentially be transferred to IEC 61980-1.

The requirements in 11.6.4 are default requirements that apply for static WPT.

The supply device shall prevent the exposure of human beings to excessive temperature rise in foreign metal objects.

The default temperature limits are

– 80 °C for metal parts bare metallic surfaces, and
– 90 °C for parts with non-metallic surfaces.

These values are default values and are based on thermal capacity assumptions about the heated object. Specific test object types may have different limits defined depending on the specific technology and test-object definition (e.g. objects with small thermal capacity, such as foil coated papers).

NOTE 2 There are objects that do not have sufficient heat capacity to cause burns; these objects may still constitute a fire hazard (see 11.7).

These values are absolute limits, to mitigate the danger of burns to anyone attempting to touch the foreign object.

Foreign objects in the critical active area shall be detected and the system shall shut off or reduce power transfer within 2 s, if the temperature of the respective object is able to reach a critical temperature. WPT system suppliers need to determine and specify the extent of the "critical active area". In most cases, the hazard will be confined to the area directly over the primary device.

Compliance is tested in accordance with 101.5.

11.7 Heat, fire and tracking

Replacement of 11.7 of IEC 61980-1:2015, including its title:

11.7 Protection against heat and fire

The supply device shall not cause the foreign materials to become a fire hazard. For the purposes of 11.7, a fire hazard is defined as

1) the emission of smoke from the object, smouldering of the object and/or ignition of the object to a flame, and
2) the object melting into the pad surface.

Foreign objects that may become a fire hazard shall be detected and the system shall shut off or reduces power transfer prior to the object entering a hazardous state (e.g. smoking, smouldering or burning).

Compliance is tested in accordance with 101.5.

NOTE Based on studies and testing of the ignition test objects specified in 101.5, it has been shown that some of those objects could become hazardous for B-fields with magnitudes larger than approximately 2 mT.

12 Power cable assembly requirements

Replacement:

Under consideration.

13 Constructional requirements

Clause 13 of IEC 61980-1:2015 is applicable.

14 Strength of materials and parts

14.2.3 Vehicle drive-over

Additional subclause:

14.2.3.101 Vehicle drive-over test

Vehicle drive-over test applies only to flush mounted and surface mounted supply devices.

Primary device with power cable shall be installed on a flat concrete floor with the manner intended by the manufacturer.

A crushing force shall be applied with a wheel load of 7 500 N by a conventional automotive tire, P225/75R15 or an equivalent tire suitable for the load, mounted on a steel rim and inflated to a pressure of (2,2 ± 0,1) bar. The wheel shall be rolled over the part of the supply device that is installed in ground or on ground at a speed of (8 ± 2) km/h.

For environments where the WPT supply device may be exposed to heavy duty vehicles, the drive-over test shall be performed with tires in the range of 275/70 R22.5 at 8 bar (typical for European and Asian transit buses) or 305/70 R22.5 at 218 kPa ± 13 kPa (according to UL 2251) (typical for USA and CA).

The crushing force shall be applied four times:

– drive-over starts from one side of the device through centre followed by the other side in each direction (X and Y) to expose whole device surface with the above specified crushing force;
– as a next step, conduct same test with the drive direction turned by 45°, i.e. a diagonal direction across the device. Follow this by turning the drive direction to 315°, i.e. the alternate diagonal direction.

For the cable test, the cable shall be laid straight and flat and then a crushing force shall be applied to the cable(s) by driving across it. The drive-over test on the cable shall not be applied if the cable is protected by an adequate conduit or equivalent protective installation.

There shall be no severe cracking, breakage, or deformation to the extent that

– live parts are made accessible to contact by the test probe of degree IPXXC according to IEC 60529,
– the integrity of the enclosure is defeated so that acceptable mechanical or environmental (degrees of) protection is not afforded to the internal parts of the device,
– there is interference with the operation, or function of the device,
– the device or its cable clamp does not provide adequate strain relief for the feeder cable,
– the creepage distances and clearances between live parts of opposite polarity, live parts and accessible dead or earthed metal are reduced below the values designed in accordance with 13.3 of IEC 61980-1:2015,
– other evidence of damage that could increase the risk of fire or electric shock occurs, and
– the accessory does not comply with a repeated dielectric test in accordance with 11.4 of IEC 61980-1:2015.

15 Service and test conditions

Clause 15 of IEC 61980-1:2015 is applicable.

16 Electromagnetic compatibility (EMC)

Clause 16 of IEC 61980-1:2015 is applicable, except as follows.

Addition:

NOTE CISPR B is currently working on radiated emission requirements in the frequency range from 9 kHz to 150 kHz applicable to wireless power transfer equipment, to be published in a future amendment of CISPR 11. The outcome of this work will be considered for future amendments of IEC TS 61980-3.

17 Marking and instructions

Clause 17 of IEC 61980-1:2015 is applicable.

Additional clause:

101 Test procedure

101.1 General

101.1.1 Test setup

Unless otherwise specified, a supply device shall be tested with the relevant reference EV power circuit (EVPC) that is specified in the annexes of this document for the tests in Clause 101.

The test bench is described below. It shall be fabricated from non-metallic elements except as listed below.

NOTE 1 Capabilities of the reference EV devices have an impact on the way a supply device can be designed.

NOTE 2 The scope of this test bench is for all electrical and magnetic testing, not just thermal measurements

The test bench incorporates receiving elements to accommodate

- a primary device,
- a secondary device, and
- a vehicle mimic plate (1,5 m x 1,5 m steel) mounted immediately above the secondary device; the thickness of the plate is 0,7 mm to 1 mm.

The relative position of the primary and secondary devices shall be changeable.

Connection of the appropriate inverters or on-board electronics is also needed for the test performance. Power measurement is done by load simulation.

101.1.2 Reference EVPCs

This document specifies reference EVPCs.

Reference EVPCs are used for testing power transfer interoperability for product supply power circuits.

NOTE 1 Reference supply power circuits for testing power transfer interoperability of product EVPCs are specified in ISO PAS 19363.

Reference EVPCs are classified according to the Z classes as specified in Table 102.

NOTE 2 Reference EVPCs are designed so that, when operated with the relevant reference supply power circuits specified in ISO PAS 19363,

– they meet the power transfer requirements as in 7.106 and the system efficiency requirements as in 7.104 over their entire Z class and the alignment tolerances in x and y direction (see Table 103), and

– they can handle the power under steady-state condition up to maximum power of the MF-WPT input power class for which it is specified.

The reference EVPCs for MF-WPT1, MF-WPT2 and MF-WPT3 are described in Annex AA to Annex CC.

A possible method for determining interoperability through measurements is given in informative Annex EE.

101.1.3 Misalignment condition for performance evaluation

The misalignment condition shall be considered as shown in Figure 105 when the performance evaluation is conducted. Every point is indicated with a three character combination of P, 0 and N. Each character represents a position in the X, Y and Z axis. Most positive side misalignment in each axis is indicated with "P"; most negative side, is indicated with "N"; and the mid-point is indicated with "0".

Subject to the test step, the secondary device is set to the following positions defined by their coordinates relative to the zero point (see Figure 105).

Either single, double or quadruple quadrant(s) cuboid part in Figure 105 can be chosen to be evaluated by the manufacturer. Table 108 shows the misalignment positions.

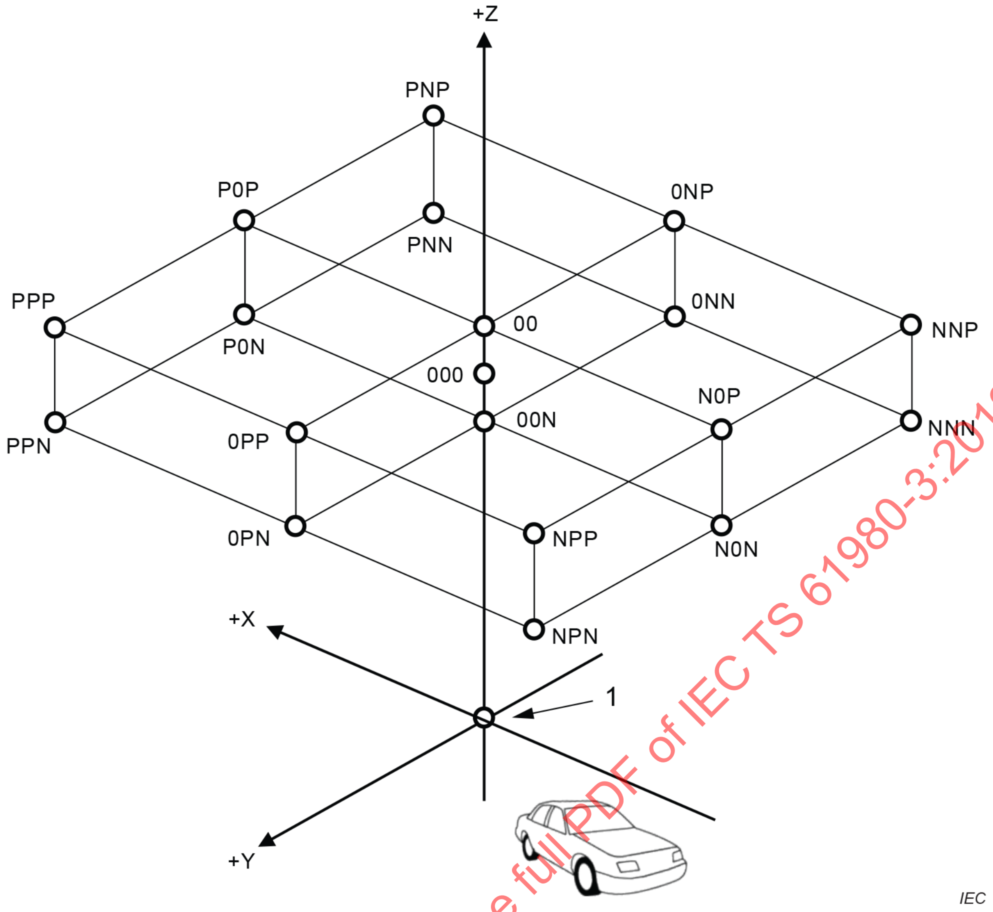


Figure 105 – Illustration of test positions

Table 108 – Misalignment positions

Point No. X Y Z	Coordinate value (mm)				
	X	Y	Ground clearance		
			Z1	Z2	Z3
P P P	+75	+100	150	210	250
P P N			100	140	170
P 0 P		0	150	210	250
P 0 N			100	140	170
P N P		–100	150	210	250
P N N			100	140	170
0 P P	0	+100	150	210	250
0 P N			100	140	170
0 0 P		0	150	210	250
0 0 0			125	175	210
0 0 N			100	140	170
0 N P		–100	150	210	250
0 N N			100	140	170
N P P	–75	+100	150	210	250
N P N			100	140	170
N 0 P		0	150	210	250
N 0 N			100	140	170
N N P		–100	150	210	250
N N N			100	140	170

101.2 System efficiency test

Under consideration

101.3 Power transfer performance test

Under consideration

101.4 Protection against electromagnetic fields test

Under consideration

101.5 Protection against heating effects of foreign objects test

101.5.1 Test body for temperature rise measurement of foreign material

The test bodies are used to assess compliance of the WPT system with respect to the temperature limits specified in 11.6 of IEC 61980-1:2015 applicable to foreign metallic objects located in the area of operation (area 1). The test objects specified in Table 109 are metallic objects that are deemed to have enough heat capacity to become a burn risk to a human being when coming into contact with one of these objects.

The manufacturer needs to specify whether testing is extended beyond the surface area of the primary device.

Table 109 – Test bodies for thermal hazard

Test objects for temperature rise				
Brief object description	**Size**	**Material (composition)**	**Test position**	**Notes**
Paper Clip No. 1, No. 2, No. 3	•No. 1: 1 3/8" •No. 2: 1 1/8" •No. 3: 15/16" Thickness of wire is 1 mm Suggestion use GEM style uncoated steel clip	Steel	Flat	Testing shall be performed at successive 30°rotation over 180°
Model of 5 cent Euro coin	Circular disc: Diameter: 21,25 mm Thickness: 1,67 mm	Fe: 94,35 % Cu: 5,65 %	Flat	Based on Euro coin most susceptible to heating by magnetic field
Model of common construction nail and brad	Model 1: 80 mm, 2,91 mm (9 gauge) wire Model 2: 30 mm, 1,63 mm diameter (14 gauge) wire	Steel S235 JR	Flat	
Model of aluminium 330 ml beverage can	Body diameter: 66,2 mm Top tapers to ~53 mm Height: 115,2 mm Wall thickness: 0,08 mm	Aluminium alloy (3004 or 3105)	Lying on side	Model of a D202 330 ml soda can. May use an empty European soda can.
Model of steel beverage can	Body diameter: 66,3 mm Top tapers to ~53 mm Height: 115,2 mm Wall thickness: 0,065 mm	Steel	Lying on side	Model of a D202 330 ml soda can. May use an empty European can.
14 gauge ring of wire with 1 cm radius	Ring of wire with 1,63 mm wire diameter (14 gauge) and ring dimension is 20 mm diameter	Steel S235 JR	Flat	
Wire mesh pads/ Steel wool	Length: 100 mm Width: 50 mm Height: 12,5 mm	#0000 steel wool pad (each fibre 0,03 mm)	Lying flat	Steel wool grade used for polishing/buffing
Model metallic stranded cable (e.g. bicycle locking device)	Diameter: 10 mm Length: 1 000 mm	Stainless steel 7 x 19 cable (S235 JR steel)	Lying coiled in double loop with ends touching	
Steel bar	Length: 100 mm Width: 70 mm Height: 10 mm	Magnetic steel S235 JR	Flat	Intended as model of cell phone.
Solid steel disc (40 mm)	Diameter: 40 mm Height: 1,5 mm	DC01 A M (EN 10130)	Horizontal	Model of metallic washer
Solid steel disc (10 mm)	Diameter: 10 mm Height: 1,5 mm	DC01 A M (EN 10130)	Horizontal	Model of metallic washer

Test objects for temperature rise				
Brief object description	**Size**	**Material (composition)**	**Test position**	**Notes**
Solid steel rod	Diameter: 30 mm Height: 100 mm	DC01 A M (EN 10130)	Horizontal (perpendicular to field lines)	Representation of a metallic tool.
Solid steel rod	Diameter: 10 mm Height: 100 mm	DC01 A M (EN 10130)	Horizontal (perpendicular to field lines)	Representation of a metallic tool.
Metal rod with wood handle	Metal rod: d = 10 mm, l = 6 cm Wood handle dimension: 8 cm length, 3 cm diameter.	Metal Rod: DC01 A M (EN 10130) Wood handle: pine	Horizontal (perpendicular to field lines)	Model of screwdriver with centre of gravity such that blade is elevated
Aluminium sheet	5 cm x 7,5 cm x 0,3 cm			
Steel sheet	5 cm x 7,5 cm x 0,3 cm			
Staple	Standard size (ferromagnetic steel, rectangular wire 0,5 x 0,7 mm, 6 mm x 12,8 mm – standardized as "type 24/6 (No. 3)" per DIN 7405:1963)			

This list will be reduced to a more manageable and testable subset once experience has been gained in identifying the critical objects. In the interim, a WPT system may be tested with a specified subset of objects that are critical for that system, based on risk assessment.

101.5.2 Test body for ignition risk assessment

The test bodies which serve to verify compliance with the requirements for resistance to ignition of foreign material located in the area of operation (area 1) is characterized by the following Table 110.

All tests are conducted at an ambient temperature of 25 °C.

Table 110 contains specifications for objects that are not deemed to have enough heat capacity to cause human burns but may reach temperature where they ignite or cause combustible material in contact with them to ignite.

Table 110 – Test objects for ignition risk test

Test objects for ignition risk				
Brief object description	**Size**	**Material (composition)**	**Test position**	**Observation**
Paper clip with paper	A4 sheets of paper (5) with No.1 paperclip	A4 paper 30 g/m^2	Lying flat	
Foil model of chocolate bar wrapper	150 mm x 180 mm	Tissue substrate: 22 g/m^2 Foil: alloy 1235; 0,008 mm	Opened flat	Assumption is that wrapper is placed fully opened on surface of pad.
Foil model of cigarette wrapper	40 mm x 150 mm	Wood free paper: 30 g/m^2 Aluminium alloy 0,00 mm	Opened flat	Need model for cigarette box. Wrapper to be placed folded in box

Test objects for ignition risk				
Staple with paper	Standard size (ferromagnetic steel, rectangular wire 0,5 x 0,7 mm, 6 mm x 12,8 mm – standardized as "type 24/6 (No. 3)" per DIN 7405:1963)	A4 paper 30 g/m^2		
Wire Mesh pads/Steel wool	Length: 100 mm Width: 50 mm Height: 12,5 mm	#0000 steel wool pad (each fibre 0,03 mm)	Lying flat	Steel wool grade used for polishing/buffing
Model of 50 mm and 75 mm yogurt cup	Two heights: 50 mm and/or 75 mm Diameter: 70 mm Wall thickness:0,2 mm Foil top: 0,04 mm	Container: PP (polypropylene) Top: aluminium alloy 8011	Lid-side facing up	The foil top is heat sealed to the top of the plastic container. The container is empty and lid is completely sealed to the top of the container. The container is placed on the primary device surface with the lid facing upwards.
Aluminium foil	300 mm x 200 mm 0,02 mm	Aluminium alloy 3004	Opened flat	
Empty cigarette pack	Height: 85 mm Width: 50 mm Depth: 20 mm	300 g/m^2 paper With cigarette foil wrap inside	Lying flat on width	Cigarette foil described above, placed in box to line inside of box

This list will be reduced to a more manageable and testable subset once experience has been gained in identifying the critical objects. In the interim, a WPT system may be tested with a specified subset of objects that are critical for that system, based on risk assessment.

101.5.3 Test body for ignition risk assessment

101.5.3.1 General

101.5.3 describes the procedures for testing WPT systems for compliance with

– the temperature limits of foreign materials in the critical area due to induced heating effects of the WPT system, and

– the mitigation of the risk of igniting foreign materials in the critical area due to heating effects of the WPT system.

The test bodies described in 101.5.1 and 101.5.2 are used to test for compliance.

Two potential scenarios for compliance exist.

a) The system may be designed in such a way that, even at maximum flux density of the rated power class according to 7.102, the induced power in the foreign material does not cause the temperature to rise above the specified limit according to 11.6 of IEC 61980-1:2015, and/or an ignition hazard of a specified test object does not occur.

b) Foreign objects are detected and the system takes corrective action (e.g. shuts off or reduces power transfer) within two seconds of the temperature of the foreign material failing to comply with the limits according to 11.6 of IEC 61980-1:2015, or an ignition hazard of a specified test object occurs.

101.5.3.2 Temperature rise

Compliance is checked by the following test.

- *For scenario a) in 101.5.3.1, the primary and secondary device shall be placed in a valid configuration (i.e. the area of operation in which power transfer will be allowed) that results in the generation of maximum flux density. The test object shall then be placed in the area of maximum flux density on the primary device, and the maximum temperature of the test object, when thermal equilibrium is reached, shall be measured for compliance with the appropriate limit. To accommodate the fact that the objects are not likely to be retrieved until the vehicle has left, the temperature measurement shall be made 1 min after shut-off. If the system, in response to detecting the test object, shuts off power prior to thermal equilibrium, the test is stopped. The test shall be repeated with the test object placed in a direction orthogonal to the previous direction.*
- *For scenario b) in 101.5.3.1, in addition to the test performed for scenario a), the primary and secondary device shall be placed in multiple valid configurations. The test object shall be placed in the area of operation at multiple random locations (as specified below), and the temperature of the test object shall be measured to verify compliance with the appropriate limits. To accommodate the fact that the objects are not likely to be retrieved until the vehicle has left, the temperature measurement shall be made 1 min after shut-off. If the system, in response to detecting the test object, shuts off power prior to thermal equilibrium the test is stopped. If the system, in response to detecting the test object, shuts off power prior to thermal equilibrium the test is stopped.*

Valid configurations are defined as maximum and minimum x, y offset and maximum and minimum z-gap specified for the coil. In case that a test object is higher than the minimum z-gap, the resulting height of the test object + 5 mm is used as minimum z-gap.

The test object shall be placed in 3 random locations with the location being determined by a pseudo-random number generator determining the x and y coordinates of the centre of the object. The random numbers shall be scaled over the applicable pad area. In addition, since there may be variability as to the detectability or heating of the object with respect to each orientation (if the object is not symmetric), the object shall be placed in two orthogonal positions. The test is passed successfully if the foreign object detection (FOD) system operates correctly in all random scenarios.

Metallic objects that are light enough to be able to rest on such materials as leaves on top of a primary device should be considered for testing at levels that are higher than the surface of the primary device. Similar situation may occur for metallic objects that have a non-metallic handle and may come to rest on the pad with the metallic part elevated above the primary device surface.

101.5.3.3 Ignition risk

Compliance is checked by the following test.

- *For scenario a) in 101.5.3.1, the primary and secondary device shall be placed in a valid configuration (i.e. the area of operation in which power transfer will be allowed) that results in the generation of maximum flux density. The test object shall then be placed in the area of maximum flux density. The test shall be run until thermal equilibrium is reached. Ignition prior to thermal equilibrium shall be considered failure of the test. The test shall be repeated with the test object placed in a direction orthogonal to the previous direction.*
- *For scenario b) in 101.5.3.1, in addition to the test performed for scenario a), the primary and secondary device shall be placed in multiple configurations. The test object shall be placed in the area of operation at multiple random locations (as specified below). In some cases, some objects may be placed directly on the surface of the primary device and in other cases, objects may be placed at some vertical distance above the primary device surface. Ignition prior to thermal equilibrium shall be considered failure of the test. If the*

system, in response to detecting the test object, shuts off power prior to thermal equilibrium or ignition, the test is stopped.

The test object shall be placed in 3 random locations with the location being determined by a pseudo-random number generator determining the x and y coordinates of the centre of the object. The random numbers shall be scaled over the applicable primary device area. In addition, since there may be variability as to the detectability or heating of the object with respect to each orientation (if the object is not symmetric), the object shall be placed in two orthogonal positions. The test is passed successfully if the FOD system operates correctly in all random scenarios.

Additional annexes:

Annex AA
(informative)

DD reference EV power circuit (EVPC) for MF-WPT1, MF-WPT2 and MF-WPT3

AA.1 DD reference EVPCs for MF-WPT1

AA.1.1 General

Clause AA.1 describes reference EVPCs for MF-WPT1 classes Z1 and Z2. The reference supply power circuit specified in Annex B of ISO PAS 19363:2017 in combination with the reference EVPCs specified in Clause AA.1 fulfil the power transfer performance requirements described in Clause 7.

The reference EVPCs specified in Clause AA.1 are intended to be used at a nominal operating frequency of 85,00 kHz.

AA.1.2 DD reference EVPC for MF-WPT1/Z1

AA.1.2.1 Mechanical

Figure AA.1 shows the mechanical dimensions of the MF-WPT1/Z1 DD reference secondary device.

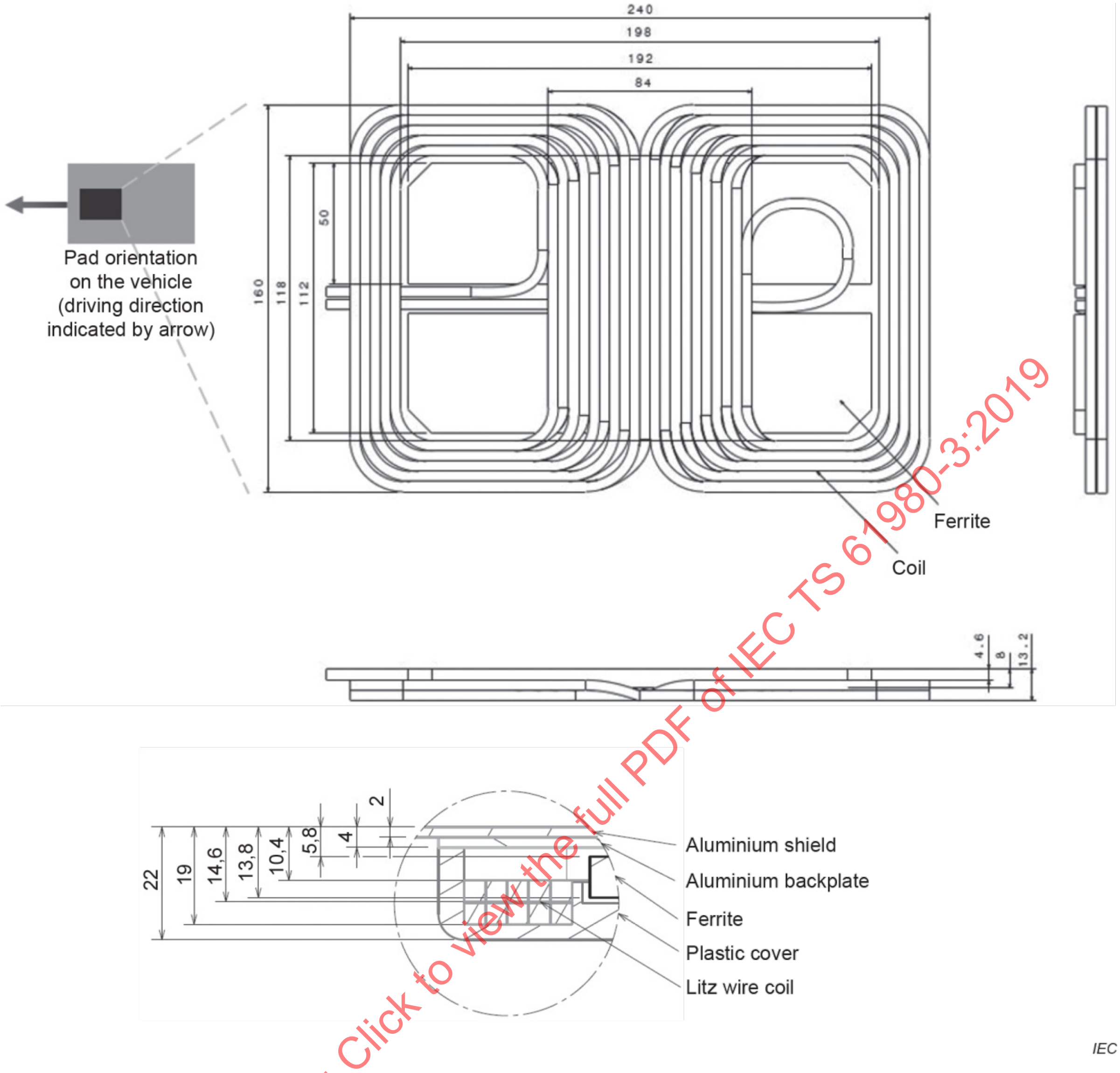


Figure AA.1 – Mechanical dimensions of the MF-WPT1/Z1 DD reference secondary device

Mechanical dimensions of this reference secondary device are shown in Table AA.1.

Table AA.1 – Mechanical dimensions of the MF-WPT1/Z1 DD reference secondary device

	Coil + ferrite only	Housing (w/o vehicle shield)
L x W x H [mm]	240 x 160 x 13,2	250 x 170 x 20

AA.1.2.2 Electrical

Figure AA.2 shows the schematic of the EV power electronics for the reference secondary device described in AA.1.1.

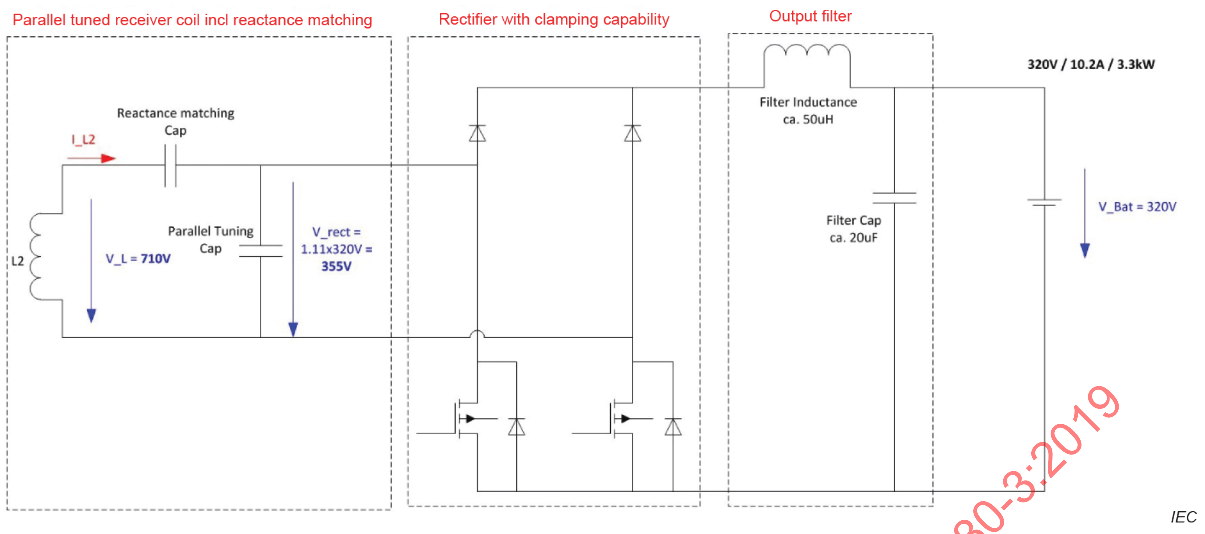


Figure AA.2 – Schematic of the EV power electronics for the MF-WPT1/Z1 DD reference EVPC

Table AA.2 shows the values of the circuit elements shown in Figure AA.2.

Table AA.2 – Values of circuit elements for Figure AA.2

Air gap class	L2_Min µH	L2_Max µH
Z1	62,8	67,3
Air gap class	**C_Parallel nF**	**C_Reactance nF**
Z1	78,4	172,3

AA.1.3 DD reference EVPC for MF-WPT1/Z2

AA.1.3.1 Mechanical

Figure AA.3 shows the mechanical dimensions of the MF-WPT1/Z2 DD reference secondary device.

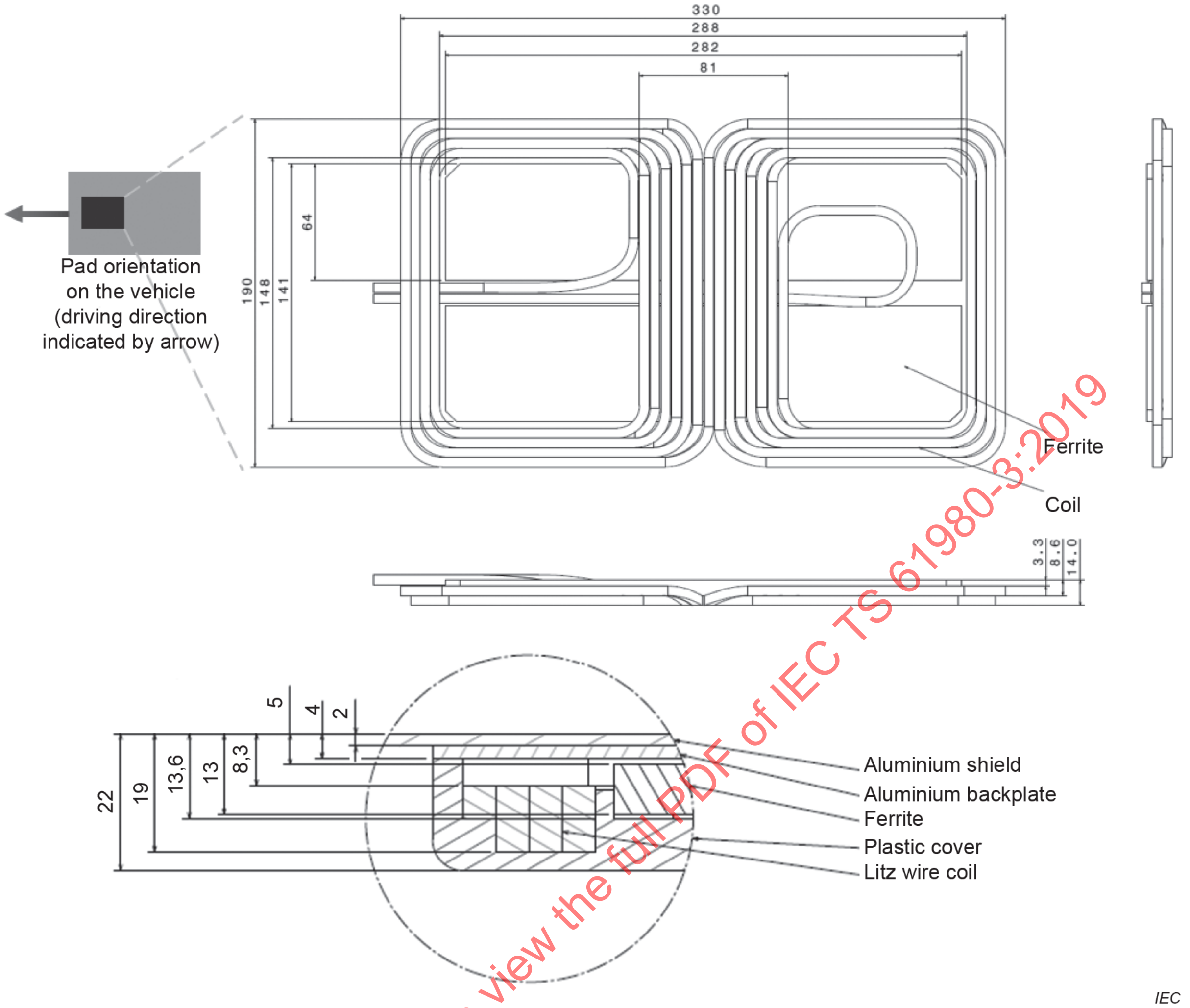


Figure AA.3 – Mechanical dimensions of the MF-WPT1/Z2 DD reference secondary device

The mechanical dimensions of this reference secondary device are shown in Table AA.3.

Table AA.3 – Mechanical dimensions of the MF-WPT1/Z2 DD reference secondary device

	Coil + ferrite only	Housing (w/o vehicle shield)
L x W x H [mm]	330 x 190 x 14	340 x 200 x 20

AA.1.3.2 Electrical

Figure AA.4 shows the schematic of the EV power electronics for the reference secondary device described in AA.1.2.

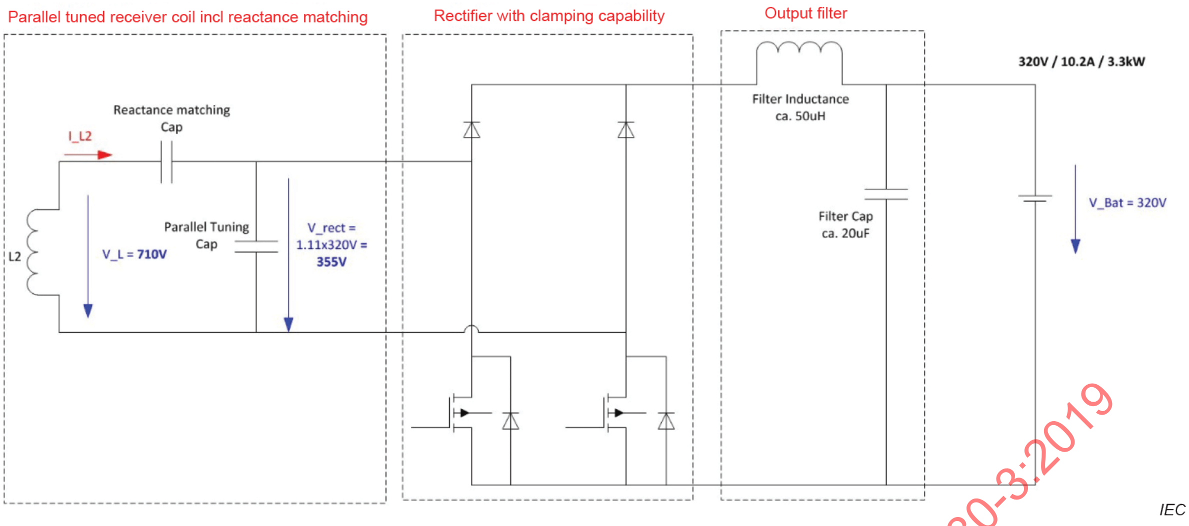


Figure AA.4 – Schematic of the EV power electronics for the MF-WPT1/Z2 DD reference EVPC

Table AA.4 shows the values of the circuit elements shown in Figure AA.4.

Table AA.4 – Values of circuit elements for Figure AA.4

Air gap class	L2_Min µH	L2_Max µH
Z2	47,4	48,8
Air gap class	**C_Parallel nF**	**C_Reactance nF**
Z2	103,7	245,5

AA.2 DD reference EVPCs for MF-WPT2

AA.2.1 General

Clause AA.2 describes reference EVPC proposals for MF-WPT2 classes Z1, Z2 and Z3. The reference supply power circuit specified in Annex B of ISO PAS 19363:2017 in combination with the reference EVPCs specified in Clause AA.2 fulfil the performance requirements described in Clause 7.

The reference EVPCs specified in Clause AA.2 are intended to be used at a nominal operating frequency of 85,00 kHz.

AA.2.2 DD reference EVPC for MF-WPT2/Z1

AA.2.2.1 Mechanical

Figure AA.5 shows the mechanical dimensions of the MF-WPT2/Z1 DD reference secondary device.

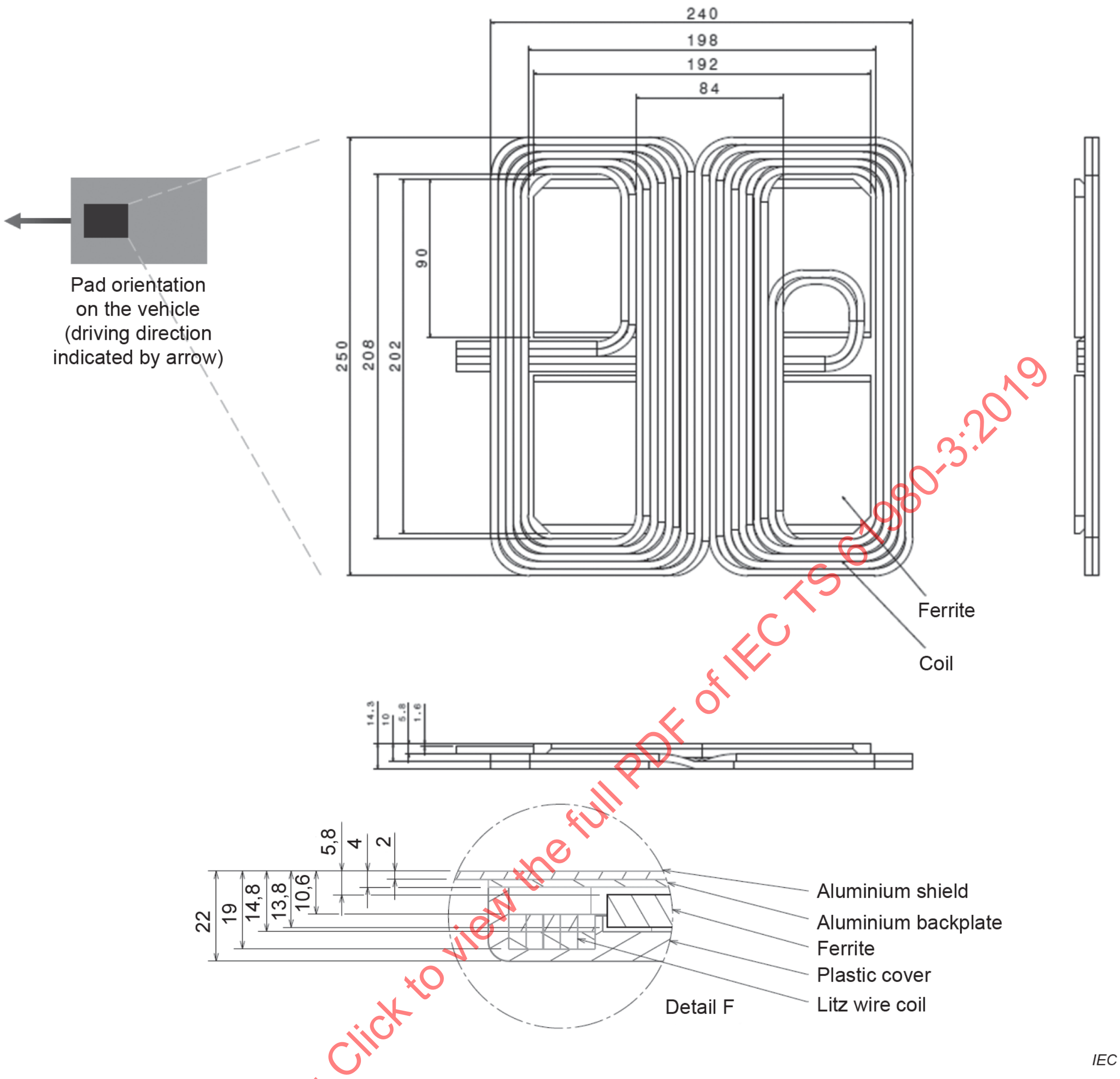


Figure AA.5 – Mechanical dimensions of the MF-WPT2/Z1 DD reference secondary device

The mechanical dimensions of this reference secondary device are shown in Table AA.5.

Table AA.5 – Mechanical dimensions of the MF-WPT2/Z1 DD reference secondary device

	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

AA.2.2.2 Electrical

Figure AA.6 shows the schematic of the EV power electronics for the reference secondary device described in AA.2.1.

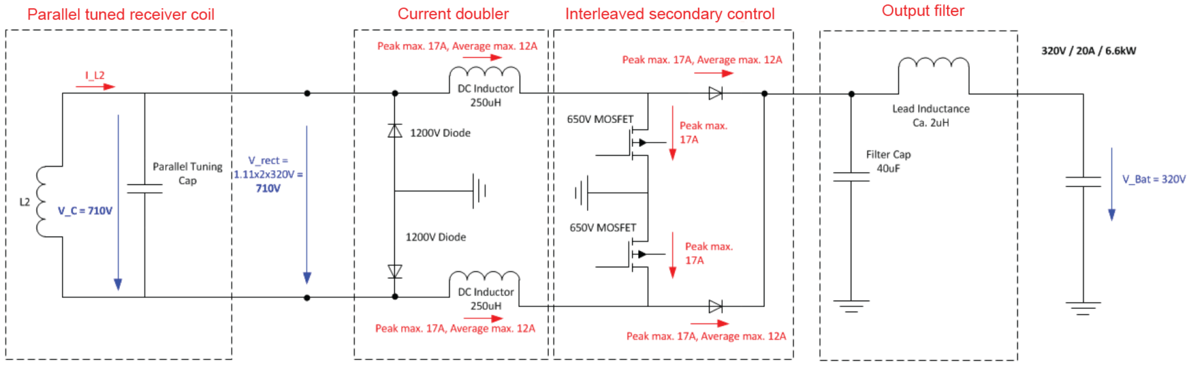


Figure AA.6 – Schematic of the EV power electronics for the MF-WPT2/Z1 DD reference EVPC

Table AA.6 shows the values of the circuit elements shown in Figure AA.6.

Table AA.6 – Values of circuit elements for Figure AA.6

Air gap Class	L2_Min µH	L2_Max µH
Z1	21,5	23,3
Air gap Class	**C_Parallel nF**	
Z1	150	

AA.2.3 DD reference EVPC for MF-WPT2/Z2

AA.2.3.1 Mechanical

Figure AA.7 shows the mechanical dimensions of the MF-WPT2/Z2 DD reference secondary device.

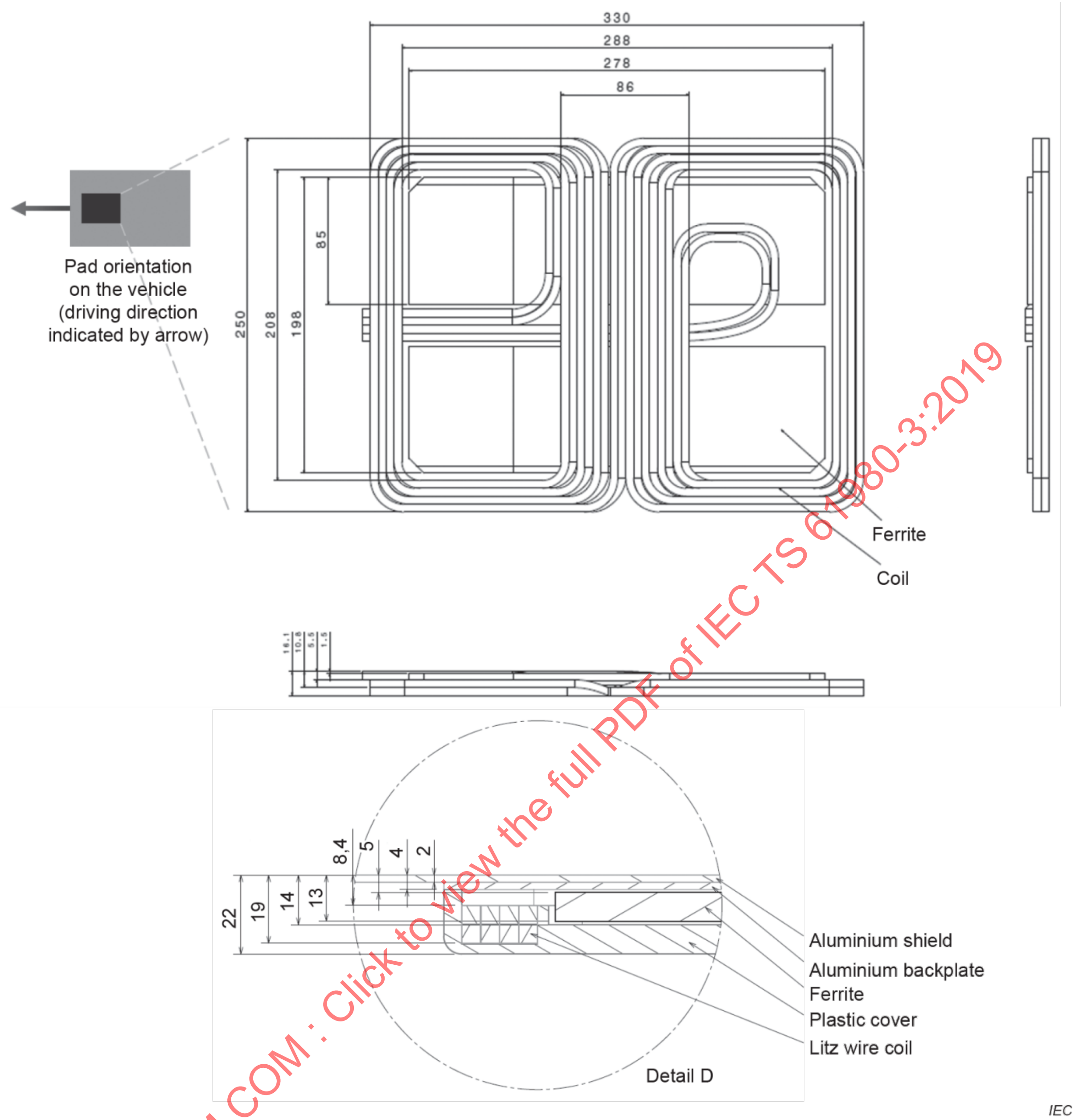


Figure AA.7 – Mechanical dimensions of the MF-WPT2/Z2 DD reference secondary device

The mechanical dimensions of this reference secondary device are shown in Table AA.7.

Table AA.7 – Mechanical dimensions of the MF-WPT2/Z2 DD reference secondary device

	Coil + ferrite only	**Housing (w/o vehicle shield)**
L x W x H [mm]	330 x 250 x 16	340 x 260 x 20

AA.2.3.2 Electrical

Figure AA.8 shows the schematic of the EV power electronics for the reference secondary device described in AA.2.2.

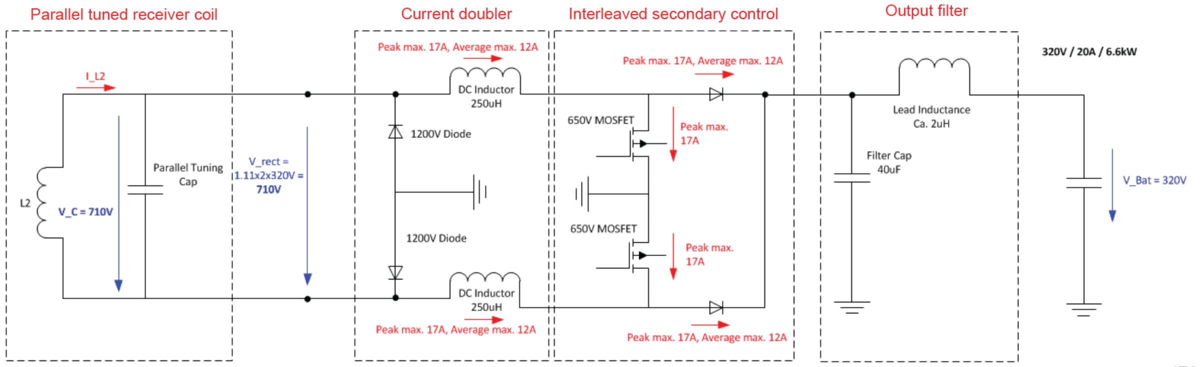


Figure AA.8 – Schematic of the EV power electronics for the MF-WPT2/Z2 DD reference EVPC

Table AA.8 shows the values of the circuit elements shown in Figure AA.8.

Table AA.8 – Values of circuit elements for Figure AA.8

Air gap class	L2_Min µH	L2_Max µH
Z2	19,8	20,5
Air gap class	**C_Parallel nF**	
Z2	175	

AA.2.4 DD reference EVPC for MF-WPT2/Z3

AA.2.4.1 Mechanical

Figure AA.9 shows the mechanical dimensions of the MF-WPT2/Z3 DD reference secondary device.

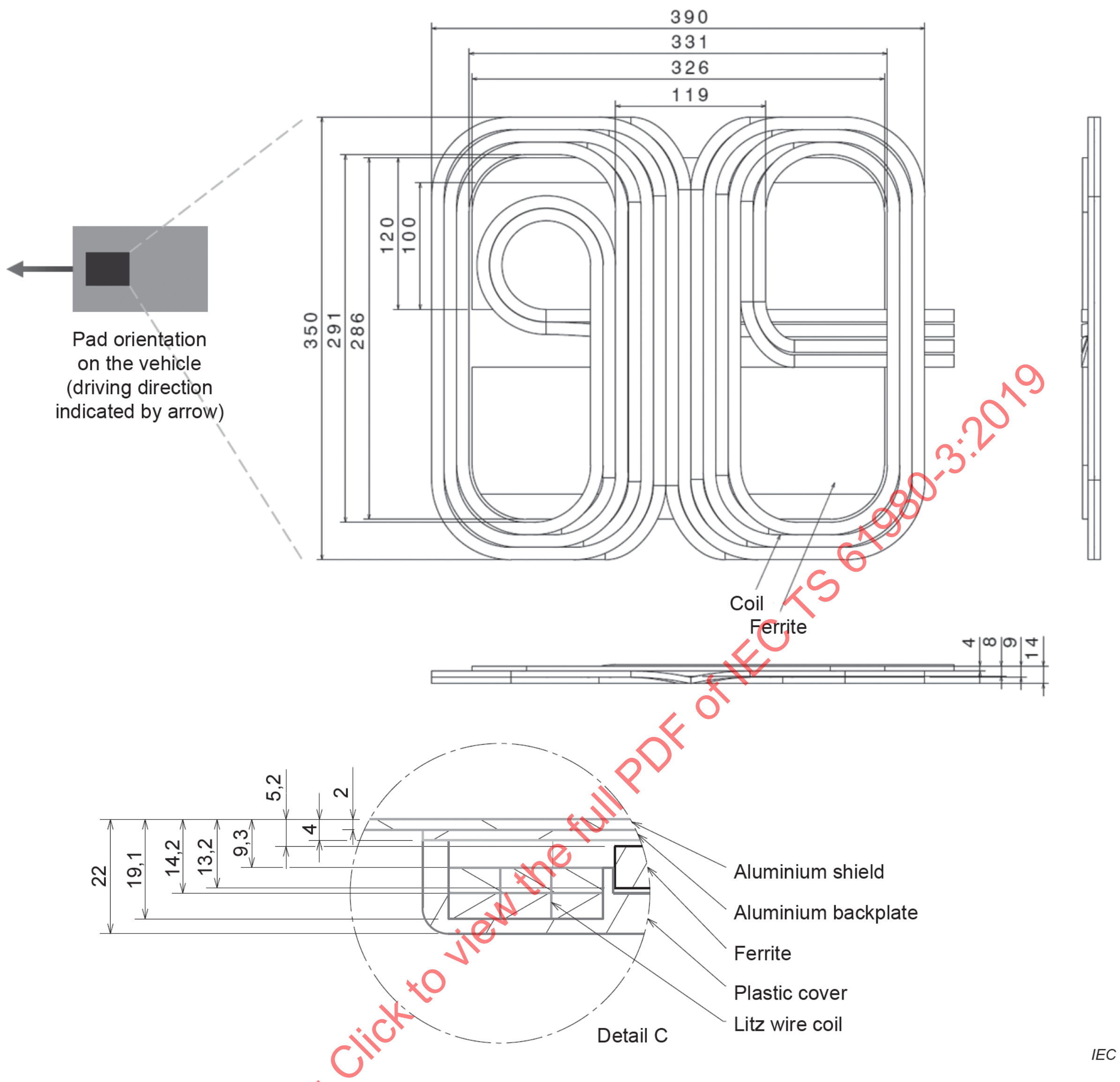


Figure AA.9 – Mechanical dimensions of the MF-WPT2/Z3 DD reference secondary device

The mechanical dimensions of this reference secondary device are shown in Table AA.9.

Table AA.9 – Mechanical dimensions of the MF-WPT2/Z3 DD reference secondary device

	Coil + ferrite only	Housing (w/o vehicle shield)
L x W x H [mm]	390 x 350 x 14	400 x 360 x 20

AA.2.4.2 Electrical

Figure AA.10 shows the schematic of the EV power electronics for the reference secondary device described in AA.2.3.

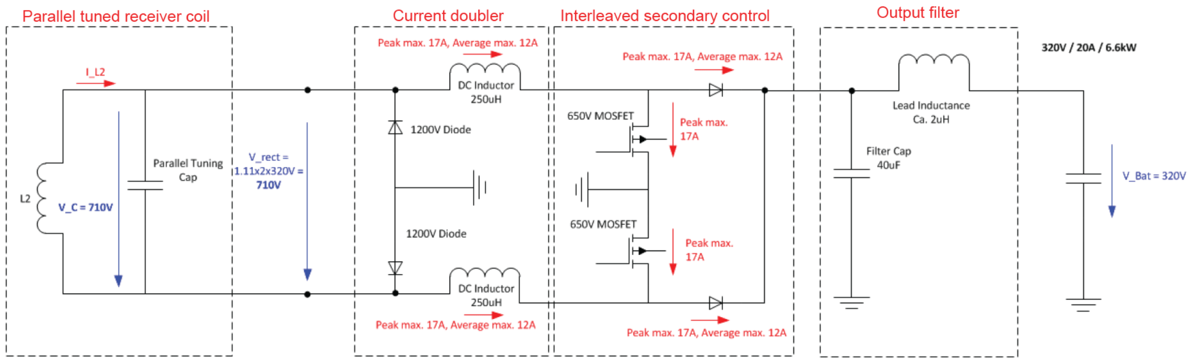


Figure AA.10 – Schematic of the EV power electronics for the MF-WPT2/Z3 DD reference EVPC

Table AA.10 shows the values of the circuit elements shown in Figure AA.10.

Table AA.10 – Values of circuit elements for Figure AA.10

Air gap class	**L2_Min µH**	**L2_Max µH**
Z3	16,8	17,1
Air gap class	**C_Parallel nF]**	
Z3	205	

AA.3 DD reference EVPCs for MF-WPT3

AA.3.1 General

Clause AA.3 describes reference EVPC proposals for MF-WPT3 classes Z1, Z2 and Z3. The reference supply power circuit specified in Annex B of ISO PAS 19363:2017 in combination with the reference EVPCs specified in Clause AA.3 fulfil the performance requirements described in Clause 7.

The reference EVPCs specified in Clause AA.3 are intended to be used at a nominal operating frequency of 85,00 kHz.

AA.3.2 DD reference EVPC for MF-WPT3/Z1

AA.3.2.1 Mechanical

Figure AA.11 shows the mechanical dimensions of the MF-WPT3/Z1 DD reference secondary device.

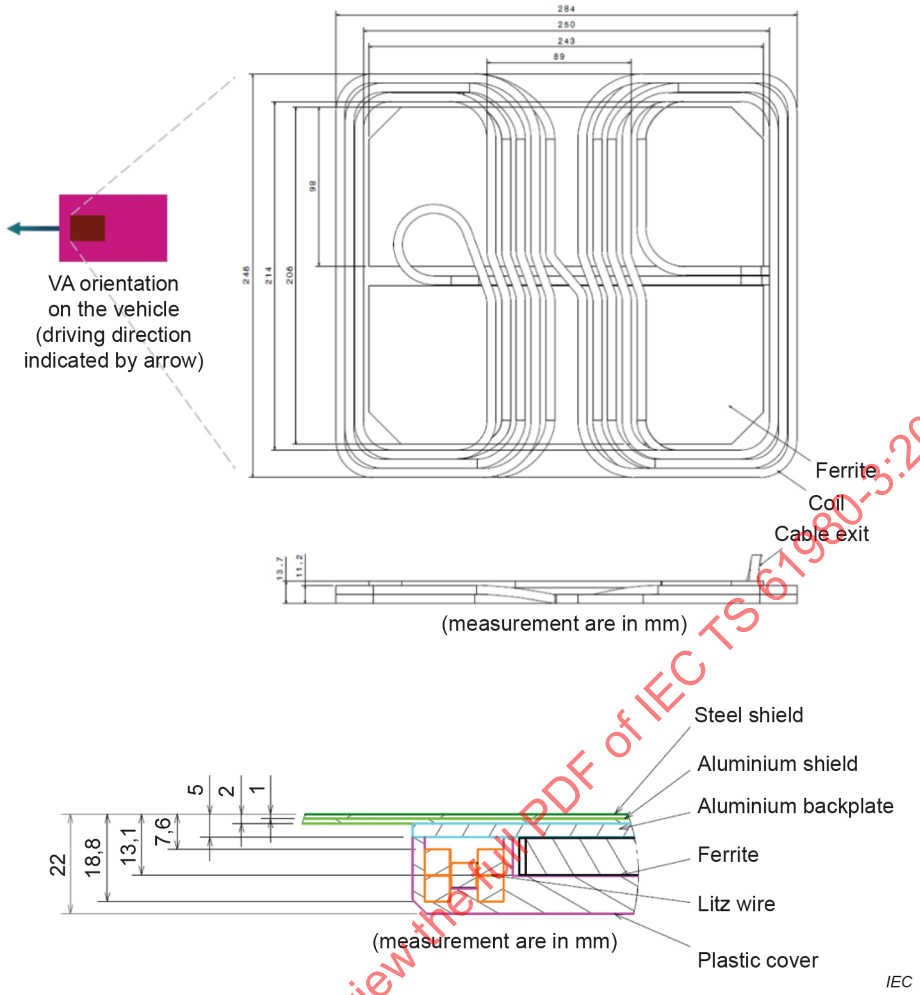


Figure AA.11 – Mechanical dimensions of the MF-WPT3/Z1 DD reference secondary device

The mechanical dimensions of this reference secondary device are shown in Table AA.11.

Table AA.11 – Mechanical dimensions of the MF-WPT3/Z1 DD reference secondary device

	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

AA.3.2.2 Electrical

Figure AA.12 shows the schematic of the EV power electronics for the reference secondary device described in AA.3.1.

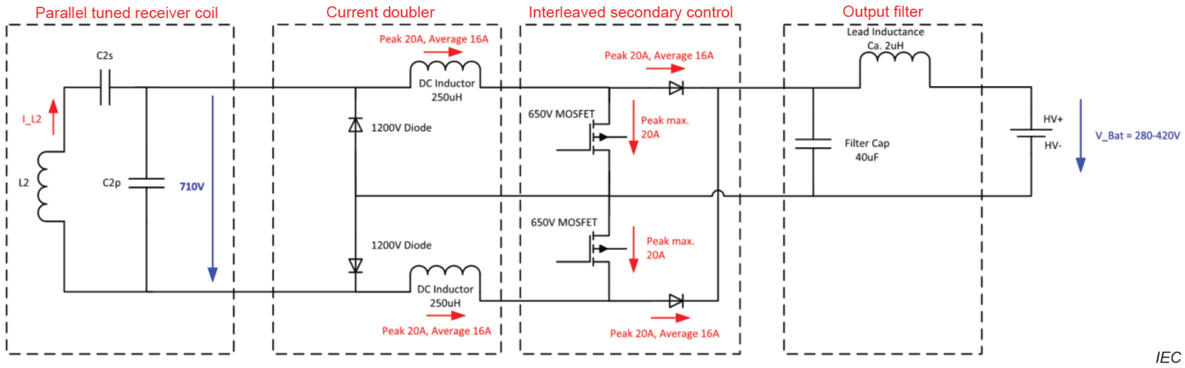


Figure AA.12 – Schematic of the EV power electronics for the MF-WPT3/Z1 DD reference EVPC

Table AA.12 shows the values of the circuit elements shown in Figure AA.12.

NOTE The lead cable length assumed for the inductance values given in Table AA.12 is 0,5 m.

Table AA.12 – Values of circuit elements for Figure AA.12

Air gap class	**L2_Min µH**	**L2_Max µH**
Z1	27,1	29,4
Air gap class	**C2s/C2p_nF**	
Z1	517 / 169	

AA.3.3 DD reference EVPC for MF-WPT3/Z2

AA.3.3.1 Mechanical

Figure AA.13 shows the mechanical dimensions of the MF-WPT3/Z2 DD reference secondary device.

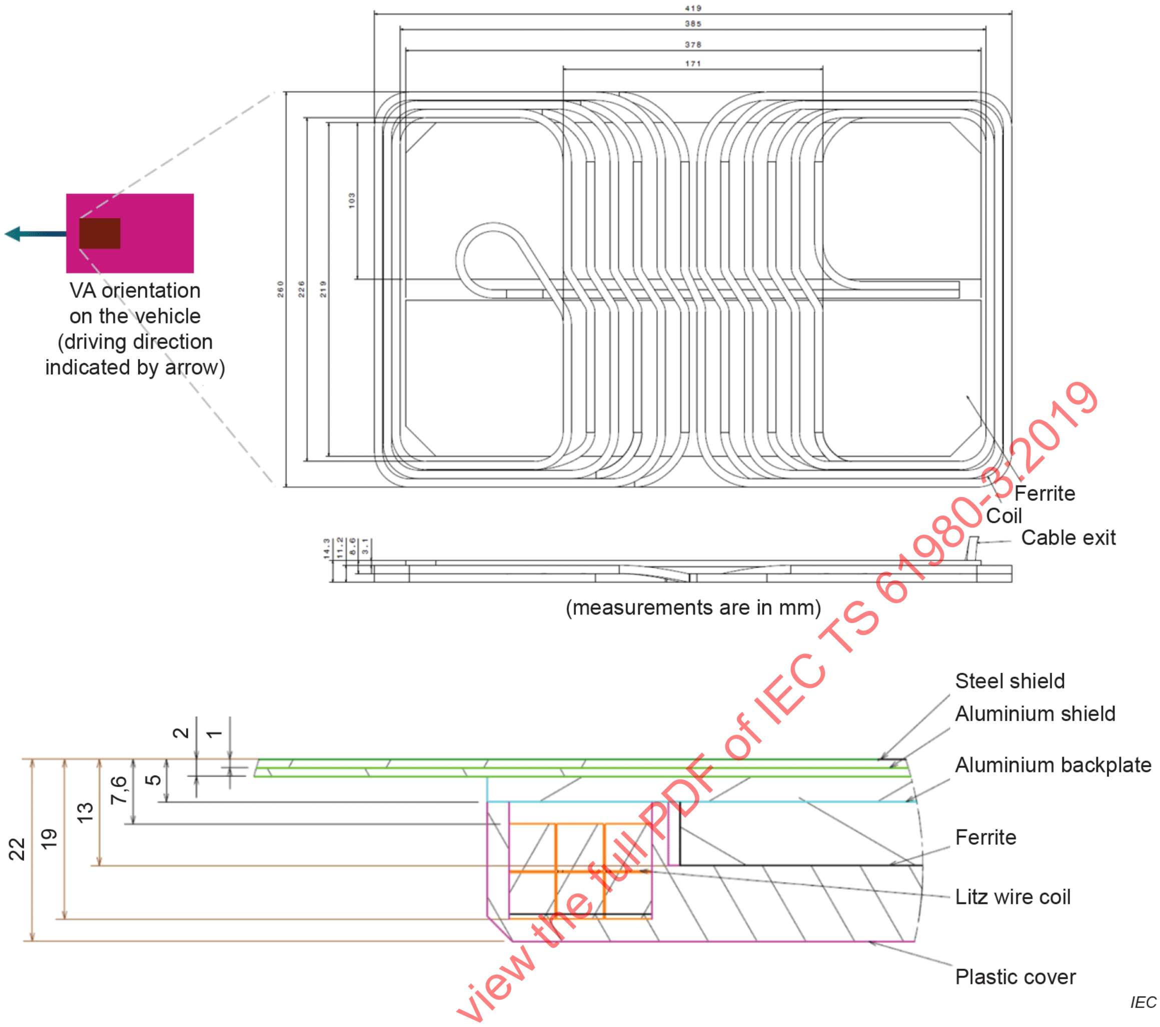


Figure AA.13 – Mechanical dimensions of the MF-WPT3/Z2 DD reference secondary device

The mechanical dimensions of this reference secondary device are shown in Table AA.13.

Table AA.13 – Mechanical dimensions of the MF-WPT3/Z2 DD reference secondary device

	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

AA.3.3.2 Electrical

Figure AA.14 shows the schematic of the EV power electronics for the reference secondary device described in AA.3.2.

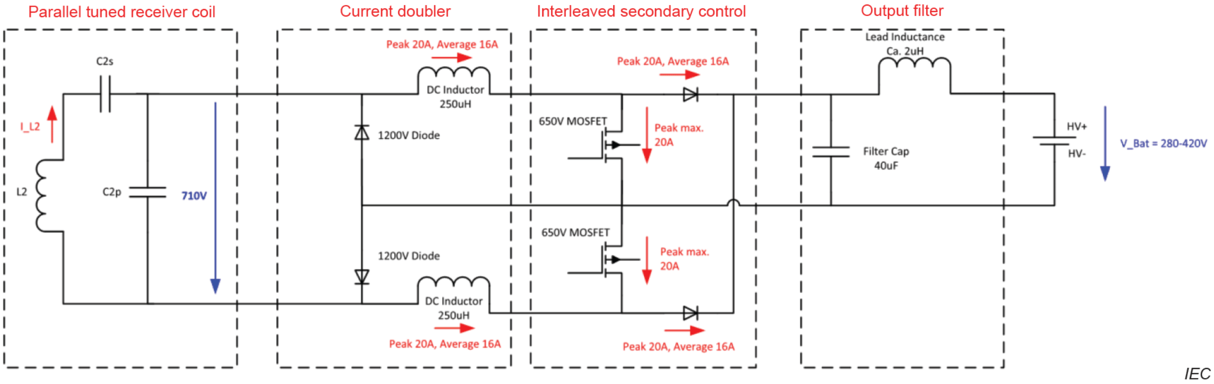


Figure AA.14 – Schematic of the EV power electronics for the MF-WPT3/Z2 DD reference EVPC

Table AA.14 shows the values of the circuit elements shown in Figure AA.14.

NOTE The lead cable length assumed for the inductance values given in Table AA.14 is 0,5 m.

Table AA.14 – Values of circuit elements for Figure AA.14

Air gap class	L2_Min µH	L2_Max µH
Z2	44,7	48,2
Air gap class	**C2s/C2p_nF**	
Z2	165 / 146	

AA.3.4 DD reference EVPC for MF-WPT3/Z3

AA.3.4.1 Mechanical

Figure AA.15 shows the mechanical dimensions of the MF-WPT3/Z3 DD reference secondary device.

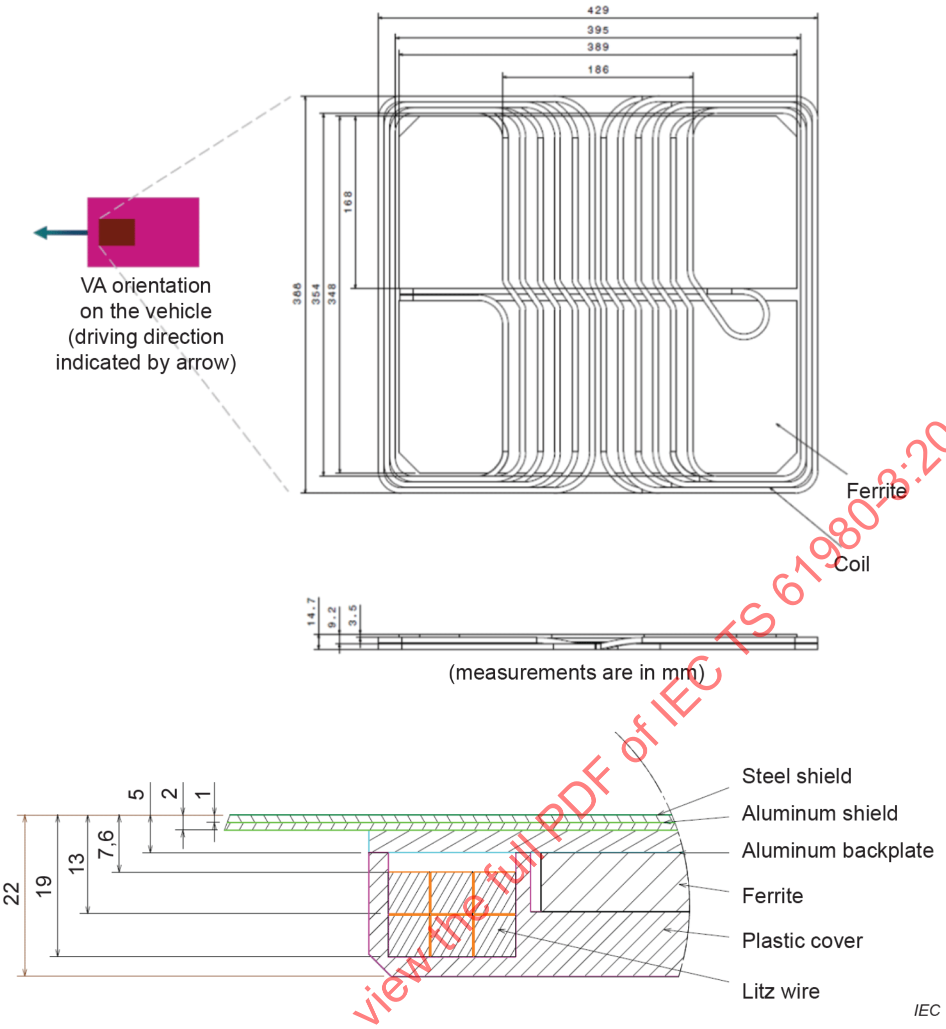


Figure AA.15 – Mechanical dimensions of the MF-WPT3/Z3 DD reference secondary device

The mechanical dimensions of this reference secondary device are shown in Table AA.15.

Table AA.15 – Mechanical dimensions of the MF-WPT3/Z3 DD reference secondary device

	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

AA.3.4.2 Electrical

Figure AA.16 shows the schematic of the EV power electronics for the reference secondary device described in AA.3.3.

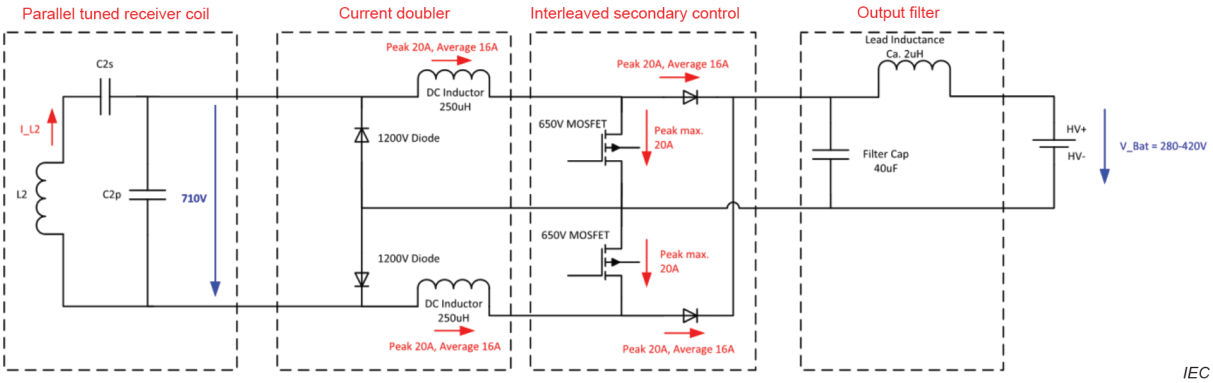


Figure AA.16 – Schematic of the EV power electronics for the MF-WPT3/Z3 DD reference EVPC

Table AA.16 shows the values of the circuit elements shown in Figure AA.16.

NOTE The lead cable length assumed for the inductance values given in Table AA.16 is 0,5 m.

Table AA.16 – Values of circuit elements for Figure AA.16

Air gap Class	L2_Min µH	L2_Max µH
Z3	61,1	64,7
Air gap Class	**C2s/C2p_nF**	
Z3	94 / 142	

Annex BB
(informative)

Circular reference EV power circuit (EVPC) for MF-WPT1, MF-WPT2 and MF-WPT3

BB.1 Circular reference EVPCs for MF-WPT1

BB.1.1 General

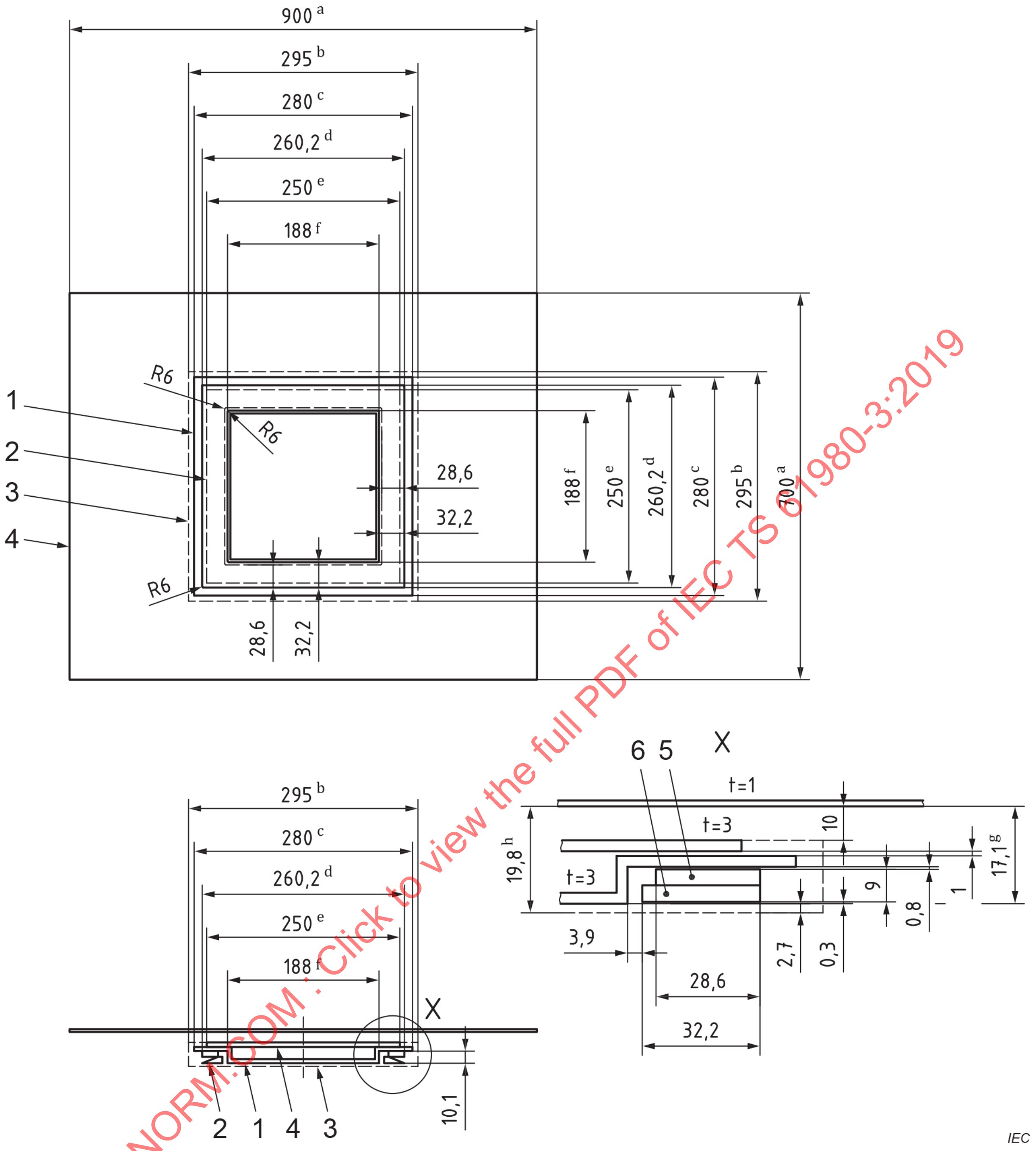
Clause BB.1 describes reference EVPCs for MF-WPT1 and Z classes Z1, Z2 and Z3. The reference supply power circuit specified in Annex C of ISO PAS 19363:2017 in combination with the reference EVPCs specified in Clause BB.1 fulfil the power transfer performance requirements described in Clause 7.

The range of coupling factors and the maximum coil currents in the tables of Annex BB correspond with an aluminium shield equal to 800 mm x 800 mm x 3 mm, which may result in different values compared to the vehicle mimic plate as described in Clause 101.

BB.1.2 Circular reference EVPC for MF-WPT1/Z1

BB.1.2.1 Mechanical

Figure BB.1 shows the mechanical dimensions of the MF-WPT1/Z1 circular reference secondary device.



Key

1 ferrite
2 coil
3 outer case (for reference)
4 aluminium shield
5 8 upper turns
6 9 lower turns

a aluminium shield dimension
b outer case dimension
c outer core dimension
d coil dimension
e shielding dimension
f inner core dimension
g core to shielding distance
h assy dimension

Figure BB.1 – Mechanical dimensions of the MF-WPT1/Z1 circular reference secondary device

BB.1.2.2 Electrical

Figure BB.2 shows the schematics of the power electronics for the reference secondary device described in BB.1.2.1.

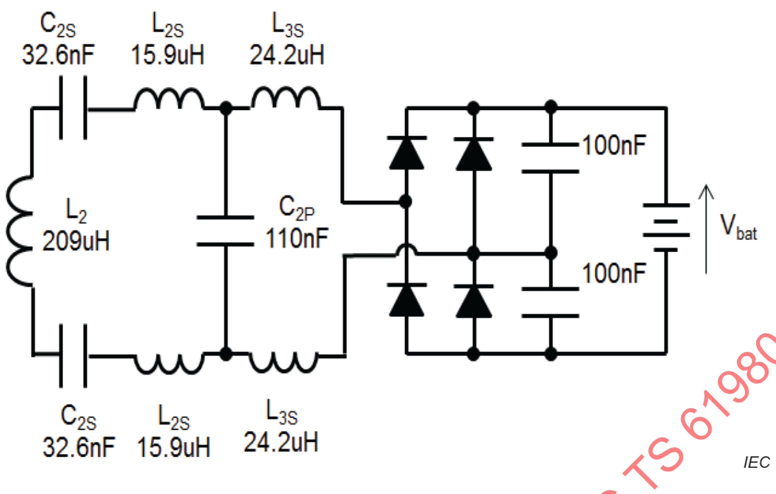


Figure BB.2 – Schematic of the EV power electronics for the MF-WPT1/Z1 circular reference EVPC

The coupling factor of this reference EV device when used in combination with the reference supply device as specified in Annex C of ISO PAS 19363:2018 is shown in Table BB.1.

Table BB.1 – Range of coupling factors

Minimum coupling factor	0,109
Maximum coupling factor	0,290

The coil accepts the current according to Table BB.2.

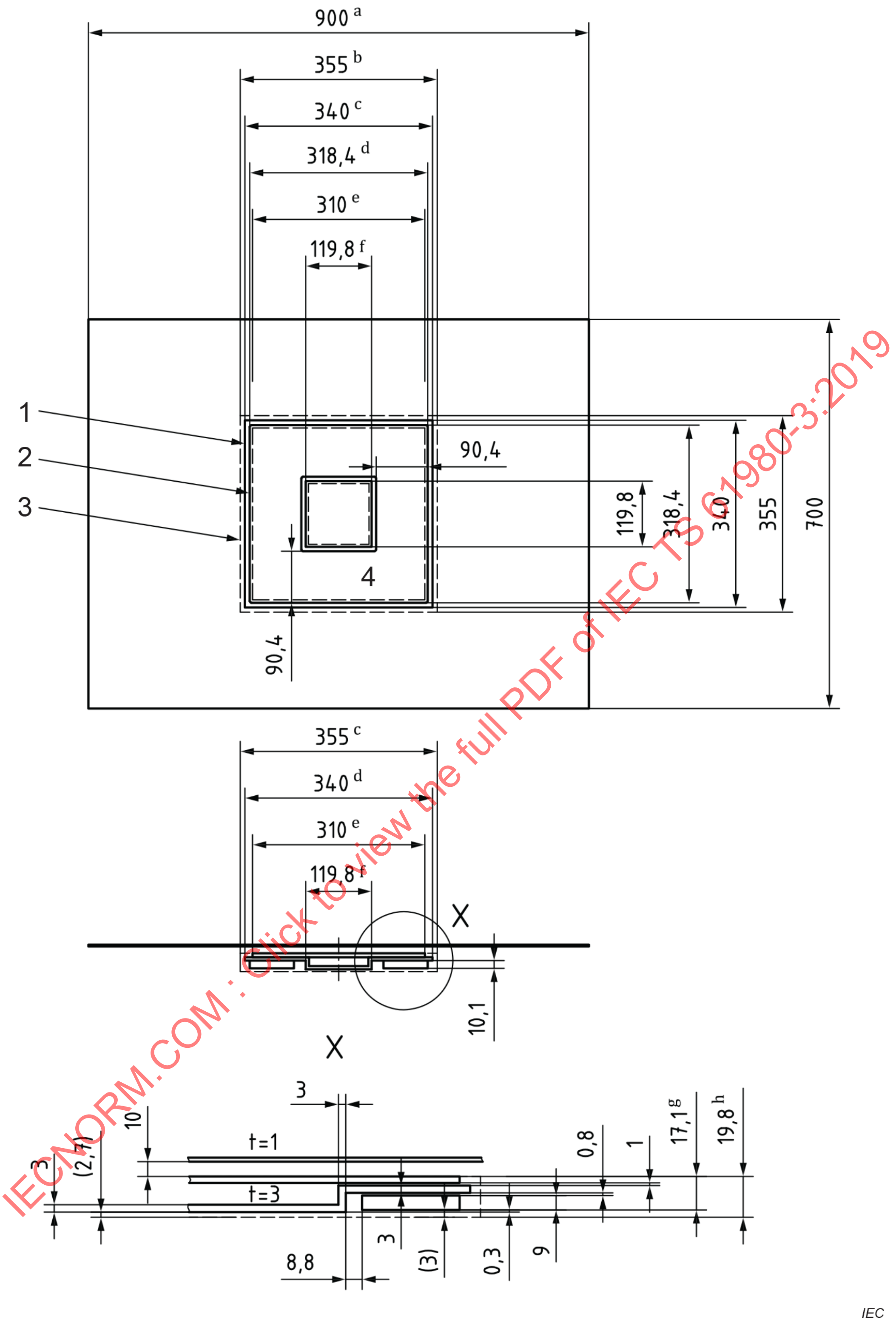
Table BB.2 – Coil current

Maximum coil current	17 A RMS

BB.1.3 Circular reference EVPC for MF-WPT1/Z2

BB.1.3.1 Mechanical

Figure BB.3 shows the mechanical dimensions of the MF-WPT1/Z2 circular reference secondary device.



Key

1 ferrite
2 coil
3 outer case (for reference)
4 aluminium shield

a aluminium shield dimension
b outer case dimension
c outer core dimension
d coil dimension
e shielding dimension
f inner core dimension
g core to shielding distance
h assy dimension

Figure BB.3 – Mechanical dimensions of the MF-WPT1/Z2 circular reference secondary device

BB.1.3.2 Electrical

Figure BB.4 shows the schematics of the power electronics for the reference secondary device described in BB.1.3.1.

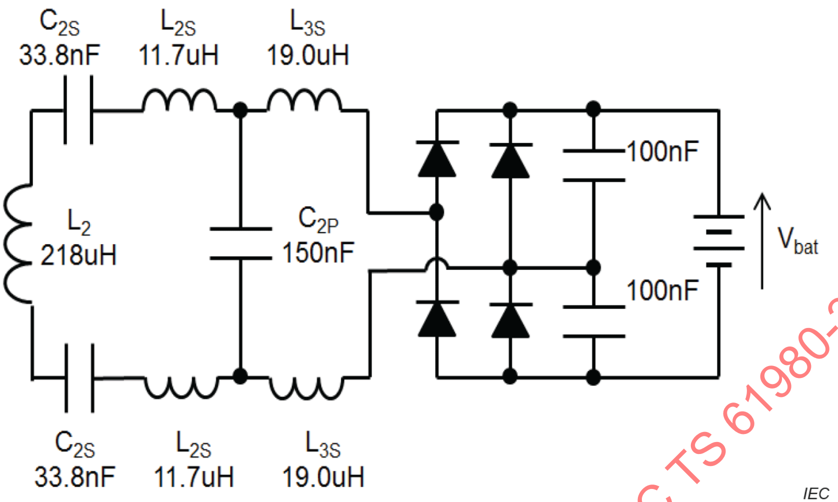


Figure BB.4– Schematic of the EV power electronics for the MF-WPT1/Z2 circular reference EVPC

The coupling factor of this reference EV device when used in combination with the reference supply device as specified in Clause EE.3 is shown in Table BB.3.

Table BB.3 – Range of coupling factors

Minimum coupling factor	0,082
Maximum coupling factor	0,215

The coil accepts the current according to Table BB.4.

Table BB.4 – Coil current

Maximum coil current	18 A RMS

BB.1.4 Circular reference EVPC for MF-WPT1/Z3

BB.1.4.1 Mechanical

Figure BB.5 shows the mechanical dimensions of the MF-WPT1/Z3 circular reference secondary device.

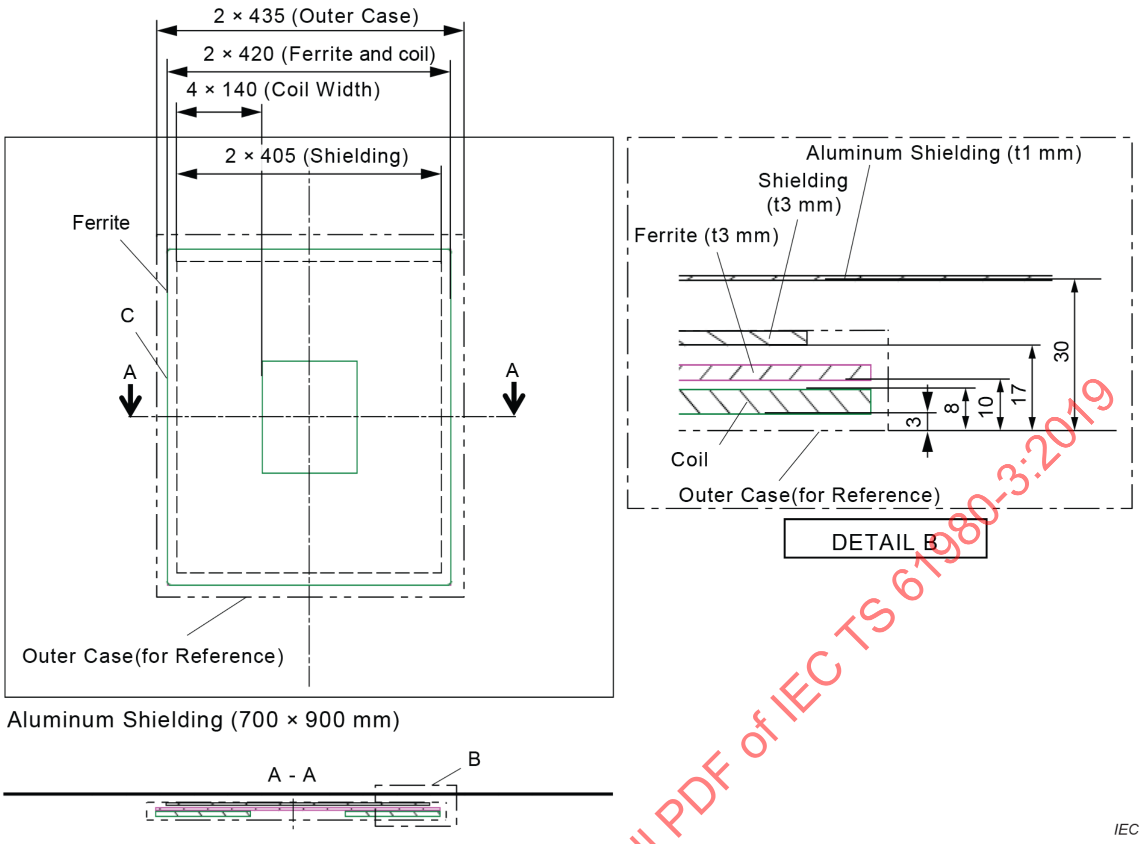


Figure BB.5 – Mechanical dimensions of the MF-WPT1/Z3 circular reference secondary device

BB.1.4.2 Electrical

Figure BB.6 shows the schematics of the power electronics for the reference secondary device described in BB.1.4.1.

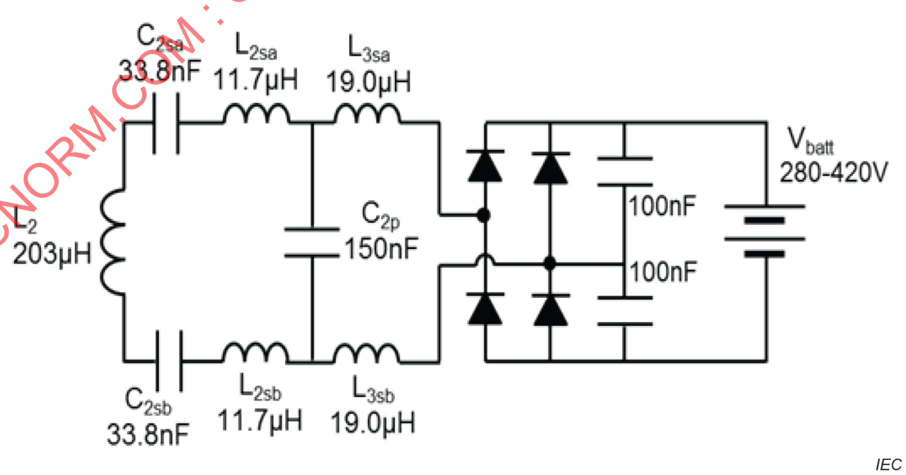


Figure BB.6 – Schematic of the EV power electronics for the MF-WPT1/Z3 circular reference EVPC

The coupling factor of this reference EV device when used in combination with the reference supply device as specified in Annex C of ISO PAS 19363:2017 is shown in Table BB.5.

Table BB.5 – Range of coupling factors

Minimum coupling factor	0,089
Maximum coupling factor	0,258

The coil accepts the current according to Table BB.6.

Table BB.6 – Coil current

Maximum coil current	A RMS

BB.2 Circular reference EVPCs for MF-WPT2

BB.2.1 General

Clause BB.2 describes reference EVPCs for MF-WPT2 classes Z1, Z2 and Z3. The reference supply power circuit specified in Annex C of ISO PAS 19363:2017 in combination with the reference EVPCs specified in Clause BB.2 fulfil the power transfer performance requirements described in Clause 7.

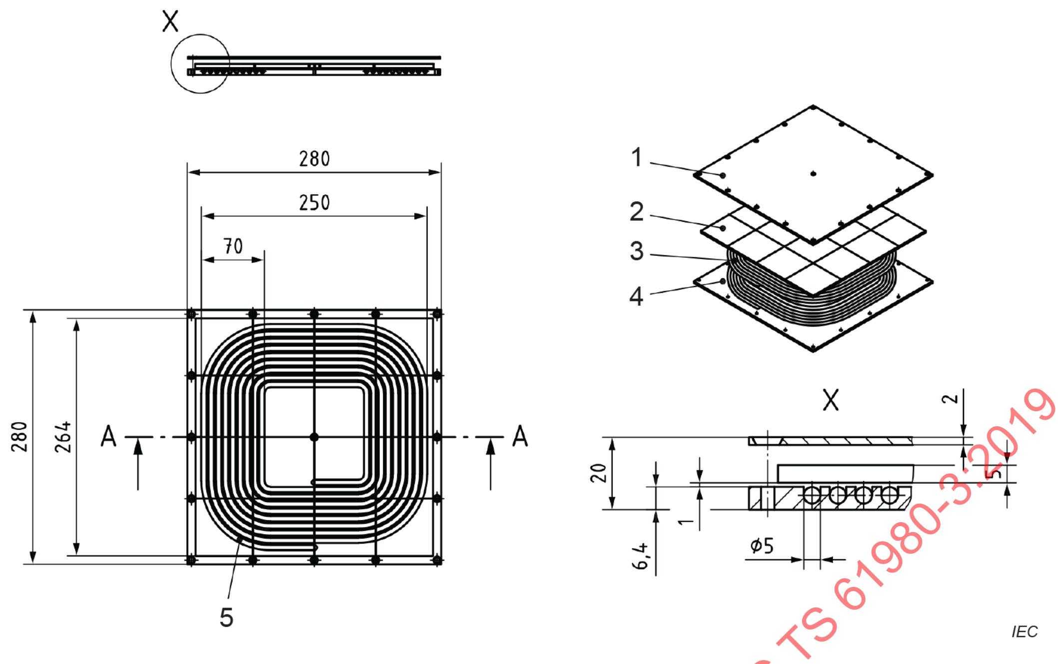
The reference EVPCs specified in Clause BB.2 will perform over the system frequency range of 81,38kHz to 90,00 kHz, with a nominal operating frequency of 85,00 kHz.

The range of coupling factors and the maximum coil currents in the tables of Annex BB correspond with an aluminium shield equal to 800 mm x 800 mm x 3 mm, which may result in different values compared to the vehicle mimic plate as described in Clause 101.

BB.2.2 Circular reference EVPC for MF-WPT2/Z1

BB.2.2.1 Mechanical

Figure BB.7 shows the mechanical dimensions of the MF-WPT2/Z1 circular reference secondary device.



Key

1 aluminium plate

2 ferrite tiles

3 litz wire

4 litz tray

5 10 turns

Figure BB.7 – Mechanical dimensions of the MF-WPT2/Z1 circular reference secondary device

The mechanical configuration of the MF-WPT2/Z1 secondary device includes an aluminium shield 800 mm x 800 mm x 3 mm (not shown in Figure BB.7).

The coupling factor of this reference secondary device when used in combination with the reference supply device specified in ISO PAS 19363:2017, Annex C, is shown in Table BB.7.

Table BB.7 – Range of coupling factors

Minimum coupling factor	0,109
Maximum coupling factor	0,238

The coil accepts the current according to Table BB.8.

Table BB.8 – Coil current

Maximum coil current	50 A (RMS)

BB.2.2.2 Electrical

Figure BB.8 shows the schematic of the EV power electronics for the reference secondary device described in BB.2.2.1.

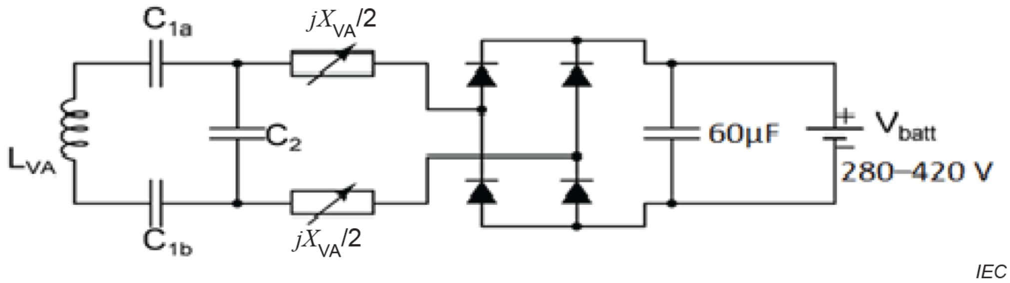


Figure BB.8 – Schematic of the EV power electronics for the MF-WPT2/Z1 circular reference EVPC

Table BB.9 shows the values of the circuit elements shown in Figure BB.8.

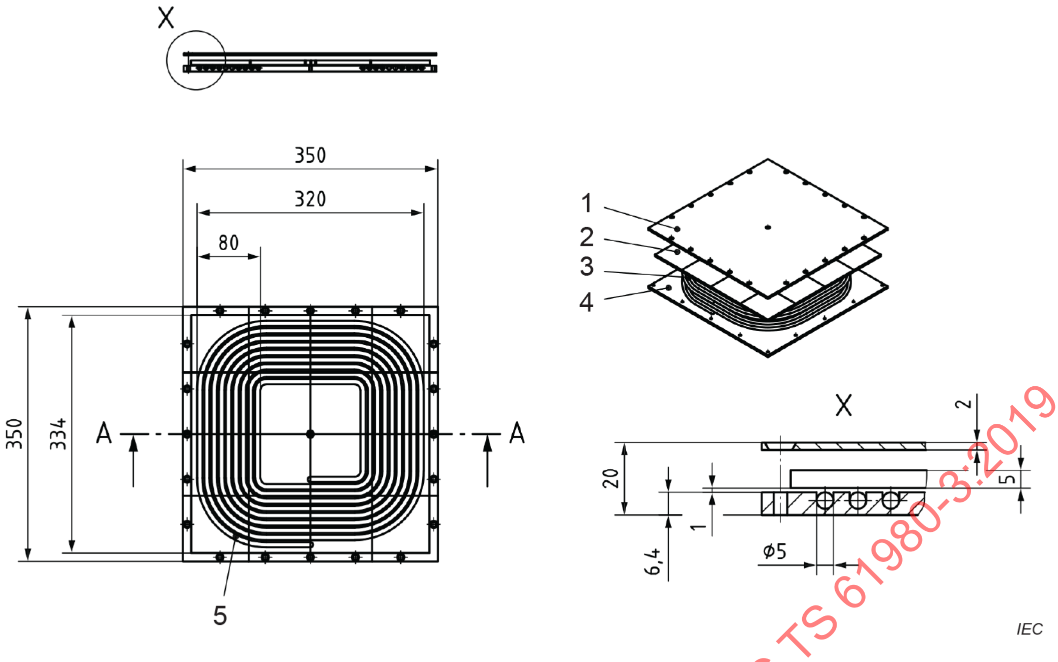
Table BB.9 – Values of circuit elements for Figure BB.8

Parameter	Symbol	Value	Frequency
Capacitance (nF)	C_{1a}, C_{1b}	290	N/A
Capacitance (nF)	C_2	170	N/A
Inductance (µH)	L_{VA}	37,2 to 38,7	N/A
Reactance range (Ω)	$jX_{VA}/2$	–10 to 4	81,38 kHz
Reactance range (Ω)	$jX_{VA}/2$	–8 to 5	85,00 kHz
Reactance range (Ω)	$jX_{VA}/2$	–6 to 6,5	90,00 kHz

BB.2.3 Circular reference EVPC for MF-WPT2/Z2

BB.2.3.1 Mechanical

Figure BB.9 shows the mechanical dimensions of the MF-WPT2/Z2 circular reference secondary device.



Key

1 aluminium plate
2 ferrite tiles
3 litz wire
4 litz tray
5 9 turns

Figure BB.9 – Mechanical dimensions of the MF-WPT2/Z2 circular reference secondary device

The mechanical configuration of the MF-WPT2/Z2 secondary device includes an aluminium shield 800 mm x 800 mm x 3 mm (not shown in Figure BB.9).

The coupling factor of this reference secondary device when used in combination with the reference supply device specified in ISO PAS 19363:2017, Annex C, is shown in Table BB.10.

Table BB.10 – Range of coupling factors

Minimum coupling factor	0,094
Maximum coupling factor	0,244

The coil accepts the current according to Table BB.11.

Table BB.11 – Coil current

Maximum coil current	50 A (RMS)

BB.2.3.2 Electrical

Figure BB.10 shows the schematic of the EV power electronics for the reference secondary device described in BB.2.3.1.

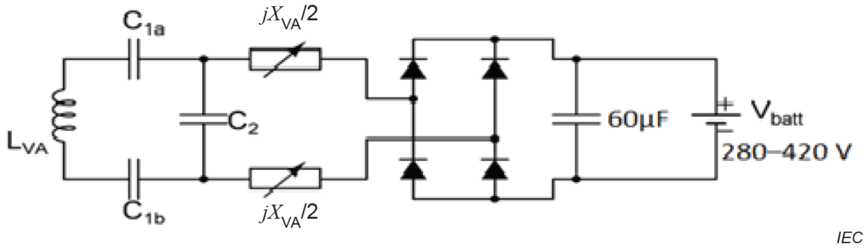


Figure BB.10 – Schematic of the EV power electronics for the MF-WPT2/Z2 circular reference EVPC

Table BB.12 shows the values of the circuit elements shown in Figure BB.10.

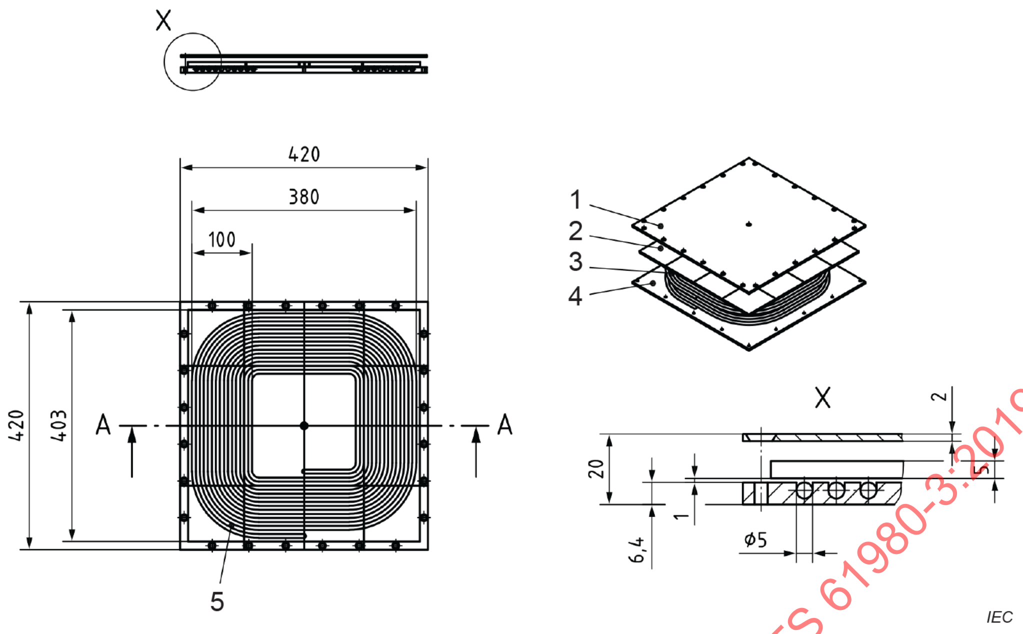
Table BB.12 – Values of circuit elements for Figure BB.10

Parameter	Symbol	Value	Frequency
Capacitance (nF)	C_{1a}, C_{1b}	250	N/A
Capacitance (nF)	C_2	170	N/A
Inductance (μH)	L_{VA}	43,1 to 44,0	N/A
Reactance range (Ω)	$jX_{VA}/2$	–8 to 6	81,38 kHz
Reactance range (Ω)	$jX_{VA}/2$	–6 to +7	85,00 kHz
Reactance range (Ω)	$jX_{VA}/2$	–4 to 8,5	90,00 kHz

BB.2.4 Circular reference EVPC for MF-WPT2/Z3

BB.2.4.1 Mechanical

Figure BB.11 shows the mechanical dimensions of the MF-WPT2/Z3 circular reference secondary device.



Key

1	aluminium plate
2	ferrite tiles
3	litz wire
4	litz tray
5	8 turns

Figure BB.11– Mechanical dimensions of the MF-WPT2/Z3 circular reference secondary device

The mechanical configuration of the MF-WPT2/Z3 secondary device includes an aluminium shield 800 mm x 800 mm x 3mm (not shown in Figure BB.11).

The coupling factor of this reference secondary device when used in combination with the reference supply device specified in ISO PAS 19363:2017, Annex C, is shown in Table BB.13.

Table BB.13 – Range of coupling factors

Minimum coupling factor	0,088
Maximum coupling factor	0,245

The coil accepts the current according to Table BB.14.

Table BB.14 – Coil current

Maximum coil current	50 A (RMS)

BB.2.4.2 Electrical

Figure BB.12 shows the schematic of the EV power electronics for the reference secondary device described in BB.2.4.1.

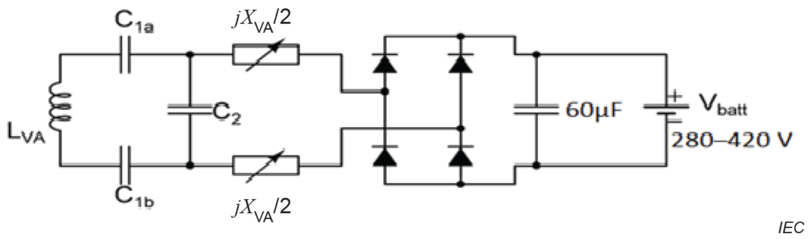


Figure BB.12 – Schematic of the EV power electronics for the MF-WPT2/Z3 circular reference EVPC

Table BB.15 shows the values of the circuit elements shown in Figure BB.12.

Table BB.15 – Values of circuit elements for Figure BB.12

Parameter	Symbol	Value	Frequency
Capacitance (nF)	C_{1a}, C_{1b}	310	N/A
Capacitance (nF)	C_2	170	N/A
Inductance (µH)	L_{VA}	39,3 to 40,0	N/A
Reactance range (Ω)	$jX_{VA}/2$	–10 to 4	81,38 kHz
Reactance range (Ω)	$jX_{VA}/2$	–8 to 5	85,00 kHz
Reactance range (Ω)	$jX_{VA}/2$	–6 to 6,5	90,00 kHz

BB.3 Circular reference EVPCs for MF-WPT3

BB.3.1 General

Clause BB.3 describes reference EVPC proposals for MF-WPT3 classes Z1, Z2 and Z3. The reference supply power circuit specified in Annex C of ISO PAS 19363:2017 in combination with the reference EVPCs specified in Clause BB.3 fulfil the performance requirements described in Clause 7.

The reference EVPCs specified in Clause BB.2 will perform over the system frequency range of 81,38 kHz to 90,00 kHz, with a nominal operating frequency of 85,00 kHz.

BB.3.2 Circular reference EVPC for MF-WPT3/Z1

BB.3.2.1 Mechanical

Figure BB.13 shows the mechanical dimensions of the MF-WPT3/Z1 circular reference secondary device.

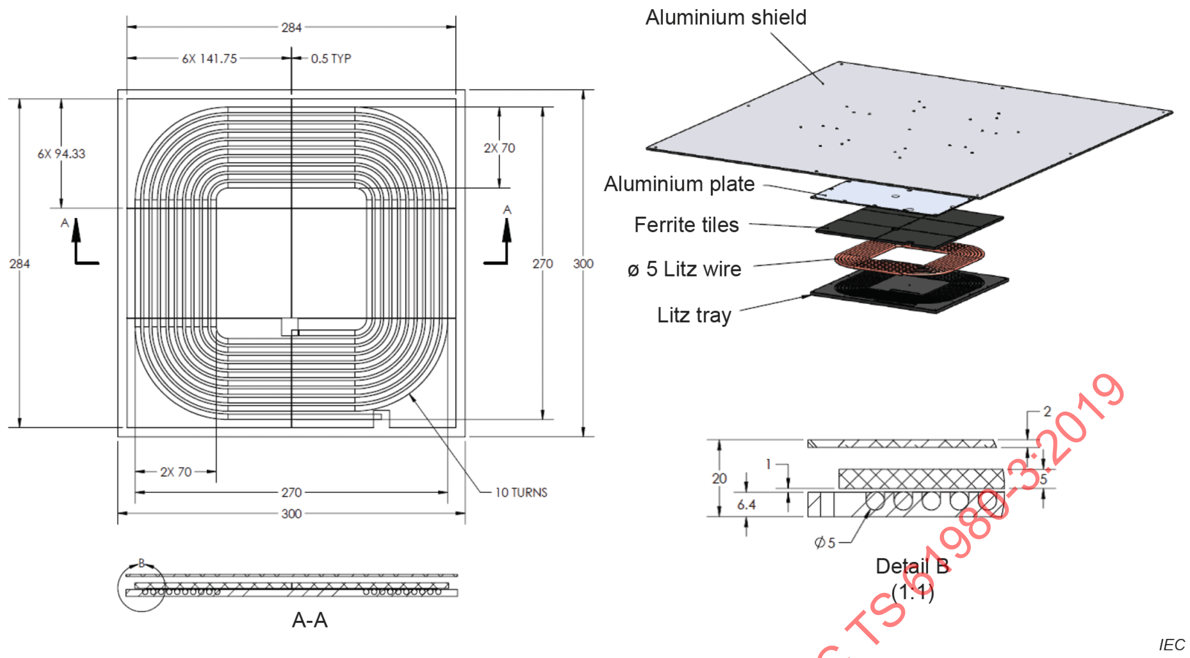


Figure BB.13 – Mechanical dimensions of the MF-WPT3/Z1 circular reference secondary device

The aluminium shield shown in Figure BB.13 is 800 mm x 800 mm x 3 mm.

The coupling factor of this reference secondary device when used in combination with the reference supply device specified in ISO PAS 19363:2017, Annex C, is shown in Table BB.16.

Table BB.16 – Range of coupling factors

Minimum coupling factor	0,120
Maximum coupling factor	0,261

The coil accepts the current according to Table BB.17.

Table BB.17 – Coil current

Maximum coil current	60 A (RMS)

BB.3.2.2 Electrical

Figure BB.14 shows the schematic of the EV power electronics for the reference secondary device described in BB.3.2.1.

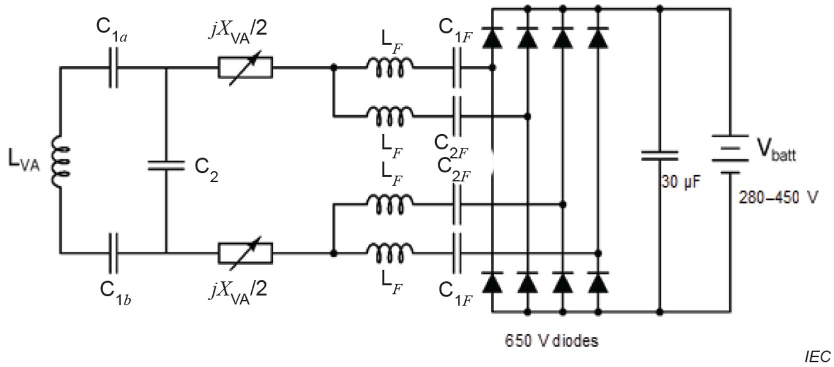


Figure BB.14 – Schematic of the EV power electronics for the MF-WPT3/Z1 circular reference EVPC

Table BB.18 shows the values of the circuit elements shown in Figure BB.14.

Table BB.18 – Values of circuit elements for Figure BB.14

Parameter	Symbol	Value	Frequency
Capacitance (nF)	C_2	143	N/A
Capacitance (nF)	C_{1a}	223	N/A
Capacitance (nF)	C_{1b}	223	N/A
Inductance (µH)	L_{VA}	45,0 to 47,0	N/A
Inductance (µH)	L_F	54	N/A
Capacitance (nF)	C_{1F}	100	N/A
Capacitance (nF)	C_{2F}	49	N/A
Reactance range (Ω)	$jX_{VA}/2$	–15,5 to 0	81,38 kHz
Reactance range (Ω)	$jX_{VA}/2$	–15 to 0	85,00 kHz
Reactance range (Ω)	$jX_{VA}/2$	–14 to 0	90,00 kHz

BB.3.3 Circular reference EVPC for MF-WPT3/Z2

BB.3.3.1 Mechanical

Figure BB.15 shows the mechanical dimensions of the MF-WPT3/Z2 circular reference secondary device.

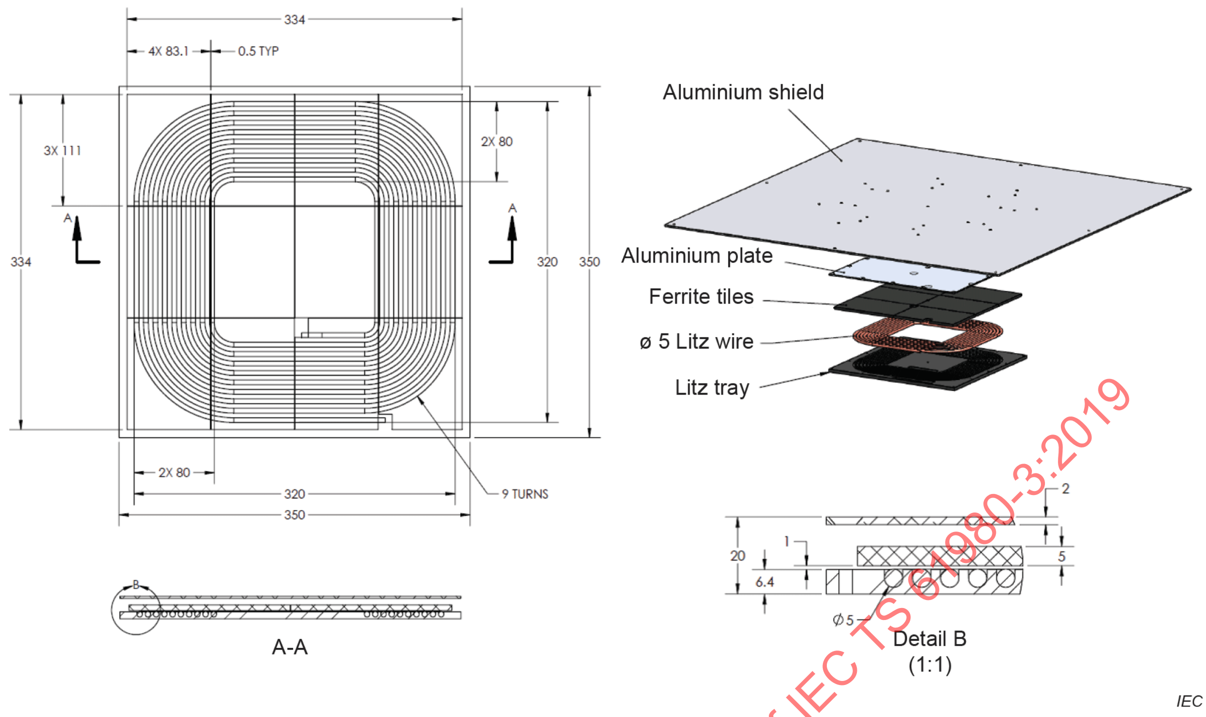


Figure BB.15 – Mechanical dimensions of the MF-WPT3/Z2 circular reference secondary device

The aluminium shield shown in Figure BB.15 is 800 mm x 800 mm x 3 mm.

The coupling factor of this reference secondary device when used in combination with the reference supply device specified in ISO PAS 19363:2017, Annex C, is shown in Table BB.19.

Table BB.19 – Range of coupling factors

Minimum coupling factor	0,094
Maximum coupling factor	0,244

The coil accepts the current according to Table BB.20.

Table BB.20 – Coil current

Maximum coil current	60 A (RMS)

BB.3.3.2 Electrical

Figure BB.16 shows the schematic of the EV power electronics for the reference secondary device described in BB.3.3.1.

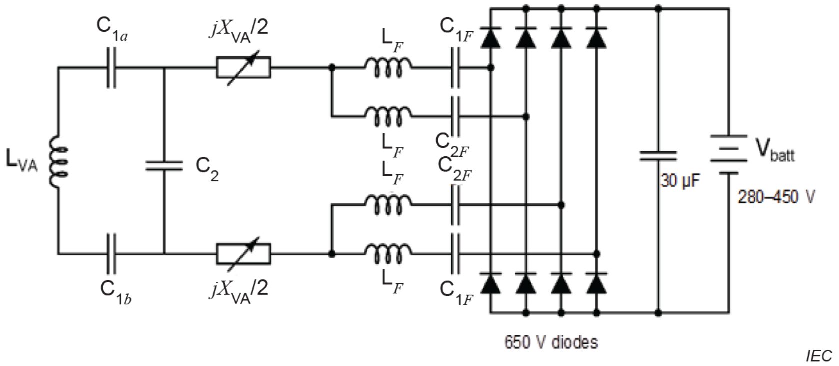


Figure BB.16 – Schematic of the EV power electronics for the MF-WPT2/Z2 circular reference EVPC

Table BB.21 shows the values of the circuit elements shown in Figure BB.16.

Table BB.21 – Values of circuit elements for Figure BB.16

Parameter	Symbol	Value	Frequency
Capacitance (nF)	C_2	145	N/A
Capacitance (nF)	C_{1a}	270	N/A
Capacitance (nF)	C_{1b}	270	N/A
Inductance (µH)	L_{VA}	43,1 to 44,0	N/A
Inductance (µH)	L_F	54	N/A
Capacitance (nF)	C_{1F}	100	N/A
Capacitance (nF)	C_{2F}	49	N/A
Reactance range (Ω)	$jX_{VA}/2$	–15,5 to 0	81,38 kHz
Reactance range (Ω)	$jX_{VA}/2$	–15 to 0	85,00 kHz
Reactance range (Ω)	$jX_{VA}/2$	–14 to 0	90,00 kHz

BB.3.4 Circular reference EVPC for MF-WPT3/Z3

BB.3.4.1 Mechanical

Figure BB.17 shows the mechanical dimensions of the MF-WPT3/Z3 circular reference secondary device.

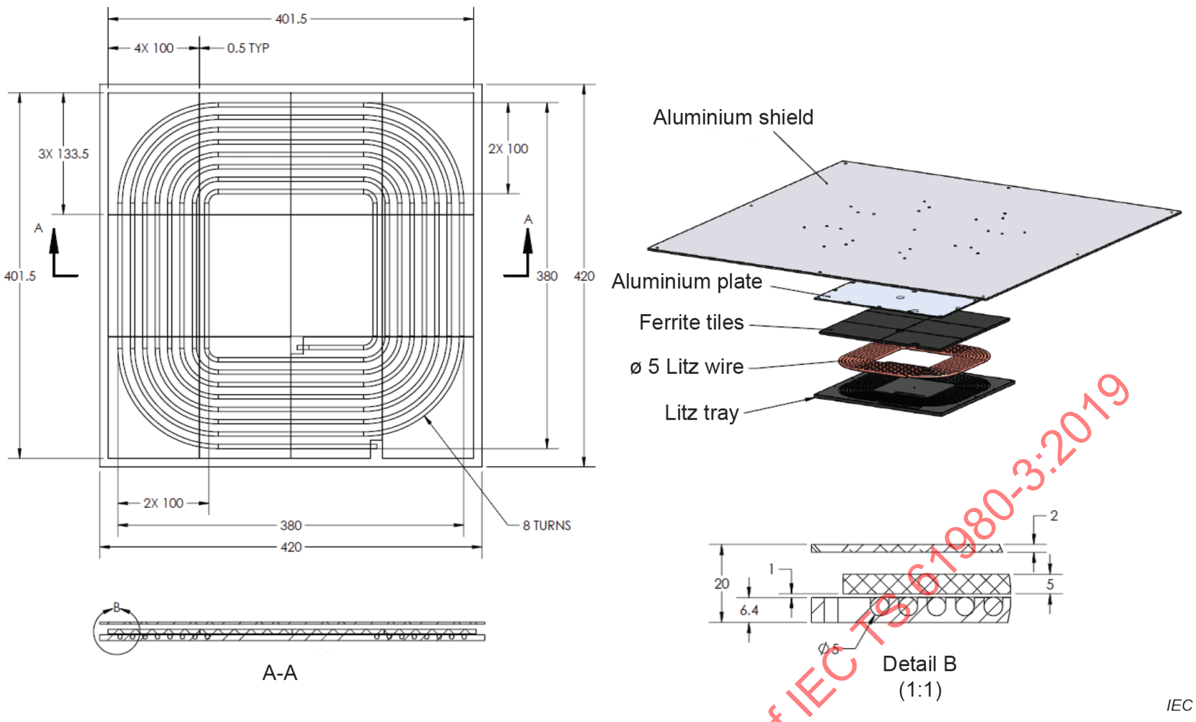


Figure BB.17 – Mechanical dimensions of the MF-WPT3/Z3 circular reference secondary device

The aluminium shield shown in Figure BB.17 is 800 mm x 800 mm x 3 mm.

The coupling factor of this reference secondary device when used in combination with the reference supply device specified in ISO PAS 19363:2017, Annex C, is shown in Table BB.22.

Table BB.22 – Range of coupling factors

Minimum coupling factor	0,088
Maximum coupling factor	0,245

The coil accepts the current according to Table BB.23

Table BB.23 – Coil current

Maximum coil current	60 A (RMS)

BB.3.4.2 Electrical

Figure BB.18 shows the schematic of the EV power electronics for the reference secondary device described in BB.3.4.1.

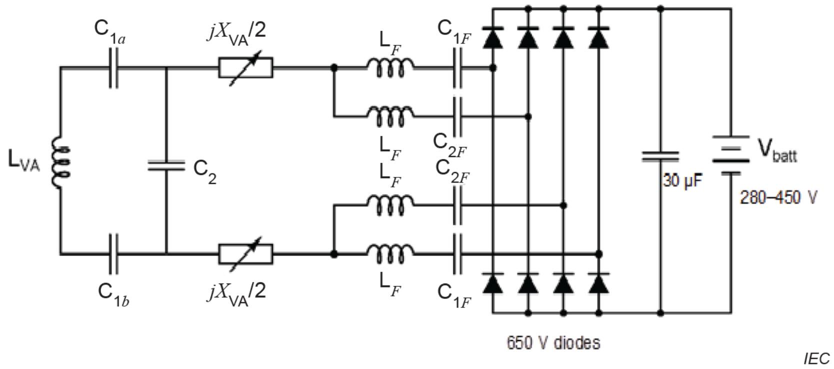


Figure BB.18– Schematic of the EV power electronics for the MF-WPT3/Z3 circular reference EVPC

Table BB.24 shows the values of the circuit elements shown in Figure BB.18.

Table BB.24 – Values of circuit elements for Figure BB.18

Parameter	Symbol	Value	Frequency
Capacitance (nF)	C_2	150	N/A
Capacitance (nF)	C_{1a}	325	N/A
Capacitance (nF)	C_{1b}	325	N/A
Inductance (μH)	L_{VA}	39,3 to 40,0	N/A
Inductance (μH)	L_F	54	N/A
Capacitance (nF)	C_{1F}	100	N/A
Capacitance (nF)	C_{2F}	49	N/A
Reactance range (Ω)	$jX_{VA}/2$	–15,5 to 0	81,38 kHz
Reactance range (Ω)	$jX_{VA}/2$	–15 to 0	85,00 kHz
Reactance range (Ω)	$jX_{VA}/2$	–14 to 0	90,00 kHz

Annex CC
(informative)

Heavy-duty magnetic field WPT

CC.1 Heavy-duty WPT reference for MF-WPT5

Clause CC.1 describes the reference supply power circuit and the secondary reference device for MF-WPT5. The reference supply power circuit and secondary reference device specified in Annex CC fulfil the power transfer performance requirements for heavy-duty MF-WPT5.

CC.2 Heavy-duty WPT infrastructure reference for MF-WPT5

CC.2.1 Mechanical

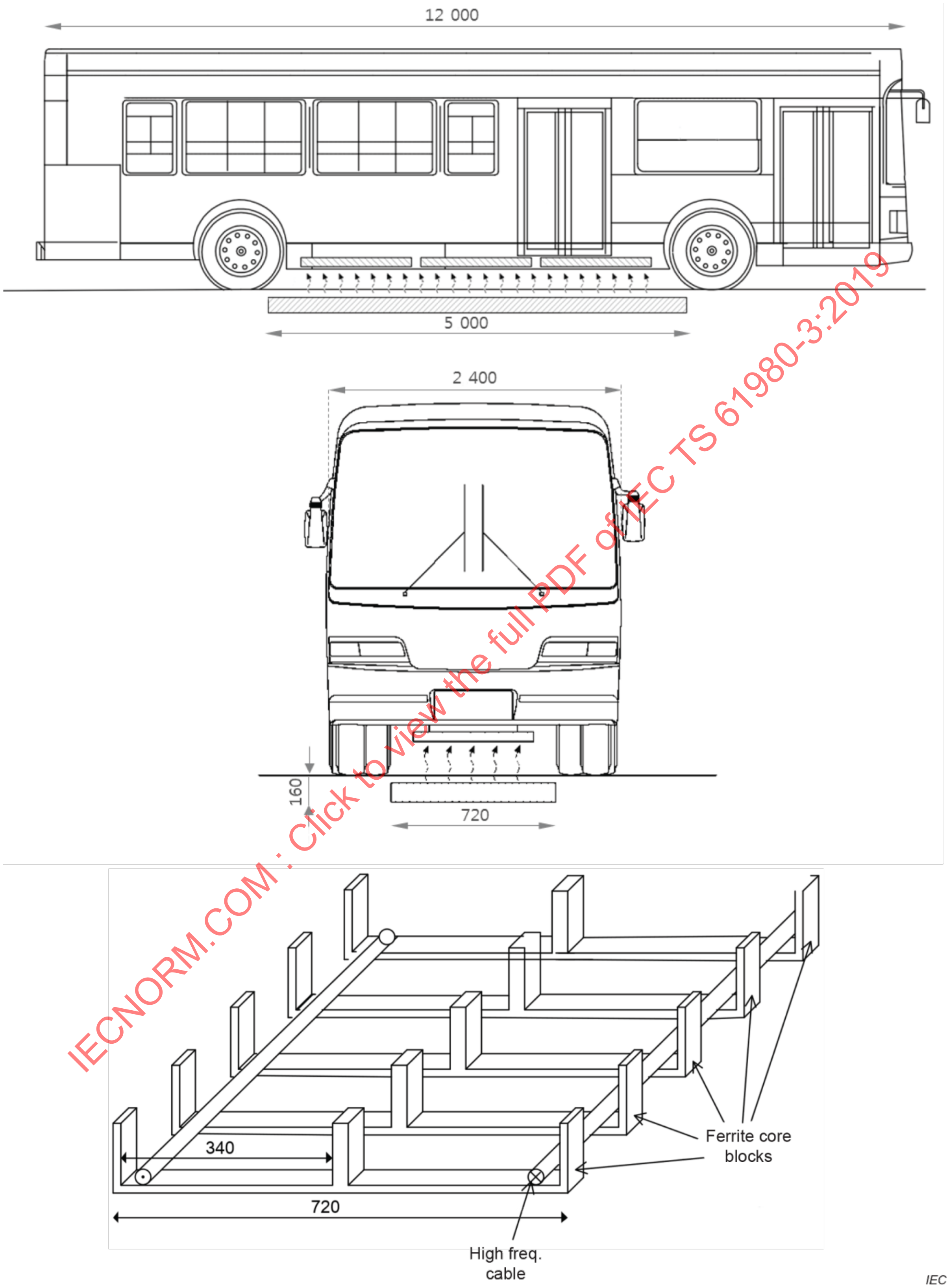
CC.2.1.1 General

Figure CC.1 shows the mechanical dimensions of the MF-WPT5 heavy-duty reference primary device. Wireless power transfer systems use magnetic cores to maximize magnetic flux density. The basic core structure with EE type is composed of a pair of E-shaped cores. In the EE type structure, road embedded power-cable module cables are wound around the central magnetic core pole. The central core has twofold greater thickness than that of the other cores.

The embedded power cable module is segmented for safety. For this purpose, the magnetic sensors are located at the entrance of the segment to detect the arrival of electric vehicles. When the sensor of the first segment detects the coming of an electric vehicle, the first segment of the embedded power cable module segment is activated. When the second sensor senses the electric vehicle, the first segment turns off, and the second segment turns on. The signal cable sends a signal from the sensor of the embedded power cable module to the inverter controller. FRP cable tube also protects this signal cable.

The common power cables or coils are used to connect each segment to the inverter. They shall be shielded so as not to affect the segment power cables magnetically. Therefore, aluminum tubes are used for the common power cables. Aluminum has low permeability and high conductivity, which are good shielding characteristics against magnetic flux.

Dimensions in millimetres



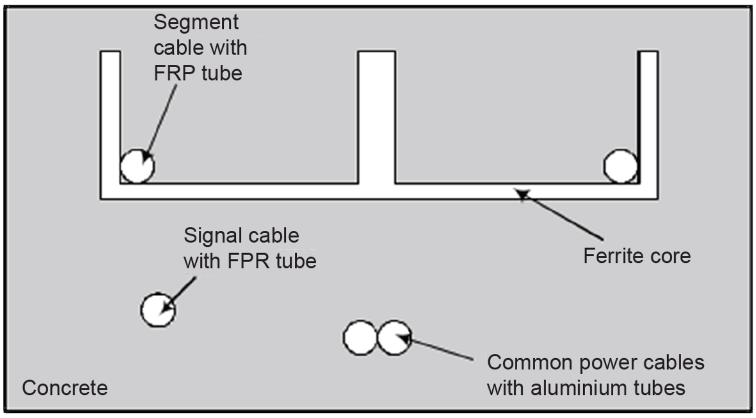


Figure CC.1 – Mechanical dimensions of the MF-WPT5 heavy-duty WPT reference primary device

The mechanical dimensions of this primary reference device are shown in Table CC.1.

Table CC.1 – Mechanical dimensions of the MF-WPT5 reference primary device

	Coil + ferrite only	Housing (w/o shield)
L x W x H [mm]	6 000 x 720 x 160	6 500 x 800 x 180

CC.2.1.2 Electrical

Figure CC.2 shows the schematic of the supply power electronics for the heavy-duty WPT reference primary device described in Annex CC. As shown in Figure CC.2, the inverter for heavy-duty WPT system uses a full-bridge resonance inverter to drive the primary coil. The inverter module consists of a rectifier, full-bridge inverter, blocking capacitor, output insulation transformer, and series resonance capacitor. The assembly of the inverter internal lines, primary coil, shielding, and ferrite core has an inductance value per meter. In order to maintain zero voltage switch operation of the inverter, the output block compensates the resonance point below the operating frequency. This helps the inverter work with reactance loads. The operating frequency of the inverter is 20 kHz or 60 kHz. To keep fixed output current with various load conditions, the power supply system uses the phase controlled rectifier to control the DC-link voltage.

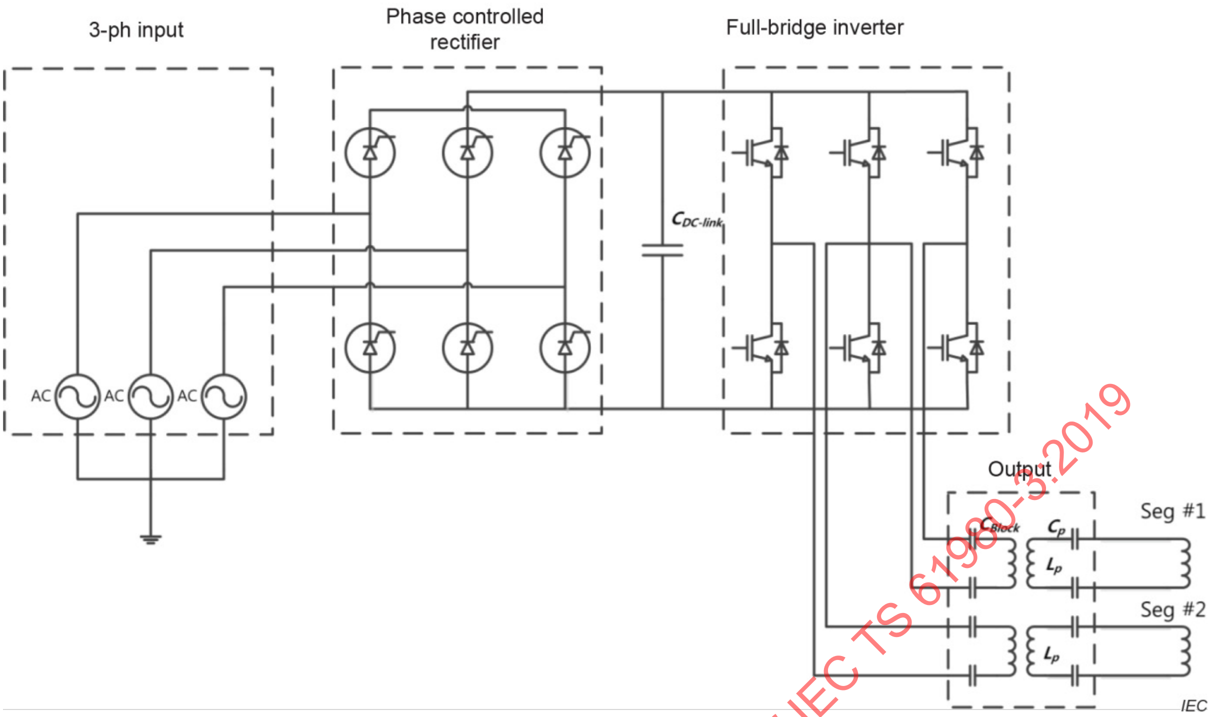


Figure CC.2 – Schematic of supply power electronics for the heavy-duty WPT reference primary device

Table CC.2 shows the values of the circuit elements for heavy-duty WPT reference primary device.

Table CC.2 – Values of circuit elements for heavy-duty WPT reference primary device

Item	Value	Comments
Road to pickup gap	100 mm to 170 mm	Distance between road and bottom side of pickup module
Rated three-phase AC voltage	380 Vac to 480 (1 % ± 10 %) Vac	This value can be changed depending on the main voltage of the place where inverter is installed.
Inverter switching frequency	20 kHz, 60 kHz	(20 ± 1) kHz, (60 ± 1) kHz
Inductance of primary side	4 µH per meter	
Coil current of primary side	200 A to 500 A (RMS)	Coil current in road embedded rail
Inverter output voltage	Up to 3 kV (RMS)	Secondary voltage of isolation transformer in power inverter
EMF	Below 270 mG	ICNIRP level

CC.2.2 Heavy-duty WPT secondary reference device for MF-WPT5

CC.2.2.1 Mechanical

Figure CC.3 shows the mechanical dimensions of the MF-WPT5 secondary reference device. The 3 coil system of secondary reference device is shown in Figure CC.3. The numbers of turns in 3 coil systems are evenly distributed like 46-46-46. The left part of 3 coil systems makes one circuit together with the upper half of the middle part of 3 coil systems, while the right part of 3 coil systems makes another circuit together with the lower half of the middle part of 3 coil systems.

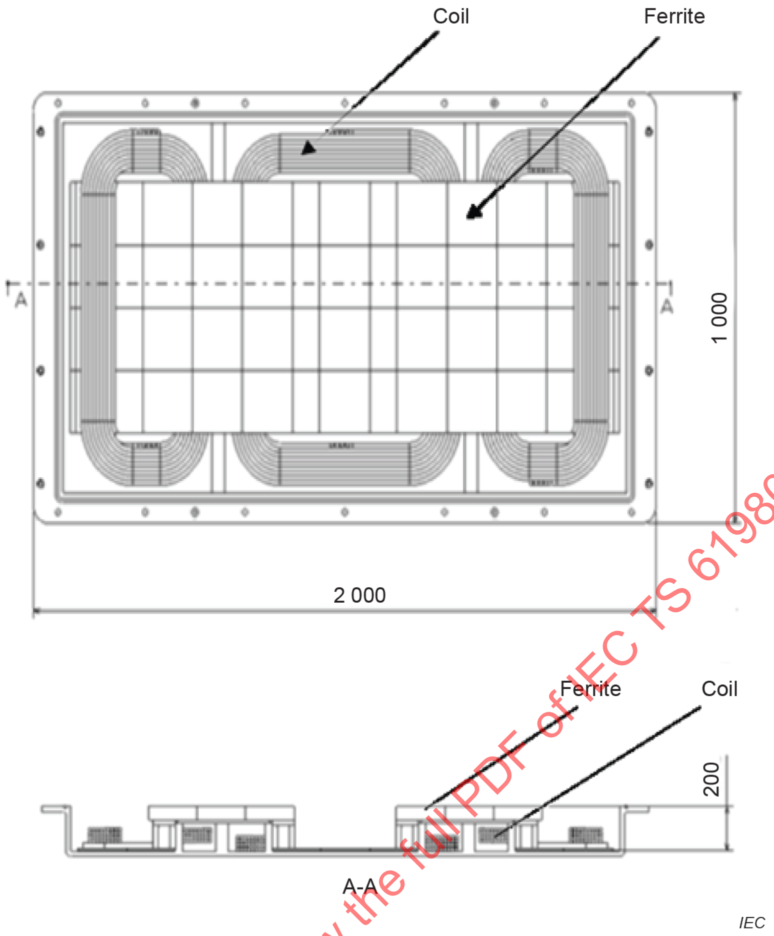


Figure CC.3 – Mechanical dimensions of the MF-WPT5 heavy-duty WPT reference secondary device

The mechanical dimensions of secondary reference device are shown in Table CC.3.

Table CC.3 – Mechanical dimensions of the MF-WPT5 reference secondary device

	Coil + ferrite only	Housing (w/o vehicle shield)
L x W x H [mm]	1 700 x 800 x 180	2 000 x 1 000 x 200

CC.2.2.2 Electrical

Figure CC.4 shows the schematic of the EV power electronics for the secondary reference device described in CC.3.1. It is composed of 3 pickup modules with 6 pickup coils, 6 rectifiers, and 6 boost type regulators for 100 kW output. Two pickup coils in each pickup module are series-connected with compensating capacitors, two rectifiers, and two boost converter modules. The rectifiers convert the AC current to DC current, and the boost converter module boosts the output voltage of each rectifier up to the rated voltage appropriate for the battery. The regulator has six boost converter modules with IGBT switching devices. The gates of the IGBTs are switched by PWM signals, and a DSP board controls the duty ratios of the PWM signals. From this process, we can obtain the rated output voltage for the battery.

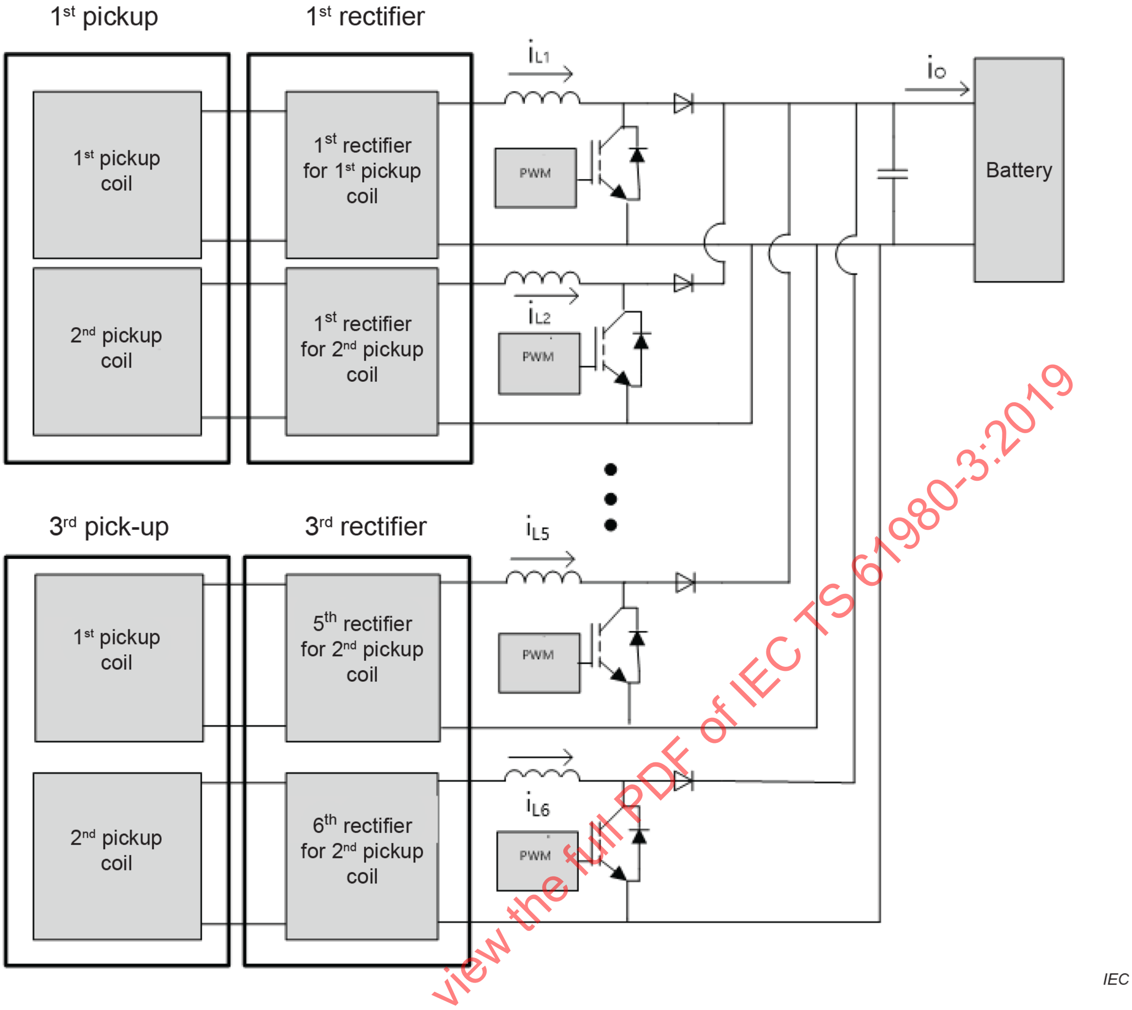


Figure CC.4 – Schematic of the EV power electronics for the MF-WPT5 heavy-duty WPT secondary reference device

Table CC.4 shows the values of the circuit elements shown in Figure CC.4.

Table CC.4 – Values of circuit elements for Figure CC.4

Specifications	Value
Power capacity of a secondary pickup module	35 kW
Total system capacity	100 kW
Number of channel	4
Road to pickup gap	100 mm to 170 mm
Operating frequency	20 kHz, 60 kHz
DC output voltage	400 V to 450 V
DC output current	75 A to 80 A
DC output current in each channel	18,5 A to 20 A
Maximum K_{max} (coupling factor)	0,345
Minimum K_{min} (coupling factor)	0,110

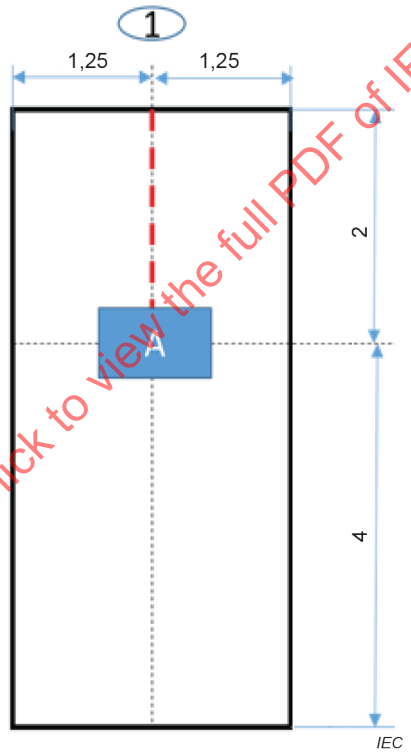
Annex DD
(informative)

Coil position in parking spot

According to the different package conditions in EVs, there is no single position that can be required for the EV device. Therefore, the position of the supply device in the parking spot is specified. To enable MF-WPT for all vehicles, the position of the supply device has to be combined with a minimum size of the parking spot.

For the position of the centre of the supply device, the position is specified with respect to a 6 m by 2,5 m parking spot. The primary device centre shall be located on the longitudinal centreline of the parking spot and 2 m from the front of the parking spot, as shown in Figure DD.1.

Dimensions in metres



Key

1 front end of parking spot

A centre of primary device

Figure DD.1 – Coil position in parking spot

In case backward parking is required, the 2,0 m is measured from the back end of the parking spot and the 4,0 m from the front end.

NOTE The mapping of the location to smaller parking spots is not yet decided.

Annex EE
(informative)

Description for system interoperability

EE.1 General

Annex EE describes parameters for system Interoperability to ensure interoperability between systems from different manufacturers, Z-classes, power classes and different coil topologies. Besides a description of necessary parameters, it also provides a possible test bench setup that can be applied to approve interoperability of any product secondary devices and product primary devices.

Annex EE is applicable to product primary devices and product secondary devices, but also for reference primary and secondary devices. It is intended to be a generic approach that is not dependent on any coil topology or any specific electronic configuration and to provide flexibility for product implementation.

To ensure overall interoperability, both magnetic and electrical interoperability are necessary. Magnetic interoperability is maintained by requiring product primary coils to provide sufficient magnetic flux to specified secondary gauge devices over the full range of coil positions. This requirement translates to a range of necessary primary coil currents for each product primary coil. Electrical interoperability is assured by placing constraints on the impedance a product secondary device can present to a primary device and requiring that product primary electronics be able to maintain the necessary primary coil current over that impedance space.

Descriptions of possible gauge devices to determine the magnetic characteristics of a primary device are also included in Annex EE. These gauge devices are intended to be used to verify that a reference primary coil is functioning as designed, but may be used for testing and development of product primary coils.

In Annex EE, primary devices can be

- reference primary devices characterized by a specified magnetic coupling $M_{0,1\rightarrow 2}$ and specified number of turns $w_{1\mathrm{R}}$, and
- product primary devices characterized by a specified magnetic coupling $M_{0,1\rightarrow 2}$ and design dependant number of turns $w_{1\mathrm{P}}$.

EE.2 System interoperability

A wireless power transfer system contains two fundamental types of functional blocks:

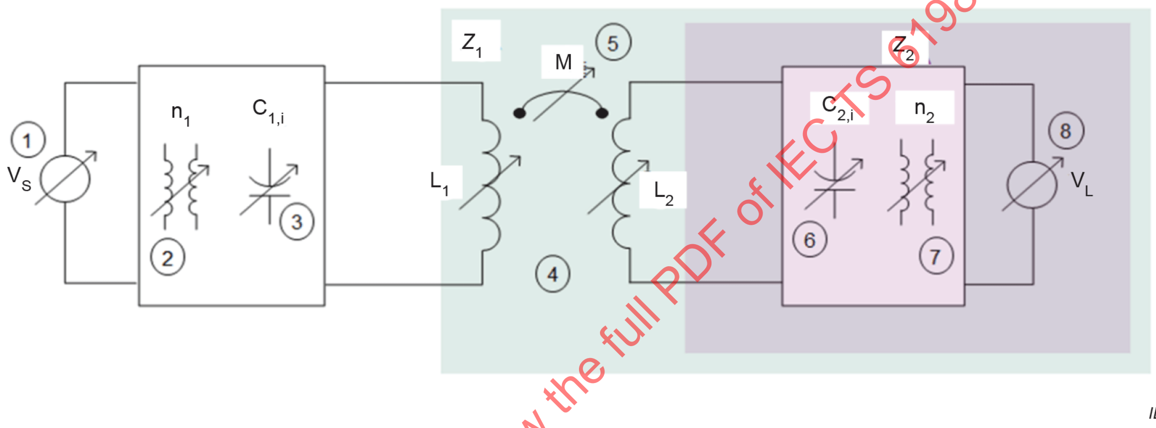
- the coil system, which serves as the magnetic transformer and is characterized by the parameters M, L_1, L_2; each of these parameters may vary with coil position;
- the electronics connected to the primary device and secondary device coils, which ensure that all EV operation points ($P_{\mathrm{b,out}}$, $U_{\mathrm{b,out}}$) will be supported by the primary device electronics.

NOTE The primary device electronics are influenced by the requirements of the secondary device electronics through the coil system.

Both coils and electronics are interdependent at the system level, as the electronics shall be designed in a manner to cover for variations of the coil system parameters, which in turn vary with displacement of primary to secondary coil. Rather than specify the details of the electronics, an impedance based specification of the electrical parameters is used to describe the requirements and behavior of the electronics at the terminals of the coils.

The following parameters are defined to describe the system interoperability (see Figure EE.1).

1) For each alignment point, there exists one set of values for the magnetic parameters (M,L_1,L_2) → $F(x,y,z) = \{M,L_1,L_2\}$. This leads to a defined range of values for the magnetic parameters covering the full range of coils positions expected.
2) Z_2: Impedance presented by the secondary device electronics for all possible EV operation points ($P_{b,out}$, $U_{b,out}$). Defined from the terminals of the secondary device coil looking toward the load.
3) Z_1: Impedance seen at the terminals of the primary coil looking toward the load (a function of Z_2 and the magnetic parameters).
4) Tolerance factor: A factor applied to the magnetic and impedance parameters to account for variations in construction, component values, and vehicle integration. This factor is necessary to guarantee interoperability across the range of systems expected in the field (covering different power and Z-classes).



Key

1	grid voltage variations
2	power conversion (PWM, variable frequency, etc.)
3	variable tuning
4	inductance variations e.g. due to ferrite of adjacent coil and conductive structure (e.g. vehicle underbody)
5	mutual inductance variations due to alignment offset and z-height variations
6	variable tuning
7	power conversion (PWM, variable frequency, etc.)
8	battery voltage variations

Figure EE.1 – General schematic of the concept showing the coil system and the ports at which the parameters are defined

EE.3 Interoperability parameters

EE.3.1 Magnetic interoperability

EE.3.1.1 General

The coil system of the WPT system serves as a magnetic transformer that maps the impedance of the secondary side Z_2 to the primary side Z_1 Physically, the coil system is characterized by the coupled magnetic flux that generates an induced voltage for power transfer and the corresponding leakage flux. This behavior is completely described by the parameters L_1, L_2, M at each alignment point (x,y,z). Therefore, there exists a set of the magnetic parameters F(x,y,z) = {M,L_1,L_2} covering the complete range of alignment tolerance.

The relation between these parameters is given by Formula (EE.1):

$$\underline{Z}_1 = j(\omega \times L_1) + \frac{\omega^2 \times M^2}{j(\omega \times L_2) + Z_2} \qquad \text{(EE.1)}$$

The second term on the right side of Formula (EE.EE.1) is the reflected impedance from the secondary device to the primary device.

Some of the parameters, for example L_1 and L_2, are mainly governed by product specific characteristics like coil size, number of windings, coil geometry, which should be open for product development.

The interoperability will be described by using a fundamental mutual inductance and normalized impedance. The manufacturer of a product primary or secondary device will need the magnetic parameters for designing new devices. However, for the description of test stand devices, stricter requirements need to be met, since for these devices, the technical parameters are fixed.

Magnetic interoperability is ensured by defining the requirements for the magnetic field distribution at key alignment points (e.g. max./min. coupling). These magnetic field requirements need to be fulfilled by all reference and product primary devices.

EE.3.1.2 Fundamental mutual inductance

To define the characteristics of the magnetic field without requiring full reference secondary device or product secondary device, simple gauge device are defined (see EE.5.3.2).These gauge devices are used to verify the magnetic flux which is transmitted by the primary coil by measuring induced voltages at the secondary gauge device (see EE.5.3), yet not at classified power levels, but at open circuit.

The relation between the voltage U_i measured with a gauge device in open circuit condition and the effective magnetic flux Φ generated by an exciting primary coil ($I_1 \times w_1$) can be expressed as follows:

$$\Phi_{1\to2} = C_{TD} \frac{U_{i2}}{\omega \times w_2} \qquad \text{(EE.2)}$$

where

C_{TD} is the calibration factor of the gauge device as provided by the gauge device manufacturer;

U_{i2} is the induced voltage in gauge device, generated by the primary excitation $I_1 \times w_1$;

ω = $2\pi f$; f = 85 kHz (nominal frequency);

w_2 is the number of turns of the gauge device;

$\Phi_{1\to2}$ magnetic flux the gauge device is exposed to, excited primary coil.

When transferring power to a reference secondary device or product secondary device, the required magnetic flux is generated by applying a primary coil specific ampere turns $I_1 \times w_1$. To create a metric that can be more generally applied, the magnetic flux Φ is normalized by the primary current I_1. The resulting metric characterizes the magnetic coupling for a specific combination of primary and secondary coils as follows:

$$\frac{\Phi_{1\to2}}{I_1} = C_{TD} \frac{U_{i2}}{\omega \times \omega_2 \times I_1} = M_0 \times w_1 \qquad \text{(EE.3)}$$

where

M_0 is the fundamental mutual inductance with $w_1 = 1$, $w_2 = 1$;

w_1 is the number of turns of the test stand or product primary device;

I_1 is the primary coil current.

The values for the fundamental mutual inductance $M_{0,\text{R}}$ given in Annex EE relate to the combination of a reference primary device being tested with the gauge device, respectively. A gauge device serves as representation of a reference or product secondary device with a comparable geometry.

Any reference and product primary device which shows the values of fundamental inductance $M_{0,\text{R}}$ with the gauge devices given in Annex EE is compliant with respect to magnetic interoperability.

Any product primary device will produce the same magnetic flux at the gauge device as a reference primary device if the following formula is fulfilled:

$$M_{0,\text{P}} \times w_{1\text{P}} \times I_{1\text{P}} \overset{!}{=} M_{0,\text{R}} \times w_{1\text{R}} \times I_{1\text{R}} = \Phi_{1\rightarrow 2} = C_{\text{TD}} \frac{U_{\text{i2}}}{\omega \times w_2} \quad \text{(EE.4)}$$

Subscript P does refer to product primary device whereas Subscript R refers to reference primary device, respectively.

Formula (EE.4) requires that product primary device and reference primary device produce the same magnetic flux on the gauge device, that is, $\Phi_{1\rightarrow 2}$ and U_{i2} are the same for both. This shall be true for all offset positions. If the product primary device and the reference device have the same fundamental mutual inductance, the ampere-turns on the two coils shall be equal:

$$w_{1\text{P}} \times I_{1\text{P}} = w_{1\text{R}} \times I_{1\text{R}} \quad \text{(EE.5)}$$

EE.3.1.3 Mutual inductance requirements

EE.3.1.3.1 General

In EE.3.1.3, the mutual inductance characteristics of reference primary devices as measured using the gauge devices are listed. The intended use of these tables is to verify that a reference primary device has the proper magnetic characteristics. The tables may also be used by system developers to compare the magnetic flux characteristics of a product primary device to that of a reference primary device. A product primary device with equivalent magnetic flux characteristics as listed in these tables shall also support coil currents that produce equivalent flux at the secondary. These coil currents are derived from the required impedance space description that follows.

Magnetic interoperability shall be confirmed by testing in accordance to EE.5.2.

Since the mutual inductance changes for different coil positions, the requirements are separately given according to the Z-classes Z1 to Z3. The values for the fundamental mutual inductance given in the tables below relate to the measurements as described in EE.5.2 together with the gauge devices described in EE.5.3.2.

EE.3.1.3.2 Fundamental mutual inductance for Z1 class

A reference primary device shall provide fundamental mutual inductance values as given in Table EE.1. Magnetic interoperability is achieved, if the measured mutual inductance values are within a tolerance band of ±10% around the values given in Table EE.1

Table EE.1 – Fundamental mutual inductance M_(0,R) values for Z1 (in [µH])

z-position	(x,y) position	Coaxial sec. gauge device coupled with:		Transversal sec. gauge device coupled with:	
		coaxial primary device	transversal primary device	coaxial primary device	transversal primary device
$Z1_{min}$ = 100 mm	Nominal position (0,0)	1,43	1,500	2,674	3,763
$Z1_{max}$ = 150 mm	Nominal position (0,0)	0,904	0,877	1,492	2,320
$Z1_{min\ =}$ 100 mm	Offset position (100,75)	1,177	0,945	1,633	3,107
$Z1_{max}$ = 150 mm	Offset position (100,75)	0,686	0,599	1,030	1,792
$Z1_{min\ =}$ 100 mm	Offset position (-100,-75)	1,088	1,090	1,676	3,067
$Z1_{max}$ = 150 mm	Offset position (–100,–75)	0,639	0,614	0,939	1,766

All values might have to be recomputed taking into account the gauge devices calibration factor and all M_{norm} are still to be converted to $M_{0,}$ w_{1R}

EE.3.1.3.3 Fundamental mutual inductance for Z2 class

A reference primary device shall provide fundamental mutual inductance values as given in Table EE.2. Magnetic interoperability is achieved, if the measured mutual inductance values are within a tolerance band of ±10% around the values given in Table EE2.

Table EE.2 – Fundamental mutual inductance M_(0,R) values for Z2 (values in [µH])

z-position	(x,y) position	Coaxial sec. gauge device coupled with:		Transversal sec. gauge device coupled with:	
		coaxial primary device	transversal primary device	coaxial primary device	transversal primary device
$Z2_{min\ =}$ 140 mm	Nominal position (0,0)	0,988	0,972	1,663	2,544
$Z2_{max}$ = 210 mm	Nominal position (0,0)	0,528	0,479	0,804	1,359
$Z2_{min}$ = 140 mm	Offset position (100,75)	0,758	0,655	1,123	1,979
$Z2_{max}$ = 210 mm	Offset position (100,75)	0,392	0,354	0,625	1,041

z-position	(x,y) position	Coaxial sec. gauge device coupled with:		Transversal sec. gauge device coupled with:	
		coaxial primary device	transversal primary device	coaxial primary device	transversal primary device
$Z2_{min}$ = 140 mm	Offset position (–100,–75)	0,705	0,688	1,049	1,950
$Z2_{max}$ = 210 mm	Offset position (–100,–75)	0,371	0,315	0,495	1,030

All values might have to be recomputed taking into account the gauge devices calibration factor and all M_{norm} are still to be converted to M_{0}, w_{1R}

EE.3.1.3.4 Fundamental mutual inductance for Z3 class

A reference primary device shall provide fundamental mutual inductance values as given in Table EE.3. Magnetic interoperability is achieved, if the measured mutual inductance values are within a tolerance band of ±10% around the values given in Table EE.3.

Table EE.3 – Fundamental mutual inductance M_(0,R) values for Z3 (values in [µH])

z-position	(x,y) position	Coaxial sec. gauge device coupled with:		Transversal sec. gauge device coupled with:	
		coaxial primary device	transversal primary device	coaxial primary device	transversal primary device
$Z3_{min}$ = 170 mm	Nominal position (0,0)	0,754	0,716	1,207	1,937
$Z3_{max}$ = 250 mm	Nominal position (0,0)	0,371	0,322	0,546	0,967
$Z3_{min}$ = 170 mm	Offset position (100,75)	0,565	0,502	0,868	1,481
$Z3_{max}$ = 250 mm	Offset position (100,75)	0,277	0,250	0,452	0,747
$Z3_{min}$ = 170 mm	Offset position (–100–75)	0,530	0,491	0,756	1,462
$Z3_{max}$ = 250 mm	Offset position (–100, –75)	0,264	0,202	0,328	0,741

All values might have to be recomputed taking into account the gauge devices calibration factor and all M_{norm} are still to be converted to M_{0}, w_{1R}

EE.3.2 Electrical Interoperability

EE.3.2.1 General

Electrical interoperability is determined based on the overlap of the impedance the secondary device presents to the primary device and the operating impedance space of the primary device. The relevant parameter for the secondary device is the impedance Z_2 presented to the secondary device coil by the secondary device electronics and load. This set of impedance values can be transformed using the magnetic parameters for this primary device- secondary device combination to determine the impedance Z_1 that would be seen at the primary device coils. If this transformed Z_1 impedance lies within the operating impedance space defined for that primary device (primary device electronic capability), the primary device-secondary device pair should be interoperable from an electrical and magnetic standpoint. That specific pair is interoperable if the transformed Z_2 meets the primary device capability. For general interoperability, it is necessary that transformed Z_2 lies within the allowed impedance range including tolerances.

NOTE The secondary device and primary device impedances are frequency dependent, so interoperability can be achieved as long as the transformed secondary device impedance lies within the primary device operating impedance space for some frequency in the allowed frequency band. However, to keep the initial development simple, we focus on an operating frequency of 85 kHz. This may be extended as a future development.

Frequency tuning

The secondary device and primary device impedances are frequency dependent, so interoperability can be achieved as long as the transformed secondary device impedance lies within the primary device operating impedance space for some frequency in the allowed frequency band.

Technical background:

The parameters L_1 and L_2 are well defined by the geometrical description of the reference primary devices and secondary devices. So as an alternative to the measurement of the fundamental mutual inductance as given in EE.5.3, it is possible to determine L_1, L_2, M via measurement:

- L_1 and L_2 can be measured by commercially available LCR-meter;
- M can be measured by low voltage measurements with the specific coil configuration or with an LCR-meter.

The manufacturer of the reference primary device shall state the primary device-electronic capability in terms of an operating impedance space Z_1 as defined in Figure EE.1. This represents the boundary of Z_1 impedance that can be supported by the primary device electronics specified with that primary device coil. Since the operating space is power dependent, each reference primary device will have the operating space specified at several levels of power transfer (e.g. 100 %, 75 %, and 50 % of full power.

The manufacturer of the reference primary or secondary device shall specify the maximum current and maximum voltage their coil is designed for.

Each manufacturer of a product device shall prove interoperability with the existing test stand designs according to the following.

1) Product secondary manufacturer
   a) The manufacturer shall prove interoperability with the existing reference designs. Therefore, the manufacturer shall show that his product secondary device creates impedance at the primary device coil which lies within the reference primary device electronic capability area including the defined tolerance factor. This can be shown with the test setup presented in EE.5.3.
2) Product primary manufacturer
   a) The manufacturer shall show that all EV operation points of all existing reference secondary devices for all possible displacements can be operated by the product primary electronics in accordance with the specified boundary constraints of the reference secondary device.
   b) Ultimately, it is desirable to define a "normalized" primary device operating impedance space that can be used for qualifying product primary devices. In this case, the product primary devices manufacturer shall demonstrate a normalized primary device operating

impedance space that meets or exceeds that of the reference primary device (including any tolerance factor).

EE.3.2.2 Measurement points

The magnetic parameters (L_1,L_2,M) should be measured at a complete set of relative coil positions. These measurements should be done at the (x,y,z) offset positions indicated below yielding 351 (L_1,L_2,M) tuples for each z-class, or a total of 1 053 points if including all z-classes. Z-heights are given in terms of ground clearance. The estimated measurement time with an automated set-up is 3 h per Z-class.

1) x = [–100,100] in steps of 25 mm (9);
2) y = [–150,150] in steps of 25 mm (13, symmetry).
3) z according to z-classes (9):
   a) z1 = [100,150] in steps of 25 mm;
   b) z2 = [140,210] in steps of 35 mm;
   c) z3 = [170,250] in steps of 40 mm.

EE.3.2.3 Informative: definition of Z_2 for WPT1

For all EV operation points ($P_{b,out}$, $U_{b,out}$), Z_2 can be determined by simulation (or measurement, if desired). The frequency is set to 85 kHz as noted above. The Z_2 values are independent of any coil geometry and simply function as a tool for calculating Z_1. $U_{b,out}$ is varied in steps of 85 V as shown in Table EE.4.

Table EE.4 – Secondary impedance Z2 for fixed power level and varying output voltage $U_{b,out}$

$U_{b,out}$	Impedance		z-height (if electronics differ with height)		Power
$U_{b,out}$ = 280 V to 450 V	Imag (Z_2)	Real (Z_2)	z_1,z_2,z_3		WPT1
$U_{b,out}$ = 280 V			z_1		WPT1
⋮	⋮	⋮	⋮		⋮
$U_{b,out}$ = 450 V			z_1		WPT1
$U_{b,out}$ = 280 V			z_2		WPT1
⋮	⋮	⋮	⋮		⋮
$U_{b,out}$ = 450 V			z_2		WPT1
$U_{b,out}$ = 280 V			z_3		WPT1
⋮	⋮	⋮	⋮		⋮
$U_{b,out}$ = 450 V			z_3		WPT1

Z_2 is independent of any coil geometry but varies for different secondary-electronic configurations. Secondary-electronic typically differs for different z-classes.

Such a table can also be completed for this secondary device operating at lower power levels (75 %, 50 %, etc.) to determine interoperability for those power levels.