WIRELESS POWER
CONSORTIUM

Qi Specification

Power Transmitter Reference Designs

Version 1.3

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RELEASE HISTORY

Specification Version	Release Date	Description
1.3	January 2021	Initial release of this document.

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1 General

The Wireless Power Consortium (WPC) is a worldwide organization that aims to develop and promote global standards for wireless power transfer in various application areas. A first application area comprises flat-surface devices such as mobile phones and chargers in the Baseline Power Profile (up to 5 W) and Extended Power Profile (above 5 W).

1.1 Structure of the Qi Specification

General documents

- Introduction
- Glossary, Acronyms, and Symbols

System description documents

- Mechanical, Thermal, and User Interface
- Power Delivery
- Communications Physical Layer
- Communications Protocol
- Foreign Object Detection
- NFC/RFID Card Protection
- Authentication Protocol

Reference design documents

- Power Transmitter Reference Designs
- Power Receiver Design Examples

Compliance testing documents

- Power Transmitter Test Tools
- Power Receiver Test Tools
- Power Transmitter Compliance Tests
- Power Receiver Compliance Tests

NOTE: The compliance testing documents are restricted and require signing in to the WPC members' website. All other specification documents are available for download on both the WPC public website and the WPC website for members.

1.2 Scope

The *Qi Specification, Power Transmitter Reference Designs* (this document) defines Power Transmitter reference designs for use in power applications up to 5 W (type A and B designs) and up to 15 W (type MP-A and MP-B designs). Type A and type MP-A Power Transmitter designs use a single, active coil for power transfer even if more than one coil is present. Type B and type MP-B Power Transmitter designs have an array of Primary Coils and may activate more than one coil at a time.

NOTE: Beginning with v1.3 of the *Qi Specification*, new Power Transmitter reference designs will remain standalone documents when they are approved by the WPC.

1.3 Compliance

All provisions in the *Qi Specification* are mandatory, unless specifically indicated as recommended, optional, note, example, or informative. Verbal expression of provisions in this Specification follow the rules provided in ISO/IEC Directives, Part 2.

Table 1: Verbal forms for expressions of provisions

Provision	Verbal form
requirement	"shall" or "shall not"
recommendation	"should" or "should not"
permission	"may" or "may not"
capability	"can" or "cannot"

1.4 References

For undated references, the most recently published document applies. The most recent WPC publications can be downloaded from http://www.wirelesspowerconsortium.com. In addition, the *Qi Specification* references documents listed below. Documents marked here with an asterisk (*) are restricted and require signing in to the WPC website for members.

- Product Registration Procedure Web page*
- Qi Product Registration Manual, Logo Licensee/Manufacturer*
- Qi Product Registration Manual, Authorized Test Lab*
- Power Receiver Manufacturer Codes,* Wireless Power Consortium
- The International System of Units (SI), Bureau International des Poids et Mesures
- Verbal forms for expressions of provisions, International Electotechnical Commission

For regulatory information about product safety, emissions, energy efficiency, and use of the frequency spectrum, visit the regulatory environment page of the WPC members' website.

1.5 Conventions

1.5.1 Notation of numbers

- Real numbers use the digits 0 to 9, a decimal point, and optionally an exponential part.
- Integer numbers in decimal notation use the digits 0 to 9.
- Integer numbers in hexadecimal notation use the hexadecimal digits 0 to 9 and A to F, and are prefixed by "0x" unless explicitly indicated otherwise.
- Single bit values use the words ZERO and ONE.

1.5.2 Tolerances

Unless indicated otherwise, all numeric values in the *Qi Specification* are exactly as specified and do not have any implied tolerance.

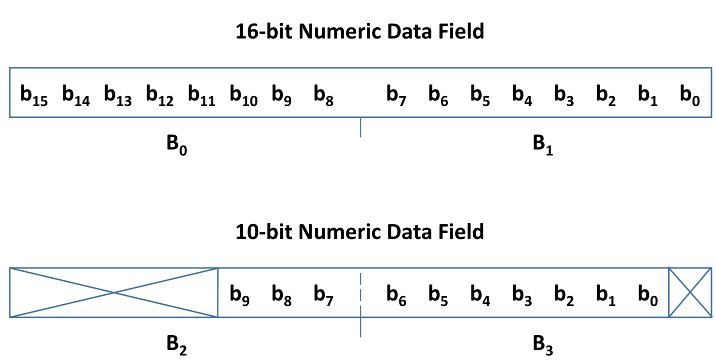
1.5.3 Fields in a data packet

A numeric value stored in a field of a data packet uses a big-endian format. Bits that are more significant are stored at a lower byte offset than bits that are less significant. Table 2 and Figure 1 provide examples of the interpretation of such fields.

Table 2: Example of fields in a data packet

	b_7	b_6	b_5	b_4	b_3	b_2	b_1	b_0
B_0	(msb) 16-bit Numeric Data Field							
B_1								(lsb)
B_2	Other Field					(msb)		
B_3	10-bit Numeric Data Field						(lsb)	Field

Figure 1. Examples of fields in a data packet



1.5.4 Notation of text strings

Text strings consist of a sequence of printable ASCII characters (i.e. in the range of 0x20 to 0x7E) enclosed in double quotes ("). Text strings are stored in fields of data structures with the first character of the string at the lowest byte offset, and are padded with ASCII NUL (0x00) characters to the end of the field where necessary.

EXAMPLE: The text string "WPC" is stored in a six-byte fields as the sequence of characters 'W', 'P', 'C', NUL, NUL, and NUL. The text string "M:4D3A" is stored in a six-byte field as the sequence 'M', ':', '4', 'D', '3', and 'A'.

1.5.5 Short-hand notation for data packets

In many instances, the *Qi Specification* refers to a data packet using the following shorthand notation:

<MNEMONIC>/<modifier>

In this notation, <MNEMONIC> refers to the data packet's mnemonic defined in the *Qi Specification, Communications Protocol*, and <modifier> refers to a particular value in a field of the data packet. The definitions of the data packets in the *Qi Specification, Communications Protocol*, list the meanings of the modifiers.

For example, EPT/cc refers to an End Power Transfer data packet having its End Power Transfer code field set to 0x01.

1.6 Power Profiles

A Power Profile determines the level of compatibility between a Power Transmitter and a Power Receiver. Table 3 defines the available Power Profiles.

- *BPP PTx*: A Baseline Power Profile Power Transmitter.
- *EPP5 PTx*: An Extended Power Profile Power Transmitter having a restricted power transfer capability, i.e. $P_{\mathrm{L}}^{(\mathrm{pot})}$ = 5 W.
- *EPP PTx*: An Extended Power Profile Power Transmitter.
- *BPP PRx*: A Baseline Power Profile Power Receiver.
- *EPP PRx*: An Extended Power Profile Power Receiver.

Table 3: Capabilities included in a Power Profile

Feature	BPP PTx	EPP5 PTx	EPP PTx	BPP PRx	EPP PRx
A*x* or B*x* design	Yes	Yes	No	N/A	N/A
MP-A*x* or MP-B*x* design	No	No	Yes	N/A	N/A
Baseline Protocol	Yes	Yes	Yes	Yes	Yes
Extended Protocol	No	Yes	Yes	No	Yes
Authentication	N/A	Optional	Yes	N/A	Optional

2 Overview

This document defines all type A and type B Power Transmitter designs in the Baseline Power Profile and all type MP-A and type MP-B Power Transmitter designs in the Extended Power Profile. In addition to the definitions in this section, each Power Transmitter design shall implement the relevant parts of the protocols defined in the *Qi Specification, Communications Protocol*.

NOTE: Power Receivers that use thin magnetic Shielding have been found to experience reduced performance on Power Transmitters that contain a permanent magnet in or near the Active Area. Such Power Receivers may exhibit, for example, less positioning freedom and/or a longer charging time. For this reason, Power Transmitter designs A1, A5, and A9 have been deprecated as of version 1.2 of the Qi Power Class 0 Specification. The remaining Power Transmitter designs provided in this Qi Specification do not use a permanent magnet. Product implementations based on these designs that include a permanent magnet in or near the Active Area are not compliant with this Specification.

IMPORTANT: Most countries and regions restrict electro-magnetic emissions across the frequency spectrum. Products have to comply with these regulations when they are sold for use in those countries and regions. Meeting the applicable requirements can be more or less difficult depending on the Power Transmitter design being used in the product. In some countries or regions, it can be economically unfeasible to use some of the Power Transmitter designs defined in this *Qi Specification, Power Transmitter Reference Designs*.

2.1 Type A and type MP-A Power Transmitter designs

Type A and type MP-A Power Transmitter designs have one or more Primary Coils. They activate a single Primary Coil at a time and therefore employ a single Primary Cell that coincides with the activated Primary Coil. In *addition*, type A and type MP-A Power Transmitter designs include means to realize proper alignment of the Primary Coil and Secondary Coil. Depending on this means, these Power Transmitters enable either Guided Positioning or Free Positioning.

A Power Transmitter serves only one Power Receiver at a time. However, a Power Transmitter Product may contain several Power Transmitters in order to serve multiple Power Receiver Products simultaneously.

2.2 Type B and type MP-B Power Transmitter designs

Type B and type MP-B Power Transmitter designs have an array of Primary Coils. All type B and type MP-B Power Transmitters enable Free Positioning. For that purpose, these Power Transmitters can activate one or more Primary Coils from the array to realize a Primary Cell at different positions across the Interface Surface.

A Power Transmitter serves only one Power Receiver at a time only. However, a Power Transmitter Product may contain several Power Transmitters in order to serve multiple Power Receiver Products simultaneously. Note that multiple type B and type MP-B Power Transmitters may share (parts of) the multiplexer and array of Primary Coils (see the *Qi Specification, Power Receiver Design Examples*).

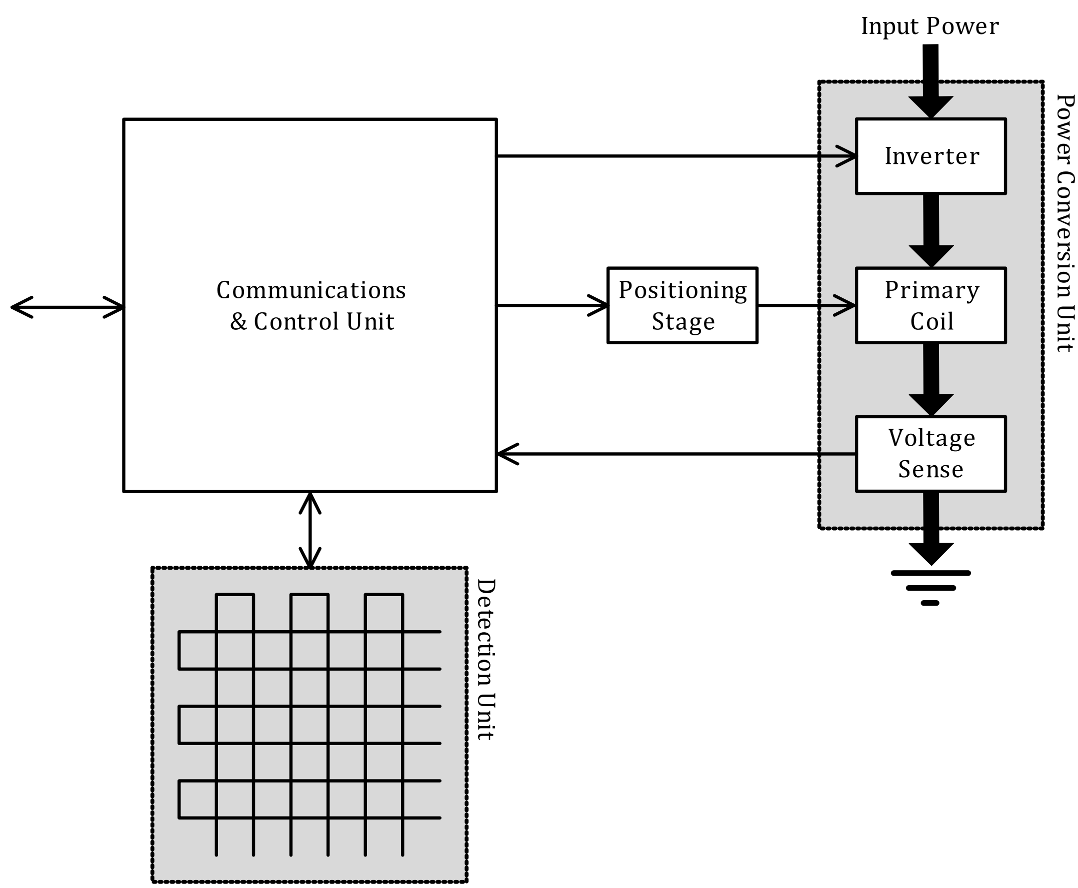
3 Power Transmitter design A1

Power Transmitter design A1 has been deprecated. For further information, see the note in Section 2, *Overview*.

4 Power Transmitter design A2

Power Transmitter design A2 enables Free Positioning. Figure 2 illustrates the functional block diagram of this design, which consists of three major functional units, namely a Power Conversion Unit, a Detection Unit, and a Communications and Control Unit.

Figure 2. Functional block diagram of Power Transmitter design A2



The Power Conversion Unit on the right-hand side of Figure 2 and the Detection Unit of the bottom of Figure 2 comprise the analog parts of the design. The Power Conversion Unit is similar to the Power Conversion Unit of Power Transmitter design A10. The inverter converts the DC input to an AC waveform that drives a resonant circuit, which consists of the Primary Coil plus a series capacitor. The Primary Coil is mounted on a positioning stage to enable accurate alignment of the Primary Coil to the Active Area of the Power Receiver Product. Finally, the voltage sense monitors the Primary Coil voltage.

The Communications and Control Unit on the left-hand side of Figure 2 comprises the digital logic part of the design. This unit is similar to the Communications and Control Unit of Power Transmitter design A10. The Communications and Control Unit receives and decodes messages from the Power Receiver, executes the relevant power control algorithms and protocols, and drives the input voltage of the AC waveform to control the power transfer. In addition, the Communications and Control Unit drives the positioning stage and operates the Detection Unit. The Communications and Control Unit also interfaces with other subsystems of the Power Transmitter Product, e.g. for user interface purposes.

The Detection Unit determines the approximate location of objects and/or Power Receivers on the Interface Surface. This version of *Power Transmitter Reference Designs* does not specify a particular detection method. However, it is recommended that the Detection Unit exploits the resonance in the Power Receiver at the detection frequency f_{d} (see the *Qi Specification, Power Delivery*, the *Qi Specification, Communications Physical Layer*, and the *Qi Specification, Foreign Object Detection*). The reason is that this approach minimizes movements of the Primary Coil, because the Power Transmitter does not need to attempt to identify objects that do not respond at this resonant frequency. The *Qi Specification, Communications Physical Layer* provides an example resonant detection method.

4.1 Mechanical details

Power Transmitter design A2 includes a single Primary Coil as defined in Section 4.1.1, *Primary Coil*, Shielding as defined in Section 4.1.2, *Shielding*, an Interface Surface as defined in Section 4.1.3, *Interface Surface*, and a positioning stage as defined in Section 4.1.4, *Positioning stage*.

4.1.1 Primary Coil

The Primary Coil is of the wire-wound type, and consists of litz wire having 30 strands of 0.1 mm diameter, or equivalent. As shown in Figure 3, the Primary Coil has a circular shape and consists of multiple layers. All layers are stacked with the same polarity. Table 4 lists the dimensions of the Primary Coil.

Figure 3. Primary Coil of Power Transmitter design A2

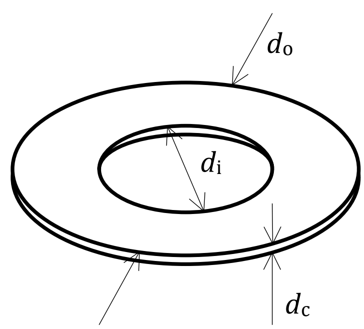


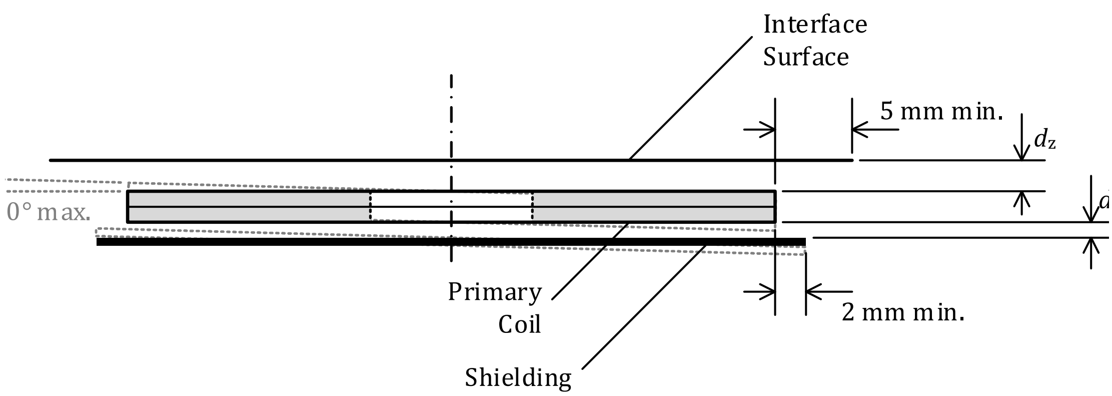
Table 4: Primary Coil parameters of Power Transmitter design A2

Parameter	Symbol	Value
Outer diameter	d_o	$40^{\pm1}$ mm
Inner diameter	d_i	$19^{\pm1}$ mm
Thickness	d_c	$2^{+0.2}$ mm
Number of turns per layer	N	10
Number of layers	–	2

4.1.2 Shielding

As shown in Figure 4, Shielding protects the Power Transmitter Product from the magnetic field that is generated in the Primary Coil. The Shielding should be Ni-Zn or Mn-Zn ferrite and should be at least 0.2 mm thick. The Shielding extends to at least 2 mm beyond the outer diameter of the Primary Coil, and is placed below the Primary Coil at a distance of at most $d_s = 0.1$ mm.

Figure 4. Primary Coil assembly of Power Transmitter design A2



4.1.3 Interface Surface

As shown in Figure 4, the distance from the Primary Coil to the Interface Surface of the Power Transmitter Product is $d_z = 2.5^{+0.5}_{0}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Power Transmitter Product extends at least 5 mm beyond the outer diameter of the Primary Coil.

4.1.4 Positioning stage

The positioning stage shall have a resolution of 0.1 mm or better in each of the two orthogonal directions parallel to the Interface Surface.

4.2 Electrical details

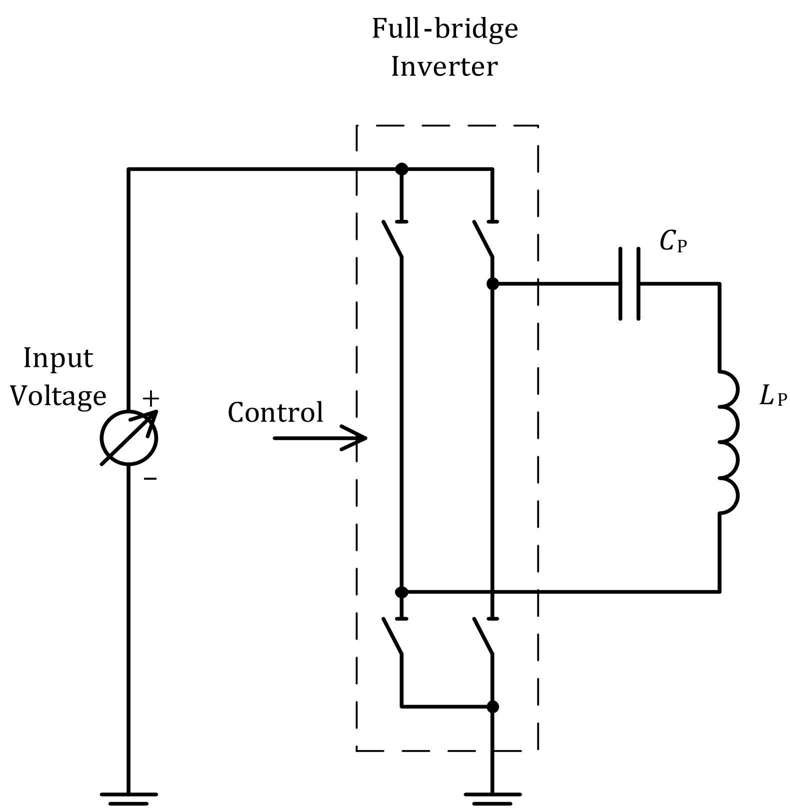
As shown in Figure 5, Power Transmitter design A2 uses a full-bridge inverter to drive the Primary Coil and a series capacitance. At the fixed Operating Frequency of 140 kHz, the assembly of Primary Coil and Shielding has a self-inductance $L_{\mathrm{P}} = 24^{\pm 1}$ μH. The value of the series capacitance is $C_{\mathrm{P}} = 200^{\pm 5\%}$ nF.

NOTE: Near resonance, the voltage developed across the series capacitance can reach levels up to 50 V pk-pk.

Power Transmitter design A2 uses the input voltage to the full-bridge inverter to control the amount of power that is transferred. For this purpose, the input voltage range is 3…12 V, where a lower input voltage results in the transfer of a lower amount of power. In order to achieve a sufficiently accurate adjustment of the power that is transferred, a type A2 Power Transmitter shall be able to control the input voltage with a resolution of 50 mV or better.

When a type A2 Power Transmitter first applies a Power Signal (Digital Ping; see the *Qi Specification, Communications Protocol*), it shall use an initial input voltage of 8 V.

Figure 5. Electrical diagram (outline) of Power Transmitter design A2



Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Qi Specification, Power Delivery*. The controlled variable $v^{(i)}$ introduced in the definition of that algorithm represents the input voltage to the full-bridge inverter. In order to guarantee sufficiently accurate power control, a type A2 Power Transmitter shall determine the amplitude of the Primary Cell voltage—which is equal to the Primary Coil voltage—with a resolution of 5 mV or better. Finally, Table 5 provides the values of several parameters that are used in the PID algorithm.

Table 5: PID parameters for voltage control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	1	mA^{-1}
Integral gain	K_i	0	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	N.A.	N.A.
PID output limit	M_{PID}	1,500	N.A.
Scaling factor	S_v	–0.5	mV

5 Power Transmitter design A3

Power Transmitter design A3 enables Free Positioning, and has a design similar to Power Transmitter design A2. See Section 4, *Power Transmitter design A2* for an overview.

5.1 Mechanical details

Power Transmitter design A3 includes a single Primary Coil as defined in Section 5.1.1, *Primary Coil*, Shielding as defined in Section 5.1.2, *Shielding*, an Interface Surface as defined in Section 5.1.3, *Interface Surface*, and a positioning stage as defined in Section 5.1.4, *Positioning stage*.

5.1.1 Primary Coil

The Primary Coil is of the wire-wound type, and consists of litz wire having 11 strands of 0.20 mm diameter, or equivalent. As shown in Figure 6, the Primary Coil has a circular shape and consists of a single layer. Table 6 lists the dimensions of the Primary Coil.

Figure 6. Primary Coil of Power Transmitter design A3

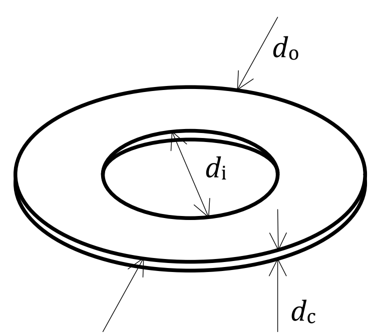


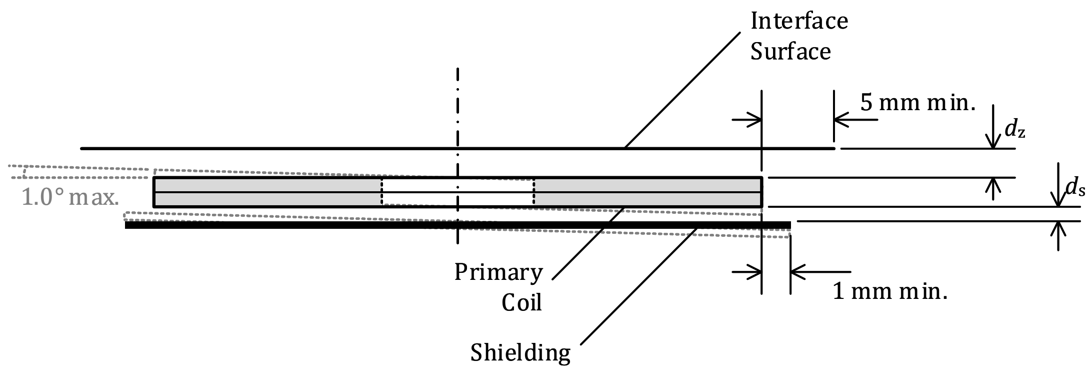
Table 6: Primary Coil parameters of Power Transmitter design A3

Parameter	Symbol	Value
Outer diameter	d_o	$33^{\pm 1}$ mm
Inner diameter	d_i	$10^{\pm 0.2}$ mm
Thickness	d_c	$1.8^{\pm 0.4}$ mm
Number of turns per layer	N	25
Number of layers	–	1

5.1.2 Shielding

As shown in Figure 7, Shielding protects the Power Transmitter Product from the magnetic field that is generated in the Primary Coil. The Shielding should be Ni-Zn or Mn-Zn ferrite and should be at least 0.6 mm thick. The Shielding extends to at least 1 mm beyond the outer diameter of the Primary Coil, and is placed below the Primary Coil at a distance of at most $d_s = 0.4$ mm.

Figure 7. Primary Coil assembly of Power Transmitter design A



5.1.3 Interface Surface

As shown in Figure 7, the distance from the Primary Coil to the Interface Surface of the Power Transmitter Product is $d_Z = 2.5^{+0.5}_{0}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Power Transmitter Product extends at least 5 mm beyond the outer diameter of the Primary Coil.

5.1.4 Positioning stage

The positioning stage shall have a resolution of 0.1 mm or better in each of the two orthogonal directions parallel to the Interface Surface.

5.2 Electrical details

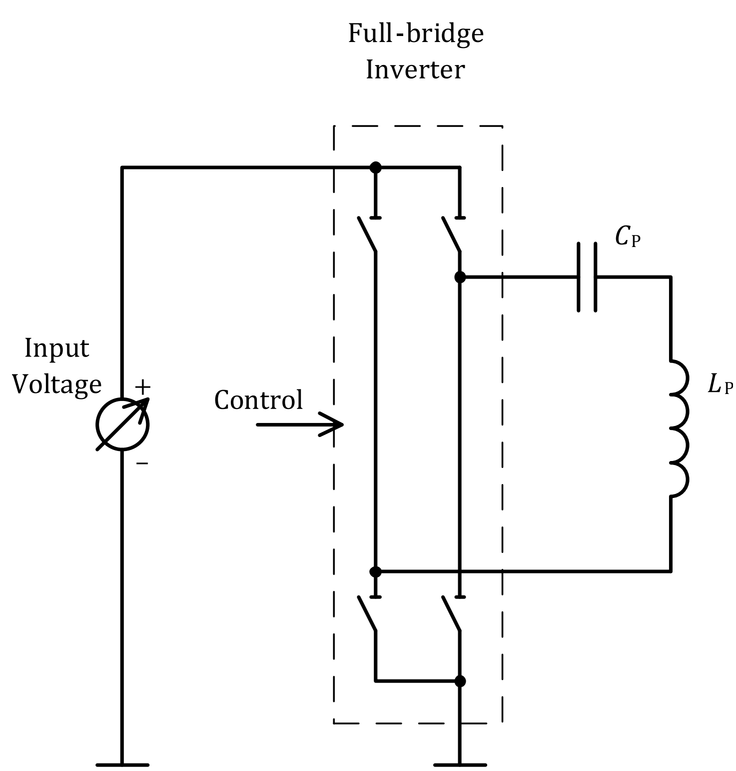
As shown in Figure 8, Power Transmitter design A3 uses a full-bridge inverter to drive the Primary Coil and a series capacitance. At an Operating Frequency range between 105 kHz and 140 kHz, the assembly of Primary Coil and Shielding has a self-inductance $P = 16.5^{\pm 10\%}$ μH. The value of the series capacitance is $P = 180^{\pm 5\%}$ nF.

NOTE: Near resonance, the voltage developed across the series capacitance can reach levels up to 100 V pk-pk.

Power Transmitter design A3 uses the input voltage to the full-bridge inverter to control the amount of power that is transferred. For this purpose, the input voltage range is 3…12 V, where a lower input voltage results in the transfer of a lower amount of power. In order to achieve a sufficiently accurate adjustment of the power that is transferred, a type A3 Power Transmitter shall be able to control the input voltage with a resolution of 50 mV or better.

When a type A3 Power Transmitter first applies a Power Signal (Digital Ping; see the *Qi Specification, Communications Protocol*), it shall use an initial input voltage of 6 V. It is recommended that the Power Transmitter uses an Operating Frequency of 140 kHz when first applying the Power Signal. If the Power Transmitter does not to receive a Signal Strength Packet from the Power Receiver, the Power Transmitter shall remove the Power Signal as defined in the *Qi Specification, Communications Protocol*. The Power Transmitter may reapply the Power Signal multiple times at other—consecutively lower—Operating Frequencies within the range specified above, until the Power Transmitter receives a Signal Strength Packet containing an appropriate Signal Strength Value.

Figure 8. Electrical diagram (outline) of Power Transmitter design A3



Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Qi Specification, Power Delivery*. The controlled variable $v^{(i)}$ introduced in the definition of that algorithm represents the input voltage to the full-bridge inverter. In order to guarantee sufficiently accurate power control, a type A3 Power Transmitter shall determine the amplitude of the Primary Cell voltage—which is equal to the Primary Coil voltage—with a resolution of 5 mV or better. Finally, Table 7 provides the values of several parameters, which are used in the PID algorithm.

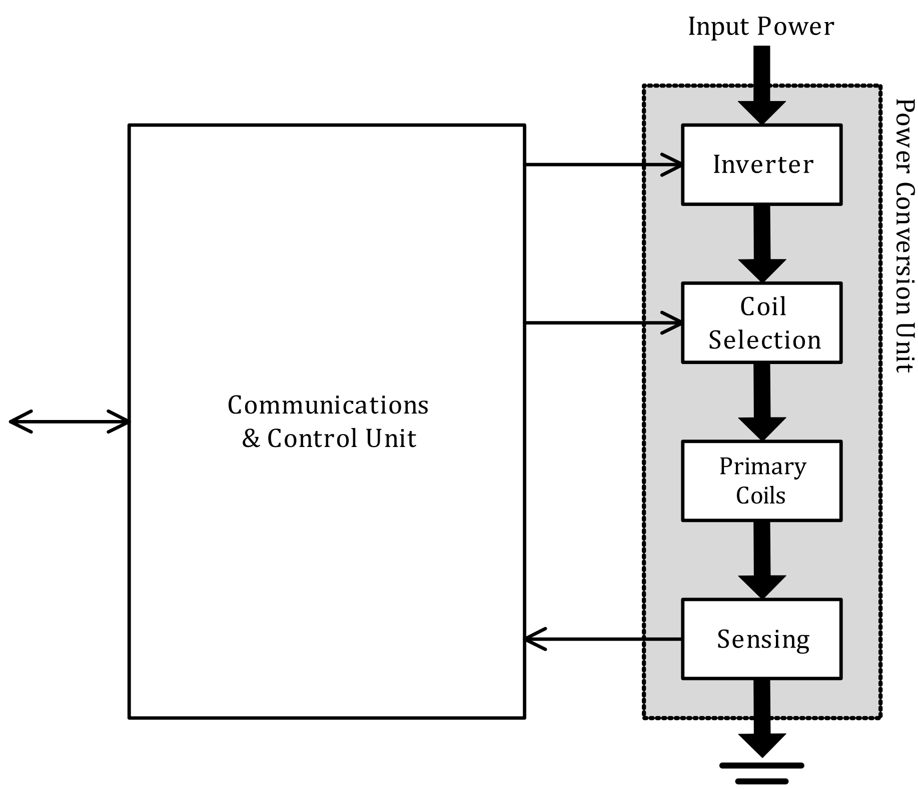
Table 7: PID parameters for voltage control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	1	mA^{-1}
Integral gain	K_i	0	$\mathrm{mA}^{-1}\mathrm{ms}^{-1}$
Derivative gain	K_d	0	$\mathrm{mA}^{-1}\mathrm{ms}$
Integral term limit	M_I	N.A.	N.A.
PID output limit	M_PID	1,500	N.A.
Scaling factor	S_v	–0.5	mV

6 Power Transmitter design A4

Power Transmitter design A4 enables Free Positioning. Figure 9 illustrates the functional block diagram of this design, which consists of two major functional units, namely a Power Conversion Unit and a Communications and Control Unit.

Figure 9. Functional block diagram of Power Transmitter design A4



The Power Conversion Unit on the right-hand side of Figure 9 and the Detection Unit of the bottom of Figure 9 comprise the analog parts of the design. The inverter converts the DC input to an AC waveform that drives a resonant circuit, which consists of the selected Primary Coil plus a series capacitor. The selected Primary Coil is one from two partially overlapping Primary Coils, as appropriate for the position of the Power Receiver relative to the two Primary Coils. Selection of the Primary Coil proceeds by the Power Transmitter attempting to establish communication with a Power Receiver using either Primary Coil. Finally, the voltage sense monitors the Primary Coil voltage and current.

The Communications and Control Unit on the left-hand side of Figure 9 comprises the digital logic part of the design. The Communications and Control Unit receives and decodes messages from the Power Receiver, configures the Coil Selection block to connect the appropriate Primary Coil, executes the relevant power control algorithms and protocols, and drives the input voltage of the AC waveform to control the power transfer. The Communications and Control Unit also interfaces with other subsystems of the Power Transmitter Product, e.g. for user interface purposes.

6.1 Mechanical details

Power Transmitter design A4 includes two Primary Coils as defined in Section 6.1.1, *Primary Coil*, Shielding as defined in Section 6.1.1.1, *Shielding*, and an Interface Surface as defined in Section 6.1.2, *Interface Surface*.

6.1.1 Primary Coil

The Primary Coils are of the wire-wound type, and consists of litz wire having 115 strands of 0.08 mm diameter, or equivalent. As shown in Figure 10, a Primary Coil has a racetrack-like shape and consists of a single layer. Table 8 lists the dimensions of a Primary Coil.

Figure 10. Primary Coil of Power Transmitter design A4

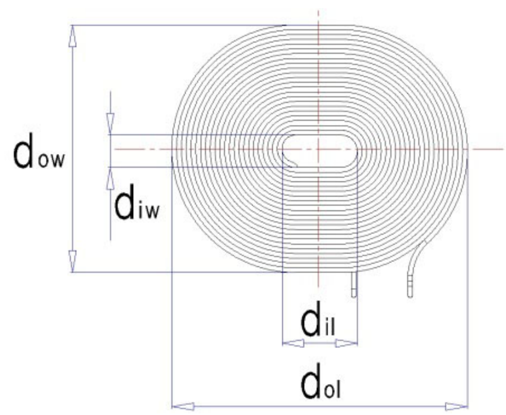
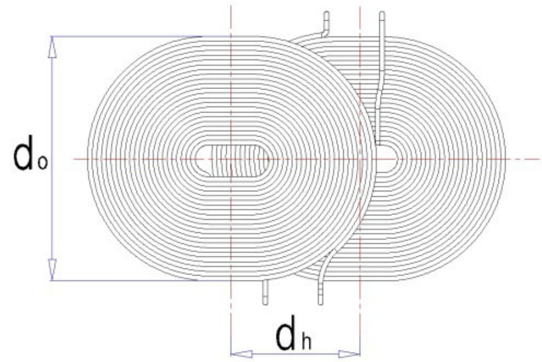


Table 8: Primary Coil parameters of Power Transmitter design A4

Parameter	Symbol	Value
Outer length	d_{ol}	$70^{\pm0.5}$ mm
Inner length	d_{il}	$15^{\pm0.5}$ mm
Outer width	d_{ow}	$59^{\pm0.5}$ mm
Inner width	d_{iw}	$4^{\pm0.5}$ mm
Thickness	d_c	$1.15^{\pm0.05}$ mm
Number of turns per layer	N	23.5
Number of layers	–	1

Power Transmitter design A4 contains two Primary Coils, which are mounted in a Shielding block (see Section 6.1.1.1, *Shielding*) with their long axes coincident, and a displacement of $d_{\text{h}} = 41^{\pm0.5}$ mm between their centers. See Figure 11.

Figure 11. Dual Primary Coils (top view)

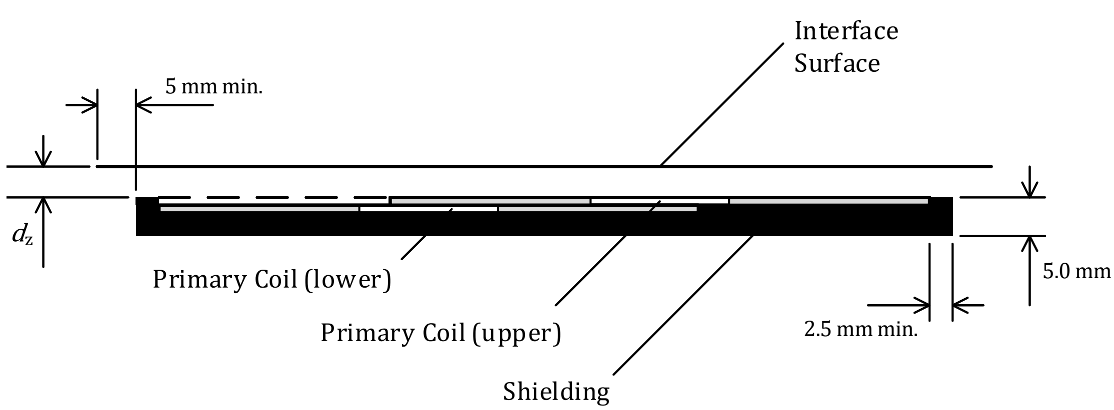


6.1.1.1 Shielding

As shown in Figure 12, Shielding protects the Power Transmitter Product from the magnetic field that is generated in the Primary Coils. The Shielding should be Ni-Zn or Mn-Zn ferrite and should be at least 5.0 mm thick.

The top face of the Shielding block is aligned with the top face of the Primary Coils, such that the Shielding surrounds the Primary Coils on all sides except for the top face. In addition, the Shielding extends to at least 2.5 mm beyond the outer edge of the Primary Coils.

Figure 12. Primary Coil assembly of Power Transmitter design A4



6.1.2 Interface Surface

As shown in Figure 12, the distance from the top face of the top Primary Coil to the Interface Surface of the Power Transmitter Product is $d_{\mathrm{Z}} = 2.0^{\pm 0.5}$ mm, across the top face of the Primary Coil. The bottom Primary Coil is mounted flush to the bottom face of the top Primary Coil. In the case of a single Primary Coil, the distance from the Primary Coil to the Interface Surface of the Power Transmitter Product is $d_{\mathrm{z}} = 3.15^{\pm 0.5}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Power Transmitter Product extends at least 5 mm beyond the outer diameter of the Primary Coil.

6.1.3 Separation between multiple Power transmitters

In a Power Transmitter Product that contains multiple type A4 Power Transmitters, the Primary Coil assemblies of any pair of Power Transmitter shall not overlap.

NOTE: The two Primary Coils within an assembly do overlap as defined in Section 6.1.1, *Primary Coil*.

6.2 Electrical details

As shown in Figure 13, Power Transmitter design A4 uses a full-bridge inverter to drive the Primary Coils and a series capacitance. In addition, Power Transmitter design A4 shall operate coil selection switches SWu and SWl such that only a single Primary Coil is connected to the inverter.

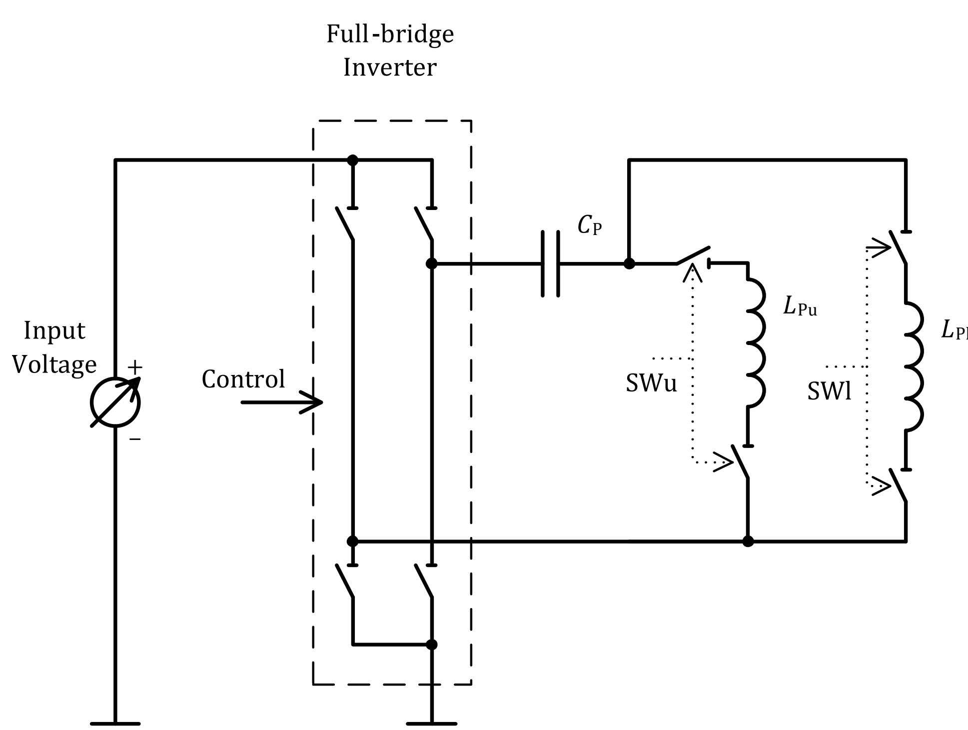
Within the Operating Frequency range of 110…180 kHz, each Primary Coil in the assembly of Primary Coils and Shielding has a self-inductance $L_P = 24^{\pm 0.5}$ μH. The value of the series capacitance is $C_P = 100^{\pm 5\%}$ nF. The input voltage to the full-bridge inverter is 5…11 V.

NOTE: Near resonance, the voltage developed across the series capacitance can reach levels up to 40 V pk-pk.

Power Transmitter design A4 uses the Operating Frequency and the input voltage to the full-bridge inverter to control the amount of power that is transferred. In order to achieve a sufficiently accurate adjustment of the power that is transferred, a type A4 Power Transmitter shall be able to control the frequency with a resolution of 0.5 kHz, and the input voltage with a resolution of 50 mV or better.

When a type A4 Power Transmitter first applies a Power Signal (Digital Ping; see the *Qi Specification, Communications Protocol*), the Power Transmitter shall use an Operating Frequency of 130 kHz, and an input voltage of 8 V. If the Power Transmitter does not to receive a Signal Strength Packet from the Power Receiver, the Power Transmitter shall remove the Power Signal as defined in the *Qi Specification, Communications Protocol*. The Power Transmitter may reapply the Power Signal multiple times at an Operating Frequency of 130 kHz using consecutively higher input voltages within the range specified above, until the Power Transmitter receives a Signal Strength Packet containing an appropriate Signal Strength Value.

Figure 13. Electrical diagram (outline) of Power Transmitter design A4



Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Qi Specification, Power Delivery*. The controlled variable $v^{(i)}$ introduced in the definition of that algorithm represents Operating Frequency as well as the input voltage to the full-bridge inverter. It is recommended that control of the power occurs primarily by means of adjustments to the Operating Frequency, and that voltage adjustments are made only at the boundaries of the Operating Frequency range. In order to guarantee sufficiently accurate power control, a type A4 Power Transmitter shall determine the amplitude of the Primary Coil current with a resolution of 5 mA or better. Finally, Table 9 and Table 10 provide the values of several parameters, which are used in the PID algorithm.

Table 9: PID parameters for Operating Frequency control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	1	mA^{-1}
Integral gain	K_i	0	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	N.A.	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_v	1.0	Hz

Table 10: PID parameters for voltage control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	1	mA^{-1}
Integral gain	K_i	0	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	N.A.	N.A.
PID output limit	M_{PID}	1,500	N.A.
Scaling factor	S_v	–0.5	mV

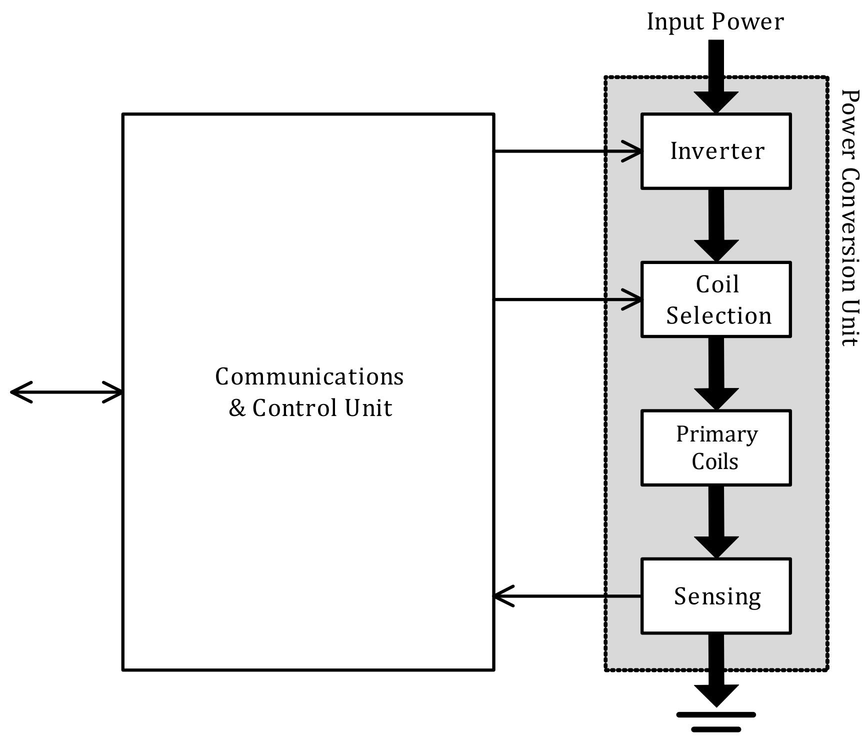
7 Power Transmitter design A5

Power Transmitter design A5 has been deprecated. For further information, see the note in Section 2, *Overview*.

8 Power Transmitter design A6

Figure 14 illustrates the functional block diagram of this design, which consists of two major functional units, namely a Power Conversion Unit and a Communications and Control Unit.

Figure 14. Functional block diagram of Power Transmitter design A6



The Power Conversion Unit on the right-hand side of Figure 14 comprises the analog parts of the design. The inverter converts the DC input to an AC waveform that drives a resonant circuit, which consists of the selected Primary Coil plus a series capacitor. The selected Primary Coil is one from a linear array of partially overlapping Primary Coils, as appropriate for the position of the Power Receiver relative to the Primary Coils. Selection of the Primary Coil proceeds by the Power Transmitter attempting to establish communication with a Power Receiver using any of the Primary Coils. Note that the array may consist of a single Primary Coil only, in which case the selection is trivial. Finally, the current sense monitors the Primary Coil current.

The Communications and Control Unit on the left-hand side of Figure 14 comprises the digital logic part of the design. This unit receives and decodes messages from the Power Receiver, configures the Coil Selection block to connect the appropriate Primary Coil, executes the relevant power control algorithms and protocols, and drives the frequency of the AC waveform to control the power transfer. The Communications and Control Unit also interfaces with other subsystems of the Power Transmitter Product, e.g. for user interface purposes.

8.1 Mechanical details

Power Transmitter design A6 includes one or more Primary Coils as defined in Section 8.1.1, *Primary Coil*, Shielding as defined in Section 8.1.2, *Shielding*, an Interface Surface as defined in Section 8.1.3, *Interface Surface*.

8.1.1 Primary Coil

The Primary Coil is of the wire-wound type, and consists of no. 17 AWG (1.15 mm diameter) type 2 litz wire having 105 strands of no. 40 AWG (0.08 mm diameter), or equivalent. As shown in Figure 15, the Primary Coil has a rectangular shape and consists of a single layer. Table 11 lists the dimensions of the Primary Coil.

Figure 15. Primary Coil of Power Transmitter design A6

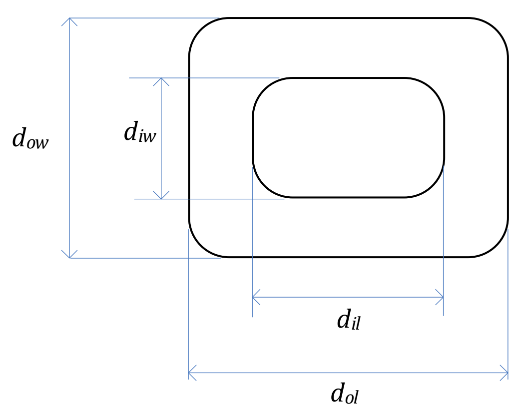
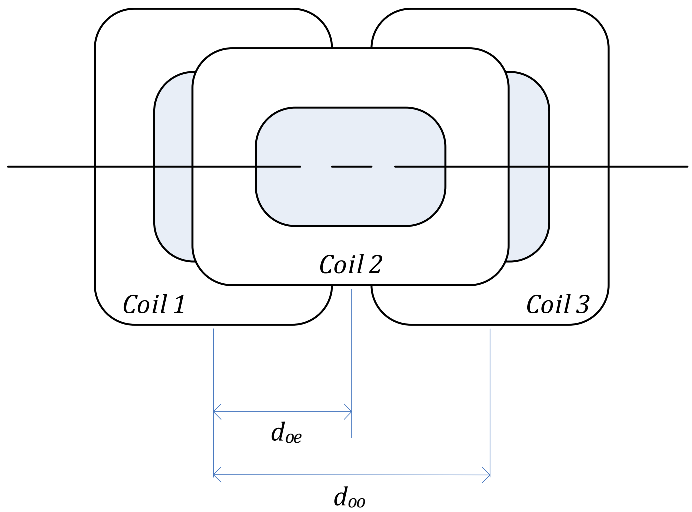


Table 11: Primary Coil parameters of Power Transmitter design A6

Parameter	Symbol	Value
Outer length	d_{ol}	$53.2^{\pm 0.5}$ mm
Inner length	d_{il}	$27.5^{\pm 0.5}$ mm
Outer width	d_{ow}	$45.2^{\pm 0.5}$ mm
Inner width	d_{iw}	$19.5^{\pm 0.5}$ mm
Thickness	d_c	$1.5^{\pm 0.5}$ mm
Number of turns per layer	N	12 turns
Number of layers	–	1

Power Transmitter design A6 contains at least one Primary Coil. Odd numbered coils are placed alongside each other with a displacement of $d_{oo} = 49.2^{\pm 4}$ mm between their centers. Even numbered coils are placed orthogonal to the odd numbered coils with a displacement of $d_{oe} = 24.6^{\pm 2}$ mm between their centers. See Figure 16.

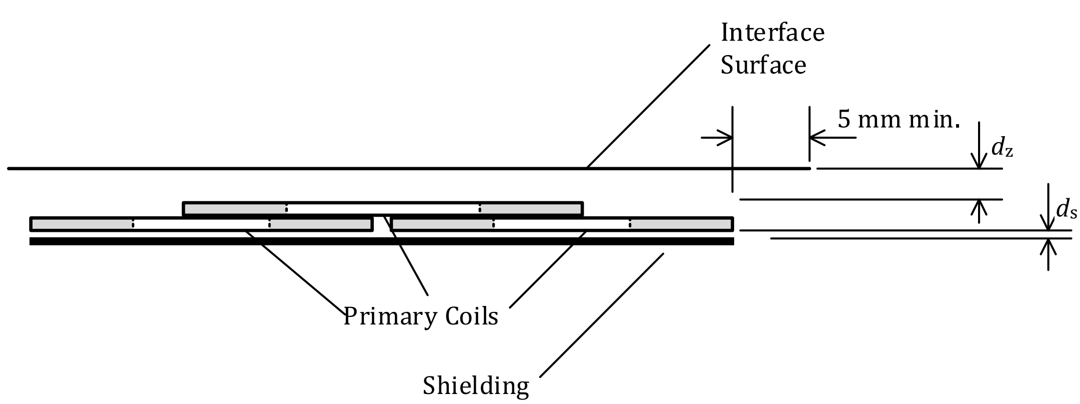
Figure 16. Primary Coils of Power Transmitter design A6



8.1.2 Shielding

As shown in Figure 17, Shielding protects the Power Transmitter Product from the magnetic field that is generated in the Primary Coil. The Shielding should be Ni-Zn or Mn-Zn ferrite and should be at least 0.5 mm thick. The Shielding extends to at least the outer dimensions of the Primary Coils, and is placed below the Primary Coil at a distance of at most $d_s = 1.0$ mm.

Figure 17. Primary Coil assembly of Power Transmitter design A6



8.1.3 Interface Surface

As shown in Figure 17, the distance from the top face of the even-numbered Primary Coil to the Interface Surface of the Power Transmitter Product is $d_{\mathrm{z}} = 2^{+0.5}_{0.25}$ mm, across the top face of the Primary Coil. The odd-numbered Primary Coils are mounted flush to the bottom face of the even-numbered Primary Coils. In the case of a single Primary Coil, the distance from the Primary Coil to the Interface Surface of the Power Transmitter Product is $d_{\mathrm{z}} = 3^{+0.5}_{0.25}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Power Transmitter Product extends at least 5 mm beyond the outer dimensions of the Primary Coils.

8.1.4 Inter coil separation

If the Power Transmitter Product contains multiple type A6 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall not overlap.

8.2 Electrical details

As shown in Figure 18, Power Transmitter design A6 uses a half-bridge inverter to drive an individual Primary Coil and a series capacitance. Within the Operating Frequency range specified below, the assembly of Primary Coils and Shielding has a self-inductance $L_{\mathrm{P}} = 11.5^{\pm 10\%}$ μH for coils closest to the Interface Surface .and inductance $L_{\mathrm{P}} = 12.5^{\pm 10\%}$ μH for coils furthest from the Interface Surface. The value of the series capacitance is $C_{\mathrm{P}} = 0.147^{\pm 5\%}$ μF for coils closest to the Interface Surface and $C_{\mathrm{P}} = 0.136^{\pm 5\%}$ μF for coils furthest from the Interface Surface. The input voltage to the half-bridge inverter is $12^{\pm 5\%}$ V.

NOTE: Near resonance, the voltage developed across the series capacitance can reach levels exceeding 100 V pk-pk.

Power Transmitter design A6 uses the Operating Frequency and duty cycle of the Power Signal in order to control the amount of power that is transferred. For this purpose, the Operating Frequency range of the half-bridge inverter is f_{op} =115...205 kHz with a duty cycle of 50%; and its duty cycle range is 10…50% at an Operating Frequency of 205 kHz. A higher Operating Frequency or lower duty cycle result in the transfer of a lower amount of power. In order to achieve a sufficiently accurate adjustment of the amount of power that is transferred, a type A6 Power Transmitter shall control the Operating Frequency with a resolution of

- $0.01 \times f_{\mathrm{op}} - 0.7$ kHz, for f_{op} in the 115…175 kHz range;
- $0.015 \times f_{\mathrm{op}} - 1.58$ kHz, for f_{op} in the 175…205 kHz range;

or better. In addition, a type A6 Power Transmitter shall control the duty cycle of the Power Signal with a resolution of 0.1% or better.

When a type A6 Power Transmitter first applies a Power Signal (Digital Ping; see the *Qi Specification, Communications Protocol*), it shall use an initial Operating Frequency of 175 kHz (and a duty cycle of 50%).

Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Qi Specification, Power Delivery*. The controlled variable $v^{(i)}$ introduced in the definition of that algorithm represents the Operating Frequency or the duty cycle. In order to guarantee sufficiently accurate power control, a type A6 Power Transmitter shall determine the amplitude of the Primary Cell current—which is equal to the Primary Coil current—with a resolution of 7 mA or better. Finally, Table 12, Table 13, and Table 14 provide the values of several parameters, which are used in the PID algorithm.

Figure 18. Electrical diagram (outline) of Power Transmitter design A6

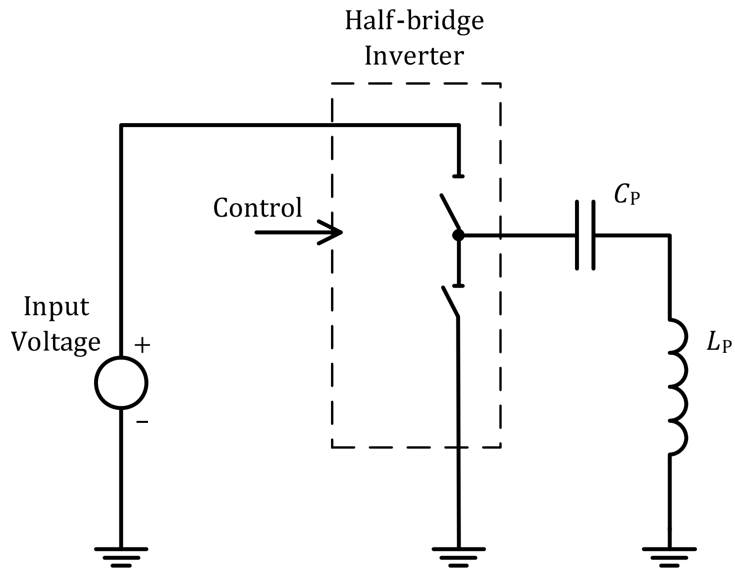


Table 12: PID parameters for Operating Frequency control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	10	mA^{-1}
Integral gain	K_i	0.05	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	3,000	N.A.
PID output limit	M_{PID}	20,000	N.A.

Table 13: Operating Frequency dependent scaling factor

Frequency Range [kHz]	Scaling Factor S_v [Hz]
115…140	1.5
140…160	2
160…180	3
180…205	5

Table 14: PID parameters for duty cycle control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	10	mA^{-1}
Integral gain	K_i	0.05	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	3,000	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_v	–0.01	%

9 Power Transmitter design A7

Power Transmitter design A7 enables Free Positioning, and has a design similar to Power Transmitter design A2. See Section 4, *Power Transmitter design A2* for an overview.

9.1 Mechanical details

Power Transmitter design A7 includes a single Primary Coil as defined in Section 9.1.1, *Primary Coil*, Shielding as defined in Section 9.1.2, *Shielding*, an Interface Surface as defined in Section 9.1.3, *Interface Surface*, and a positioning stage as defined in Section 9.1.4, *Positioning stage*.

9.1.1 Primary Coil

The Primary Coil is of the wire-wound type, and consists of litz wire having 100 strands of 0.08 mm diameter, or equivalent. As shown in Figure 19, the Primary Coil has a circular shape and consists of a single layer. Table 15 lists the dimensions of the Primary Coil.

Figure 19. Primary Coil of Power Transmitter design A7

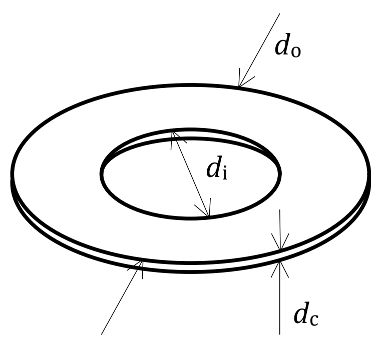


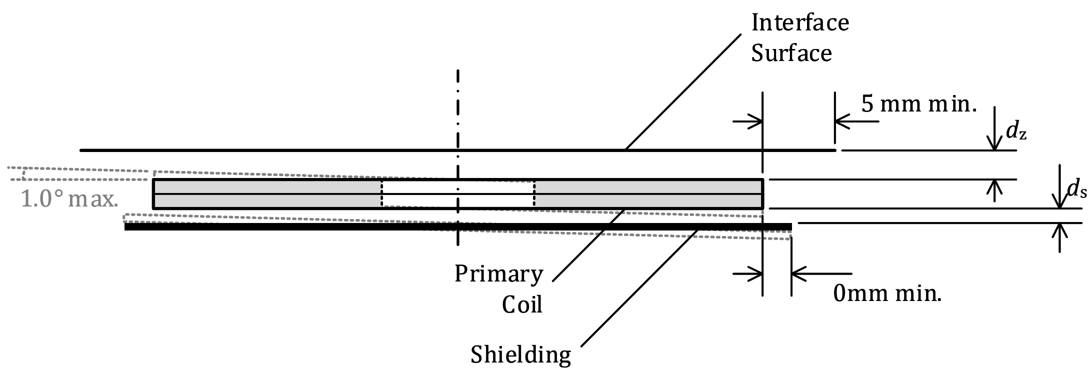
Table 15: Primary Coil parameters of Power Transmitter design A7

Parameter	Symbol	Value
Outer diameter	d_o	$39^{\pm 2}$ mm
Inner diameter	d_i	$12^{\pm 0.2}$ mm
Thickness	d_c	$1.9^{\pm 0.2}$ mm
Number of turns per layer	N	20
Number of layers	–	1

9.1.2 Shielding

As shown in Figure 20, Shielding protects the Power Transmitter Product from the magnetic field that is generated in the Primary Coil. The Shielding should be Ni-Zn or Mn-Zn ferrite and should be at least 0.6 mm thick. The Shielding extends to at least the edges of the Primary Coil, and is placed below the Primary Coil at a distance of at most $d_s = 0.5$ mm.

Figure 20. Primary Coil assembly of Power Transmitter design A7



9.1.3 Interface Surface

As shown in Figure 20, the distance from the Primary Coil to the Interface Surface of the Power Transmitter Product is $d_Z = 3.0^{\pm 0.5}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Power Transmitter Product extends at least 5mm beyond the outer diameter of the Primary Coil.

9.1.4 Positioning stage

The positioning stage shall have a resolution of 0.1mm or better in each of the two orthogonal directions parallel to the Interface Surface.

9.2 Electrical details

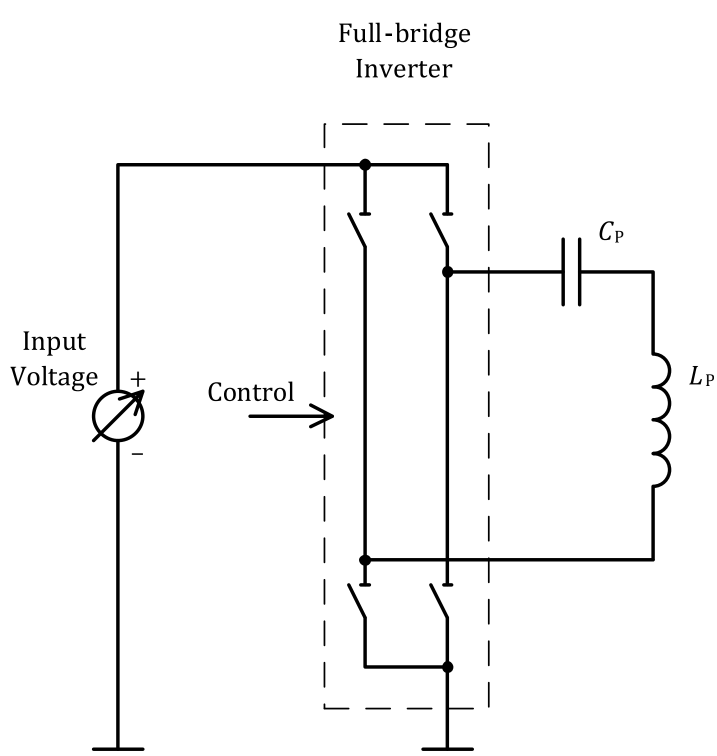
As shown in Figure 21, Power Transmitter design A7 uses a full-bridge inverter to drive the Primary Coil and a series capacitance. At an Operating Frequency range between 105 kHz and 140 kHz, the assembly of Primary Coil and Shielding has a self-inductance $L_\mathrm{P} = 13.6^{\pm 10\%}$ μH. The value of the series capacitance is $C_\mathrm{P} = 180^{\pm 5\%}$ nF.

NOTE: Near resonance, the voltage developed across the series capacitance can reach levels up to 100 V pk-pk.

Power Transmitter design A7 uses the input voltage to the full-bridge inverter to control the amount of power that is transferred. For this purpose, the input voltage range is 3…12 V, where a lower input voltage results in the transfer of a lower amount of power. In order to achieve a sufficiently accurate adjustment of the power that is transferred, a type A7 Power Transmitter shall be able to control the input voltage with a resolution of 50 mV or better.

When a type A7 Power Transmitter first applies a Power Signal (Digital Ping; the *Qi Specification, Communications Protocol*), it shall use an initial input voltage of 6.5 V. It is recommended that the Power Transmitter uses an Operating Frequency of 140 kHz when first applying the Power Signal. If the Power Transmitter does not to receive a Signal Strength Packet from the Power Receiver, the Power Transmitter shall remove the Power Signal as defined in the *Qi Specification, Communications Protocol*. The Power Transmitter may reapply the Power Signal multiple times at other—consecutively lower—Operating Frequencies within the range specified above, until the Power Transmitter receives a Signal Strength Packet containing an appropriate Signal Strength Value.

Figure 21. Electrical diagram (outline) of Power Transmitter design A7



Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Qi Specification, Power Delivery*. The controlled variable $v^{(i)}$ introduced in the definition of that algorithm represents the input voltage to the full-bridge inverter. In order to guarantee sufficiently accurate power control, a type A7 Power Transmitter shall determine the amplitude of the Primary Cell voltage—which is equal to the Primary Coil voltage—with a resolution of 5 mV or better. Finally, Table 16 provides the values of several parameters, which are used in the PID algorithm.

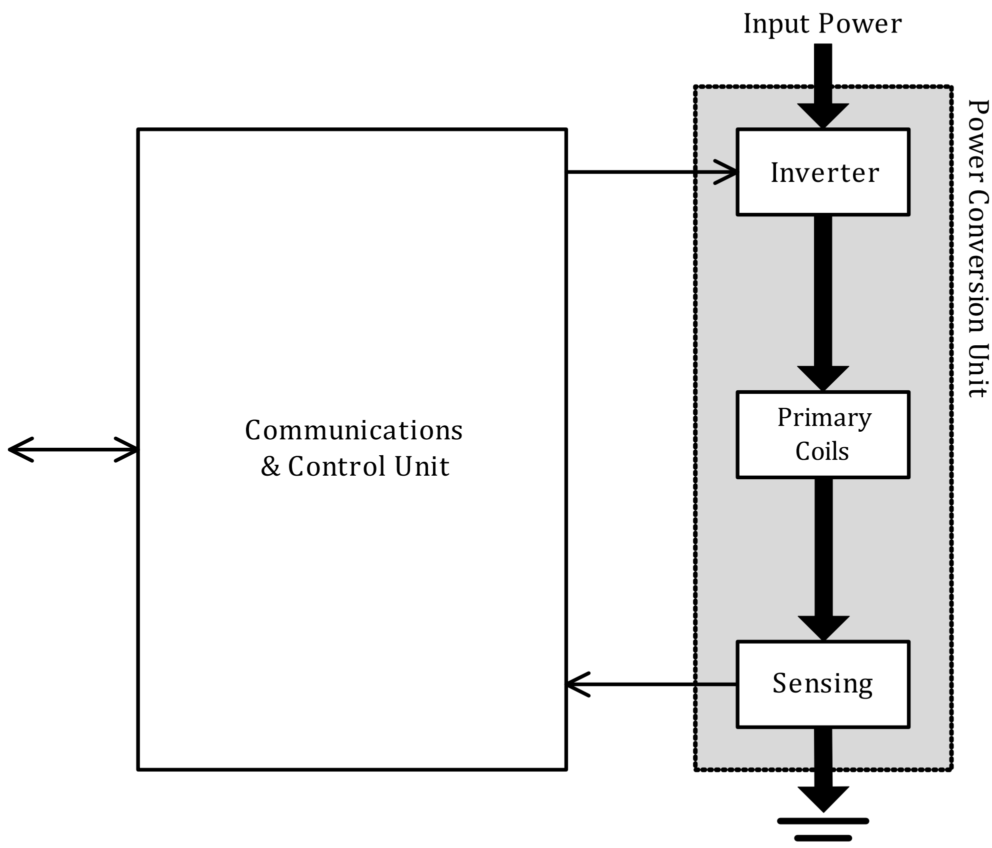
Table 16: PID parameters for voltage control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	1	mA^{-1}
Integral gain	K_i	0	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	N.A.	N.A.
PID output limit	M_{PID}	1,500	N.A.
Scaling factor	S_v	–0.5	mV

10 Power Transmitter design A8

Power Transmitter design A8 enables Free Positioning. Figure 22 illustrates the functional block diagram of this design, which consists of two major functional units, namely a Power Conversion Unit and a Communications and Control Unit.

Figure 22. Functional block diagram of Power Transmitter design A8



The Power Conversion Unit on the right-hand side of Figure 22 comprises the analog parts of the design. The inverter converts the DC input to an AC waveform that drives a resonant circuit, which consists of the Primary Coil plus a series capacitor. Finally, the voltage and current sense monitors the Primary Coil voltage and current.

The Communications and Control Unit on the left-hand side of Figure 22 comprises the digital logic part of the design. The unit receives and decodes messages from the Power Receiver, executes the relevant power control algorithms and protocols, and drives the input power and frequency of the AC waveform to control the power transfer. The Communications and Control Unit also interfaces with other subsystems of the Power Transmitter Product, e.g. for user interface purposes.

10.1 Mechanical details

Power Transmitter design A8 includes one Primary Coil as defined in Section 10.1.1, *Primary Coil*, Shielding as defined in Section 10.1.2, *Shielding*, and an Interface Surface as defined in Section 10.1.3, *Interface Surface*.

10.1.1 Primary Coil

The Primary Coil is of the wire-wound type, and consists of litz wire having 115 strands of 0.08 mm diameter, or equivalent. As shown in Figure 23, a Primary Coil has a racetrack-like shape and consists of a single layer. Table 17 lists the dimensions of a Primary Coil.

Figure 23. Primary Coil of Power Transmitter design A8

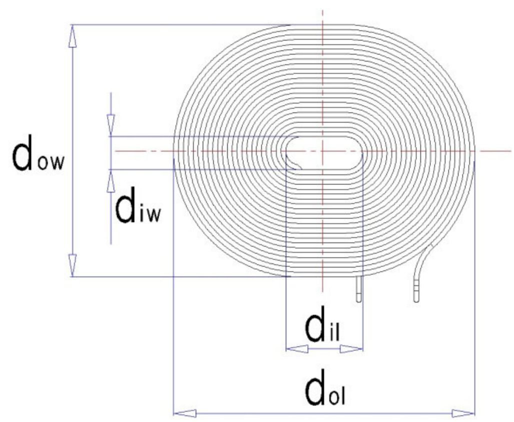


Table 17: Primary Coil parameters of Power Transmitter design A8

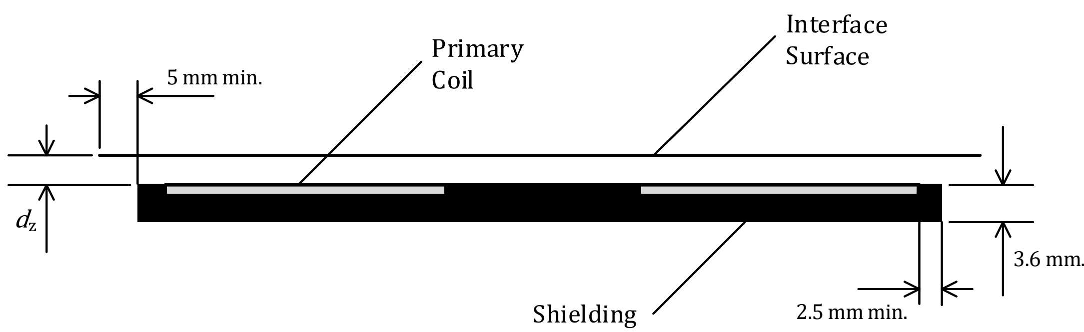
Parameter	Symbol	Value
Outer length	d_{ol}	$70^{\pm 0.5}$ mm
Inner length	d_{il}	$15^{\pm 0.5}$ mm
Outer width	d_{ow}	$59^{\pm 0.5}$ mm
Inner width	d_{iw}	$4^{\pm 0.5}$ mm
Thickness	d_c	$1.2^{\pm 0.15}$ mm
Number of turns per layer	N	23.5
Number of layers	–	1

10.1.2 Shielding

As shown in Figure 24, Shielding protects the Power Transmitter Product from the magnetic field that is generated in the Primary Coil. The Shielding should be Ni-Zn or Mn-Zn ferrite and should be at least 3.1 mm thick.

The top face of the Shielding block is aligned with the top face of the Primary Coil, such that the Shielding surrounds the Primary Coil on all sides except for the top face. In addition, the Shielding extends to at least 2.5 mm beyond the outer edge of the Primary Coil.

Figure 24. Primary Coil assembly of Power Transmitter design A8



10.1.3 Interface Surface

As shown in Figure 24, the distance from the Primary Coil to the Interface Surface of the Power Transmitter Product is $d_z = 2.0^{\pm 0.5}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Power Transmitter Product extends at least 5 mm beyond the outer diameter of the Primary Coil.

10.1.4 Separation between multiple Power transmitters

If the Power Transmitter Product contains multiple type A8 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall not overlap.

10.2 Electrical details

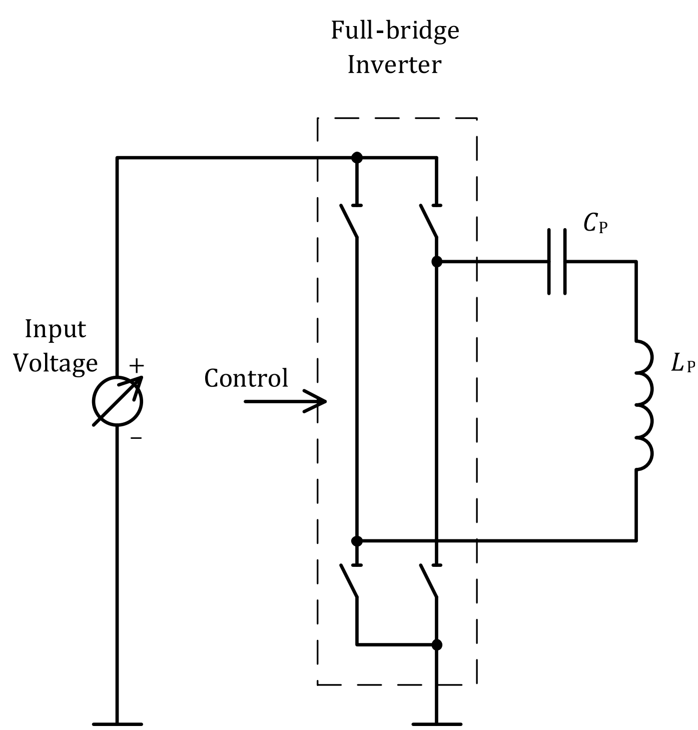
As shown in Figure 25, Power Transmitter design A8 uses a full-bridge inverter to drive the Primary Coil and a series capacitance. Within the Operating Frequency range of 110…180 kHz, the assembly of Primary Coil and Shielding has a self-inductance $L_{\mathrm{P}} = 24^{\pm 0.5}$ μH. The value of the series capacitance is $C_{\mathrm{P}} = 100^{\pm 5\%}$ nF. The input voltage to the full-bridge inverter is $5^{\pm 0.5}$…$11^{\pm 0.5}$ V.

NOTE: Near resonance, the voltage developed across the series capacitance can reach levels up to 100 V pk-pk.

Power Transmitter design A8 uses the Operating Frequency and the input voltage to the full-bridge inverter to control the amount of power that is transferred. In order to achieve a sufficiently accurate adjustment of the power that is transferred, a type A8 Power Transmitter shall be able to control the frequency with a resolution of 0.5 kHz, and the input voltage with a resolution of 50 mV or better.

When a type A8 Power Transmitter first applies a Power Signal (Digital Ping; see the *Qi Specification, Communications Protocol*), the Power Transmitter shall use an Operating Frequency of 130 kHz, and an input voltage of 8 V. If the Power Transmitter does not to receive a Signal Strength Packet from the Power Receiver, the Power Transmitter shall remove the Power Signal as defined in the *Qi Specification, Communications Protocol*. The Power Transmitter may reapply the Power Signal multiple times at an Operating Frequency of 130 kHz using consecutively higher input voltages within the range specified above, until the Power Transmitter receives a Signal Strength Packet containing an appropriate Signal Strength Value.

Figure 25. Electrical diagram (outline) of Power Transmitter design A8



Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Qi Specification, Power Delivery*. The controlled variable $v^{(i)}$ introduced in the definition of that algorithm represents Operating Frequency as well as the input voltage to the full-bridge inverter. It is recommended that control of the power occurs primarily by means of adjustments to the Operating Frequency, and that voltage adjustments are made only at the boundaries of the Operating Frequency range. In order to guarantee sufficiently accurate power control, a type A8 Power Transmitter shall determine the amplitude of the Primary Coil current with a resolution of 5 mA or better. Finally, Table 18 and Table 19 provide the values of several parameters, which are used in the PID algorithm.

Table 18: PID parameters for Operating Frequency control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	1	mA^{-1}
Integral gain	K_i	0	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	N.A.	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_v	1.0	Hz

Table 19: PID parameters for voltage control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	1	mA^{-1}
Integral gain	K_i	0	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	N.A.	N.A.
PID output limit	M_{PID}	1,500	N.A.
Scaling factor	S_v	–0.5	mV

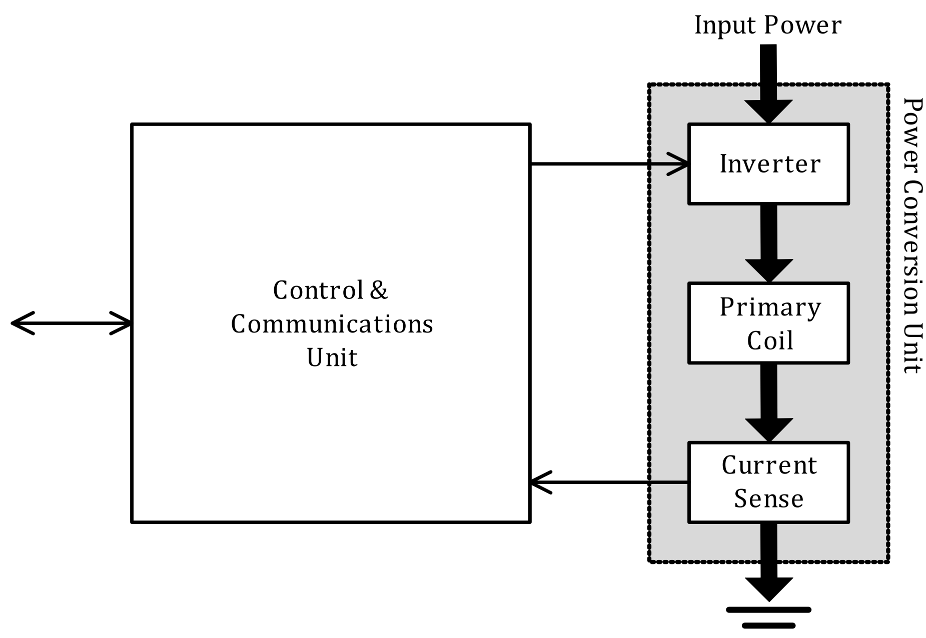
11 Power Transmitter design A9

Power Transmitter design A9 has been deprecated. For further information, see the note in Section 2, *Overview*.

12 Power Transmitter design A10

Power Transmitter design A10 enables Guided Positioning. Figure 26 illustrates the functional block diagram of this design, which consists of two major functional units, namely a Power Conversion Unit and a Communications and Control Unit.

Figure 26. Functional block diagram of Power Transmitter design A10



The Power Conversion Unit on the right-hand side of Figure 26 comprises the analog parts of the design. The inverter converts the DC input to an AC waveform that drives a resonant circuit, which consists of the Primary Coil plus a series capacitor. Finally, the current sense monitors the Primary Coil current.

The Communications and Control Unit on the left-hand side of Figure 26 comprises the digital logic part of the design. This unit receives and decodes messages from the Power Receiver, executes the relevant power control algorithms and protocols, and drives the frequency of the AC waveform to control the power transfer. The Communications and Control Unit also interfaces with other subsystems of the Power Transmitter Product, e.g. for user interface purposes.

12.1 Mechanical details

Power Transmitter design A10 includes a single Primary Coil as defined in Section 12.1.1, *Primary Coil*, Shielding as defined in Section 12.1.2, *Shielding*, an Interface Surface as defined in Section 12.1.3, *Interface Surface*, and an alignment aid as defined in Section 12.1.4, *Alignment aid*.

12.1.1 Primary Coil

The Primary Coil is of the wire-wound type, and consists of no. 17 AWG (1.15 mm diameter) type 2 litz wire having 105 strands of no. 40 AWG (0.08 mm diameter), or equivalent. As shown in Figure 27, the Primary Coil has a circular shape and consists of multiple layers. All layers are stacked with the same polarity. Table 20 lists the dimensions of the Primary Coil.

Figure 27. Primary Coil of Power Transmitter design A10

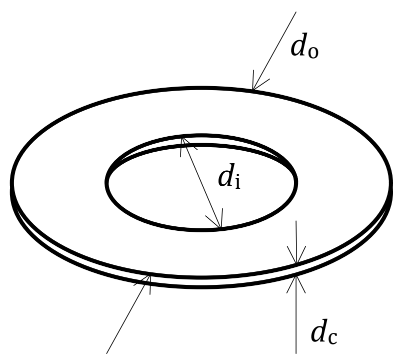


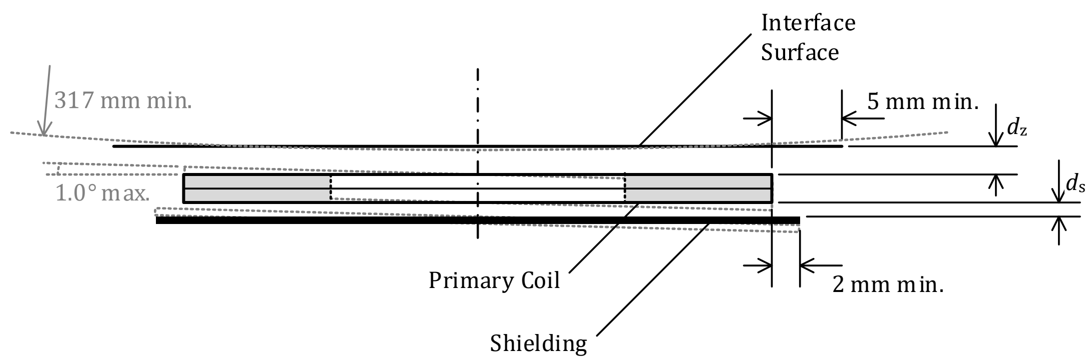
Table 20: Primary Coil parameters of Power Transmitter design A10

Parameter	Symbol	Value
Outer diameter	d_o	$43^{\pm 0.5}$ mm
Inner diameter	d_i	$20.5^{\pm 0.5}$ mm
Thickness	d_c	$2.1^{+0.5}$ mm
Number of turns per layer	N	10
Number of layers	–	2

12.1.2 Shielding

As shown in Figure 28, Shielding protects the Power Transmitter Product from the magnetic field that is generated in the Primary Coil. The Shielding should be Ni-Zn or Mn-Zn ferrite and should be at least 0.5 mm thick. The Shielding extends to at least 2 mm beyond the outer diameter of the Primary Coil, and is placed below the Primary Coil at a distance of at most d_s = 1.0 mm.

Figure 28. Primary Coil assembly of Power Transmitter design A10



12.1.3 Interface Surface

As shown in Figure 28 the distance from the Primary Coil to the Interface Surface of the Power Transmitter Product is $d_Z = 2^{+0.5}_{\ 0.25}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Power Transmitter Product extends at least 5 mm beyond the outer diameter of the Primary Coil.

NOTE: This Primary-Coil-to-Interface-Surface distance implies that the tilt angle between the Primary Coil and a flat Interface Surface is at most 1.0°. Alternatively, in case of a non-flat Interface Surface, this Primary-Coil-to-Interface-Surface distance implies a radius of curvature of the Interface Surface of at least 317 mm, centered on the Primary Coil. See Figure 28.

12.1.4 Alignment aid

The user manual of the Power Transmitter Product containing a type A10 Power Transmitter shall have information about the location of its Active Area(s).

For the best user experience, it is recommended to employ at least one user feedback mechanism during Power Receiver Product positioning to help alignment.

Examples of Power Transmitter Product alignment aids to assist the user positioning of the Power Receiver Product include:

- A marked Interface Surface to indicate the location of the Active Area(s)—e.g. by means of the logo or other visual marking, lighting, etc.
- A visual feedback display—e.g. by means of illuminating an LED to indicate proper alignment.
- An audible or haptic feedback mechanism.

12.1.5 Inter coil separation

If the Power Transmitter Product contains multiple type A10 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall not overlap.

12.2 Electrical details

As shown in Figure 29, Power Transmitter design A10 uses a half-bridge inverter to drive the Primary Coil and a series capacitance. Within the Operating Frequency range specified below, the assembly of Primary Coil and Shielding has a self-inductance $L_P = 24^{\pm10\%}$ μH. The value of the series capacitance is $C_P = 100^{\pm5\%}$ nF. The input voltage to the half-bridge inverter is $19^{\pm1}$ V.

NOTE: Near resonance, the voltage developed across the series capacitance can reach levels exceeding 200 V pk-pk.

Power Transmitter design A10 uses the Operating Frequency and duty cycle of the Power Signal in order to control the amount of power that is transferred. For this purpose, the Operating Frequency range of the half-bridge inverter is f_{op} = 110...205 kHz with a duty cycle of 50%; and its duty cycle range is 10…50% at an Operating Frequency of 205 kHz. A higher Operating Frequency or lower duty cycle result in the transfer of a lower amount of power. In order to achieve a sufficiently accurate adjustment of the amount of power that is transferred, a type A10 Power Transmitter shall control the Operating Frequency with a resolution of

- $0.01 \times f_{op} - 0.7$ kHz, for f_{op} in the 110…175 kHz range;
- $0.015 \times f_{op} - 1.58$ kHz, for f_{op} in the 175…205 kHz range;

or better. In addition, a type A10 Power Transmitter shall control the duty cycle of the Power Signal with a resolution of 0.1% or better.

When a type A10 Power Transmitter first applies a Power Signal (Digital Ping; see the *Qi Specification, Communications Protocol*), it shall use an initial Operating Frequency of 175 kHz (and a duty cycle of 50%).

Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Qi Specification, Power Delivery*. The controlled variable $v^{(i)}$ introduced in the definition of that algorithm represents the Operating Frequency or the duty cycle. In order to guarantee sufficiently accurate power control, a type A10 Power Transmitter shall determine the amplitude of the Primary Cell current—which is equal to the Primary Coil current—with a resolution of 7 mA or better. Finally, Table 21, Table 22, and Table 23 provide the values of several parameters, which are used in the PID algorithm.

Figure 29. Electrical diagram (outline) of Power Transmitter design A10

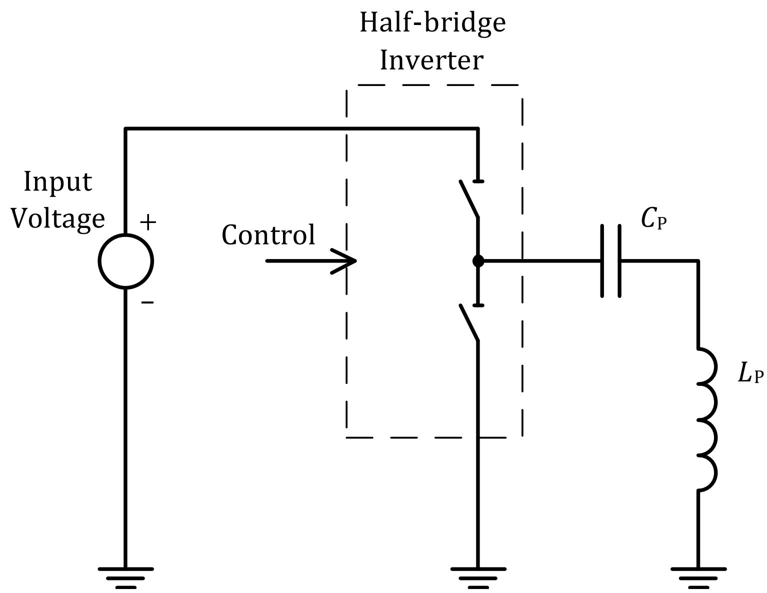


Table 21: PID parameters for Operating Frequency control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	10	mA^{-1}
Integral gain	K_i	0.05	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	3,000	N.A.
PID output limit	M_{PID}	20,000	N.A.

Table 22: Operating Frequency dependent scaling factor

Frequency Range [kHz]	Scaling Factor S_v [Hz]
110…140	1.5
140…160	2
160…180	3
180…205	5

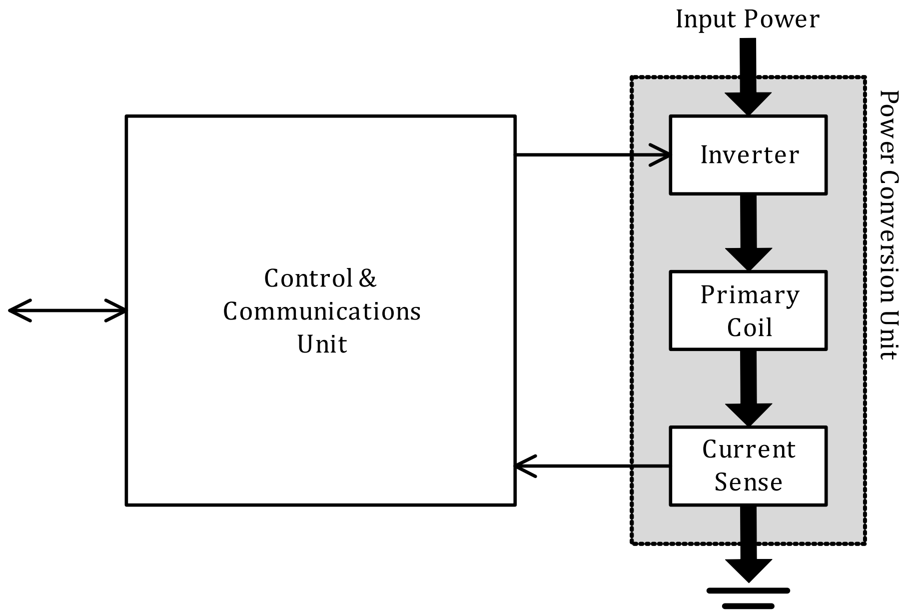
Table 23: PID parameters for duty cycle control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	10	mA^{-1}
Integral gain	K_i	0.05	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	3,000	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_v	–0.01	%

13 Power Transmitter design A11

Power Transmitter design A11 enables Guided Positioning. Figure 30 illustrates the functional block diagram of this design, which consists of two major functional units, namely a Power Conversion Unit and a Communications and Control Unit.

Figure 30. Functional block diagram of Power Transmitter design A11



The Power Conversion Unit on the right-hand side of Figure 30 comprises the analog parts of the design. The inverter converts the DC input to an AC waveform that drives a resonant circuit, which consists of the Primary Coil plus a series capacitor. Finally, the current sense monitors the Primary Coil current.

The Communications and Control Unit on the left-hand side of Figure 30 comprises the digital logic part of the design. This unit receives and decodes messages from the Power Receiver, executes the relevant power control algorithms and protocols, and drives the frequency of the AC waveform to control the power transfer. The Communications and Control Unit also interfaces with other subsystems of the Power Transmitter Product, e.g. for user interface purposes.

13.1 Mechanical details

Power Transmitter design A11 includes a single Primary Coil as defined in Section 13.1.1, *Primary Coil*, Shielding as defined in Section 13.1.2, *Shielding*, an Interface Surface as defined in Section 13.1.3, *Interface Surface*, and an alignment aid as defined in Section 13.1.4, *Alignment aid*.

13.1.1 Primary Coil

The Primary Coil is of the wire-wound type, and consists of no. 17 AWG (1.15 mm diameter) type 2 litz wire having 105 strands of no. 40 AWG (0.08 mm diameter), or equivalent. As shown in Figure 31, the Primary Coil has a circular shape and consists of one or two layers. Table 24 lists the dimensions of the Primary Coil.

Figure 31. Primary Coil of Power Transmitter design A11

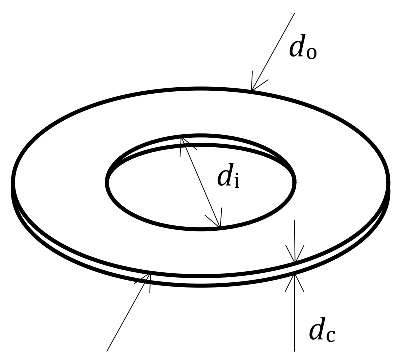


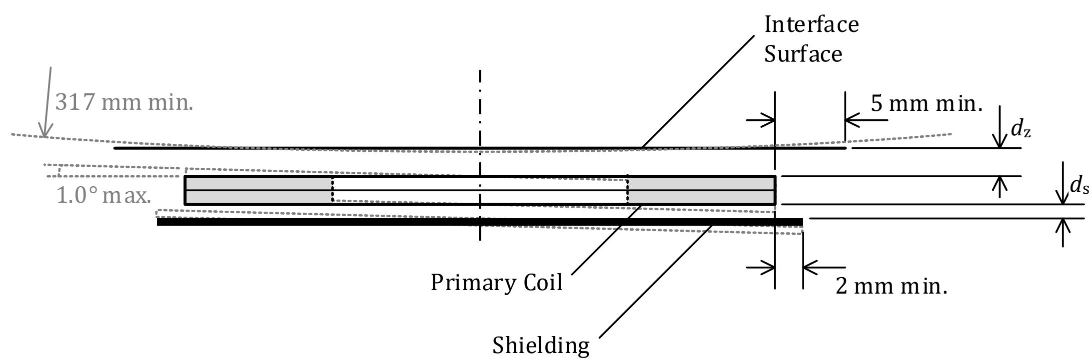
Table 24: Primary Coil parameters of Power Transmitter design A11

Parameter	Symbol	Value
Outer diameter	d_o	$44^{\pm1.5}$ mm
Inner diameter	d_i	$20.5^{\pm0.5}$ mm
Thickness	d_c	$2.1^{+0.5}$ mm
Number of turns per layer	N	10 (5 bifilar turns)
Number of layers	–	1 or 2

13.1.2 Shielding

As shown in Figure 32, Shielding protects the Power Transmitter Product from the magnetic field that is generated in the Primary Coil. The Shielding should be Ni-Zn or Mn-Zn ferrite and should be at least 0.5 mm thick. The Shielding extends to at least 2 mm beyond the outer diameter of the Primary Coil, and is placed below the Primary Coil at a distance of at most d_s = 1.0 mm.

Figure 32. Primary Coil assembly of Power Transmitter design A11



13.1.3 Interface Surface

As shown in Figure 32 the distance from the Primary Coil to the Interface Surface of the Power Transmitter Product is $d_Z = 2^{+0.5}_{0.25}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Power Transmitter Product extends at least 5 mm beyond the outer diameter of the Primary Coil.

NOTE: This Primary-Coil-to-Interface-Surface distance implies that the tilt angle between the Primary Coil and a flat Interface Surface is at most 1.0°. Alternatively, in case of a non-flat Interface Surface, this Primary-Coil-to-Interface-Surface distance implies a radius of curvature of the Interface Surface of at least 317 mm, centered on the Primary Coil. See Figure 32.

13.1.4 Alignment aid

The user manual of the Power Transmitter Product containing a type A11 Power Transmitter shall have information about the location of its Active Area(s).

For the best user experience, it is recommended to employ at least one user feedback mechanism during Power Receiver Product positioning to help alignment.

Examples of Power Transmitter Product alignment aids to assist the user positioning of the Power Receiver Product include:

- A marked Interface Surface to indicate the location of the Active Area(s)—e.g. by means of the logo or other visual marking, lighting, etc.
- A visual feedback display—e.g. by means of illuminating an LED to indicate proper alignment.
- An audible or haptic feedback mechanism.

13.1.5 Inter coil separation

If the Power Transmitter Product contains multiple type A11 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall not overlap.

13.2 Electrical details

As shown in Figure 33, Power Transmitter design A11 uses a full-bridge inverter to drive the Primary Coil and a series capacitance. Within the Operating Frequency range specified below, the assembly of Primary Coil and Shielding has a self-inductance $L_P = 6.3^{\pm 10\%}$ μH. The value of the series capacitance is $C_P = 0.4^{\pm 5\%}$ μF. The input voltage to the full-bridge inverter is $5^{\pm 5\%}$ V.

NOTE: Near resonance, the voltage developed across the series capacitance can reach levels exceeding 100 V pk-pk.

Power Transmitter design A11 uses the Operating Frequency and duty cycle of the Power Signal in order to control the amount of power that is transferred. For this purpose, the Operating Frequency range of the full-bridge inverter is f_{op} = 110...205 kHz with a duty cycle of 50%; and its duty cycle range is 10…50% at an Operating Frequency of 205 kHz. A higher Operating Frequency or lower duty cycle result in the transfer of a lower amount of power. In order to achieve a sufficiently accurate adjustment of the amount of power that is transferred, a type A11 Power Transmitter shall control the Operating Frequency with a resolution of

- $0.01 \times f_{op} - 0.7$ kHz, for f_{op} in the 110…175 kHz range;
- $0.015 \times f_{op} - 1.58$ kHz, for f_{op} in the 175…205 kHz range;

or better. In addition, a type A11 Power Transmitter shall control the duty cycle of the Power Signal with a resolution of 0.1% or better.

When a type A11 Power Transmitter first applies a Power Signal (Digital Ping; see the *Qi Specification, Communications Protocol*), it shall use an initial Operating Frequency of 175 kHz (and a duty cycle of 50%).

Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Qi Specification, Power Delivery*. The controlled variable $v^{(i)}$ introduced in the definition of that algorithm represents the Operating Frequency or the duty cycle. In order to guarantee sufficiently accurate power control, a type A11 Power Transmitter shall determine the amplitude of the Primary Cell current—which is equal to the Primary Coil current—with a resolution of 7 mA or better. Finally, Table 25, Table 26, and Table 27 provide the values of several parameters, which are used in the PID algorithm.

Figure 33. Electrical diagram (outline) of Power Transmitter design A11

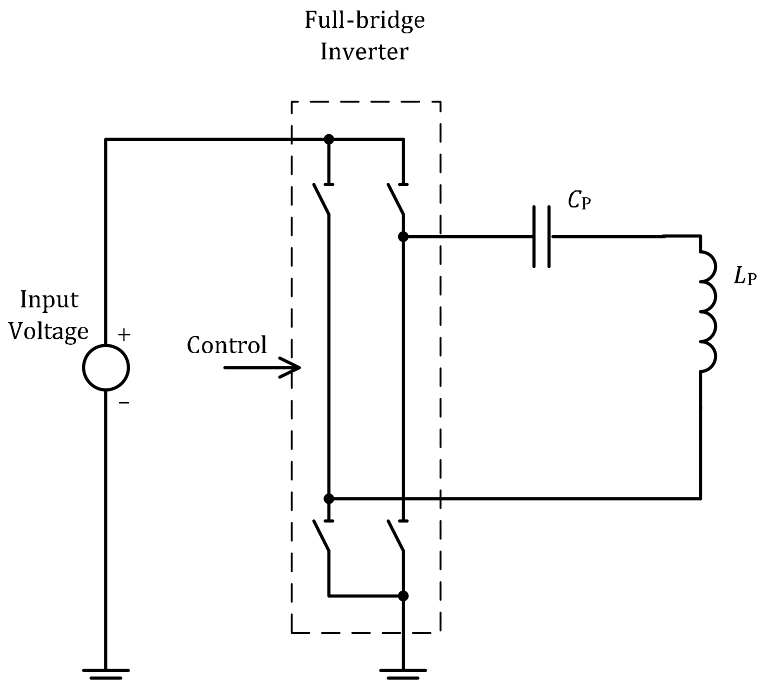


Table 25: PID parameters for Operating Frequency control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	10	mA^{-1}
Integral gain	K_i	0.05	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	3,000	N.A.
PID output limit	M_{PID}	20,000	N.A.

Table 26: Operating Frequency dependent scaling factor

Frequency Range [kHz]	Scaling Factor S_v [Hz]
110…140	1.5
140…160	2
160…180	3
180…205	5

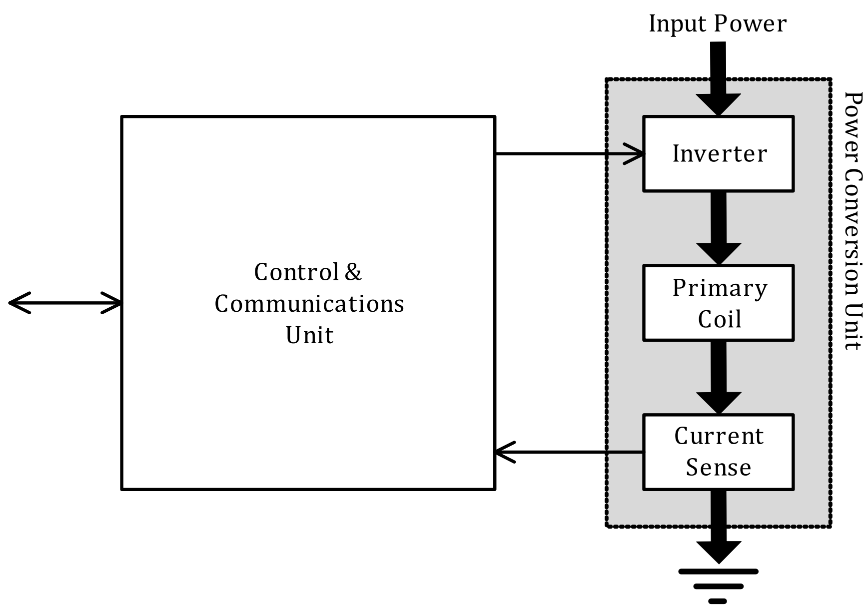
Table 27: PID parameters for duty cycle control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	10	mA^{-1}
Integral gain	K_i	0.05	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	3,000	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_v	–0.01	%

14 Power Transmitter design A11a

Power Transmitter design A11a enables Guided Positioning. Figure 34 illustrates the functional block diagram of this design, which consists of two major functional units, namely a Power Conversion Unit and a Communications and Control Unit.

Figure 34. Functional block diagram of Power Transmitter design A11a



The Power Conversion Unit on the right-hand side of Figure 34 comprises the analog parts of the design. The inverter converts the DC input to an AC waveform that drives a resonant circuit, which consists of the Primary Coil plus a series capacitor. Finally, the current sense monitors the Primary Coil current.

The Communications and Control Unit on the left-hand side of Figure 34 comprises the digital logic part of the design. This unit receives and decodes messages from the Power Receiver, executes the relevant power control algorithms and protocols, and drives the frequency of the AC waveform to control the power transfer. The Communications and Control Unit also interfaces with other subsystems of the Power Transmitter Product, e.g. for user interface purposes.

14.1 Mechanical details

Power Transmitter design A11a includes a single Primary Coil as defined in Section 14.1.1, *Primary Coil*, Shielding as defined in Section 14.1.2, *Shielding*, an Interface Surface as defined in Section 14.1.3, *Interface Surface*, and an alignment aid as defined in Section 14.1.4, *Alignment aid*.

14.1.1 Primary Coil

The Primary Coil is of the wire-wound type, and consists of no. 17 AWG (1.15 mm diameter) type 2 litz wire having 105 strands of no. 40 AWG (0.08 mm diameter), or equivalent. As shown in Figure 35, the Primary Coil has a circular shape and consists of one or two layers. Table 28 lists the dimensions of the Primary Coil.

Figure 35. Primary Coil of Power Transmitter design A11a

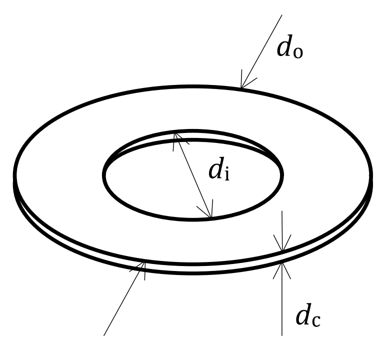


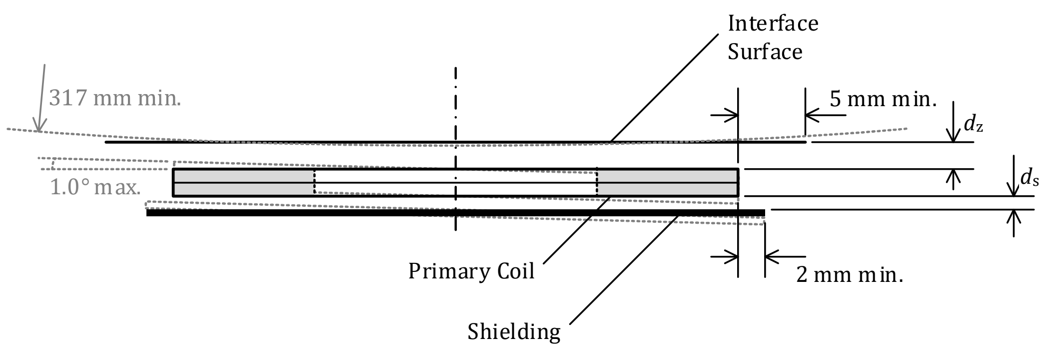
Table 28: Primary Coil parameters of Power Transmitter design A11a

Parameter	Symbol	Value
Outer diameter	d_o	$44^{\pm 1.5}$ mm
Inner diameter	d_i	$20.5^{\pm 0.5}$ mm
Thickness	d_c	$2.1^{+0.5}$ mm
Number of turns per layer	N	10 (5 bifilar turns)
Number of layers	–	1 or 2

14.1.2 Shielding

As shown in Figure 36, Shielding protects the Power Transmitter Product from the magnetic field that is generated in the Primary Coil. The Shielding should be Ni-Zn or Mn-Zn ferrite and should be at least 0.5 mm thick. The Shielding extends to at least 2 mm beyond the outer diameter of the Primary Coil, and is placed below the Primary Coil at a distance of at most d_s = 1.0 mm.

Figure 36. Primary Coil assembly of Power Transmitter design A11a



14.1.3 Interface Surface

As shown in Figure 36, the distance from the Primary Coil to the Interface Surface of the Power Transmitter Product is $d_Z = 2^{+0.5}_{-0.25}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Power Transmitter Product extends at least 5 mm beyond the outer diameter of the Primary Coil.

NOTE: This Primary-Coil-to-Interface-Surface distance implies that the tilt angle between the Primary Coil and a flat Interface Surface is at most 1.0°. Alternatively, in case of a non-flat Interface Surface, this Primary-Coil-to-Interface-Surface distance implies a radius of curvature of the Interface Surface of at least 317 mm, centered on the Primary Coil. See Figure 36.

14.1.4 Alignment aid

The user manual of the Power Transmitter Product containing a type A11a Power Transmitter shall have information about the location of its Active Area(s).

For the best user experience, it is recommended to employ at least one user feedback mechanism during Power Receiver Product positioning to help alignment.

NOTE: Examples of Power Transmitter Product alignment aids to assist the user positioning of the Power Receiver Product include:

- A marked Interface Surface to indicate the location of the Active Area(s)—e.g. by means of the logo or other visual marking, lighting, etc.
- A visual feedback display—e.g. by means of illuminating an LED to indicate proper alignment.
- An audible or haptic feedback mechanism.

14.1.5 Inter coil separation

If the Power Transmitter Product contains multiple type A11a Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall not overlap.

14.2 Electrical details

As shown in Figure 37, Power Transmitter design A11a uses a full-bridge inverter to drive the Primary Coil and a series capacitance. Within the Operating Frequency range specified below, the assembly of Primary Coil and Shielding has a self-inductance $L_{\mathrm{P}} = 6.3^{\pm 10\%}$ μH. The value of the series capacitance is $C_{\mathrm{P}} = 0.4^{\pm 5\%}$ μF. The input voltage to the full-bridge inverter is $5^{\pm 5\%}$ V.

NOTE: Near resonance, the voltage developed across the series capacitance can reach levels exceeding 100 V pk-pk.

Power Transmitter design A11a uses the Operating Frequency and duty cycle of the Power Signal in order to control the amount of power that is transferred. For this purpose, the Operating Frequency range of the full-bridge inverter is $f_{\mathrm{op}} = 110...148$ kHz. At frequencies below 148 kHz, its duty cycle is 50%, and at the frequency of 148 kHz its duty cycle is in the range of 10%…50%. A higher Operating Frequency or lower duty cycle results in the transfer of a lower amount of power.

In order to achieve a sufficiently accurate adjustment of the amount of power that is transferred, a type A11a Power Transmitter shall control the Operating Frequency with a resolution of $0.01 \times f_{\mathrm{op}} - 0.7$ kHz or better for f_{op} in the 110…148 kHz range. In addition, a type A11a Power Transmitter shall control the duty cycle of the Power Signal with a resolution of 0.1% or better.

When a type A11a Power Transmitter first applies a Power Signal (Digital Ping; see the *Qi Specification, Communications Protocol*), it shall use an initial Operating Frequency of 146 kHz and a duty cycle of 50%.

Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Qi Specification, Power Delivery*. The controlled variable $v^{(i)}$ introduced in the definition of that algorithm represents the Operating Frequency or the duty cycle. In order to guarantee sufficiently accurate power control, a type A11a Power Transmitter shall determine the amplitude of the Primary Cell current—which is equal to the Primary Coil current—with a resolution of 7 mA or better. Finally, Table 29, Table 30, and Table 31 provide the values of several parameters, which are used in the PID algorithm.

Figure 37. Electrical diagram (outline) of Power Transmitter design A11a

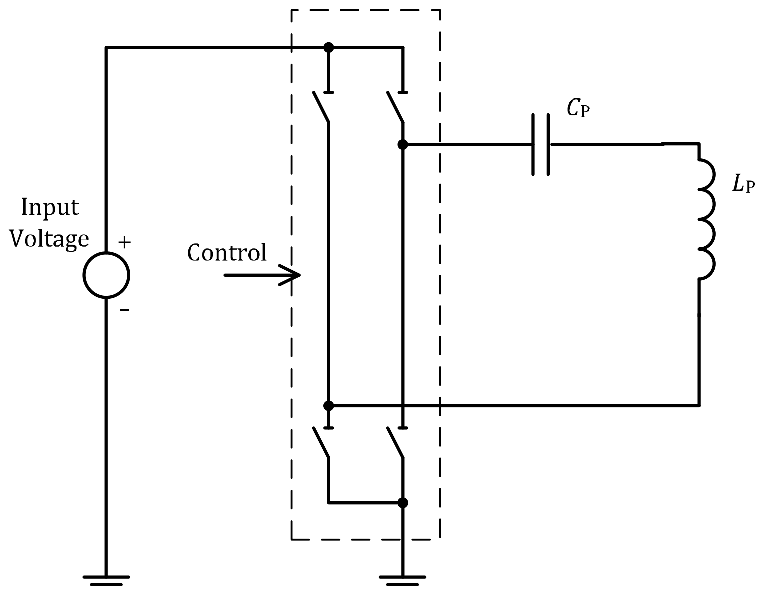


Table 29: PID parameters for Operating Frequency control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	10	mA-1
Integral gain	K_i	0.05	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	3,000	N.A.
PID output limit	M_{PID}	20,000	N.A.

Table 30: Operating Frequency dependent scaling factor

Frequency Range [kHz]	Scaling Factor S_v [Hz]
110…140	1.5
140…148	2

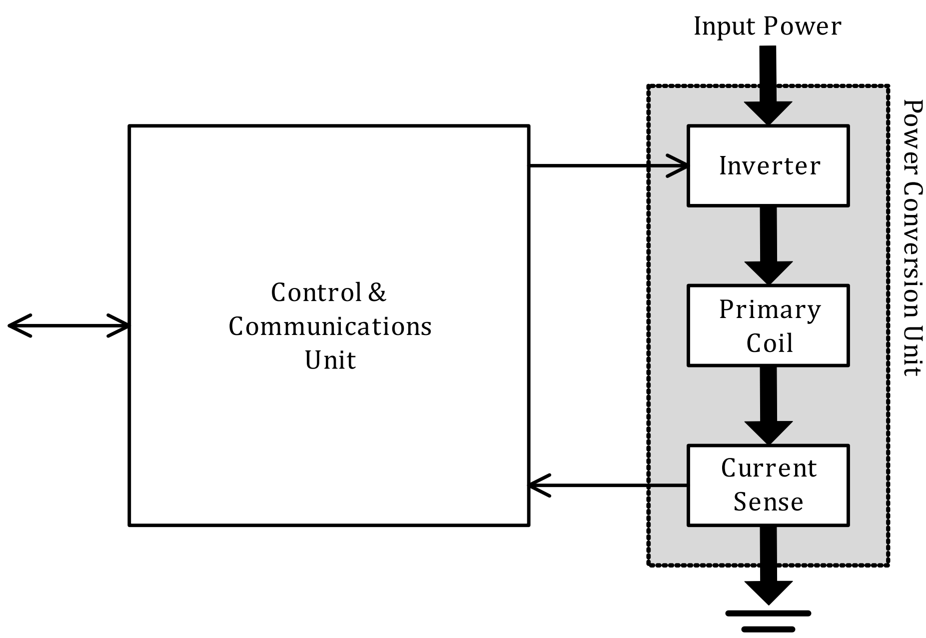
Table 31: PID parameters for duty cycle control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	10	mA^{-1}
Integral gain	K_i	0.05	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	3,000	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_v	–0.01	%

15 Power Transmitter design A12

Figure 38 illustrates the functional block diagram of Power Transmitter design A12, which consists of two major functional units, namely a Power Conversion Unit and a Communications and Control Unit.

Figure 38. Functional block diagram of Power Transmitter design A12



The Power Conversion Unit on the right-hand side of Figure 38 comprises the analog parts of the design. The inverter converts the DC input to an AC waveform that drives a resonant circuit, which consists of the Primary Coil plus a series capacitor. Finally, the current sense monitors the Primary Coil current.

The Communications and Control Unit on the left-hand side of Figure 38 comprises the digital logic part of the design. This unit receives and decodes messages from the Power Receiver, executes the relevant power control algorithms and protocols, and drives the frequency of the AC waveform to control the power transfer. The Communications and Control Unit also interfaces with other subsystems of the Power Transmitter Product, e.g. for user interface purposes.

15.1 Mechanical details

Power Transmitter design A12 includes a single Primary Coil as defined in Section 15.1.1, *Primary Coil*, Shielding as defined in Section 15.1.2, *Shielding*, and an Interface Surface as defined in Section 15.1.3, *Interface Surface*.

15.1.1 Primary Coil

The Primary Coil is of the wire-wound type, and consists of litz wire having 115 strands of 0.08 mm diameter, or equivalent. As shown in Figure 39, a Primary Coil has a racetrack-like shape and consists of a single layer. Table 32 lists the dimensions of a Primary Coil.

Figure 39. Primary Coil of Power Transmitter design A12

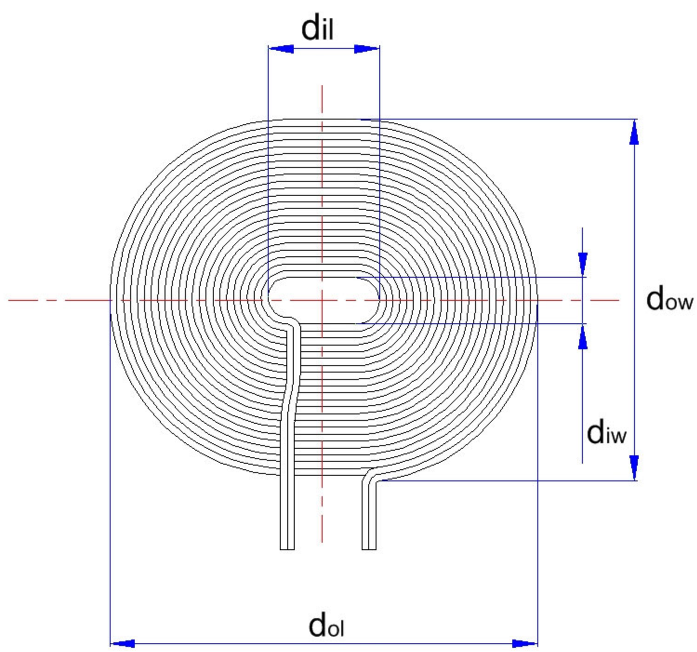


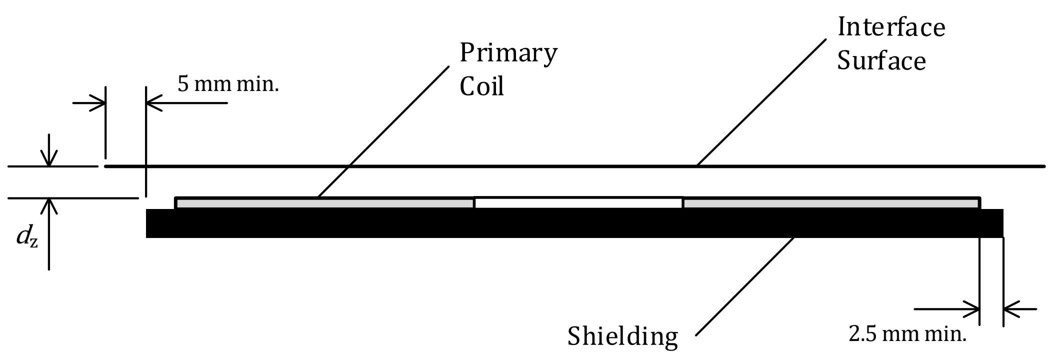
Table 32: Primary Coil parameters of Power Transmitter design A12

Parameter	Symbol	Value
Outer length	d_{ol}	$70^{\pm 0.5}$ mm
Inner length	d_{il}	$15^{\pm 0.5}$ mm
Outer width	d_{ow}	$59^{\pm 0.5}$ mm
Inner width	d_{iw}	$4^{\pm 0.5}$ mm
Thickness	d_c	$1.2^{\pm 0.15}$ mm
Number of turns per layer	N	12 (bifilar turns)
Number of layers	–	1

15.1.2 Shielding

As shown in Figure 40, Shielding protects the Power Transmitter Product from the magnetic field that is generated in the Primary Coil. The Shielding should be Ni-Zn or Mn-Zn ferrite and should be at least 0.5 mm thick. The Shielding extends to at least 2.5 mm beyond the outer edge of the Primary Coil.

Figure 40. Primary Coil assembly of Power Transmitter design A12



15.1.3 Interface Surface

As shown in Figure 40, the distance from the Primary Coil to the Interface Surface of the Power Transmitter Product is $d_z = 2.0^{\pm 0.5}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Power Transmitter Product extends at least 5 mm beyond the outer diameter of the Primary Coil.

15.1.4 Inter coil separation

If the Power Transmitter Product contains multiple type A12 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall not overlap.

15.2 Electrical details

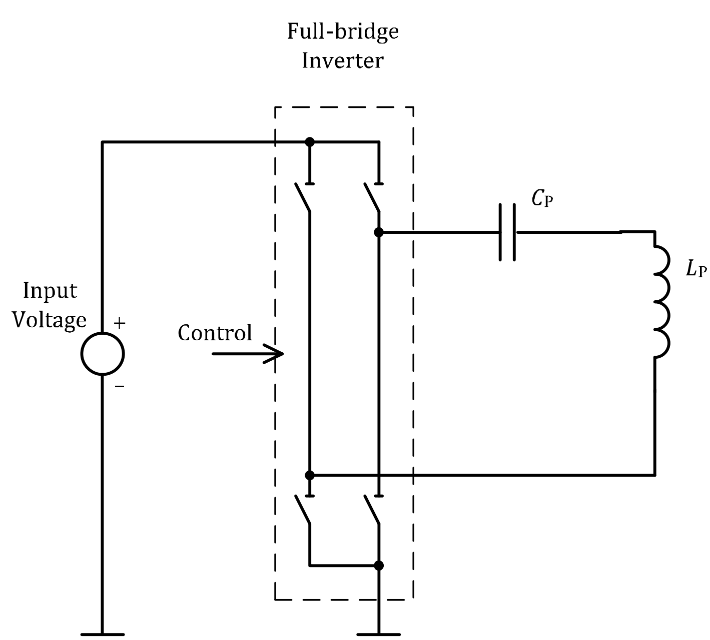
As shown in Figure 41, Power Transmitter design A12 uses a full-bridge inverter to drive the Primary Coil and a series capacitance. Within the Operating Frequency range specified below, the assembly of Primary Coil and Shielding has a self-inductance $L_P = 7^{\pm 10\%}$ μH. The value of the series capacitance is $C_P = 400^{\pm 5\%}$ nF. The input voltage to the full-bridge inverter is $5^{\pm 0.5}$ V.

NOTE: Near resonance, the voltage developed across the series capacitance can reach levels up to 100 V pk-pk.

Power Transmitter design A12 uses the Operating Frequency and duty cycle of the full-bridge inverter to control the amount of power that is transferred. For this purpose, the Operating Frequency range of the full-bridge inverter is f_{op} = 110...205 kHz with a duty cycle of 50% and its duty cycle range is 2 ... 50% at an Operating Frequency of 205 kHz. A higher Operating Frequency and lower duty cycle result in the transfer of a lower amount of power. In order to achieve a sufficiently accurate adjustment of the power that is transferred, a type A12 Power Transmitter shall be able to control the frequency with a resolution of 0.5 kHz or better. a type A12 Power Transmitter shall control the duty cycle of the Power Signal with a resolution of 0.1% or better.

When a type A12 Power Transmitter first applies a Power Signal (Digital Ping; see the *Qi Specification, Communications Protocol*), the Power Transmitter shall use an initial Operating Frequency of 175 kHz, and a duty cycle of 50%. If the Power Transmitter does not to receive a Signal Strength Packet from the Power Receiver, the Power Transmitter shall remove the Power Signal as defined in the *Qi Specification, Communications Protocol*. The Power Transmitter may reapply the Power Signal multiple times at other-consecutively lower-Operating Frequencies within the range specified above, until the Power Transmitter receives a Signal Strength Packet containing an appropriate Signal Strength Value.

Figure 41. Electrical diagram (outline) of Power Transmitter design A12



Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Qi Specification, Power Delivery*. The controlled variable $v^{(i)}$ introduced in the definition of that algorithm represents Operating Frequency or duty cycle. In order to guarantee sufficiently accurate power control, a type A12 Power Transmitter shall determine the amplitude of the Primary Cell current-which is equal to the Primary Coil current-with a resolution of 5 mA or better. Finally, Table 33 and Table 34 provide the values of several parameters, which are used in the PID algorithm.

Table 33: PID parameters for Operating Frequency control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	1	mA^{-1}
Integral gain	K_i	0	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	N.A.	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_v	1.0	Hz

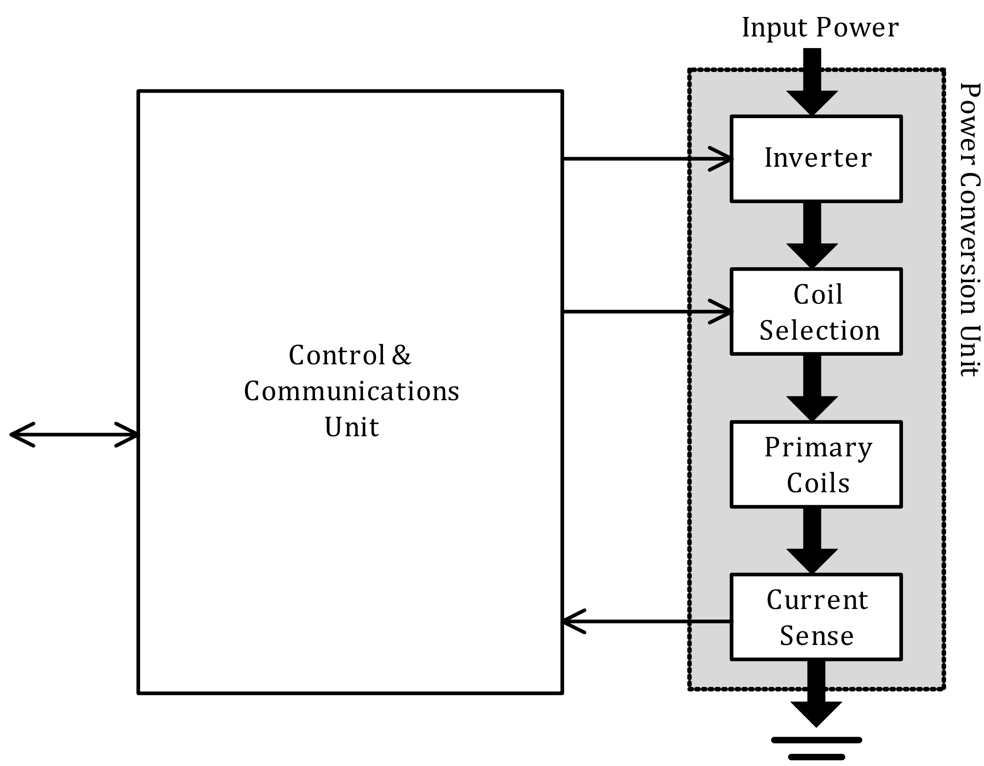
Table 34: PID parameters for duty cycle control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	1	mA^{-1}
Integral gain	K_i	0	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	N.A.	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_v	0.1	%

16 Power Transmitter design A13

Figure 42 illustrates the functional block diagram of Power Transmitter design A13, which consists of two major functional units, namely a Power Conversion Unit and a Communications and Control Unit.

Figure 42. Functional block diagram of Power Transmitter design A13



The Power Conversion Unit on the right-hand side of Figure 42 comprises the analog parts of the design. The inverter converts the DC input to an AC waveform that drives a resonant circuit, which consists of the selected Primary Coil plus a series capacitor. The selected Primary Coil is one from a linear array of partially overlapping Primary Coils, as appropriate for the position of the Power Receiver relative to the Primary Coils. Selection of the Primary Coil proceeds by the Power Transmitter attempting to establish communication with a Power Receiver using any of the Primary Coils. Note that the array may consist of a single Primary Coil only, in which case the selection is trivial. Finally, the current sense monitors the Primary Coil current.

The Communications and Control Unit on the left-hand side of Figure 42 comprises the digital logic part of the design. This unit receives and decodes messages from the Power Receiver, configures the Coil Selection block to connect the appropriate Primary Coil, executes the relevant power control algorithms and protocols, and drives the frequency of the AC waveform to control the power transfer. The Communications and Control Unit also interfaces with other subsystems of the Power Transmitter Product, e.g. for user interface purposes.

16.1 Mechanical details

Power Transmitter design A13 includes one or more Primary Coils as defined in Section 16.1.1, *Primary Coil*, Shielding as defined in Section 16.1.2, *Shielding*, an Interface Surface as defined in Section 16.1.3, *Interface Surface*.

16.1.1 Primary Coil

The Primary Coil is of the wire-wound type, and consists of no. 17 AWG (1.15 mm diameter) type 2 litz wire having 105 strands of no. 40 AWG (0.08 mm diameter), or equivalent. As shown in Figure 43, the Primary Coil has a rectangular shape and consists of a single layer. Table 35 lists the dimensions of the Primary Coil.

Figure 43. Primary Coil of Power Transmitter design A13

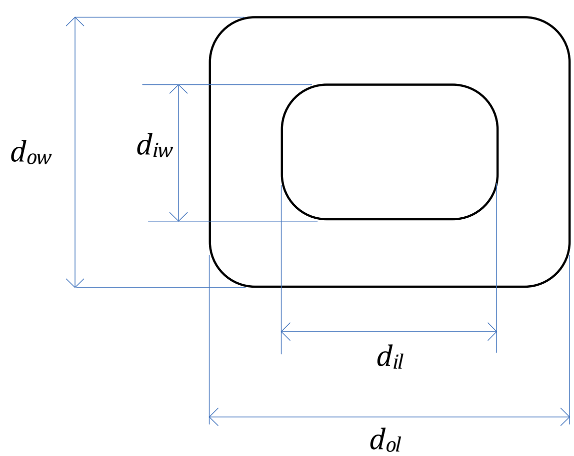
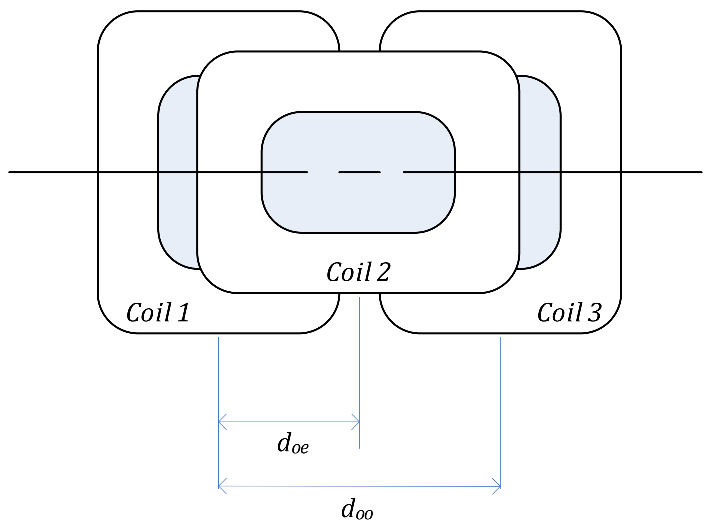


Table 35: Primary Coil parameters of Power Transmitter design A13

Parameter	Symbol	Value
Outer length	d_{ol}	$53.2^{\pm 0.5}$ mm
Inner length	d_{il}	$27.5^{\pm 0.5}$ mm
Outer width	d_{ow}	$45.2^{\pm 0.5}$ mm
Inner width	d_{iw}	$19.5^{\pm 0.5}$ mm
Thickness	d_c	$1.5^{\pm 0.5}$ mm
Number of turns per layer	N	12 turns
Number of layers	–	1

Power Transmitter design A13 contains at least one Primary Coil. Odd numbered coils are placed alongside each other with a displacement of $d_{oo} = 49.2^{\pm4}$ mm between their centers. Even numbered coils are placed orthogonal to the odd numbered coils with a displacement of $d_{oe} = 24.6^{\pm2}$ mm between their centers. See Figure 44.

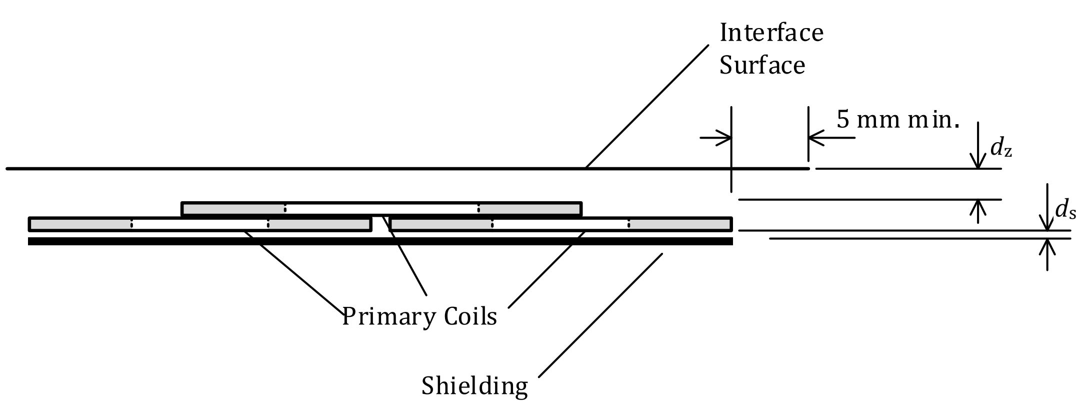
Figure 44. Primary Coils of Power Transmitter design A13



16.1.2 Shielding

As shown in Figure 45, Shielding protects the Power Transmitter Product from the magnetic field that is generated in the Primary Coil. The Shielding should be Ni-Zn or Mn-Zn ferrite and should be at least 0.5 mm thick. The Shielding extends to at least the outer dimensions of the Primary Coils, and is placed below the Primary Coil at a distance of at most $d_s = 1.0$ mm.

Figure 45. Primary Coil assembly of Power Transmitter design A13



16.1.3 Interface Surface

As shown in Figure 45, the distance from the top face of the even-numbered Primary Coil to the Interface Surface of the Power Transmitter Product is $d_{\mathrm{Z}} = 3^{\pm 1}$ mm, across the top face of the Primary Coil. The odd-numbered Primary Coils are mounted flush to the bottom face of the even-numbered Primary Coils. In the case of a single Primary Coil, the distance from the Primary Coil to the Interface Surface of the Power Transmitter Product is $d_{\mathrm{Z}} = 4.5^{\pm 1}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Power Transmitter Product extends at least 5 mm beyond the outer dimensions of the Primary Coils.

16.1.4 Inter coil separation

If the Power Transmitter Product contains multiple type A13 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall not overlap.

16.2 Electrical details

As shown in Figure 46, Power Transmitter design A13 uses a full-bridge inverter to drive an individual Primary Coil and a series capacitance. Within the Operating Frequency range specified below, the assembly of Primary Coils and Shielding has a self-inductance $L_{\text{P}} = 11.5^{\pm 10\%}$ µH for coils closest to the Interface Surface and inductance $L_{\text{P}} = 12.5^{\pm 10\%}$ µH for coils furthest from the Interface Surface. The value of inductances L_1 and L_2 is $1^{\pm 20\%}$ µH. The value of the total series capacitance is $1 / C_{\text{ser1}} + 1 / C_{\text{ser2}} = 1 / 200^{\pm 10\%}$ 1/nF. The value of the parallel capacitance is $C_{\text{par}} = 400^{\pm 10\%}$ nF.

NOTE: Near resonance, the voltage developed across the series capacitance can reach levels exceeding 100 V pk-pk.

Power Transmitter design A13 uses the input voltage of the inverter to control the amount of power that is transferred. For this purpose, the input voltage has a range of 1…12 V, with a resolution of 10 mV or better. The Operating Frequency is f_{op} = 105...115 kHz, with a duty cycle of 50%.

When a type A13 Power Transmitter first applies a Power Signal (Digital Ping; see the *Qi Specification, Communications Protocol*), it shall use an initial voltage of $3.5^{\pm 0.5}$ V for a bottom Primary Coil, and $3.0^{\pm 0.5}$ V for a top Primary Coil, and a recommended Operating Frequency of 110 kHz.

Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Qi Specification, Power Delivery*. The controlled variable $v^{(i)}$ introduced in the definition of that algorithm represents the input voltage to the inverter. In order to guarantee sufficiently accurate power control, a type A13 Power Transmitter shall determine the amplitude of the Primary Cell current—which is equal to the Primary Coil current—with a resolution of 7 mA or better. Finally, Table 36 provides the values of several parameters, which are used in the PID algorithm.

Figure 46. Electrical diagram (outline) of Power Transmitter design A13

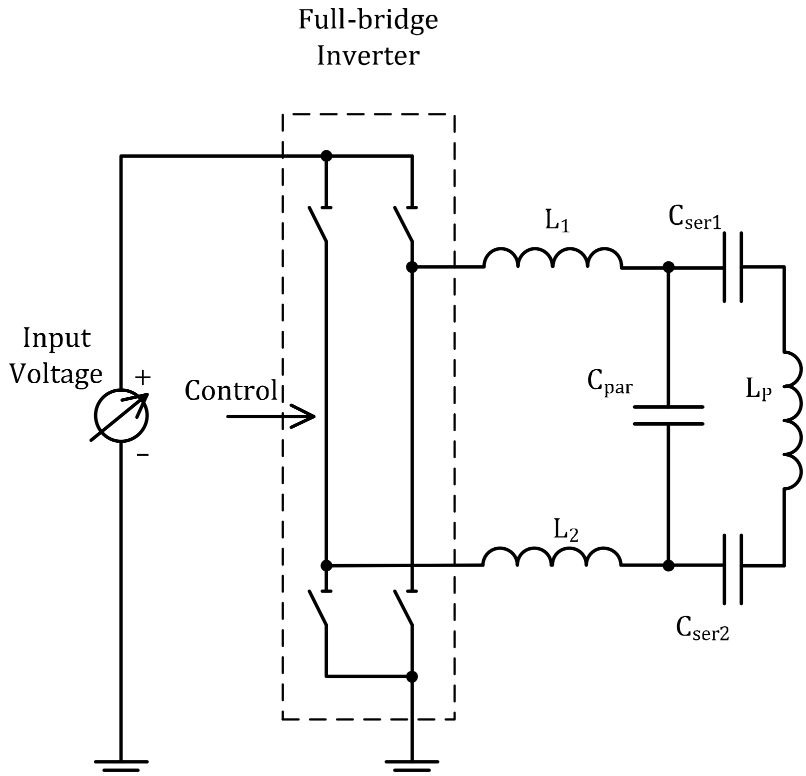


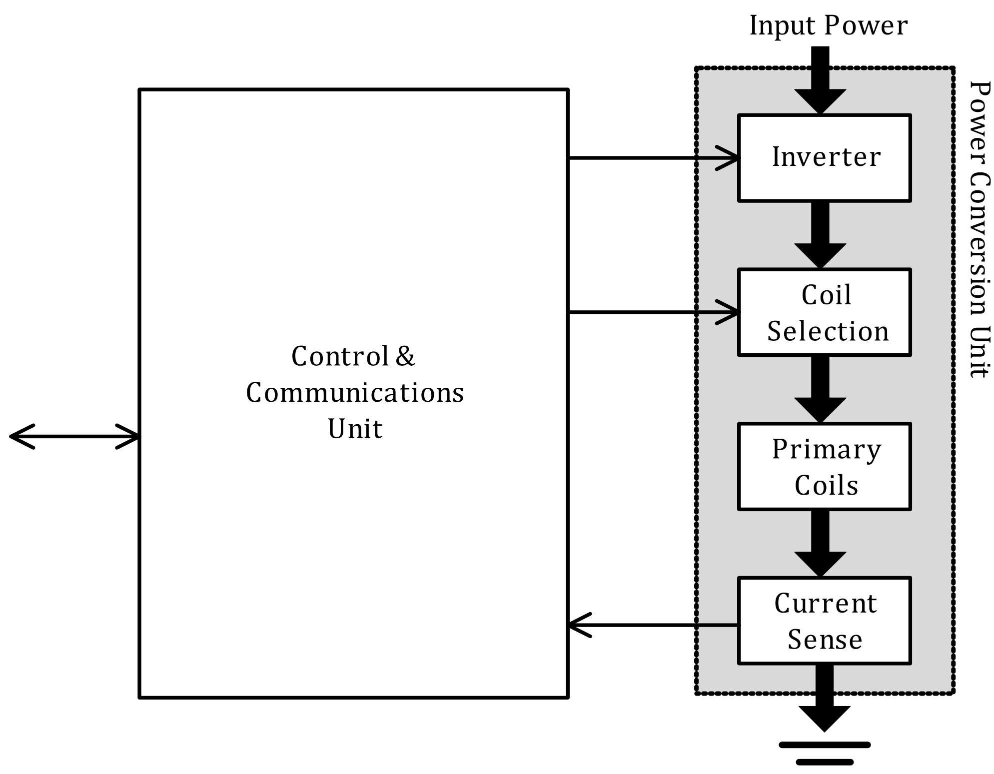
Table 36: PID parameters for voltage control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	0.03	mA^{-1}
Integral gain	K_i	0.01	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	3,000	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_v	-1	mV

17 Power Transmitter design A14

Figure 47 illustrates the functional block diagram of Power Transmitter design A14, which consists of two major functional units, namely a Power Conversion Unit and a Communications and Control Unit.

Figure 47. Functional block diagram of Power Transmitter design A14



The Power Conversion Unit on the right-hand side of Figure 47 comprises the analog parts of the design. The inverter converts the DC input to an AC waveform that drives a resonant circuit, which consists of the selected Primary Coil plus a series capacitor. The selected Primary Coil is one from a linear array of partially overlapping Primary Coils, as appropriate for the position of the Power Receiver relative to the Primary Coils. Selection of the Primary Coil proceeds by the Power Transmitter attempting to establish communication with a Power Receiver using any of the Primary Coils. Note that the array may consist of a single Primary Coil only, in which case the selection is trivial. Finally, the current sense monitors the Primary Coil current.

The Communications and Control Unit on the left-hand side of Figure 47 comprises the digital logic part of the design. This unit receives and decodes messages from the Power Receiver, configures the Coil Selection block to connect the appropriate Primary Coil, executes the relevant power control algorithms and protocols, and drives the frequency of the AC waveform to control the power transfer. The Communications and Control Unit also interfaces with other subsystems of the Power Transmitter Product, e.g. for user interface purposes.

17.1 Mechanical details

Power Transmitter design A14 includes one or more Primary Coils as defined in Section 17.1.1, *Primary Coil*, Shielding as defined in Section 17.1.2, *Shielding*, an Interface Surface as defined in Section 17.1.3, *Interface Surface*.

17.1.1 Primary Coil

The Primary Coil is of the wire-wound type, and consists of litz wire having 115 strands of 0.08 mm diameter, or equivalent. As shown in Figure 48, the Primary Coil has a racetrack-like shape and consists of a single layer. Table 37 lists the dimensions of the Primary Coil.

Figure 48. Primary Coil of Power Transmitter design A14

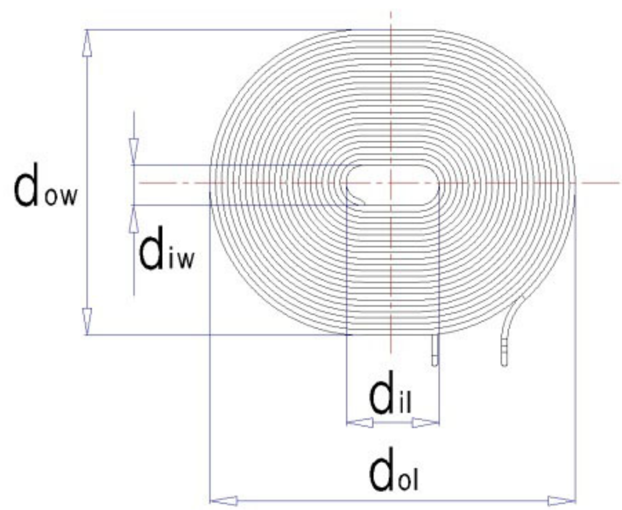
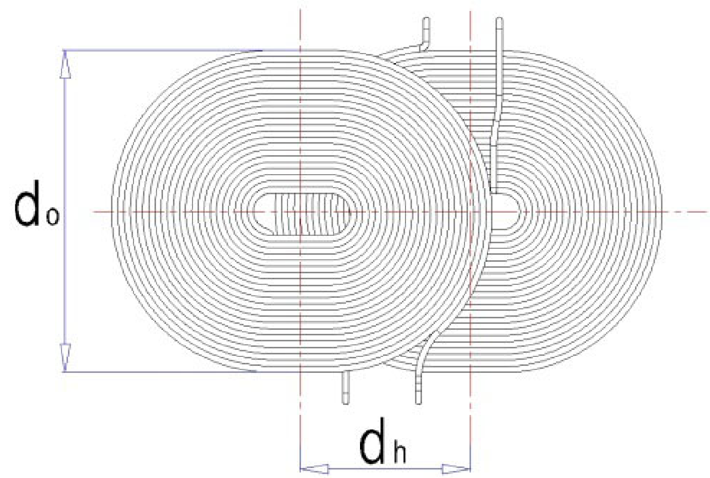


Table 37: Primary Coil parameters of Power Transmitter design A14

Parameter	Symbol	Value
Outer length	d_{ol}	$70^{\pm 0.5}$ mm
Inner length	d_{il}	$16^{\pm 1.0}$ mm
Outer width	d_{ow}	$59^{\pm 0.5}$ mm
Inner width	d_{iw}	$4.5^{\pm 0.5}$ mm
Thickness	d_{c}	$1.3^{\pm 0.1}$ mm
Number of turns per layer	N	23.5
Number of layers	–	1

Power Transmitter design A14 contains two Primary Coils, which are mounted in a Shielding block (see Section 17.1.2, *Shielding*) with their long axes coincident, and a displacement of $d_h = 38^{\pm 0.5}$ mm between their centers. See Figure 49.

Figure 49. Primary Coils of Power Transmitter design A14

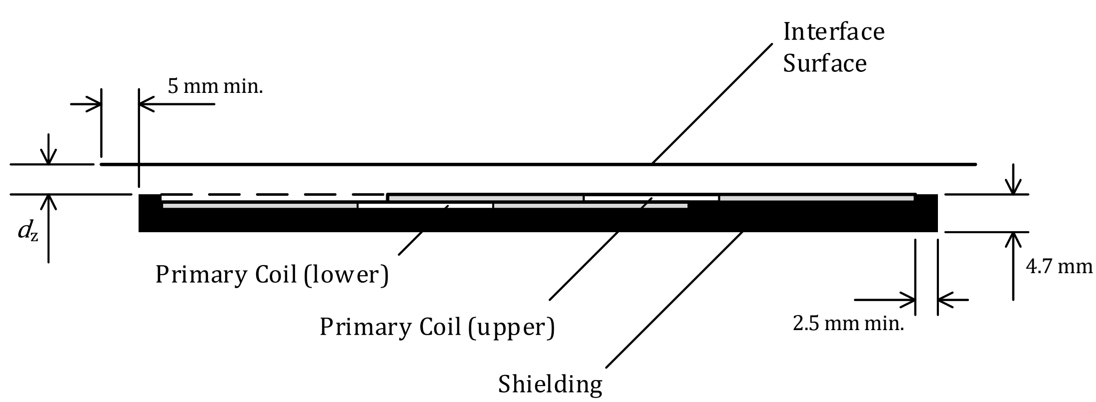


17.1.2 Shielding

As shown in Figure 50, Shielding protects the Power Transmitter Product from the magnetic field that is generated in the Primary Coil. The Shielding should be Ni-Zn or Mn-Zn ferrite and should be at least 4.7 mm thick.

The top face of the Shielding block is aligned with the top face of the Primary Coils, such that the Shielding surrounds the Primary Coils on all sides except for the top face. In addition, the Shielding extends to at least 2.5 mm beyond the outer edge of the Primary Coils.

Figure 50. Primary Coil assembly of Power Transmitter design A14



17.1.3 Interface Surface

As shown in Figure 50, the distance from the top face of the top Primary Coil to the Interface Surface of the Power Transmitter Product is $d_z = 2.0^{\pm 0.5}$ mm, across the top face of the Primary Coil. The bottom Primary Coil is mounted flush to the bottom face of the top Primary Coil. If the Power Transmitter contains only one Primary Coil, the distance from its top face to the Interface Surface of the Power Transmitter Product is $d_z = 3.3^{\pm 0.5}$ mm. In addition, the Interface Surface of the Power Transmitter Product extends at least 5 mm beyond the outer edges of the Primary Coils.

17.1.4 Inter coil separation

If the Power Transmitter Product contains multiple type A14 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall not overlap.

17.2 Electrical details

As shown in Figure 51, Power Transmitter design A14 uses a full-bridge inverter to drive the Primary Coils and a series capacitance. In addition, Power Transmitter design A14 shall operate coil selection switches SWu and SWl such that only a single Primary Coil is connected to the inverter.

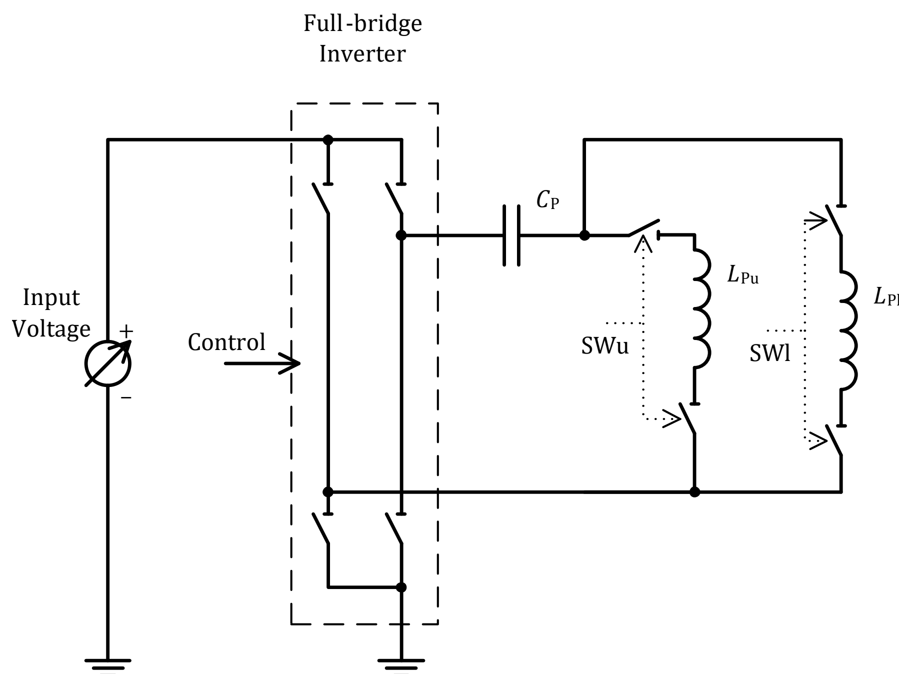
Within the Operating Frequency range specified below, the assembly of Primary Coils and Shielding has a self-inductance $L_P = 24^{\pm 1.0}$ μH. The value of the series capacitance is $C_P = 100^{\pm 5\%}$ nF. The input voltage to the full-bridge inverter is $12^{\pm 10\%}$ V.

NOTE: Near resonance, the voltage developed across the series capacitance can reach levels up to 100 V pk-pk.

Power Transmitter design A14 uses the Operating Frequency and duty cycle of the full-bridge inverter to control the amount of power that is transferred. For this purpose, the Operating Frequency range of the full-bridge inverter is f_{op} = 110...205 kHz with a duty cycle of 50% and its duty cycle range is 2…50% at an Operating Frequency of 110…205 kHz. A higher Operating Frequency and lower duty cycle result in the transfer of a lower amount of power. In order to achieve a sufficiently accurate adjustment of the power that is transferred, a type A14 Power Transmitter shall be able to control the frequency with a resolution of 0.5 kHz or better, and the duty cycle of the Power Signal with a resolution of 0.1% or better.

When a type A14 Power Transmitter first applies a Power Signal (Digital Ping; see the *Qi Specification, Communications Protocol*), the Power Transmitter shall use an initial Operating Frequency of 142 kHz, and a duty cycle of 50%. If the Power Transmitter does not to receive a Signal Strength Packet from the Power Receiver, the Power Transmitter shall remove the Power Signal as defined in the *Qi Specification, Communications Protocol*. The Power Transmitter may reapply the Power Signal multiple times at other-consecutively lower-Operating Frequencies within the range specified above, until the Power Transmitter receives a Signal Strength Packet containing an appropriate Signal Strength Value.

Figure 51. Electrical diagram (outline) of Power Transmitter design A14



Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Qi Specification, Power Delivery*. The controlled variable $v^{(j)}$ introduced in the definition of that algorithm represents Operating Frequency or duty cycle. In order to guarantee sufficiently accurate power control, a type A14 Power Transmitter shall determine the amplitude of the Primary Cell current-which is equal to the Primary Coil current-with a resolution of 5 mA or better. Finally, Table 38 and Table 39 provide the values of several parameters, which are used in the PID algorithm.

Table 38: PID parameters for Operating Frequency control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	1	mA^{-1}
Integral gain	K_i	0	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	N.A.	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_v	1.0	Hz

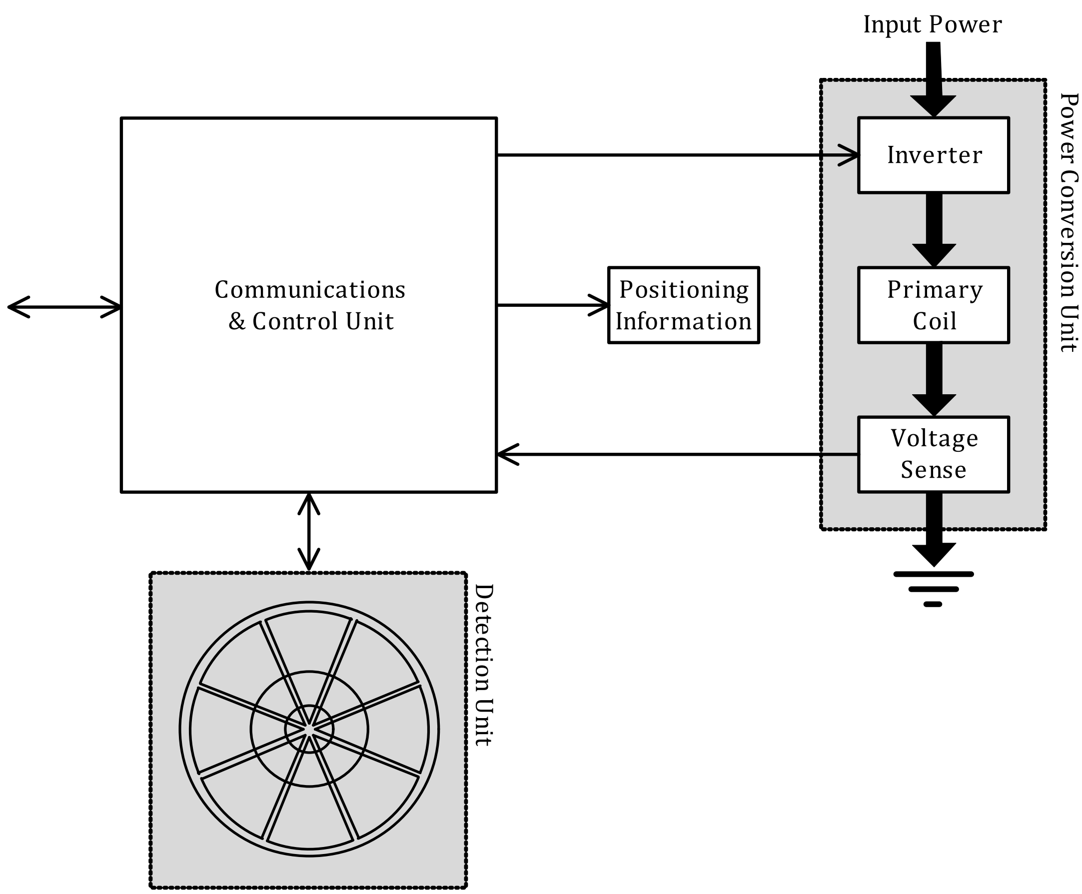
Table 39: PID parameters for duty cycle control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	1	mA^{-1}
Integral gain	K_i	0	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	N.A.	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_v	0.1	%

18 Power Transmitter design A15

Figure 52 illustrates the functional block diagram of Power Transmitter design A15, which consists of three major functional units, namely a Power Conversion Unit, a Detection Unit, and a Communications and Control Unit.

Figure 52. Functional block diagram of Power Transmitter design A15



The Power Conversion Unit on the right-hand side of Figure 52 and the Detection Unit at the bottom of Figure 52 comprises the analog parts of the design. The inverter converts the DC input to an AC waveform that drives a resonant circuit, which consists of the Primary Coil plus a series capacitor. Finally, the voltage sense monitors the Primary Coil voltage.

The Communications and Control Unit on the left-hand side of Figure 52 comprises the digital logic part of the design. This unit receives and decodes messages from the Power Receiver, executes the relevant power control algorithms and protocols, and drives the frequency of the AC waveform to control the power transfer. The Communications and Control Unit also interfaces with other subsystems of the Power Transmitter Product, e.g. for user interface purposes.

The Detection Unit determines the approximate location of objects and/or Power Receivers on the Interface Surface. This version of the *Power Transmitter Reference Designs* does not specify a particular detection method. However, it is recommended that the Detection Unit exploits the resonance in the Power Receiver at the detection frequency f_d (see *Power Interface*). The reason is that this approach minimizes movements of the Secondary Coil, because the Power Transmitter does not need to inform the user about objects that do not respond at this resonant frequency. *Power Interface*, provides an example resonant detection method.

18.1 Mechanical details

Power Transmitter design A15 includes a single Primary Coil as defined in Section 18.1.1, *Primary Coil*, Shielding as defined in Section 18.1.2, *Shielding*, an Interface Surface as defined in Section 18.1.3, *Interface Surface*, and an alignment aid as defined in Section 18.1.4, *Alignment aid*.

18.1.1 Primary Coil

The Primary Coil is of the wire-wound type, and consists of litz wire having 100 strands of 0.08 mm diameter, or equivalent. As shown in Figure 53, the Primary Coil has a circular shape and consists of a single layer. Table 40 lists the dimensions of the Primary Coil.

NOTE: This Primary Coil is identical to the Primary Coil of Power Transmitter Design A7.

Figure 53. Primary Coil of Power Transmitter design A15

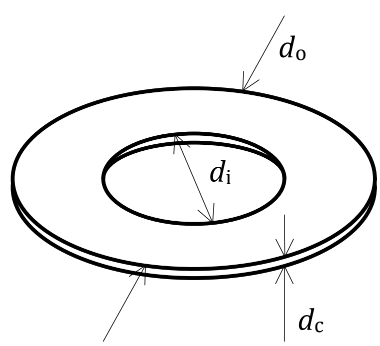


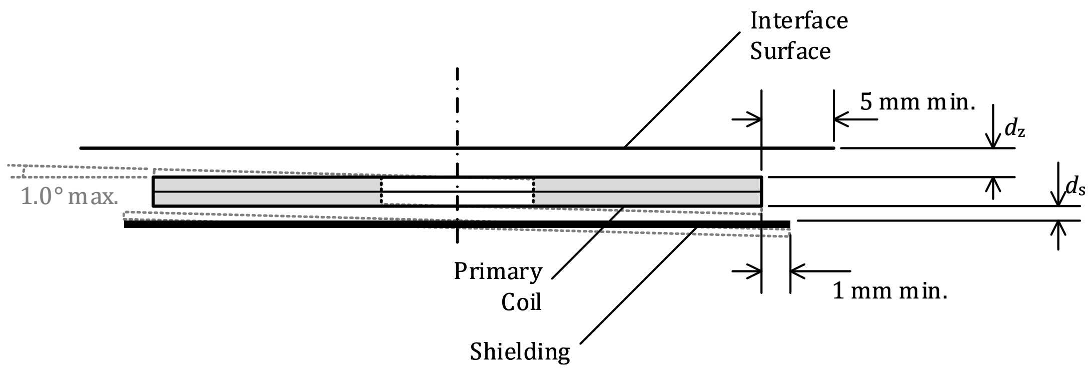
Table 40: Primary Coil parameters of Power Transmitter design A15

Parameter	Symbol	Value
Outer diameter	d_o	$39^{\pm 2}$ mm
Inner diameter	d_i	$12^{\pm 0.2}$ mm
Thickness	d_c	$1.9^{\pm 0.2}$ mm
Number of turns per layer	N	20
Number of layers	–	1

18.1.2 Shielding

As shown in Figure 54, Shielding protects the Power Transmitter Product from the magnetic field that is generated in the Primary Coil. The Shielding should be Ni-Zn or Mn-Zn ferrite and should be at least 0.6 mm thick. The Shielding extends to at least 1 mm beyond the outer diameter of the Primary Coil, and is placed below the Primary Coil at a distance of at most d_s = 1.5mm.

Figure 54. Primary Coil assembly of Power Transmitter design A15



18.1.3 Interface Surface

As shown in Figure 54, the distance from the Primary Coil to the Interface Surface of the Power Transmitter Product is $d_z = 3.0^{\pm 0.5}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Power Transmitter Product extends at least 5 mm beyond the outer diameter of the Primary Coil.

18.1.4 Alignment aid

The alignment aid consists of a visual, audible or tactile indication, which helps a user to guide a Power Receiver into the Active Area of the Interface Surface by giving directional feedback.

NOTE: An example is a LED indicator, which shows at least two directions.

18.2 Electrical details

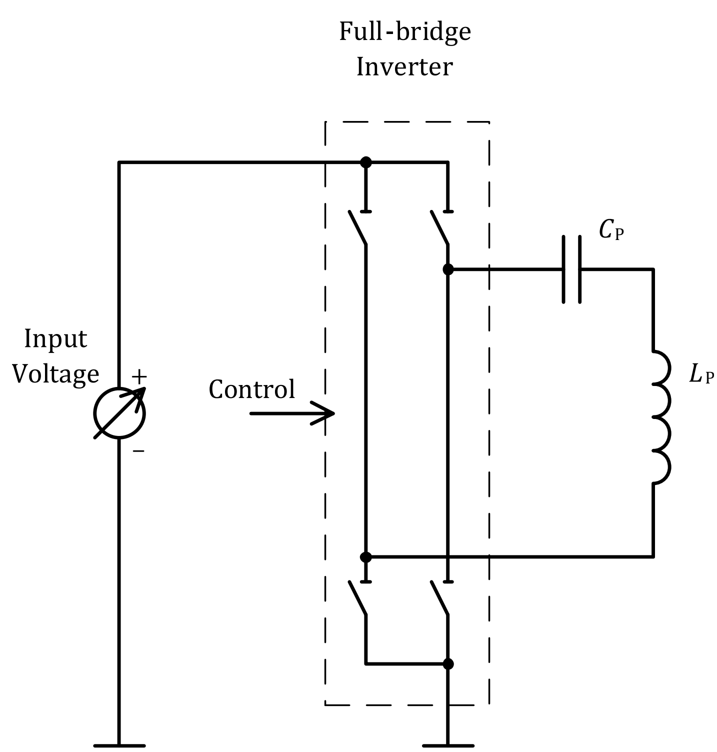
As shown in Figure 55, Power Transmitter design A15 uses a full-bridge inverter to drive the Primary Coil and a series capacitance. At an Operating Frequency range between 105 kHz and 140 kHz, the assembly of Primary Coil and Shielding has a self-inductance $L_P = 13.6^{\pm 10\%}$ μH. The value of the series capacitance is $C_P = 180^{\pm 5\%}$ nF.

NOTE: Near resonance, the voltage developed across the series capacitance can reach levels up to 100 V pk-pk.

Power Transmitter design A15 uses the input voltage to the full-bridge inverter to control the amount of power that is transferred. For this purpose, the input voltage range is 3…12 V, where a lower input voltage results in the transfer of a lower amount of power. In order to achieve a sufficiently accurate adjustment of the power that is transferred, a type A15 Power Transmitter shall be able to control the input voltage with a resolution of 50 mV or better.

When a type A15 Power Transmitter first applies a Power Signal (Digital Ping; see the *Qi Specification, Communications Protocol*), it shall use an initial input voltage of 5.7 V. It is recommended that the Power Transmitter uses an Operating Frequency of 140 kHz when first applying the Power Signal. If the Power Transmitter does not to receive a Signal Strength Packet from the Power Receiver, the Power Transmitter shall remove the Power Signal as defined in the *Qi Specification, Communications Protocol*. The Power Transmitter may reapply the Power Signal multiple times at other—consecutively lower—Operating Frequencies within the range specified above, until the Power Transmitter receives a Signal Strength Packet containing an appropriate Signal Strength Value.

Figure 55. Electrical diagram (outline) of Power Transmitter design A15



Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Qi Specification, Power Delivery*. The controlled variable $v^{(i)}$ introduced in the definition of that algorithm represents the input voltage to the full-bridge inverter. In order to guarantee sufficiently accurate power control, a type A15 Power Transmitter shall determine the amplitude of the Primary Cell voltage—which is equal to the Primary Coil voltage—with a resolution of 5 mV or better. Finally, Table 41 provides the values of several parameters, which are used in the PID algorithm.

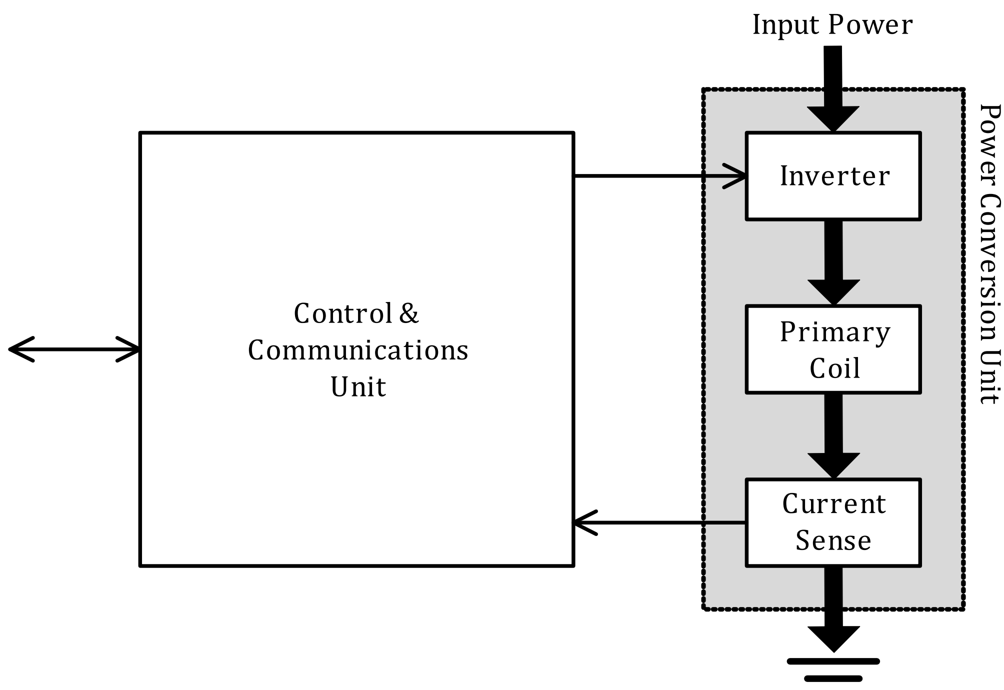
Table 41: PID parameters for voltage control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	1	mA^{-1}
Integral gain	K_i	0	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	N.A.	N.A.
PID output limit	M_{PID}	1,500	N.A.
Scaling factor	S_v	–0.5	mV

19 Power Transmitter design A16

Figure 56 illustrates the functional block diagram of Power Transmitter design A16, which consists of two major functional units, namely a Power Conversion Unit and a Communications and Control Unit.

Figure 56. Functional block diagram of Power Transmitter design A16



The Power Conversion Unit on the right-hand side of Figure 56 comprises the analog parts of the design. The inverter converts the DC input to an AC waveform that drives a resonant circuit, which consists of the Primary Coil plus a series capacitor. Finally, the current sense monitors the Primary Coil current.

The Communications and Control Unit on the left-hand side of Figure 56 comprises the digital logic part of the design. This unit receives and decodes messages from the Power Receiver, executes the relevant power control algorithms and protocols, and drives the frequency of the AC waveform to control the power transfer. The Communications and Control Unit also interfaces with other subsystems of the Power Transmitter Product, e.g. for user interface purposes.

Product development based on Power Transmitter designs A16 is discouraged. The WPC have noticed that Power Transmitters based on this design underperform with Foreign Object Detection. The WPC therefore have decided to phase out the registration of new Base Station products based on this design. The exact cut-off date has not been decided yet.

19.1 Mechanical details

Power Transmitter design A16 includes a single Primary Coil as defined in Section 19.1.1, *Primary Coil*, Shielding as defined in Section 19.1.2, *Shielding*, an Interface Surface as defined in Section 19.1.3, *Interface Surface*, and an alignment aid as defined in Section 19.1.4, *Alignment aid*.

19.1.1 Primary Coil

The Primary Coil is of the wire-wound type, and consists of litz wire having 105 strands of no. 40 AWG (0.08 mm diameter), or equivalent. As shown in Figure 57, the Primary Coil has a triangular shape and consists of a single layer. Table 42 lists the dimensions of the Primary Coil.

Figure 57. Primary Coil of Power Transmitter design A16

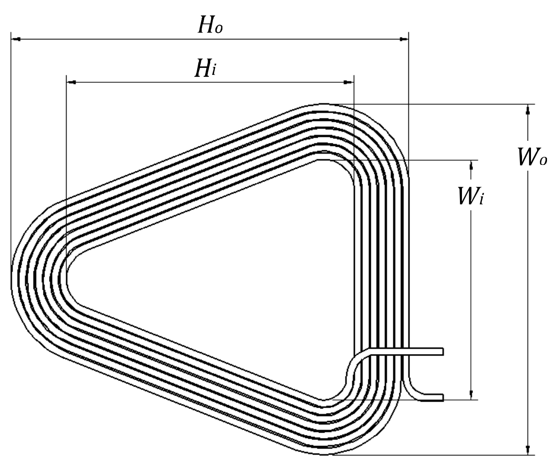


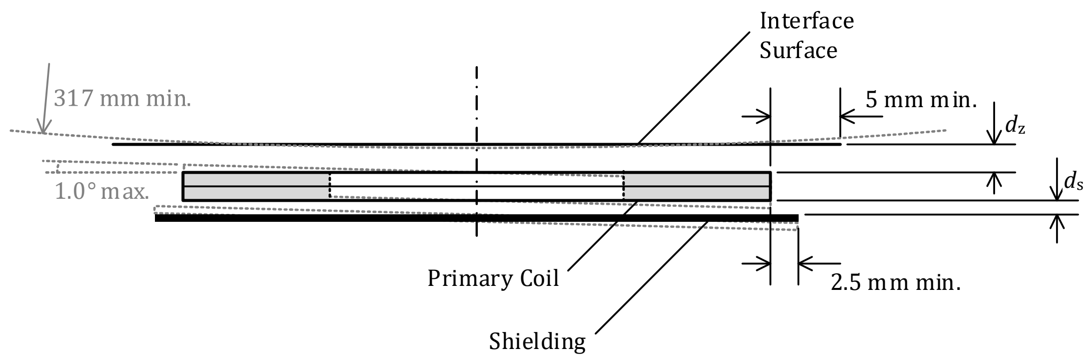
Table 42: Primary Coil parameters of Power Transmitter design A16

Parameter	Symbol	Value
Outer height	H_o	$59^{\pm0.5}$ mm
Inner height	H_i	$43^{\pm0.5}$ mm
Outer width	W_o	$52^{\pm0.5}$ mm
Inner width	W_i	$36^{\pm0.5}$ mm
Thickness	d_c	$1.1^{\pm0.3}$ mm
Number of turns per layer	N	7
Number of layers	–	1

19.1.2 Shielding

As shown in Figure 58, Shielding protects the Power Transmitter Product from the magnetic field that is generated in the Primary Coil. The Shielding should be Ni-Zn or Mn-Zn ferrite and should be at least 0.5 mm thick. The Shielding extends to at least 2.5 mm beyond the outer diameter of the Primary Coil, and is placed below the Primary Coil at a distance of at most d_s = 1.0 mm.

Figure 58. Primary Coil assembly of Power Transmitter design A16



19.1.3 Interface Surface

As shown in Figure 58, the distance from the Primary Coil to the Interface Surface of the Power Transmitter Product is $d_Z = 2^{+0.5}_{-0.5}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Power Transmitter Product extends at least 5 mm beyond the outer diameter of the Primary Coil.

NOTE: This Primary-Coil-to-Interface-Surface distance implies that the tilt angle between the Primary Coil and a flat Interface Surface is at most 1.0°. Alternatively, in case of a non-flat Interface Surface, this Primary-Coil-to-Interface-Surface distance implies a radius of curvature of the Interface Surface of at least 317 mm, centered on the Primary Coil. See Figure 58.

19.1.4 Alignment aid

The user manual of the Power Transmitter Product containing a type A16 Power Transmitter shall have information about the location of its Active Area(s).

For the best user experience, it is recommended to employ at least one user feedback mechanism during Power Receiver Product positioning to help alignment.

Examples of Power Transmitter Product alignment aids to assist the user positioning of the Power Receiver Product include:

- A marked Interface Surface to indicate the location of the Active Area(s)—e.g. by means of the logo or other visual marking, lighting, etc.
- A visual feedback display—e.g. by means of illuminating an LED to indicate proper alignment.
- An audible or haptic feedback mechanism.

19.1.5 Inter coil separation

If the Power Transmitter Product contains multiple type A16 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall not overlap.

19.2 Electrical details

As shown in Figure 59, Power Transmitter design A16 uses a full-bridge inverter to drive the Primary Coil and a series capacitance. Within the Operating Frequency range specified below, the assembly of Primary Coil and Shielding has a self-inductance $L_{\mathrm{P}} = 6.3^{\pm 10\%}$ μH. The value of the series capacitance is $C_{\mathrm{P}} = 0.4^{\pm 5\%}$ μF. The input voltage to the full-bridge inverter is $5^{\pm 5\%}$ V.

NOTE: Near resonance, the voltage developed across the series capacitance can reach levels exceeding 100 V pk-pk.

Power Transmitter design A16 uses the Operating Frequency and duty cycle of the Power Signal in order to control the amount of power that is transferred. For this purpose, the Operating Frequency range of the full-bridge inverter is f_{op} = 110...205 kHz with a duty cycle of 50%; and its duty cycle range is 10…50% at an Operating Frequency of 205 kHz. A higher Operating Frequency or lower duty cycle result in the transfer of a lower amount of power. In order to achieve a sufficiently accurate adjustment of the amount of power that is transferred, a type A16 Power Transmitter shall control the Operating Frequency with a resolution of

- $0.01 \times f_{\mathrm{op}} - 0.7$ kHz, for f_{op} in the 110…175 kHz range;
- $0.015 \times f_{\mathrm{op}} - 1.58$ kHz, for f_{op} in the 175…205 kHz range;

or better. In addition, a type A16 Power Transmitter shall control the duty cycle of the Power Signal with a resolution of 0.1% or better.

When a type A16 Power Transmitter first applies a Power Signal (Digital Ping; see the *Qi Specification, Communications Protocol*), it shall use an initial Operating Frequency of 175 kHz (and a duty cycle of 50%).

Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Qi Specification, Power Delivery*. The controlled variable $v^{(i)}$ introduced in the definition of that algorithm represents the Operating Frequency or the duty cycle. In order to guarantee sufficiently accurate power control, a type A16 Power Transmitter shall determine the amplitude of the Primary Cell current—which is equal to the Primary Coil current—with a resolution of 7 mA or better. Finally, Table 43, Table 44, and Table 45 provide the values of several parameters, which are used in the PID algorithm.

Product development based on Power Transmitter designs A16 is discouraged. The WPC have noticed that Power Transmitters based on this design underperform with Foreign Object Detection. The WPC therefore have decided to phase out the registration of new Base Station products based on this design. The exact cut-off date has not been decided yet.

Figure 59. Electrical diagram (outline) of Power Transmitter design A16

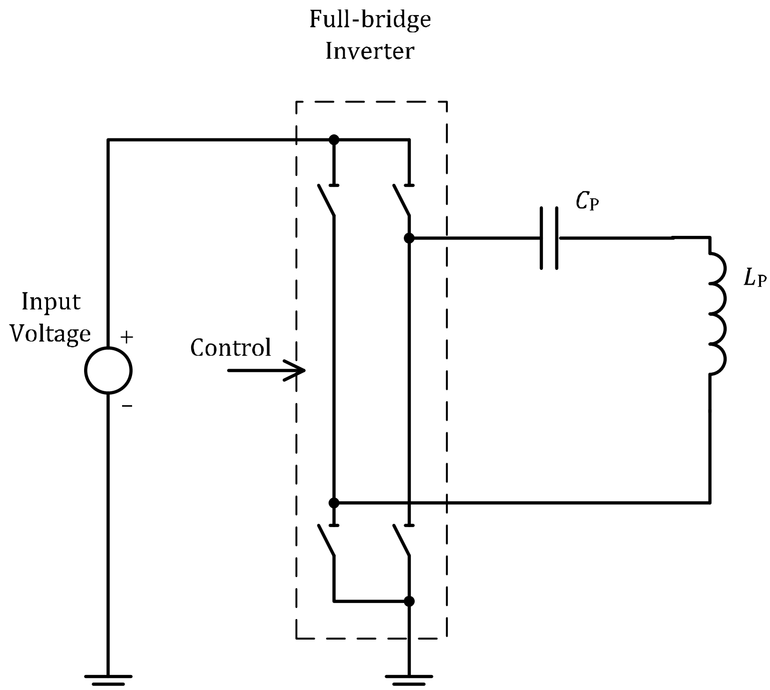


Table 43: PID parameters for Operating Frequency control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	10	mA^{-1}
Integral gain	K_i	0.05	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	3,000	N.A.
PID output limit	M_{PID}	20,000	N.A.

Table 44: Operating Frequency dependent scaling factor

Frequency Range [kHz]	Scaling Factor S_v [Hz]
110…140	1.5
140…160	2
160…180	3
180…205	5

Product development based on Power Transmitter designs A16 is discouraged. The WPC have noticed that Power Transmitters based on this design underperform with Foreign Object Detection. The WPC therefore have decided to phase out the registration of new Base Station products based on this design. The exact cut-off date has not been decided yet.

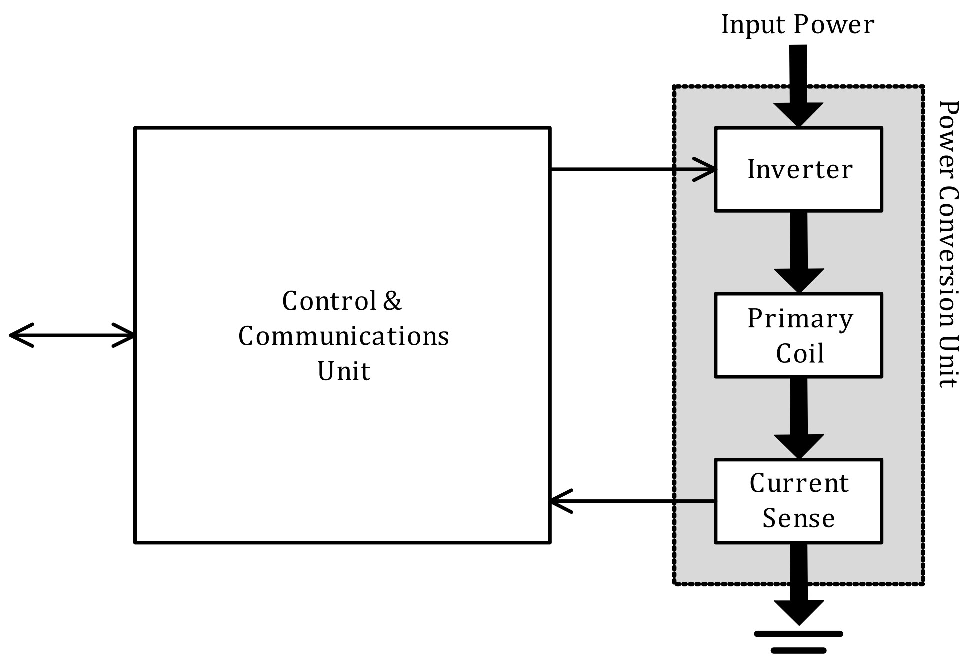
Table 45: PID parameters for duty cycle control

Parameter	**Symbol**	**Value**	**Unit**
Proportional gain	K_p	10	mA^{-1}
Integral gain	K_i	0.05	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	3,000	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_v	–0.01	%

20 Power Transmitter design A17

Power Transmitter design A17 enables Guided Positioning. Figure 60 illustrates the functional block diagram of this design, which consists of two major functional units, namely a Power Conversion Unit and a Communications and Control Unit.

Figure 60. Functional block diagram of Power Transmitter design A17



The Power Conversion Unit on the right-hand side of Figure 60 comprises the analog parts of the design. The inverter converts the DC input to an AC waveform that drives a resonant circuit, which consists of the Primary Coil plus one or more capacitors. Finally, the current sense monitors the Primary Coil current.

The Communications and Control Unit on the left-hand side of Figure 60 comprises the digital logic part of the design. This unit receives and decodes messages from the Power Receiver, executes the relevant power control algorithms and protocols, and drives the rail voltage of the AC waveform to control the power transfer. The Communications and Control Unit also interfaces with other subsystems of the Power Transmitter Product, e.g. for user interface purposes.

20.1 Mechanical details

Power Transmitter design A17 includes a single Primary Coil as defined in Section 20.1.1, *Primary Coil*, Shielding as defined in Section 20.1.2, *Shielding*, an Interface Surface as defined in Section 20.1.3, *Interface Surface*, and an alignment aid as defined in Section 20.1.4, *Alignment aid*.

20.1.1 Primary Coil

The Primary Coil is of the wire-wound type, and consists of no. 17 AWG (1.15 mm diameter) type 2 litz wire having 105 strands of no. 40 AWG (0.08 mm diameter), or equivalent. As shown in Figure 61, the Primary Coil has a circular shape and consists of multiple layers. All layers are stacked with the same polarity. Table 46 lists the dimensions of the Primary Coil.

Figure 61. Primary Coil of Power Transmitter design A17

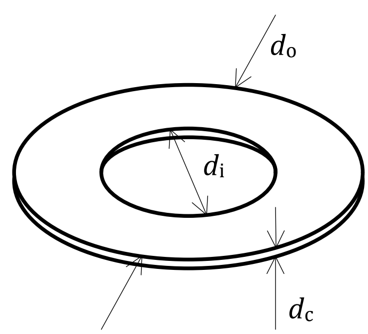


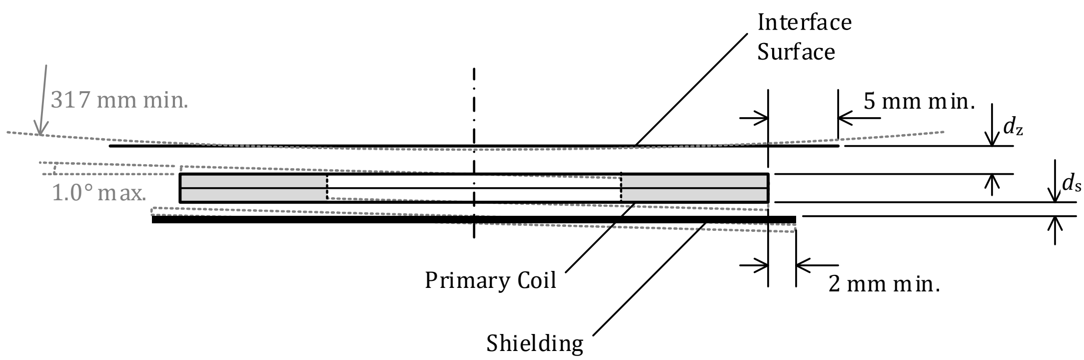
Table 46: Primary Coil parameters of Power Transmitter design A17

Parameter	Symbol	Value
Outer diameter	d_o	$43^{\pm 0.5}$ mm
Inner diameter	d_i	$20.5^{\pm 0.5}$ mm
Thickness	d_c	$2.1^{+0.5}$ mm
Number of turns per layer	N	10
Number of layers	–	2

20.1.2 Shielding

As shown in Figure 62, Shielding protects the Power Transmitter Product from the magnetic field that is generated in the Primary Coil. The Shielding should be Ni-Zn or Mn-Zn ferrite and should be at least 0.5 mm thick. The Shielding extends to at least 2 mm beyond the outer diameter of the Primary Coil, and is placed below the Primary Coil at a distance of at most $d_s = 1.0$ mm.

Figure 62. Primary Coil assembly of Power Transmitter design A17



20.1.3 Interface Surface

As shown in Figure 62, the distance from the Primary Coil to the Interface Surface of the Power Transmitter Product is $d_Z = 7^{+0.5}_{-5.25}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Power Transmitter Product extends at least 5 mm beyond the outer diameter of the Primary Coil.

NOTE: This Primary-Coil-to-Interface-Surface distance implies that the tilt angle between the Primary Coil and a flat Interface Surface is at most 1.0°. Alternatively, in case of a non-flat Interface Surface, this Primary-Coil-to-Interface-Surface distance implies a radius of curvature of the Interface Surface of at least 317 mm, centered on the Primary Coil. See Figure 62.

20.1.4 Alignment aid

The user manual of the Power Transmitter Product containing a type A17 Power Transmitter shall have information about the location of its Active Area(s).

For the best user experience, it is recommended to employ at least one user feedback mechanism during Power Receiver Product positioning to help alignment.

Examples of Power Transmitter Product alignment aids to assist the user positioning of the Power Receiver Product include:

- A marked Interface Surface to indicate the location of the Active Area(s)—e.g. by means of the logo or other visual marking, lighting, etc.
- A visual feedback display—e.g. by means of illuminating an LED to indicate proper alignment.
- An audible or haptic feedback mechanism.

20.1.5 Inter coil separation

If the Power Transmitter Product contains multiple type A17 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall not overlap.

20.2 Electrical details

As shown in Figure 63, Power Transmitter design A17 uses a full-bridge inverter to drive the resonant network including filter inductors, a primary Coil with a series and parallel capacitance. Within the Operating Frequency range specified below, the assembly of Primary Coil and Shielding has a self-inductance $L_{\mathrm{P}} = 24^{\pm 10\%}$ μH. The value of inductances L_1 and L_2 is $2.2^{\pm 20\%}$ μH. The value of the total series capacitance is $C_{\mathrm{ser1}} + C_{\mathrm{ser2}} = 100^{\pm 5\%}$ nF, where the individual series capacitances may have any value less than the sum. The value of the parallel capacitance is $C_{\mathrm{par}} = 200^{\pm 5\%}$ nF.

NOTE: Near resonance, the voltage developed across the series capacitance can reach levels exceeding 100 V pk-pk.

Power Transmitter design A17 uses the input voltage to the inverter to control the amount of power transferred. For this purpose, the input voltage has a range 1.4…15 V, with a resolution of 10 mV or better; a higher input voltage results in more power transferred. The Operating Frequency is f_{op} = 105...116 kHz with a duty cycle of 50%

When a type A17 Power Transmitter first applies a Power Signal (Digital Ping; see the *Qi Specification, Communications Protocol*), it shall use an input voltage of 5.75 V, and a recommended Operating Frequency of 111 kHz.

Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Qi Specification, Power Delivery*. The controlled variable $v^{(i)}$ introduced in the definition of that algorithm represents the input voltage. In order to guarantee sufficiently accurate power control, a type A17 Power Transmitter shall determine the amplitude of the Primary Cell current—which is equal to the Primary Coil current—with a resolution of 7 mA or better. Finally, Table 47 provides the values of several parameters, which are used in the PID algorithm.

Figure 63. Electrical diagram (outline) of Power Transmitter design A17

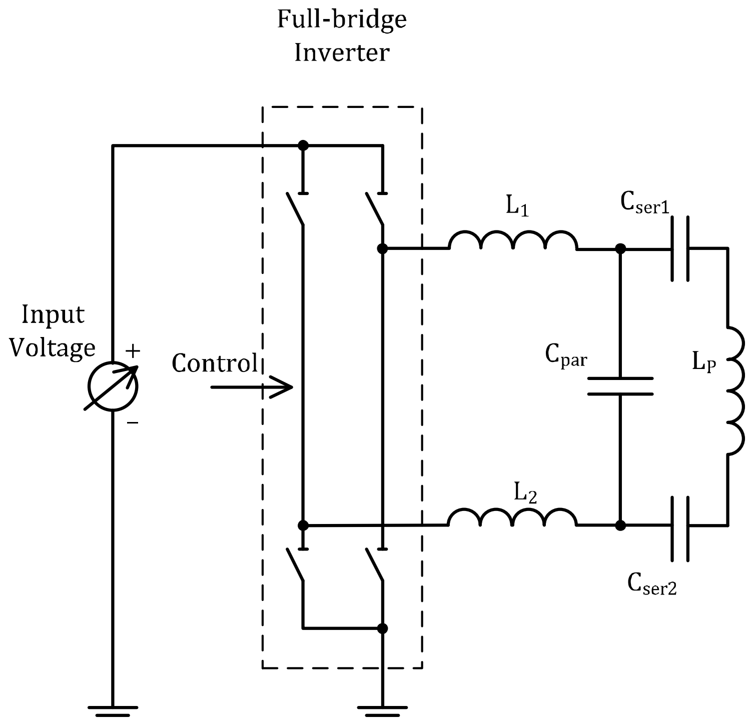


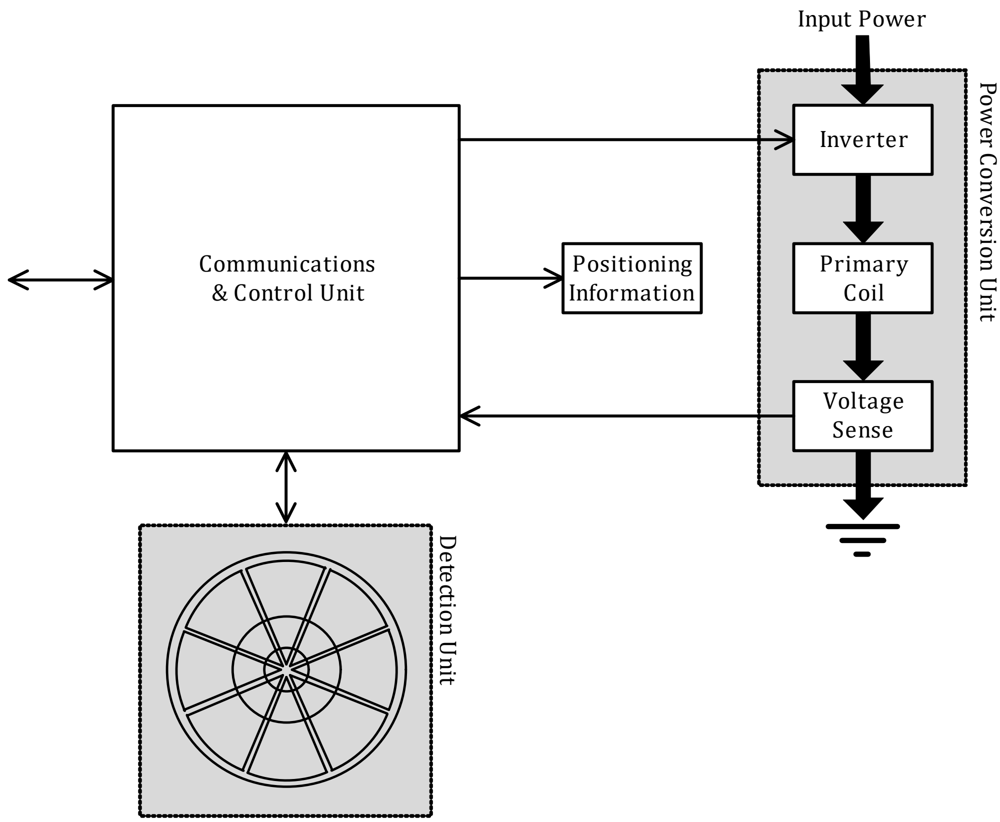
Table 47: PID parameters for voltage control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	10	mA^{-1}
Integral gain	K_i	1	$mA^{-1}ms^{-1}$
Derivative gain	K_d	1	$mA^{-1}ms$
Integral term limit	M_I	3,000	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_v	200	mV

21 Power Transmitter design A18

Figure 64 illustrates the functional block diagram of this design, which consists of three major functional units, namely a Power Conversion Unit, a Detection Unit, and a Communications and Control Unit.

Figure 64. Functional block diagram of Power Transmitter design A18



The Power Conversion Unit on the right-hand side of Figure 64 and the Detection Unit of the bottom of Figure 64 comprise the analog parts of the design. The Power Conversion Unit is similar to the Power Conversion Unit of Power Transmitter design A7. The inverter converts the DC input to an AC waveform that drives a resonant circuit, which consists of the Primary Coil plus a series capacitor. Finally, the voltage sense monitors the Primary Coil voltage.

The Communications and Control Unit on the left-hand side of Figure 64 comprises the digital logic part of the design. This unit is similar to the Communications and Control Unit of Power Transmitter design A7. The Communications and Control Unit receives and decodes messages from the Power Receiver, executes the relevant power control algorithms and protocols, and drives the input voltage of the AC waveform to control the power transfer. The Communications and Control Unit also interfaces with other subsystems of the Power Transmitter Product, e.g. for user interface purposes.

The Detection Unit determines the approximate location of objects and/or Power Receivers on the Interface Surface. This version of the *Qi Specification, Power Transmitter* Ax *and* Bx *Reference Designs* does not specify a particular detection method. However, it is recommended that the Detection Unit exploits the resonance in the Power Receiver at the detection frequency f_d (see *Power Interface*). The reason is that this approach minimizes movements of the Secondary Coil, because the Power Transmitter does not need to inform the user about objects that do not respond at this resonant frequency. *Power Interface*, provides an example resonant detection method.

21.1 Mechanical details

Power Transmitter design A18 includes a single Primary Coil as defined in Section 21.1.1, *Primary Coil*, Shielding as defined in Section 21.1.2, *Shielding*, an Interface Surface as defined in Section 21.1.3, *Interface Surface*, and an alignment aid as defined in Section 21.1.4, *Alignment aid*.

21.1.1 Primary Coil

The Primary Coil is of the wire-wound type, and consists of litz wire having 80 strands of 0.08 mm diameter, or equivalent. As shown in Figure 65, the Primary Coil has a circular shape and consists of a single layer. Table 48 lists the dimensions of the Primary Coil.

Figure 65. Primary Coil of Power Transmitter design A18

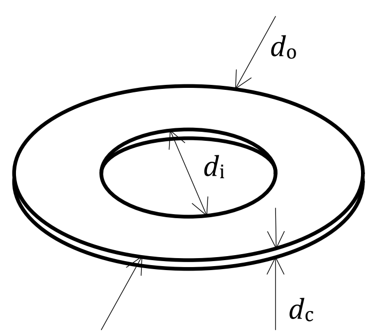


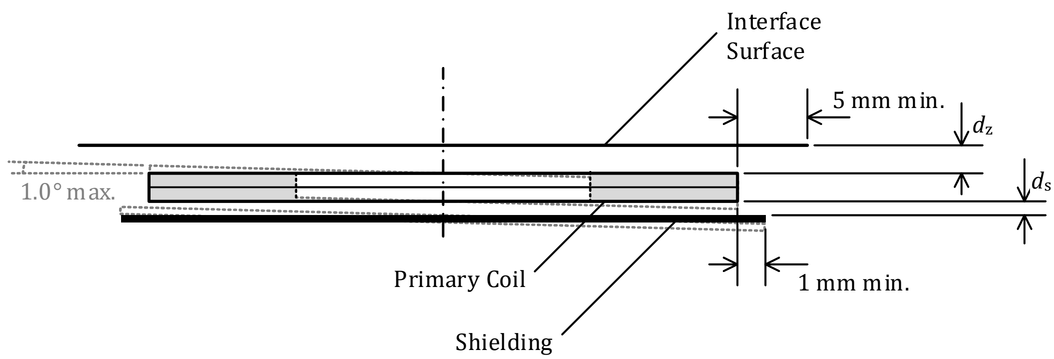
Table 48: Primary Coil parameters of Power Transmitter design A18

Parameter	Symbol	Value
Outer diameter	d_o	$39^{\pm 2}$ mm
Inner diameter	d_i	$12^{\pm 0.2}$ mm
Thickness	d_c	$1.5^{\pm 0.2}$ mm
Number of turns per layer	N	20
Number of layers	–	1

21.1.2 Shielding

As shown in Figure 66, Shielding protects the Power Transmitter Product from the magnetic field that is generated in the Primary Coil. The Shielding should be Ni-Zn or Mn-Zn ferrite and should be at least 0.6 mm thick. The Shielding extends to at least 1 mm beyond the outer diameter of the Primary Coil, and is placed below the Primary Coil at a distance of at most d_s = 0.5 mm.

Figure 66. Primary Coil assembly of Power Transmitter design A18



21.1.3 Interface Surface

As shown in Figure 66, the distance from the Primary Coil to the Interface Surface of the Power Transmitter Product is $d_z = 2.0^{+1.5}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Power Transmitter Product extends at least 5mm beyond the outer diameter of the Primary Coil.

21.1.4 Alignment aid

The alignment aid consists of a visual, audible or tactile indication, which helps a user to guide a Power Receiver into the Active Area of the Interface Surface by giving directional or distance feedback.

21.2 Electrical details

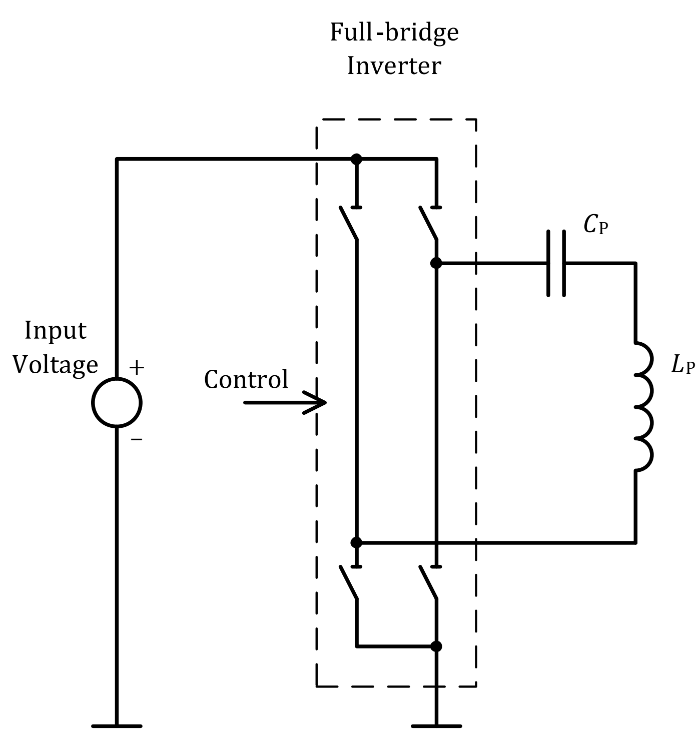
As shown in Figure 67, Power Transmitter design A18 uses a full-bridge inverter to drive the Primary Coil and a series capacitance. At an Operating Frequency range between 105 kHz and 140 kHz, the assembly of Primary Coil and Shielding has a self-inductance $L_{\mathrm{P}} = 13.6^{\pm 10\%}$ μH. The value of the series capacitance is $C_{\mathrm{P}} = 180^{\pm 5\%}$ nF.

NOTE: Near resonance, the voltage developed across the series capacitance can reach levels up to 100 V pk-pk.

Power Transmitter design A18 uses the input voltage to the full-bridge inverter to control the amount of power that is transferred. For this purpose, the input voltage range is 3…12 V, where a lower input voltage results in the transfer of a lower amount of power. In order to achieve a sufficiently accurate adjustment of the power that is transferred, a type A18 Power Transmitter shall be able to control the input voltage with a resolution of 50 mV or better.

When a type A18 Power Transmitter first applies a Power Signal (Digital Ping; see the *Qi Specification, Communications Protocol*), it shall use an initial input voltage of 6.5 V. It is recommended that the Power Transmitter uses an Operating Frequency of 140 kHz when first applying the Power Signal. If the Power Transmitter does not to receive a Signal Strength Packet from the Power Receiver, the Power Transmitter shall remove the Power Signal as defined in the *Qi Specification, Communications Protocol*. The Power Transmitter may reapply the Power Signal multiple times at other—consecutively lower—Operating Frequencies within the range specified above, until the Power Transmitter receives a Signal Strength Packet containing an appropriate Signal Strength Value.

Figure 67. Electrical diagram (outline) of Power Transmitter design A18



Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Qi Specification, Power Delivery*. The controlled variable $v^{(i)}$ introduced in the definition of that algorithm represents the input voltage to the full-bridge inverter. In order to guarantee sufficiently accurate power control, a type A18 Power Transmitter shall determine the amplitude of the Primary Cell voltage—which is equal to the Primary Coil voltage—with a resolution of 5 mV or better. Finally, Table 49 provides the values of several parameters, which are used in the PID algorithm.

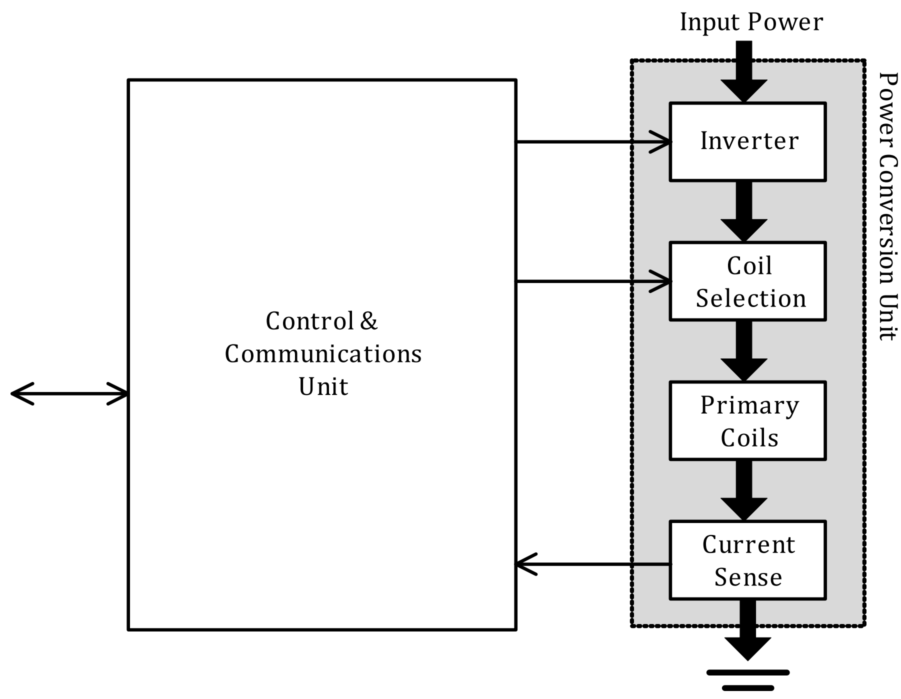
Table 49: PID parameters for voltage control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	1	mA^{-1}
Integral gain	K_i	0	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	N.A.	N.A.
PID output limit	M_{PID}	1,500	N.A.
Scaling factor	S_v	–0.5	mV

22 Power Transmitter design A19

Figure 68 illustrates the functional block diagram of this design, which consists of two major functional units, namely a Power Conversion Unit and a Communications and Control Unit.

Figure 68. Functional block diagram of Power Transmitter design A19



The Power Conversion Unit on the right-hand side of Figure 68 comprises the analog parts of the design. The inverter converts the DC input to an AC waveform that drives a resonant circuit, which consists of the selected Primary Coil plus a series capacitor. The selected Primary Coil is one from two partially overlapping Primary Coils, as appropriate for the position of the Power Receiver relative to the Primary Coils. Selection of the Primary Coil proceeds by the Power Transmitter attempting to establish communication with a Power Receiver using any of the Primary Coils. Finally, the current sense monitors the Primary Coil current.

The Communications and Control Unit on the left-hand side of Figure 68 comprises the digital logic part of the design. This unit receives and decodes messages from the Power Receiver, configures the Coil Selection block to connect the appropriate Primary Coil, executes the relevant power control algorithms and protocols, and drives the frequency of the AC waveform to control the power transfer. The Communications and Control Unit also interfaces with other subsystems of the Power Transmitter Product, e.g. for user interface purposes.

22.1 Mechanical details

Power Transmitter design A19 includes two Primary Coils as defined in Section 22.1.1, *Primary Coil*, Shielding as defined in Section 22.1.2, *Shielding*, and an Interface Surface as defined in Section 22.1.3, *Interface Surface*.

22.1.1 Primary Coil

The Primary Coil is of the wire-wound type, and consists of no. 20 AWG (0.81 mm diameter) type 2 litz wire having 105 strands of no. 40 AWG (0.08 mm diameter), or equivalent. As shown in Figure 69, the Primary Coil has a rectangular shape and consists of a single layer. Table 50 lists the dimensions of the Primary Coil.

Figure 69. Primary Coil of Power Transmitter design A19

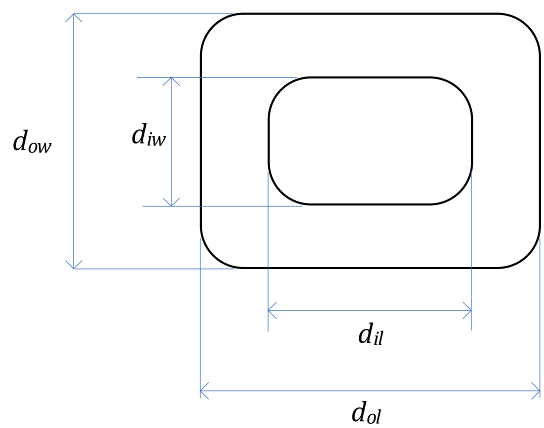
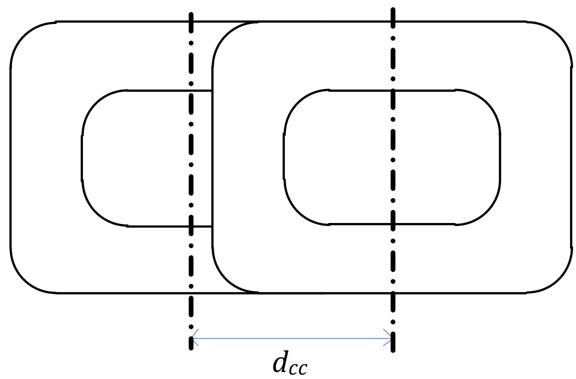


Table 50: Primary Coil parameters of Power Transmitter design A19

Parameter	Symbol	Value
Outer length	d_{ol}	$51.5^{\pm 0.5}$ mm
Inner length	d_{il}	$29.5^{\pm 0.5}$ mm
Outer width	d_{ow}	$43.3^{\pm 0.5}$ mm
Inner width	d_{iw}	$21.3^{\pm 0.5}$ mm
Thickness	d_c	$1.1^{\pm 0.5}$ mm
Number of turns per layer	N	12 turns
Number of layers	–	1

Power Transmitter design A19 contains two overlapping Primary Coils, with coinciding long axes. The distance between the Primary Coil centers is $d_{cc} = 27^{\pm 4}$ mm. See Figure 70.

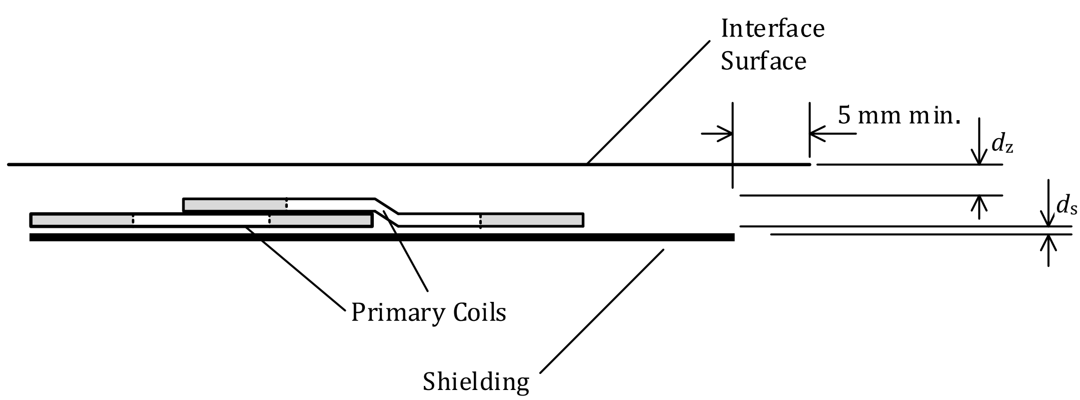
Figure 70. Primary Coils of Power Transmitter design A19



22.1.2 Shielding

As shown in Figure 71, Shielding protects the Power Transmitter Product from the magnetic field that is generated in the Primary Coil. The Shielding should be Ni-Zn or Mn-Zn ferrite and should be at least 0.5 mm thick. The Shielding extends to at least the outer dimensions of the Primary Coils, and is placed below the Primary Coil at a distance of at most $d_s = 1.0$ mm.

Figure 71. Primary Coil assembly of Power Transmitter design A19



22.1.3 Interface Surface

As shown in Figure 71, the distance from the Primary Coil to the Interface Surface of the Power Transmitter Product is $d_Z = 2^{+0.5}_{0.25}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Power Transmitter Product extends at least 5 mm beyond the outer dimensions of the Primary Coils.

22.1.4 Inter coil separation

If the Power Transmitter Product contains multiple type A19 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall not overlap.

22.2 Electrical details

As shown in Figure 72, Power Transmitter design A19 uses a half-bridge inverter to drive an individual Primary Coil and a series capacitance. Within the Operating Frequency range specified below, the assembly of Primary Coils and Shielding has a self-inductance $L_\mathrm{P} = 12.2^{\pm 10\%}$ μH for coils closest to the Interface Surface .and inductance $L_\mathrm{P} = 12.5^{\pm 10\%}$ μH for coils furthest from the Interface Surface. The value of the series capacitance is $C_\mathrm{P} = 0.138^{\pm 5\%}$ μF for coils closest to the Interface Surface and $C_\mathrm{P} = 0.136^{\pm 5\%}$ μF for coils furthest from the Interface Surface. The input voltage to the half-bridge inverter is $12^{\pm 5\%}$ V.

NOTE: Near resonance, the voltage developed across the series capacitance can reach levels exceeding 100 V pk-pk.

Power Transmitter design A19 uses the Operating Frequency and duty cycle of the Power Signal in order to control the amount of power that is transferred. For this purpose, the Operating Frequency range of the half-bridge inverter is f_op = 115...205 kHz with a duty cycle of 50%; and its duty cycle range is 10…50% at an Operating Frequency of 205 kHz. A higher Operating Frequency or lower duty cycle result in the transfer of a lower amount of power. In order to achieve a sufficiently accurate adjustment of the amount of power that is transferred, a type A6 Power Transmitter shall control the Operating Frequency with a resolution of

- $0.01 \times f_\mathrm{op} - 0.7$ kHz, for f_op in the 115…175 kHz range;
- $0.015 \times f_\mathrm{op} - 1.58$ kHz, for f_op in the 175…205 kHz range;

or better. In addition, a type A19 Power Transmitter shall control the duty cycle of the Power Signal with a resolution of 0.1% or better.

When a type A19 Power Transmitter first applies a Power Signal (Digital Ping; see the *Qi Specification, Communications Protocol*), it shall use an initial Operating Frequency of 175 kHz (and a duty cycle of 50%).

Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Qi Specification, Power Delivery*. The controlled variable $v^{(i)}$ introduced in the definition of that algorithm represents the Operating Frequency or the duty cycle. In order to guarantee sufficiently accurate power control, a type A19 Power Transmitter shall determine the amplitude of the Primary Cell current—which is equal to the Primary Coil current—with a resolution of 7 mA or better. Finally, Table 51, Table 52, and Table 53 provide the values of several parameters, which are used in the PID algorithm.

Figure 72. Electrical diagram (outline) of Power Transmitter design A19

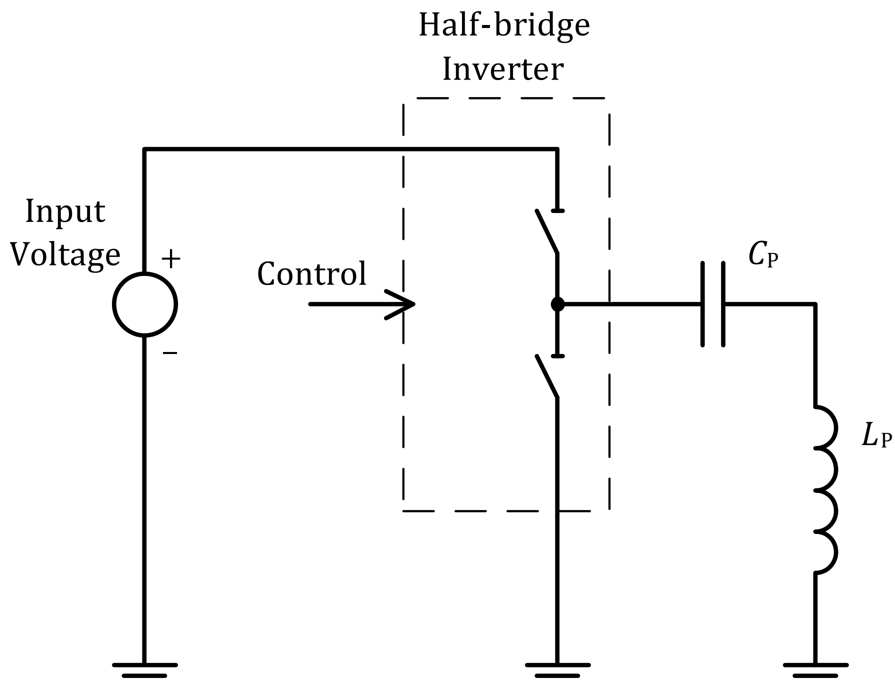


Table 51: PID parameters for Operating Frequency control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	10	mA^{-1}
Integral gain	K_i	0.05	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	3,000	N.A.
PID output limit	M_{PID}	20,000	N.A.

Table 52: Operating Frequency dependent scaling factor

Frequency Range [kHz]	Scaling Factor S_v [Hz]
115…140	1.5
140…160	2
160…180	3
180…205	5

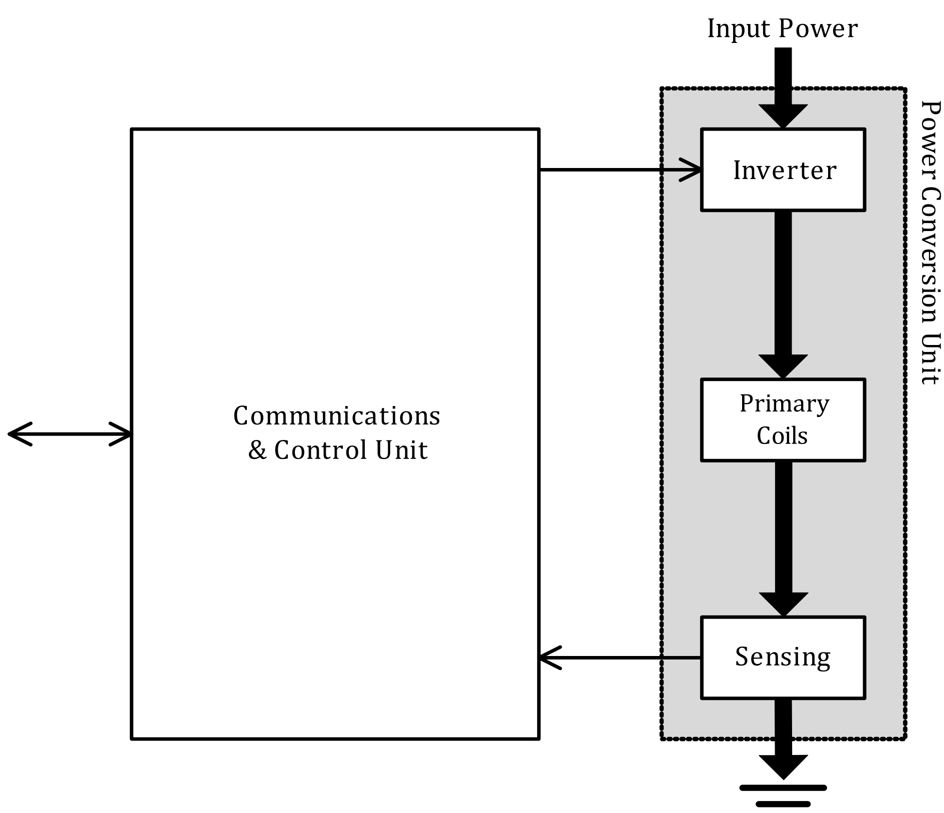
Table 53: PID parameters for duty cycle control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	10	mA^{-1}
Integral gain	K_i	0.05	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	3,000	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_v	–0.01	%

23 Power Transmitter design A20

Figure 73 illustrates the functional block diagram of Power Transmitter design A20, which consists of two major functional units, namely a Power Conversion Unit and a Communications and Control Unit.

Figure 73. Functional block diagram of Power Transmitter design A20



The Power Conversion Unit on the right-hand side of Figure 73 comprises the analog parts of the design. The inverter converts the DC input to an AC waveform that drives a resonant circuit, which consists of the Primary Coil plus a series capacitor. Finally, the voltage and current sense monitors the Primary Coil voltage and current.

The Communications and Control Unit on the left-hand side of Figure 73 comprises the digital logic part of the design. The unit receives and decodes messages from the Power Receiver, executes the relevant power control algorithms and protocols, and drives the input power and frequency of the AC waveform to control the power transfer. The Communications and Control Unit also interfaces with other subsystems of the Power Transmitter Product, e.g. for user interface purposes.

23.1 Mechanical details

Power Transmitter design A20 includes one Primary Coil as defined in Section 23.1.1, *Primary Coil*, Shielding as defined in Section 23.1.2, *Shielding*, and an Interface Surface as defined in Section 23.1.3, *Interface Surface*.

23.1.1 Primary Coil

The Primary Coil is of the wire-wound type, and consists of litz wire having 115 strands of 0.08 mm diameter, or equivalent. As shown in Figure 74, a Primary Coil has a racetrack-like shape and consists of a single layer. Table 54 lists the dimensions of a Primary Coil.

Figure 74. Primary Coil of Power Transmitter design A20

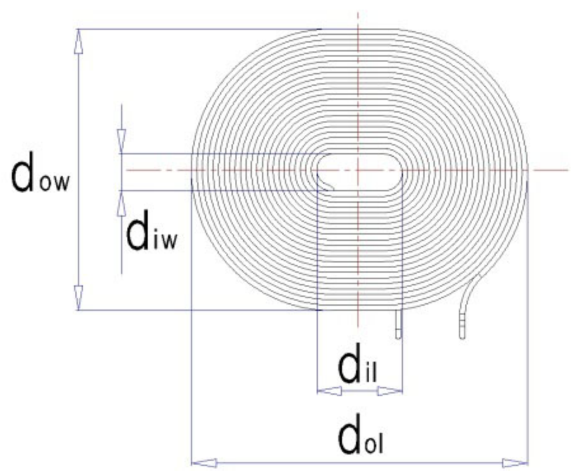


Table 54: Primary Coil parameters of Power Transmitter design A20

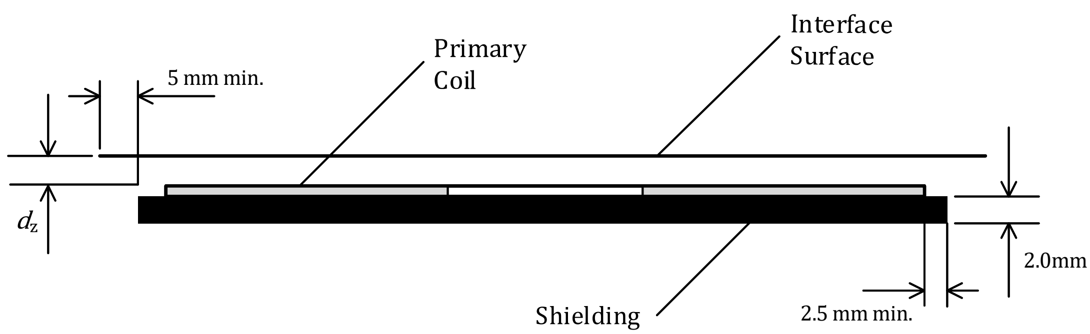
Parameter	Symbol	Value
Outer length	d_{ol}	$65.5^{\pm 0.5}$ mm
Inner length	d_{il}	$16.5^{\pm 0.5}$ mm
Outer width	d_{ow}	$57.1^{\pm 0.5}$ mm
Inner width	d_{iw}	$4.5^{\pm 0.5}$ mm
Thickness	d_c	$1.3^{\pm 0.15}$ mm
Number of turns per layer	N	**22**
Number of layers	–	**1**

23.1.2 Shielding

As shown in Figure 75, Shielding protects the Power Transmitter Product from the magnetic field that is generated in the Primary Coil. The Shielding should be Ni-Zn or Mn-Zn ferrite and should be at least 2.0 mm thick.

The top face of the Shielding block is aligned with the top face of the Primary Coil, such that the Shielding surrounds the Primary Coil on all sides except for the top face. In addition, the Shielding extends to at least 2.5 mm beyond the outer edge of the Primary Coil.

Figure 75. Primary Coil assembly of Power Transmitter design A20



23.1.3 Interface Surface

As shown in Figure 75, the distance from the Primary Coil to the Interface Surface of the Power Transmitter Product is $d_z = 3.0^{\pm 0.5}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Power Transmitter Product extends at least 5 mm beyond the outer diameter of the Primary Coil.

23.1.4 Separation between multiple Power transmitters

If the Power Transmitter Product contains multiple type A20 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall not overlap.

23.2 Electrical details

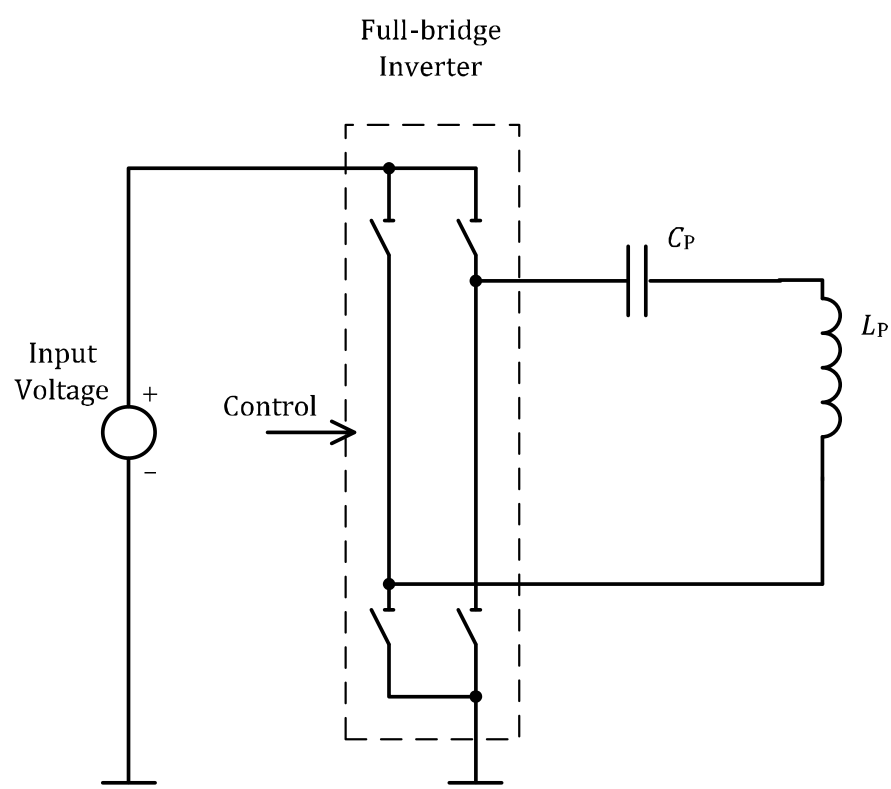
As shown in Figure 76, Power Transmitter design A20 uses a full-bridge inverter to drive the Primary Coil and a series capacitance. Within the Operating Frequency range specified below, the assembly of Primary Coil and Shielding has a self-inductance $L_{\mathrm{P}} = 24^{\pm 10\%}$ μH. The value of the series capacitance is $C_{\mathrm{P}} = 148^{\pm 5\%}$ nF.

NOTE: Near resonance, the voltage developed across the series capacitance can reach levels up to 100 V pk-pk.

Power Transmitter design A20 uses the input voltage to the full-bridge inverter to control the amount of power transferred. For this purpose, the input voltage has a range $2.5^{\pm 0.5}…11.5^{\pm 0.5}$ V, with a resolution of 10mV or better; a higher input voltage results in more power transferred. The Operating Frequency range is $f_{\mathrm{op}} = 87…110$ kHz.

When a type A20 Power Transmitter first applies a Power Signal (Digital Ping; see the *Qi Specification, Communications Protocol*), the Power Transmitter shall use an Operating Frequency of 98 kHz, and an input voltage of $5.5^{\pm 2.0}$ V. If the Power Transmitter does not to receive a Signal Strength Packet from the Power Receiver, the Power Transmitter shall remove the Power Signal as defined in the *Qi Specification, Communications Protocol*. The Power Transmitter may reapply the Power Signal multiple times at consecutively lower-Operating Frequencies within the range specified above, until the Power Transmitter receives a Signal Strength Packet containing an appropriate Signal Strength Value.

Figure 76. Electrical diagram (outline) of Power Transmitter design A20



Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Qi Specification, Power Delivery*. The controlled variable $v^{(i)}$ introduced in the definition of that algorithm represents Operating Frequency as well as the input voltage to the full-bridge inverter. It is recommended that control of the power occurs primarily by means of adjustments to the Operating Frequency, and that voltage adjustments are made only at the boundaries of the Operating Frequency range. In order to guarantee sufficiently accurate power control, a type A20 Power Transmitter shall determine the amplitude of the Primary Coil current with a resolution of 5 mA or better. Finally, Table 55 and Table 56 provide the values of several parameters, which are used in the PID algorithm.

Table 55: PID parameters for Operating Frequency control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	1	mA^{-1}
Integral gain	K_i	0	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	N.A.	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_v	1.0	Hz

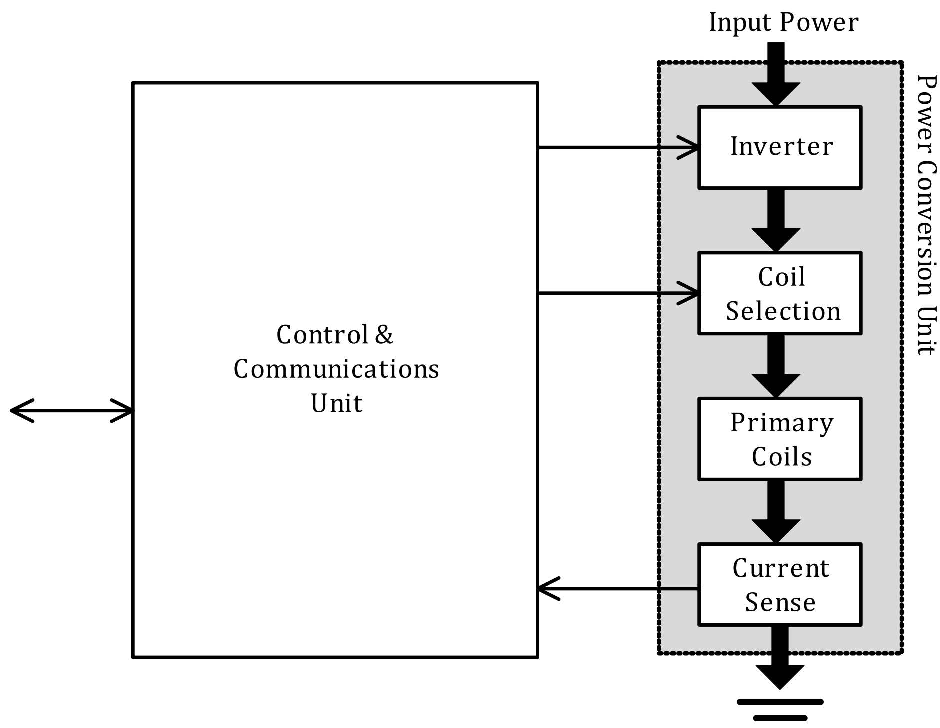
Table 56: PID parameters for voltage control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	1	mA^{-1}
Integral gain	K_i	0	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	N.A.	N.A.
PID output limit	M_{PID}	1,500	N.A.
Scaling factor	S_v	–0.5	mV

24 Power Transmitter design A21

Figure 77 illustrates the functional block diagram of this Power Transmitter design A21, which consists of two major functional units, namely a Power Conversion Unit and a Communications and Control Unit.

Figure 77. Functional block diagram of Power Transmitter design A21



The Power Conversion Unit on the right-hand side of Figure 77 comprises the analog parts of the design. The inverter converts the DC input to an AC waveform that drives a resonant circuit, which consists of the selected Primary Coil plus a series capacitor. The selected Primary Coil is one from at least three partially overlapping Primary Coils, as appropriate for the position of the Power Receiver relative to the Primary Coils. Selection of the Primary Coil proceeds by the Power Transmitter attempting to establish communication with a Power Receiver using any of the Primary Coils. Finally, the current sense monitors the Primary Coil current.

The Communications and Control Unit on the left-hand side of Figure 77 comprises the digital logic part of the design. This unit receives and decodes messages from the Power Receiver, configures the Coil Selection block to connect the appropriate Primary Coil, executes the relevant power control algorithms and protocols, and drives the frequency of the AC waveform to control the power transfer. The Communications and Control Unit also interfaces with other subsystems of the Power Transmitter Product, e.g. for user interface purposes.

24.1 Mechanical details

Power Transmitter design A21 includes one or more Primary Coils as defined in Section 24.1.1, *Primary Coil*, Shielding as defined in Section 24.1.2, *Shielding*, an Interface Surface as defined in Section 24.1.3, *Interface Surface*.

24.1.1 Primary Coil

The Primary Coil consists of at least one PCB coil. Figure 78 shows a view of a single Primary Coil. Table 57 lists the dimensions of the Primary Coil.

Figure 78. Primary Coil of Power Transmitter design A21

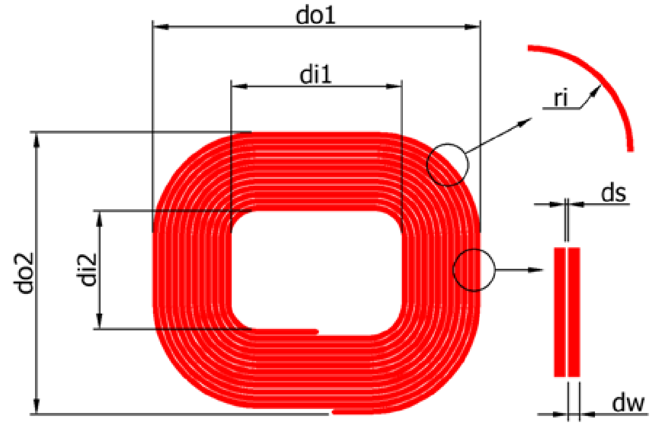


Table 57: Primary Coil parameters of Power Transmitter design A21

Parameter	Symbol	Value
Outer length	d_{o1}	$53.4^{\pm 0.7}$ mm
Inner length	d_{i1}	$27.5^{\pm 0.7}$ mm
Outer width	d_{o2}	$45.8^{\pm 0.7}$ mm
Inner width	d_{i2}	$19.5^{\pm 075}$ mm
4-layer PCB		
Track width	d_w	$0.82^{\pm 0.2}$ mm
Track width plus spacing	$d_w + d_s$	$1.08^{\pm 0.2}$ mm
Corner rounding*	r_i	$16.7^{\pm 1.0}$ mm
Number of turns	N	12
5…8-layer PCB		
Track width	d_w	$0.55^{\pm 0.15}$ mm
Track width plus spacing	$d_w + d_s$	$1.1^{\pm 0.15}$ mm
Corner rounding*	r_i	$13.1^{\pm 1.31}$ mm
Number of turns	N	12 ± 0.25
* Outermost winding only		

Power Transmitter design A21 contains at least one Primary Coil. Odd numbered coils are placed alongside each other with a displacement of d_{h2} between their centers. Even numbered coils are placed orthogonal to the odd numbered coils with a displacement of d_{h1} mm between their centers. See Figure 79.

Figure 79. Primary Coils of Power Transmitter design A21

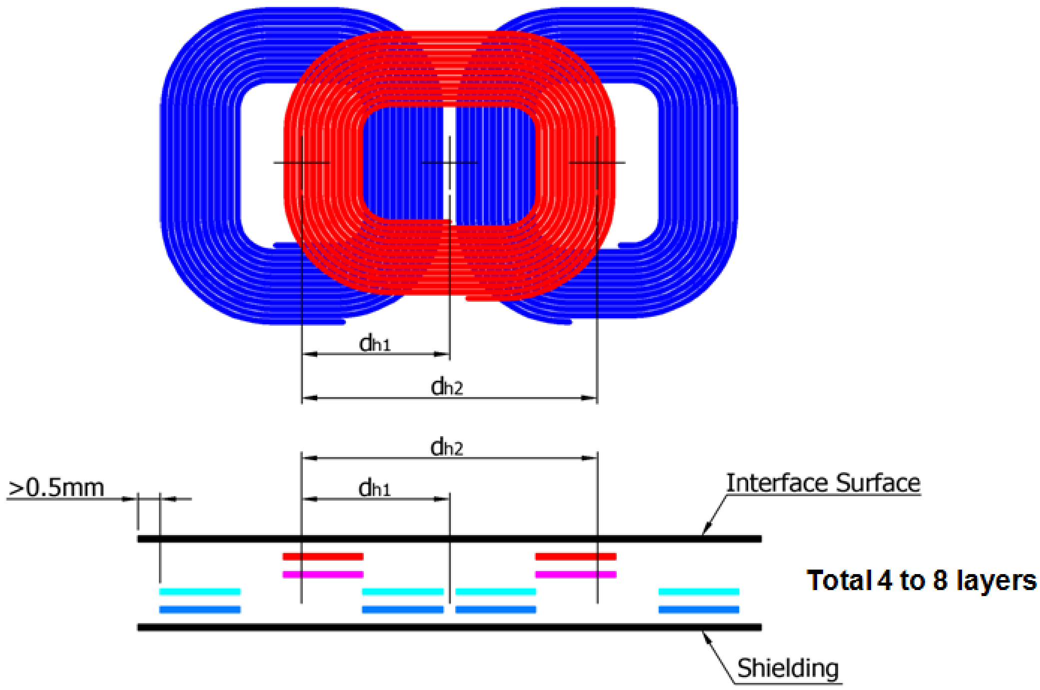


Figure 80. Primary Coils of Power Transmitter design A21

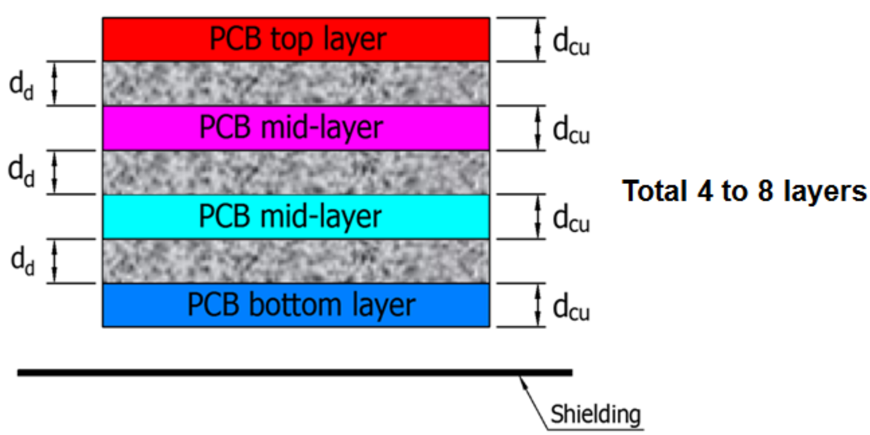


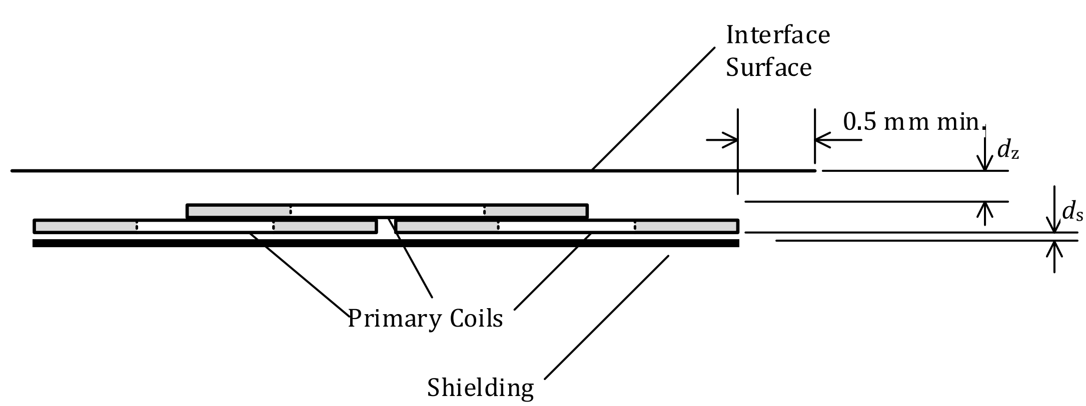
Table 58: Primary Coil parameters of Power Transmitter design A21

Parameter	Symbol	Value
4-layer PCB		
Center-to-center distance	d_{h1}	$23.8^{\pm 1.0}$ mm
Center-to-center distance	d_{h2}	$47.52^{\pm 2.0}$ mm
PCB copper thickness	d_{Cu}	$0.105^{\pm 0.015}$ mm
Dielectric thickness	d_d	$0.375^{\pm 0.063}$ mm
5...8-layer PCB		
Center-to-center distance	d_{h1}	$23.76^{\pm 1.5}$ mm
Center-to-center distance	d_{h2}	$47.52^{\pm 3}$ mm
PCB copper thickness	d_{Cu}	$0.105^{\pm 0.0161}$ mm
Dielectric thickness	d_d	$0.125^{\pm 0.0254}$ mm

24.1.2 Shielding

As shown in Figure 81, Shielding protects the Power Transmitter Product from the magnetic field that is generated in the Primary Coil. The Shielding should be Ni-Zn or Mn-Zn ferrite and should be at least 0.8 mm thick. The Shielding extends to at least the outer dimensions of the Primary Coils, and is placed below the Primary Coil at a distance of at most d_s = 1.0 mm.

Figure 81. Primary Coil assembly of Power Transmitter design A21



24.1.3 Interface Surface

As shown in Figure 81, the distance from the top face of the even-numbered Primary Coil to the Interface Surface of the Power Transmitter Product is $d_z = 2.75^{\pm 1}$ mm, across the top face of the Primary Coil. The odd-numbered Primary Coils are mounted flush to the bottom face of the even-numbered Primary Coils. If the Power Transmitter contains only one Primary Coil, the distance from its top face to the Interface Surface of the Power Transmitter Product is also $d_z = 2.75^{\pm 1}$ mm. In addition, the Interface Surface of the Power Transmitter Product extends at least 0.5 mm beyond the outer dimensions of the Primary Coils.

24.1.4 Inter coil separation

If the Power Transmitter Product contains multiple type A21 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall not overlap.

24.2 Electrical details

As shown in Figure 82, Power Transmitter design A21 uses a half-bridge inverter to drive an individual Primary Coil and a series capacitance. Within the Operating Frequency range specified below, the assembly of Primary Coils and Shielding has a self-inductance $L_{\mathrm{P}} = 11.5^{\pm 10\%}$ μH for coils closest to the Interface Surface .and inductance $L_{\mathrm{P}} = 12.5^{\pm 10\%}$ μH for coils furthest from the Interface Surface. The value of the series capacitance is $C_{\mathrm{P}} = 0.147^{\pm 5\%}$ μF for coils closest to the Interface Surface and $C_{\mathrm{P}} = 0.136^{\pm 5\%}$ μF for coils furthest from the Interface Surface. The input voltage to the half-bridge inverter is $12^{\pm 5\%}$ V.

NOTE: Near resonance, the voltage developed across the series capacitance can reach levels exceeding 100 V pk-pk.

Power Transmitter design A21 uses the Operating Frequency and duty cycle of the Power Signal in order to control the amount of power that is transferred. For this purpose, the Operating Frequency range of the half-bridge inverter is f_{op} = 115...205 kHz with a duty cycle of 50%; and its duty cycle range is 10…50% at an Operating Frequency of 205 kHz. A higher Operating Frequency or lower duty cycle result in the transfer of a lower amount of power. In order to achieve a sufficiently accurate adjustment of the amount of power that is transferred, a type A21 Power Transmitter shall control the Operating Frequency with a resolution of

- $0.01 \times f_{\mathrm{op}} - 0.7$ kHz, for f_{op} in the 115…175 kHz range;
- $0.015 \times f_{\mathrm{op}} - 1.58$ kHz, for f_{op} in the 175…205 kHz range;

or better. In addition, a type A21 Power Transmitter shall control the duty cycle of the Power Signal with a resolution of 0.1% or better.

When a type A21 Power Transmitter first applies a Power Signal (Digital Ping; see the *Qi Specification, Communications Protocol*), it shall use an initial Operating Frequency of 175 kHz (and a duty cycle of 50%).

Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Qi Specification, Power Delivery*. The controlled variable $v^{(i)}$ introduced in the definition of that algorithm represents the Operating Frequency or the duty cycle. In order to guarantee sufficiently accurate power control, a type A21 Power Transmitter shall determine the amplitude of the Primary Cell current—which is equal to the Primary Coil current—with a resolution of 7 mA or better. Finally, Table 59, Table 60, and Table 61 provide the values of several parameters, which are used in the PID algorithm.

Figure 82. Electrical diagram (outline) of Power Transmitter design A21

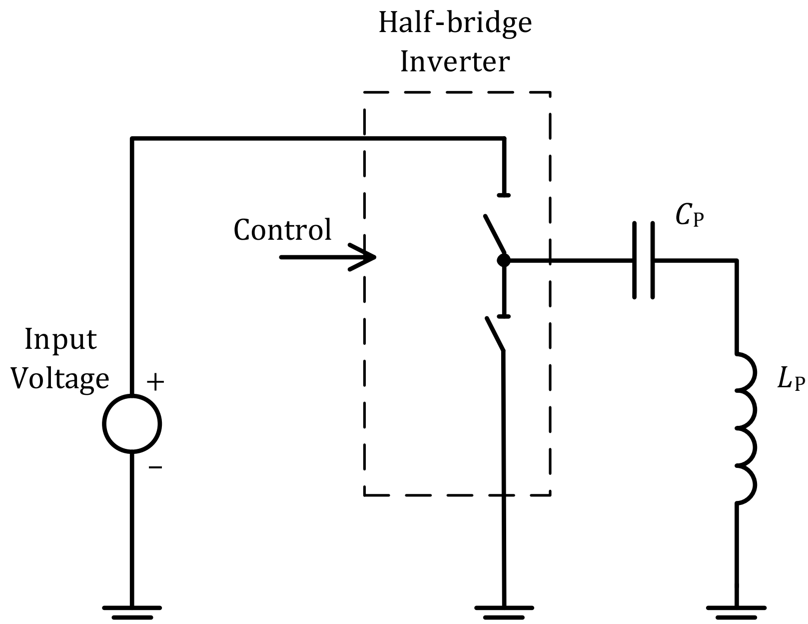


Table 59: PID parameters for Operating Frequency control

Parameter	**Symbol**	**Value**	**Unit**
Proportional gain	K_p	10	mA^{-1}
Integral gain	K_i	0.05	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	3,000	N.A.
PID output limit	M_{PID}	20,000	N.A.

Table 60: Operating Frequency dependent scaling factor

Frequency Range [kHz]	**Scaling Factor S_v [Hz]**
115…140	1.5
140…160	2
160…180	3
180…205	5

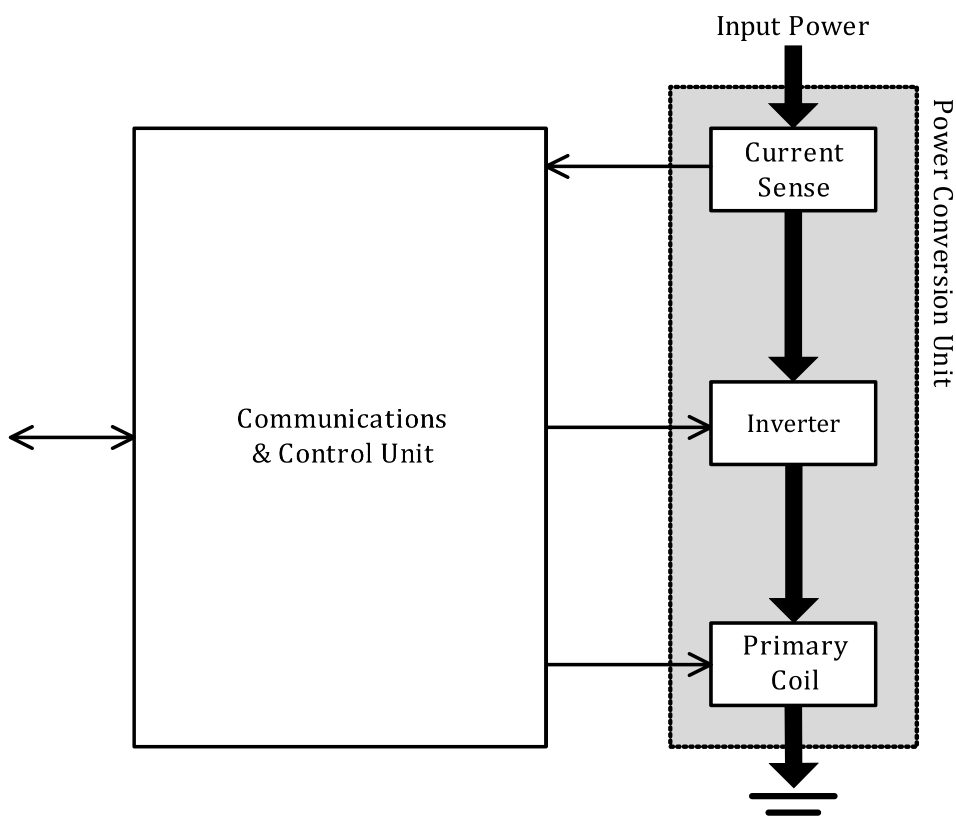
Table 61: PID parameters for duty cycle control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	10	mA^{-1}
Integral gain	K_i	0.05	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	3,000	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_v	–0.01	%

25 Power Transmitter design A22

Figure 83 illustrates the functional block diagram of Power Transmitter design A22, which consists of two major functional units, namely a Power Conversion Unit and a Communications and Control Unit.

Figure 83. Functional block diagram of Power Transmitter design A22



The Power Conversion Unit on the right-hand side of Figure 83 comprises the analog parts of the design. The voltage and current sense monitors the input voltage and current. The inverter converts the DC input to an AC waveform that drives a resonant circuit, which consists of the Primary Coil plus a series capacitor.

The Communications and Control Unit on the left-hand side of Figure 83 comprises the digital logic part of the design. The unit receives and decodes messages from the Power Receiver, executes the relevant power control algorithms and protocols, and drives the input power and frequency of the AC waveform to control the power transfer. The Communications and Control Unit also interfaces with other subsystems of the Power Transmitter Product, e.g. for user interface purposes.

25.1 Mechanical details

Power Transmitter design A22 includes one Primary Coil as defined in Section 25.1.1, *Primary Coil*, Shielding as defined in Section 25.1.2, *Shielding*, and an Interface Surface as defined in Section 25.1.3, *Interface Surface*.

25.1.1 Primary Coil

The Primary Coil is of the wire-wound type, and consists of litz wire having 115 strands of 0.08 mm diameter, or equivalent. As shown in Figure 84, a Primary Coil has a racetrack-like shape and consists of a single layer. Table 62 lists the dimensions of a Primary Coil.

Figure 84. Primary Coil of Power Transmitter design A22

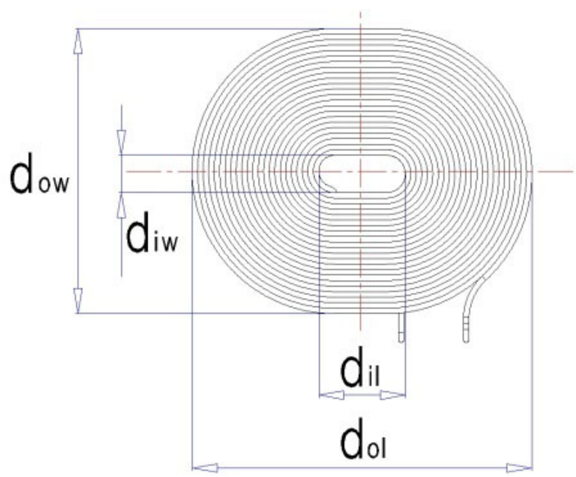


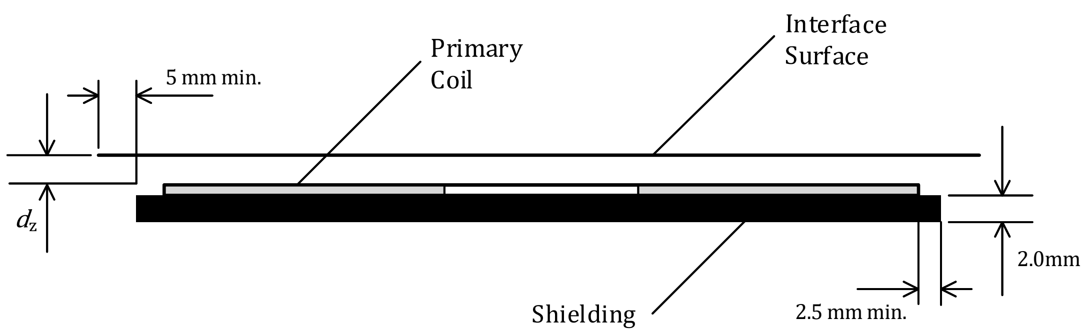
Table 62: Primary Coil parameters of Power Transmitter design A22

Parameter	Symbol	Value
Outer length	d_{ol}	$65.5^{\pm 0.5}$ mm
Inner length	d_{il}	$16.5^{\pm 0.5}$ mm
Outer width	d_{ow}	$57.1^{\pm 0.5}$ mm
Inner width	d_{iw}	$4.5^{\pm 0.5}$ mm
Thickness	d_c	$1.3^{\pm 0.15}$ mm
Number of turns per layer	N	22
Number of layers	–	1

25.1.2 Shielding

As shown in Figure 85, Shielding protects the Power Transmitter Product from the magnetic field that is generated in the Primary Coil. The Shielding should be Ni-Zn or Mn-Zn ferrite and should be at least 2.0 mm thick. The Shielding may surround the Primary Coil on all sides except for the top face. In addition, the Shielding extends to at least 2.5 mm beyond the outer edge of the Primary Coil.

Figure 85. Primary Coil assembly of Power Transmitter design A22



25.1.3 Interface Surface

As shown in Figure 85, the distance from the Primary Coil to the Interface Surface of the Power Transmitter Product is $d_z = 2.5^{\pm1.0}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Power Transmitter Product extends at least 5 mm beyond the outer diameter of the Primary Coil.

25.1.4 Separation between multiple Power transmitters

If the Power Transmitter Product contains multiple type A22 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall not overlap.

25.2 Electrical details

As shown in Figure 86, Power Transmitter design A22 uses a full-bridge inverter to drive the Primary Coil and a series capacitance. Within the Operating Frequency range specified below, the assembly of Primary Coil and Shielding has a self-inductance $L_\mathrm{P} = 19.0^{\pm 10\%}$ μH. The value of the series capacitance is $C_\mathrm{P} = 122^{\pm 10\%}$ nF.

NOTE: Near resonance, the voltage developed across the series capacitance can reach levels up to 100 V pk-pk.

Power Transmitter design A22 uses the input voltage to the full-bridge inverter as well as its Operating Frequency and duty cycle to control the amount of power transferred. For this purpose, the input voltage range is 2...12 V, with a resolution of 10 mV or better; the Operating Frequency range is110…205 kHz; and the duty cycle range is 2...50%.

When a type A22 Power Transmitter first applies a Power Signal (Digital Ping; see the *Qi Specification, Communications Protocol*), the Power Transmitter shall use an Operating Frequency of $125^{\pm 10}$ kHz, and an input voltage of 3.5...7.5 V. If the Power Transmitter does not to receive a Signal Strength Packet from the Power Receiver, the Power Transmitter shall remove the Power Signal as defined in the *Qi Specification, Communications Protocol.* The Power Transmitter may re-apply the Power Signal multiple times at consecutively higher input voltage to the full-bridge inverter within the range specified above, until the Power Transmitter receives a Signal Strength Packet containing an appropriate Signal Strength Value.

Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Qi Specification, Power Delivery*. The controlled variable $v^{(i)}$ introduced in the definition of that algorithm represents the input voltage to the full-bridge inverter, Operating Frequency and duty cycle. It is recommended that control of the power occurs primarily by means of adjustments to the input voltage. In order to guarantee sufficiently accurate power control, a type A22 Power Transmitter shall determine the amplitude of the Primary Coil current with a resolution of 5 mA or better. Finally, Table 63, Table 64, and Table 65 provide the values of several parameters, which are used in the PID algorithm.

Figure 86. Electrical diagram (outline) of Power Transmitter design A22

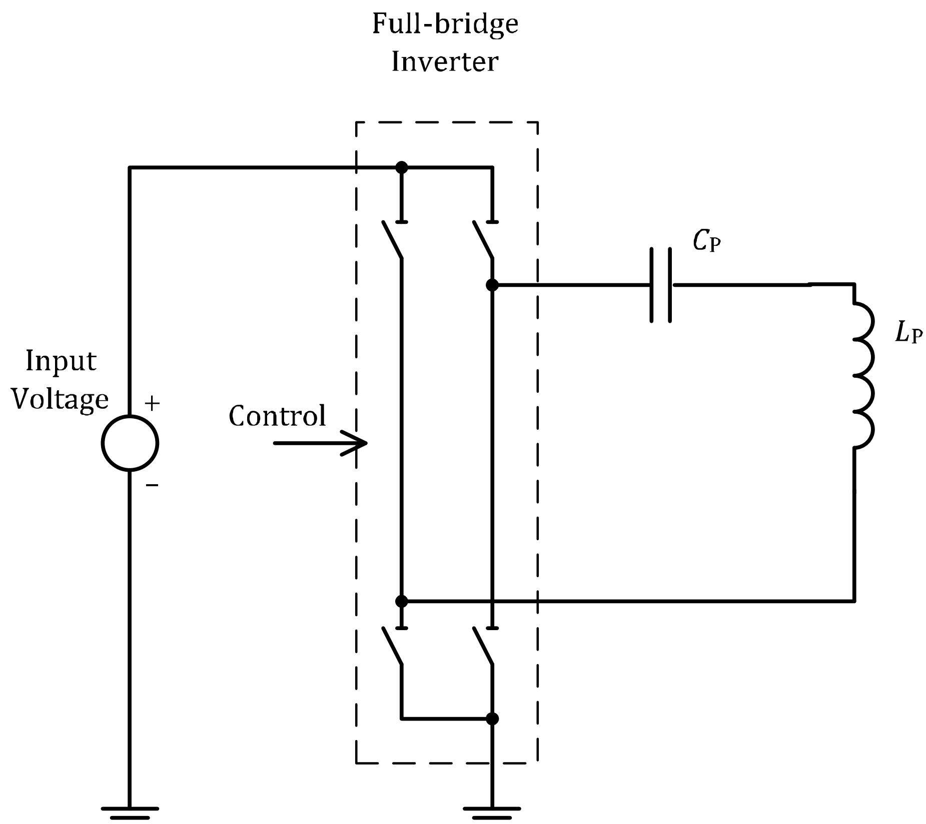


Table 63: PID parameters for voltage control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	1	mA-1
Integral gain	K_i	0	mA-1ms-1
Derivative gain	K_d	0	mA-1ms
Integral term limit	M_I	N.A.	N.A.
PID output limit	M_{PID}	1,500	N.A.
Scaling factor	S_v	-0.5	mV

Table 64: PID parameters for Operating Frequency control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	1	mA^{-1}
Integral gain	K_i	0	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	N.A.	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_v	1.0	Hz

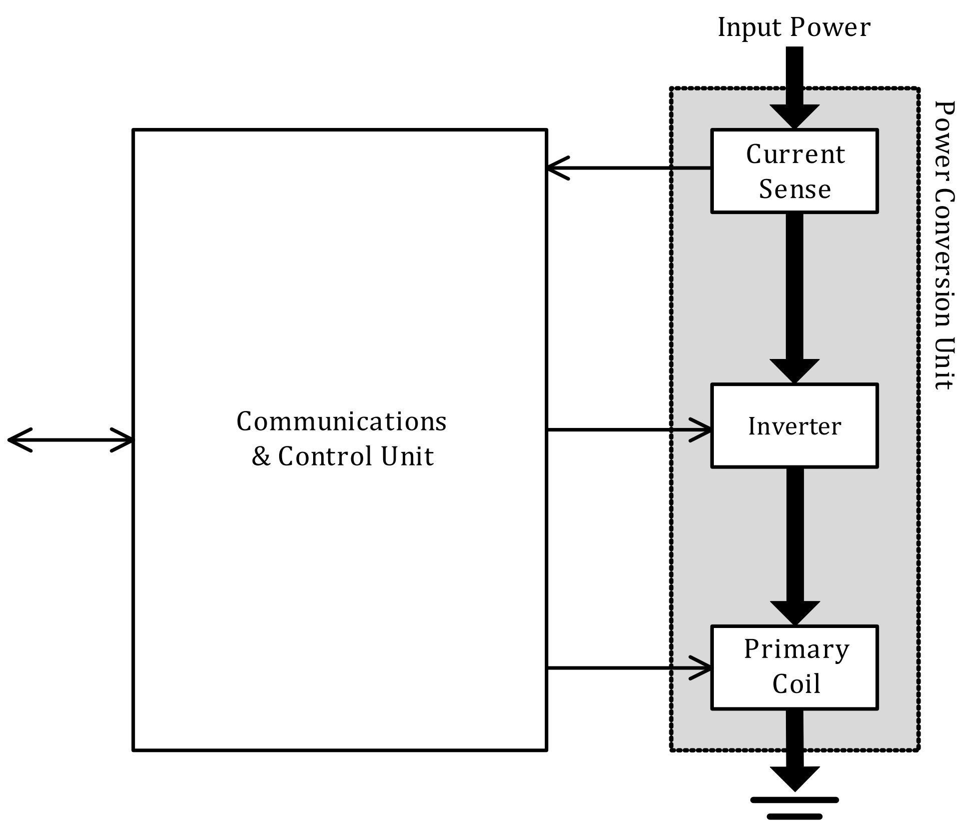
Table 65: PID parameters for duty control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	1	mA^{-1}
Integral gain	K_i	0	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	N.A.	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_v	-0.1	°

26 Power Transmitter design A23

Figure 87 illustrates the functional block diagram of Power Transmitter design A23, which consists of two major functional units, namely a Power Conversion Unit and a Communications and Control Unit.

Figure 87. Functional block diagram of Power Transmitter design A23



The Power Conversion Unit on the right-hand side of Figure 87 comprises the analog parts of the design. The voltage and current sense monitors the input voltage and current. The inverter converts the DC input to an AC waveform that drives a resonant circuit, which consists of the Primary Coil plus a series capacitor.

The Communications and Control Unit on the left-hand side of Figure 87 comprises the digital logic part of the design. The unit receives and decodes messages from the Power Receiver, executes the relevant power control algorithms and protocols, and drives the input power and frequency of the AC waveform to control the power transfer. The Communications and Control Unit also interfaces with other subsystems of the Power Transmitter Product, e.g. for user interface purposes.

26.1 Mechanical details

Power Transmitter design A23 includes one Primary Coil as defined in Section 26.1.1, *Primary Coil*, Shielding as defined in Section 26.1.2, *Shielding*, and an Interface Surface as defined in Section 26.1.3, *Interface Surface*.

26.1.1 Primary Coil

The Primary Coil is of the wire-wound type, and consists of litz wire having 115 strands of 0.08 mm diameter, or equivalent. As shown in Figure 88, a Primary Coil has a racetrack-like shape and consists of a single layer. Table 66 lists the dimensions of a Primary Coil.

Figure 88. Primary Coil of Power Transmitter design A23

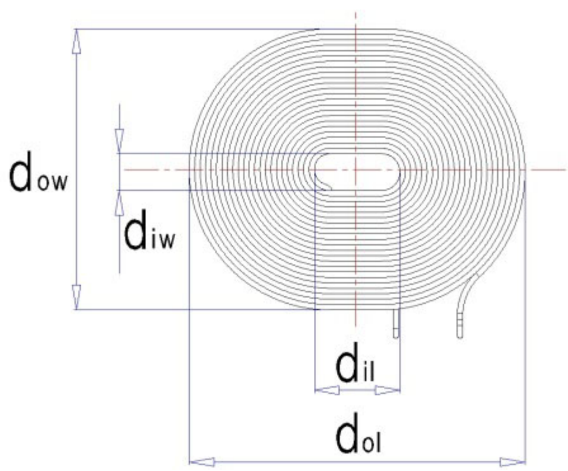


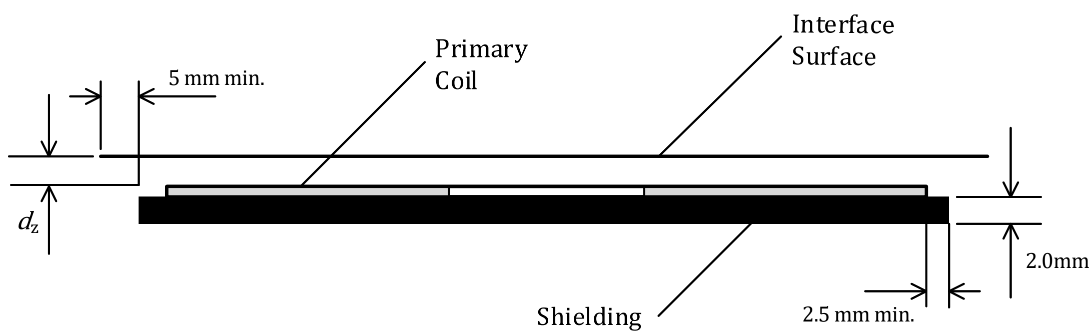
Table 66: Primary Coil parameters of Power Transmitter design A23

Parameter	Symbol	Value
Outer length	d_{ol}	$65.5^{\pm 0.5}$ mm
Inner length	d_{il}	$16.5^{\pm 0.5}$ mm
Outer width	d_{ow}	$57.1^{\pm 0.5}$ mm
Inner width	d_{iw}	$4.5^{\pm 0.5}$ mm
Thickness	d_c	$1.3^{\pm 0.15}$ mm
Number of turns per layer	N	22
Number of layers	–	1

26.1.2 Shielding

As shown in Figure 89, Shielding protects the Power Transmitter Product from the magnetic field that is generated in the Primary Coil. The Shielding should be Ni-Zn or Mn-Zn ferrite and should be at least 2.0 mm thick. The Shielding may surround the Primary Coil on all sides except for the top face. In addition, the Shielding extends to at least 2.5 mm beyond the outer edge of the Primary Coil.

Figure 89. Primary Coil assembly of Power Transmitter design A23



26.1.3 Interface Surface

As shown in Figure 89, the distance from the Primary Coil to the Interface Surface of the Power Transmitter Product is $d_z = 2.5^{\pm 1.0}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Power Transmitter Product extends at least 5 mm beyond the outer diameter of the Primary Coil.

26.1.4 Separation between multiple Power transmitters

If the Power Transmitter Product contains multiple type A23 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall not overlap.

26.2 Electrical details

As shown in Figure 90, Power Transmitter design A23 uses a full-bridge inverter to drive the Primary Coil and a series capacitance. Within the Operating Frequency range specified below, the assembly of Primary Coil and Shielding has a self-inductance $L_{\mathrm{P}} = 19.0^{\pm 10\%}$ μH. The value of the series capacitance is $C_{\mathrm{P}} = 168^{\pm 10\%}$ nF.

NOTE: Near resonance, the voltage developed across the series capacitance can reach levels up to 100 V pk-pk.

Power Transmitter design A23 uses the input voltage to the full-bridge inverter as well as its Operating Frequency and duty cycle to control the amount of power transferred. For this purpose, the input voltage range is 2...12 V, with a resolution of 10 mV or better; the Operating Frequency range is 101…115 kHz; and the duty cycle range is 2...50%.

When a type A23 Power Transmitter first applies a Power Signal (Digital Ping; see the *Qi Specification, Communications Protocol*), the Power Transmitter shall use an Operating Frequency of $108^{\pm 5}$ kHz, and an input voltage of 3.5...7.5 V. If the Power Transmitter does not to receive a Signal Strength Packet from the Power Receiver, the Power Transmitter shall remove the Power Signal as defined in the *Qi Specification, Communications Protocol.* The Power Transmitter may re-apply the Power Signal multiple times at consecutively higher input voltage to the full-bridge inverter within the range specified above, until the Power Transmitter receives a Signal Strength Packet containing an appropriate Signal Strength Value.

Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Qi Specification, Power Delivery*. The controlled variable $v^{(j)}$ introduced in the definition of that algorithm represents the input voltage to the full-bridge inverter, Operating Frequency and duty cycle. It is recommended that control of the power occurs primarily by means of adjustments to the input voltage. In order to guarantee sufficiently accurate power control, a type A23 Power Transmitter shall determine the amplitude of the Primary Coil current with a resolution of 5 mA or better. Finally, Table 67, Table 68, and Table 69 provide the values of several parameters, which are used in the PID algorithm.

Figure 90. Electrical diagram (outline) of Power Transmitter design A23

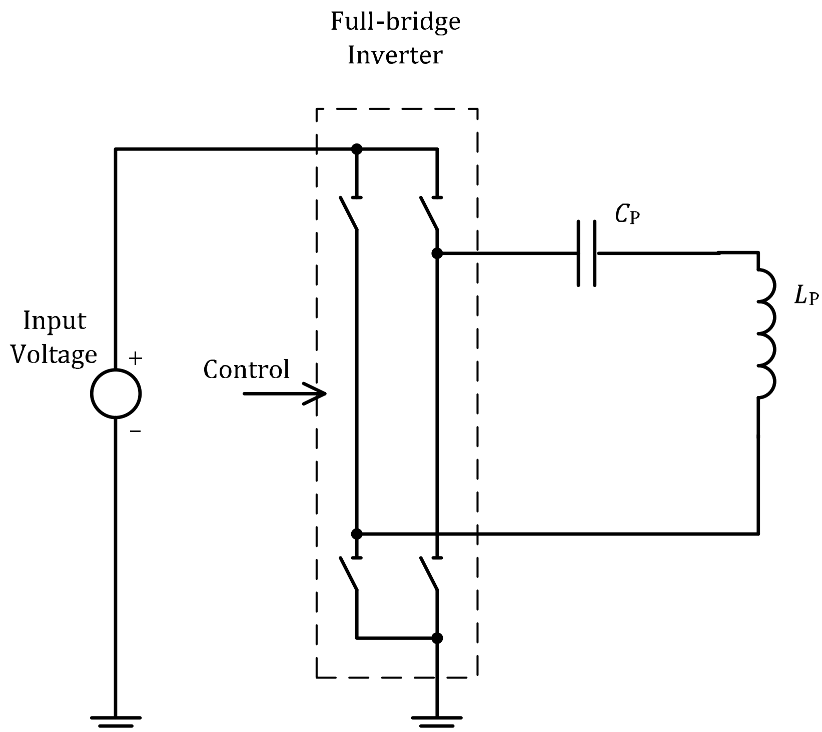


Table 67: PID parameters for voltage control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	1	mA-1
Integral gain	K_i	0	mA-1ms-1
Derivative gain	K_d	0	mA-1ms
Integral term limit	M_I	N.A.	N.A.
PID output limit	M_{PID}	1,500	N.A.
Scaling factor	S_v	-0.5	mV

Table 68: PID parameters for Operating Frequency control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	1	mA^{-1}
Integral gain	K_i	0	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	N.A.	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_v	1.0	Hz

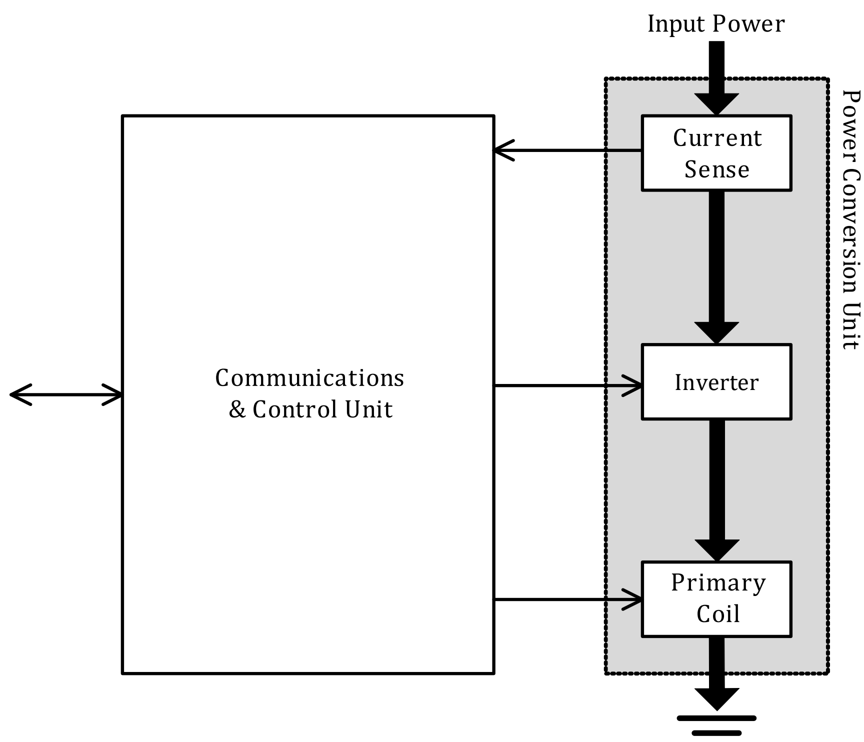
Table 69: PID parameters for duty control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	1	mA^{-1}
Integral gain	K_i	0	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	N.A.	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_v	-0.1	°

27 Power Transmitter design A24

Figure 91 illustrates the functional block diagram of Power Transmitter design A24, which consists of two major functional units, namely a Power Conversion Unit and a Communications and Control Unit.

Figure 91. Functional block diagram of Power Transmitter design A24



The Power Conversion Unit on the right-hand side of Figure 91 comprises the analog parts of the design. The voltage and current sense monitors the input voltage and current. The inverter converts the DC input to an AC waveform that drives a resonant circuit, which consists of the Primary Coil plus a series capacitor.

The Communications and Control Unit on the left-hand side of Figure 91 comprises the digital logic part of the design. The unit receives and decodes messages from the Power Receiver, executes the relevant power control algorithms and protocols, and drives the input power and frequency of the AC waveform to control the power transfer. The Communications and Control Unit also interfaces with other subsystems of the Power Transmitter Product, e.g. for user interface purposes.

27.1 Mechanical details

Power Transmitter design A24 includes one Primary Coil as defined in Section 27.1.1, *Primary Coil*, Shielding as defined in Section 27.1.2, *Shielding*, and an Interface Surface as defined in Section 27.1.3, *Interface Surface*.

27.1.1 Primary Coil

The Primary Coil is of the wire-wound type, and consists of litz wire having 105 strands of 0.08 mm diameter, or equivalent. As shown in Figure 92, a Primary Coil has a circular shape and consists of a single layer. Table 70 lists the dimensions of a Primary Coil.

Figure 92. Primary Coil of Power Transmitter design A24

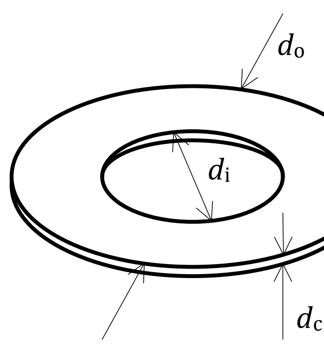


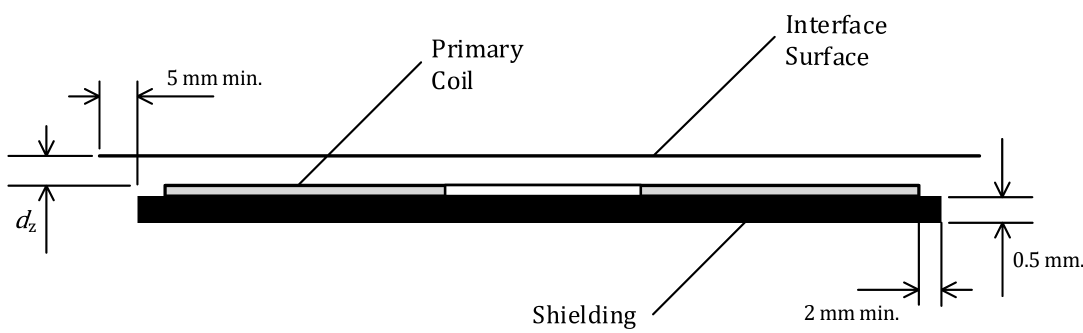
Table 70: Primary Coil parameters of Power Transmitter design A24

Parameter	Symbol	Value
Outer diameter	d_o	$44.0^{\pm 1.5}$ mm
Inner diameter	d_i	$22.5^{\pm 1.0}$ mm
Thickness	d_c	$1.3^{\pm 0.15}$ mm
Number of turns per layer	N	9
Number of layers	–	1

27.1.2 Shielding

As shown in Figure 93, Shielding protects the Power Transmitter Product from the magnetic field that is generated in the Primary Coil. The Shielding should be Ni-Zn or Mn-Zn ferrite and should be at least 0.5 mm thick. The Shielding extends to at least 2.0 mm beyond the outer edge of the Primary Coil.

Figure 93. Primary Coil assembly of Power Transmitter design A24



27.1.3 Interface Surface

As shown in Figure 93, the distance from the Primary Coil to the Interface Surface of the Power Transmitter Product is $d_z = 3.0^{\pm 0.5}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Power Transmitter Product extends at least 5 mm beyond the outer diameter of the Primary Coil.

27.1.4 Separation between multiple Power transmitters

If the Power Transmitter Product contains multiple type A24 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall not overlap.

27.2 Electrical details

As shown in Figure 94, Power Transmitter design A24 uses a full-bridge inverter to drive the Primary Coil and a series capacitance. Within the Operating Frequency range specified below, the assembly of Primary Coil and Shielding has a self-inductance $L_{\mathrm{P}} = 6.1^{\pm 10\%}$ μH. The value of the series capacitance is $C_{\mathrm{P}} = 400^{\pm 10\%}$ nF. The input voltage to the full-bridge is $5.0^{\pm 5\%}$ V.

NOTE: Near resonance, the voltage developed across the series capacitance can reach levels up to 100 V pk-pk.

Power Transmitter design A24 uses the Operating Frequency and duty cycle of the Power Signal in order to control the amount of power transferred. For this purpose, the Operating Frequency range is $f_{\mathrm{op}} = 110...205$ kHz, and the duty cycle range is 2…50%. A higher Operating Frequency and lower duty cycle result in the transfer of a lower amount of power. In order to achieve a sufficiently accurately adjustment of the power that is transferred, a type A24 Power Transmitter shall be able to control the Operating Frequency with a resolution of 0.1 kHz or better.

When a type A24 Power Transmitter first applies a Power Signal (Digital Ping; see the *Qi Specification, Communications Protocol*), the Power Transmitter shall use an Operating Frequency of $155^{\pm 15}$ kHz, and a duty cycle of $30^{\pm 10}$ %. If the Power Transmitter does not to receive a Signal Strength Packet from the Power Receiver, the Power Transmitter shall remove the Power Signal as defined in the *Qi Specification, Communications Protocol.* The Power transmitter may re-apply the Power Signal multiple times at consecutively Operating Frequencies within the range specified above, until the Power Transmitter receives a Signal Strength Packet containing an appropriate Signal Strength Value.

Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Qi Specification, Power Delivery*. The controlled variable $v^{(i)}$ introduced in the definition of that algorithm represents the input voltage to the full-bridge inverter, Operating Frequency and duty cycle. It is recommended that control of the power occurs primarily by means of adjustments to the duty cycle. In order to guarantee sufficiently accurate power control, a type A24 Power Transmitter shall determine the amplitude of the Primary Coil current with a resolution of 5 mA or better. Finally, Table 71 and Table 72 provide the values of several parameters, which are used in the PID algorithm.

Figure 94. Electrical diagram (outline) of Power Transmitter design A24

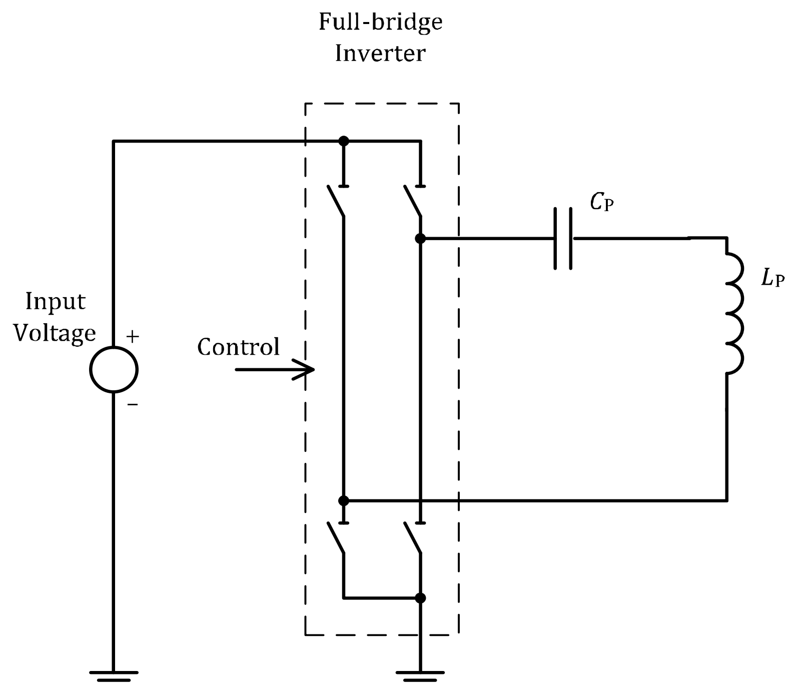


Table 71: PID parameters for Operating Frequency control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	1	mA^{-1}
Integral gain	K_i	0	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	N.A.	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_v	1.0	Hz

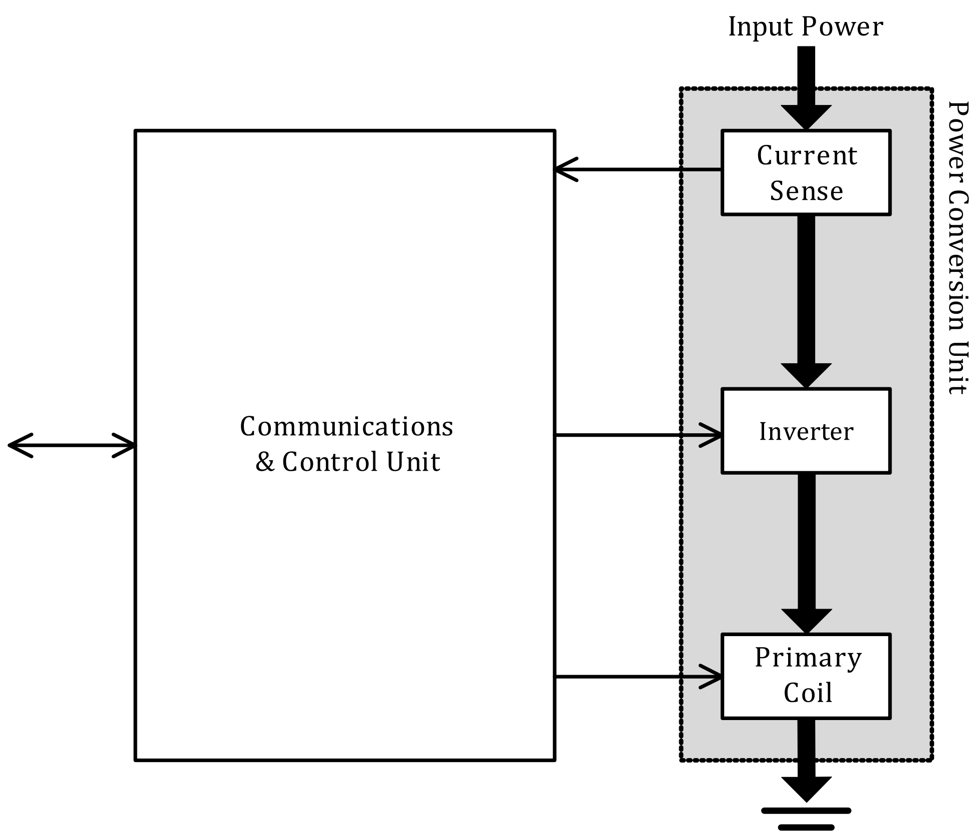
Table 72: PID parameters for duty cycle control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	1	mA^{-1}
Integral gain	K_i	0	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	N.A.	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_v	-0.1	°

28 Power Transmitter design A25

Figure 95 illustrates the functional block diagram of Power Transmitter design A25, which consists of two major functional units, namely a Power Conversion Unit and a Communications and Control Unit.

Figure 95. Functional block diagram of Power Transmitter design A25



The Power Conversion Unit on the right-hand side of Figure 95 comprises the analog parts of the design. The voltage and current sense monitors the input voltage and current. The inverter converts the DC input to an AC waveform that drives a resonant circuit, which consists of the Primary Coil plus a series capacitor.

The Communications and Control Unit on the left-hand side of Figure 95 comprises the digital logic part of the design. The unit receives and decodes messages from the Power Receiver, executes the relevant power control algorithms and protocols, and drives the input power and frequency of the AC waveform to control the power transfer. The Communications and Control Unit also interfaces with other subsystems of the Power Transmitter Product, e.g. for user interface purposes.

28.1 Mechanical details

Power Transmitter design A25 includes one Primary Coil as defined in Section 28.1.1, *Primary Coil*, Shielding as defined in Section 28.1.2, *Shielding*, and an Interface Surface as defined in Section 28.1.3, *Interface Surface*.

28.1.1 Primary Coil

The Primary Coil is of the wire-wound type, and consists of litz wire having 115 strands of 0.08 mm diameter, or equivalent. As shown in Figure 96, a Primary Coil has a racetrack-like shape and consists of a single layer. Table 73 lists the dimensions of a Primary Coil.

Figure 96. Primary Coil of Power Transmitter design A25

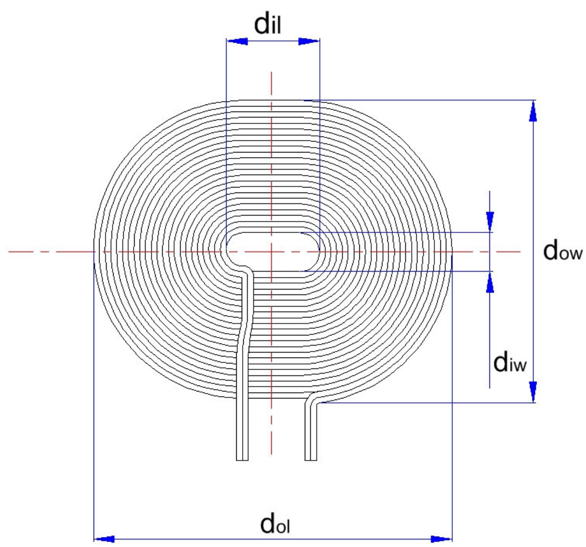


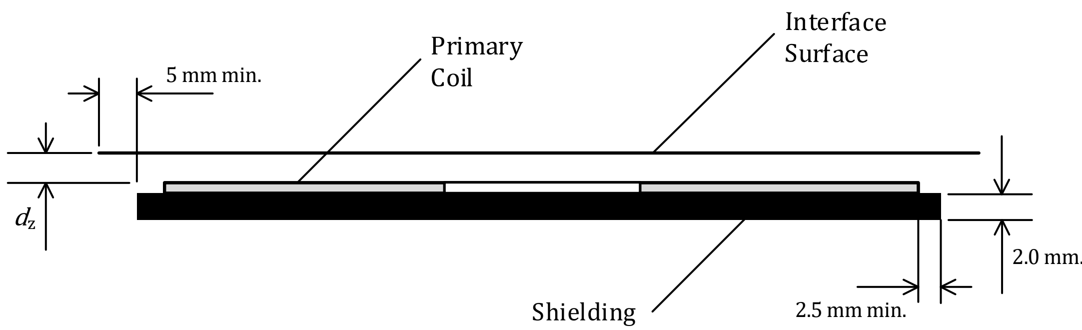
Table 73: Primary Coil parameters of Power Transmitter design A25

Parameter	Symbol	Value
Outer length	d_{ol}	$65.7^{\pm 1.5}$ mm
Inner length	d_{il}	$16.3^{\pm 1.0}$ mm
Outer width	d_{ow}	$59.2^{\pm 1.5}$ mm
Inner width	d_{iw}	$5.1^{\pm 1.0}$ mm
Thickness	d_c	$1.3^{\pm 0.15}$ mm
Number of turns per layer	N	11 (bifilar turns)
Number of layers	–	1

28.1.2 Shielding

As shown in Figure 97, Shielding protects the Power Transmitter Product from the magnetic field that is generated in the Primary Coil. The Shielding should be Ni-Zn or Mn-Zn ferrite and should be at least 2.0 mm thick. The Shielding extends to at least 2.5 mm beyond the outer edge of the Primary Coil.

Figure 97. Primary Coil assembly of Power Transmitter design A25



28.1.3 Interface Surface

As shown in Figure 97, the distance from the Primary Coil to the Interface Surface of the Power Transmitter Product is $d_z = 2.5^{\pm 1.0}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Power Transmitter Product extends at least 5 mm beyond the outer diameter of the Primary Coil.

28.1.4 Separation between multiple Power transmitters

If the Power Transmitter Product contains multiple type A25 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall not overlap.

28.2 Electrical details

As shown in Figure 98, Power Transmitter design A25 uses a full-bridge inverter to drive the Primary Coil and a series capacitance. Within the Operating Frequency range specified below, the assembly of Primary Coil and Shielding has a self-inductance $L_{\mathrm{P}} = 6.1^{\pm 10\%}$ μH. The value of the series capacitance is $C_{\mathrm{P}} = 400^{\pm 10\%}$ nF. The input voltage to the full-bridge is $5.0^{\pm 5.0\%}$V.

NOTE: Near resonance, the voltage developed across the series capacitance can reach levels up to 100 V pk-pk.

Power Transmitter design A25 uses the Operating Frequency and duty cycle of the Power Signal in order to control the amount of power transferred. For this purpose, the Operating Frequency range is $f_{\mathrm{op}} = 110...205$ kHz, and the duty cycle range is 2...50%. A higher Operating Frequency and lower duty cycle result in the transfer of a lower amount of power. In order to achieve a sufficiently accurately adjustment of the power that is transferred, a type A25 Power Transmitter shall be able to control the Operating Frequency with a resolution of 0.1kHz or better.

When a type A25 Power Transmitter first applies a Power Signal (Digital Ping; see the *Qi Specification, Communications Protocol*), the Power Transmitter shall use an Operating Frequency of $155^{\pm 15}$ kHz, and a duty cycle of $30^{\pm 10}$%. If the Power Transmitter does not to receive a Signal Strength Packet from the Power Receiver, the Power Transmitter shall remove the Power Signal as defined in the *Qi Specification, Communications Protocol.* The Power Transmitter may re-apply the Power Signal multiple times at consecutively lower Operating Frequencies within the range specified above, until the Power Transmitter receives a Signal Strength Packet containing an appropriate Signal Strength Value.

Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Qi Specification, Power Delivery*. The controlled variable $v^{(i)}$ introduced in the definition of that algorithm represents the input voltage to the full-bridge inverter, Operating Frequency and duty cycle. It is recommended that control of the power occurs primarily by means of adjustments to the duty cycle. In order to guarantee sufficiently accurate power control, a type A25 Power Transmitter shall determine the amplitude of the Primary Coil current with a resolution of 5 mA or better. Finally, Table 74 and Table 75 provide the values of several parameters, which are used in the PID algorithm.

Figure 98. Electrical diagram (outline) of Power Transmitter design A25

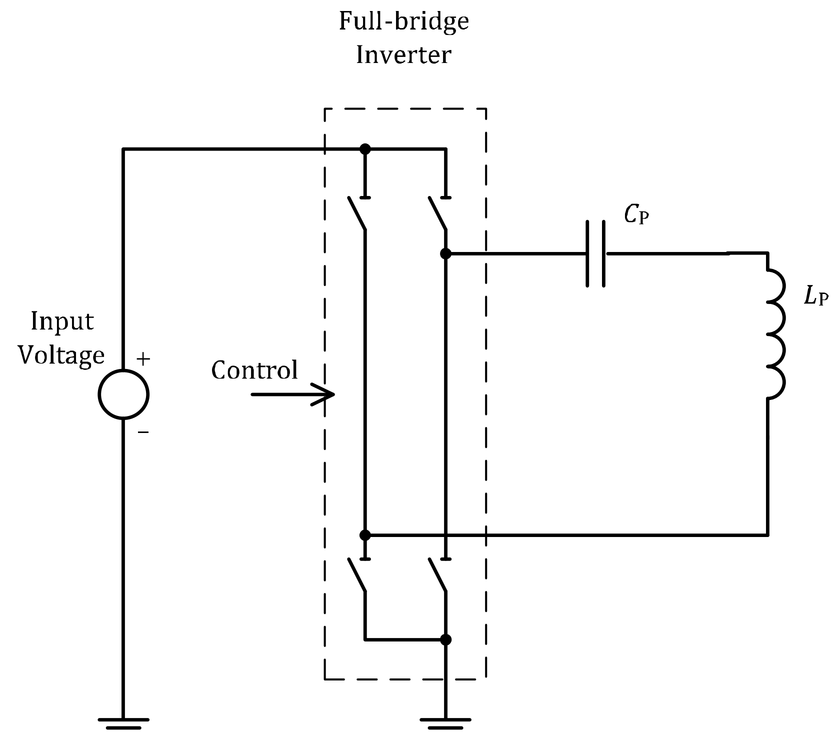


Table 74: PID parameters for Operating Frequency control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	1	mA^{-1}
Integral gain	K_i	0	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	N.A.	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_v	1.0	Hz

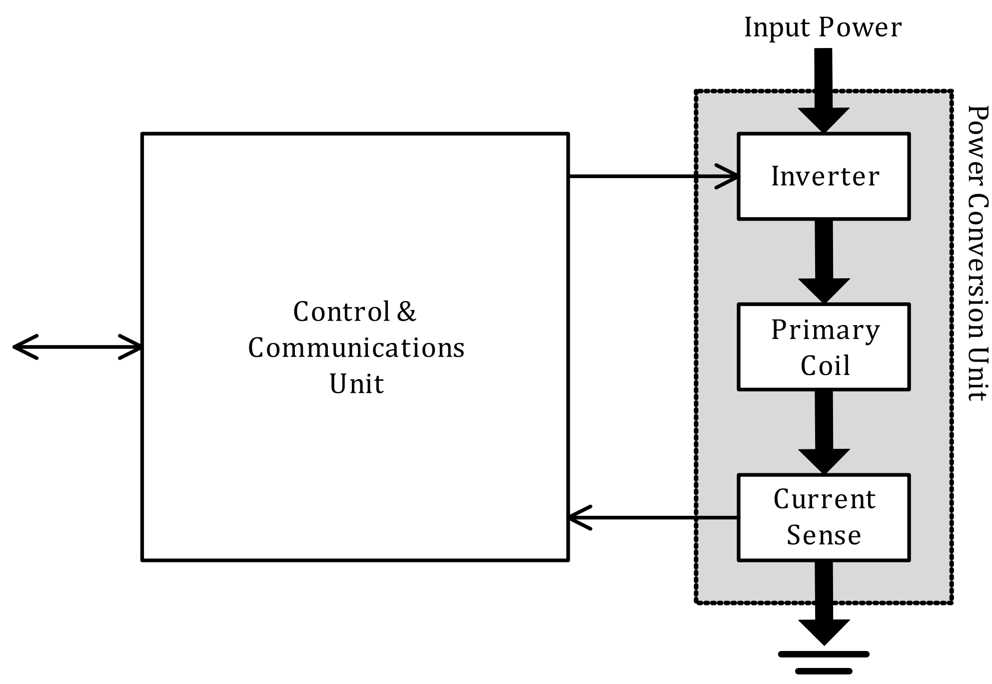
Table 75: PID parameters for duty cycle control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	1	mA^{-1}
Integral gain	K_i	0	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	N.A.	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_v	-0.1	°

29 Power Transmitter design A26

Figure 99 illustrates the functional block diagram of Power Transmitter design A26, which consists of two major functional units, namely a Power Conversion Unit and a Communications and Control Unit.

Figure 99. Functional block diagram of Power Transmitter design A26



The Power Conversion Unit on the right-hand side of Figure 99 comprises the analog parts of the design. The inverter converts the DC input to an AC waveform that drives a resonant circuit, which consists of the Primary Coil plus a series capacitor. Finally, the current sense monitors the Primary Coil current.

The Communications and Control Unit on the left-hand side of Figure 99 comprises the digital logic part of the design. This unit receives and decodes messages from the Power Receiver, executes the relevant power control algorithms and protocols, and drives the frequency of the AC waveform to control the power transfer. The Communications and Control Unit also interfaces with other subsystems of the Power Transmitter Product, e.g. for user interface purposes.

29.1 Mechanical details

Power Transmitter design A26 includes a single Primary Coil as defined in Section 29.1.1, *Primary Coil*, Shielding as defined in Section 29.1.2, *Shielding*, an Interface Surface as defined in Section 29.1.3, *Interface Surface*, and an alignment aid as defined in Section 29.1.4, *Alignment aid*.

29.1.1 Primary Coil

The Primary Coil is of the wire-wound type, and consists of litz wire having 105 strands of no. 40 AWG (0.08 mm diameter), or equivalent. As shown in Figure 100, the Primary Coil has a triangular shape and consists of a single layer. Table 76 lists the dimensions of the Primary Coil.

Figure 100. Primary Coil of Power Transmitter design A26

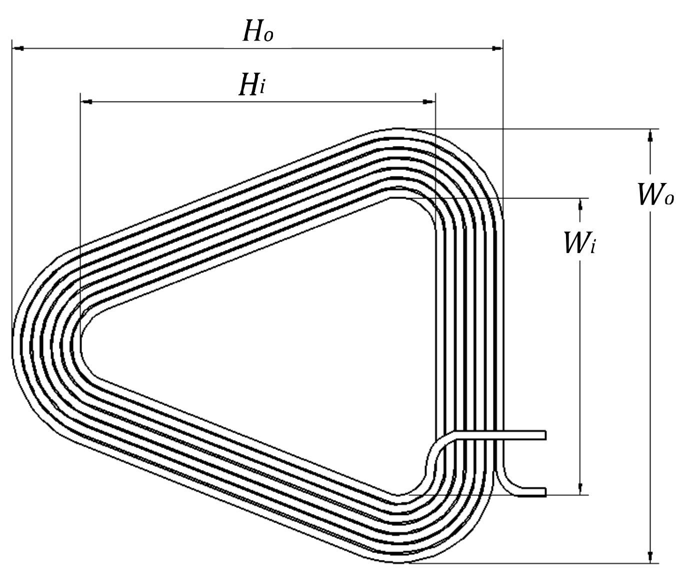


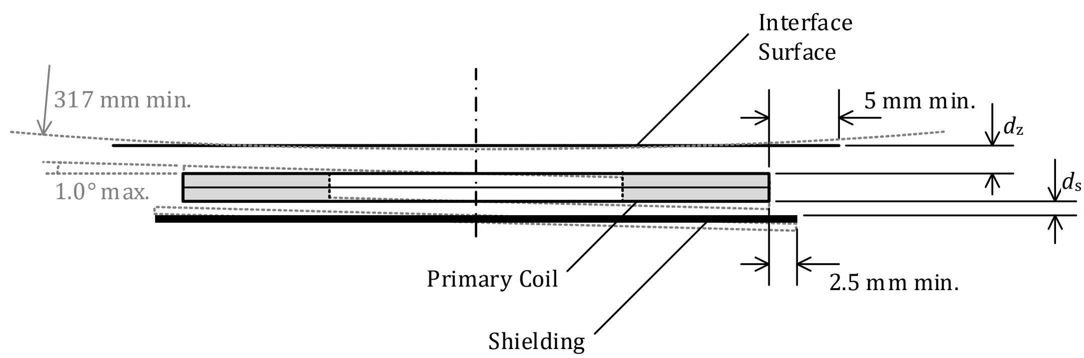
Table 76: Primary Coil parameters of Power Transmitter design A26

Parameter	Symbol	Value
Outer height	H_o	$52^{\pm 0.5}$ mm
Inner height	H_i	$34^{\pm 0.5}$ mm
Outer width	W_o	$46^{\pm 0.5}$ mm
Inner width	W_i	$28^{\pm 0.5}$ mm
Thickness	d_c	$1.1^{+0.3}$ mm
Number of turns per layer	N	8
Number of layers	–	1

29.1.2 Shielding

As shown in Figure 101, Shielding protects the Power Transmitter Product from the magnetic field that is generated in the Primary Coil. The Shielding should be Ni-Zn or Mn-Zn ferrite and should be at least 0.7 mm thick. The Shielding extends to at least 2.5 mm beyond the outer diameter of the Primary Coil, and is placed below the Primary Coil at a distance of at most d_s = 1.0 mm.

Figure 101. Primary Coil assembly of Power Transmitter design A26



29.1.3 Interface Surface

As shown in Figure 101, the distance from the Primary Coil to the Interface Surface of the Power Transmitter Product is $d_Z = 2^{+0.5}_{-0.5}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Power Transmitter Product extends at least 5 mm beyond the outer diameter of the Primary Coil.

NOTE: This Primary-Coil-to-Interface-Surface distance implies that the tilt angle between the Primary Coil and a flat Interface Surface is at most 1.0°. Alternatively, in case of a non-flat Interface Surface, this Primary-Coil-to-Interface-Surface distance implies a radius of curvature of the Interface Surface of at least 317 mm, centered on the Primary Coil. See Figure 101.

29.1.4 Alignment aid

The user manual of the Power Transmitter Product containing a type A26 Power Transmitter shall have information about the location of its Active Area(s).

For the best user experience, it is recommended to employ at least one user feedback mechanism during Power Receiver Product positioning to help alignment.

Examples of Power Transmitter Product alignment aids to assist the user positioning of the Power Receiver Product include:

- A marked Interface Surface to indicate the location of the Active Area(s)—e.g. by means of the logo or other visual marking, lighting, etc.
- A visual feedback display—e.g. by means of illuminating an LED to indicate proper alignment.
- An audible or haptic feedback mechanism.

29.1.5 Inter coil separation

If the Power Transmitter Product contains multiple type A26 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall not overlap.

29.2 Electrical details

As shown in Figure 102, Power Transmitter design A26 uses a full-bridge inverter to drive the Primary Coil and a series capacitance. Within the Operating Frequency range specified below, the assembly of Primary Coil and Shielding has a self-inductance $L_{\mathrm{P}} = 6.3^{\pm 10\%}$ μH. The value of the series capacitance is $C_{\mathrm{P}} = 0.4^{\pm 5\%}$ μF. The input voltage to the full-bridge inverter is $5^{\pm 5\%}$ V.

NOTE: Near resonance, the voltage developed across the series capacitance can reach levels exceeding 100 V pk-pk.

Power Transmitter design A26 uses the Operating Frequency and duty cycle of the Power Signal in order to control the amount of power that is transferred. For this purpose, the Operating Frequency range of the full-bridge inverter is f_{op} = 110...205 kHz with a duty cycle of 50%; and its duty cycle range is 10…50% at an Operating Frequency of 205 kHz. A higher Operating Frequency or lower duty cycle result in the transfer of a lower amount of power. In order to achieve a sufficiently accurate adjustment of the amount of power that is transferred, a type A26 Power Transmitter shall control the Operating Frequency with a resolution of

- $0.01 \times f_{\mathrm{op}} - 0.7$ kHz, for f_{op} in the 110…175 kHz range;
- $0.015 \times f_{\mathrm{op}} - 1.58$ kHz, for f_{op} in the 175…205 kHz range;

or better. In addition, a type A26 Power Transmitter shall control the duty cycle of the Power Signal with a resolution of 0.1% or better.

When a type A26 Power Transmitter first applies a Power Signal (Digital Ping; see the *Qi Specification, Communications Protocol*), it shall use an initial Operating Frequency of 175 kHz (and a duty cycle of 50%).

Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Qi Specification, Power Delivery*. The controlled variable $v^{(i)}$ introduced in the definition of that algorithm represents the Operating Frequency or the duty cycle. In order to guarantee sufficiently accurate power control, a type A16 Power Transmitter shall determine the amplitude of the Primary Cell current—which is equal to the Primary Coil current—with a resolution of 7 mA or better. Finally, Table 77, Table 78, and Table 79 provide the values of several parameters, which are used in the PID algorithm.

Figure 102. Electrical diagram (outline) of Power Transmitter design A26

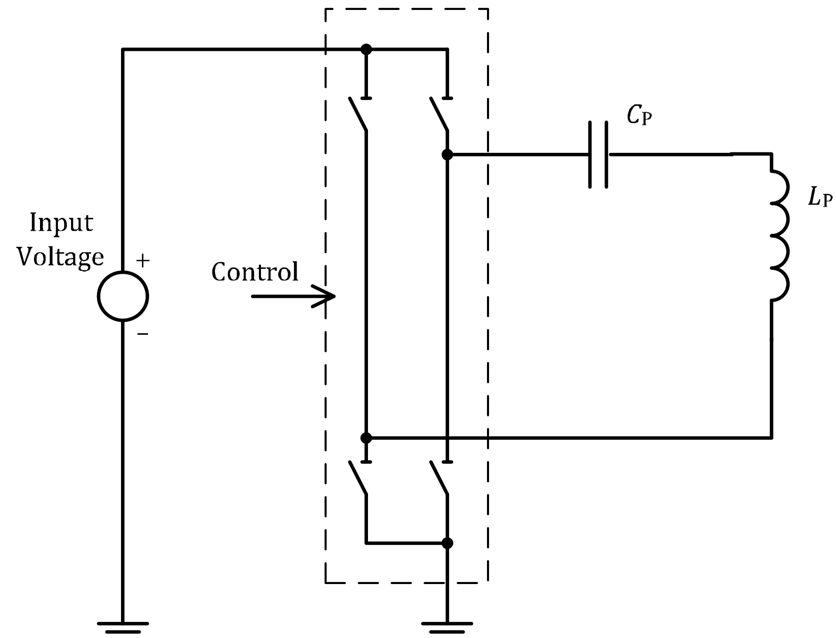


Table 77: PID parameters for Operating Frequency control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	10	mA^{-1}
Integral gain	K_i	0.05	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	3,000	N.A.
PID output limit	M_{PID}	20,000	N.A.

Table 78: Operating Frequency dependent scaling factor

Frequency Range [kHz]	Scaling Factor S_v [Hz]
110…140	1.5
140…160	2
160…180	3
180…205	5

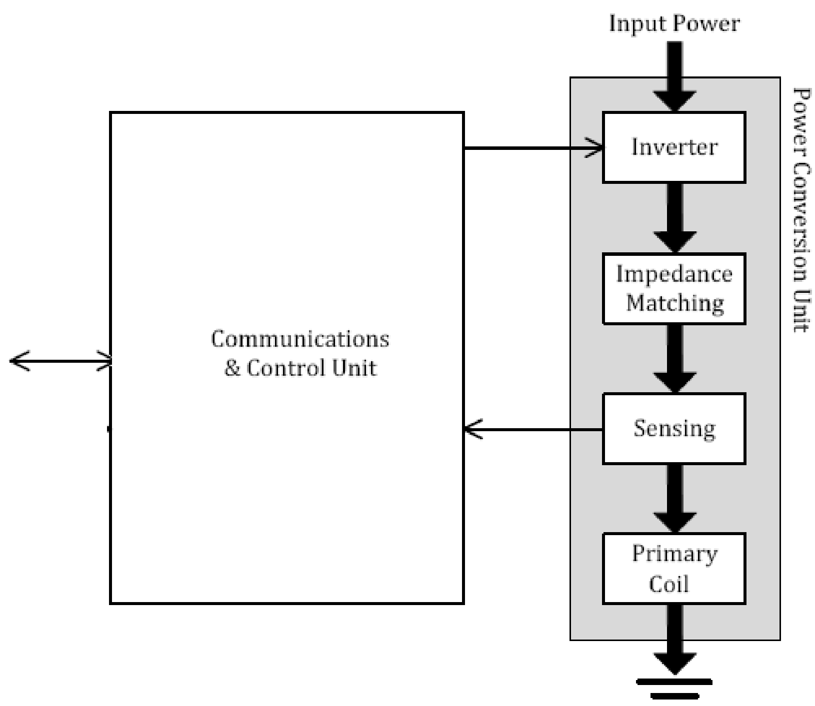
Table 79: PID parameters for duty cycle control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	10	mA^{-1}
Integral gain	K_i	0.05	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	3,000	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_v	–0.01	%

30 Power Transmitter design A27

Figure 103 illustrates the functional block diagram of Power Transmitter design A27, which consists of two major functional units, namely a Power Conversion Unit and a Communications and Control Unit.

Figure 103. Functional block diagram of Power Transmitter design A27



The Power Conversion Unit on the right-hand side of Figure 103 comprises the analog parts of the design. The impedance matching network forms a resonant circuit with the Primary Coil. The sensing circuits monitor (amongst others) the Primary Coil current and voltage, and the inverter converts the DC input to an AC waveform that drives the Primary Coil.

The Communications and Control Unit on the left-hand side of Figure 103 comprises the digital logic part of the design. This unit receives and decodes messages from the Power Receiver, executes the relevant power control algorithms and protocols, and drives the inverter to control the amount of power provided to the Power Receiver. The Communications and Control Unit also interfaces with the other subsystems of the Power Transmitter Product, e.g. for user interface purposes.

30.1 Mechanical details

Power Transmitter design A27 includes a Primary Coil array as defined in Section 30.1.1, *Primary Coil*, Shielding as defined in Section 30.1.2, *Shielding*, and an Interface Surface as defined in Section 30.1.3, *Interface Surface*.

30.1.1 Primary Coil

The Primary Coil is of the wire-wound type, and consists of 17 AWG (1.15 mm diameter) type 2 litz wire having 105 strands of no. 40 AWG (0.08 mm diameter), or equivalent. As shown in Figure 104, the Primary Coil has a circular shape and consists of one layer. Table 80 lists the dimensions of the Primary Coil.

Figure 104. Primary Coil of Power Transmitter design A27

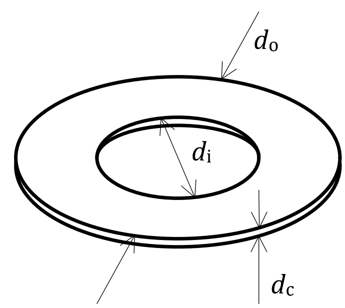


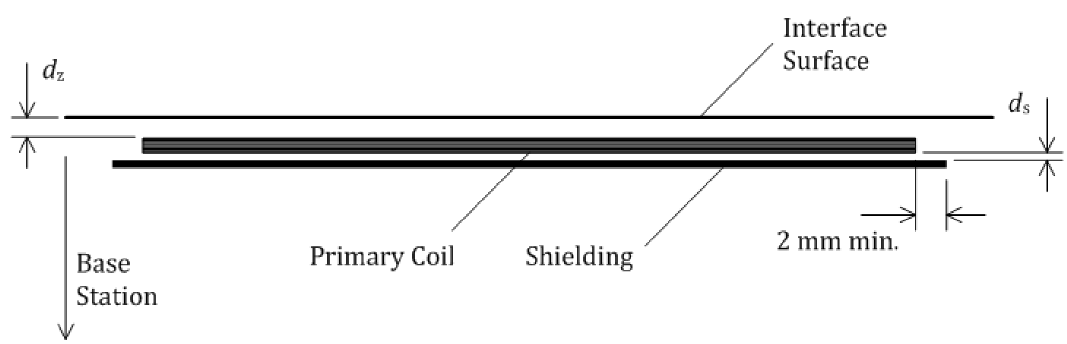
Table 80: Primary Coil parameters of Power Transmitter design A27

Parameter	Symbol	Value
Outer diameter	d_o	$60.0^{+3.0}_{-0.0}$ mm
Inner diameter	d_i	$20.5^{\pm 0.5}$ mm
Number of turns	N	18
Thickness	d_c	$1.2^{\pm 0.2}$ mm
Number of layers	-	1

30.1.2 Shielding

As shown in Figure 105, Transmitter design A27 employs Shielding to protect the Power Transmitter Product from the magnetic field that is generated in the Primary Coil. The Shielding should be Ni-Zn or Mn-Zn ferrite and should be at least 0.5 mm thick. The Shielding extends to at least 2 mm beyond the outer edges of the Primary Coil array, and is placed at a distance of at most $d_s = 0.5$ mm below the Primary Coil array.

Figure 105. Primary Coil array assembly of Power Transmitter design A27



30.1.3 Interface Surface

As shown in Figure 105, the distance from the Primary Coil to the Interface Surface of the Power Transmitter Product is $d_Z = 2^{+0.5}_{-0.5}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface extends at least 5 mm beyond the outer edges of the Primary Coil array.

30.1.4 Alignment aid

The user manual of the Power Transmitter Product containing a type A27 Power Transmitter shall have information about the location of its Active Area(s).

For the best user experience, it is recommended to employ at least one user feedback mechanism during Power Receiver Product positioning to help alignment.

Examples of Power Transmitter Product alignment aids to assist the user positioning of the Power Receiver Product include:

- A marked Interface Surface to indicate the location of the Active Area(s)—e.g. by means of the logo or other visual marking, lighting, etc.
- A visual feedback display—e.g. by means of illuminating an LED to indicate proper alignment.
- An audible or haptic feedback mechanism.

30.1.5 Inter coil separation

If the Power Transmitter Product contains multiple type A27 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall not overlap.

30.2 Electrical details

As shown in Figure 106, Power Transmitter design A27 uses a full-bridge inverter to drive the resonant network including filter inductor, a Primary Coil with a series and parallel capacitance. Within the Operating Frequency range f_{op} = 110...120 kHz, the assembly of Primary Coil and Shielding has an inductance of $24.0^{\pm 10\%}$ μH. The inductance and capacitances in the impedance matching circuit are, respectively, $L_m = 8.2^{\pm 20\%}$ μH, $C_{ser} = 100^{\pm 5\%}$ nF and $C_{par} = 100^{\pm 5\%}$ nF. The input voltage to the full-bridge inverter is $12^{\pm 5\%}$ V.

NOTE: Near resonance, the voltage developed across the series capacitance can reach levels exceeding 100V pk-pk.

Power Transmitter design A27 uses the phase difference between the control signals to two halves of the full-bridge inverter to control the amount of power that is transferred, see Figure 107. For this purpose, the range of the phase difference α is 0…180°—with a larger phase difference resulting in a lower power transfer. In order to achieve a sufficient accurate adjustment of the power that is transferred, a type A27 Power Transmitter shall be able to control the phase difference with a resolution of 0.42° or better. When a type A27 Power Transmitter first applies a Power Signal (Digital Ping; see the *Qi Specification, Communications Protocol*), it shall use an initial phase difference of 120°.

Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Qi Specification, Power Delivery*. The controlled variable $v^{(j)}$ introduced in the definition of that algorithm represents the phase difference between the two halves of the full-bridge inverter. In order to guarantee sufficiently accurate power control, a type A27 Transmitter shall determine the amplitude of the current into the Primary Coil with a resolution of 7 mA or better. Finally, Table 81 provides the values of several parameters, which are used in the PID algorithm.

Figure 106. Electrical diagram (outline) of Power Transmitter design A27

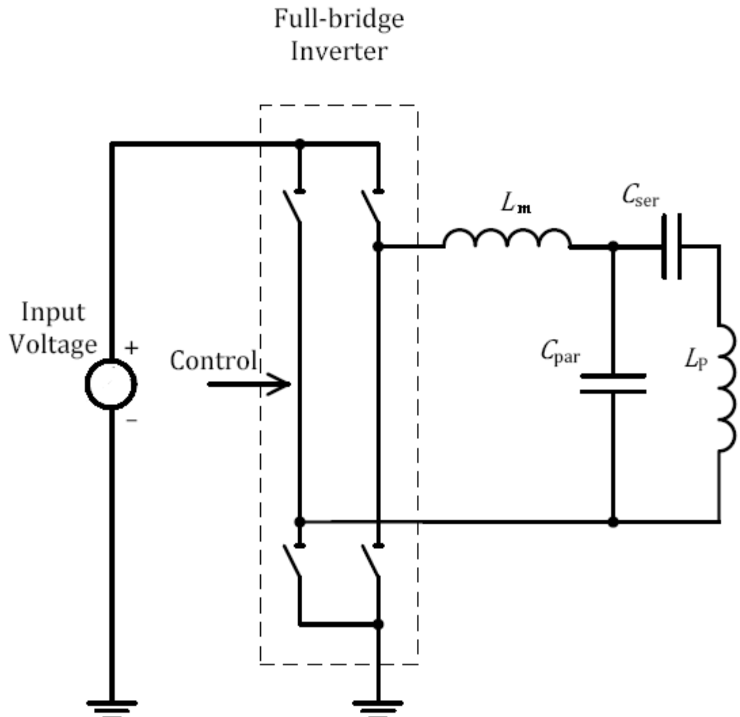


Figure 107. Control signals to the inverter

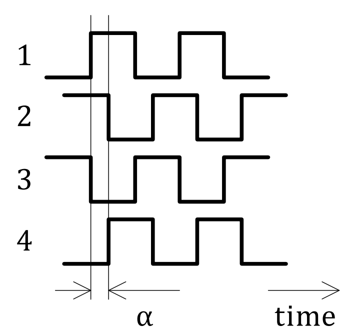


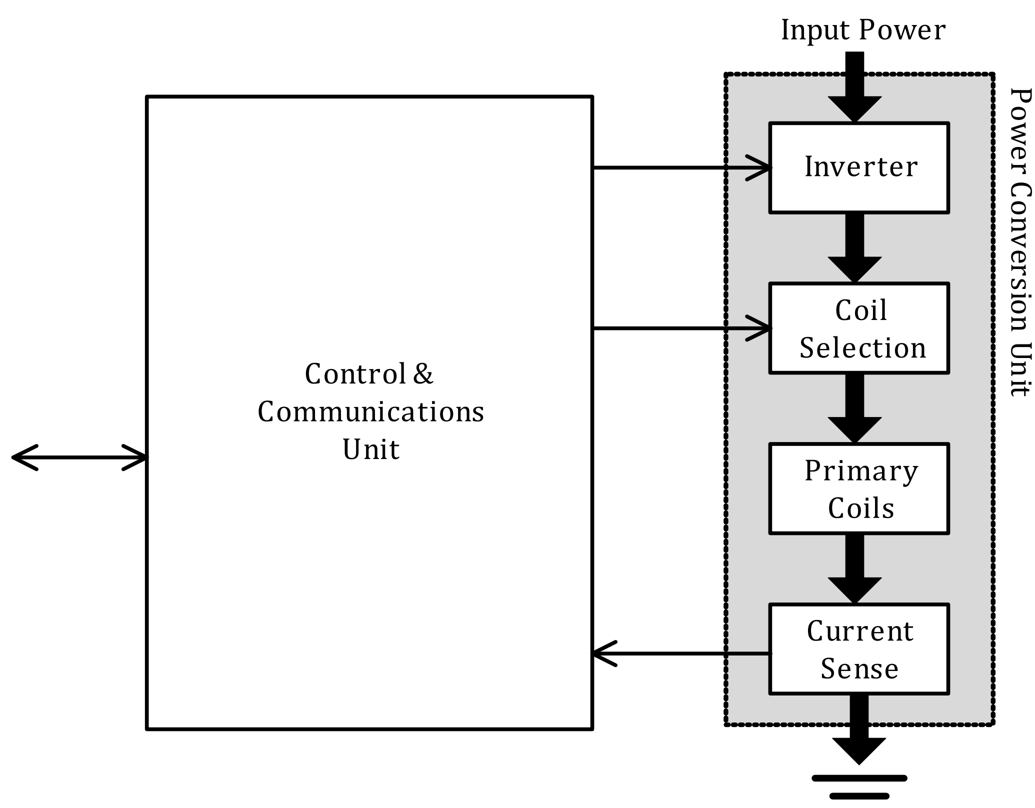
Table 81: Control parameters for power control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	1	mA^{-1}
Integral gain	K_i	0	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	N.A.	N.A.
PID output limit	M_{PID}	2,000	N.A.
Scaling factor	S_v	0.01	°

31 Power Transmitter design A28

Figure 108 illustrates the functional block diagram of this Power Transmitter design A28, which consists of two major functional units, namely a Power Conversion Unit and a Communications and Control Unit.

Figure 108. Functional block diagram of Power Transmitter design A28



The Power Conversion Unit on the right-hand side of Figure 108 comprises the analog parts of the design. The inverter converts the DC input to an AC waveform that drives a resonant circuit, which consists of the selected Primary Coil plus a series capacitor. The selected Primary Coil is one from three partially overlapping Primary Coils, as appropriate for the position of the Power Receiver relative to the Primary Coils. Selection of the appropriate Primary Coil proceeds by the Power Transmitter attempting to establish communication with a Power Receiver using anyone of the Primary Coils. Finally, the current sense monitors the Primary Coil current.

The Communications and Control Unit on the left-hand side of Figure 108 comprises both analog circuit and digital logic. This unit receives and decodes messages from the Power Receiver, configures the Coil Selection block to connect the appropriate Primary Coil, executes the relevant power control algorithms and protocols, and drives the frequency of the AC waveform to control the power transfer. The Communications and Control Unit also interfaces with other subsystems of the Power Transmitter Product, e.g. for user interface purposes.

31.1 Mechanical details

Power Transmitter design A28 includes one or more Primary Coils as defined in Section 31.1.1, *Primary Coil*, Shielding as defined in Section 31.1.2, *Shielding*, and Interface Surface as defined in Section 31.1.3, *Interface Surface*.

31.1.1 Primary Coil

The Primary Coil is of the wire-wound type, and consists of no. 17 AWG (1.15 mm diameter) type 2 litz wire having 105 strands of no. 40 AWG (0.08 mm diameter), or equivalent. As shown in Figure 109, the Primary Coil has a rectangular shape and consists of a single layer. Table 82 lists the dimensions of the Primary Coil.

Figure 109. Primary Coil of Power Transmitter design A28

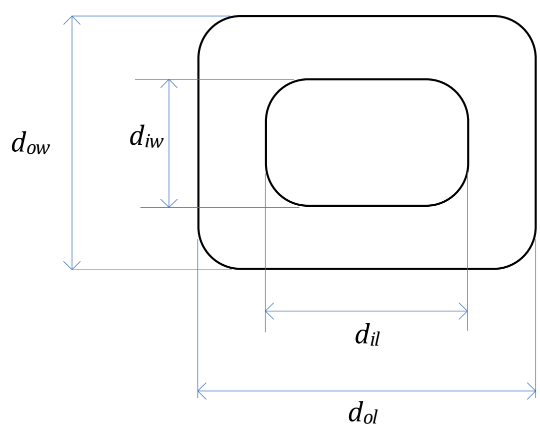
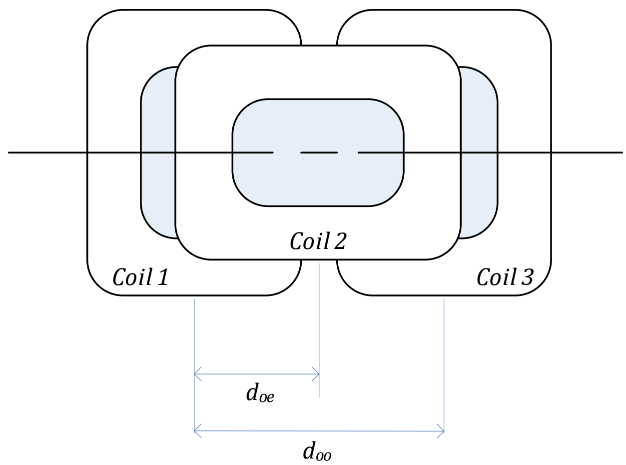


Table 82: Primary Coil parameters of Power Transmitter design A28

Parameter	Symbol	Value
Outer length	d_{ol}	$47.5^{\pm 1.0}$ mm
Inner length	d_{il}	$28.0^{\pm 1.0}$ mm
Outer width	d_{ow}	$39.5^{\pm 1.0}$ mm
Inner width	d_{iw}	$19.5^{\pm 1.0}$ mm
Thickness	d_c	$1.5^{\pm 0.5}$ mm
Number of turns per layer	N	9
Number of layers	–	1

Power Transmitter design A28 contains one or more Primary Coils. Power Transmitter design A28 contains at least one Primary Coil. Odd numbered coils are placed alongside each other with a displacement of $d_{oo} = 49.2^{\pm 4}$ mm between their centers. Even numbered coils are placed orthogonal to the odd numbered coils with a displacement of $d_{oe} = 24.6^{\pm 2}$ mm between their centers. See Figure 110.

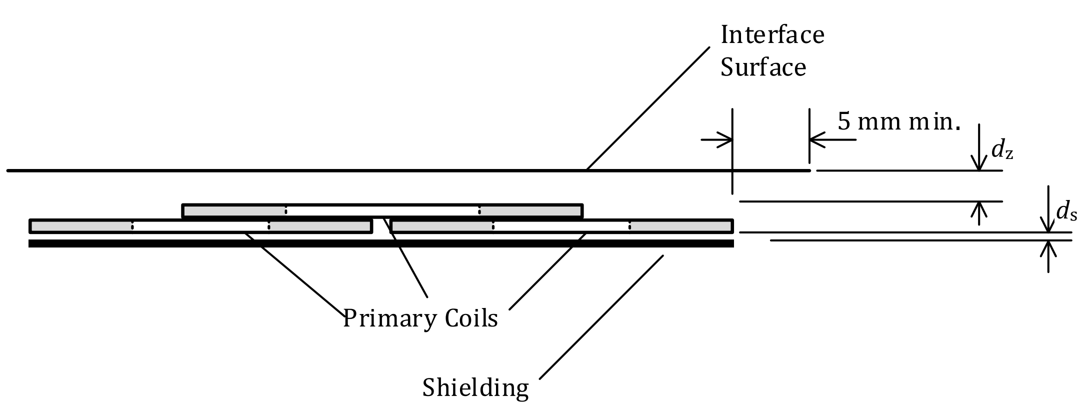
Figure 110. Primary Coils of Power Transmitter design A28



31.1.2 Shielding

As shown in Figure 111, Shielding protects the Power Transmitter Product from the magnetic field that is generated in the Primary Coils. The Shielding should be Ni-Zn or Mn-Zn ferrite and should be at least 0.5 mm thick. The Shielding extends to at least the outer dimensions of the Primary Coils, and is placed below the Primary Coils at a distance of at most $d_s = 1.0$ mm.

Figure 111. Primary Coil assembly of Power Transmitter design A28



31.1.3 Interface Surface

As shown in Figure 111, the distance from the top face of the even-numbered Primary Coil to the Interface Surface of the Power Transmitter Product is $d_Z = 2^{+0.5}_{-0.25}$ mm, across the top face of the Primary Coil. The odd-numbered Primary Coils are mounted flush to the bottom face of the even-numbered Primary Coils. In addition, the Interface Surface of the Power Transmitter Product extends at least 5 mm beyond the outer dimensions of the Primary Coils.

31.1.4 Inter coil separation

If the Power Transmitter Product contains multiple type A28 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall not overlap.

31.2 Electrical details

As shown in Figure 112, Power Transmitter design A28 uses a full-bridge inverter to drive an individual Primary Coil and a series capacitance. Within the Operating Frequency range specified below, the assembly of Primary Coils and Shielding has a self-inductance $6.4^{\pm 10\%}$ μH for coils closest to the Interface Surface and inductance $6.9^{\pm 10\%}$ μH for coils furthest from the Interface Surface. The value of the series capacitance is $400^{\pm 5\%}$ nF for coils closest to the Interface Surface and $357^{\pm 5\%}$ nF for coils furthest from the Interface Surface. The input voltage to the full-bridge inverter is $5^{\pm 5\%}$ V.

NOTE: Near resonance, the voltage developed across the series capacitance can reach levels exceeding 100 V pk-pk.

Power Transmitter design A28 uses the Operating Frequency and duty cycle of the Power Signal in order to control the amount of power that is transferred. For this purpose, the Operating Frequency range of the full-bridge inverter is f_{op} = 115...205 kHz with a duty cycle of 50%; and its duty cycle range is 10…50% at an Operating Frequency of 205 kHz. A higher Operating Frequency or lower duty cycle result in the transfer of a lower amount of power. In order to achieve a sufficiently accurate adjustment of the amount of power that is transferred, a type A28 Power Transmitter shall control the Operating Frequency with a resolution of

- $0.01 \times f_{op} - 0.7$ kHz, for f_{op} in the 115…175 kHz range;
- $0.015 \times f_{op} - 1.58$ kHz, for f_{op} in the 175…205 kHz range;

or better. In addition, a type A28 Power Transmitter shall control the duty cycle of the Power Signal with a resolution of 0.1% or better.

When a type A28 Power Transmitter first applies a Power Signal (Digital Ping; see the *Qi Specification, Communications Protocol*), it shall use an initial Operating Frequency of 175 kHz (and a duty cycle of 50%).

Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Qi Specification, Power Delivery*. The controlled variable $v^{(i)}$ introduced in the definition of that algorithm represents the Operating Frequency or the duty cycle. In order to guarantee sufficiently accurate power control, a type A28 Power Transmitter shall determine the amplitude of the Primary Cell current—which is equal to the Primary Coil current—with a resolution of 7 mA or better. Finally, Table 83, Table 84, and Table 85 provide the values of several parameters, which are used in the PID algorithm.

Figure 112. Electrical diagram (outline) of Power Transmitter design A28

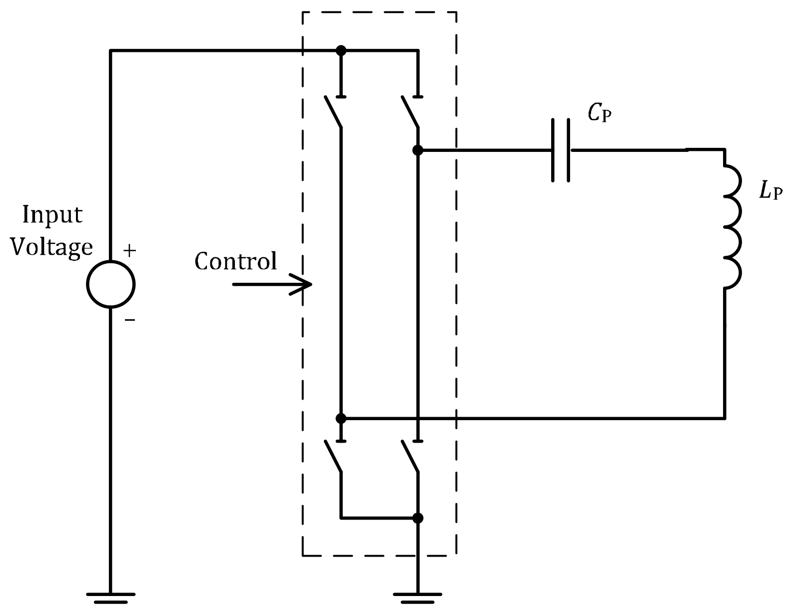


Table 83: PID parameters for Operating Frequency control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	10	mA^{-1}
Integral gain	K_i	0.05	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	3,000	N.A.
PID output limit	M_{PID}	20,000	N.A.

Table 84: Operating Frequency dependent scaling factor

Frequency Range [kHz]	Scaling Factor S_v [Hz]
115…140	1.5
140…160	2
160…180	3
180…205	5

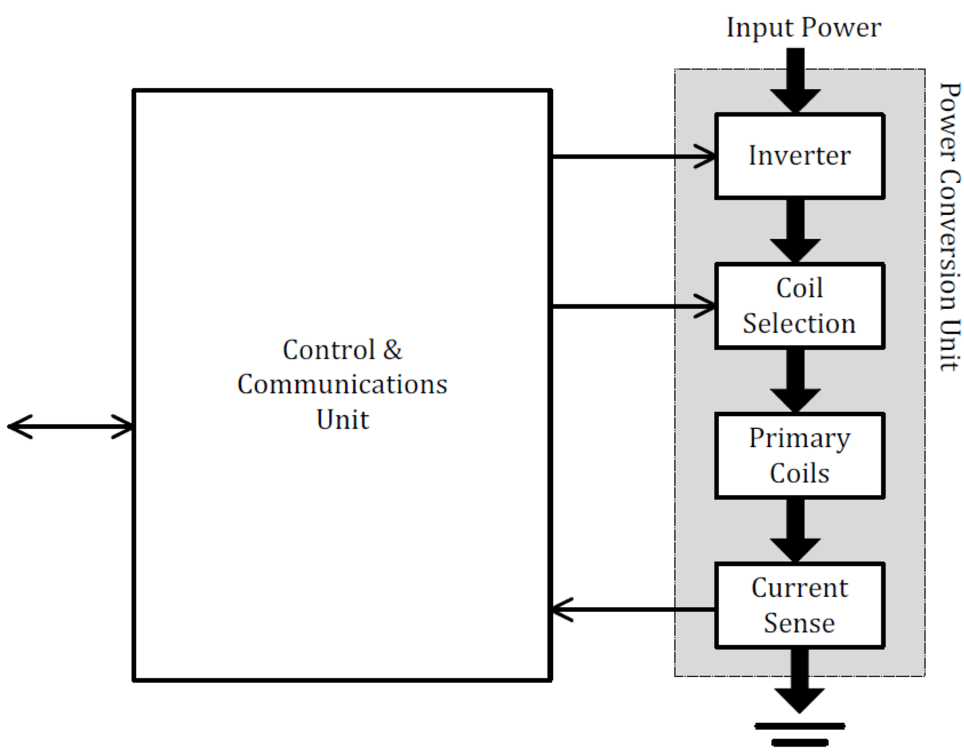
Table 85: PID parameters for duty cycle control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	10	mA^{-1}
Integral gain	K_i	0.05	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	3,000	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_v	–0.01	%

32 Power Transmitter design A28a

Figure 113 illustrates the functional block diagram of this Power Transmitter design A28a, which consists of two major functional units, namely a Power Conversion Unit and a Communications and Control Unit.

Figure 113. Functional block diagram of Power Transmitter design A28a



The Power Conversion Unit on the right-hand side of Figure 113 comprises the analog parts of the design. The inverter converts the DC input to an AC waveform that drives a resonant circuit, which consists of the selected Primary Coil plus a series capacitor. The selected Primary Coil is one from three partially overlapping Primary Coils, as appropriate for the position of the Power Receiver relative to the Primary Coils. Selection of the appropriate Primary Coil proceeds by the Power Transmitter attempting to establish communication with a Power Receiver using anyone of the Primary Coils. Finally, the current sense monitors the Primary Coil current.

The Communications and Control Unit on the left-hand side of Figure 113 comprises both analog circuit and digital logic. This unit receives and decodes messages from the Power Receiver, configures the Coil Selection block to connect the appropriate Primary Coil, executes the relevant power control algorithms and protocols, and drives the frequency of the AC waveform to control the power transfer. The Communications and Control Unit also interfaces with other subsystems of the Power Transmitter Product, e.g. for user interface purposes.

32.1 Mechanical details

Power Transmitter design A28a includes one or more Primary Coils as defined in Section 32.1.1, *Primary Coil*, Shielding as defined in Section 32.1.2, *Shielding*, and Interface Surface as defined in Section 32.1.3, *Interface Surface*.

32.1.1 Primary Coil

The Primary Coil is of the wire-wound type, and consists of no. 17 AWG (1.15 mm diameter) type 2 litz wire having 105 strands of no. 40 AWG (0.08 mm diameter), or equivalent. As shown in Figure 114, the Primary Coil has a rectangular shape and consists of a single layer. Table 86 lists the dimensions of the Primary Coil.

Figure 114. Primary Coil of Power Transmitter design A28a

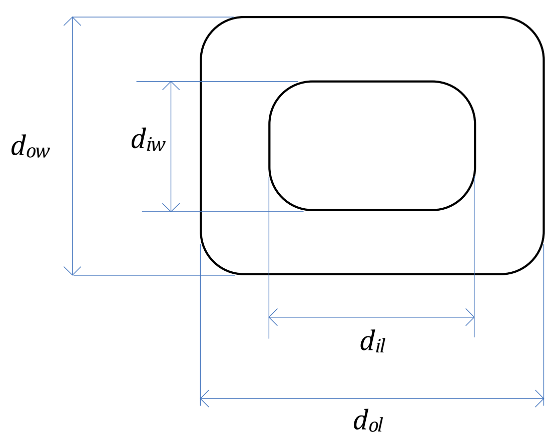
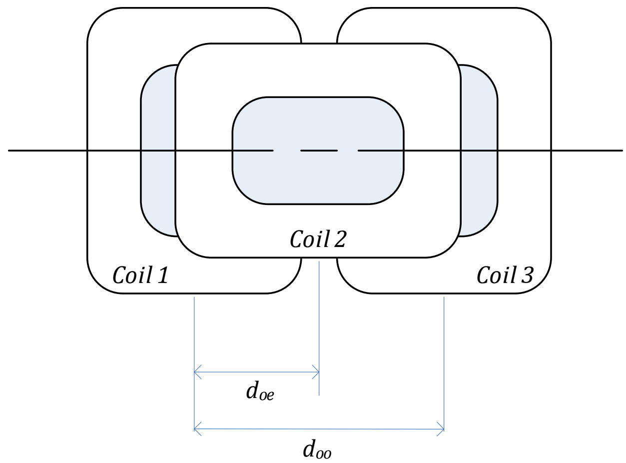


Table 86: Primary Coil parameters of Power Transmitter design A28a

Parameter	Symbol	Value
Outer length	d_{ol}	$47.5^{\pm1.0}$ mm
Inner length	d_{il}	$28.0^{\pm1.0}$ mm
Outer width	d_{ow}	$39.5^{\pm1.0}$ mm
Inner width	d_{iw}	$19.5^{\pm1.0}$ mm
Thickness	d_c	$1.5^{\pm0.5}$ mm
Number of turns per layer	N	9
Number of layers	–	1

Power Transmitter design A28a contains one or more Primary Coils. Power Transmitter design A28a contains at least one Primary Coil. Odd numbered coils are placed alongside each other with a displacement of $d_{oo} = 49.2^{\pm 4}$ mm between their centers. Even numbered coils are placed orthogonal to the odd numbered coils with a displacement of $d_{oe} = 24.6^{\pm 2}$ mm between their centers. See Figure 115.

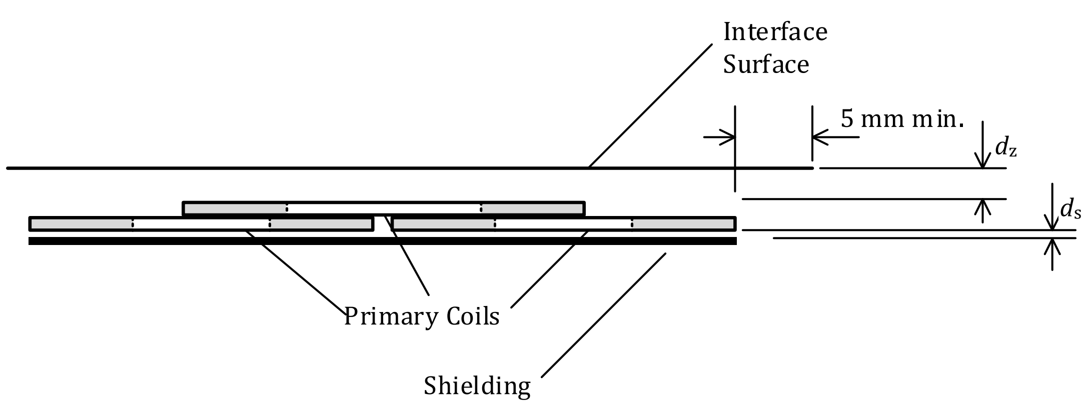
Figure 115. Primary Coils of Power Transmitter design A28a



32.1.2 Shielding

As shown in Figure 116, Shielding protects the Power Transmitter Product from the magnetic field that is generated in the Primary Coils. The Shielding should be Ni-Zn or Mn-Zn ferrite and should be at least 0.5 mm thick. The Shielding extends to at least the outer dimensions of the Primary Coils, and is placed below the Primary Coils at a distance of at most $d_s = 1.0$ mm.

Figure 116. Primary Coil assembly of Power Transmitter design A28a



32.1.3 Interface Surface

As shown in Figure 116, the distance from the top face of the even-numbered Primary Coil to the Interface Surface of the Power Transmitter Product is $d_Z = 2^{+0.5}_{-0.25}$ mm, across the top face of the Primary Coil. The odd-numbered Primary Coils are mounted flush to the bottom face of the even-numbered Primary Coils. If the Power Transmitter contains only one Primary Coil, the distance from its top face to the Interface Surface of the Power Transmitter Product is also $d_Z = 3.5^{+0.5}_{-0.25}$ mm. In addition, the Interface Surface of the Power Transmitter Product extends at least 5 mm beyond the outer dimensions of the Primary Coils.

32.1.4 Inter coil separation

If the Power Transmitter Product contains multiple type A28a Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall not overlap.

32.2 Electrical details

As shown in Figure 117, Power Transmitter design A28a uses a full-bridge inverter to drive an individual Primary Coil and a series capacitance. Within the Operating Frequency range specified below, the assembly of Primary Coils and Shielding has a self-inductance $6.4^{\pm 10\%}$ μH for coils closest to the Interface Surface and inductance $6.9^{\pm 10\%}$ μH for coils furthest from the Interface Surface. The value of the series capacitance is $400^{\pm 5\%}$ nF for coils closest to the Interface Surface and $357^{\pm 5\%}$ nF for coils furthest from the Interface Surface. The input voltage to the full-bridge inverter is $5^{\pm 5\%}$ V.

NOTE: Near resonance, the voltage developed across the series capacitance can reach levels exceeding 100 V pk-pk.

Power Transmitter design A28a uses the Operating Frequency and duty cycle of the Power Signal in order to control the amount of power that is transferred. For this purpose, the Operating Frequency range of the full-bridge inverter is $f_{\text{op}} = 115 \ldots 148$ kHz. At frequencies below 148 kHz, its duty cycle is 50%, and at the frequency of 148 kHz its duty cycle is in the range of 10%…50%. A higher Operating Frequency or lower duty cycle result in the transfer of a lower amount of power.

In order to achieve a sufficiently accurate adjustment of the amount of power that is transferred, a type A28a Power Transmitter shall control the Operating Frequency with a resolution of $0.01 \times f_{\text{op}} - 0.7$ kHz or better for f_{op} in the 115…148 kHz range. In addition, a type A28a Power Transmitter shall control the duty cycle of the Power Signal with a resolution of 0.1% or better.

When a type A28a Power Transmitter first applies a Power Signal (Digital Ping; see the *Qi Specification, Communications Protocol*), it shall use an initial Operating Frequency of 146 kHz and a duty cycle of 50%.

Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Qi Specification, Power Delivery*. The controlled variable $v^{(i)}$ introduced in the definition of that algorithm represents the Operating Frequency or the duty cycle. In order to guarantee sufficiently accurate power control, a type A28a Power Transmitter shall determine the amplitude of the Primary Cell current—which is equal to the Primary Coil current—with a resolution of 7 mA or better. Finally, Table 87, Table 88, and Table 89 provide the values of several parameters, which are used in the PID algorithm.

Figure 117. Electrical diagram (outline) of Power Transmitter design A28a

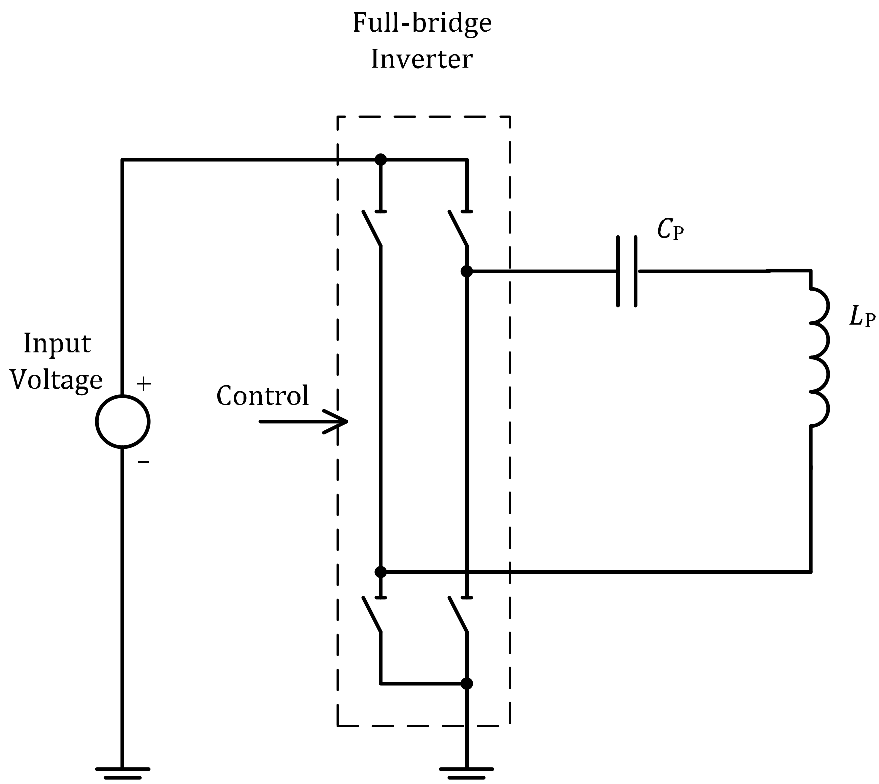


Table 87: PID parameters for Operating Frequency control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	10	mA^{-1}
Integral gain	K_i	0.05	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	3,000	N.A.
PID output limit	M_{PID}	20,000	N.A.

Table 88: Operating Frequency dependent scaling factor

Frequency Range [kHz]	Scaling Factor S_v [Hz]
115…140	1.5
140…148	2

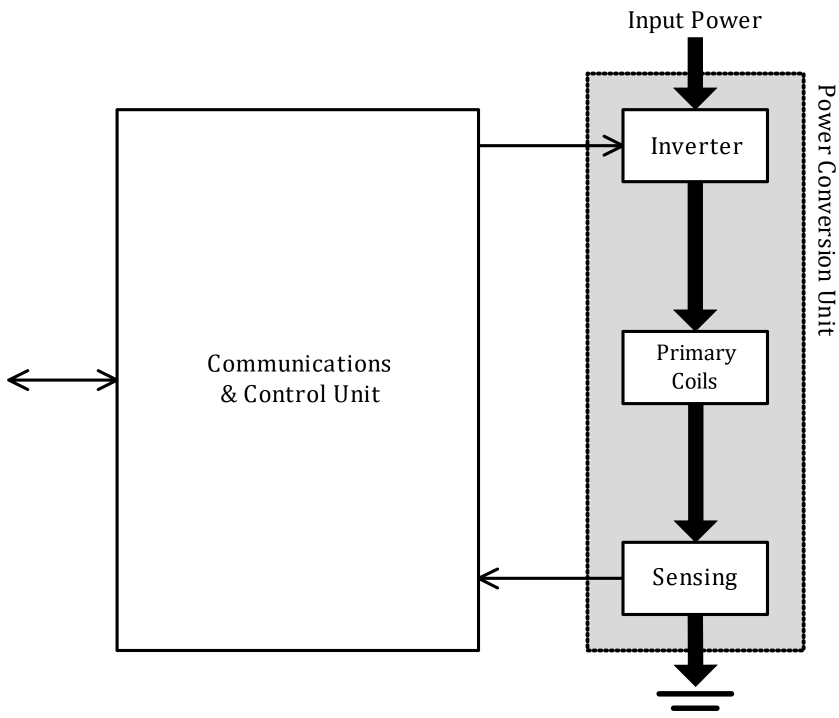
Table 89: PID parameters for duty cycle control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	10	mA^{-1}
Integral gain	K_i	0.05	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	3,000	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_v	–0.01	%

33 Power Transmitter design A29

Figure 118 illustrates the functional block diagram of Power Transmitter Design A29.

Figure 118. Functional block diagram of Power Transmitter A29



The Power Conversion Unit on the right-hand side of Figure 118 comprises the analog parts of the design. The inverter converts the DC input to an AC waveform that drives a resonant circuit, which consists of the Primary Coil plus a series capacitor. Finally, the voltage and current sense monitors the Primary Coil voltage and current.

The Communications and Control Unit on the left-hand side of Figure 118 comprises the digital logic part of the design. The unit receives and decodes messages from the Power Receiver, executes the relevant power control algorithms and protocols, and drives the input power and frequency of the AC waveform to control the power transfer. The Communications and Control Unit also interfaces with other subsystems of the Power Transmitter Product, e.g. for user interface purposes.

33.1 Mechanical details

Power Transmitter design A29 includes a Primary Coil array as defined in Section 33.1.1, *Primary Coil*, Shielding as defined in Section 33.1.2, *Shielding*, and an Interface Surface as defined in Section 33.1.3, *Interface Surface*.

33.1.1 Primary Coil

The Primary Coil is of the wire-wound type, and consists of litz wire with nylon spinning having 180 strands of no. 40 AWG (0.08 mm diameter), or equivalent. As shown in Figure 119 the Primary Coil has a circular shape and consists of two layers with a total of 13 turns. Table 90 lists the dimensions of the Primary Coil.

Figure 119. Primary Coil of Power Transmitter A29

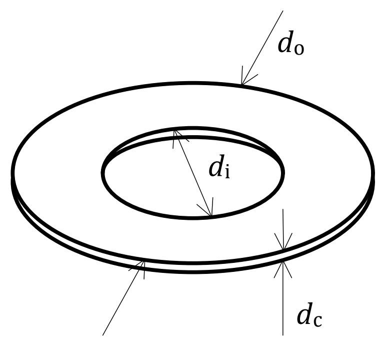


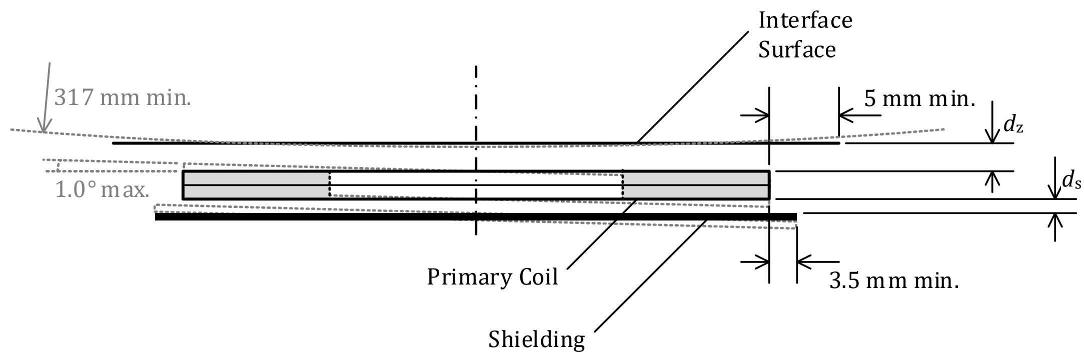
Table 90: Primary Coil parameters of Power Transmitter design A29

Parameter	Symbol	Value
Outer diameter	d_o	$41^{\pm 2}$ mm
Inner diameter	d_i	$21^{\pm 0.5}$ mm
Thickness	d_c	$3^{\pm 0.5}$ mm
Numbers of turns per layer	N	6.5
Number of layers	–	2

33.1.2 Shielding

As shown in Figure 120, Shielding protects the Power Transmitter Product from the magnetic field that is generated in the Primary Coil. The Shielding should be Ni-Zn or Mn-Zn ferrite and should be at least 2.5 mm thick. The Shielding extends to at least 3.5 mm beyond the outer diameter of the Primary Coil, and is placed below the Primary Coil at a distance of at most $d_s = 1.0$ mm.

Figure 120. Primary Coil assembly of Power Transmitter design A29



33.1.3 Interface Surface

As shown in Figure 120, the distance from the Primary Coil to the Interface Surface of the Power Transmitter Product is $d_z = 2.5^{\pm 0.5}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Power Transmitter Product extends at least 5 mm beyond the outer diameter of the Primary Coil.

NOTE: This Primary- Coil-to-Interface-Surface distance implies that the tilt angle between the Primary Coil and a flat Interface Surface is at most 1.0° Alternatively, in case of a non-flat Interface Surface, this Primary-Coil-to-Interface-Surface distance implies a radius of curvature of the Interface Surface of at least 317 mm, centered on the Primary Coil. See Figure 120.

33.1.4 Alignment Aid

The user manual of the Power Transmitter Product containing a type A29 Power Transmitter shall have information about the location of its Active Area(s).

For the best user experience, it is recommended to employ at least one user feedback mechanism during Power Receiver Product positioning to help alignment.

Examples of Power Transmitter Product alignment aids to assist the user positioning of the Power Receiver Product include:

- A marked Interface Surface to indicate the location of the Active Area(s)—e.g. by means of the logo or other visual marking, lighting, etc.
- A visual feedback display—e.g. by means of illuminating an LED to indicate proper alignment.
- An audible or haptic feedback mechanism.

33.1.5 Inter coil separation

If the Power Transmitter Product contains multiple type A29 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall not overlap.

33.2 Electrical Details

As shown in Figure 121, Power Transmitter design A29 uses a full-bridge inverter to drive the resonant network with a primary Coil with a series capacitance. Within the Operating Frequency range specified below, the assembly of Primary Coil and Shielding, has a self-inductance $L_p = 10^{\pm 10\%}$ µH. The value of the total series capacitance $C_p = 247^{\pm 5\%}$ nF, where the individual series capacitances may have any value less than the sum.

NOTE: Near resonance, the voltage developed across the series capacitance can reach levels exceeding 100 V pk-pk.

Power Transmitter design A29 uses the input voltage to the inverter to control the amount of power transferred. For this purpose, the input voltage has a range $1^{\pm 5\%}...12^{\pm 5\%}$ V, with a resolution of 40 mV or better; a higher input voltage results in more power transferred. The Operating Frequency is $130^{\pm 3\%}$ kHz with a duty cycle of 50%.

When a type A29 Power Transmitter first applies a Power Signal (Digital Ping; see the *Qi Specification, Communications Protocol*), it shall use an Operating Frequency of 130 kHz and a recommended input voltage of 4 V.

Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Qi Specification, Power Delivery*. The controlled variable $v^{(i)}$ introduced in the definition of that algorithm represents the input voltage. Finally, Table 91 provides the values of several parameters, which are used in the PID algorithm.

Figure 121. Electrical diagram (outline) Primary Coil of Power Transmitter design A29

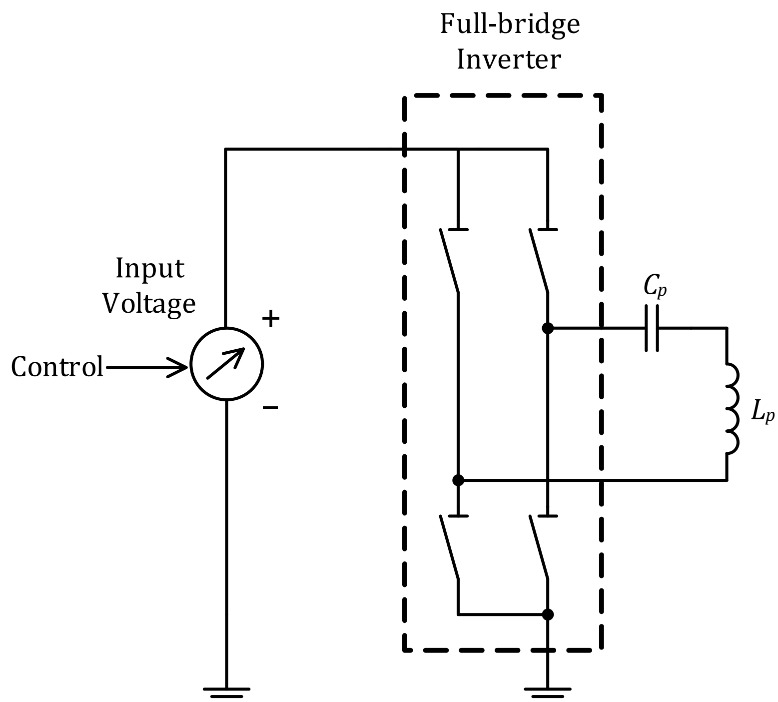


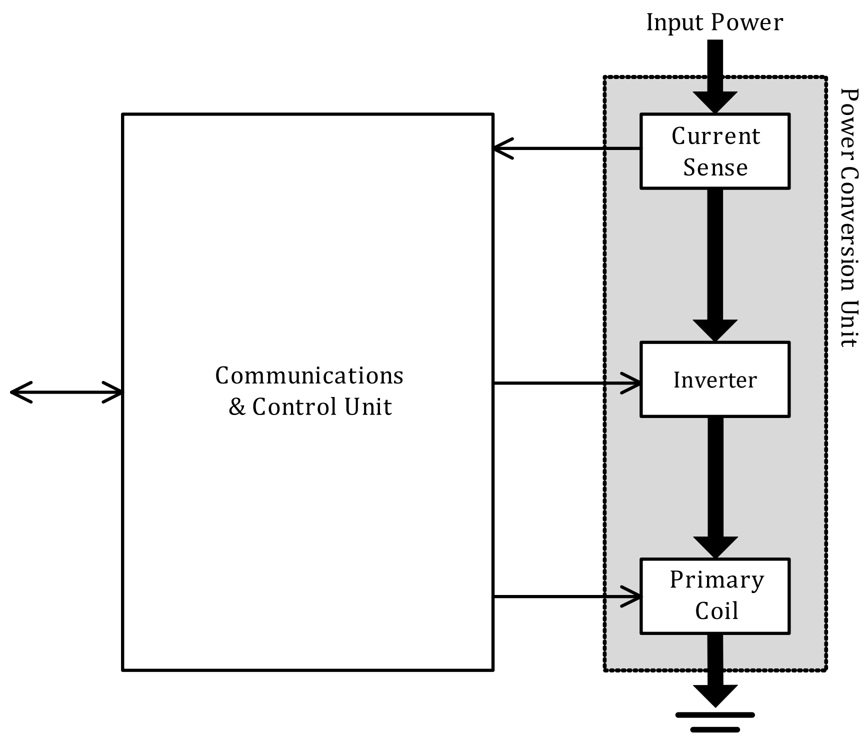
Table 91: PID parameters for voltage control

Parameter	Symbol	Value	Unit
Proportional Gain	K_p	10	mA^{-1}
Integral Gain	K_i	0.05	$mA^{-1}ms^{-1}$
Derivative Gain	K_d	0	$mA^{-1}ms^{-1}$
Integral Term Limit	M_I	3,000	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_v	0.01	%

34 Power Transmitter design A30

Figure 122 illustrates the functional block diagram of the Power Transmitter design A30, which consists of two major functional units, namely a Power Conversion Unit and a Communications and Control Unit.

Figure 122. Functional block diagram of Power Transmitter design A30



The Power Conversion Unit on the right-hand side of Figure 122 comprises the analog parts of the design. The voltage and current sense monitors the System voltage and current. The inverter converts the DC input to an AC waveform that drives a resonant circuit, which consists of the Primary Coil plus a series capacitor.

The Communications and Control Unit on the left-hand side of Figure 122 comprises the digital logic part of the design. The unit receives and decodes messages from the Power Receiver, executes the relevant power control algorithms and protocols, and drives the input power and frequency of the AC waveform to control the power transfer. The Communications and Control Unit also interfaces with other subsystems of the Power Transmitter Product, e.g. for user interface purposes.

34.1 Mechanical details

Power Transmitter design A30 includes one Primary Coil as defined in Section 34.1.1, *Primary Coil*, Shielding as defined in Section 34.1.2, *Shielding*, and an Interface Surface as defined in Section 34.1.3, *Interface Surface*.

34.1.1 Primary Coil

The Primary Coil is of the wire-wound type, and consists of litz wire having 115 strands of 0.08 mm diameter, or equivalent. As shown in Figure 123, a Primary Coil has a racetrack-like shape and consists of a single layer. Table 92 lists the dimensions of a Primary Coil.

Figure 123. Primary Coil of Power Transmitter design A30

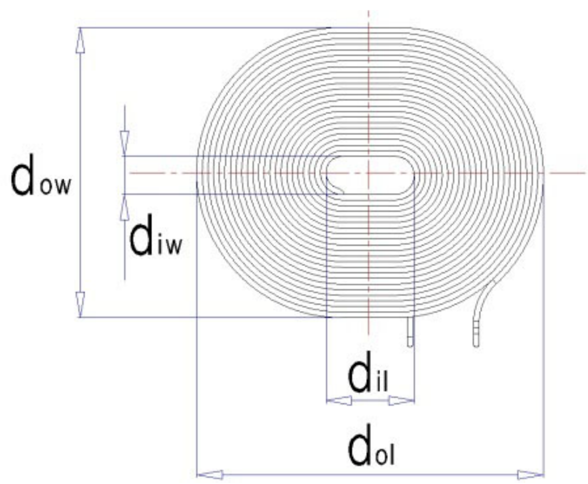


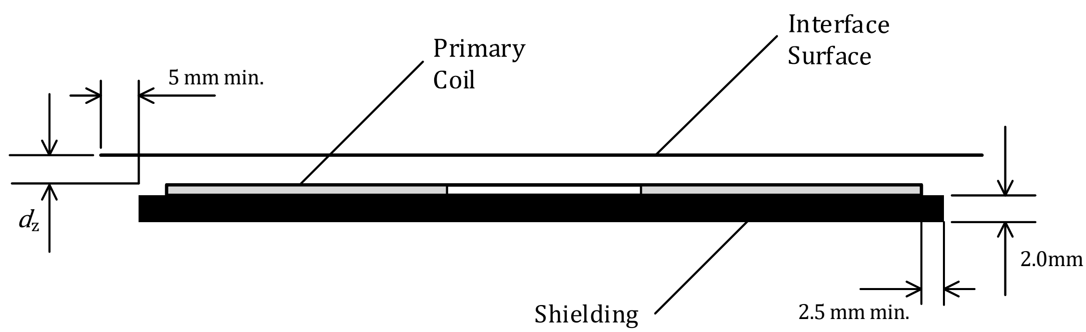
Table 92: Primary Coil parameters of Power Transmitter design A30

Parameter	Symbol	Value
Outer length	d_{ol}	$65.5^{\pm 0.5}$ mm
Inner length	d_{il}	$16.5^{\pm 0.5}$ mm
Outer width	d_{ow}	$57.1^{\pm 0.5}$ mm
Inner width	d_{iw}	$4.5^{\pm 0.5}$ mm
Thickness	d_c	$1.3^{\pm 0.15}$ mm
Number of turns per layer	N	22
Number of layers	–	1

34.1.2 Shielding

As shown in Figure 124, Shielding protects the Power Transmitter Product from the magnetic field that is generated in the Primary Coil. The Shielding should be Ni-Zn or Mn-Zn ferrite and should be at least 2.0 mm thick. The Shielding extends to at least 2.5 mm beyond the outer edge of the Primary Coil.

Figure 124. Primary Coil assembly of Power Transmitter design A30



34.1.3 Interface Surface

As shown in Figure 124, the distance from the Primary Coil to the Interface Surface of the Power Transmitter Product is $d_z = 5^{\pm 1.0}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Power Transmitter Product extends at least 5 mm beyond the outer diameter of the Primary Coil.

34.1.4 Separation between multiple Power transmitters

If the Power Transmitter Product contains multiple type A30 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall not overlap.

34.2 Electrical details

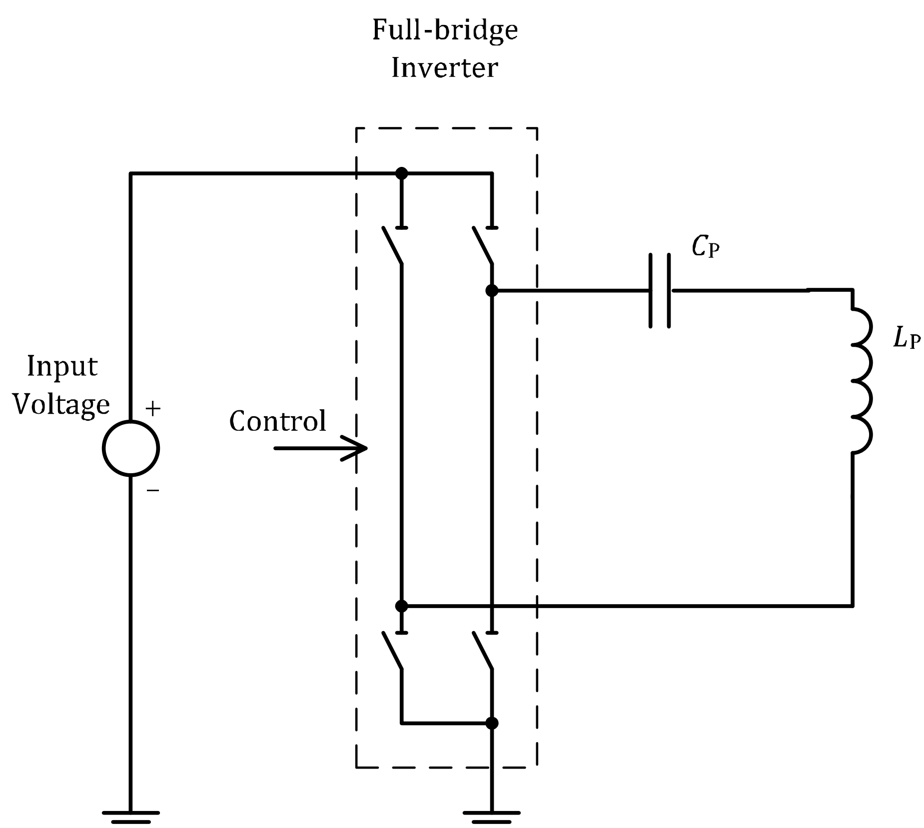
As shown in Figure 125, Power Transmitter design A30 uses a full-bridge inverter to drive the Primary Coil and a series capacitance. Within the Operating Frequency range specified below, the assembly of Primary Coil and Shielding has a self-inductance $L_P = 24.0^{\pm 10\%}$ μH. The input voltage to the full-bridge inverter is $12^{\pm 5\%}$ V. The value of the series capacitance is $C_P = 100^{\pm 10\%}$ nF.

NOTE: Near resonance, the voltage developed across the series capacitance can reach levels up to 100 V pk-pk.

Power Transmitter design A30 uses the Operating Frequency and duty cycle of the Power Signal in order to control the amount of power transferred. For this purpose, The Operating Frequency range is f_{op} = 110...205 kHz, and the duty cycle range of 2…50%.

When a type A30 Power Transmitter first applies a Power Signal (Digital Ping; see the *Qi Specification, Communications Protocol*), the Power Transmitter shall use an Operating Frequency of $130^{\pm 10}$ kHz, and a duty cycle of $25^{\pm 15}$ %. If the Power Transmitter does not to receive a Signal Strength Packet from the Power Receiver, the Power Transmitter shall remove the Power Signal as defined in the *Qi Specification, Communications Protocol*. The Power Transmitter may re-apply the Power Signal multiple times at consecutively higher duty cycle to the full-bridge inverter within the range specified above, until the Power Transmitter receives a Signal Strength Packet containing an appropriate Signal Strength Value.

Figure 125. Electrical diagram (outline) of Power Transmitter design A30



Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Qi Specification, Power Delivery*. The controlled variable $v^{(i)}$ introduced in the definition of that algorithm represents the Operating Frequency to the full-bridge inverter and duty cycle. It is recommended that control of the power occurs primarily by means of adjustments to the Operating Frequency and that duty cycle adjustments are made according to the amount of current. In order to guarantee sufficiently accurate power control, a type A30 Power Transmitter shall determine the amplitude of the Primary Coil current with a resolution of 5 mA or better. Finally, Table 93 and Table 94 provide the value of several parameters, which are used in the PID algorithm.

Table 93: PID parameters for Operating Frequency control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	1	mA^{-1}
Integral gain	K_i	0	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	N.A.	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_v	1.0	Hz

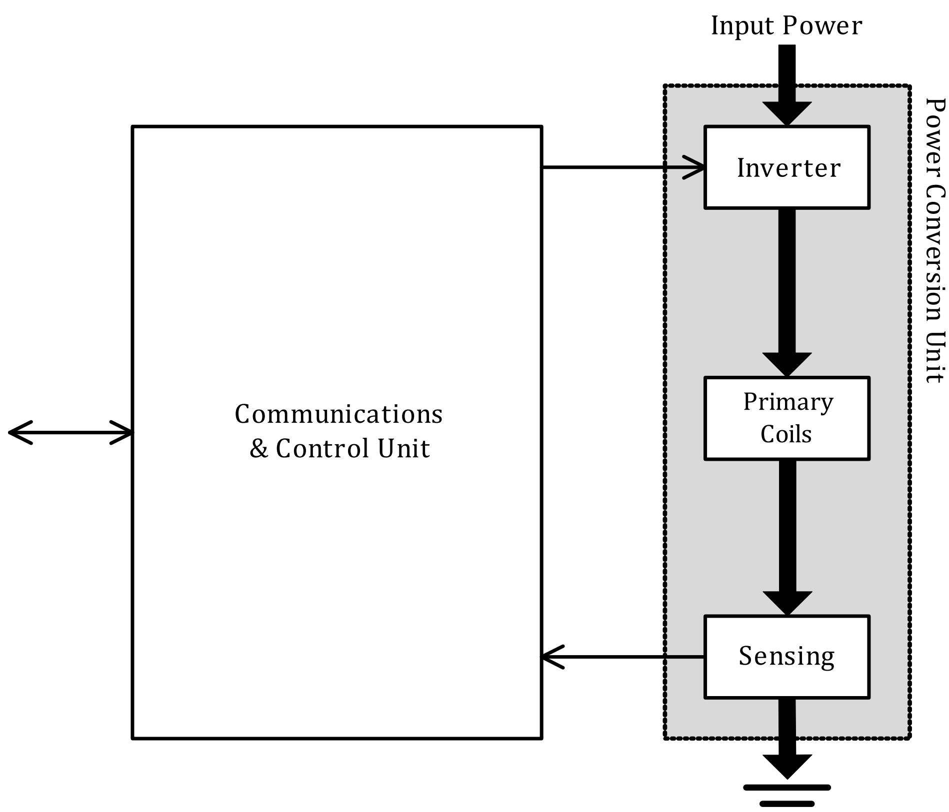
Table 94: PID parameters for duty cycle control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	1	mA^{-1}
Integral gain	K_i	0	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	N.A.	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_v	-0.1	°

35 Power Transmitter design A31

Figure 126 illustrates the functional block diagram of Power Transmitter design A31, which consists of two major functional units, namely a Power Conversion Unit and a Communications and Control Unit.

Figure 126. Functional block diagram of Power Transmitter design A31



The Power Conversion Unit on the right-hand side of Figure 126 comprises the analog parts of the design. The inverter converts the DC input to an AC waveform that drives a resonant circuit, which consists of the Primary Coil plus a series capacitor. Finally, the voltage and current sense monitors the Primary Coil voltage and current.

The Communications and Control Unit on the left-hand side of Figure 126 comprises the digital logic part of the design. The unit receives and decodes messages from the Power Receiver, executes the relevant power control algorithms and protocols, and drives the input power and frequency of the AC waveform to control the power transfer. The Communications and Control Unit also interfaces with other subsystems of the Power Transmitter Product, e.g. for user interface purposes.

35.1 Mechanical details

Power Transmitter design A31 includes one Primary Coil as defined in Section 35.1.1, *Primary Coil*, Shielding as defined in Section 35.1.2, *Shielding*, and an Interface Surface as defined in Section 35.1.3, *Interface Surface*.

35.1.1 Primary Coil

The Primary Coil is of the wire-wound type, and consists of litz wire having 115 strands of 0.08 mm diameter, or equivalent. As shown in Figure 127, a Primary Coil has a racetrack-like shape and consists of a single layer. Table 95 lists the dimensions of a Primary Coil.

Figure 127. Primary Coil of Power Transmitter design A31

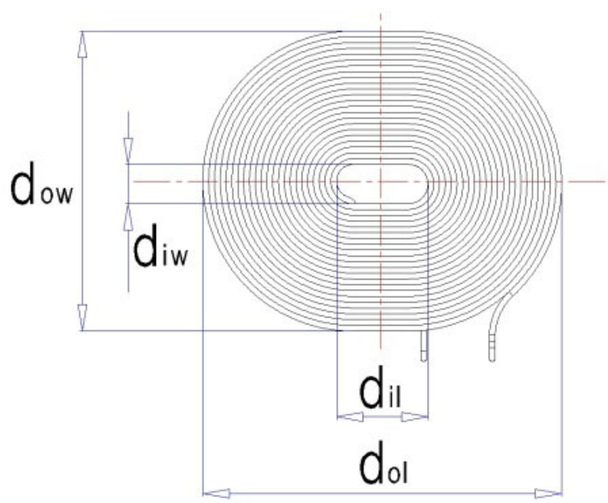


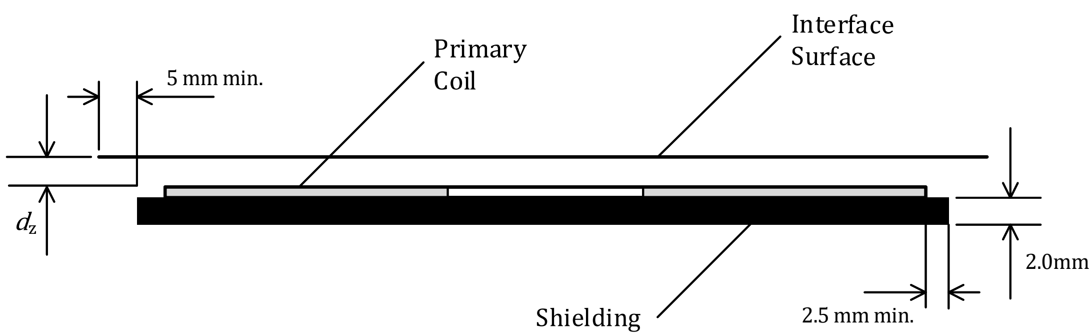
Table 95: Primary Coil parameters of Power Transmitter design A31

Parameter	Symbol	Value
Outer length	d_{ol}	$65.5^{\pm0.5}$ mm
Inner length	d_{il}	$16.5^{\pm0.5}$ mm
Outer width	d_{ow}	$57.1^{\pm0.5}$ mm
Inner width	d_{iw}	$4.5^{\pm0.5}$ mm
Thickness	d_{c}	$1.3^{\pm0.15}$ mm
Number of turns per layer	N	22
Number of layers	–	1

35.1.2 Shielding

As shown in Figure 128, Shielding protects the Power Transmitter Product from the magnetic field that is generated in the Primary Coil. The Shielding should be Ni-Zn or Mn-Zn ferrite and should be at least 2.0 mm thick. The Shielding extends to at least 2.5 mm beyond the outer edge of the Primary Coil.

Figure 128. Primary Coil assembly of Power Transmitter design A31



35.1.3 Interface Surface

As shown in Figure 128, the distance from the Primary Coil to the Interface Surface of the Power Transmitter Product is $d_z = 3.0^{\pm 0.5}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Power Transmitter Product extends at least 5.0 mm beyond the outer diameter of the Primary Coil.

35.1.4 Separation between multiple Power transmitters

If the Power Transmitter Product contains multiple type A31Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall not overlap.

35.2 Electrical details

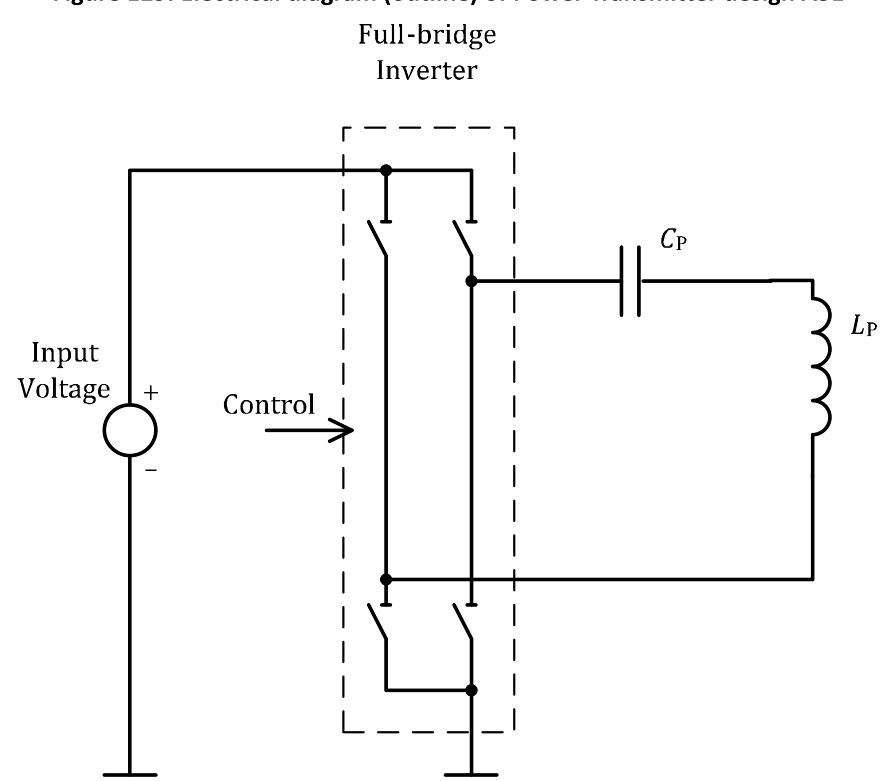
As shown in Figure 129, Power Transmitter design A31 uses a full-bridge inverter to drive the Primary Coil and a series capacitance. Within the Operating Frequency range specified below, the assembly of Primary Coil and Shielding has a self-inductance $L_P = 24^{\pm 10\%}$ μH. The input voltage to the full-bridge inverter is $12^{\pm 5\%}$ V. The value of the series capacitance is $C_P = 148^{\pm 5\%}$ nF.

NOTE: Near resonance, the voltage developed across the series capacitance can reach levels up to 100 V pk-pk.

Power Transmitter design A31 uses the Operating Frequency and duty cycle of the Power Signal in order to control the amount of power transferred. For this purpose, the Operating Frequency is f_{op} = 87...110 kHz and the duty cycle range of 2…50%.

When a type A31 Power Transmitter first applies a Power Signal (Digital Ping; see the *Qi Specification, Communications Protocol*), the Power Transmitter shall use an Operating Frequency of $98^{\pm 10}$ kHz, and a duty cycle of $25^{\pm 10\%}$. If the Power Transmitter does not to receive a Signal Strength Packet from the Power Receiver, the Power Transmitter shall remove the Power Signal as defined in the *Qi Specification, Communications Protocol*. The Power Transmitter may reapply the Power Signal multiple times at consecutively higher duty cycles to the full bridge inverter within the range specified above, until the Power Transmitter receives a Signal Strength Packet containing an appropriate Signal Strength Value.

Figure 129. Electrical diagram (outline) of Power Transmitter design A31



Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Qi Specification, Power Delivery*. The controlled variable $v^{(j)}$ introduced in the definition of that algorithm represents the Operating Frequency as well as the duty cycle to the full-bridge inverter. It is recommended that control of the power occurs primarily by means of adjustments to the Operating Frequency, and that duty cycle adjustments are made according to the amount of current. In order to guarantee sufficiently accurate power control, a type A31 Power Transmitter shall determine the amplitude of the Primary Coil current with a resolution of 5 mA or better. Finally, Table 96 and Table 97 provide the values of several parameters, which are used in the PID algorithm.

Table 96: PID parameters for Operating Frequency control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	1	mA^{-1}
Integral gain	K_i	0	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	N.A.	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_v	1.0	Hz

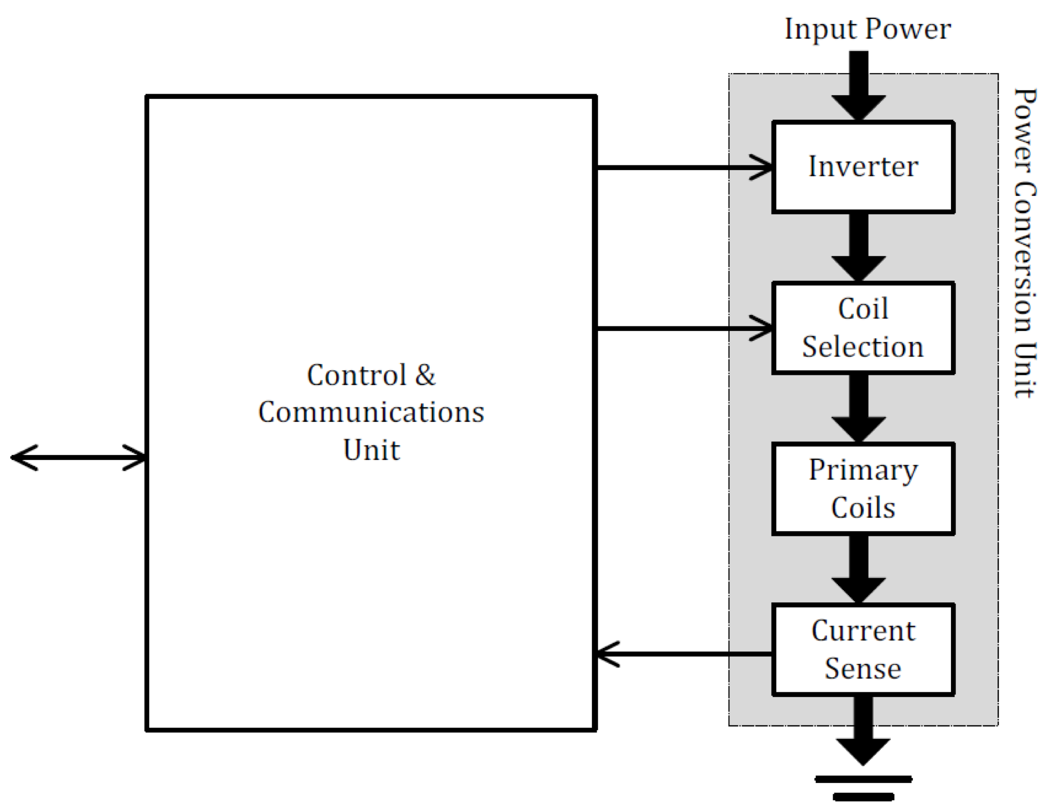
Table 97: PID parameters for duty control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	1	mA^{-1}
Integral gain	K_i	0	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	N.A.	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_v	–0.1	°

36 Power Transmitter design A32

Figure 130 illustrates the functional block diagram of Power Transmitter design A32, which consists of two major functional units, namely a Power Conversion Unit and a Communications and Control Unit.

Figure 130. Functional block diagram of Power Transmitter design A32



The Power Conversion Unit on the right-hand side of Figure 130 comprises the analog parts of the design. The inverter converts the DC input to an AC waveform that drives a resonant circuit, which consists of the selected Primary Coil plus a series capacitor. The selected Primary Coil is one from a linear array of partially overlapping Primary Coils, as appropriate for the position of the Power Receiver relative to the Primary Coils. Selection of the Primary Coil proceeds by the Power Transmitter attempting to establish communication with a Power Receiver using any of the Primary Coils. Note that the array may consist of a single Primary Coil only, in which case the selection is trivial. Finally, the current sense monitors the Primary Coil current.

The Communications and Control Unit on the left-hand side of Figure 130 comprises the digital logic part of the design. This unit receives and decodes messages from the Power Receiver, configures the Coil Selection block to connect the appropriate Primary Coil, executes the relevant power control algorithms and protocols, and drives the frequency of the AC waveform to control the power transfer. The Communications and Control Unit also interfaces with other subsystems of the Power Transmitter Product, e.g. for user interface purposes.

36.1 Mechanical details

Power Transmitter design A32 includes at least one Primary Coil as defined in Section 36.1.1, *Primary coil*, Shielding as defined in Section 36.1.2, *Shielding*, and an Interface Surface as defined in Section 36.1.3, *Interface Surface*.

36.1.1 Primary coil

The Primary Coil consists of at least one PCB coil. Figure 131 shows a view of a single Primary Coil. Table 98 lists the dimensions of the Primary Coil.

Figure 131. Primary Coil of Power Transmitter design A32

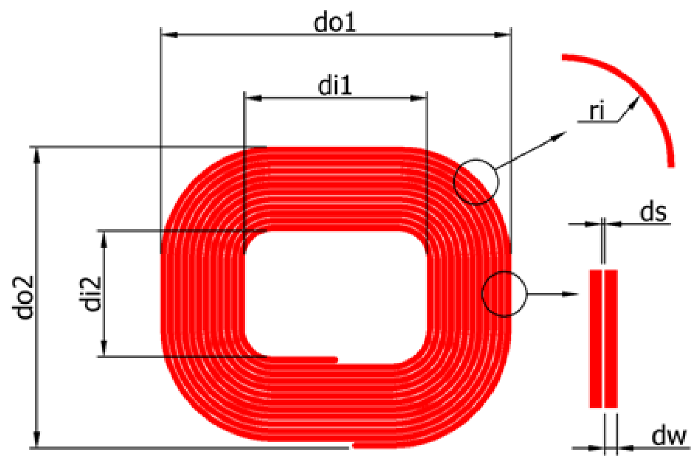


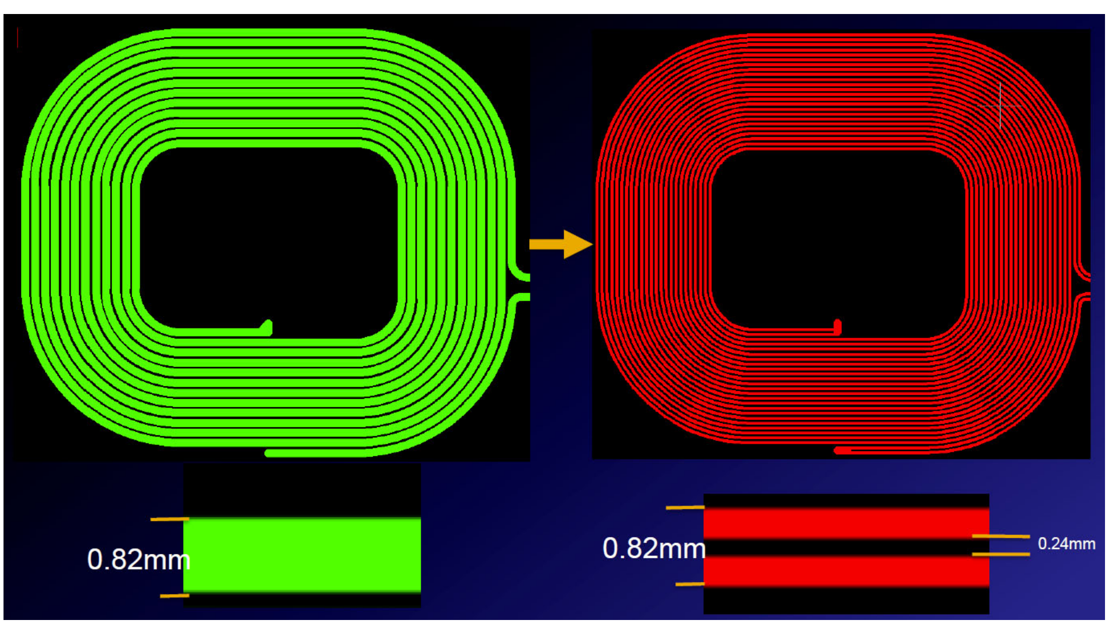
Table 98: Primary Coil parameters of Power Transmitter design A32

Parameter	Symbol	Value
Outer length	d_{o1}	$53.4^{\pm0.7}$ mm
Inner length	d_{i1}	$27.5^{\pm0.7}$ mm
Outer width	d_{o2}	$45.8^{\pm0.7}$ mm
Inner width	d_{i2}	$19.5^{\pm075}$ mm
4- layer PCB		
Track width**	d_w	$0.82^{\pm0.2}$ mm
Track width plus spacing	d_w+d_s	$1.08^{\pm0.2}$ mm
Corner rounding*	r_i	$16.7^{\pm1.0}$ mm
Number of turns	N	$12^{\pm0.25}$
5…8 layer PCB		
Track width	d_w	$0.55^{\pm0.15}$ mm
Track width plus spacing	d_w+d_s	$1.1^{\pm0.15}$ mm
Corner rounding*	r_i	$13.1^{\pm1.31}$ mm
Number of turns	N	$12^{\pm0.25}$

* Outermost winding only

** The trace may be divided, as shown in Figure 132

Figure 132. Coil trace examples: single trace (left) and divided trace (right)



Power Transmitter design A32 contains at least one Primary Coil. Odd numbered coils are placed alongside each other with a displacement of d_{h2} between their centers. Even numbered coils are placed orthogonal to the odd numbered coils with a displacement of d_{h1} mm between their centers. See Figure 133.

Figure 133. Primary Coils of Power Transmitter design A32

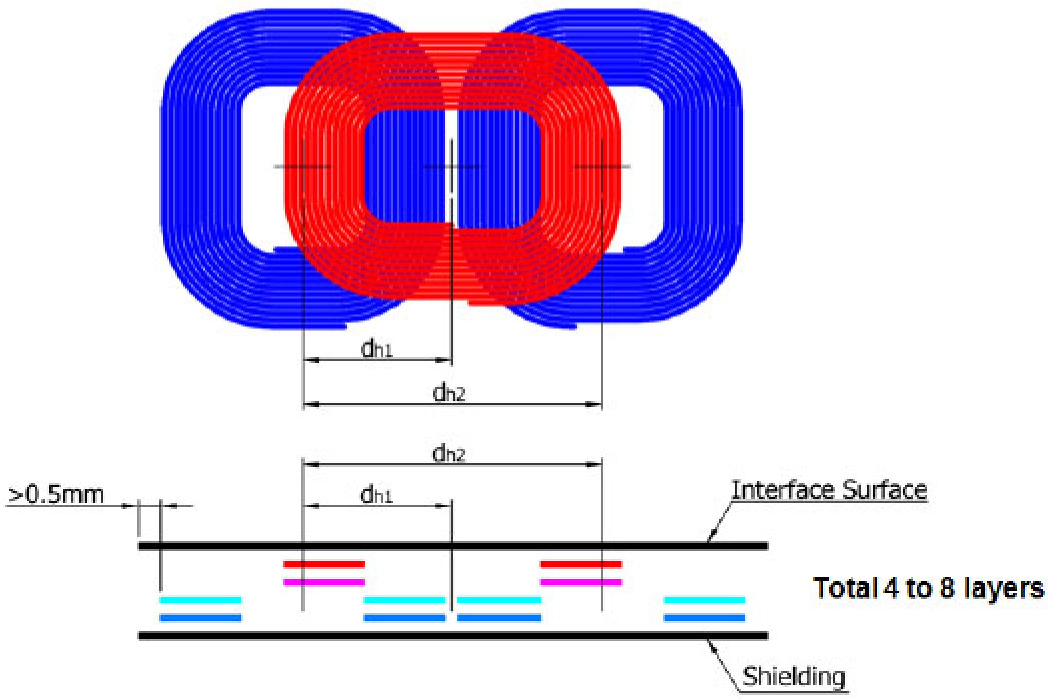


Figure 134. Primary Coils of Power Transmitter design A32

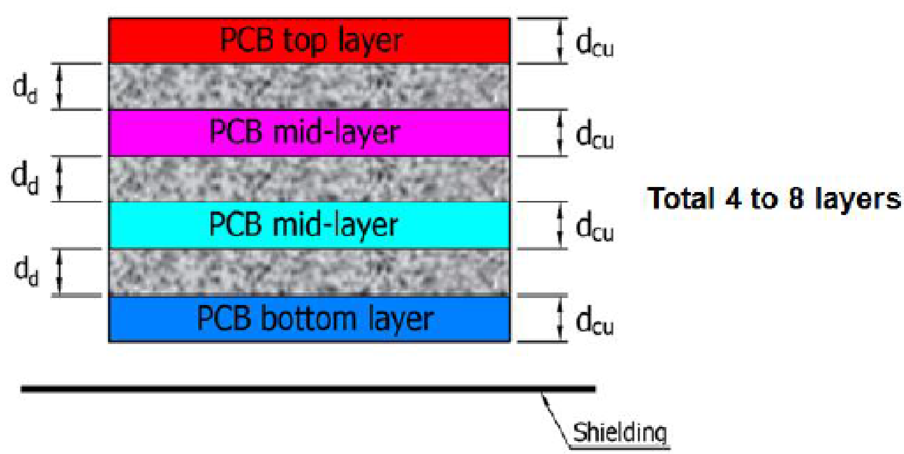


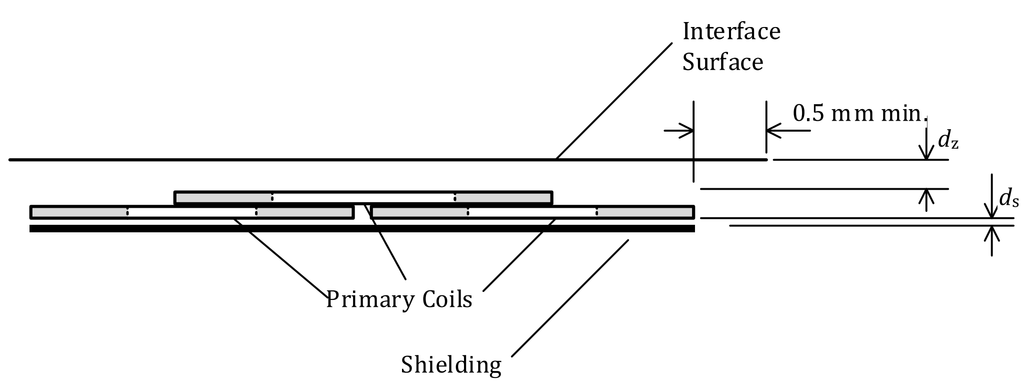
Table 99: Primary Coil parameters of Power Transmitter design A32

Parameter	Symbol	Value
4- layer PCB		
Center-to-center distance	d_{h1}	$23.8^{\pm 1.0}$ mm
Center-to-center distance	d_{h2}	$47.52^{\pm 2.0}$ mm
PCB copper thickness	d_{Cu}	$0.105^{\pm 0.015}$ mm
Dielectric thickness	d_d	$0.375^{\pm 0.063}$ mm
5…8 layer PCB		
Center-to-center distance	d_{h1}	$23.76^{\pm 1.5}$ mm
Center-to-center distance	d_{h2}	$47.52^{\pm 3.0}$ mm
PCB copper thickness	d_{Cu}	$0.105^{\pm 0.0161}$ mm
Dielectric thickness	d_d	$0.125^{\pm 0.0254}$ mm

36.1.2 Shielding

As shown in Figure 135, Shielding protects the Power Transmitter Product from the magnetic field that is generated in the Primary Coil. The Shielding should be Ni-Zn or Mn-Zn ferrite and should be at least 0.5 mm thick. The Shielding extends to at least the outer dimensions of the Primary Coils, and is placed below the Primary Coil at a distance of at most d_s = 1.0 mm.

Figure 135. Primary Coil assembly of Power Transmitter design A32



36.1.3 Interface Surface

As shown in Figure 135, the distance from the top face of the even-numbered Primary Coil to the Interface Surface of the Power Transmitter Product is $d_{\mathrm{Z}} = 2.75^{\pm 1}$ mm, across the top face of the Primary Coil. The odd-numbered Primary Coils are mounted flush to the bottom face of the even-numbered Primary Coils. If the Power Transmitter contains only one Primary Coil, the distance from its top face to the Interface Surface of the Power Transmitter Product is also $d_{\mathrm{z}} = 2.75^{\pm 1}$ mm. In addition, the Interface Surface of the Power Transmitter Product extends at least 0.5 mm beyond the outer dimensions of the Primary Coils.

36.1.4 Separation between multiple Power transmitters

If the Power Transmitter Product contains multiple type A32 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall not overlap.

36.2 Electrical details

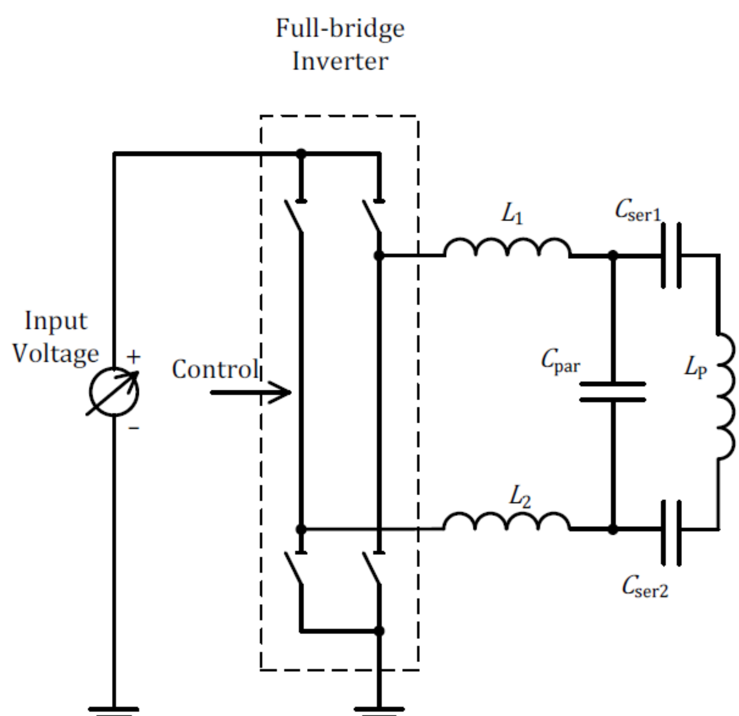
As shown in Figure 136, Power Transmitter design A32 uses a full-bridge inverter to drive an individual Primary Coil and a series capacitance. Within the Operating Frequency range specified below, the assembly of Primary Coil and Shielding has a self-inductance $L_P = 11.5^{\pm 10\%}$ μH for coils closest to the Interface Surface, and inductance $L_P = 12.5^{\pm 10\%}$ for coils furthest from the Interface Surface. The value of inductances L_1 and L_2 is $1^{\pm 20\%}$ μH. The value of the total series capacitance is $1/C_{ser1} + 1/C_{ser2} = 1/200^{\pm 10\%}$ 1/nF. The value of the parallel capacitance is $C_{par} = 400^{\pm 10\%}$ nF.

NOTE: Near resonance, the voltage developed across the series capacitance can reach levels exceeding 100 V pk-pk.

Power Transmitter design A32 uses the input voltage of the inverter to control the amount of power that is transferred. For this purpose, the input voltage has a range of 1…12 V, with a resolution of 10 mV or better. The Operating Frequency is f_{op} = 105 … 115 kHz, with a duty cycle of 50%.

When a type A32 Power Transmitter first applies a Power Signal (Digital Ping; see the *Qi Specification, Communications Protocol*), it shall use an initial voltage of $3.5^{\pm 0.5}$ V for a bottom Primary Coil, and $3.0^{\pm 0.5}$ V for a top Primary Coil, and a recommended Operating Frequency of 110 kHz.

Figure 136. Electrical diagram (outline) of Power Transmitter design A32



Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Qi Specification, Power Delivery*. The controlled variable $v^{(i)}$ introduced in the definition of that algorithm represents the input voltage to the inverter. In order to guarantee sufficiently accurate power control, a type A32 Power Transmitter shall determine the amplitude of the Primary Cell current—which is equal to the Primary Coil current— with a resolution of 7 mA or better. Finally, Table 100 provides the values of several parameters, which are used in the PID algorithm.

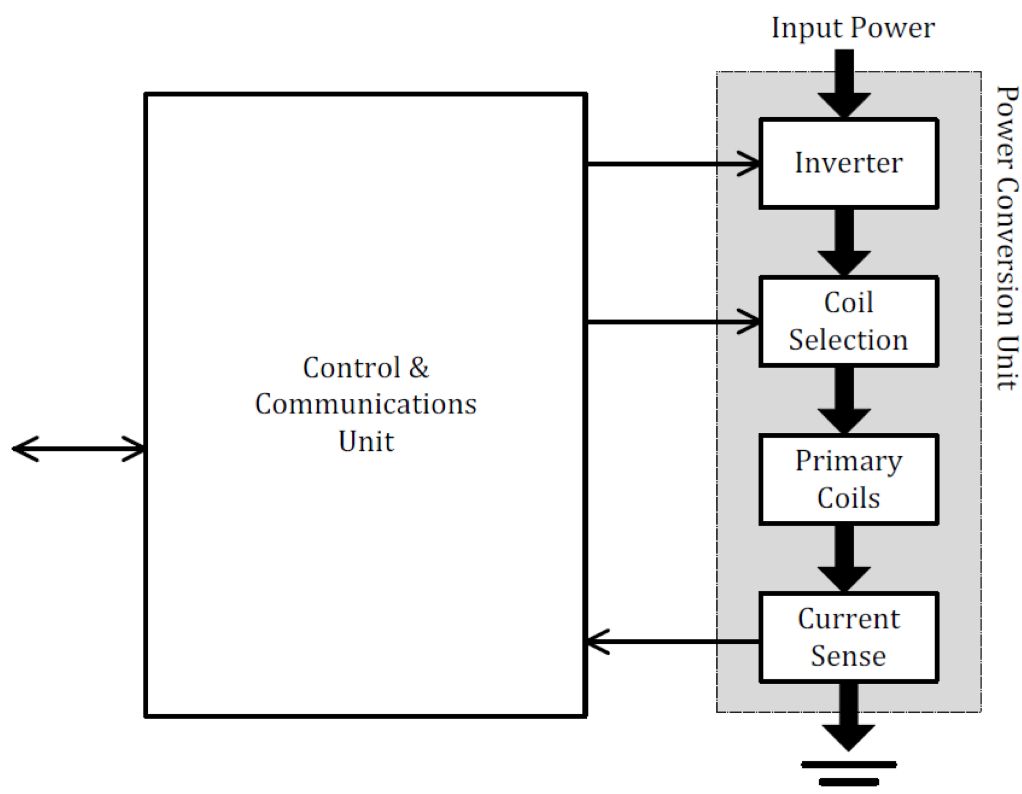
Table 100: PID parameters for voltage control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	0.03	mA-1
Integral gain	K_i	0.01	mA-1ms-1
Derivative gain	K_d	0	mA-1ms
Integral term limit	M_I	3,000	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_v	-1	mV

37 Power Transmitter design A33

Power Transmitter design A33 enables Free Positioning of Power Receiver. Figure 137 illustrates the functional block diagram of this Power Transmitter design A33, which consists of two major functional units, namely a Power Conversion Unit and a Communications and Control Unit.

Figure 137. Functional block diagram of Power Transmitter design A33



The Power Conversion Unit on the right-hand side of Figure 137 comprises the analog parts of the design. The inverter converts the DC input to an AC waveform that drives a resonant circuit, which consists of the selected Primary Coil plus a series capacitor. The selected Primary Coil is one from a linear array of partially overlapping Primary Coils, as appropriate for the position of the Power Receiver relative to the Primary Coils. Selection of the Primary Coil proceeds by the Power Transmitter attempting to establish communication with a Power Receiver using any of the Primary Coils. Note that the array may consist of a single Primary Coil only, in which case the selection is trivial. Finally, the current sense monitors the Primary Coil current.

The Communications and Control Unit on the left-hand side of Figure 137 comprises the digital logic part of the design. This unit receives and decodes messages from the Power Receiver, configures the Coil Selection block to connect the appropriate Primary Coil, executes the relevant power control algorithms and protocols, and drives the frequency of the AC waveform to control the power transfer. The Communications and Control Unit also interfaces with other subsystems of the Power Transmitter Product, e.g. for user interface purposes.

37.1 Mechanical details

Power Transmitter design A33 includes one or more Primary Coils as defined in Section 37.1.1, *Primary coil*, Shielding as defined in Section 37.1.2, *Shielding*, an Interface Surface as defined in Section 37.1.3, *Interface Surface*.

37.1.1 Primary coil

The Primary Coil consists of at least one PCB coil. Figure 138 shows a view of a single Primary Coil. Table 101 lists the dimensions of the Primary Coil.

Figure 138. Primary Coil of Power Transmitter design A33

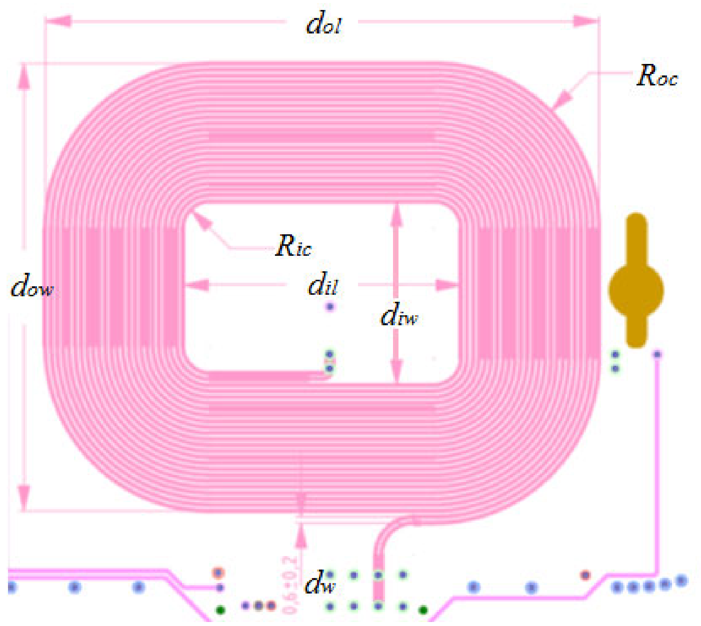


Table 101: Primary Coil parameters of Power Transmitter design A33

Parameter	Symbol	Value
Outer length	d_{ol}	$55.5^{\pm 0.2}$ mm
Inner length	d_{il}	$27.9^{\pm 0.2}$ mm
Outer width	d_{ow}	$44.8^{\pm 0.2}$ mm
Inner width	d_{iw}	$18.4^{\pm 0.2}$ mm
Track width	d_{w}	$0.6^{\pm 0.2}$ mm
Outer Corner rounding*	R_{oc}	$16.5^{\pm 0.2}$ mm
Inner Corner rounding**	R_{ic}	$2.7^{\pm 0.2}$ mm
Number of turns	N	12
* outermost winding only ** innermost winding only		

Power Transmitter design A33 contains at least one Primary Coil. Odd numbered coils are placed alongside each other with a displacement of d_{oo} between their centers. Even numbered coils are placed orthogonal to the odd numbered coils with a displacement of d_{oe} between their centers. See Figure 139 and Figure 140. Table 102 lists the dimensions of the Primary Coils.

Figure 139. Three Primary Coils of Power Transmitter design A33

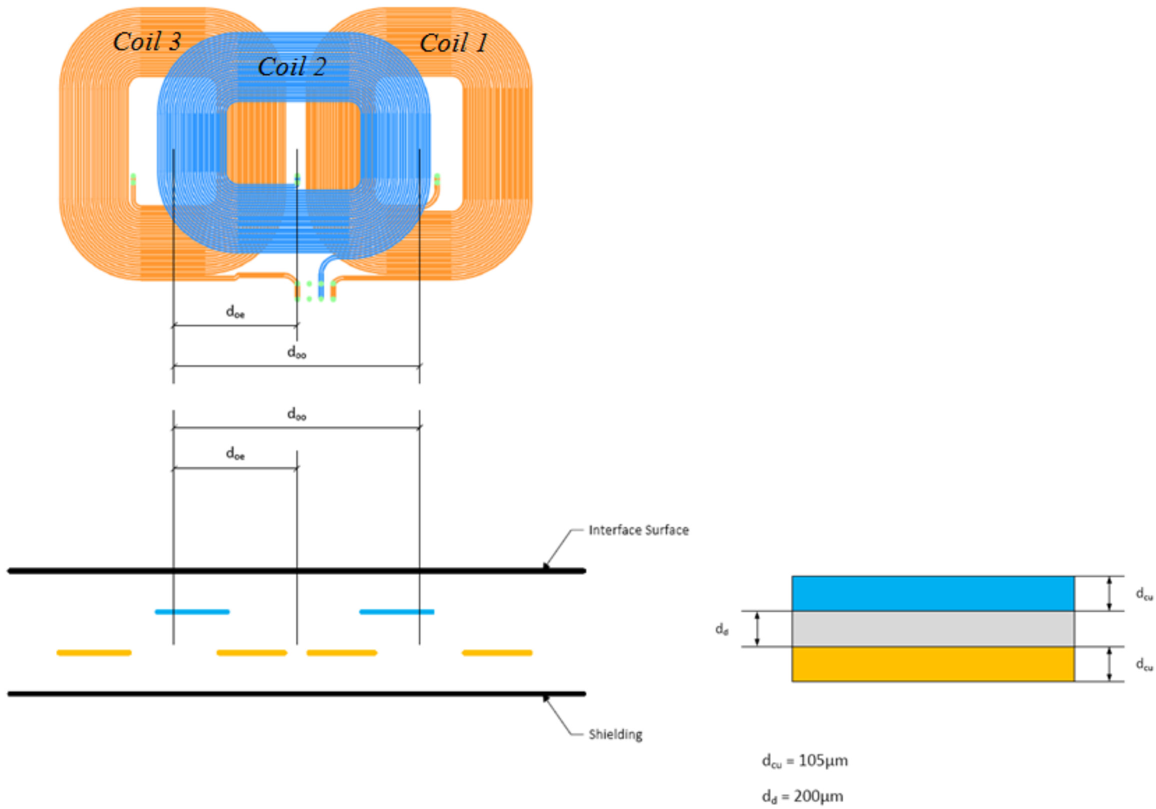


Figure 140. Four Primary Coils of Power Transmitter design A33

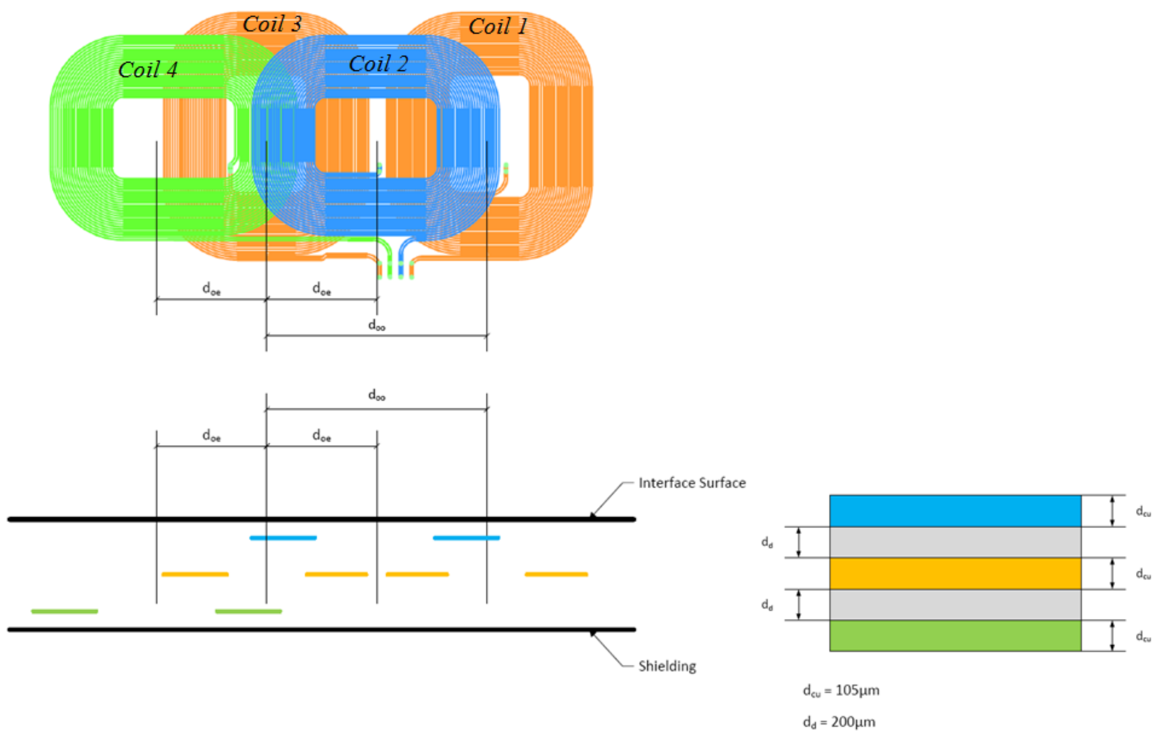
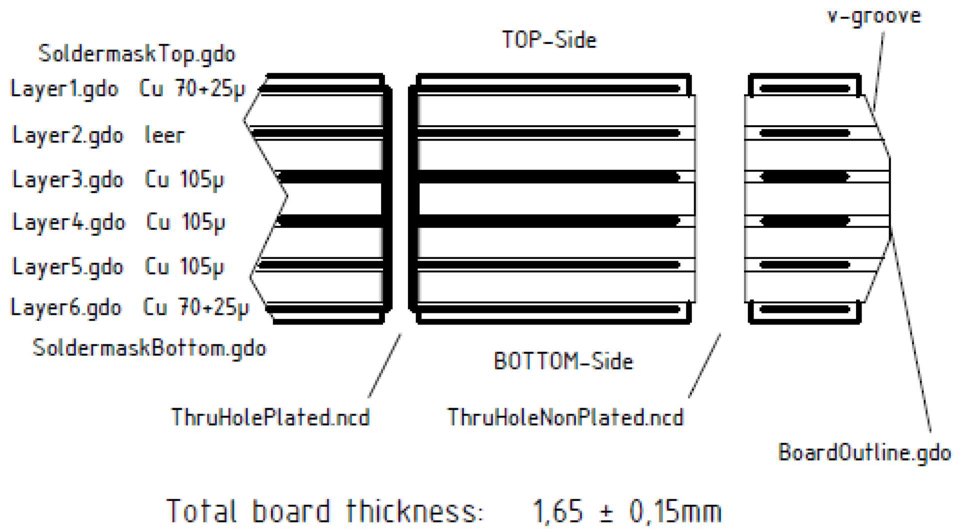


Table 102: Primary Coil parameters of Power Transmitter design A33

Parameter	Symbol	Value
Center-to-center distance	d_{oo}	$49.2^{\pm 0.2}$ mm
Center-to-center distance	d_{oe}	$24.6^{\pm 0.2}$ mm
PCB copper thickness	d_{cu}	105 µm
Dielectric thickness	d_d	200 µm

Figure 141 shows the layered structure of the Primary Coils array. Note: 1 coil configuration uses 1 metal layer, 2 and 3 coils configuration uses 2 metal layers, 4 coils and more coils configuration use 3 metal layers.

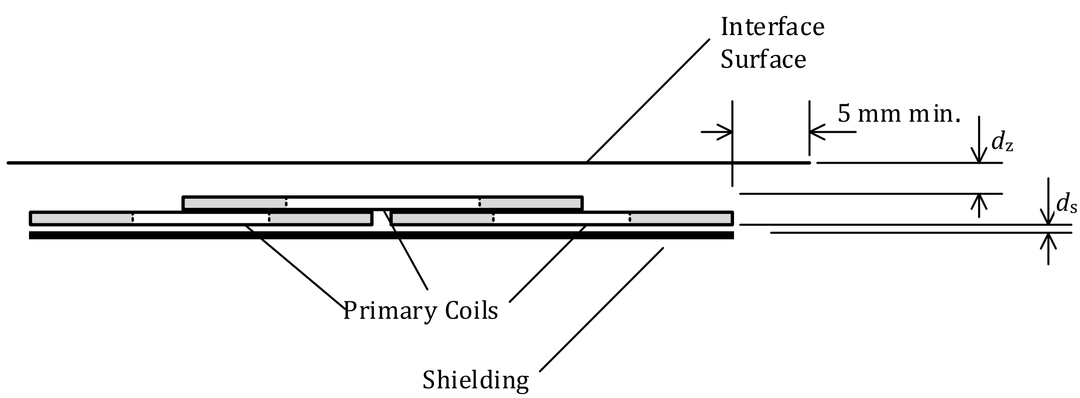
Figure 141. Layered structure of the Primary Coils of Power Transmitter design A33



37.1.2 Shielding

As shown in Figure 142, Shielding protects the Power Transmitter Product from the magnetic field that is generated in the Primary Coil. The Shielding should be Ni-Zn or Mn-Zn ferrite and should be at least 0.5 mm thick. The Shielding extends to at least the outer dimensions of the Primary Coils, and is placed below the Primary Coil at a distance of at most $d_s = 1.0$ mm.

Figure 142. Primary Coil assembly of Power Transmitter design A33



37.1.3 Interface Surface

As shown in Figure 142, the distance from the top face of the even-numbered Primary Coil to the Interface Surface of the Power Transmitter Product is $d_z = 3^{\pm 1}$ mm, across the top face of the Primary Coil. The odd-numbered Primary Coils are mounted flush to the bottom face of the even-numbered Primary Coils. In the case of a single Primary Coil, the distance from the Primary Coil to the Interface Surface of the Power Transmitter Product is $d_z = 4.5^{\pm 1}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Power Transmitter Product extends at least 5 mm beyond the outer dimensions of the Primary Coils.

37.1.4 Inter coil separation

If the Power Transmitter Product contains multiple type A33 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall not overlap.

37.2 Electrical details

As shown in Figure 143, Power Transmitter design A33 uses a full-bridge inverter to drive an individual Primary Coil and a series capacitance. Within the Operating Frequency range specified below, the assembly of Primary Coils and Shielding has a self-inductance $L_{\mathrm{p}} = 11.5^{\pm 10\%}$ μH for coils closest to the Interface Surface and inductance $L_{\mathrm{p}} = 12.5^{\pm 10\%}$ μH for coils furthest from the Interface Surface. The value of inductances L_1 and L_2 is $1^{\pm 20\%}$ μH. The value of the total series capacitance is $1 / C_{\mathrm{ser1}} + 1 / C_{\mathrm{ser2}} = 1 / 200^{\pm 10\%}$ 1/nF, where the individual series capacitances may have any value less than the sum. The value of the parallel capacitance is $C_{\mathrm{par}} = 400^{\pm 10\%}$ nF.

NOTE: Near resonance, the voltage developed across the series capacitance can reach levels exceeding 100 V pk-pk.

Power Transmitter design A33 uses the input voltage of the inverter to control the amount of power that is transferred. For this purpose, the input voltage has a range of 1…9V, with a resolution of 10mV or better. The Operating Frequency is $f_{\mathrm{op}} = 120…130$ kHz, with a duty cycle of 50%.

When a type A33 Power Transmitter first applies a Power Signal (Digital Ping; see the *Qi Specification, Communications Protocol*), it shall use an initial voltage of $4^{\pm 5\%}$ V, and a recommended Operating Frequency of 125 kHz.

Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Qi Specification, Power Delivery*. The controlled variable $v^{(i)}$ introduced in the definition of that algorithm represents the input voltage to the inverter. In order to guarantee sufficiently accurate power control, a type A33 Power Transmitter shall determine the amplitude of the Primary Cell current—which is equal to the Primary Coil current—with a resolution of 7 mA or better. Finally, Table 103 provides the values of several parameters, which are used in the PID algorithm.

Figure 143. Electrical diagram (outline) of Power Transmitter design A33

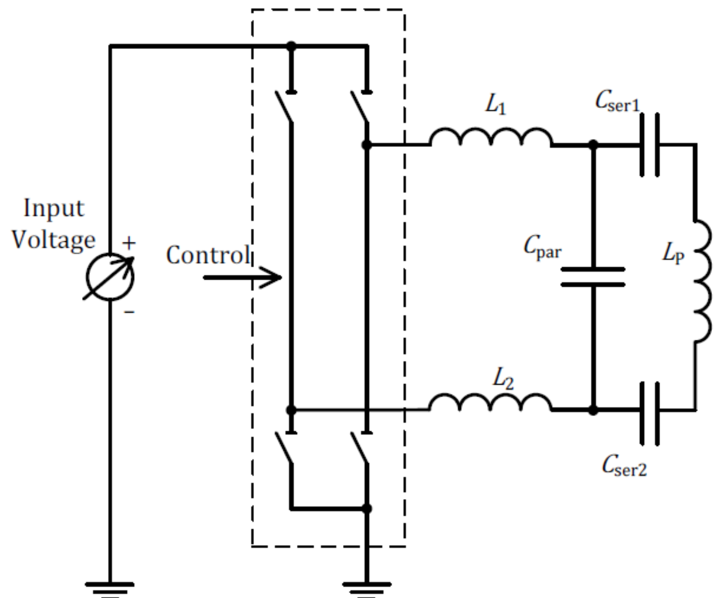


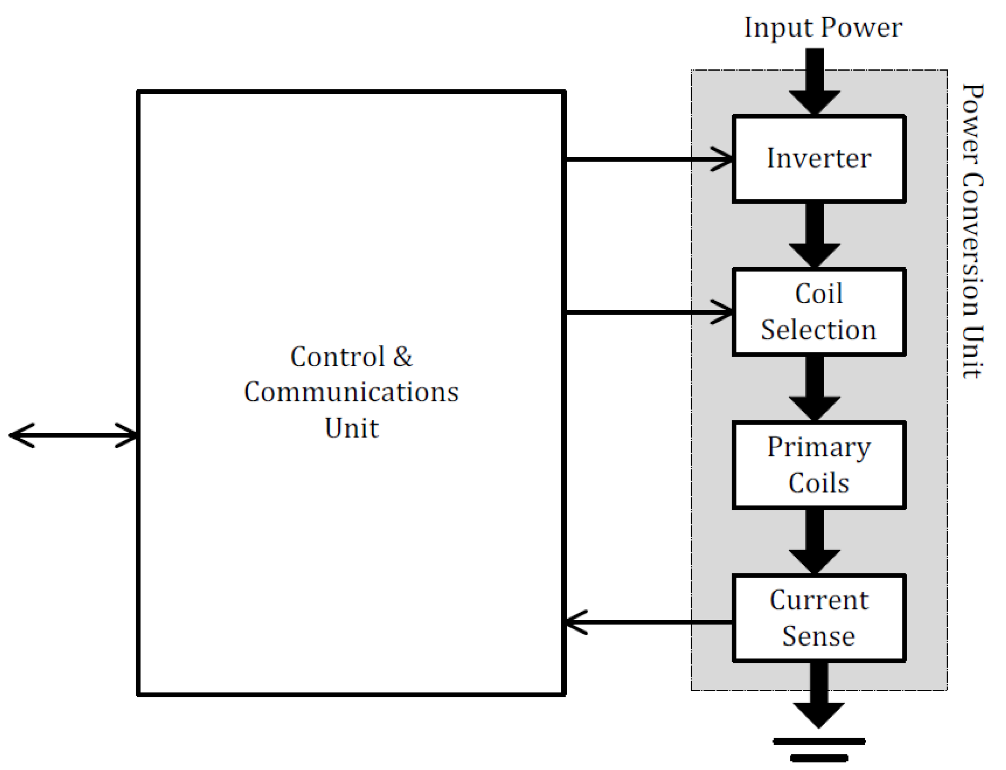
Table 103: PID parameters for voltage control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	0.03	mA^{-1}
Integral gain	K_i	0.01	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	3,000	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_v	-1	mV

38 Power Transmitter design A34

Figure 144 illustrates the functional block diagram of Power Transmitter design A34, which consists of two major functional units, namely a Power Conversion Unit and a Communications and Control Unit.

Figure 144. Functional block diagram of Power Transmitter design A34



The Power Conversion Unit on the right-hand side of Figure 144 comprises the analog parts of the design. The inverter converts the DC input to an AC waveform that drives a resonant circuit, which consists of the selected Primary Coil plus a series capacitor. The selected Primary Coil is one from a linear array of partially overlapping Primary Coils, as appropriate for the position of the Power Receiver relative to the Primary Coils. Selection of the Primary Coil proceeds by the Power Transmitter attempting to establish communication with a Power Receiver using any of the Primary Coils. Note that the array may consist of a single Primary Coil only, in which case the selection is trivial. Finally, the current sense monitors the Primary Coil current.

The Communications and Control Unit on the left-hand side of Figure 144 comprises the digital logic part of the design. This unit receives and decodes messages from the Power Receiver, configures the Coil Selection block to connect the appropriate Primary Coil, executes the relevant power control algorithms and protocols, and drives the frequency of the AC waveform to control the power transfer. The Communications and Control Unit also interfaces with other subsystems of the Power Transmitter Product, e.g. for user interface purposes.

38.1 Mechanical details

Power Transmitter design A34 includes one or more Primary Coils as defined in Section 38.1.1, *Primary Coil*, Shielding as defined in Section 38.1.2, *Shielding*, an Interface Surface as defined in Section 38.1.3, *Interface Surface*.

38.1.1 Primary Coil

The Primary Coil is of the wire-wound type, and consists of no. 17 AWG (1.15 mm diameter) type 2 litz wire having 105 strands of no. 40 AWG (0.08 mm diameter), or equivalent. As shown in Figure 145, the Primary Coil has a rectangular shape and consists of a single layer. Table 104 lists the dimensions of the Primary Coil.

Figure 145. Primary Coil of Power Transmitter design A34

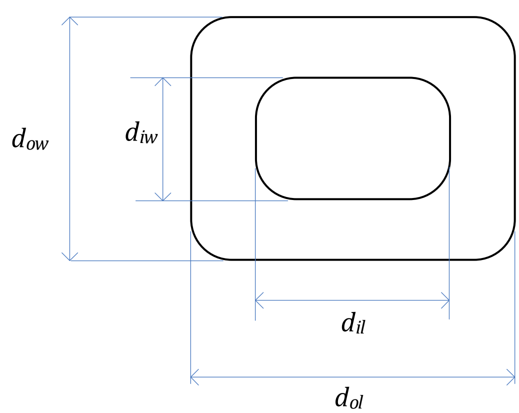
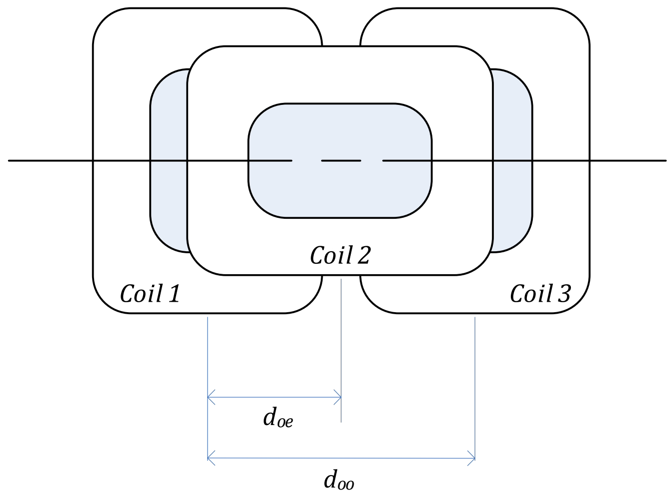


Table 104: Primary Coil parameters of Power Transmitter design A34

Parameter	Symbol	Value
Outer length	d_{ol}	$53.2^{\pm 0.5}$ mm
Inner length	d_{il}	$27.5^{\pm 0.5}$ mm
Outer width	d_{ow}	$45.2^{\pm 0.5}$ mm
Inner width	d_{iw}	$19.5^{\pm 0.5}$ mm
Thickness	d_c	$1.5^{\pm 0.5}$ mm
Number of turns per layer	N	12 turns
Number of layers	–	1

Power Transmitter design A34 contains at least one Primary Coil. Odd numbered coils are placed alongside each other with a displacement of $d_{oo} = 49.2^{\pm 4}$ mm between their centers. Even numbered coils are placed orthogonal to the odd numbered coils with a displacement of $d_{oe} = 24.6^{\pm 2}$ mm between their centers. See Figure 146.

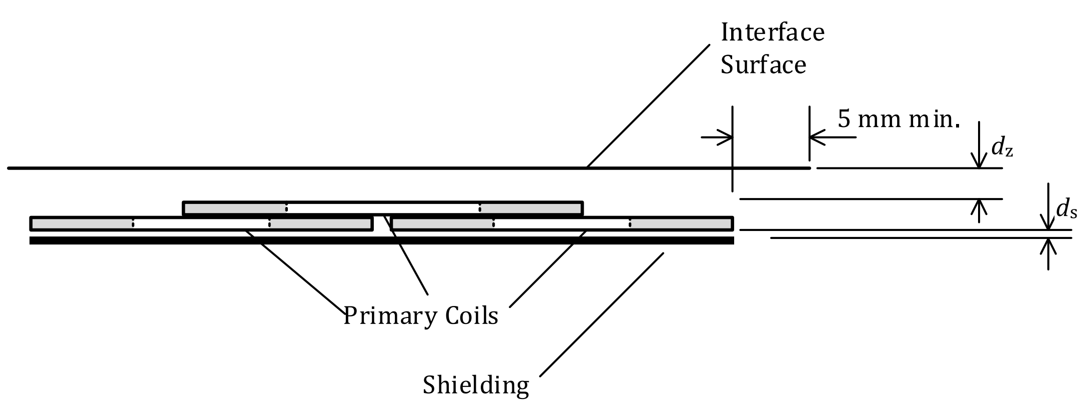
Figure 146. Primary Coils of Power Transmitter design A34



38.1.2 Shielding

As shown in Figure 147, Shielding protects the Power Transmitter Product from the magnetic field that is generated in the Primary Coil. The Shielding should be Ni-Zn or Mn-Zn ferrite and should be at least 0.5 mm thick. The Shielding extends to at least the outer dimensions of the Primary Coils, and is placed below the Primary Coil at a distance of at most $d_S = 1.0$ mm.

Figure 147. Primary Coil assembly of Power Transmitter design A34



38.1.3 Interface Surface

As shown in Figure 147, the distance from the top face of the even-numbered Primary Coil to the Interface Surface of the Power Transmitter Product is $d_z = 3^{\pm 1}$ mm, across the top face of the Primary Coil. The odd-numbered Primary Coils are mounted flush to the bottom face of the even-numbered Primary Coils. In the case of a single Primary Coil, the distance from the Primary Coil to the Interface Surface of the Power Transmitter Product is $d_z = 4.5^{\pm 1}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Power Transmitter Product extends at least 5 mm beyond the outer dimensions of the Primary Coils.

38.1.4 Inter coil separation

If the Power Transmitter Product contains multiple type A34 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall not overlap.

38.2 Electrical details

As shown in Figure 148, Power Transmitter design A34 uses a half-bridge inverter to drive an individual Primary Coil and a series capacitance. Within the Operating Frequency range specified below, the assembly of Primary Coils and Shielding has a self-inductance $L_P = 11.5^{\pm 10\%}$ μH for coils closest to the Interface Surface and inductance $L_P = 12.5^{\pm 10\%}$ μH for coils furthest from the Interface Surface. The value of inductance L is $3.3^{\pm 20\%}$ μH. The value of series capacitance is $C_{ser} = 168^{\pm 10\%}$ nF. The value of the parallel capacitance is $C_{par} = 400^{\pm 10\%}$ nF.

NOTE: Near resonance, the voltage developed across the series capacitance can reach levels exceeding 100 V pk-pk.

Power Transmitter design A34 uses the input voltage of the inverter to control the amount of power that is transferred. For this purpose, the input voltage has a range of 2…24 V, with a resolution of 20 mV or better. The Operating Frequency is f_{op} = 105...115 kHz, with a duty cycle of 50%.

When a type A34 Power Transmitter first applies a Power Signal (Digital Ping; see the *Qi Specification, Communications Protocol*), it shall use an initial voltage of $7.0^{\pm 1.0}$ V for a bottom Primary Coil, and $6.0^{\pm 1.0}$ V for a top Primary Coil, and a recommended Operating Frequency of 110 kHz.

Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Qi Specification, Power Delivery*. The controlled variable $v^{(i)}$ introduced in the definition of that algorithm represents the input voltage to the inverter. In order to guarantee sufficiently accurate power control, a type A34 Power Transmitter shall determine the amplitude of the Primary Cell current—which is equal to the Primary Coil current—with a resolution of 7 mA or better. Finally, Table 105 provides the values of several parameters, which are used in the PID algorithm.

Figure 148. Electrical diagram (outline) of Power Transmitter design A34

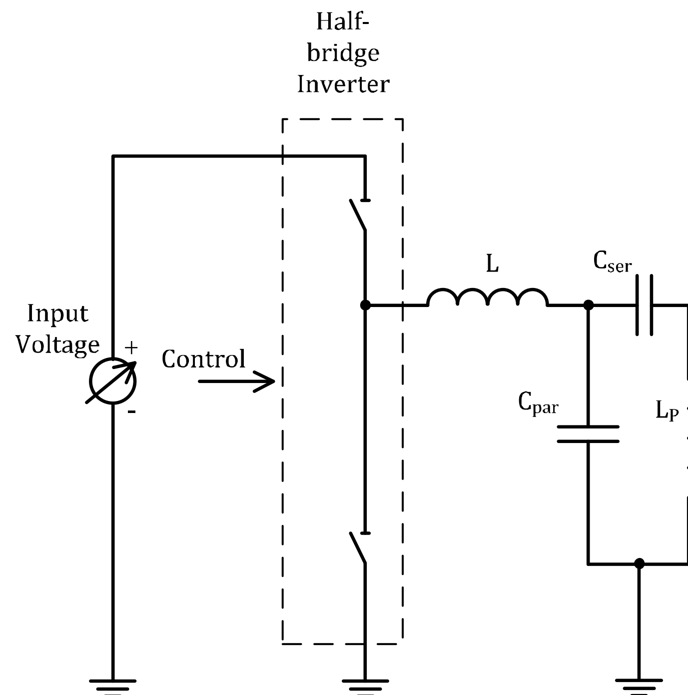


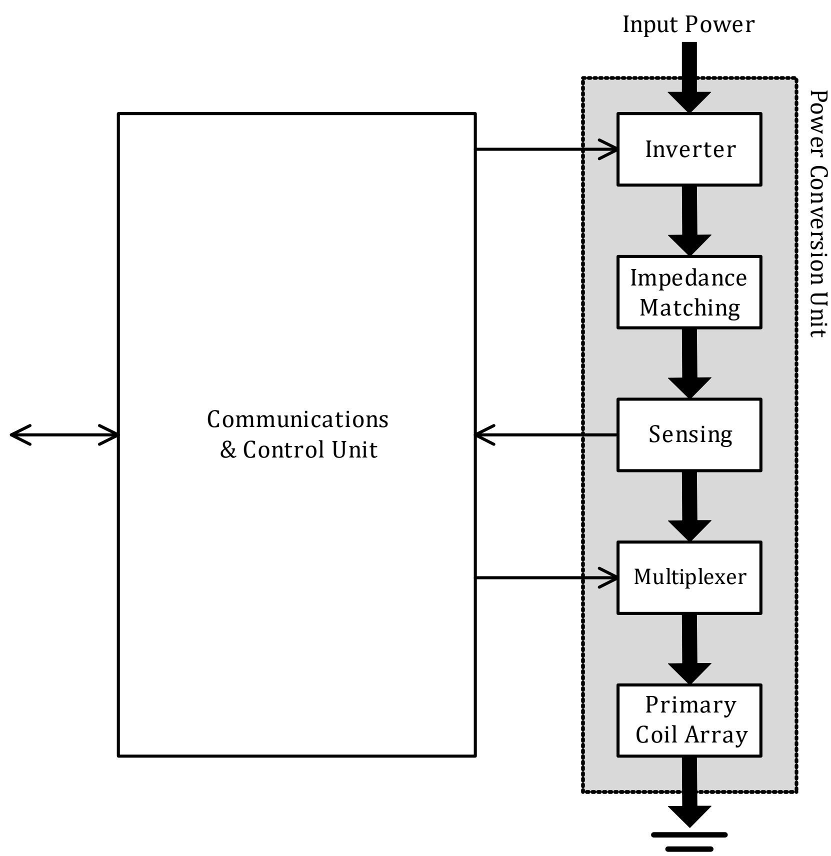
Table 105: PID parameters for voltage control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	0.03	mA^{-1}
Integral gain	K_i	0.01	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	3,000	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_v	-2	mV

39 Power Transmitter design B1

Power Transmitter design B1 enables Free Positioning. Figure 149 illustrates the functional block diagram of this design, which consists of two major functional units, namely a Power Conversion Unit and a Communications and Control Unit.

Figure 149. Functional block diagram of Power Transmitter design B1



The Power Conversion Unit on the right-hand side of Figure 149 comprises the analog parts of the design. The design uses an array of partly overlapping Primary Coils to provide for Free Positioning. Depending on the position of the Power Receiver, the multiplexer connects and/or disconnects the appropriate Primary Coils. The impedance matching network forms a resonant circuit with the parts of the Primary Coil array that are connected. The sensing circuits monitor (amongst others) the Primary Cell current and voltage, and the inverter converts the DC input to an AC waveform that drives the Primary Coil array.

The Communications and Control Unit on the left-hand side of Figure 149 comprises the digital logic part of the design. This unit receives and decodes messages from the Power Receiver, configures the multiplexer to connect the appropriate parts of the Primary Coil array, executes the relevant power control algorithms and protocols, and drives the frequency and input voltage to the inverter to control the amount of power provided to the Power Receiver. The Communications and Control Unit also interfaces with the other subsystems of the Power Transmitter Product, e.g. for user interface purposes.

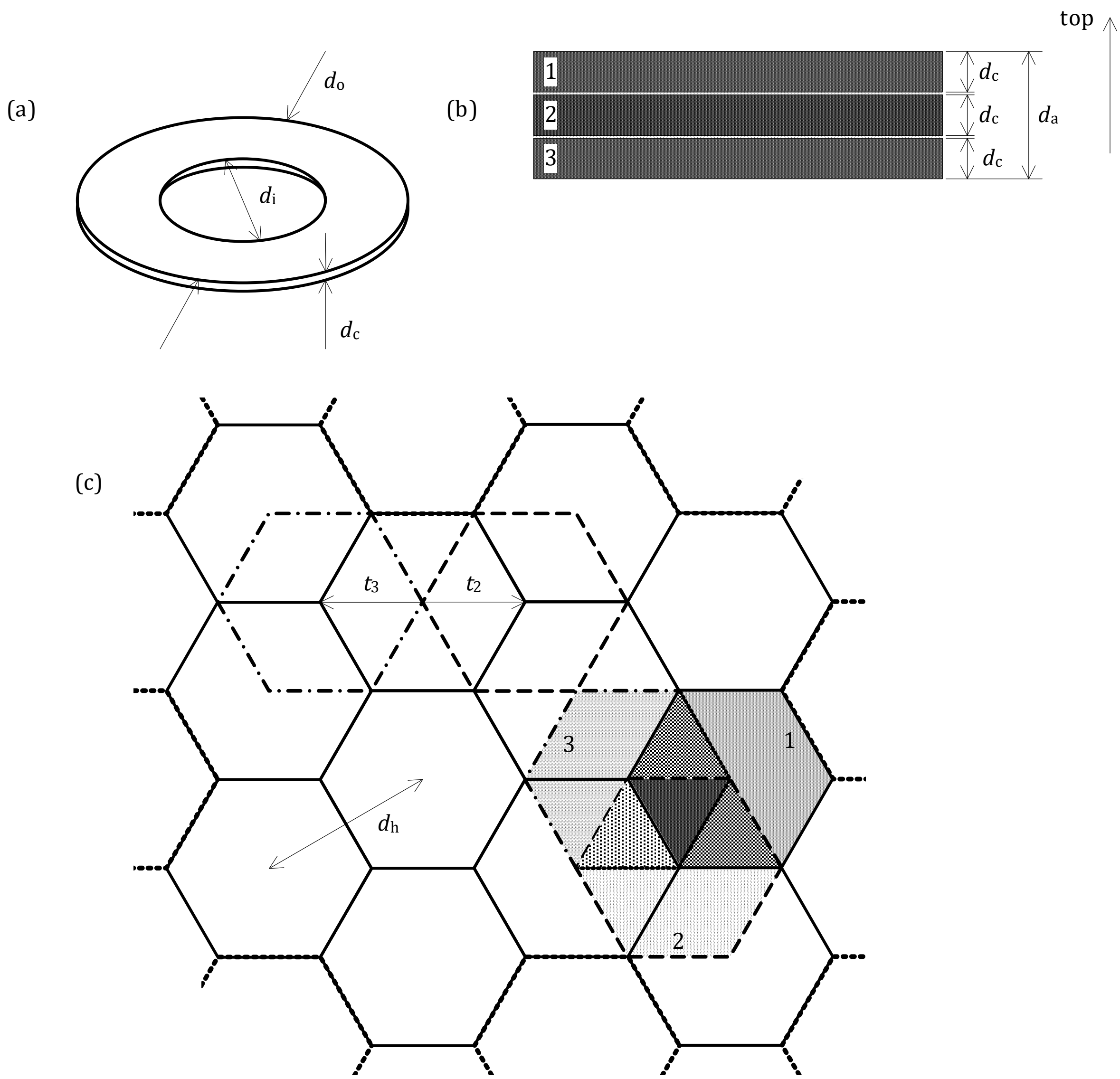
39.1 Mechanical details

Power Transmitter design B1 includes a Primary Coil array as defined in Section 39.1.1, *Primary Coil array*, Shielding as defined in Section 39.1.2, *Shielding*, and an Interface Surface as defined in Section 39.1.3, *Interface Surface*.

39.1.1 Primary Coil array

The Primary Coil array consists of 3 layers. Figure 150(a) shows a top view of a single Primary Coil, which is of the wire-wound type, and consists of litz wire having 24 strands of no. 40 AWG (0.08 mm diameter), or equivalent.

Figure 150. Primary Coil array of Power Transmitter design B1



As shown in Figure 150(a), the Primary Coil has a circular shape and consists of a single layer. Figure 150(b) shows a side view of the layer structure of the Primary Coil array. Figure 150(c) provides a top view of the Primary Coil array, showing that the individual Primary Coils are packed in a hexagonal grid. The solid hexagons show the closely packed structure of the grid of Primary Coils on layer 1 of the Primary Coil array. The dashed hexagon illustrates that the grid of Primary Coils on layer 2 is offset over a distance t_2 to the right, such that the centers of the Primary Coils in layer 2 coincide with the corners of Primary Coils in layer 1. Likewise, the dash-dotted hexagon illustrates that the grid of Primary Coils on layer 3 is offset over a distance t_3 to the left, such that the centers of the Primary Coils in layer 3 coincide with the corners of Primary Coils in layer 1. As a result, the centers, respectively corners, of the Primary Coils on layer 2 and the corners, respectively centers, of the Primary Coils on layer 3 coincide as well. All Primary Coils are stacked with the same polarity. See Section 39.2, *Electrical details* for the meaning of the shaded hexagons.

Table 106 lists the relevant parameters of the Primary Coil array.

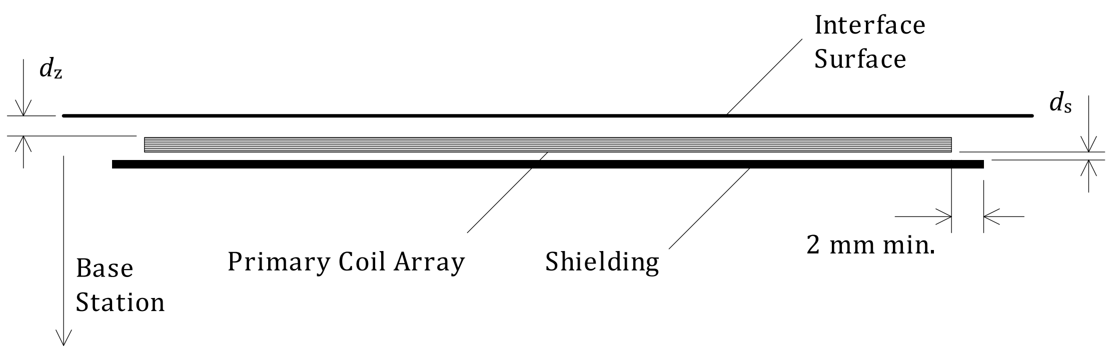
Table 106: Primary Coil array parameters of Power Transmitter design B1

Parameter	Symbol	Value
Outer diameter	d_o	$28.5_{-0.7}$ mm
Inner diameter	d_i	$10.5^{\pm 0.3}$ mm
Layer thickness*	d_c	$0.6^{+0.05}_{0.1}$ mm
Number of turns	N	16
Array thickness	d_a	$1.9^{+0.3}_{0.2}$ mm
Center-to-center distance	d_h	28.6^{+1} mm
Offset 2nd layer array	t_2	$16.5^{+0.6}$ mm
Offset 3rd layer array	t_3	$16.5^{+0.6}$ mm
*Value includes thickness of connection wires.		

39.1.2 Shielding

As shown in Figure 151, Transmitter design B1 employs Shielding to protect the Power Transmitter Product from the magnetic field that is generated in the Primary Coil array. The Shielding should be Ni-Zn or Mn-Zn ferrite and should be at least 0.5 mm thick. The Shielding extends to at least 2 mm beyond the outer edges of the Primary Coil array, and is placed at a distance of at most d_s = 0.5 mm below the Primary Coil array.

Figure 151. Primary Coil array assembly of Power Transmitter design B1



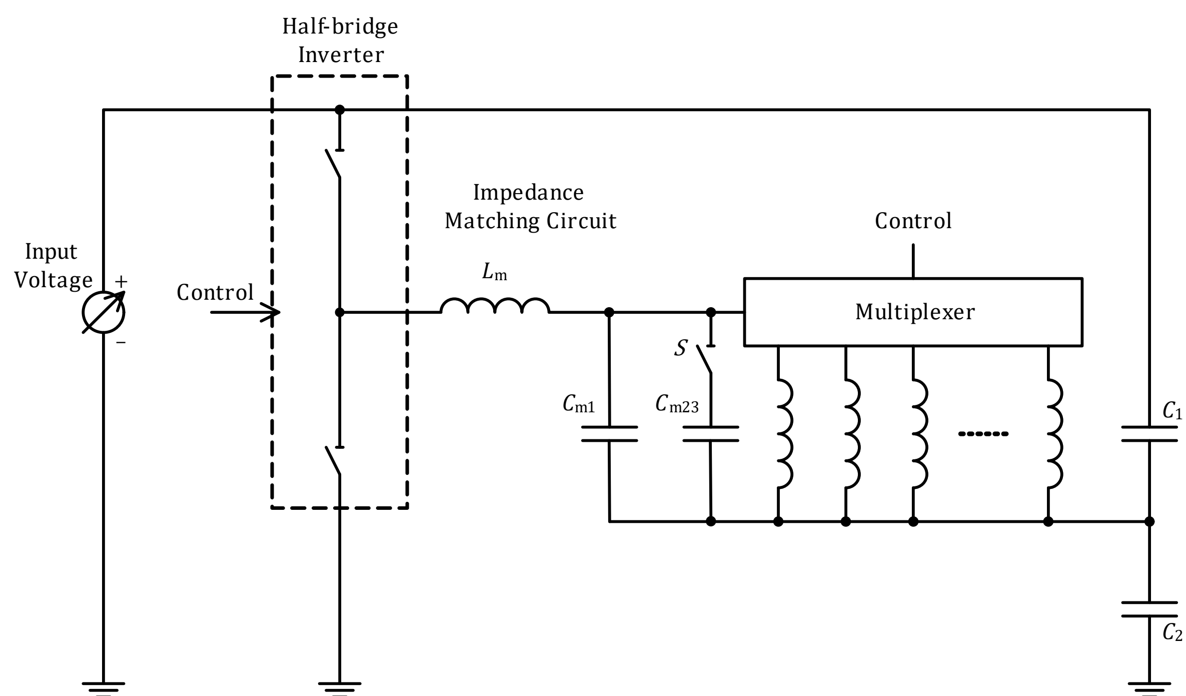
39.1.3 Interface Surface

As shown in Figure 151, the distance from the Primary Coil array to the Interface Surface of the Power Transmitter Product is $d_Z = 2^{+0.5}_{0.25}$ mm, across the top face of the Primary Coil array. In addition, the Interface Surface extends at least 5 mm beyond the outer edges of the Primary Coil array.

39.2 Electrical details

As shown in Figure 152, Power Transmitter design B1 uses a half-bridge inverter to drive the Primary Coil array. In addition, Power Transmitter design B1 uses a multiplexer to select the position of the Active Area. The multiplexer shall configure the Primary Coil array in such a way that one, two, or three Primary Coils are connected—in parallel—to the driving circuit. The connected Primary Coils together constitute a Primary Cell. As an additional constraint, the multiplexer shall select the Primary Coils such that each selected Primary Coil has an overlap with every other selected Primary Coil; see Figure 149(c) for an example.

Figure 152. Electrical diagram (outline) of Power Transmitter design B1



Within the Operating Frequency range f_{op} = 105...113 kHz, the assembly of Primary Coil array and Shielding has an inductance of $8.1^{\pm 1}$ μH for each individual Primary Coil in layer 1 (closest to the Interface Surface), $8.7^{\pm 1}$ μH for each individual Primary Coil in layer 2, and $9.6^{\pm 1}$ μH for each individual Primary Coil in layer 3. The capacitances and inductance in the impedance matching circuit are, respectively, $C_{m1} = 300^{\pm 5\%}$ nF, $C_{m23} = 200^{\pm 5\%}$ nF, and $L_m = 3.8^{\pm 5\%}$ μH. The capacitances C_1 and C_2 in the half-bridge inverter both are 68 μF. The switch S is open if the Primary Cell consists of a single Primary Coil; otherwise, the switch S is closed.

NOTE: The voltage across the capacitance C_m can reach levels exceeding 36 V pk-pk.

Power Transmitter design B1 uses the input voltage to the half-bridge inverter to control the amount of power that is transferred. For this purpose, the input voltage range is 0…20 V, where a lower input voltage results in the transfer of a lower amount of power. In order to achieve a sufficiently accurate adjustment of the power that is transferred, a type B1 Power Transmitter shall be able to control the input voltage with a resolution of 35 mV or better.

When a type B1 Power Transmitter first applies a Power Signal (Digital Ping: see the *Qi Specification, Communications Protocol*), it shall use an initial input voltage of 12 V.

Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Qi Specification, Power Delivery*. The controlled variable $v^{(i)}$ introduced in the definition of that algorithm represents the input voltage to the half-bridge inverter. In order to guarantee sufficiently accurate power control, a type B1 Transmitter shall determine the amplitude of the current into the Primary Cell with a resolution of 5 mA or better. In addition to the PID algorithm, a type B1 Power Transmitter shall limit the current into the Primary Cell to at most 4 A RMS in the case that the Primary Cell consists of two or three Primary Coils, or at most 2 A RMS in the case that the Primary Cell consists of one Primary Coil. For that purpose, the Power Transmitter may limit the input voltage to the half-bridge inverter to value that is lower than 20 V. Finally, Table 107 provides the values of several parameters, which are used in the PID algorithm.

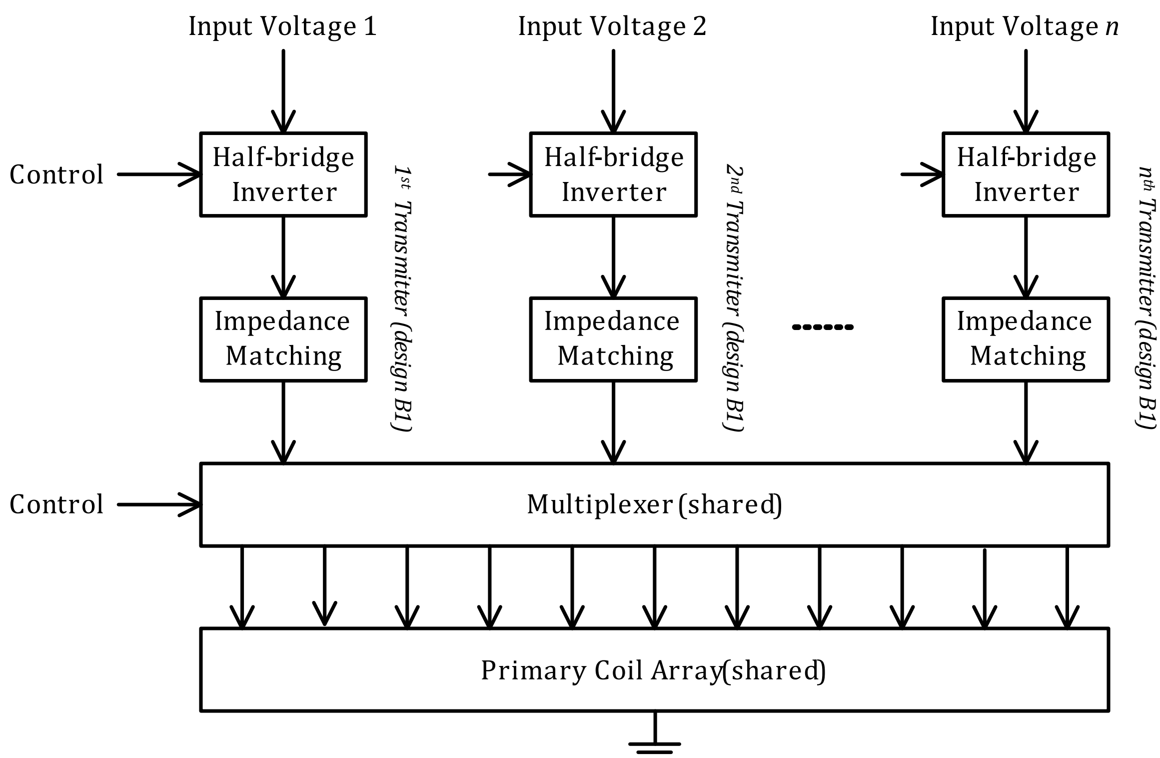
Table 107: PID parameters for voltage control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	1	mA^{-1}
Integral gain	K_i	0	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	N.A.	N.A.
PID output limit	M_{PID}	2,000	N.A.
Scaling factor	S_v	–1	mV

39.2.1 Scalability

Section 39.1, *Mechanical details* and Section 39.2, *Electrical details* define the mechanical and electrical details of Power Transmitter design B1. As defined in Section 2, *Overview*, a type B1 Power Transmitter serves a single Power Receiver only. In order to serve multiple Power Receivers simultaneously, a Power Transmitter Product may contain multiple type B1 Power Transmitters. As shown in Figure 153, these Power Transmitters may share the Primary Coil array and multiplexer. However, each individual Power Transmitter shall have a separately controllable inverter, impedance matching circuit, and means to determine the Primary Cell current, as defined in Section 39.2, *Electrical details*. In addition, the multiplexer shall ensure that it does not connect multiple inverters to any individual Primary Coil.

Figure 153. Multiple type B1 Power Transmitters sharing a multiplexer and Primary Coil array



40 Power Transmitter design B2

Power Transmitter design B2 enables Free Positioning. The main difference between Power Transmitter design B2 and Power Transmitter design B1 is the Primary Coil array. Power Transmitter design B2 is based on a Printed Circuit Board (PCB) type Primary Coil array. The functional block diagram of a type B2 Power Transmitter is identical to the functional block diagram of a type B1 Power Transmitter; see Figure 149 (in Section 39.1) and the descriptive text in Section 2, *Overview*.

40.1 Mechanical details

Power Transmitter design B2 includes a Primary Coil array as defined in Section 40.1.1, *Primary Coil array*, Shielding as defined in Section 40.1.2, *Shielding*, and an Interface Surface as defined in Section 40.1.3, *Interface Surface*.

40.1.1 Primary Coil array

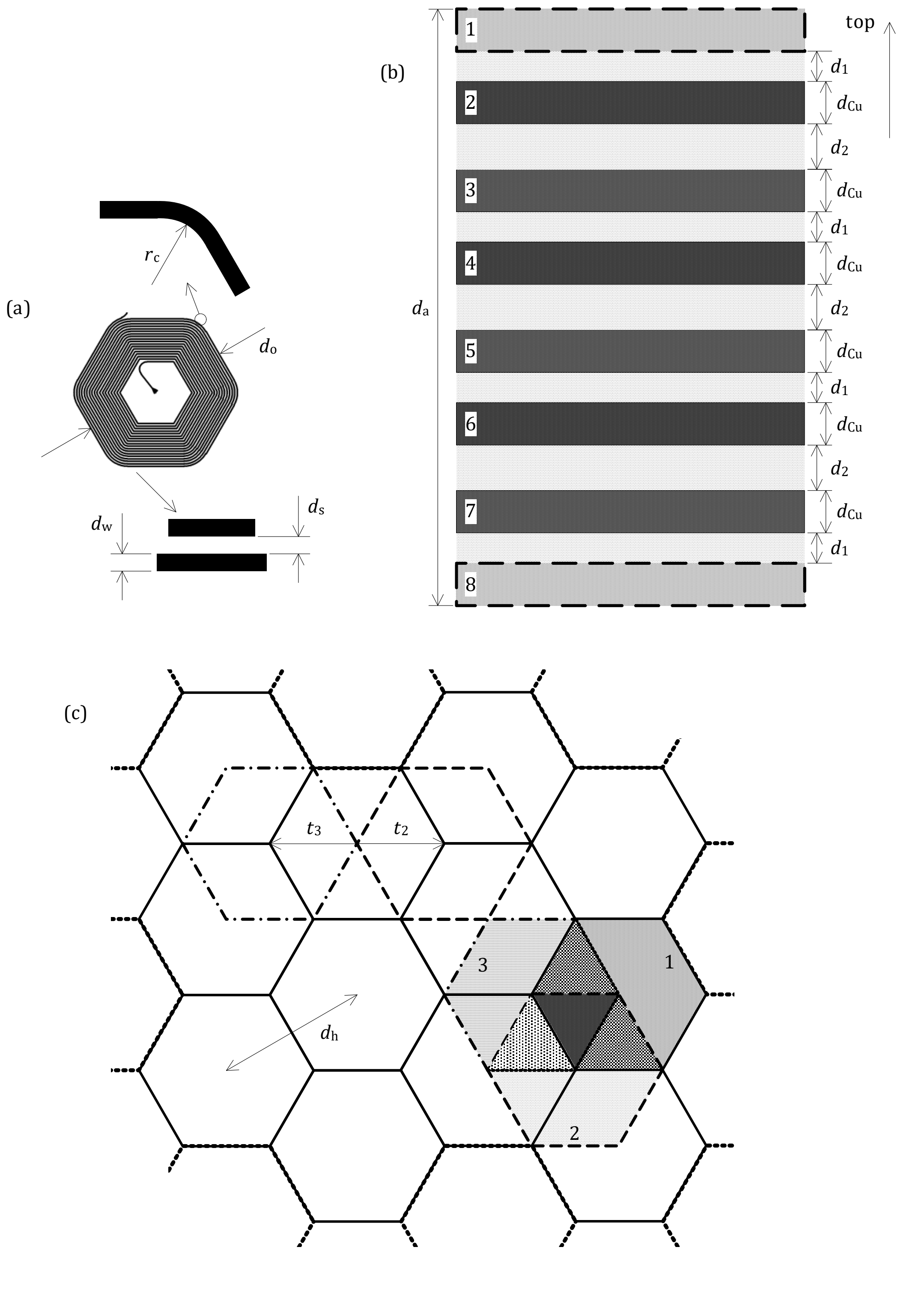
The Primary Coil array consists of an 8 layer PCB. The inner six layers of the PCB each contain a grid of Primary Coils, and the bottom layer contains the leads to each of the individual Primary Coils. The top layer can be used for any purpose, but shall not influence the inductance values of the Primary Coils. Figure 154(a) shows a top view of a single Primary Coil, which consists of a trace that runs through 18 hexagonal turns. As shown in the top inset of Figure 154(a), the corners of this hexagonal shape are rounded. The bottom inset of Figure 154(a) shows the width of the trace as well as the distance between two adjacent turns. Figure 154(b) shows a side view of the layer structure of the PCB. Copper layers 2, 3, 4, 5, 6, and 7 each contain a grid of Primary Coils. Copper layer 8 contains the leads to each of the Primary Coils. Figure 154(c) provides a top view of the Primary Coil array, showing that the individual Primary Coils are packed in a hexagonal grid. The solid hexagons show the closely packed structure of the grids of Primary Coils on layer 2 and layer 7 of the Primary Coil array. Each solid hexagon represents a set of two identical Primary Coils—in this case one Primary Coil on layer 2 and one Primary Coil on layer 7, respectively—which are connected in parallel. The dashed hexagon illustrates that the grids of Primary Coils on layer 3 and layer 6 are offset over a distance t_2 to the right, such that the centers of the Primary Coils in layer 3 and layer 6 coincide with the corners of Primary Coils in layer 2 and layer 7. Likewise, the dash-dotted hexagon illustrates that the grids of Primary Coils on layer 4 and layer 5 are offset over a distance t_3 to the left, such that the centers of the Primary Coils in layer 4 and layer 5 coincide with the corners of Primary Coils in layer 2 and layer7. As a result, the centers, respectively corners, of the Primary Coils on layer 3 and layer 6 and the corners, respectively centers, of the Primary Coils on layer 4 and layer 5 coincide as well. See Section 40.2, *Electrical details* for the meaning of the shaded hexagons.

Table 108 lists the relevant parameters of the Primary Coil array. The finished PCB thickness is $1.3^{\pm 10\%}$ mm.

Table 108: Primary Coil array parameters of Power Transmitter design B2

Parameter	Symbol	Value
Outer diameter	d_o	$31^{\pm 0.4}$ mm
Track width	d_w	$0.42^{\pm 0.03}$ mm
Track width plus spacing	$d_w + d_s$	$0.6^{\pm 0.03}$ mm
Corner rounding*	r_c	$5^{\pm 3}$ mm
Number of turns	N	18
Track thickness	d_{Cu}	$0.07^{\pm 0.014}$ mm
Dielectric thickness 1	d_{d1}	$0.089^{+0.15}_{0}$ mm
Dielectric thickness 2	d_{d2}	$0.1^{\pm 0.013}$ mm
Array thickness	d_a	$1.14^{\pm 0.05}$ mm
Center-to-center distance	d_h	$31.855^{\pm 0.2}$ mm
Offset 2nd layer array	t_2	$18.4^{\pm 0.1}$ mm
Offset 3rd layer array	t_3	$18.4^{\pm 0.1}$ mm
* Value applies to the outermost winding.		

Figure 154. Primary Coil array of Power Transmitter design B2



40.1.2 Shielding

Power Transmitter design B2 employs Shielding that is identical to the Shielding of Power Transmitter design B1. See Section 39.1.2, *Shielding*.

40.1.3 Interface Surface

The distance from the Primary Coil array to the Interface Surface of the Power Transmitter Product is $d_{\mathrm{Z}} = 2^{+0.1}_{\ 0.5}$ mm, across the top face of the Primary Coil array. See also Figure 151 (in Section 39.1). In addition, the Interface Surface extends at least 5 mm beyond the outer edges of the Primary Coil array.

40.2 Electrical details

The outline of the electrical diagram of Power Transmitter design B2 follows the outline of the electrical diagram of Power Transmitter design B1. See also Figure 152 (in Section 39.1).

Power Transmitter design B2 uses a half-bridge inverter to drive the Primary Coil array. In addition, Power Transmitter design B2 uses a multiplexer to select the position of the Active Area. The multiplexer shall configure the Primary Coil array in such a way that one, two, or three sets of two Primary Coils are connected—in parallel—to the driving circuit. The connected Primary Coils together constitute a Primary Cell. As an additional constraint, the multiplexer shall select the Primary Coils such that each selected Primary Coil has an overlap with every other selected Primary Coil; see Figure 154(c) for an example.

Within the Operating Frequency range f_{op} = 105...113 kHz, the assembly of Primary Coil array and Shielding has an inductance of $11.7^{\pm1}$ μH for each set of Primary Coils in layer 2 and layer 7 (connected in parallel), $11.8^{\pm1}$ μH for each set of Primary Coils in layer 3 and layer 6 (connected in parallel), and $12.3^{\pm1}$ μH for each set of Primary Coils in layer 4 and 5 (connected in parallel). The capacitance and inductance in the impedance matching circuit (Figure 152 (in Section 39.1)) are, respectively, $C_{m1} = 256^{\pm5\%}$ nF, $C_{m23} = 147^{\pm5\%}$ nF and $L_m = 3.8^{\pm5\%}$ μH. The capacitances C_1 and C_2 in the half-bridge inverter both are 68 μF. The switch S is open if the Primary Cell consists of a single Primary Coil; otherwise, the switch S is closed.

NOTE: The voltage across the capacitance C_m can reach levels exceeding 36 V pk-pk.

Power Transmitter design B2 uses the input voltage to the half-bridge inverter to control the amount of power that is transferred. For this purpose, the input voltage range is 0…20 V, where a lower input voltage results in the transfer of a lower amount of power. In order to achieve a sufficiently accurate adjustment of the power that is transferred, a type B2 Power Transmitter shall be able to control the input voltage with a resolution of 35 mV or better.

When a type B2 Power Transmitter first applies a Power Signal (Digital Ping: see the *Qi Specification, Communications Protocol*), it shall use an initial input voltage of 12 V.

Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Qi Specification, Power Delivery*. The controlled variable $v^{(i)}$ introduced in the definition of that algorithm represents the input voltage to the half-bridge inverter. In order to guarantee sufficiently accurate power control, a type B2 Transmitter shall determine the amplitude of the current into the Primary Cell (i.e. the sum of the currents through each of its three constituent Primary Coils) with a resolution of 5 mA or better. In addition to the PID algorithm, a type B2 Power Transmitter shall limit the current into the Primary Cell to at most 3.5 A RMS in the case that the Primary Cell consists of two or three Primary Coils, or at most 1.75 A RMS in the case that the Primary Cell consists of one Primary Coil. For that purpose, the Power Transmitter may limit the input voltage to the half-bridge inverter to value that is lower than 20 V. Finally, Table 107 (in Section 39.1) provides the values of several parameters, which are used in the PID algorithm.

40.2.1 Scalability

Power Transmitter Design B2 offers the same scalability options as Power Transmitter design B1. See Section 39.2.1, *Scalability*.

41 Power Transmitter design B3

Power Transmitter design B3 enables Free Positioning, and has a design similar to Power Transmitter design B1. See Section 39, *Power Transmitter design B1* for an overview.

41.1 Mechanical details

Power Transmitter design B3 includes a Primary Coil array as defined in Section 41.1.1, *Primary Coil array*, Shielding as defined in Section 41.1.2, *Shielding*, and an Interface Surface as defined in Section 41.1.3, *Interface Surface*.

41.1.1 Primary Coil array

The Primary Coil array consists of a hybrid PCB/wire wound coil structure. As shown Figure 155(a), the central part of this structure is a 4-layer PCB. The inner two layers of this PCB each contain an identical grid of coils, where corresponding coils are connected in parallel to form a single two-layer Primary Coil. The outer two layers of the PCB serve as a mounting area for the wire wound Primary Coils (layers (a) and (b). In addition, layer 4 of the PCB contains the leads to both the internal and the wire wound Primary Coils; and layer 1 can be used for any purpose, but shall not influence the inductance values of the Primary Coils.

The wire-wound Primary Coils consist of litz wire having 24 strands of no. 40 AWG (0.08 mm diameter), or equivalent. Each wire wound Primary Coil has a circular shape as shown in Figure 155(b).

Each Primary Coil inside the PCB consists of a trace that runs through 18 hexagonal turns as shown in Figure 155(c), and are identical to the Primary Coils of Power Transmitter design B2 defined in Section 41.1.1, *Primary Coil array*.

Figure 155(d) provides a top view of the Primary Coil array, showing that the individual Primary Coils are packed in a hexagonal grid. The solid hexagons show the closely packed structure of the grid of Primary Coils on layer (a) of the Primary Coil array. The dashed hexagon illustrates that the identical grids of Primary Coils on layers (2) and (3) are offset over a distance t_2 to the right, such that the centers of the Primary Coils in layers (2) and (3) coincide with the corners of Primary Coils in layer (a). Likewise, the dash-dotted hexagon illustrates that the grid of Primary Coils on layer (b) is offset over a distance t_3 to the left, such that the centers of the Primary Coils in layer (b) coincide with the corners of Primary Coils in layer (a). As a result, the centers, respectively corners, of the Primary Coils on layer (2) and (3), and the corners, respectively centers, of the Primary Coils on layer (b) coincide as well. All Primary Coils are stacked with the same polarity. See Section 41.2, *Electrical details* for the meaning of the shaded hexagons.

Table 109 lists the relevant parameters of the Primary Coil array.

Figure 155. Primary Coil array of Power Transmitter design B3

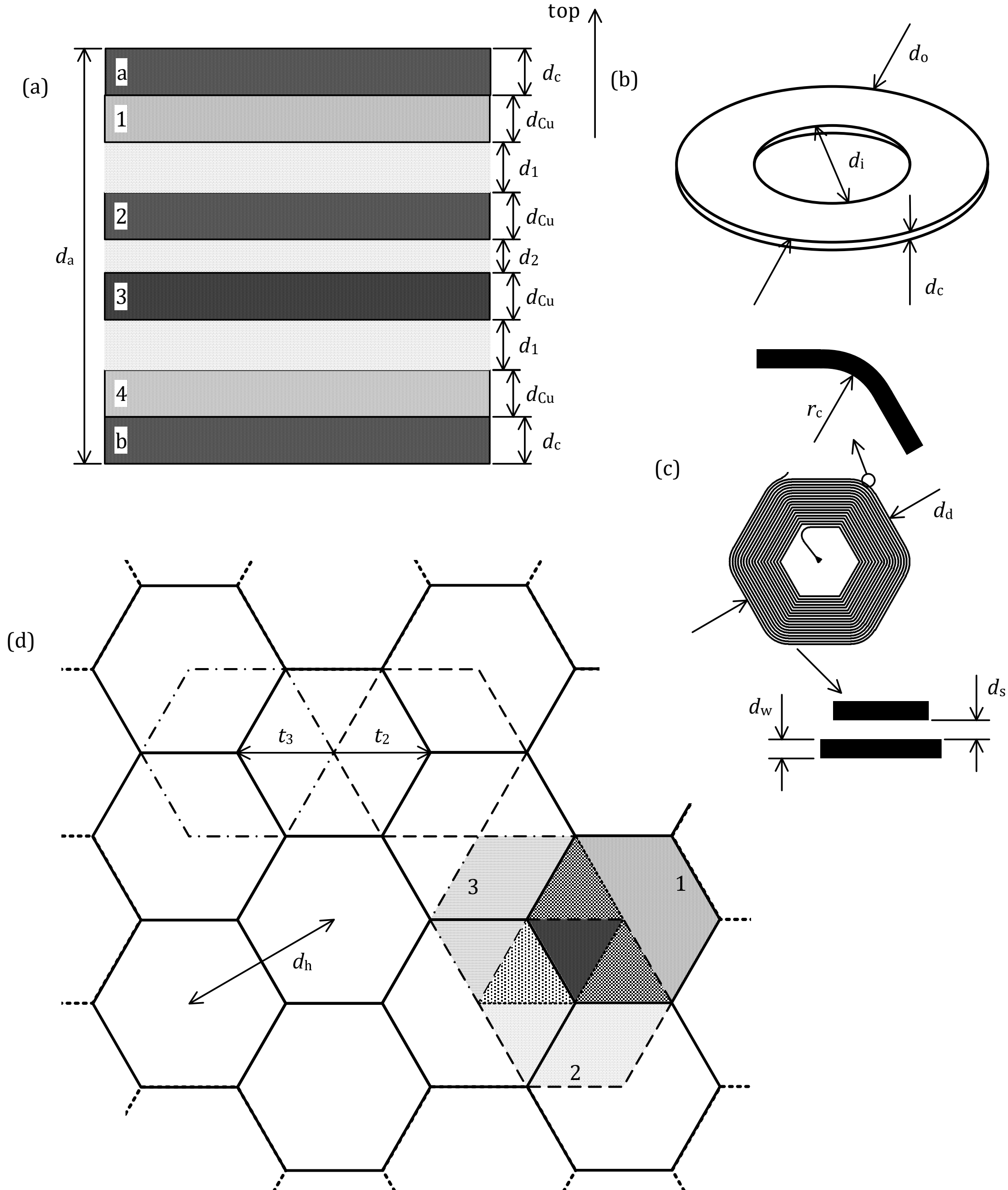


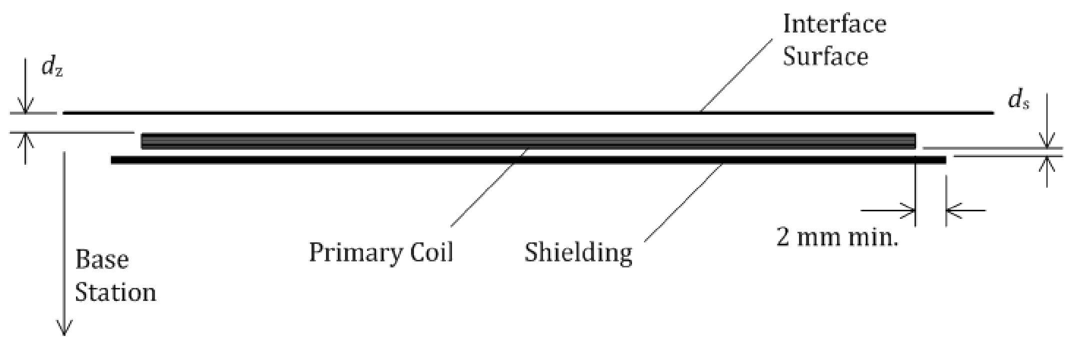
Table 109: Primary Coil array parameters of Power Transmitter design B3

Parameter	Symbol	Value
Outer diameter	d_o	$31.1^{\pm 0.5}$ mm
Inner diameter	d_i	$10.6^{\pm 0.3}$ mm
Layer thickness	d_c	$0.4^{\pm 0.05}$ mm
Number of turns	N	18
Outer diameter	d_d	$31^{\pm 0.4}$ mm
Track width	d_w	$0.42^{\pm 0.03}$ mm
Track width plus spacing	$d_w + d_s$	$0.6^{\pm 0.03}$ mm
Corner rounding*	r_c	$5^{\pm 3}$ mm
Number of turns	N	18
Track thickness	d_{Cu}	$0.07^{\pm 0.015}$ mm
Dielectric thickness 1	d_{d1}	$0.088^{+0.1}_{0}$ mm
Dielectric thickness 2	d_{d2}	$0.145^{\pm 0.02}$ mm
PCB thickness		$0.6^{\pm 0.1}$ mm
Array thickness	d_a	$1.5^{\pm 0.2}$ mm
Center-to-center distance	d_h	$31.855^{\pm 0.2}$ mm
Offset 2nd layer array	t_2	$18.4^{\pm 0.1}$ mm
Offset 3rd layer array	t_3	$18.4^{\pm 0.1}$ mm

41.1.2 Shielding

As shown in Figure 156, Transmitter design B3 employs Shielding to protect the Power Transmitter Product from the magnetic field that is generated in the Primary Coil array. The Shielding should be Ni-Zn or Mn-Zn ferrite and should be at least 0.5 mm thick. The Shielding extends to at least 2 mm beyond the outer edges of the Primary Coil array, and is placed at a distance of at most $d_s = 0.5$ mm below the Primary Coil array.

Figure 156. Primary Coil array assembly of Power Transmitter design B3



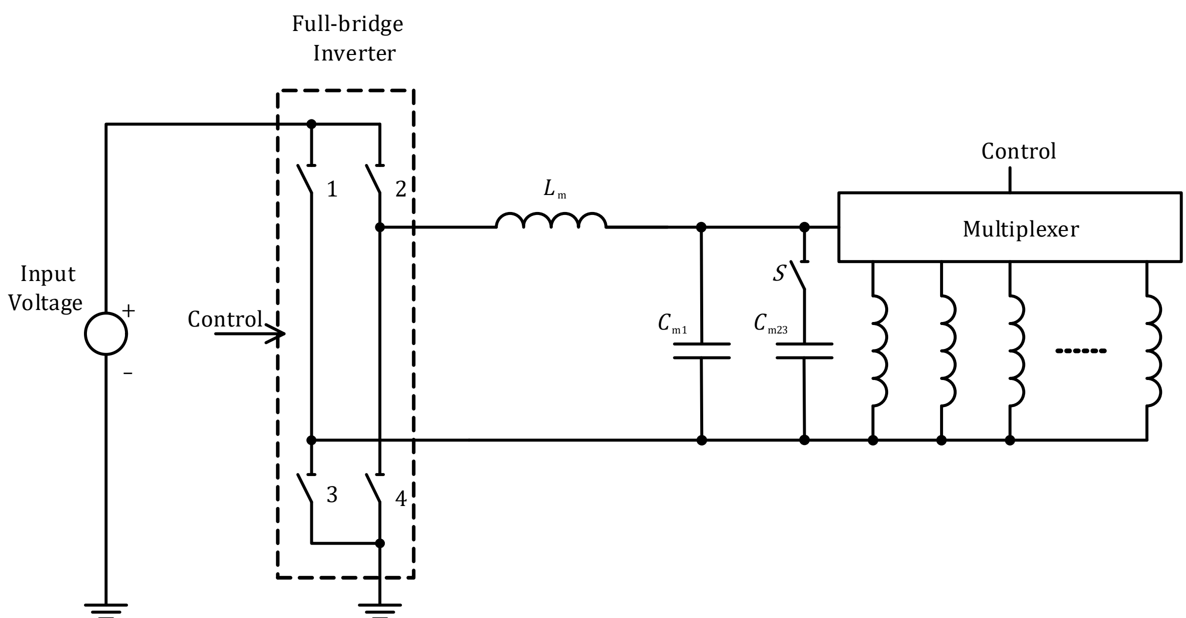
41.1.3 Interface Surface

As shown in Figure 156, the distance from the Primary Coil array to the Interface Surface of the Power Transmitter Product is $d_Z = 2^{+0.1}_{0.5}$ mm, across the top face of the Primary Coil array. In addition, the Interface Surface extends at least 5 mm beyond the outer edges of the Primary Coil array.

41.2 Electrical details

As shown in Figure 157, Power Transmitter design B3 uses a full-bridge inverter to drive the Primary Coil array. In addition, Power Transmitter design B3 uses a multiplexer to select the position of the Active Area. The multiplexer shall configure the Primary Coil array in such a way that one, two, or three Primary Coils are connected—in parallel—to the driving circuit. The connected Primary Coils together constitute a Primary Cell. As an additional constraint, the multiplexer shall select the Primary Coils such that each selected Primary Coil has an overlap with every other selected Primary Coil; see Figure 155(d) for an example.

Figure 157. Electrical diagram (outline) of Power Transmitter design B3

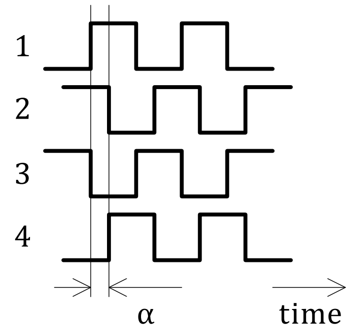


Within the Operating Frequency range f_{op} = 105...113 kHz, the assembly of Primary Coil array and Shielding has an inductance of $11.6^{\pm1}$ µH for each individual Primary Coil in layer (a) (closest to the Interface Surface), $12.4^{\pm1}$ µH for each individual Primary Coil in PCB layers 2 and 3, and $13.5^{\pm1.5}$ µH for each individual Primary Coil in layer (b). The capacitances and inductance in the impedance matching circuit are, respectively, $C_{m1} = 222^{\pm5\%}$ nF, $C_{m23} = 133^{\pm5\%}$ nF, and $L_m = 3.8^{\pm5\%}$ µH. The switch S is open if the Primary Cell consists of a single Primary Coil; otherwise, the switch S is closed. The input voltage to the full-bridge inverter is $12^{\pm5\%}$ V.

NOTE: The voltage across the capacitance C_m can reach levels exceeding 36 V pk-pk.

Power Transmitter design B3 uses the phase difference between the control signals to two halves of the full-bridge inverter to control the amount of power that is transferred, see Figure 158. For this purpose, the range of the phase difference α is 0…180°—with a larger phase difference resulting in a lower power transfer. In order to achieve a sufficient accurate adjustment of the power that is transferred, a type B3 Power transmitter shall be able to control the phase difference with a resolution of 0.42° or better. When a type B3 Power Transmitter first applies a Power Signal (Digital Ping: see the *Qi Specification, Communications Protocol*), it shall use an initial phase difference of 120°.

Figure 158. Control signals to the inverter



Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Qi Specification, Power Delivery*. The controlled variable $v^{(i)}$ introduced in the definition of that algorithm represents the phase difference between the two halves of the full-bridge inverter. In order to guarantee sufficiently accurate power control, a type B3 Transmitter shall determine the amplitude of the current into the Primary Cell with a resolution of 5 mA or better. In addition to the PID algorithm, a type B3 Power Transmitter shall limit the current into the Primary Cell to at most 4 A RMS in the case that the Primary Cell consists of two or three Primary Coils, or at most 2 A RMS in the case that the Primary Cell consists of one Primary Coil. Finally, Table 110 provides the values of several parameters that are used in the PID algorithm.

Table 110: PID parameters for voltage control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	1	mA^{-1}
Integral gain	K_i	0	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	N.A.	N.A.
PID output limit	M_{PID}	2,000	N.A.
Scaling factor	S_v	0.01	°

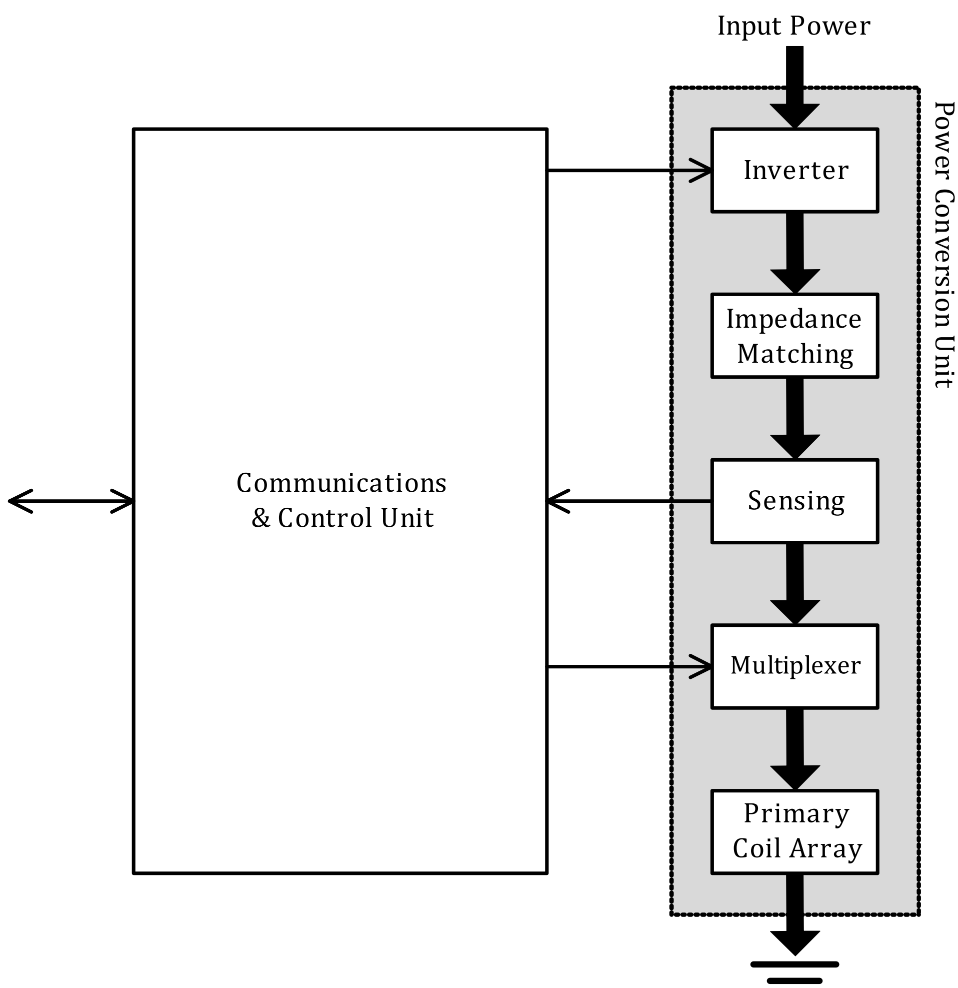
41.2.1 Scalability

Power Transmitter Design B3 offers the same scalability options as Power Transmitter design B1. See Section 39.2.1, *Scalability*.

42 Power Transmitter design B4

Power Transmitter design B4 enables Free Positioning. Figure 159 illustrates the functional block diagram of this design, which consists of two major functional units, namely a Power Conversion Unit and a Communications and Control Unit.

Figure 159. Functional block diagram of Power Transmitter design B4



The Power Conversion Unit on the right-hand side of Figure 159 comprises the analog parts of the design. The design uses an array of partly overlapping Primary Coils to provide for Free Positioning. Depending on the position of the Power Receiver, the multiplexer connects and/or disconnects the appropriate Primary Coils. The impedance matching network forms a resonant circuit with the parts of the Primary Coil array that are connected. The sensing circuits monitor (amongst others) the Primary Cell current and voltage, and the inverter converts the DC input to an AC waveform that drives the Primary Coil array.

The Communications and Control Unit on the left-hand side of Figure 159 comprises the digital logic part of the design. This unit receives and decodes messages from the Power Receiver, configures the multiplexer to connect the appropriate parts of the Primary Coil array, executes the relevant power control algorithms and protocols, and drives the inverter to control the amount of power provided to the Power Receiver. The Communications and Control Unit also interfaces with the other subsystems of the Power Transmitter Product, e.g. for user interface purposes.

42.1 Mechanical details

Power Transmitter design B4 includes a Primary Coil array as defined in Section 42.1.1, *Primary Coil array*, Shielding as defined in Section 42.1.2, *Shielding*, and an Interface Surface as defined in Section 42.1.3, *Interface Surface*.

42.1.1 Primary Coil array

The Primary Coil array consists of partly overlapping square shaped planar coils. Figure 160(a) shows a top view of a single Primary Coil, which consists of a bifilar trace that runs through 11 square shaped turns in a single layer of a PCB. Another realization of a single Primary Coil is to construct it from litz wire having 24 strands of no. 40 AWG (0.08 mm diameter), or equivalent. Figure 160(b) shows a top view of such wire-wound Primary Coil. Table 111 lists the relevant parameters of the coils shown in Figure 160.

Figure 160. Top view of PCB and wire-wound Primary Coil of Power Transmitter design B4

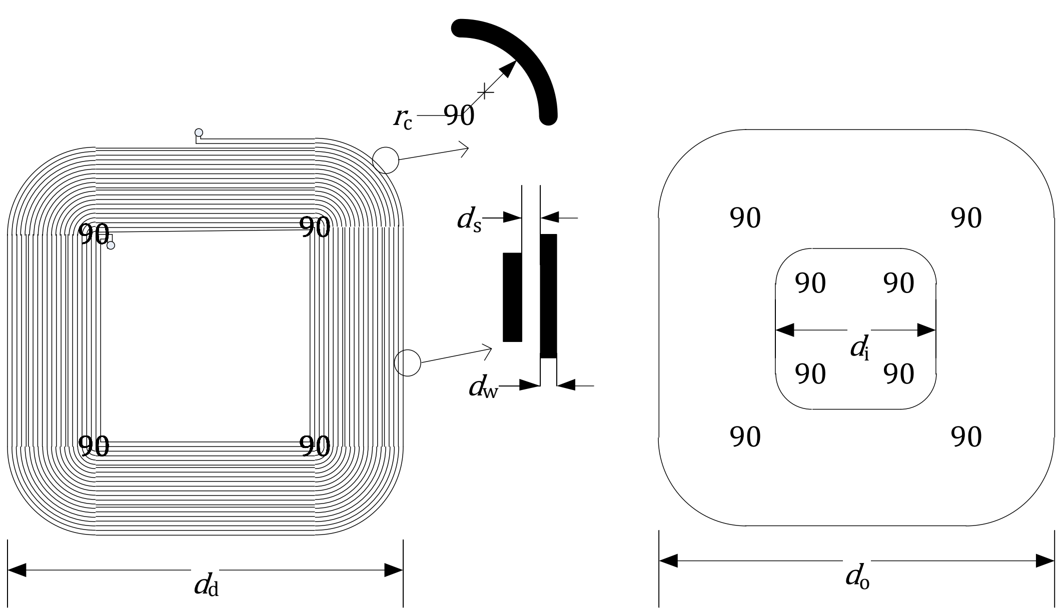


Table 111: Primary Coil parameters of Power Transmitter design B4

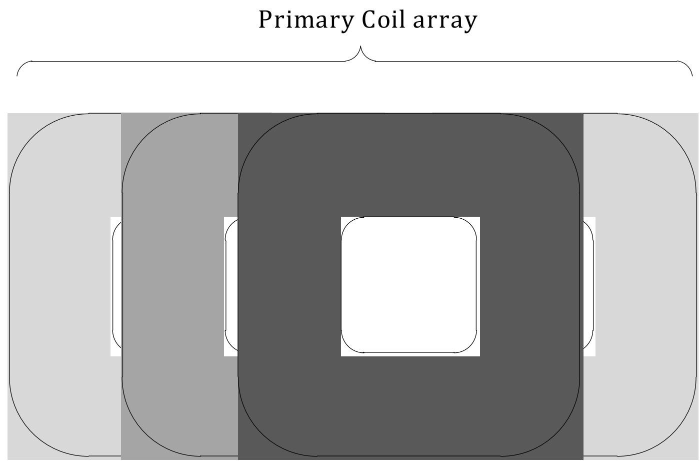
Parameter	Symbol	Value
Litz wire based Primary Coil		
Outer diameter	d_o	$45.0^{+0.5}_{1.0}$ mm
Inner diameter	d_i	$18.6^{\pm 0.3}$ mm
Number of turns	N	11
PCB based Primary Coil		
Outer diameter	d_d	$45^{\pm 0.4}$ mm
Track width	d_w	$0.42^{\pm 0.03}$ mm
Track width plus spacing	$d_w + d_s$	$0.6^{\pm 0.03}$ mm
Corner rounding*	r_c	$9^{\pm 1}$ mm
Number of turns	N	11

* Value applies to the outermost winding.

The Primary Coil array may be constructed from PCB-coils, wire-wound coils or any combination thereof (hybrid). Power Transmitter design B4 enables one-dimensional freedom of positioning. For that purpose the Primary Coils are placed in a row, such that there is an overlap of approximately two-thirds of the area. Each Primary Coil (except for the Primary Coils at both ends of the Primary Coil array) overlaps with two Primary Coils in different layers. Figure 161 shows the layout of the Primary Coil array. Figure 162 shows the layered structure of the Primary Coil array in the case of a PCB only implementation, a litz wire only implementation and a hybrid PCB-litz wire implementation. Table 112 lists the relevant parameters of the Primary Coil array. Any layer of the PCB—if present—may contain functionality other than, or in addition to, the Primary Coils. If such other functionality is present, that functionality shall not affect the inductance values of the Primary Coils.

Figure 161. Top view (a) and cross section (b) of the Primary Coil array of Power Transmitter design B4.

(a)



(b)

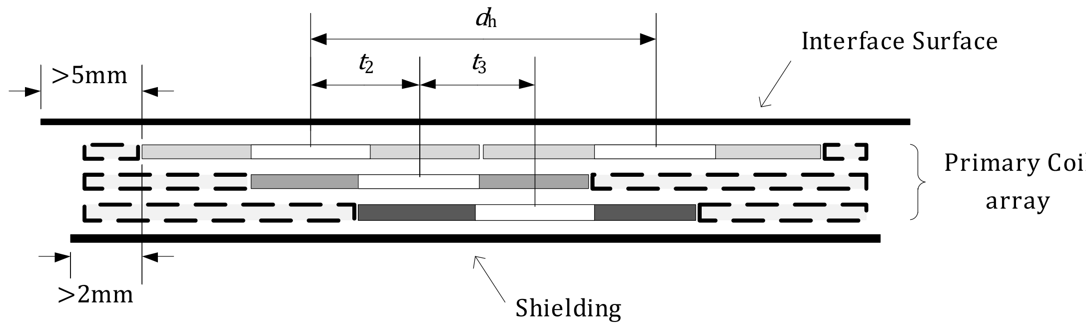


Figure 162. Layered structure of the Primary Coil array

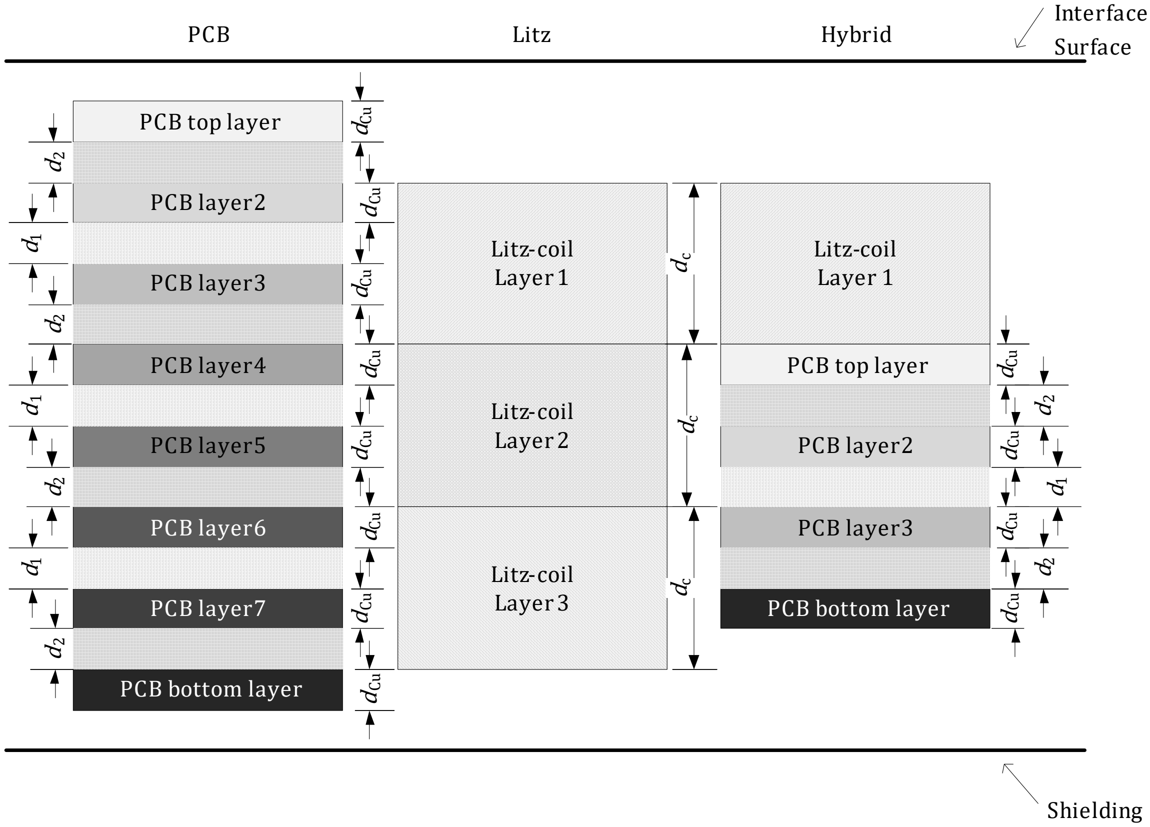


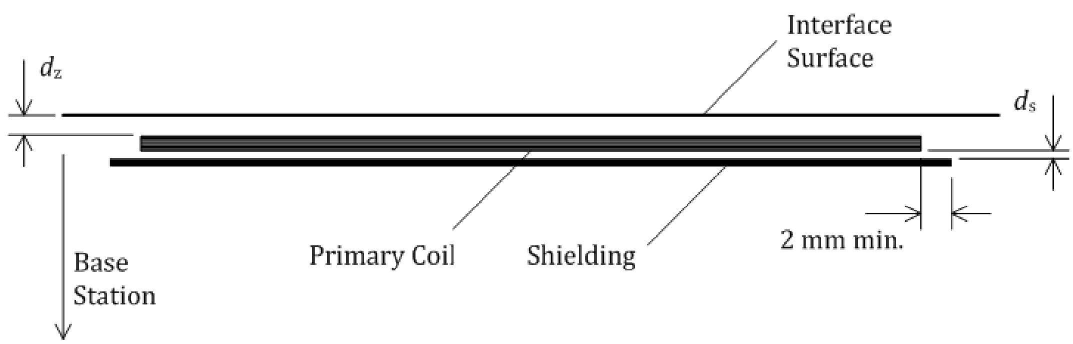
Table 112: Primary Coil array parameters of Power Transmitter design B4

Parameter	Symbol	Value
Center-to-center distance	d_h	$46.5^{\pm 0.2}$ mm
Offset 2nd layer array	t_2	$15.5^{\pm 0.1}$ mm
Offset 3rd layer array	t_3	$15.5^{\pm 0.1}$ mm
Litz-layer thickness	d_c	$0.4^{+0.1}_{\ 0.05}$ mm
PCB-copper thickness	d_{Cu}	$0.07^{\pm 0.015}$ mm
Dielectric thickness 1	d_{d1}	$0.088^{+0.15}_{\ 0}$ mm
Dielectric thickness 2	d_{d2}	$0.126^{\pm 0.039}$ mm

42.1.2 Shielding

As shown in Figure 162, Transmitter design B4 employs Shielding to protect the Power Transmitter Product from the magnetic field that is generated in the Primary Coil array. The Shielding should be Ni-Zn or Mn-Zn ferrite and should be at least 0.5 mm thick. The Shielding extends to at least 2 mm beyond the outer edges of the Primary Coil array, and is placed at a distance of at most d_s = 0.5 mm below the Primary Coil array.

Figure 163. Primary Coil array assembly of Power Transmitter design B4



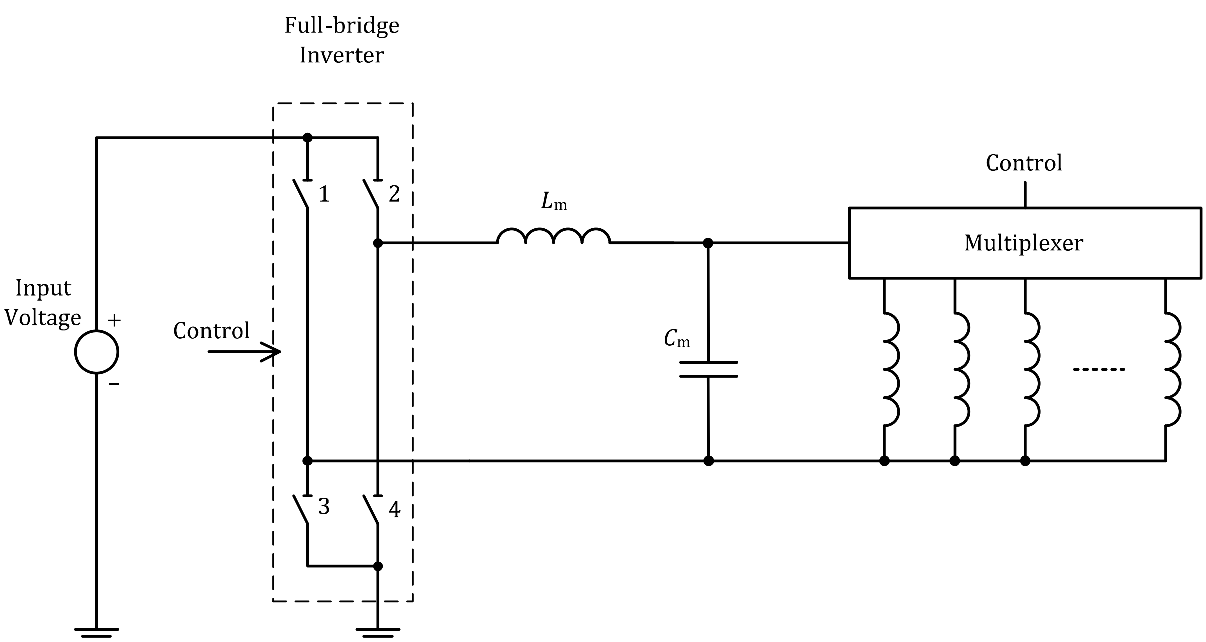
42.1.3 Interface Surface

As shown in Figure 163, the distance from the Primary Coil array to the Interface Surface of the Power Transmitter Product is $d_z = 2^{\pm 0.5}$ mm, across the top face of the Primary Coil array. In addition, the Interface Surface extends at least 5 mm beyond the outer edges of the Primary Coil array.

42.2 Electrical details

As shown in Figure 164, Power Transmitter design B4 uses a full-bridge inverter to drive the Primary Coil array. In addition, Power Transmitter design B4 uses a multiplexer to select the position of the Active Area. The multiplexer shall configure the Primary Coil array in such a way that one, or two Primary Coils are connected—in parallel—to the driving circuit. The connected Primary Coils together constitute a Primary Cell. In the case that two Primary Coils are selected, these two Primary Coils shall have an overlap of two-thirds of the area of a single Primary Coil.

Figure 164. Electrical diagram (outline) of Power Transmitter design B4

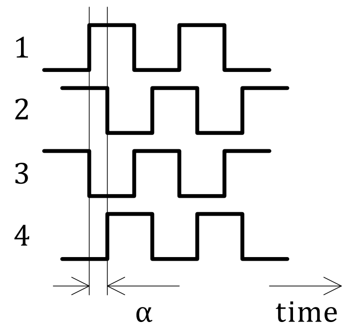


Within the Operating Frequency range f_{op} = 105...113 kHz, the assembly of Primary Coil array and Shielding has an inductance of $8.8^{\pm1}$ μH for each individual Primary Coil in layer (a) (closest to the Interface Surface), $9.1^{\pm1}$ μH for each individual Primary Coil in layer (b), and $9.5^{\pm1}$ μH for each individual Primary Coil in layer (c) (closest to the Shielding). The capacitances and inductance in the impedance matching circuit are, respectively, $C_m = 300^{\pm5\%}$ nF, and $L_m = 3.8^{\pm5\%}$ μH. The input voltage to the full-bridge inverter is $12^{\pm5\%}$ V.

NOTE: The voltage across the capacitance C_m can reach levels exceeding 36 V pk-pk.

Power Transmitter design B4 uses the phase difference between the control signals to two halves of the full-bridge inverter to control the amount of power that is transferred, see Figure 165. For this purpose, the range of the phase difference α is 0…180°—with a larger phase difference resulting in a lower power transfer. In order to achieve a sufficient accurate adjustment of the power that is transferred, a type B4 Power Transmitter shall be able to control the phase difference with a resolution of 0.42° or better. When a type B4 Power Transmitter first applies a Power Signal (Digital Ping: see the *Qi Specification, Communications Protocol*), it shall use an initial phase difference of 120°.

Figure 165. Control signals to the inverter



Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Qi Specification, Power Delivery*. The controlled variable $v^{(i)}$ introduced in the definition of that algorithm represents the phase difference between the two halves of the full-bridge inverter. In order to guarantee sufficiently accurate power control, a type B4 Transmitter shall determine the amplitude of the current into the Primary Cell with a resolution of 5 mA or better. In addition to the PID algorithm, a type B4 Power Transmitter shall limit the current into the Primary Cell to at most 4 A RMS in the case that the Primary Cell consists of two Primary Coils, or at most 2 A RMS in the case that the Primary Cell consists of one Primary Coil. Finally, Table 113 provides the values of several parameters, which are used in the PID algorithm.

Table 113: Control parameters for power control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	1	mA^{-1}
Integral gain	K_i	0	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	N.A.	N.A.
PID output limit	M_{PID}	2,000	N.A.
Scaling factor	S_v	0.01	°

42.2.1 Scalability

Power Transmitter Design B4 offers the same scalability options as Power Transmitter design B1. See Section 39.2.1, *Scalability*.

43 Power Transmitter design B5

Figure 166 illustrates the functional block diagram of Power Transmitter design B5, which consists of two major functional units, namely a Power Conversion Unit and a Communications and Control Unit.

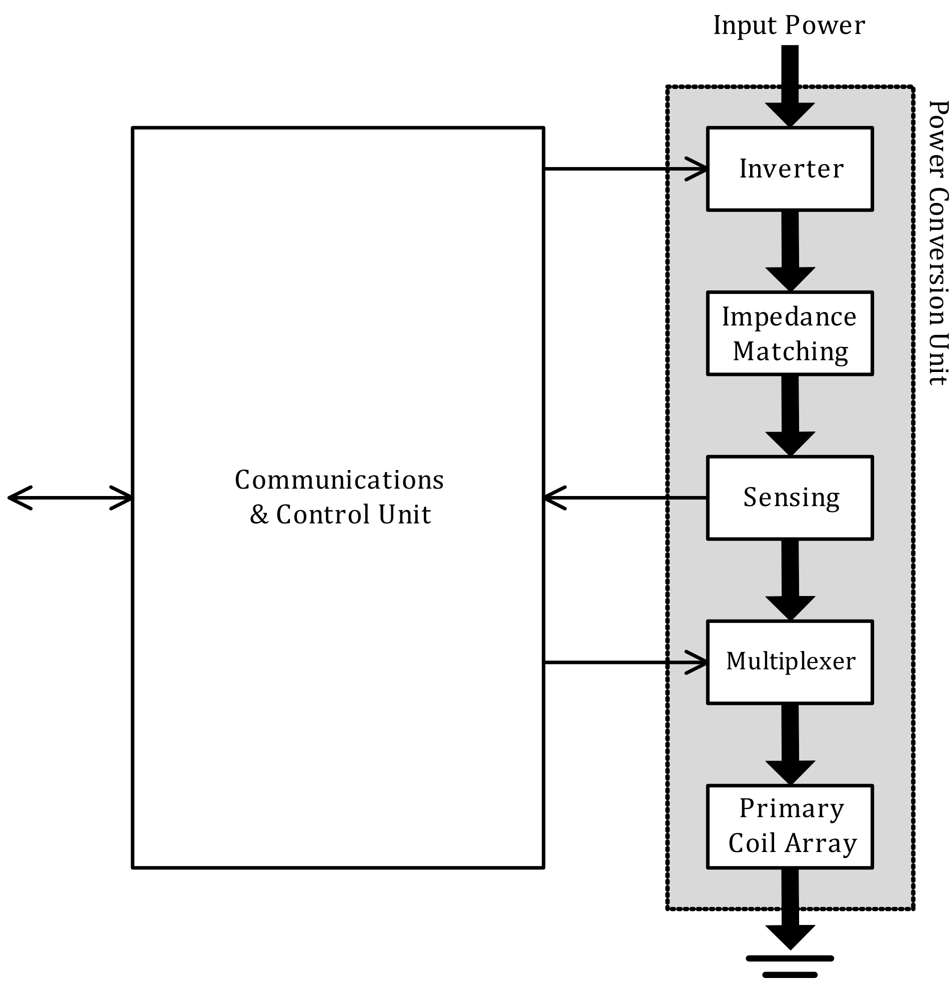


Figure 166. Functional block diagram of Power Transmitter design B5

The Power Conversion Unit on the right-hand side of Figure 166 comprises the analog parts of the design. The design uses an array of partly overlapping Primary Coils to provide for Free Positioning. Depending on the position of the Power Receiver, the multiplexer connects and/or disconnects the appropriate Primary Coils. The impedance matching network forms a resonant circuit with the parts of the Primary Coil array that are connected. The sensing circuits monitor (amongst others) the Primary Cell current and voltage, and the inverter converts the DC input to an AC waveform that drives the Primary Coil array.

The Communications and Control Unit on the left-hand side of Figure 166 comprises the digital logic part of the design. This unit receives and decodes messages from the Power Receiver, configures the multiplexer to connect the appropriate parts of the Primary Coil array, executes the relevant power control algorithms and protocols, and drives the inverter to control the amount of power provided to the Power Receiver. The Communications and Control Unit also interfaces with the other subsystems of the Power Transmitter Product, e.g. for user interface purposes.

43.1 Mechanical details

Power Transmitter design B5 includes a Primary Coil array as defined in Section 43.1.1, *Primary Coil array*, Shielding as defined in Section 43.1.2, *Shielding*, and an Interface Surface as defined in Section 43.1.3, *Interface Surface*.

43.1.1 Primary Coil array

The Primary Coil array consists of partly overlapping square shaped planar coils. Figure 167(a) shows a top view of a single Primary Coil, which consists of a bifilar trace that runs through 11 square shaped turns in a single layer of a PCB. Another realization of a single Primary Coil is to construct it from litz wire having 24 strands of no. 40 AWG (0.08 mm diameter), or equivalent. Figure 167(b) shows a top view of such wire-wound Primary Coil. Table 114 lists the relevant parameters of the coils shown in Figure 167.

Figure 167. Top view of PCB and wire-wound Primary Coil of Power Transmitter design B5

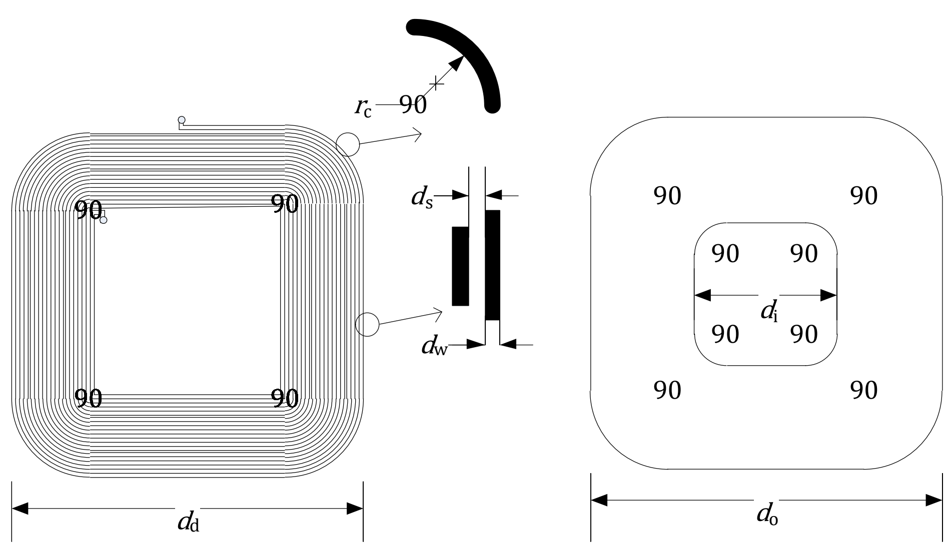


Table 114: Primary Coil parameters of Power Transmitter design B5

Parameter	Symbol	Value
Litz wire based Primary Coil		
Outer diameter	d_o	$45.0^{+0.5}_{-1.0}$ mm
Inner diameter	d_i	$18.6^{\pm 0.3}$ mm
Number of turns	N	11
PCB based Primary Coil		
Outer diameter	d_d	$45^{\pm 0.4}$ mm
Track width	d_w	$0.42^{\pm 0.03}$ mm
Track width plus spacing	$d_w + d_s$	$0.6^{\pm 0.03}$ mm
Corner rounding*	r_c	$9^{\pm 1}$ mm
Number of turns	N	11
* Value applies to the outermost winding.		

The Primary Coil array may be constructed from PCB-coils, wire-wound coils or any combination thereof (hybrid). Power Transmitter design B5 enables one-dimensional freedom of positioning. For that purpose, the Primary Coils are placed in a row, such that there is an overlap of approximately two-thirds of the area. Each Primary Coil (except for the Primary Coils at both ends of the Primary Coil array) overlaps with two Primary Coils in different layers. Figure 168 shows the layout of the Primary Coil array. Figure 169 shows the layered structure of the Primary Coil array in the case of a PCB only implementation, a litz wire only implementation and a hybrid PCB-litz wire implementation. Table 115 lists the relevant parameters of the Primary Coil array. Any layer of the PCB—if present—may contain functionality other than, or in addition to, the Primary Coils. If such other functionality is present, that functionality shall not affect the inductance values of the Primary Coils.

Figure 168. Top view (a) and cross section (b) of the Primary Coil array of Power Transmitter design B5.

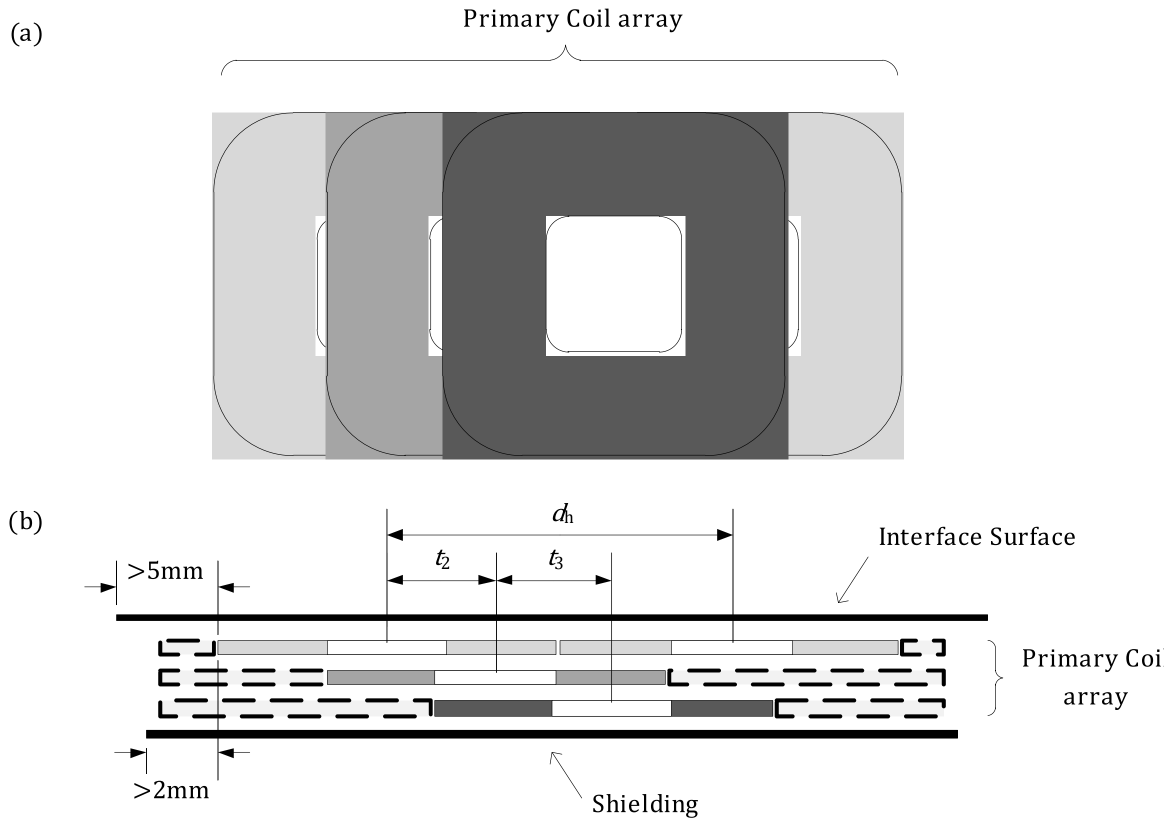


Figure 169. Layered structure of the Primary Coil array

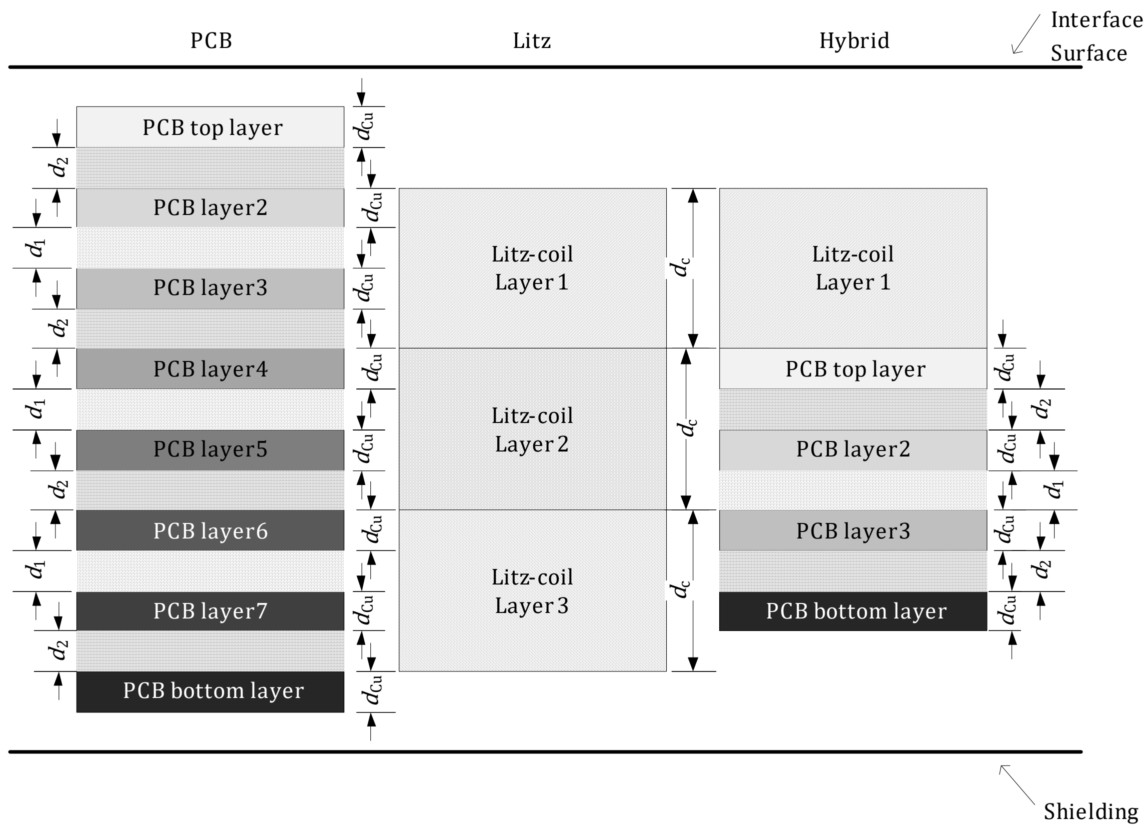


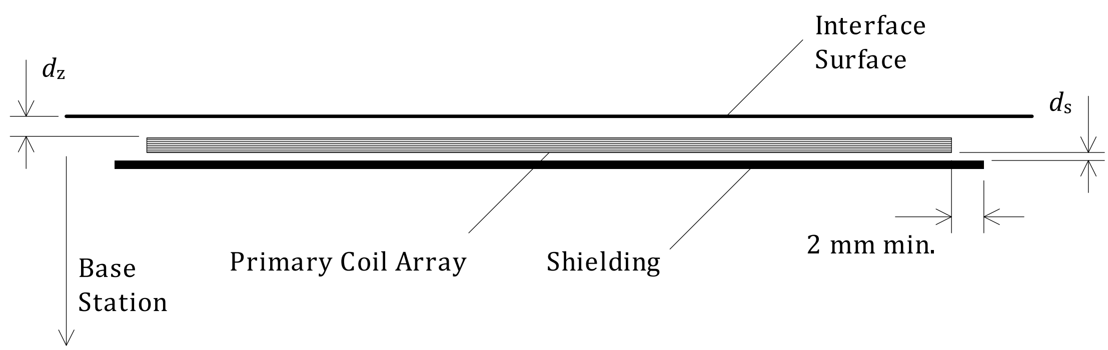
Table 115: Primary Coil array parameters of Power Transmitter design B5

Parameter	Symbol	Value
Center-to-center distance	d_h	$46.5^{\pm 0.2}$ mm
Offset 2nd layer array	t_2	$15.5^{\pm 0.1}$ mm
Offset 3rd layer array	t_3	$15.5^{\pm 0.1}$ mm
Litz-layer thickness	d_c	$0.4^{+0.1}_{-0.05}$ mm
PCB-copper thickness	d_{Cu}	$0.07^{\pm 0.015}$ mm
Dielectric thickness 1	d_{d1}	$0.088^{+0.15}_{-0}$ mm
Dielectric thickness 2	d_{d2}	$0.126^{\pm 0.039}$ mm

43.1.2 Shielding

As shown in Figure 168, Transmitter design B5 employs Shielding to protect the Power Transmitter Product from the magnetic field that is generated in the Primary Coil array. The Shielding should be Ni-Zn or Mn-Zn ferrite and should be at least 0.5 mm thick. The Shielding extends to at least 2 mm beyond the outer edges of the Primary Coil array, and is placed at a distance of at most $d_s = 0.5$ mm below the Primary Coil array.

Figure 170. Primary Coil array assembly of Power Transmitter design B5



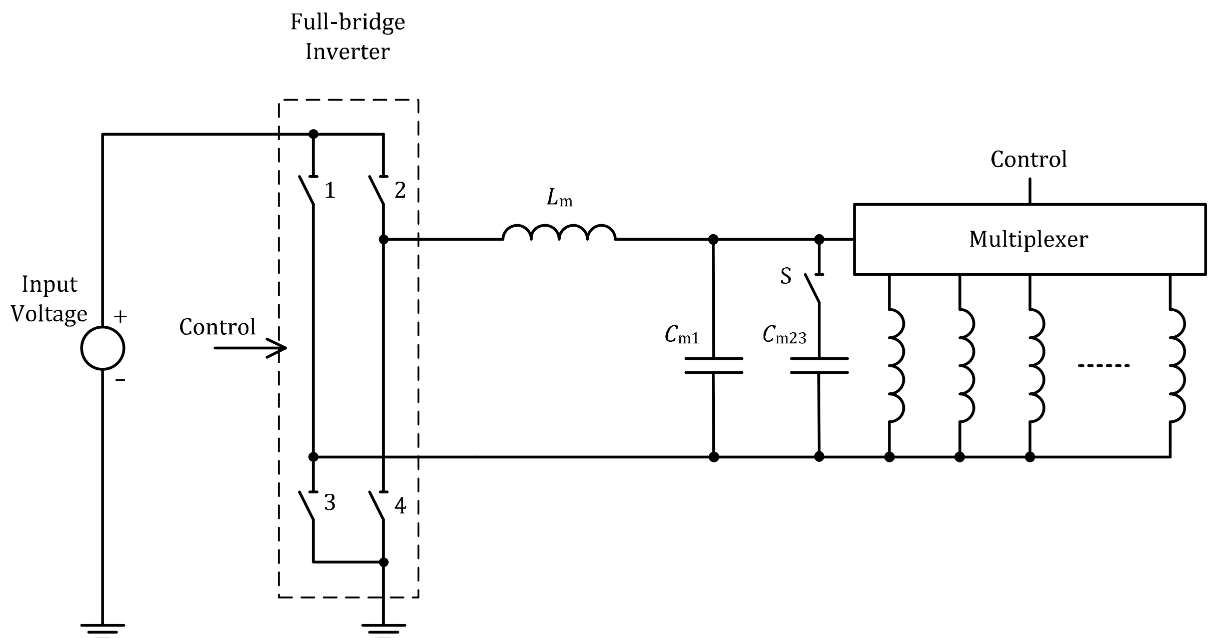
43.1.3 Interface Surface

As shown in Figure 170, the distance from the Primary Coil array to the Interface Surface of the Power Transmitter Product is $d_z = 2^{+0.5}_{-0.25}$ mm, across the top face of the Primary Coil array. In addition, the Interface Surface extends at least 5 mm beyond the outer edges of the Primary Coil array.

43.2 Electrical details

As shown in Figure 171, Power Transmitter design B5 uses a full-bridge inverter to drive the Primary Coil array. In addition, Power Transmitter design B5 uses a multiplexer to select the position of the Active Area. The multiplexer shall configure the Primary Coil array in such a way that one, or two Primary Coils are connected—in parallel—to the driving circuit. The connected Primary Coils together constitute a Primary Cell. In the case that two Primary Coils are selected, these two Primary Coils shall have an overlap of two-thirds of the area of a single Primary Coil.

Figure 171. Electrical diagram (outline) of Power Transmitter design B5

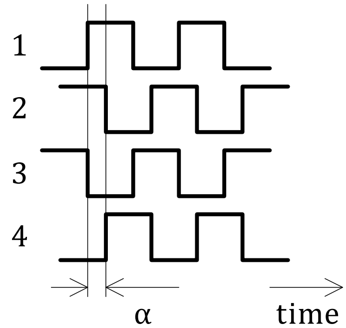


Within the Operating Frequency range $f_{op} = 96 \pm 2$ kHz, the assembly of Primary Coil array and Shielding has an inductance of $8.8^{\pm1}$ μH for each individual Primary Coil in layer (a) (closest to the Interface Surface), $9.1^{\pm1}$ μH for each individual Primary Coil in layer (b), and $9.5^{\pm1}$ μH for each individual Primary Coil in layer (c) (closest to the Shielding). The capacitances and inductance in the impedance matching circuit are, respectively, $C_{m1} = 356^{\pm5\%}$ nF, $C_{m23} = 82^{\pm5\%}$ nF, and $L_m = 3.8^{\pm5\%}$ μH. The switch S is open if the Primary Cell consists of a single Primary Coil; otherwise, the switch S is closed. The input voltage to the full-bridge inverter is $12^{\pm5\%}$ V.

NOTE: The voltage across the capacitance C_m can reach levels exceeding 36 V pk-pk.

Power Transmitter design B5 uses the phase difference between the control signals to two halves of the full-bridge inverter to control the amount of power that is transferred, see Figure 172. For this purpose, the range of the phase difference α is 0…180°—with a larger phase difference resulting in a lower power transfer. In order to achieve a sufficient accurate adjustment of the power that is transferred, a type B5 Power Transmitter shall be able to control the phase difference with a resolution of 0.42° or better. When a type B5 Power Transmitter first applies a Power Signal (Digital Ping: see the *Qi Specification, Communications Protocol*), it shall use an initial phase difference of 120°.

Figure 172. Control signals to the inverter



Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Qi Specification, Power Delivery*. The controlled variable $v^{(i)}$ introduced in the definition of that algorithm represents the phase difference between the two halves of the full-bridge inverter. In order to guarantee sufficiently accurate power control, a type B5 Transmitter shall determine the amplitude of the current into the Primary Cell with a resolution of 5 mA or better. In addition to the PID algorithm, a type B5 Power Transmitter shall limit the current into the Primary Cell to at most 4 A RMS in the case that the Primary Cell consists of two Primary Coils, or at most 2 A RMS in the case that the Primary Cell consists of one Primary Coil. Finally, Table 116 provides the values of several parameters, which are used in the PID algorithm.

Table 116: Control parameters for power control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	1	mA^{-1}
Integral gain	K_i	0	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	N.A.	N.A.
PID output limit	M_{PID}	2,000	N.A.
Scaling factor	S_v	0.01	°

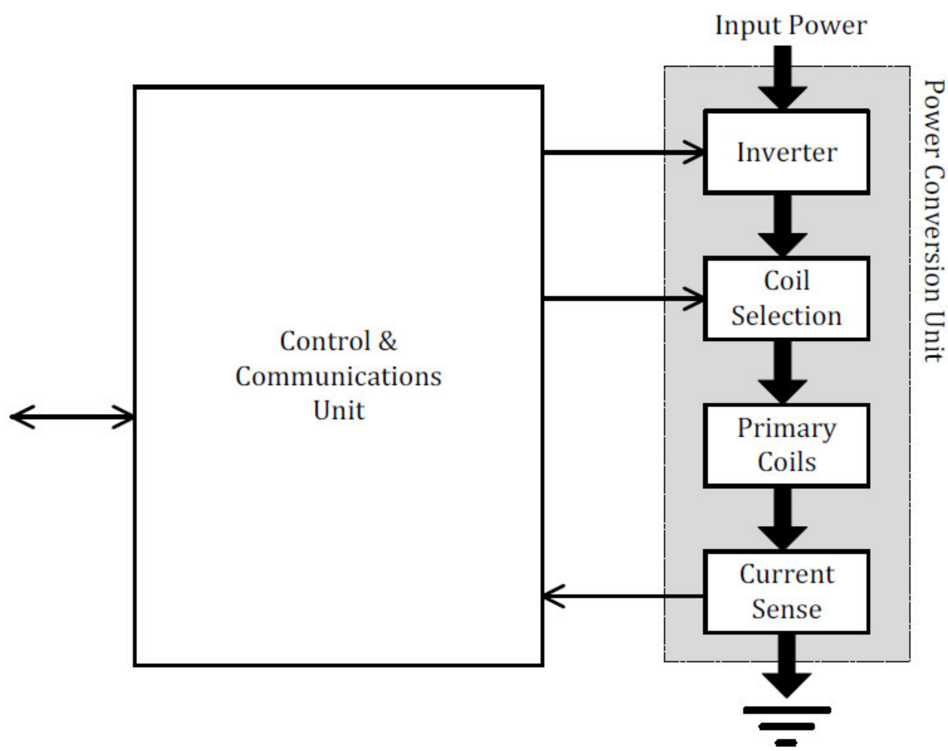
43.2.1 Scalability

Power Transmitter Design B5 offers the same scalability options as Power Transmitter design B1. See Section 39.2.1, *Scalability*.

44 Power Transmitter design B6

Figure 173 illustrates the functional block diagram of Power Transmitter design B6, which consists of two major functional units, namely a Power Conversion Unit and a Communications and Control Unit.

Figure 173. Functional block diagram of Power Transmitter design B6



The Power Conversion Unit on the right-hand side of Figure 173 comprises the analog parts of the design. The design uses an array of partly overlapping Primary Coils to provide for Free Positioning. Depending on the position of the Power Receiver, the multiplexer connects and/or disconnects the appropriate Primary Coil(s). The resonance capacitor forms a resonant circuit with the parts of the Primary Coil array that are connected. The sensing circuits monitor (amongst others) the Primary Cell current and voltage, and the inverter converts the DC input to an AC waveform that drives the Primary Coil array.

The Communications and Control Unit on the left-hand side of Figure 173 comprises the digital logic part of the design. This unit receives and decodes messages from the Power Receiver, configures the multiplexer to connect the appropriate parts of the Primary Coil array, executes the relevant power control algorithms and protocols, and drives the inverter to control the amount of power provided to the Power Receiver. The Communications and Control Unit also interfaces with the other subsystems of the Power Transmitter Product, e.g. for user interface purposes.

44.1 Mechanical details

Power Transmitter design B6 includes a Primary Coil array as defined in Section 44.1.1, *Primary Coil array*, Shielding as defined in Section 44.1.2, *Shielding*, and an Interface Surface as defined in Section 44.1.3, *Interface Surface*.

44.1.1 Primary Coil array

Each Primary Coil within the Primary Coil array is of the wire-wound type, and consists of 2 bifilar windings of each 11 turns of litz wire having 24 strands of no. 40 AWG (0.08 mm diameter), or equivalent[1]. As shown in Figure 174, the Primary Coil has an oval shape and consists of a single layer. Table 117 lists the dimensions of the Primary Coil.

Figure 174. Primary coil of Power Transmitter design B6

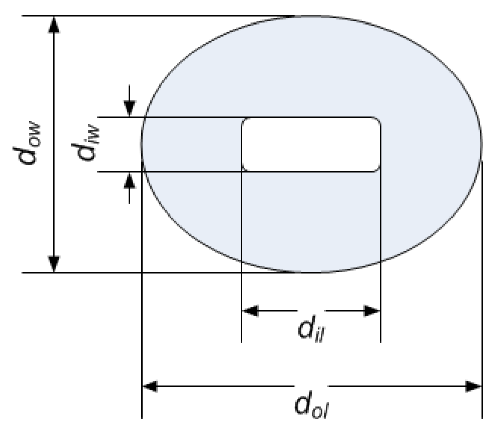


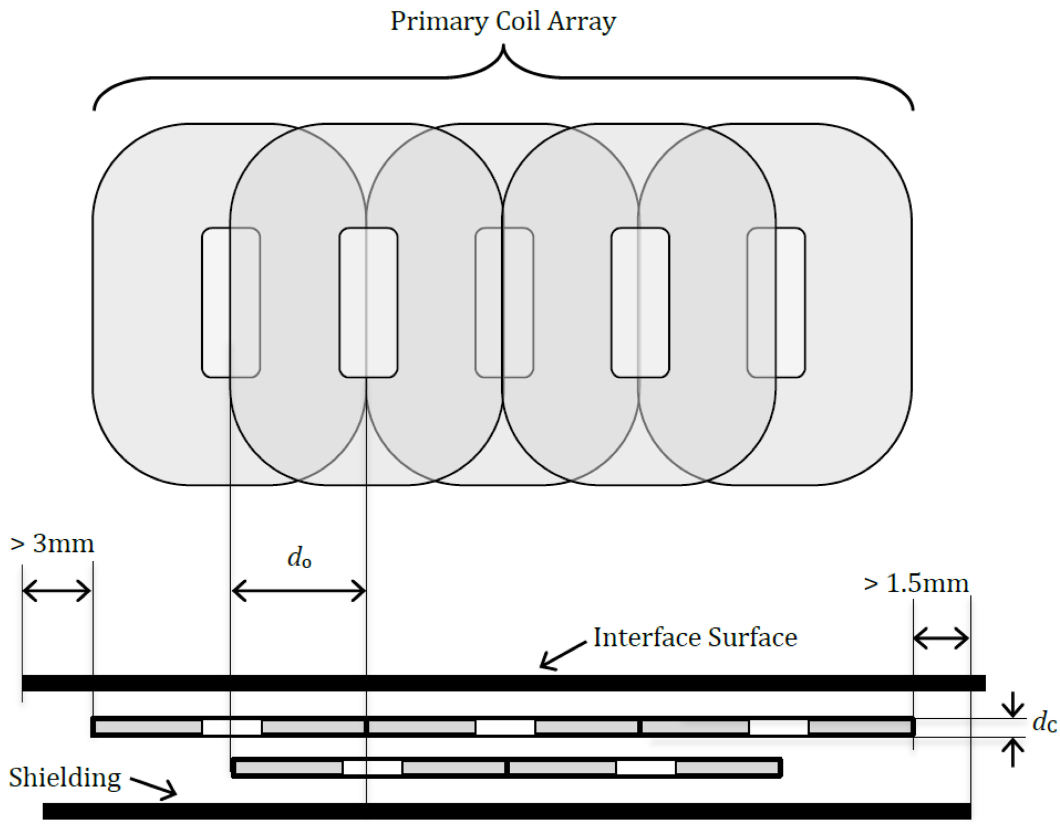
Table 117: Design parameters for Primary Coil array of Power Transmitter B6

Parameter	Symbol	Value
Outer length	d_{ol}	$45.0^{\pm 0.5}$ mm
Inner length	d_{il}	$18.4^{\pm 0.5}$ mm
Outer width	d_{ow}	$34.0^{+0.0}_{-1.0}$ mm
Inner width	d_{iw}	$7.2^{\pm 0.5}$ mm
Litz layer thickness	d_c	$0.65^{\pm 0.3}$ mm
Number of turns per layer	N	11 turns
Number of layers	-	1

[1] One equivalent example is a single winding of 11 turns of Litz wire having 96 strands of no. 40 AWG (0.08mm diameter)

Power Transmitter design B6 contains at least two Primary Coils and allows for 1-dimensional freedom of positioning. All adjacent Primary Coils are placed with their long sides alongside each other with a displacement of $d_o = 17.0^{+2.0}_{-0.0}$ mm between their centers, such that there is an overlap of about 50% of the area. Figure 175 shows the functional arrangement of coils in the Primary Coil array. See also Table 117 for details of the parameters.

Figure 175. Arrangement of coils in the Primary Coil array of Power Transmitter B6

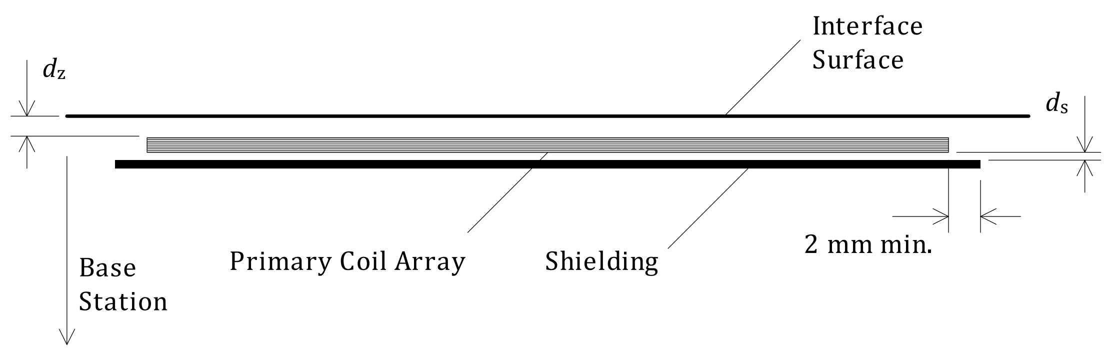


The Communications & Control Unit of a single Power Transmitter selects 1 or 2 coils from the array to form a Primary Cell for power transfer when a Power Receiver is positioned on the Active Area. In the case where 2 coils are selected, these 2 coils shall have an overlap.

44.1.2 Shielding

As shown in Figure 175, Transmitter design B6 employs Shielding to protect the Power Transmitter Product from the magnetic field that is generated in the Primary Coil array. The Shielding should be Ni-Zn or Mn-Zn ferrite and should be at least 0.5 mm thick. The Shielding extends to at least 1.5 mm beyond the outer edges of the Primary Coil array, and is placed at a distance of at most $d_s = 0.5$ mm below the Primary Coil array.

Figure 176. Primary Coil array assembly of Power Transmitter design B6



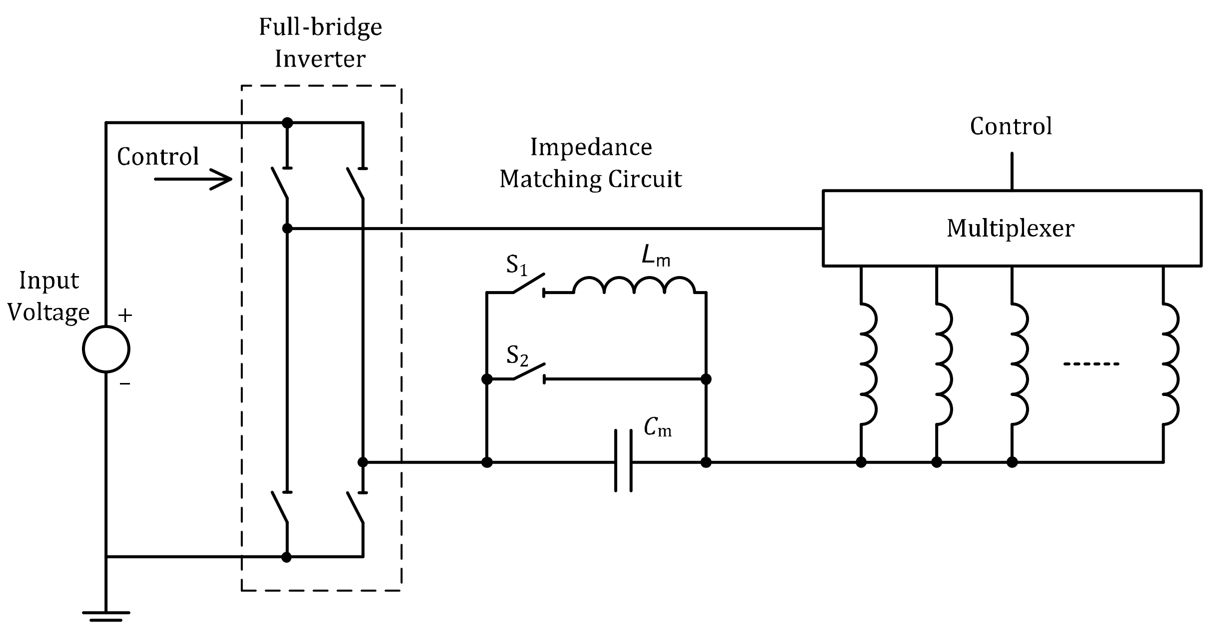
44.1.3 Interface Surface

As shown in Figure 176, the distance from the Primary Coil array to the Interface Surface of the Power Transmitter Product is $d_z = 2^{+0.25}_{-0.5}$ mm, across the top face of the Primary Coil array. In addition, the Interface Surface extends at least 3 mm beyond the outer edges of the Primary Coil array.

44.2 Electrical details

As shown in Figure 177, Power Transmitter design B6 uses a full-bridge inverter to drive the Primary Coil array. In addition, Power Transmitter design B6 uses a multiplexer to select the position of the Active Area. The multiplexer shall configure the Primary Coil array in such a way that one or two (overlapping; see Section 44.1.1, *Primary Coil array*) Primary Coils are connected—in parallel—to the driving circuit. The connected Primary Coil(s) together constitute a Primary Cell.

Figure 177. Electrical diagram (outline) of Power Transmitter design B6



Within the Operating Frequency range f_{op} = 125...135 kHz, the assembly of Primary Coil array and Shielding has an inductance of $5.8^{\pm 0.5}$ μH for each individual Primary Coil in layer (a) (closest to the Interface Surface), and $6.2^{\pm 0.5}$ μH for each individual Primary Coil in layer (b) (closest to the Shielding). The capacitance in the impedance matching circuit is $C_m = 1000^{\pm 5\%}$ nF. The inductance in the impedance matching circuit is $L_m = 1$ μH. The input voltage to the full-bridge inverter is $5^{\pm 5\%}$ V.

NOTE: The voltage across the capacitance C_m can reach levels exceeding 25V pk-pk.

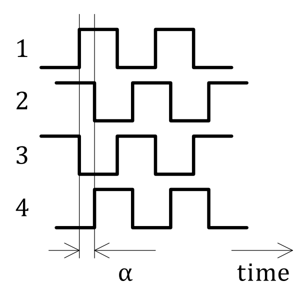
Switches S_1 and S_2 may be used to change the impedance the inverter sees when driving the Primary Cell, allowing the inverter to drive the Primary Cell at Operating Points that are more efficient (i.e. requiring less current). During normal operation both switches should be open. However, during a Digital Ping switch S_1 should be closed and switch S_2 should be open. Basically there are three combinations of switch positions as indicated in the Table 118 below. The initial Operating Point of the Power Transmitter occurs during a Digital Ping. In this situation a low amount of power is transferred to allow any Power Receiver to initialize and respond. Switch S_2 may be used to provide a smooth transition from the damped inductive state to the resonant state (both switches open) and ensures that there is no magnetizing current flowing through L_m when switch S_1 is turned off.

Table 118: Power Transmitter design B6 switch configurations

S_1	S_2	**Inverter state**	**Comment**
Closed	Open	Damped inductive	Digital Ping—low power
Any	Closed	Normal inductive	Transition—medium power
Open	Open	Resonant	Power Transfer—high power

Power Transmitter design B6 uses the phase difference between the control signals to two halves of the full-bridge inverter to control the amount of power that is transferred, see Figure 178. For this purpose, the range of the phase difference α is 0…180°—with a larger phase difference resulting in a higher power transfer. In order to achieve a sufficient accurate adjustment of the power that is transferred, a type B6 Power Transmitter shall be able to control the phase difference with a resolution of 0.42° or better. When a type B6 Power Transmitter first applies a Power Signal (Digital Ping: see the *Qi Specification, Communications Protocol*), it shall use an initial phase difference of 180° and switch S_1 closed and switch S_2 open.

Figure 178. Control signals to the inverter



Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Qi Specification, Power Delivery*. The controlled variable $v^{(i)}$ introduced in the definition of that algorithm represents the phase difference between the two halves of the full-bridge inverter. In order to guarantee sufficiently accurate power control, a type B6 Transmitter shall determine the amplitude of the current into the Primary Cell with a resolution of 5 mA or better. In addition to the PID algorithm, a type B6 Power Transmitter shall limit the current into the Primary Cell to at most 5 A RMS in the case that the Primary Cell consists of two Primary Coils, or at most 3 A RMS in the case that the Primary Cell consists of one Primary Coil. Finally, Table 119 provides the values of several parameters, which are used in the PID algorithm.

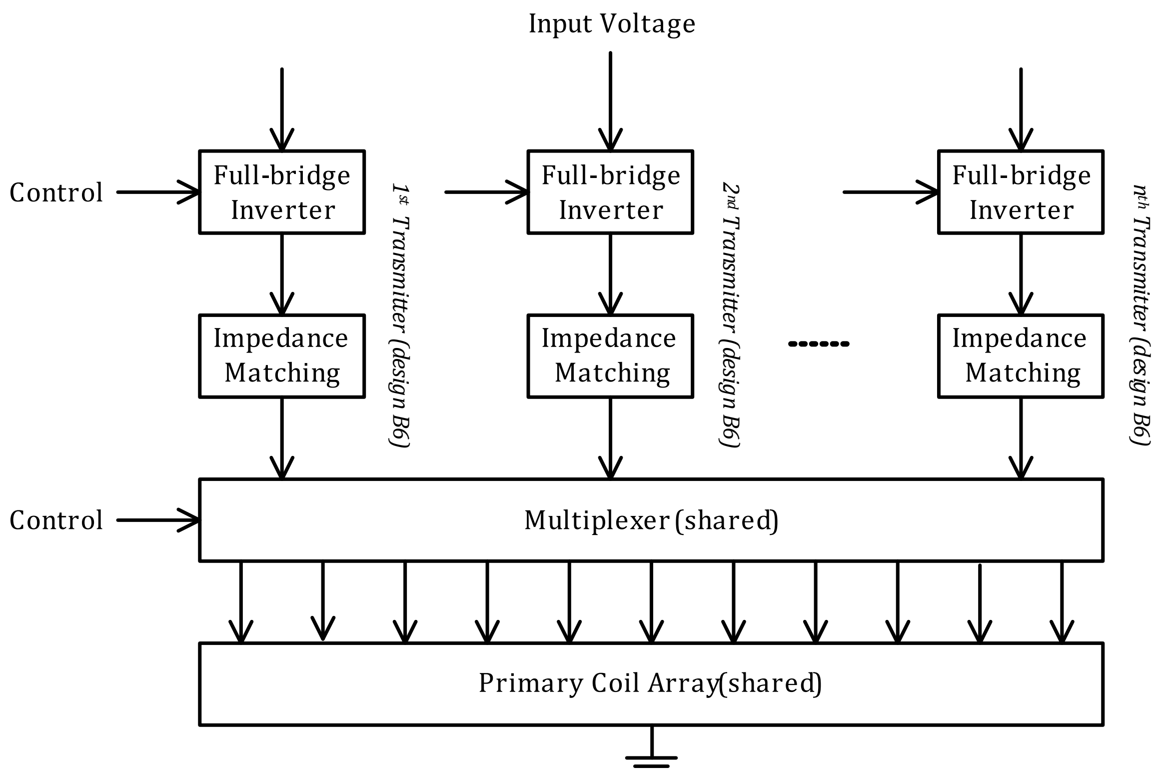
Table 119: Control parameters for power control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	1	mA^{-1}
Integral gain	K_i	0	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	N.A.	N.A.
PID output limit	M_{PID}	2,000	N.A.
Scaling factor	S_v	0.01	°

44.2.1 Scalability

Section 44.1, *Mechanical details*, and Section 44.2, *Electrical details*, define the mechanical and electrical details of Power Transmitter design B6. As defined in Section 2, *Overview*, a type B6 Power Transmitter serves a single Power Receiver only. In order to serve multiple Power Receivers simultaneously, a Power Transmitter Product may contain multiple type B6 Power Transmitters. As shown in Figure 179, these Power Transmitters may share the Primary Coil array and multiplexer. However, each individual Power Transmitter shall have a separately controllable inverter, resonance circuit, and means to determine the Primary Cell current, as defined in Section 44.2, *Electrical details*. In addition, the multiplexer shall ensure that it does not connect multiple inverters to any individual Primary Coil.

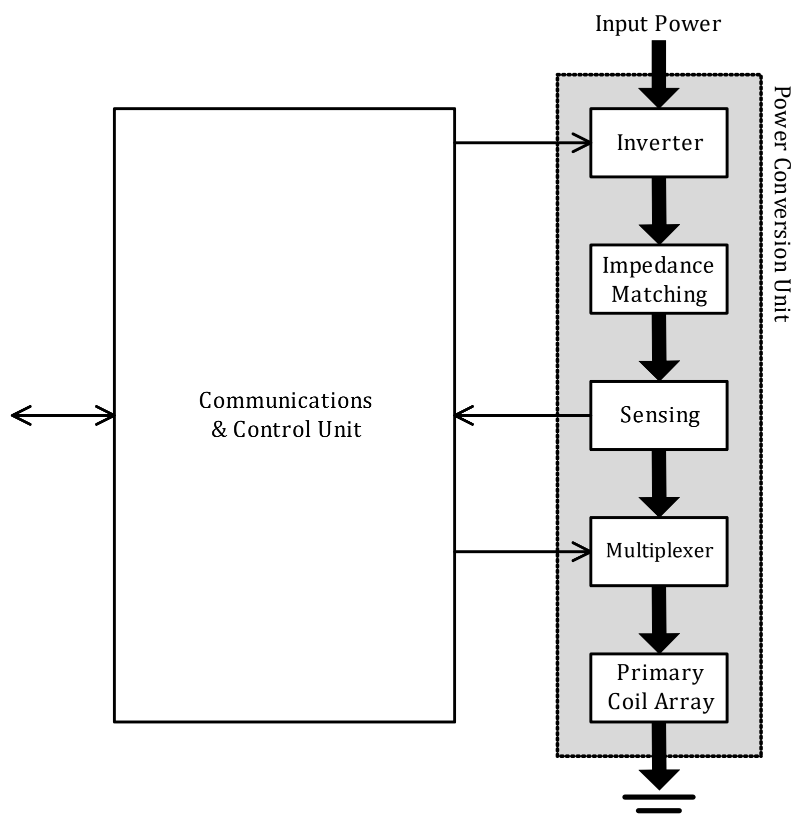
Figure 179. Multiple type B6 Power Transmitters sharing a multiplexer and Primary Coil array



45 Power Transmitter design B7

Figure 180 illustrates the functional block diagram of Power Transmitter design B7, which consists of two major functional units, namely a Power Conversion Unit and a Communications and Control Unit.

Figure 180. Functional block diagram of Power Transmitter design B7



The Power Conversion Unit on the right-hand side of Figure 180 comprises the analog parts of the design. The design uses an array of partly overlapping Primary Coils to provide for Free Positioning. Depending on the position of the Power Receiver, the multiplexer connects and/or disconnects the appropriate Primary Coil(s). The impedance matching network forms a resonant circuit with the parts of the Primary Coil array that are connected. The sensing circuits monitor (amongst others) the Primary Cell current and voltage, and the inverter converts the DC input to an AC waveform that drives the Primary Coil array.

The Communications and Control Unit on the left-hand side of Figure 180 comprises the digital logic part of the design. This unit receives and decodes messages from the Power Receiver, configures the multiplexer to connect the appropriate parts of the Primary Coil array, executes the relevant power control algorithms and protocols, and drives the inverter to control the amount of power provided to the Power Receiver. The Communications and Control Unit also interfaces with the other subsystems of the Power Transmitter Product, e.g. for user interface purposes.

45.1 Mechanical details

Power Transmitter design B7 includes a Primary Coil array as defined in Section 45.1.1, *Primary Coil array*, Shielding as defined in Section 45.1.2, *Shielding*, and an Interface Surface as defined in Section 45.1.3, *Interface Surface*.

45.1.1 Primary Coil array

The Primary Coil array consists of partly-overlapping, rectangular-shaped planar coils. In order to keep the inductance of each coil similar in the final assembly there are two coils specified for this transmitter type, Primary Coil A and Primary Coil B. On the left side of Figure 181 is a top view of Primary Coil A (left), which consists of a 17 AWG (1.2 mm diameter) wire that runs through 9 rectangular-shaped turns in a single layer. On the right is a top view of Primary Coil B, which consists of a 17 AWG (1.2 mm diameter) wire that runs through 10 rectangular-shaped turns in a single layer. Another realization of a single Primary Coil A or B is to construct it from litz wire having 105 strands of no. 40 AWG (0.08 mm diameter), or equivalent. Table 120 lists the relevant parameters of the coils shown in Figure 181.

NOTE: Primary Coil B can be constructed from Primary Coil A by adding one inner turn, conversely, Primary Coil A can be constructed from Primary Coil B by removing one inner turn.

In this Primary Coil array the coils closest to the Shielding shall be according to Primary Coil A, and the coils closest to the Interface Surface shall be according to Primary Coil B. Moreover, a transmitter execution that uses only one Primary Coil shall use Primary Coil A.

Figure 181. Top view of Primary Coil A (left) and Primary Coil B (right) of Power Transmitter design B7

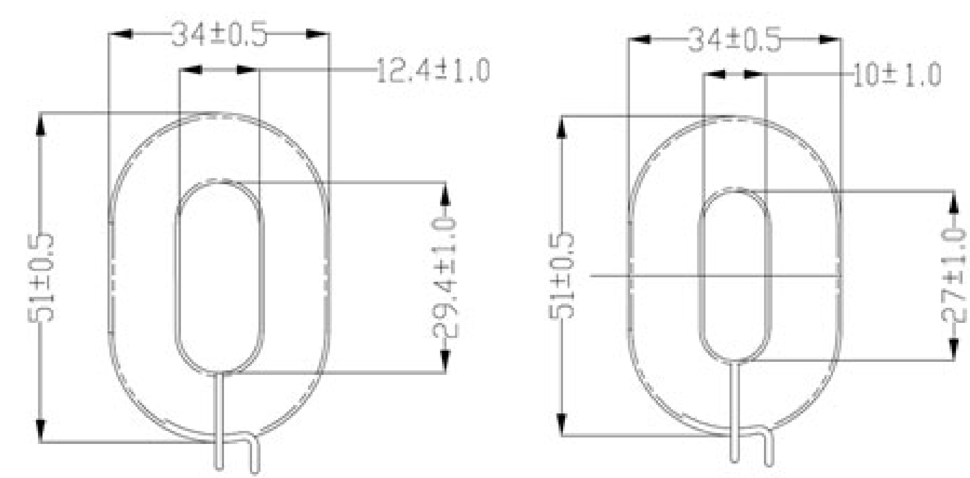


Table 120: Primary Coil parameters of Power Transmitter design B7

Parameter	Symbol	Value
Primary Coil A (closest to the Shielding)		
Outer width	w_o	$34.0^{+0.5}_{0.5}$ mm
Outer length	l_o	$51.0^{+0.5}_{0.5}$ mm
Inner width	w_i	$12.4^{+1.0}_{1.0}$ mm
Inner length	l_i	$29.4^{+1.0}_{1.0}$ mm
Number of turns	N	9
Primary Coil B (closest to Interface Surface)		
Outer width	w_o	$34.0^{+0.5}_{0.5}$ mm
Outer length	l_o	$51.0^{+0.5}_{0.5}$ mm
Inner width	w_i	$10.0^{+1.0}_{1.0}$ mm
Inner length	l_i	$27.0^{+1.0}_{1.0}$ mm
Number of turns	N	10

Power Transmitter design B7 enables one-dimensional freedom of positioning. For that purpose the Primary Coils are placed in a row, such that there is an overlap of approximately 50% of the area. Each Primary Coil (except for an execution that uses only one Primary Coil) overlaps with one other Primary Coils in a different layer. Figure 182 shows the layout of an example execution of the Primary Coil array using four Primary Coils. Table 121 lists the relevant parameters of the Primary Coil array.

Figure 182. Example of Power Transmitter design B7 in a 4-coil execution

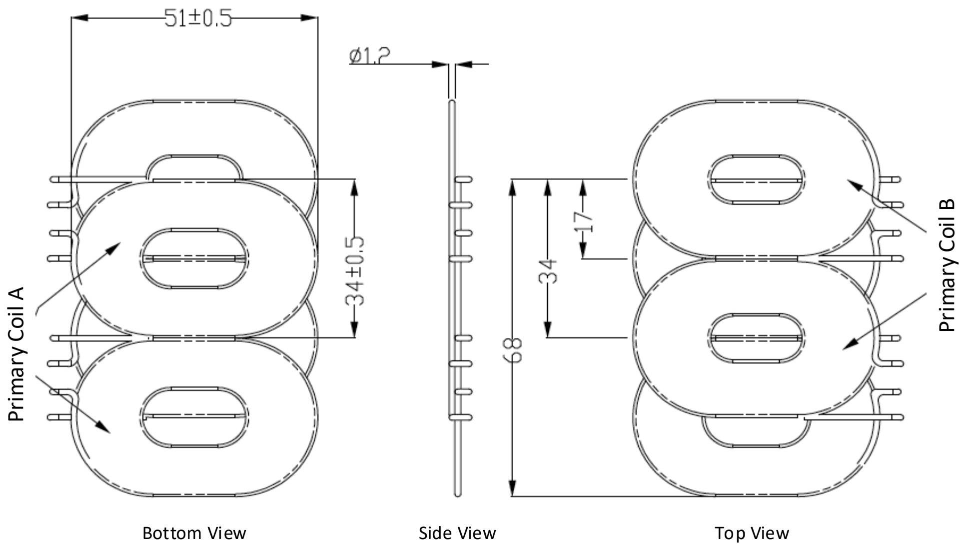


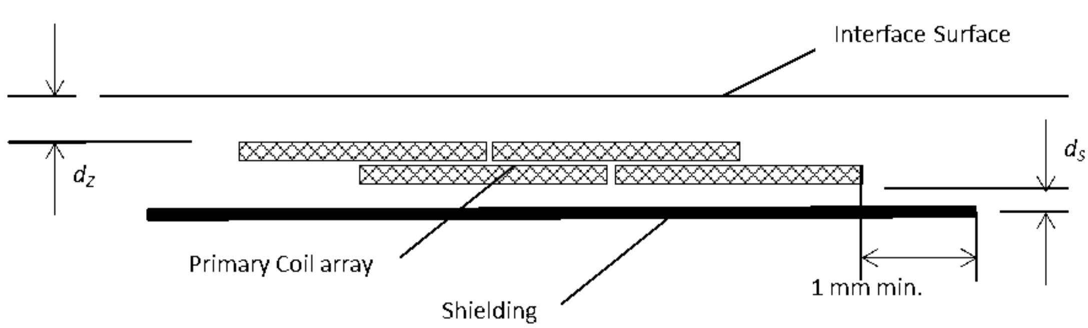
Table 121: Primary Coil array parameters of Power Transmitter design B7

Parameter	Symbol	Value
Center-to-center distance	d_h	$34.0^{\pm 0.5}$mm
Offset 2nd layer array	t_2	$17.0^{\pm 0.5}$mm
Litz-layer thickness	d_c	$1.2^{\pm 0.5}$mm

45.1.2 Shielding

As shown in Figure 183, Transmitter design B7 employs Shielding to protect the Power Transmitter Product from the magnetic field that is generated in the Primary Coil array. The Shielding should be Ni-Zn or Mn-Zn ferrite and should be at least 0.5 mm thick. The Shielding extends to at least 1 mm beyond the outer edges of the Primary Coil array, and is placed at a distance of at most d_s = 0.5 mm below the Primary Coil array.

Figure 183. Primary Coil array assembly of Power Transmitter design B7



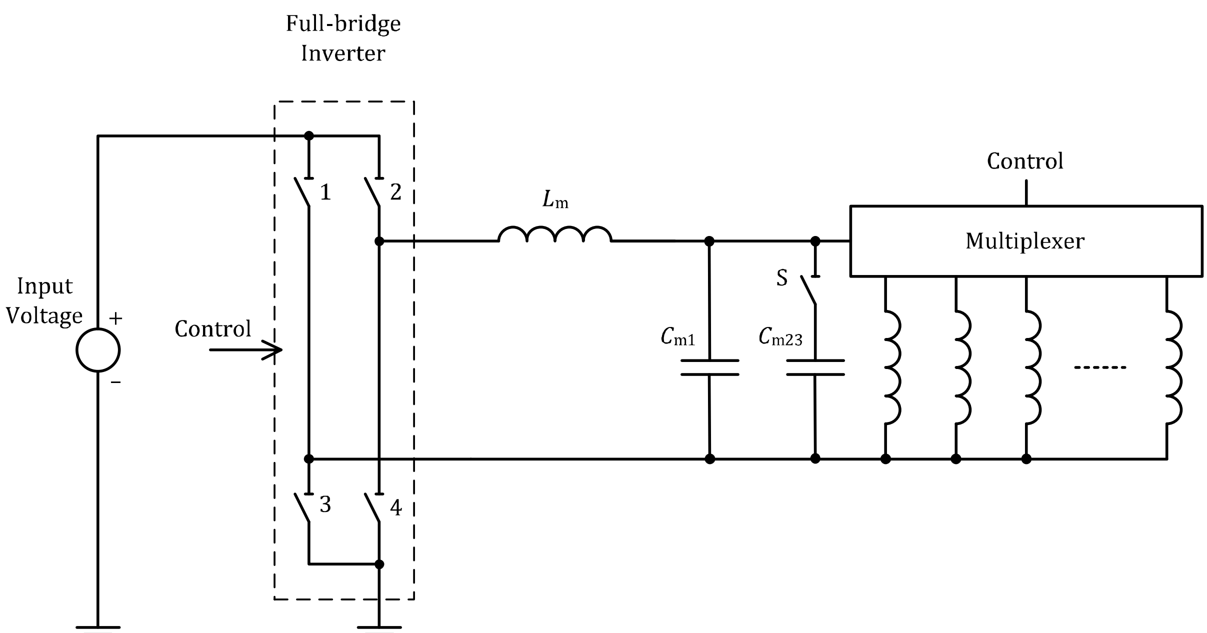
45.1.3 Interface Surface

As shown in Figure 183, the distance from the Primary Coil array to the Interface Surface of the Power Transmitter Product is $d_Z = 2^{\pm 0.5}$ mm, across the top face of the Primary Coil array. In addition, the Interface Surface extends at least 2 mm beyond the outer edges of the Primary Coil array.

45.2 Electrical details

As shown in Figure 184, Power Transmitter design B7 uses a full-bridge inverter to drive the Primary Coil array. In addition, Power Transmitter design B7 uses a multiplexer to select the position of the Active Area. The multiplexer shall configure the Primary Coil array in such a way that one, or two Primary Coils are connected—in parallel—to the driving circuit. The connected Primary Coils together constitute a Primary Cell. In the case that two Primary Coils are selected, these two Primary Coils shall have an overlap of approximately 50% of the area of a single Primary Coil.

Figure 184. Electrical diagram (outline) of Power Transmitter design B7

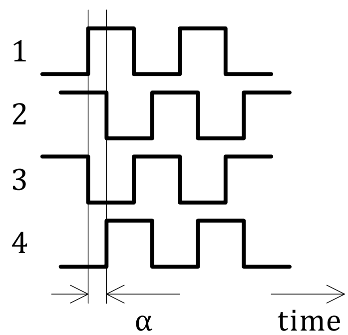


Within the Operating Frequency range $f_{0p} = 115^{\pm 5}$ kHz, the assembly of Primary Coil array and Shielding has an inductance of $6.1^{\pm 0.6}$ μH for each individual Primary Coil. The capacitances and inductance in the impedance matching circuit are, respectively, $C_{m1} = 300^{\pm 5\%}$ nF, $C_{m23} = 100^{\pm 5\%} - 300^{\pm 5\%}$ nF, $L_m = 3.8^{\pm 5\%}$ μH. The switch S is open if the Primary Cell consists of a single Primary Coil; otherwise, the switch S is closed. The input voltage to the full-bridge inverter is $15^{\pm 5\%}$ V.

NOTE: The voltage across the capacitance C_m can reach levels exceeding 40 V pk-pk.

Power Transmitter design B7 uses the phase difference between the control signals to two halves of the full-bridge inverter to control the amount of power that is transferred, see Figure 185. For this purpose, the range of the phase difference α is 0…180°—with a larger phase difference resulting in a lower power transfer. In order to achieve a sufficient accurate adjustment of the power that is transferred, a type B7 Power Transmitter shall be able to control the phase difference with a resolution of 0.42° or better. When a type B7 Power Transmitter first applies a Power Signal (Digital Ping: see the *Qi Specification, Communications Protocol*), it shall use an initial phase difference of 150°.

Figure 185. Control signals to the inverter



Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Qi Specification, Power Delivery*. The controlled variable $v^{(i)}$ introduced in the definition of that algorithm represents the phase difference between the two halves of the full-bridge inverter. In order to guarantee sufficiently accurate power control, a type B7 Transmitter shall determine the amplitude of the current into the Primary Cell with a resolution of 5 mA or better. In addition to the PID algorithm, a type B7 Power Transmitter shall limit the current into the Primary Cell to at most 4 A RMS in the case that the Primary Cell consists of two Primary Coils, or at most 3 A RMS in the case that the Primary Cell consists of one Primary Coil. Finally, Table 122 provides the values of several parameters that are used in the PID algorithm.

Table 122: Power control parameters for Power Transmitter design B7

Parameter	Symbol	Value	Unit
Proportional gain	K_p	1	mA^{-1}
Integral gain	K_i	0	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	N.A.	N.A.
PID output limit	M_{PID}	2,000	N.A.
Scaling factor	S_v	0.01	°

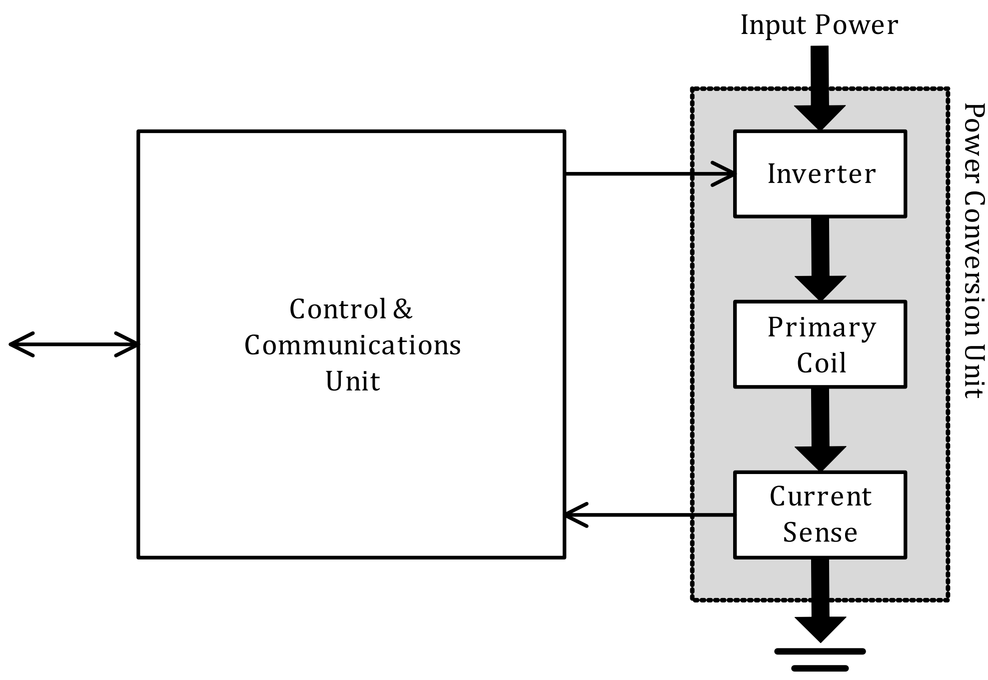
45.2.1 Scalability

Power Transmitter Design B7 offers the same scalability options as Power Transmitter design B1. See Section 39.2.1, *Scalability*.

46 Power Transmitter design MP-A1

Figure 186 illustrates the functional block diagram of Power Transmitter design MP-A1. This design consists of two major functional units, namely a Power Conversion Unit and a Communications and Control Unit.

Figure 186. Functional block diagram of Power Transmitter design MP-A1



The Power Conversion Unit on the right-hand side of Figure 186 comprises the analog parts of the design. The inverter converts the DC input to an AC waveform that drives a resonant circuit consisting of the Primary Coil plus a series capacitor. Finally, the current sense monitors the Primary Coil current.

The Communications and Control Unit on the left-hand side of Figure 186 comprises the digital logic part of the design. This unit receives and decodes messages from the Power Receiver, executes the relevant power control algorithms and protocols, and drives the frequency (duty cycle control or phase shift control after reaching the maximum frequency) of the AC waveform to control the power transfer. The Communications and Control Unit also interfaces with other subsystems of the Power Transmitter Product, e.g. for user interface purposes.

46.1 Mechanical details

This section defines the Primary Coil, the Shielding, the Interface Surface, and the alignment aid for Power Transmitter design MP-A1.

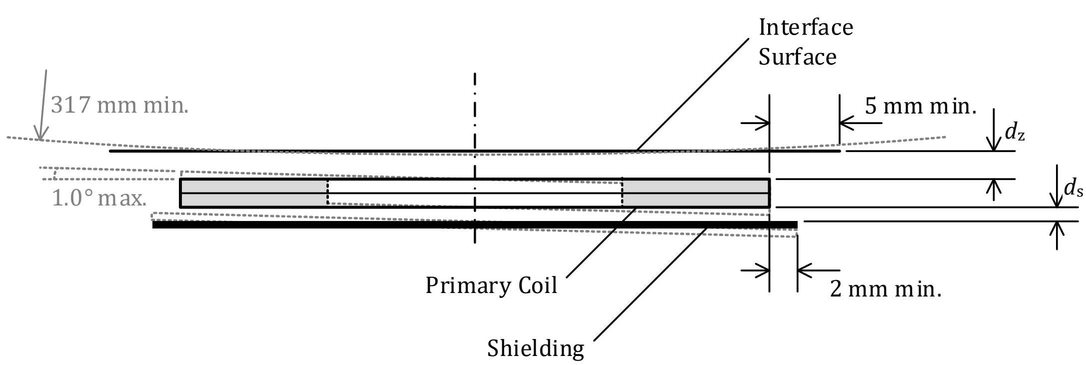
46.1.1 Primary Coil

The Primary Coil of the MP-A1 design is identical to the Primary Coil of the type A10 Power Transmitter defined in the *Qi Specification, Power Transmitter* A*x and* B*x Reference Designs*.

46.1.2 Shielding

As shown in Figure 187, Shielding protects the Power Transmitter Product from the magnetic field that is generated in the Primary Coil. The Shielding should be Ni-Zn or Mn-Zn ferrite and should be at least 2.0 mm thick. The Shielding extends to at least 2 mm beyond the outer diameter of the Primary Coil, and is placed below the Primary Coil at a distance of at most $d_s = 1.0$ mm.

Figure 187. Primary Coil assembly of Power Transmitter design MP-A1



46.1.3 Interface Surface

As shown in Figure 187, the distance from the Primary Coil to the Interface Surface of the Power Transmitter Product is $d_z = 2^{+0.5}_{-0.25}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Power Transmitter Product extends at least 5 mm beyond the outer diameter of the Primary Coil.

NOTE: This Primary-Coil-to-Interface-Surface distance implies that the tilt angle between the Primary Coil and a flat Interface Surface is at most 1.0°. Alternatively, in case of a non-flat Interface Surface, this Primary-Coil-to-Interface-Surface distance implies a radius of curvature of the Interface Surface of at least 317 mm, centered on the Primary Coil. See Figure 187.

46.1.4 Alignment aid

The user manual of a Power Transmitter Product containing a type MP-A1 Power Transmitter shall provide information about the location of its Active Area(s).

For the best user experience, it is recommended to employ at least one user feedback mechanism during Power Receiver Product positioning to help alignment.

Examples of Power Transmitter Product alignment aids to assist the user positioning of the Power Receiver Product include:

- A marked Interface Surface to indicate the location of the Active Area(s)—e.g. a logo or other visual marking, lighting, etc.
- A visual feedback display—e.g. by means of illuminating an LED to indicate proper alignment.
- An audible or tactile feedback mechanism.

46.1.5 Inter-coil separation

If the Power Transmitter Product contains multiple type MP-A1 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall not overlap.

46.2 Electrical details

As shown in Figure 188, Power Transmitter design MP-A1 uses a full-bridge inverter to drive the Primary Coil and a series capacitance. Within the Operating Frequency range specified below, the assembly of Primary Coil and Shielding has a self-inductance $L_{\mathrm{p}} = 24^{\pm 10\%}$ μH. The value of the series capacitance is $C_{\mathrm{p}} = 100^{\pm 5\%}$ nF.

NOTE: Near resonance, the voltage developed across the series capacitance can reach levels exceeding 200 V pk-pk.

Power Transmitter design MP-A1 uses the Operating Frequency and the phase difference of the full-bridge inverter's driving signals (see Figure 189), or uses the Operating Frequency and duty cycle of the half-bridge inverter's driving signals (see Figure 190) in order to control the amount of power that is transferred. For this purpose, the Operating Frequency range of the inverter is f_{op} = 110 kHz to 205 kHz with a driving signal phase difference of α = 0° to 135° or a duty cycle of $t_{\mathrm{on}} / t_{\mathrm{period}}$ = 10% to 50%. A higher Operating Frequency, higher phase, or lower duty cycle will result in the transfer of a lower amount of power. In order to achieve a sufficiently accurate adjustment of the amount of power that is transferred, a type MP-A1 Power Transmitter shall control the Operating Frequency with a minimum resolution of:

- $0.01 \times f_{\mathrm{op}} - 0.7$ kHz for f_{op} in the 110 kHz to 175 kHz range;
- $0.015 \times f_{\mathrm{op}} - 1.58$ kHz for f_{op} in the 175 kHz to 205 kHz range

In addition, a type MP-A1 Power Transmitter shall control the driving-signal phase difference with a resolution of 0.18° or better. Moreover, a type MP-A1 Power Transmitter shall control the driving-signal duty cycle with a resolution of 0.1% or better.

When a type MP-A1 Power Transmitter first applies a Power Signal (Digital Ping), it shall use an initial input voltage to the half-bridge inverter of $19^{\pm 1}$ V and an initial Operating Frequency range of 170 kHz to 180 kHz and a duty cycle of 50%.

Control of the power transfer shall proceed using the PID algorithm, which is defined in . The controlled variable $v^{(i)}$ introduced in the definition of that algorithm represents the Operating Frequency, operating duty cycle, or operating phase difference depending on the required power of the Power Receiver. In order to guarantee sufficiently accurate power control, a type MP-A1 Power Transmitter shall determine the amplitude of the Primary Cell current—which is equal to the Primary Coil current—with a resolution of 7 mA or better. Finally, Table 123, Table 124, Table 125, and Table 126 provide the values of several parameters that are used in the PID algorithm.

The type MP-A1 Power Transmitter shall handle the different control methodologies as follows.

- At an Operating Frequency of 205 kHz, the Power Transmitter shall operate in half-bridge mode, using duty cycle control with a range of 10% to 50%.
- At Operating Frequencies between 160 kHz and 205 kHz, the Power Transmitter shall operate in half-bridge mode at 50% duty cycle, using frequency control.
- At an Operating Frequency of 160 kHz, the Power Transmitter shall operate in full-bridge mode with a phase difference of 0° to 135°.
- At Operating Frequencies below 160 kHz, the Power Transmitter shall operate in full-bridge mode with a phase difference of 0° using frequency control.

When the Power Transmitter reaches the 160-kHz transition point, it shall

- switch from half-bridge mode to full-bridge mode at a 135° phase difference if moving down in Operating Frequency, or
- switch from full-bridge mode at a 135° phase difference to half-bridge mode if moving up in Operating Frequency.

If the Power Transmitter reaches the 160-kHz transition point in the middle of a PID control loop, the Power Transmitter shall terminate the control loop and wait for subsequent Control Error Packets.

Figure 188. Electrical diagram (outline) of Power Transmitter design MP-A1

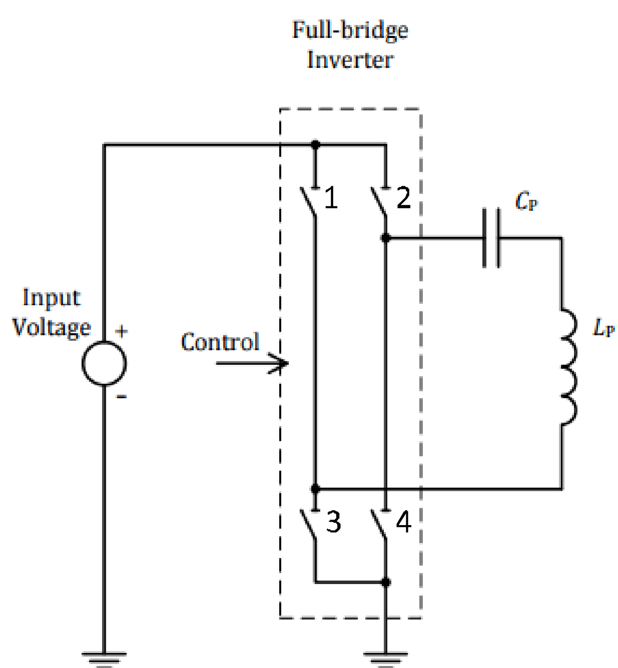


Table 123: PID parameters for Operating Frequency control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	10	mA^{-1}
Integral gain	K_i	0.05	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	3,000	N.A.
PID output limit	M_{PID}	20,000	N.A.

Figure 189. Phase control signals to Full Bridge inverter

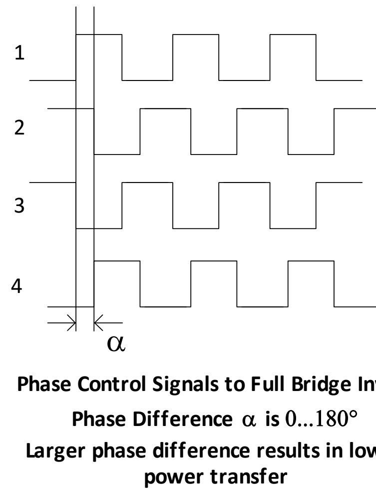


Figure 190. Duty control signals to Half Bridge inverter

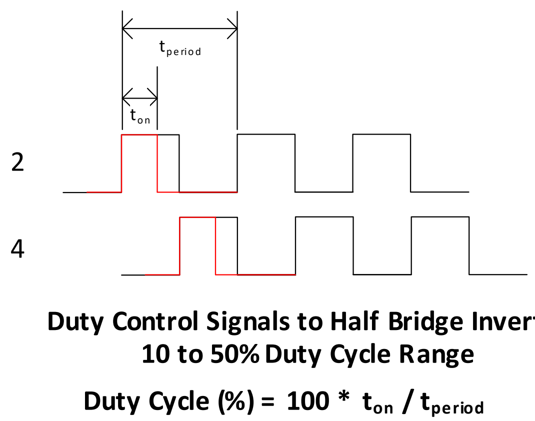


Table 124: Operating Frequency dependent scaling factor

Frequency Range [kHz]	Scaling Factor S_v [Hz]
110 to 130	1
130 to 140	1.5
140 to 160	2
160 to 180	3
180 to 205	5

Table 125: PID parameters for phase control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	1	mA^{-1}
Integral gain	K_i	0.01	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	3,000	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_v	0.036	°

Table 126: PID parameters for duty cycle control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	10	mA^{-1}
Integral gain	K_i	1	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	3,000	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_v	-0.01	%

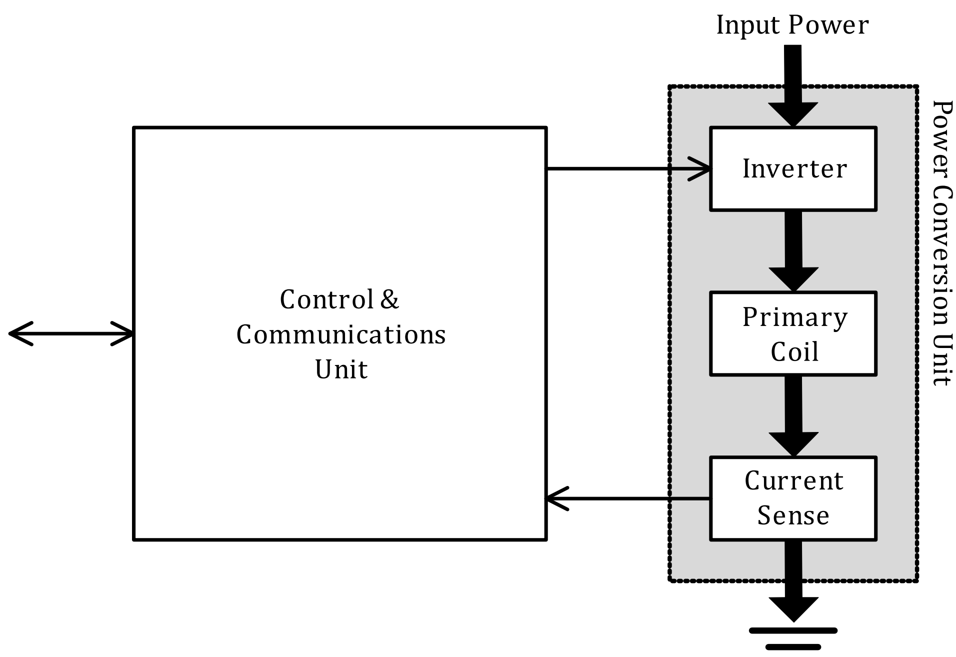
46.2.1 Information interface

The Not Res Sens Bit in the Power Transmitter Capability Packet shall be set to ZERO.

47 Power Transmitter design MP-A2

Figure 191 illustrates the functional block diagram of Power Transmitter design MP-A2. This design consists of two major functional units, namely a Power Conversion Unit and a Communications and Control Unit.

Figure 191. Functional block diagram of Power Transmitter design MP-A2



The Power Conversion Unit on the right-hand side of Figure 191 comprises the analog parts of the design. The inverter converts the DC input to an AC waveform that drives a resonant circuit consisting of the Primary Coil plus a series capacitor. Finally, the current sense monitors the Primary Coil current.

The Communications and Control Unit on the left-hand side of Figure 191 comprises the digital logic part of the design. This unit receives and decodes messages from the Power Receiver, executes the relevant power control algorithms and protocols, and drives the frequency of the AC waveform to control the power transfer. The Communications and Control Unit also interfaces with other subsystems of the Power Transmitter Product, e.g. for user interface purposes.

47.1 Mechanical details

This section defines the single Primary Coil, the Shielding, the Interface Surface and the alignment aid for Power Transmitter design MP-A2.

47.1.1 Primary Coil

The Primary Coil is of the wire-wound type, and consists of no. 17 AWG litz wire having 105 strands of no. 40 AWG (0.08 mm diameter), or equivalent. As shown in Figure 192 the Primary Coil has a rectangular shape and consists of a single layer. Table 127 lists the dimensions and other parameters of the Primary Coil.

Figure 192. Primary Coil parameters of Power Transmitter design MP-A2

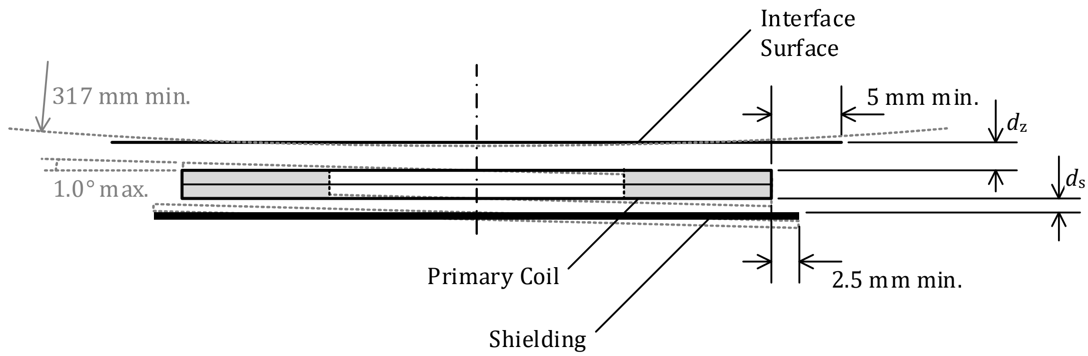
Table 127: Primary Coil parameters of Power Transmitter design MP-A2

Parameter	Symbol	Value
Outer height	H_o	$48^{\pm 0.5}$ mm
Inner height	H_i	$19^{\pm 0.5}$ mm
Outer width	W_o	$48^{\pm 0.5}$ mm
Inner width	W_i	$19^{\pm 0.5}$ mm
Thickness	d_c	$1.1^{\pm 0.3}$ mm
Number of turns per layer	N	12
Number of layers	–	1

47.1.2 Shielding

As shown in Figure 193, a soft-magnetic material protects the Power Transmitter Product from the magnetic field that is generated in the Primary Coil. The Shielding should be Ni-Zn or Mn-Zn ferrite and should be at least 1.5 mm thick. The Shielding extends to at least 2.5 mm beyond the outer rectangle of the Primary Coil, and is placed below the Primary Coil at a distance of at most $d_s = 1.0$ mm.

Figure 193. Primary Coil assembly of Power Transmitter design MP-A2



47.1.3 Interface Surface

As shown in Figure 193, the distance from the Primary Coil to the Interface Surface of the Power Transmitter Product is $d_z = 3.0^{+0.5}_{-0.25}$ mm across the top face of the Primary Coil. In addition, the Interface Surface of the Power Transmitter Product extends at least 5 mm beyond the outer diameter of the Primary Coil.

NOTE: This Primary-Coil-to-Interface-Surface distance implies that the tilt angle between the Primary Coil and a flat Interface Surface is at most 1.0°. Alternatively, in case of a non-flat Interface Surface, this Primary-Coil-to-Interface-Surface distance implies a radius of curvature of the Interface Surface of at least 317 mm, centered on the Primary Coil. See Figure 193.

47.1.4 Alignment aid

The user manual of a Power Transmitter Product containing a type MP-A2 Power Transmitter shall provide information about the location of its Active Area(s).

For the best user experience, it is recommended to employ at least one user feedback mechanism during Power Receiver Product placement to help alignment.

Examples of Power Transmitter Product alignment aids to assist the user placement of the Power Receiver Product include:

- A marked Interface Surface to indicate the location of its Active Area(s)—e.g. a logo or other visual marking, lighting, etc.
- A visual feedback display—e.g. by means of illuminating an LED to indicate proper alignment.
- An audible or tactile feedback mechanism.

47.1.5 Inter-coil separation

If the Power Transmitter Product contains multiple type MP-A2 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall not overlap.

47.2 Electrical details

As shown in Figure 194, Power Transmitter design MP-A2 uses half-bridge and full-bridge inverter topologies to drive the Primary Coil and a series capacitance. Within the Operating Frequency range specified below, the assembly of Primary Coil and Shielding, has a self-inductance $L_P = 10.0^{\pm 10\%}$ μH. The value of the series capacitance is $C_P = 247^{\pm 5\%}$ nF. The input voltage to the inverter is $12^{\pm 1}$ V.

NOTE: Near resonance, the voltage developed across the series capacitance can reach levels exceeding 200 V pk-pk.

Power Transmitter design MP-A2 uses a combination of the Operating Frequency and the duty cycle of the Power Signal to control the amount of power that is transferred. For this purpose, the Operating Frequency range of the inverter is f_{op} = 110 kHz to 145 kHz. The duty cycle of the full-bridge inverter is 40% to 50% if f_{op} = 110 kHz to 145 kHz and is 5% to 50% at f_{op} = 145 kHz. A higher Operating Frequency or a lower duty cycle will result in the transfer of a lower amount of power. In order to achieve a sufficiently accurate adjustment of the amount of power that is transferred, a type MP-A2 Power Transmitter shall control the Operating Frequency with a minimum resolution of $0.007 \times f_{op} - 0.5$ kHz for f_{op} in the 110 kHz to 145 kHz range. In addition, a Type MP-A2 Power Transmitter shall control the duty cycle of the Power Signal with a resolution of 0.1% or better.

When a type MP-A2 Power Transmitter first applies a Power Signal (Digital Ping), it shall use the half-bridge inverter topology with an initial input voltage of $12^{\pm 1}$ V and an initial Operating Frequency in the range of 135 kHz to 145 kHz and a duty cycle of 50%. If a type MP-A2 Power Transmitter establishes the Power Transfer Contract at the end of the *negotiation* phase (see the *Qi Specification, Communications Protocol*) with a Maximum Power greater than 5 W, it shall change its inverter to use the full-bridge topology after receiving the first Control Error Packet. The Initial Operating Frequency of the full-bridge inverter topology is in the range of 135 kHz to 145 kHz and the initial duty cycle is 20%.

Control of the power transfer shall proceed using the PID algorithm that is defined in the *Qi Specification, Power Delivery*. The controlled variable $v^{(i)}$ introduced in the definition of that algorithm represents the Operating Frequency or the duty cycle. In order to guarantee sufficiently accurate power control, a type MP-A2 Power Transmitter shall determine the amplitude of the Primary Coil current with a resolution of 7 mA or better. Finally, Table 128, Table 129, and Table 130 provide the values of the parameters that are used in the PID algorithm for the full-bridge inverter topology; Table 131, Table 132, and Table 133 provide the same parameters for the half-bridge inverter topology.

Figure 194. Electrical diagram (outline) of Power Transmitter design MP-A2 (full-bridge topology)

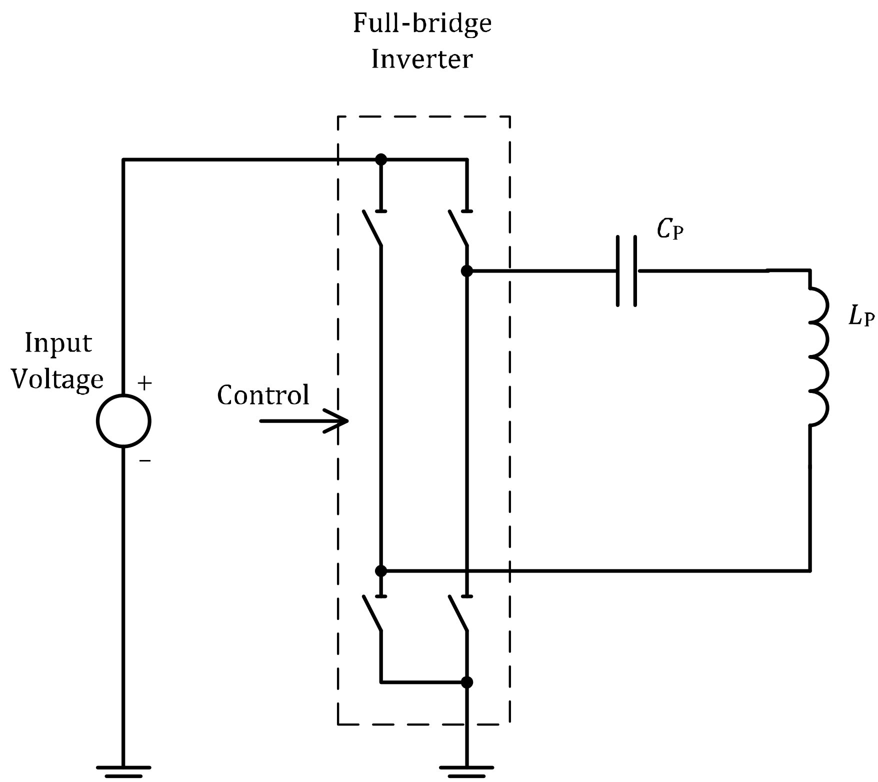


Table 128: PID parameters for Operating Frequency control design MP-A2 (full-bridge topology)

Parameter	Symbol	Value	Unit
Proportional gain	K_p	2	mA^{-1}
Integral gain	K_i	0.01	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	500	N.A.
PID output limit	M_{PID}	5,000	N.A.

Table 129: Operating Frequency dependent scaling factor (full-bridge topology)

Frequency Range [kHz]	Scaling Factor S_v [Hz]
110 to 115	1.5
115 to 120	2
120 to 135	3
135 to 140	5

Table 130: PID parameters for duty control (full-bridge topology)

Parameter	Symbol	Value	Unit
Proportional gain	K_p	2	mA^{-1}
Integral gain	K_i	0.01	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	500	N.A.
PID output limit	M_{PID}	5,000	N.A.
Scaling factor	S_v	-0.01	%

Table 131: Electrical diagram of Power Transmitter design MP-A2 (half-bridge topology)

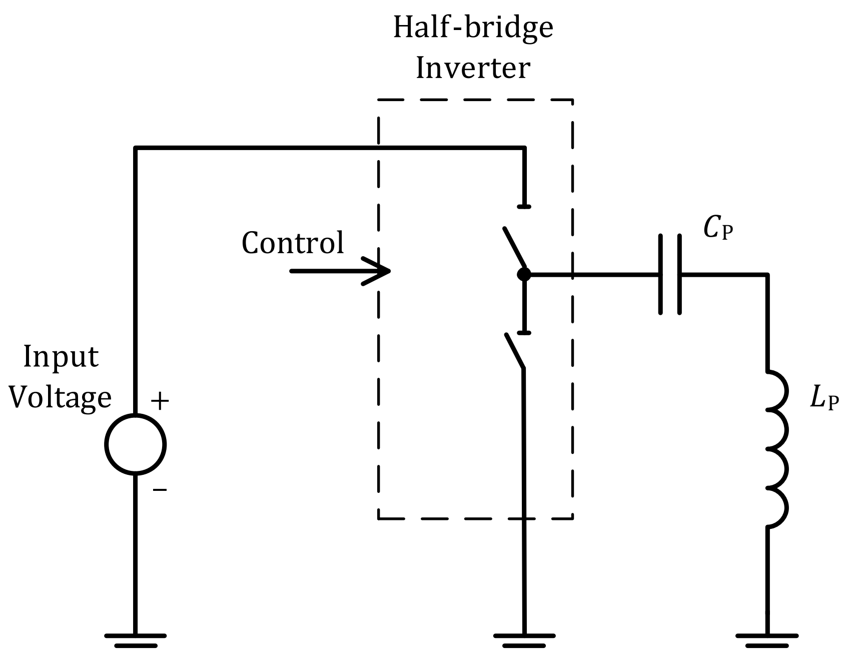


Table 132: PID parameters for Operating Frequency control (half-bridge topology)

Parameter	Symbol	Value	Unit
Proportional gain	K_p	5	mA^{-1}
Integral gain	K_i	0.02	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	1,000	N.A.
PID output limit	M_{PID}	10,000	N.A.

Table 133: Operating Frequency dependent scaling factor (half-bridge topology)

Frequency Range [kHz]	Scaling Factor S_v [Hz]
110 to 115	1.5
115 to 120	2
120 to 135	3
135 to 140	5

Table 134: PID parameters for duty cycle control (half-bridge topology)

Parameter	Symbol	Value	Unit
Proportional gain	K_p	5	mA^{-1}
Integral gain	K_i	0.02	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	1,000	N.A.
PID output limit	M_{PID}	10,000	N.A.
Scaling factor	S_v	-0.01	%

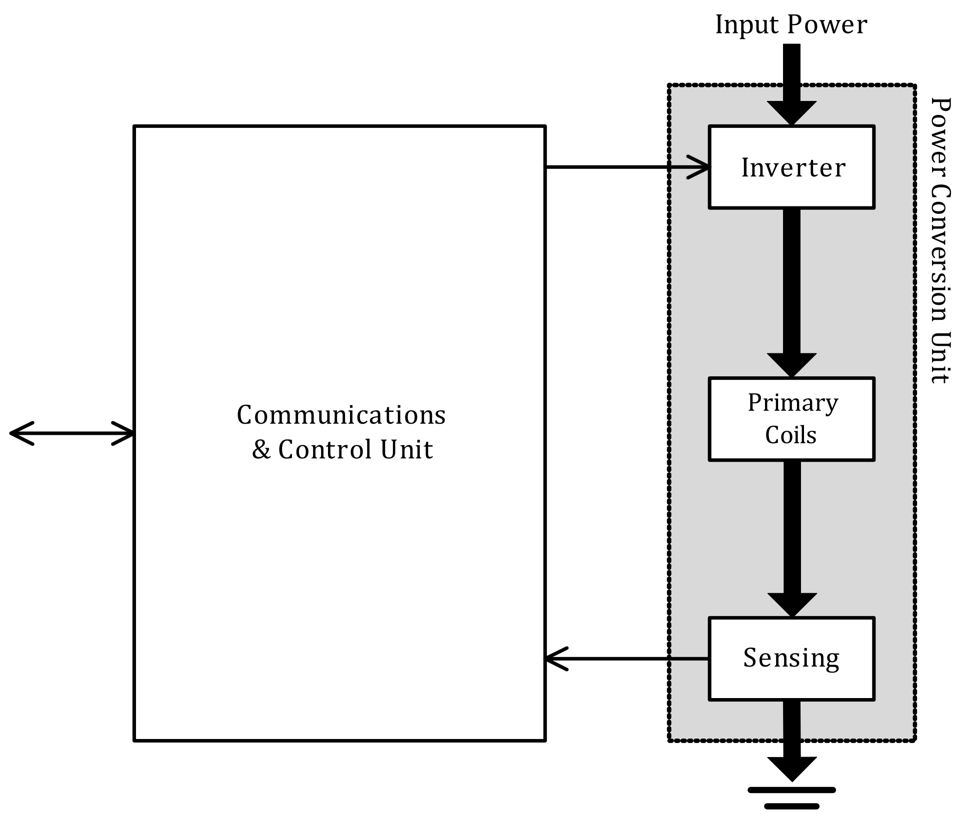
47.2.1 Information interface

The Not Res Sens Bit in the Power Transmitter Capability Packet shall be set to ZERO.

48 Power Transmitter design MP-A3

Figure 195 illustrates the functional block diagram of Power Transmitter design MP-A3. This design consists of two major functional units, namely a Power Conversion Unit and a Communications and Control Unit.

Figure 195. Functional block diagram of Power Transmitter design MP-A3



The Power Conversion Unit on the right-hand side of Figure 195 comprises the analog parts of the design. The inverter converts the DC input to an AC waveform that drives a resonant circuit consisting of the Primary Coil plus a series capacitor. Finally, the voltage and current sense monitors the Primary Coil voltage and current.

The Communications and Control Unit on the left-hand side of Figure 195 comprises the digital logic part of the design. The unit receives and decodes messages from the Power Receiver, executes the relevant power control algorithms and protocols, and drives the input power and frequency of the AC waveform to control the power transfer. The Communications and Control Unit also interfaces with other subsystems of the Power Transmitter Product, e.g. for user interface purposes.

48.1 Mechanical details

Power Transmitter design MP-A3 includes one Primary Coil, Shielding, and an Interface Surface as defined in the subsections below.

48.1.1 Primary Coil

The Primary Coil is of the wire-wound type, and consists of no. 14 AWG litz wire having 140 strands of no. 38 AWG (0.1 mm diameter), or equivalent. As shown in Figure 196, the Primary Coil has a racetrack-like shape and consists of multiple layers. All layers are stacked with the same polarity. The dimensions of the Primary Coil are listed in Table 135.

Figure 196. Primary Coil of Power Transmitter design MP-A3

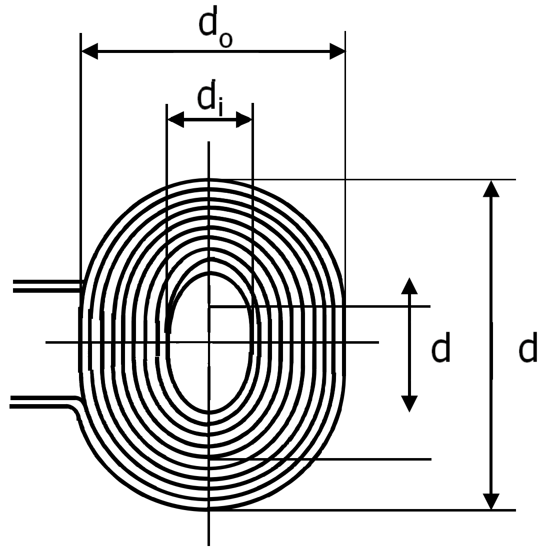


Table 135: Primary Coil parameters of Power Transmitter design MP-A3

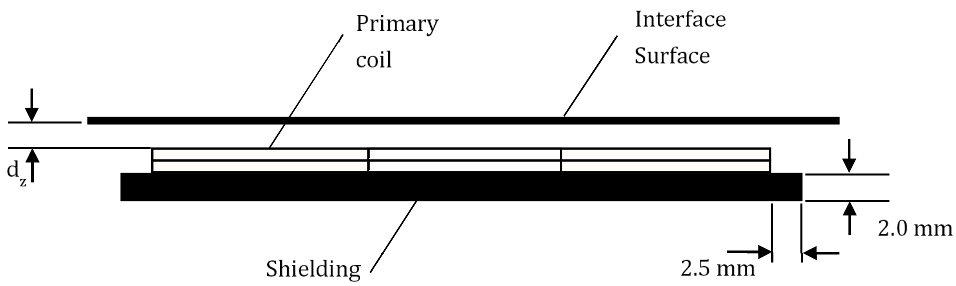
Parameter	Symbol	Value
Outer length	d_{ol}	$42.8^{\pm 2.0}$ mm
Inner length	d_{il}	$17.2^{\pm 1.0}$ mm
Outer width	d_{ow}	$36.2^{\pm 2.0}$ mm
Inner width	d_{iw}	$9.3^{\pm 1.0}$ mm
Thickness	d_{c}	$3.8^{\pm 0.5}$ mm
Number of turns per layer	N	8
Number of layers	–	2

48.1.2 Shielding

As shown in Figure 196, Shielding protects the Power Transmitter Product from the magnetic field that is generated in the Primary Coil. The Shielding should be Ni-Zn or Mn-Zn ferrite and should be at least 2.0 mm thick.

The top face of the Shielding block is aligned with the top face of the Primary Coil, such that the Shielding surrounds the Primary Coil on all sides except for the top face. In addition, the Shielding extends to at least 2.5 mm beyond the outer edge of the Primary Coil.

Table 136: Primary Coil assembly of Power Transmitter design MP-A3



48.1.3 Interface Surface

As shown in Figure 196, the distance from the Primary Coil to the Interface Surface of the Power Transmitter Product is $d_z = 3.0^{\pm 0.5}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Power Transmitter Product extends at least 5 mm beyond the outer diameter of the Primary Coil.

48.1.4 Inter-coil separation

If the Power Transmitter Product contains multiple type MP-A3 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall not overlap.

48.2 Electrical details

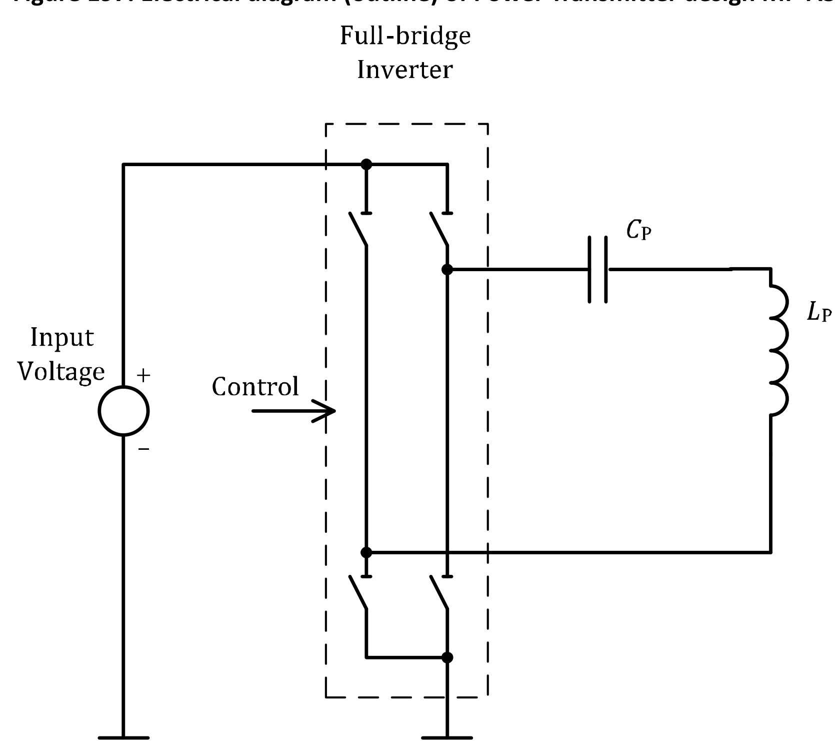
As shown in Figure 197, Power Transmitter design MP-A3 uses a full-bridge inverter topology to drive the Primary Coil and a series capacitance. Within the Operating Frequency range specified in this section, the Primary Coil and Shielding assembly has a self-inductance value of $L_{\mathrm{P}} = 10.1^{\pm 5\%}$ μH. The value of the series capacitance is $C_{\mathrm{P}} = 251^{\pm 10\%}$ nF.

NOTE: Near resonance, the voltage developed across the series capacitance can reach levels up to 100 V pk-pk.

Power Transmitter design MP-A3 uses the combination of the Operating Frequency, the input voltage, and the duty cycle of the full-bridge inverter to control the amount of power transferred. For this purpose, the input voltage has a range of $2.5^{\pm 0.5}$ V to $11.5^{\pm 0.5}$ V, with a resolution of 10 mV or better. A higher input voltage results in more power transferred. The Operating Frequency is f_{op} = 110 kHz to 205 kHz with a duty cycle of 50%, and the duty cycle range is 0 to 50% at an Operating Frequency of 205 kHz.

When a type MP-A3 Power Transmitter first applies a Power Signal (Digital Ping), the Power Transmitter shall use an Operating Frequency in the range of 160 kHz to 180 kHz with an input voltage of $12.0^{\pm 0.25}$ V. If the Power Transmitter does not receive a Signal Strength Packet from the Power Receiver, the Power Transmitter shall remove the Power Signal. The Power Transmitter may reapply the Power Signal multiple times at other, consecutively lower, Operating Frequencies within the range specified above until the Power Transmitter receives a Signal Strength Packet containing an appropriate Signal Strength Value.

Figure 197. Electrical diagram (outline) of Power Transmitter design MP-A3



Control of the power transfer shall proceed using the PID algorithm that is defined in the *Qi Specification, Power Delivery*. The controlled variable $v^{(i)}$ introduced in the definition of that algorithm represents the Operating Frequency, the input voltage, or the duty cycle of the full-bridge inverter. It is recommended that control of the power occurs primarily by means of adjustments to the Operating Frequency, and that voltage or duty cycle adjustments are made only at the boundaries of the Operating Frequency range. In order to guarantee sufficiently accurate power control, a type MP-A3 Power Transmitter shall determine the amplitude of the Primary Coil current with a resolution of 7 mA or better.

Table 137, Table 138, and Table 139 provide the values of the parameters that are used in the PID algorithm.

Table 137: PID parameters for Operating Frequency control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	1	mA^{-1}
Integral gain	K_i	0	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	N.A.	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_v	1.0	Hz

Table 138: PID parameters for voltage control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	1	mA^{-1}
Integral gain	K_i	0	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	N.A.	N.A.
PID output limit	M_{PID}	1,500	N.A.
Scaling factor	S_v	–0.5	mV

Table 139: PID parameters for duty cycle control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	1	mA^{-1}
Integral gain	K_i	0	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	N.A.	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_v	0.1	%

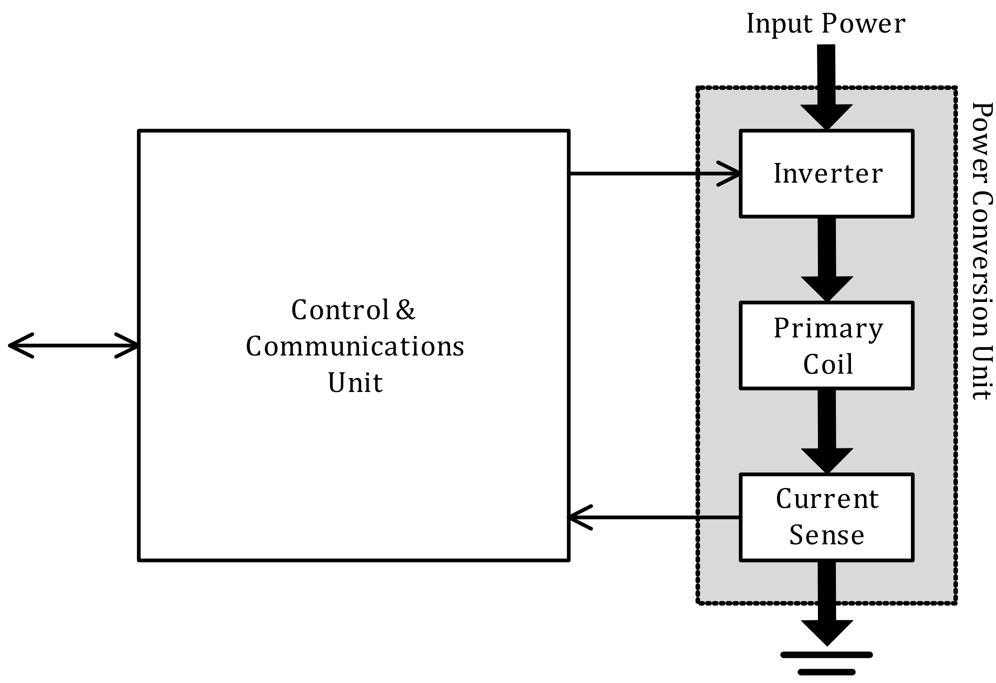
48.2.1 Information interface

The Not Res Sens Bit in the Power Transmitter Capability Packet shall be set to ZERO.

49 Power Transmitter design MP-A4

Figure 198 illustrates the functional block diagram of Power Transmitter design MP-A4, which consists of two major functional units, namely a Power Conversion Unit and a Communications and Control Unit.

Figure 198. Functional block diagram of Power Transmitter design MP-A4



The Power Conversion Unit on the right-hand side of Figure 198 comprises the analog parts of the design. The inverter converts the DC input to an AC waveform that drives a resonant circuit, which consists of the Primary Coil plus a series capacitor. Finally, the current sense monitors the Primary Coil current.

The Communications and Control Unit on the left-hand side of Figure 198 comprises the digital logic part of the design. This unit receives and decodes messages from the Power Receiver, executes the relevant power control algorithms and protocols, and drives the frequency of the AC waveform to control the power transfer. The Communications and Control Unit also interfaces with other subsystems of the Power Transmitter Product, e.g. for user interface purposes.

49.1 Mechanical details

This section defines the Primary Coil, the Shielding, the Interface Surface, and the alignment aid for Power Transmitter design MP-A4.

49.1.1 Primary Coil

The Primary Coil is of the wire-wound type, and consists of litz wire with nylon spinning having 180 strands of no. 42 AWG (0.06 mm diameter), or equivalent. As shown in Figure 199 the Primary Coil has a round shape and consists of a single layer. Table 140 lists the dimensions and other parameters of the Primary Coil.

Figure 199. Primary Coil of Power Transmitter design MP-A4

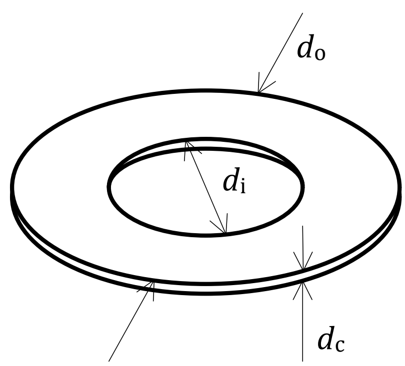


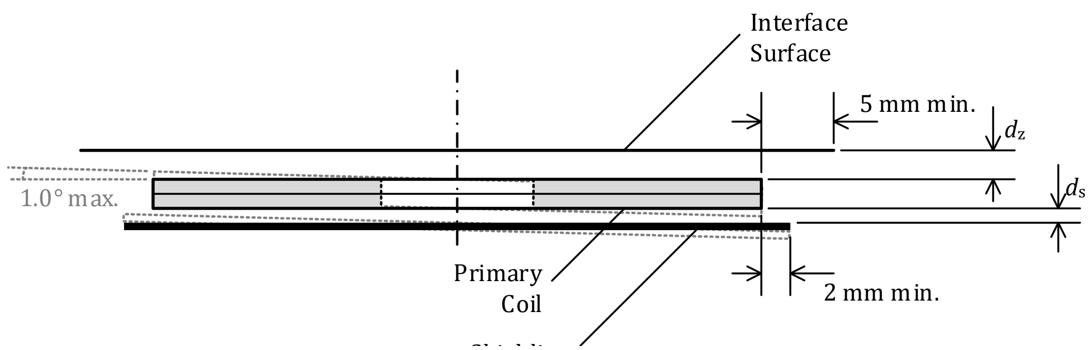
Table 140: Primary Coil parameters of Power Transmitter design MP-A4

Parameter	Symbol	Value
Outer diameter	d_o	$48.5^{\pm 1.0}$ mm
Inner diameter	d_i	$23.0^{\pm 1.0}$ mm
Coil thickness	d_c	$2.0^{\pm 0.5}$ mm
Number of turns per layer	N	11
Number of layers	—	1

49.1.2 Shielding

As shown in Figure 200, Shielding protects the Power Transmitter Product from the magnetic field that is generated in the Primary Coil. The Shielding should be Ni-Zn or Mn-Zn ferrite and should be at least 0.5 mm thick. The Shielding extends to at least 2 mm beyond the outer diameter of the Primary Coils, and is placed below the Primary Coil at a distance of at most d_s = 1.0 mm.

Figure 200. Primary Coil assembly of Power Transmitter design MP-A4



49.1.3 Interface surface

As shown in Figure 200, the distance from the Primary Coil to the Interface Surface of the Power Transmitter Product is $d_z = 2^{\pm 1}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Power Transmitter Product extends at least 5 mm beyond the outer dimensions of the Primary Coils.

49.1.4 Alignment aid

The user manual of a Power Transmitter Product containing a type MP-A4 Power Transmitter shall provide information about the location of its Active Area(s).

For the best user experience, it is recommended to employ at least one user feedback mechanism during Power Receiver Product positioning to help alignment.

Examples of Power Transmitter Product alignment aids to assist the user positioning of the Power Receiver Product include:

- A marked Interface Surface to indicate the location of its Active Area(s)—e.g. a logo or other visual marking, lighting, etc.
- A visual feedback display—e.g. by means of illuminating an LED to indicate proper alignment.
- An audible or tactile feedback mechanism.

49.1.5 Inter-coil separation

If the Power Transmitter Product contains multiple type MP-A4 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall not overlap.

49.2 Electrical details

As shown in Figure 201, Power Transmitter design MP-A4 uses a full-bridge inverter to drive the Primary Coil and a series capacitance. Within the Operating Frequency range specified below, the assembly of Primary Coil and Shielding has a self-inductance of $L_{\mathrm{p}} = 8.9^{\pm 10\%} \mu H$. The value of the series capacitance is $C_{\mathrm{p}} = 276^{\pm 5\%} nF$.

NOTE: Near resonance, the voltage developed across the series capacitance can reach levels exceeding 200 V pk-pk.

Power Transmitter design MP-A4 uses the Operating Frequency and the phase difference of the full-bridge inverter's driving signals (see Figure 202), or uses the Operating Frequency and duty cycle of the half-bridge inverter's driving signals (see Figure 203) in order to control the amount of power that is transferred. For this purpose, the Operating Frequency range of the inverter is f_{op} = 110 kHz to 205 kHz with a driving signal phase difference of α = 0° to 133° or a duty cycle of D = 10% to 50%. A higher Operating Frequency, higher phase difference, or lower duty cycle will result in the transfer of a lower amount of power. In order to achieve a sufficiently accurate adjustment of the amount of power that is transferred, a type MP-A4 Power Transmitter shall control the Operating Frequency with a minimum resolution of:

- $0.01 \times f_{\mathrm{op}} - 0.7$ kHz for f_{op} in the 110 kHz to 175 kHz range;
- $0.015 \times f_{\mathrm{op}} - 1.58$ kHz for f_{op} in the 175 kHz to 205 kHz range.

In addition, a type MP-A4 Power Transmitter shall control the driving-signal phase difference with a resolution of 0.18° or better. Moreover, a type MP-A4 Power Transmitter shall control the driving-signal duty cycle with a resolution of 0.1% or better.

When a type MP-A4 Power Transmitter first applies a Power Signal (Digital Ping), it shall use an initial input voltage to the half-bridge inverter of $12^{\pm 5\%}$ V and an initial Operating Frequency of 175 kHz and a duty cycle of 50%.

Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Qi Specification, Power Delivery*. The controlled variable $v^{(i)}$ introduced in the definition of that algorithm represents the Operating Frequency, operating duty cycle, or operating phase difference depending on the required power of the Power Receiver. In order to guarantee sufficiently accurate power control, a type MP-A4 Power Transmitter shall determine the amplitude of the Primary Cell current—which is equal to the Primary Coil current—with a resolution of 7 mA or better. Finally, Table 141, Table 142, Table 143, Table 144, and Table 145 provide the values of several parameters that are used in the PID algorithm.

The type MP-A4 Power Transmitter shall handle the different control methodologies as follows.

- At an Operating Frequency of 205 kHz, the Power Transmitter shall operate in half-bridge mode, using duty cycle control with a range of 10% to 50%.
- At Operating Frequencies between 172 kHz and 205 kHz, the Power Transmitter shall operate in half-bridge mode at 50% duty cycle, using frequency control.
- At an Operating Frequency of 172 kHz, the Power Transmitter shall operate in full-bridge mode with a phase difference of 0° to 133°.

- At Operating Frequencies below 172 kHz, the Power Transmitter shall operate in full-bridge mode with a phase difference of 0° using frequency control.

When the Power Transmitter reaches the 172-kHz transition point, it shall

- switch from half-bridge mode to full-bridge mode at a 133° phase difference if moving down in Operating Frequency, or
- switch from full-bridge mode at a 133° phase difference to half-bridge mode if moving up in Operating Frequency.

If the Power Transmitter reaches the 172-kHz transition point in the middle of a PID control loop, the Power Transmitter shall terminate the control loop and wait for subsequent Control Error Packets.

Figure 201. Electrical diagram (outline) of Power Transmitter design MP-A4

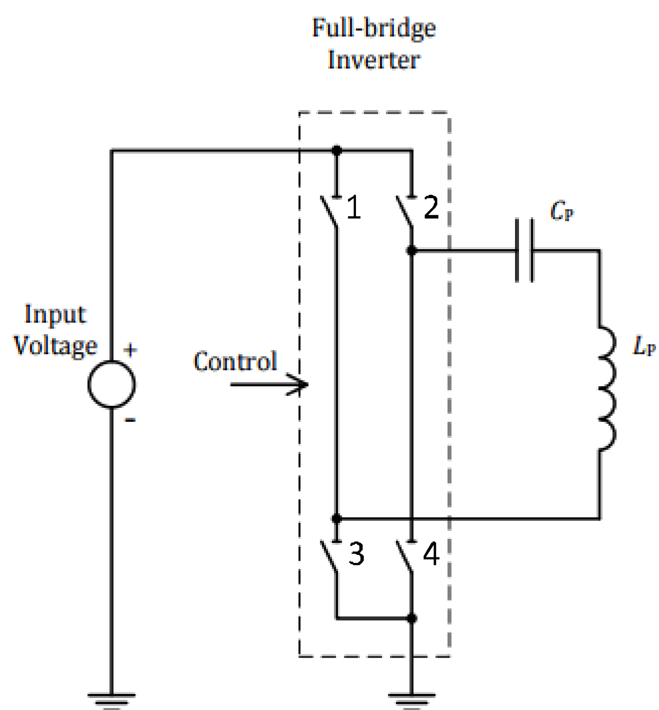


Figure 202. Phase control signals to Full Bridge inverter

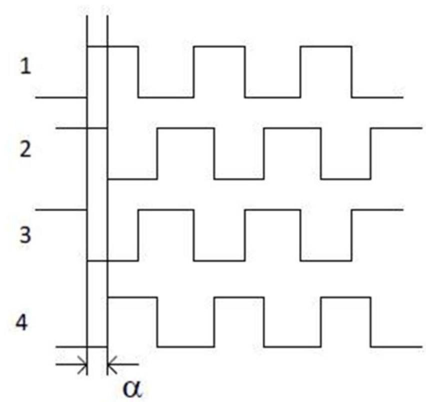


Figure 203. Duty control signals to Half Bridge inverter

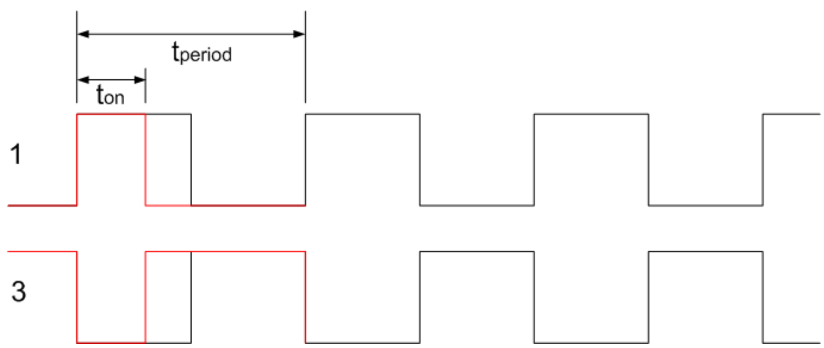


Table 141: PID parameters for Operating Frequency control (half bridge)

Parameter	Symbol	Value	Unit
Proportional gain	K_p	10	mA^{-1}
Integral gain	K_i	1	$mA^{-1}ms^{-1}$
Derivative gain	K_d	1	$mA^{-1}ms$
Integral term limit	M_I	3,000	N.A.
PID output limit	M_{PID}	20,000	N.A.

Table 142: PID parameters for Operating Frequency control (full bridge)

Parameter	Symbol	Value	Unit
Proportional gain	K_p	5	mA^{-1}
Integral gain	K_i	1	$mA^{-1}ms^{-1}$
Derivative gain	K_d	1	$mA^{-1}ms$
Integral term limit	M_I	3,000	N.A.
PID output limit	M_{PID}	20,000	N.A.

Table 143: Operating Frequency dependent scaling factor

Frequency Range[kHz]	Scaling Factor S_V [Hz]
110…140	1.5
140…160	2
160…180	3
180…205	5

Table 144: PID parameters for phase control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	1	mA^{-1}
Integral gain	K_i	1	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	3,000	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_v	0.009	°

Table 145: PID parameters for duty cycle control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	10	mA^{-1}
Integral gain	K_i	1	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	3,000	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_v	-0.01	%

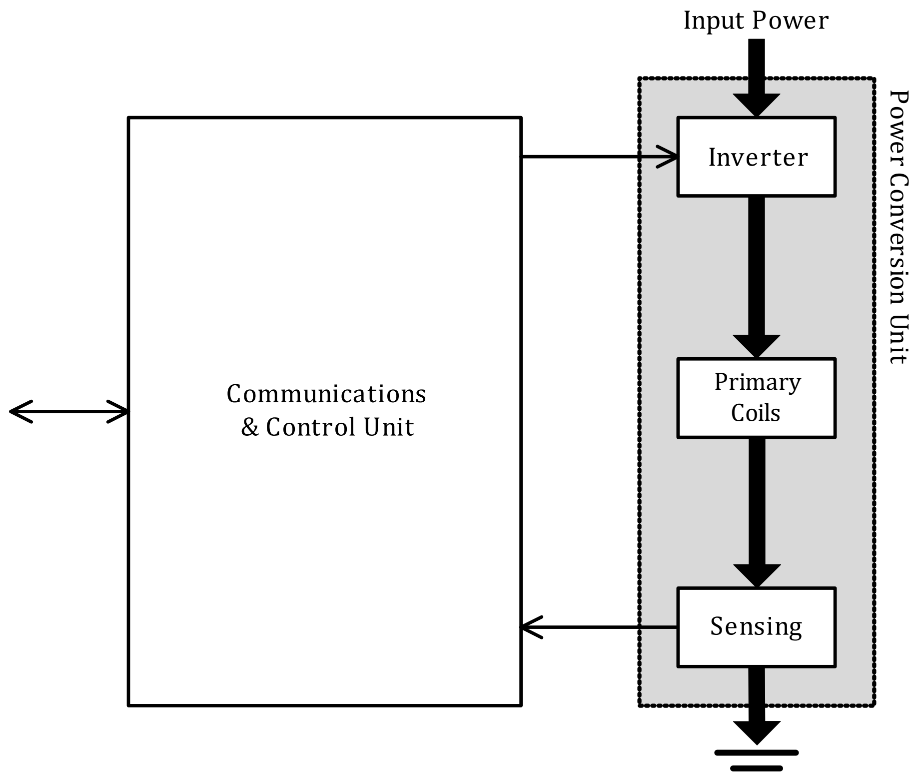
49.2.1 Information interface

The Not Res Sens Bit in the Power Transmitter Capability Packet shall be set to ZERO.

50 Power Transmitter design MP-A5

Figure 204 illustrates the functional block diagram of Power Transmitter Design MP-A5.

Figure 204. Functional block diagram of Power Transmitter MP-A5



The Power Conversion Unit on the right-hand side of Figure 204 comprises the analog parts of the design. The inverter converts the DC input to an AC waveform that drives a resonant circuit, which consists of the Primary Coil plus a series capacitor. Finally, the voltage and current sense monitors the Primary Coil voltage and current.

The Communications and Control Unit on the left-hand side of Figure 204 comprises the digital logic part of the design. The unit receives and decodes messages from the Power Receiver, executes the relevant power control algorithms and protocols, and drives the input power and frequency of the AC waveform to control the power transfer. The Communications and Control Unit also interfaces with other subsystems of the Power Transmitter Product, e.g. for user interface purposes.

50.1 Mechanical details

Power Transmitter design MP-A5 includes a Primary Coil array as defined in Section 50.1.1, *Primary Coil*, Shielding as defined in Section 50.1.2, *Shielding*, and an Interface Surface as defined in Section 50.1.3, *Interface Surface*.

50.1.1 Primary Coil

The Primary Coil is of the wire-wound type, and consists of litz wire with nylon spinning having 180 strands of no. 40 AWG (0.08 mm diameter), or equivalent. As shown in Figure 205 the Primary Coil has a circular shape and consists of two layers with a total of 13 turns. Table 146 lists the dimensions of the Primary Coil.

Figure 205. Primary Coil of Power Transmitter MP-A5

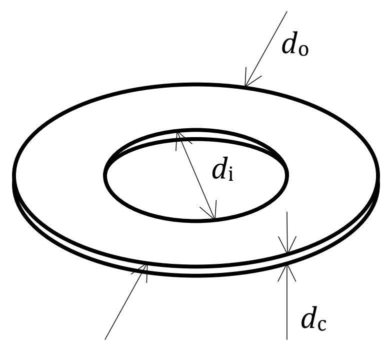


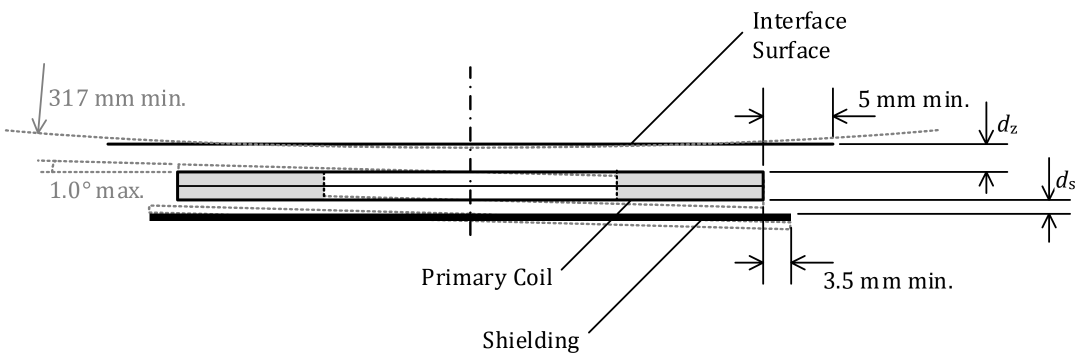
Table 146: Primary Coil of Power Transmitter MP-A5

Parameter	Symbol	Value
Outer diameter	d_o	$41^{\pm 2}$ mm
Inner diameter	d_i	$21^{\pm 0.5}$ mm
Thickness	d_c	$3^{\pm 0.5}$ mm
Numbers of turns per layer	N	6.5
Number of layers	–	2

50.1.2 Shielding

As shown in Figure 206, Shielding protects the Power Transmitter Product from the magnetic field that is generated in the Primary Coil. The Shielding should be Ni-Zn or Mn-Zn ferrite and should be at least 2.5 mm thick. The Shielding extends to at least 3.5 mm beyond the outer diameter of the Primary Coil, and is placed below the Primary Coil at a distance of at most d_s = 1.0 mm.

Figure 206. Primary Coil assembly of Power Transmitter design MP-A5



50.1.3 Interface Surface

As shown in Figure 206, the distance from the Primary Coil to the Interface Surface of the Power Transmitter Product is $d_z = 2.5^{\pm 0.5}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Power Transmitter Product extends at least 5 mm beyond the outer diameter of the Primary Coil.

NOTE: NOTE This Primary- Coil-to-Interface-Surface distance implies that the tilt angle between the Primary Coil and a flat Interface Surface is at most 1.0°. Alternatively, in case of a non-flat Interface Surface, this Primary-Coil-to-Interface-Surface distance implies a radius of curvature of the Interface Surface of at least 317 mm, centered on the Primary Coil. See Figure 206.

50.1.4 Alignment Aid

The user manual of the Power Transmitter Product containing a type MP-A5 Power Transmitter shall have information about the location of its Active Area(s).

For the best user experience, it is recommended to employ at least one user feedback mechanism during Power Receiver Product positioning to help alignment.

NOTE: Examples of Power Transmitter Product alignment aids to assist the user positioning of the Power Receiver Product include:

A marked Interface Surface to indicate the location of the Active Area(s)—e.g. by means of the logo or other visual marking, lighting, etc.

A visual feedback display—e.g. by means of illuminating an LED to indicate proper alignment.

An audible or haptic feedback mechanism.

50.1.5 Inter coil separation

If the Power Transmitter Product contains multiple type MP-A5 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall not overlap.

50.2 Electrical Details

As shown in Figure 207, Power Transmitter design MP-A5 uses a full-bridge inverter to drive the resonant network with a primary Coil with a series capacitance. Within the Operating Frequency range specified below, the assembly of Primary Coil and Shielding, has a self-inductance $L_p = 10^{\pm 10\%}$ μH. The value of the total series capacitance $C_p = 247^{\pm 5\%}$ nF, where the individual series capacitances may have any value less than the sum.

NOTE: Near resonance, the voltage developed across the series capacitance can reach levels exceeding 100 V pk-pk.

Power Transmitter design MP-A5 uses the input voltage to the inverter to control the amount of power transferred. For this purpose, the input voltage has a range $1^{\pm 5\%}$...$12^{\pm 5\%}$ V, with a resolution of 40 mV or better; a higher input voltage results in more power transferred. The Operating Frequency is $130^{\pm 3\%}$ kHz with a duty cycle of 50%.

When a type MP-A5 Power Transmitter first applies a Power Signal (Digital Ping; see the *Qi Specification, Communications Protocol*), it shall use an Operating Frequency of 130 kHz and a recommended input voltage of 4 V.

Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Qi Specification, Power Delivery*. The controlled variable $v^{(i)}$ introduced in the definition of that algorithm represents the input voltage. Finally, Table 147 provides the values of several parameters that are used in the PID algorithm.

Figure 207. Electrical diagram (outline) Primary Coil of Power Transmitter design MP-A5

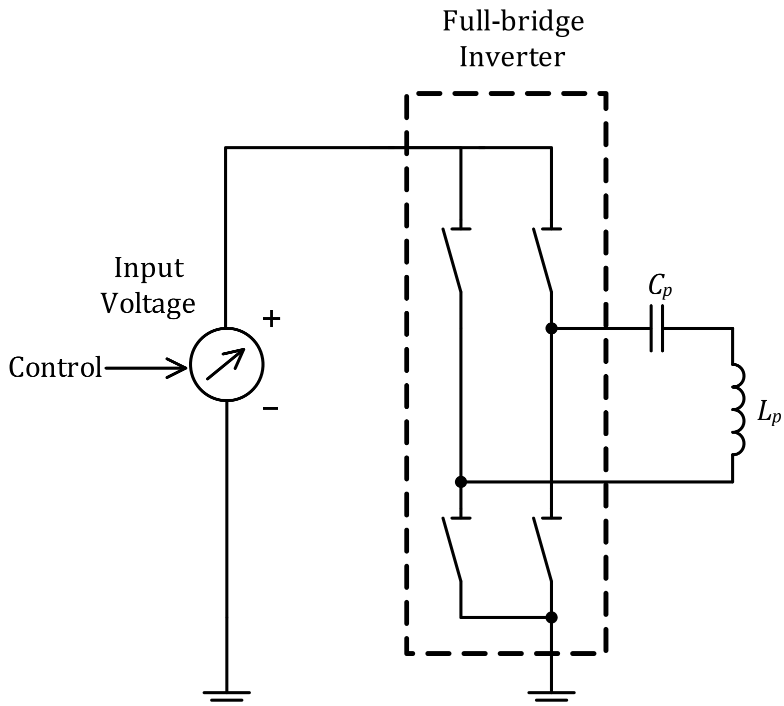


Table 147: PID parameters for voltage control

Parameter	Symbol	Value	Unit
Proportional Gain	K_p	10	mA^{-1}
Integral Gain	K_i	0.05	$mA^{-1}ms^{-1}$
Derivative Gain	K_d	0	$mA^{-1}ms^{-1}$
Integral Term Limit	M_I	3,000	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_v	-0.01	%

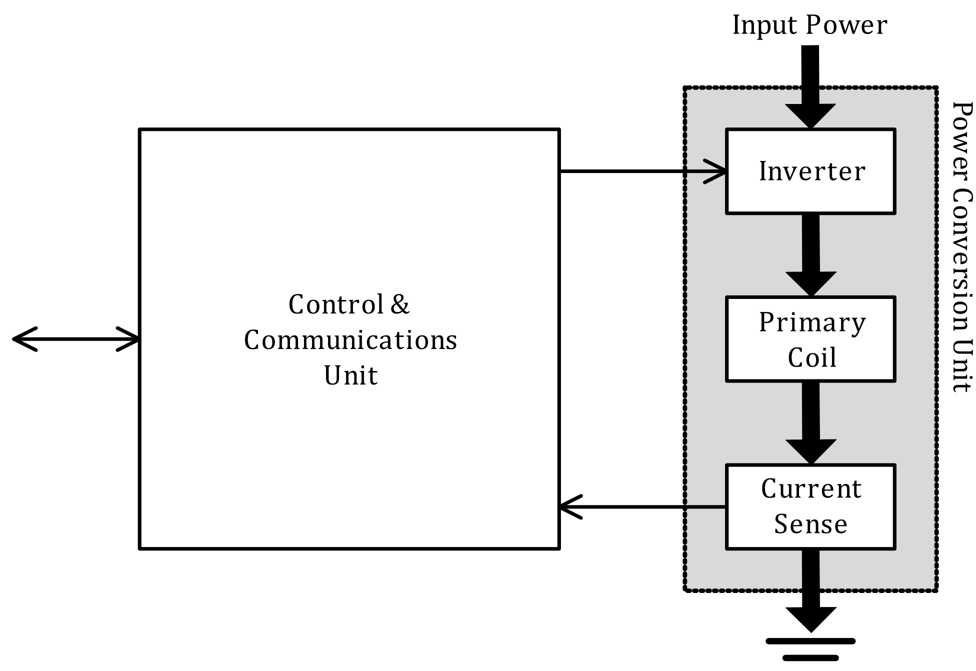
50.2.1 Information interface

The Not Res Sens Bit in the Power Transmitter Capability Packet shall be set to ONE.

51 Power Transmitter design MP-A6

Figure 208 illustrates the functional block diagram of Power Transmitter design MP-A6. This design consists of two major functional units, namely a Power Conversion Unit and a Communications and Control Unit.

Figure 208. Functional block diagram of Power Transmitter design MP-A6



The Power Conversion Unit on the right-hand side of Figure 208 comprises the analog parts of the design. The inverter converts the DC input to an AC waveform that drives a resonant circuit, which consists of the Primary Coil plus a series capacitor. Finally, the current sense monitors the Primary Coil current.

The Communications and Control Unit on the left-hand side of Figure 208 comprises the digital logic part of the design. This unit receives and decodes messages from the Power Receiver, executes the relevant power control algorithms and protocols, and drives the frequency of the AC waveform to control the power transfer. The Communications and Control Unit also interfaces with other subsystems of the Power Transmitter Product, e.g. for user interface purposes.

51.1 Mechanical details

This section defines the Primary Coils, the Shielding, and the Interface Surface for Power Transmitter design MP-A6.

51.1.1 Primary Coil

The Primary Coil is of the wire-wound type, and consists of no. 17 AWG litz wire having 105 strands of no. 40 AWG (0.08 mm diameter), or equivalent. As shown in Figure 209, the Primary Coils have two types of rectangular shape and each coil consists of a single layer. Table 148 and Table 149 list the dimensions of both bottom (close to ferrite) and top (close to interface) Primary Coil.

Figure 209. Bottom and Top Primary Coils of Power Transmitter design MP-A6

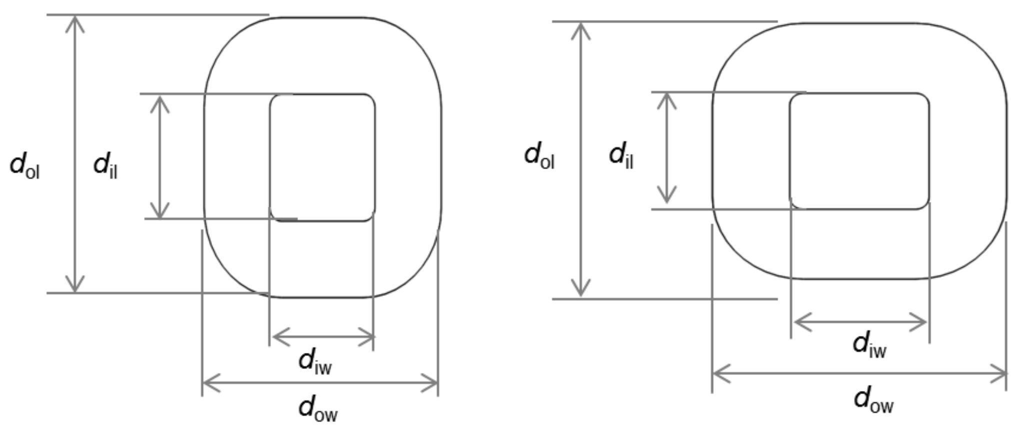


Table 148: Bottom Primary Coil parameters of Power Transmitter design MP-A6

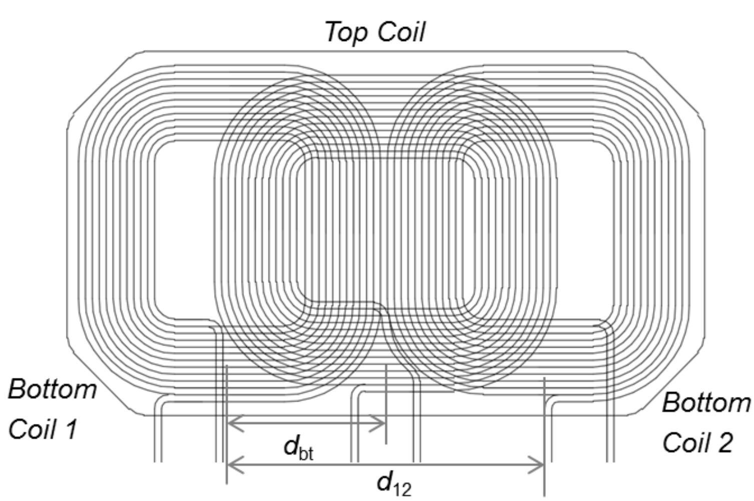
Parameter	Symbol	Value
Outer height	d_{ol}	$49.0^{\pm 1.0}$ mm
Inner height	d_{il}	$26.0^{\pm 1.0}$ mm
Outer width	d_{ow}	$44.0^{\pm 1.0}$ mm
Inner width	d_{iw}	$22.0^{\pm 1.0}$ mm
Thickness	d_c	$1.1^{\pm 0.2}$ mm
Number of turns per layer	N	11
Number of layers	—	1

Table 149: Top Primary Coil parameters of Power Transmitter design MP-A6

Parameter	Symbol	Value
Outer height	d_{ol}	$46.0^{\pm 1.0}$ mm
Inner height	d_{il}	$21.0^{\pm 1.0}$ mm
Outer width	d_{ow}	$49.5^{\pm 1.0}$ mm
Inner width	d_{iw}	$25.5^{\pm 1.0}$ mm
Thickness	d_c	$1.1^{\pm 0.2}$ mm
Number of turns per layer	N	12
Number of layers	—	1

Power Transmitter design MP-A6 contains three Primary Coils. Bottom Primary Coil #1 and bottom Primary Coil #2 are placed alongside each other with a displacement of $d_{12} = 46^{\pm 4}$ mm between their centers. The top Primary Coil is placed orthogonal to the bottom Primary Coils, with a displacement of $d_{bt} = 23^{\pm 2}$ mm between their centers. See Figure 210.

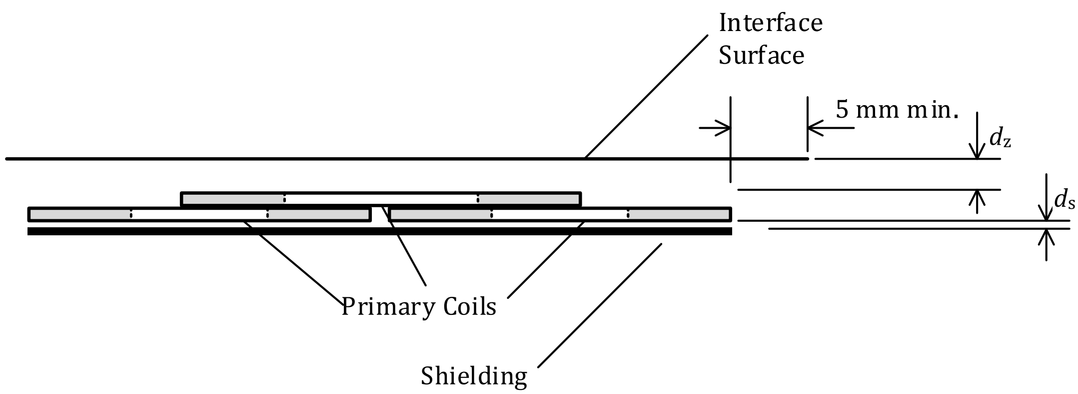
Figure 210. Bottom and Top Primary Coils of Power Transmitter design MP-A6



51.1.2 Shielding

As shown in Figure 211, a soft-magnetic material protects the Power Transmitter Product from the magnetic field that is generated in the Primary Coils. The Shielding extends to at least 2 mm beyond the outer dimensions of the Primary Coils, has a thickness of at least 1.5 mm, and is placed below the Primary Coils at a distance of at most d_s = 1.0 mm. This version of the *Qi Specification, Power Transmitter MP-A*x *and MP-B*x *Reference Designs* limits the composition of the Shielding to any Mn-Zn (for example, PM12 from TODAISU).

Figure 211. Primary Coil assembly of Power Transmitter design MP-A6



51.1.3 Interface Surface

As shown in Figure 211, the distance from the top face of the top Primary Coil to the Interface Surface of the Power Transmitter Product is $d_z = 5.5^{\pm1.5}$ mm, across the top face of the Primary Coil. The bottom Primary Coils are mounted flush to the bottom face of the even-numbered Primary Coils. In addition, the Interface Surface of the Power Transmitter Product extends at least 5 mm beyond the outer dimensions of the Primary Coils.

51.1.4 Alignment aid

The user manual of the Power Transmitter Product containing type MP-A6 Power Transmitter shall provide information about the location of its Active Area(s).

For the best user experience, it is recommended to employ at least one user feedback mechanism during Power Receiver Product placement to help alignment.

Examples of Power Transmitter Product alignment aids to assist the user placement of the Power Receiver Product include:

- A marked Interface Surface to indicate the location of its Active Area(s)—e.g. a logo or other visual marking, lighting, etc.
- A visual feedback display—e.g. by means of illuminating an LED to indicate proper alignment.
- An audible or haptic feedback mechanism.

51.1.5 Inter coil separation

If the Power Transmitter Product contains multiple type MP-A6 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall not overlap.

51.2 Electrical details

As shown in Figure 212, Power Transmitter design MP-A6 uses a full-bridge inverter to drive an individual Primary Coil and a series capacitance. Within the Operating Frequency range specified below, the assembly of Primary Coils and Shielding has a self-inductance $L_{\mathrm{P}} = 11.3^{\pm 0.7}$ μH. The value of the series capacitance is $C_{\mathrm{P}} = 139^{\pm 6\%}$ nF.

NOTE: Near resonance, the voltage developed across the series capacitance can reach levels exceeding 200 V pk-pk.

Power Transmitter design MP-A6 uses the input voltage of the inverter to control the amount of power that is transferred. For this purpose, the input voltage has a range of 1 to 18 V with a resolution of 10 mV or better. The Operating Frequency is f_{op} = 140 to 150 kHz with a duty cycle of 50%.

When Power Transmitter design MP-A6 first applies a Power Signal (see Digital Ping in *Parts 1 and 2: Interface Definitions*), it shall use an initial voltage of $5.0^{\pm 0.5}$ V for a bottom and top Primary Coils, and a recommended Operating Frequency of 145 kHz.

Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Qi Specification, Power Delivery*. The controlled variable $v^{(i)}$ introduced in the definition of that algorithm represents the input voltage to the inverter. In order to guarantee sufficiently accurate power control, Power Transmitter design MP-A6 shall determine the amplitude of the Primary Cell current—which is equal to the Primary Coil current—with a resolution of 7 mA or better. Finally, Table 150 provides the values of several parameters, which are used in the PID algorithm.

Figure 212. Electrical diagram (outline) of Power Transmitter design MP-A6

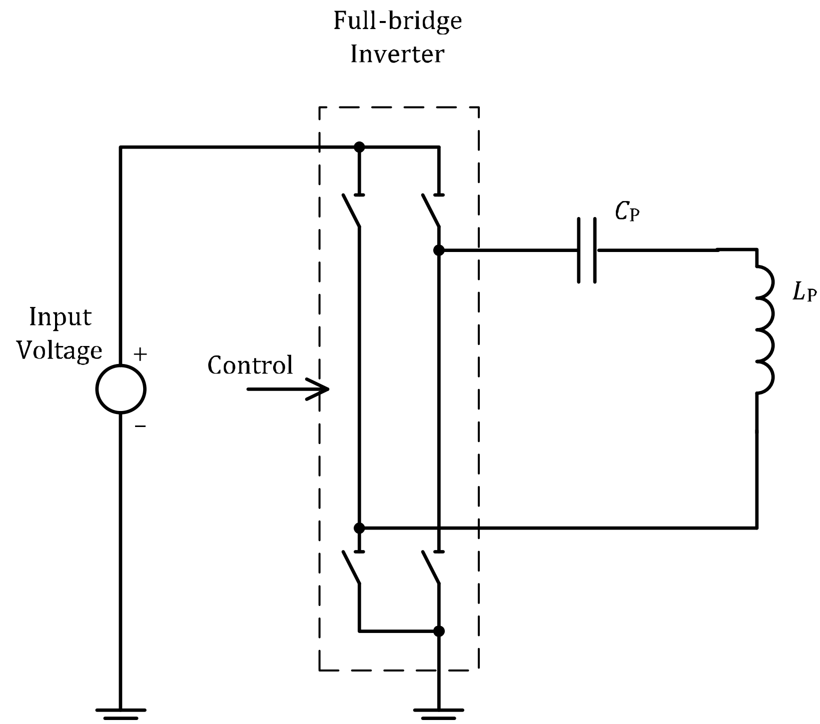


Table 150: PID parameters for Voltage control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	10	mA^{-1}
Integral gain	K_i	1	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	3,000	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_v	100	mV

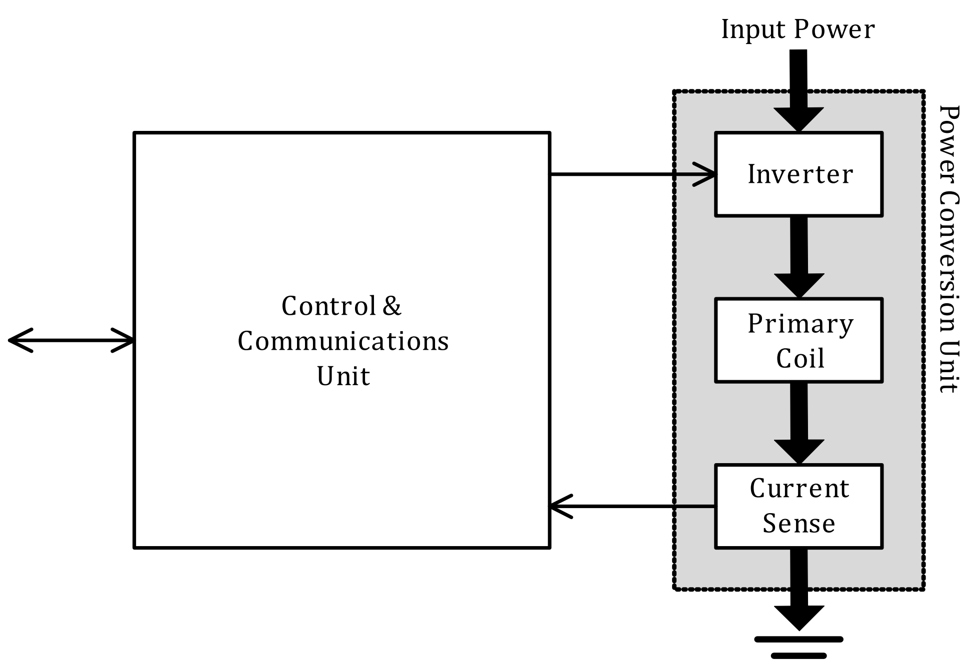
51.2.1 Information interface

The Not Res Sens Bit in the Power Transmitter Capability Packet shall be set to ONE.

52 Power Transmitter design MP-A7

Figure 213 illustrates the functional block diagram of Power Transmitter design MP-A7. This design consists of two major functional units, namely a Power Conversion Unit and a Communications and Control Unit.

Figure 213. Functional block diagram of Power Transmitter design MP-A7



The Power Conversion Unit on the right-hand side of Figure 213 comprises the analog parts of the design. The inverter converts the DC input to an AC waveform that drives a resonant circuit consisting of the Primary Coil plus a series capacitor. Finally, the current sense monitors the Primary Coil current.

The Communications and Control Unit on the left-hand side of Figure 213 comprises the digital logic part of the design. This unit receives and decodes messages from the Power Receiver, executes the relevant power control algorithms and protocols, and drives the frequency of the AC waveform to control the power transfer. The Communications and Control Unit also interfaces with other subsystems of the Power Transmitter Product, e.g. for user interface purposes.

52.1 Mechanical details

This section defines the Primary Coil, the Shielding, the Interface Surface, and the alignment aid for Power Transmitter design MP-A7.

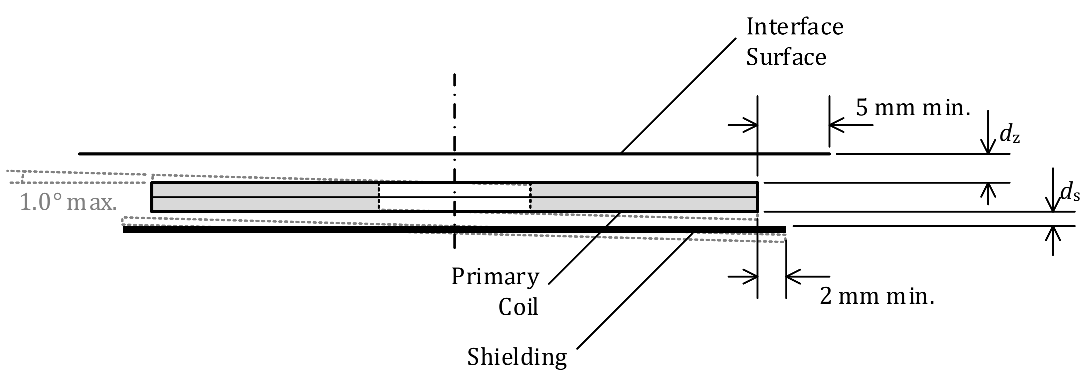
52.1.1 Primary Coil

The Primary Coil of the MP-A7 design is identical to the Primary Coil of the type A10 Power Transmitter.

52.1.2 Shielding

As shown in Figure 214, Shielding protects the Power Transmitter Product from the magnetic field that is generated in the Primary Coil. The Shielding should be Ni-Zn or Mn-Zn ferrite and should be at least 2.0 mm thick. The Shielding extends to at least 2 mm beyond the outer diameter of the Primary Coil, and is placed below the Primary Coil at a distance of at most d_s = 1.0 mm.

Figure 214. Primary Coil assembly of Power Transmitter design MP-A7



52.1.3 Interface Surface

As shown in Figure 214, the distance from the Primary Coil to the Interface Surface of the Power Transmitter Product is $d_z = 2^{+0.5}_{0.25}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Power Transmitter Product extends at least 5 mm beyond the outer diameter of the Primary Coil.

NOTE: This Primary-Coil-to-Interface-Surface distance implies that the tilt angle between the Primary Coil and a flat Interface Surface is at most 1.0°. Alternatively, in case of a non-flat Interface Surface, this Primary-Coil-to-Interface-Surface distance implies a radius of curvature of the Interface Surface of at least 317 mm, centered on the Primary Coil. See Figure 214.

52.1.4 Alignment aid

The user manual of a Power Transmitter Product containing a type MP-A7 Power Transmitter shall provide information about the location of its Active Area(s).

For the best user experience, it is recommended to employ at least one user feedback mechanism during Power Receiver Product positioning to help alignment.

Examples of Power Transmitter Product alignment aids to assist the user positioning of the Power Receiver Product include:

- A marked Interface Surface to indicate the location of the Active Area(s)—e.g. a logo or other visual marking, lighting, etc.
- A visual feedback display—e.g. by means of illuminating an LED to indicate proper alignment.
- An audible or tactile feedback mechanism.

52.1.5 Inter-coil separation

If the Power Transmitter Product contains multiple type A7 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall not overlap.

52.2 Electrical details

As shown in Figure 217, Power Transmitter design MP-A7 uses a full-bridge inverter to drive the Primary Coil and a series capacitance. Within the Operating Frequency range specified below, the assembly of Primary Coil and Shielding has a self-inductance $L_{\mathrm{p}} = 24^{\pm 10\%}$ μH. The value of the series capacitance is $C_{\mathrm{p}} = 100^{\pm 5\%}$ nF.

NOTE: Near resonance, the voltage developed across the series capacitance can reach levels exceeding 200 V pk-pk.

Power Transmitter design MP-A7 uses the Operating Frequency and the phase difference of the full-bridge inverter's driving signals (see Figure 218), or uses the Operating Frequency and duty cycle of the half-bridge inverter's driving signals (see Figure 219) in order to control the amount of power that is transferred. For this purpose, the Operating Frequency range of the inverter is f_{op} = 110 kHz to 205 kHz with a driving signal phase difference of α = 0° to 90° or a duty cycle of $t_{\mathrm{on}} / t_{\mathrm{period}}$ = 10% to 50%. A higher Operating Frequency, higher phase, or lower duty cycle will result in the transfer of a lower amount of power.

In order to achieve a sufficiently accurate adjustment of the amount of power that is transferred, a type MP-A7 Power Transmitter shall control the Operating Frequency with a minimum resolution of:

- $0.01 \times f_{\mathrm{op}} - 0.7$ kHz for f_{op} in the 110 kHz to 175 kHz range;
- $0.015 \times f_{\mathrm{op}} - 1.58$ kHz for f_{op} in the 175 kHz to 205 kHz range;

In addition, a type MP-A7 Power Transmitter shall control the driving-signal phase difference with a resolution of 0.18° or better. Moreover, a type MP-A7 Power Transmitter shall control the driving-signal duty cycle with a resolution of 0.1% or better.

When a type MP-A7 Power Transmitter first applies a Power Signal (Digital Ping), it shall use an initial input voltage to the half-bridge inverter of $19^{\pm 1}$ V and an initial Operating Frequency range of 170 kHz to 180 kHz and a duty cycle of 50%.

Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Qi Specification, Power Delivery*. The controlled variable $v^{(i)}$ introduced in the definition of that algorithm represents the Operating Frequency, operating duty cycle, or operating phase difference depending on the required power of the Power Receiver. In order to guarantee sufficiently accurate power control, a type MP-A7 Power Transmitter shall determine the amplitude of the Primary Cell current—which is equal to the Primary Coil current—with a resolution of 7 mA or better. Finally, Table 153, Table 154, Table 155, and Table 156 provide the values of several parameters that are used in the PID algorithm.

The type MP-A7 Power Transmitter shall operate as follows to control the power transfer.

1. If the Power Transmitter serves a Power Receiver in the Baseline Power Profile, the Power Transmitter shall operate only in half-bridge mode. Additional operating requirements:
   - At an Operating Frequency of 205 kHz, the Power Transmitter shall operate using duty cycle control in the range of 10% to 50%.
   - At Operating Frequencies below 205 kHz, the Power Transmitter shall operate at 50% duty cycle using frequency control.
2. If the Power Transmitter serves a Power Receiver in the Extended Power Profile, the Power Transmitter operates in either half-bridge or full-bridge mode depending on the control parameters in use. This is illustrated in Figure 215 and Figure 216 and their corresponding tables of control parameter requirements. Note that the dashed line in these figures indicates the crossover point between the two operating modes (full bridge and half bridge) where both control variables change simultaneously.

Figure 215. Increasing power

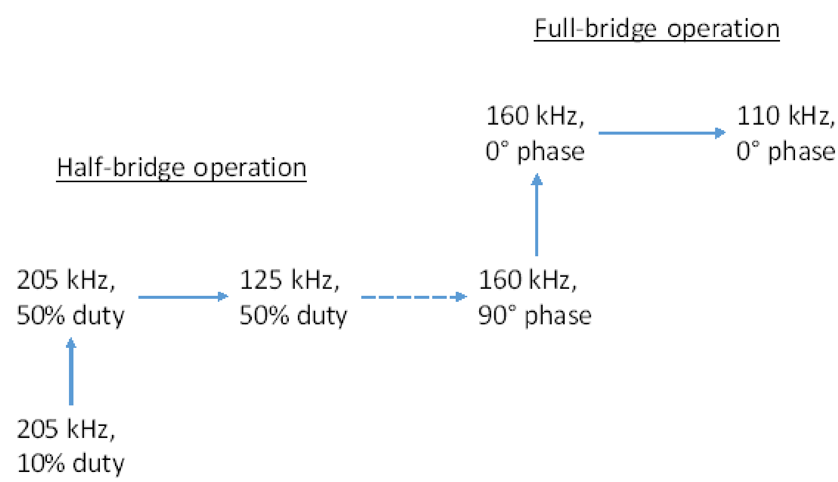


Table 151: Control parameter requirements for increasing power

Control parameters	Mode	Description
10% to 50% duty cycle at 205 kHz	Half bridge	Low-power range in half-bridge operation.
205 kHz to 125 kHz at 50% duty cycle	Half bridge	High-power range in half-bridge operation.
125 kHz, 50% duty cycle to 160 kHz, 90° phase	Half bridge to Full bridge	Crossover from half-bridge to full-bridge operation; the power may go up or down depending on the PRx design, load, and coupling.
90° to 0° phase at 160 kHz	Full bridge	Low-power range in full-bridge operation.
160 kHz to 110 kHz at 0° phase	Full bridge	High-power range in full-bridge operation.

Figure 216. Decreasing power

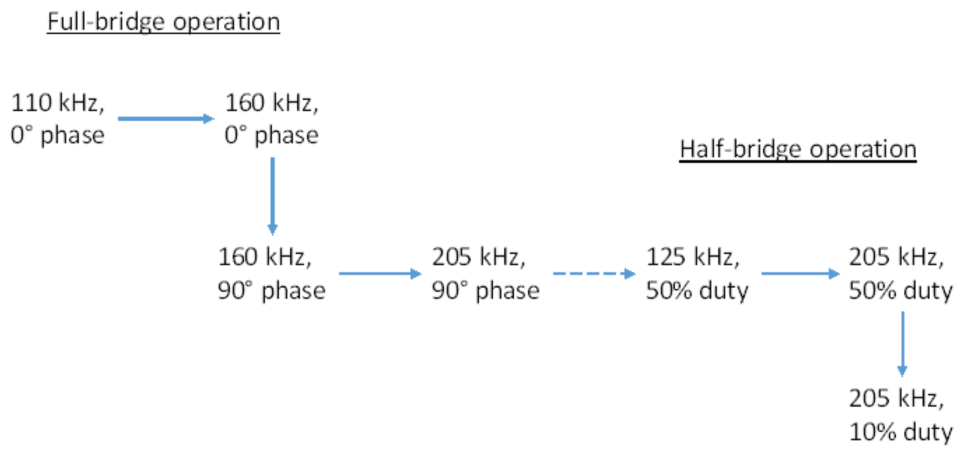


Table 152: Control parameter requirements for decreasing power

Control parameters	Mode	Description
110 kHz to 160 kHz at 0° phase	Full bridge	High-power range in full-bridge operation.
0° to 90° phase at 160 kHz	Full bridge	Medium-power range in full-bridge operation.
160 kHz to 205 kHz at 90° phase	Full bridge	Low-power range in full-bridge operation.
205 kHz at 90° phase to 125 kHz, 50% duty cycle	Full bridge to Half bridge	Crossover from FB to HB operation; the power may go up or down depending on the PRx design, load and coupling.
125 kHz to 205 kHz at 50% duty cycle	Half bridge	High-power range in half-bridge operation.
50% to 10% duty cycle at 205 kHz	Half bridge	Low-power range in half-bridge operation.

If the Power Transmitter reaches the crossover point (half bridge ↔ full bridge) in the middle of a PID control loop, the Power Transmitter shall terminate the control loop and wait for subsequent Control Error Packets.

Figure 217. Electrical diagram (outline) of Power Transmitter design MP-A7

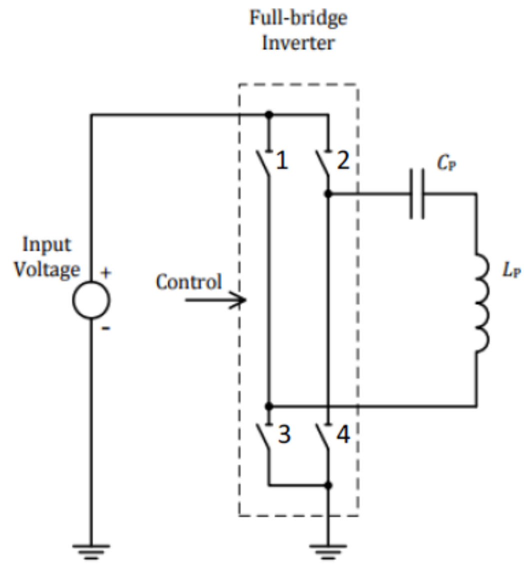
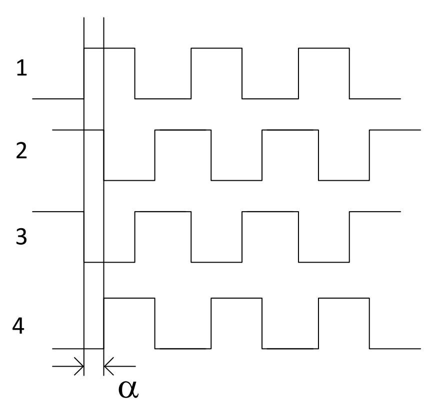


Table 153: PID parameters for Operating Frequency control

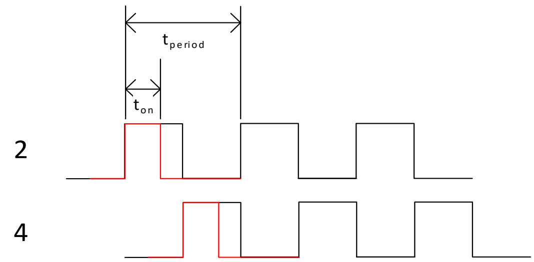
Parameter	Symbol	Value	Unit
Proportional gain	K_p	10	mA^{-1}
Integral gain	K_i	0.05	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	3,000	N.A.
PID output limit	M_{PID}	20,000	N.A.

Figure 218. Phase control signals to Full Bridge inverter



Phase Control Signals to Full Bridge Inverter
Phase Difference α is $0 \ldots 180°$
Larger phase difference results in lower power transfer

Figure 219. Duty control signals to Half Bridge inverter



Duty Control Signals to Half Bridge Inverter
10 to 50% Duty Cycle Range

Duty Cycle (%) = 100 * t_{on} / t_{period}

Table 154: Operating Frequency dependent scaling factor

Frequency Range [kHz]	Scaling Factor S_v [Hz]
110 to 130	1
130 to 140	1.5
140 to 160	2
160 to 180	3
180 to 205	5

Table 155: PID parameters for phase control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	1	mA^{-1}
Integral gain	K_i	0.01	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	3,000	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_v	0.036	°

Table 156: PID parameters for duty cycle control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	1	mA^{-1}
Integral gain	K_i	0.01	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	3,000	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_v	-0.002	%

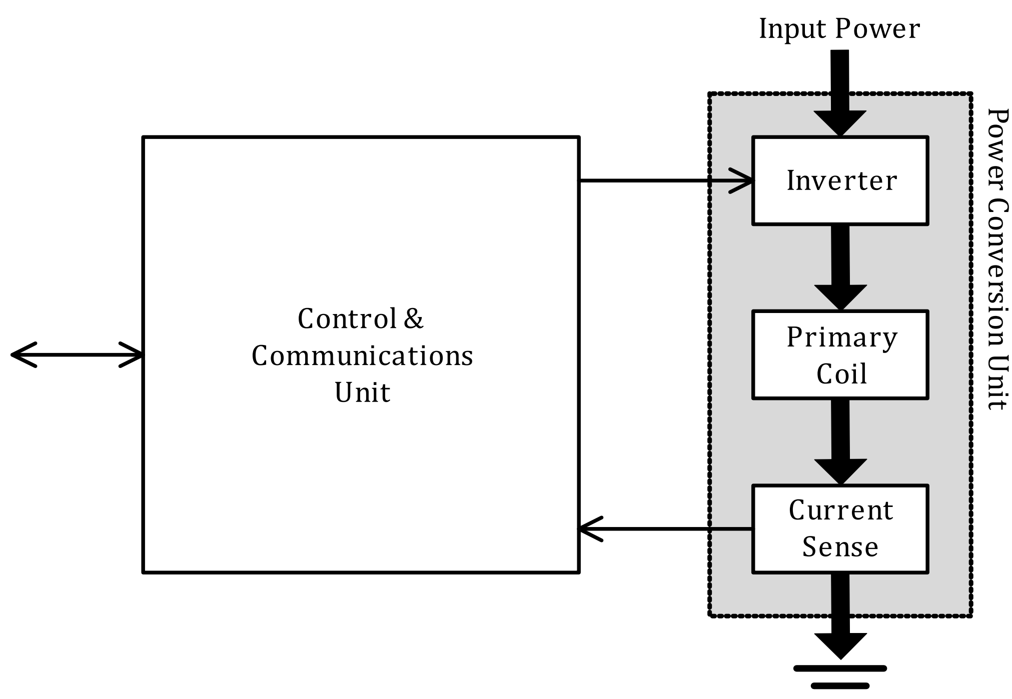
52.2.1 Information interface

The Not Res Sens Bit in the Power Transmitter Capability Packet shall be set to ZERO.

53 Power Transmitter design MP-A8

Figure 220 illustrates the functional block diagram of Power Transmitter design MP-A8. This design consists of two major functional units, namely a Power Conversion Unit and a Communications and Control Unit.

Figure 220. Functional block diagram of Power Transmitter design MP-A8



The Power Conversion Unit on the right-hand side of Figure 220 comprises the analog parts of the design. The inverter converts the DC input to an AC waveform that drives a resonant circuit consisting of the Primary Coil plus a series capacitor. Finally, the current sense monitors the Primary Coil current.

The Communications and Control Unit on the left-hand side of Figure 220 comprises the digital logic part of the design. This unit receives and decodes messages from the Power Receiver, executes the relevant power control algorithms and protocols, and drives the frequency of the AC waveform to control the power transfer. The Communications and Control Unit also interfaces with other subsystems of the Power Transmitter Product, e.g. for user interface purposes.

53.1 Mechanical details

This section defines the Primary Coil, the Shielding, the Interface Surface, and the alignment aid for Power Transmitter design MP-A8.

53.1.1 Primary Coil

The Primary Coil is of the wire-wound type, and consists of type 2 litz wire having 180 strands of no. 42 AWG (0.06 mm diameter), or equivalent. As shown in Figure 4, the Primary Coil has a rectangular shape and consists of a single layer. Table 1 lists the dimensions of the Primary Coil.

Figure 221. Primary Coil of Power Transmitter design MP-A8

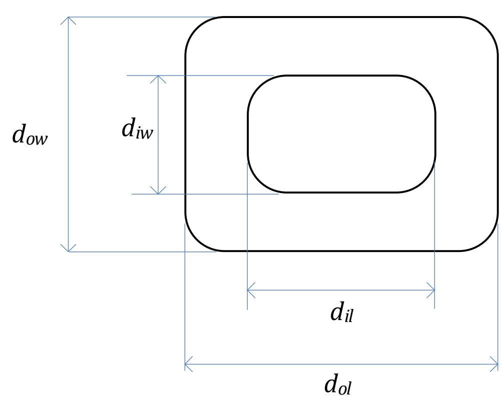
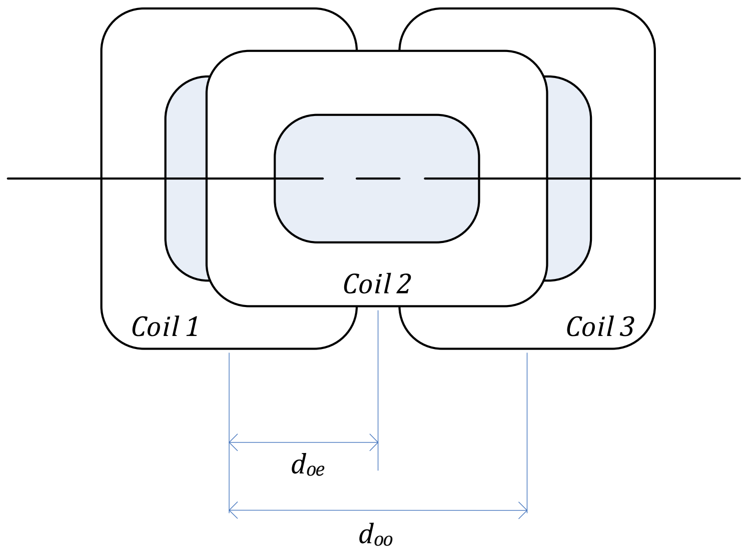


Table 157: Primary Coil parameters of Power Transmitter design MP-A8

Parameter	Symbol	Value
Outer length	d_{ol}	$51.0^{\pm1.0}$ mm
Inner length	d_{il}	$27.5^{\pm0.5}$ mm
Outer width	d_{ow}	$43.0^{\pm1.0}$ mm
Inner width	d_{iw}	$19.5^{\pm0.5}$ mm
Thickness	d_c	$1.6^{\pm0.5}$ mm
Number of turns per layer	N	10
Number of layers	–	1

Power Transmitter design MP-A8 contains at least one Primary Coil. The use of multiple Primary Coils enables one-dimensional freedom of positioning. For that purpose, odd-numbered Primary Coils are placed in a row with a displacement of $d_{\mathrm{oo}} = 44.0^{\pm 1.0}$ mm between their centers. Even-numbered Primary Coils are placed in a similar row on top of the odd numbered Primary Coils with a displacement of $d_{\mathrm{oe}} = 22.0^{\pm 1.0}$ mm. Figure 222 shows this arrangement using three Primary Coils.

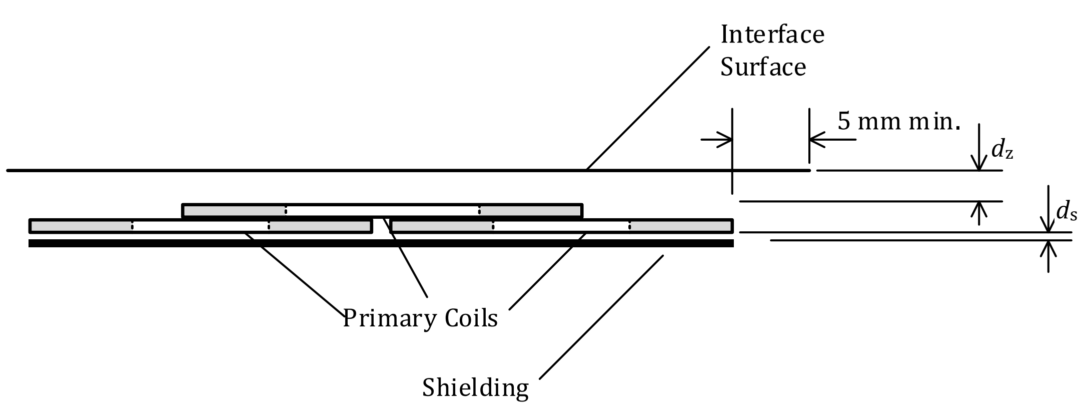
Figure 222. Primary Coil of Power Transmitter design MP-A8



53.1.2 Shielding

As shown in Figure 223, soft-magnetic material protects the Power Transmitter Product from the magnetic field that is generated in the Primary Coil. The Shielding extends to at least 2 mm beyond the outer diameter of the Primary Coil, has a thickness of at least 2.0 mm, and is placed below the Primary Coil at a distance of at most $d_{\mathrm{s}} = 1.0$ mm. This version of *Power Transmitter Reference Designs* limits the composition of the Shielding to a Ni-Zn or Mn-Zn ferrite core from any supplier.

Figure 223. Primary Coil assembly of Power Transmitter design MP-A8



53.1.3 Interface Surface

As shown in Figure 223, the distance from the top face of the even-numbered Primary Coil to the Interface Surface of the Power Transmitter Product is $d_z = 2.0^{+0.5}_{-0.25}$ mm, across the top face of the Primary Coil. The odd-numbered Primary Coils are mounted flush to the bottom face of the even-numbered Primary Coils. If the Power Transmitter contains only one Primary Coil, the distance from its top face to the Interface Surface of the Power Transmitter Product is $d_z = 3.6^{+0.5}_{-0.25}$ mm. In addition, the Interface Surface of the Power Transmitter Product extends at least 5.0 mm beyond the outer diameter of the Primary Coil.

NOTE: This Primary-Coil-to-Interface-Surface distance implies that the tilt angle between the Primary Coil and a flat Interface Surface is at most 1.0°. Alternatively, in case of a non-flat Interface Surface, this Primary-Coil-to-Interface-Surface distance implies a radius of curvature of the Interface Surface of at least 317 mm, centered on the Primary Coil. See Figure 223.

53.1.4 Alignment aid

The user manual of a Power Transmitter Product containing a type MP-A8 Power Transmitter shall provide information about the location of its Active Area(s).

For the best user experience, it is recommended to employ at least one user feedback mechanism during Power Receiver Product positioning to help alignment.

NOTE: Examples of Power Transmitter Product alignment aids to assist the user positioning of the Power Receiver Product include:

- A marked Interface Surface to indicate the location of the Active Area(s)—e.g. a logo or other visual marking, lighting, etc.
- A visual feedback display—e.g. by means of illuminating an LED to indicate proper alignment.
- An audible or tactile feedback mechanism.

53.1.5 Inter-coil separation

If the Power Transmitter Product contains multiple type MP-A8 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall not overlap.

53.2 Electrical details

As shown in Figure 224, Power Transmitter design MP-A8 uses a full-bridge inverter to drive the individual Primary Coil and a series capacitor. Within the Operating Frequency range specified below, the assembly of Primary Coil and Shielding has an inductance of $7.5^{\pm10\%}$ μH for cells closest to the Interface Surface and an inductance of $8.5^{\pm10\%}$ μH for cells furthest from the Interface Surface. The value of the series capacitance is $420^{\pm5\%}$ nF for cells closest to the Interface Surface and $400^{\pm5\%}$ nF for cells farthest from the Interface Surface. The input voltage to the full bridge inverter is $12^{\pm1}$ V.

NOTE: Near resonance, the voltage developed across the series capacitance can reach levels exceeding 200 V pk-pk.

Power Transmitter design MP-A8 uses the Operating Frequency and the phase difference of the full-bridge inverter's driving signals (see Figure 225), or uses the Operating Frequency and duty cycle of the half-bridge inverter's driving signals (see Figure 226) in order to control the amount of power that is transferred. For this purpose, the Operating Frequency range of the inverter is f_{op} = 110 kHz to 205 kHz with a driving signal phase difference of α = 0° to 133° or a duty cycle of D= 10% to 50%. A higher Operating Frequency, bigger phase difference, or lower duty cycle will result in the transfer of a lower amount of power. In order to achieve a sufficiently accurate adjustment of the amount of power that is transferred, a type MP-A8 Power Transmitter shall control the Operating Frequency with a minimum resolution of:

- $0.01 \times f_{op} - 0.7$ kHz for f_{op} in the 110 kHz to 175 kHz range;
- $0.015 \times f_{op} - 1.58$ kHz for f_{op} in the 175 kHz to 205 kHz range.

In addition, a type MP-A8 Power Transmitter shall control the driving-signal phase difference with a resolution of 0.18° or better. Moreover, a type MP-A8 Power Transmitter shall control the driving-signal duty cycle with a resolution of 0.1% or better.

When a type MP-A8 Power Transmitter first applies a Power Signal (Digital Ping), it shall use an initial input voltage to the half-bridge inverter of $12^{\pm1}$ V and an initial Operating Frequency range of 170 kHz to 180 kHz and a duty cycle of 50%.

Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Qi Specification, Power Delivery*. The controlled variable introduced in the definition of that algorithm represents the Operating Frequency, operating duty cycle, or operating phase difference depending on the required power of the Power Receiver. In order to guarantee sufficiently accurate power control, a type MP-A8 Power Transmitter shall determine the amplitude of the Primary Coil current—which is equal to the Primary Coil current—with a resolution of 7 mA or better. Finally, Table 158, Table 159, Table 160, Table 161, and Table 162 provide the values of several parameters that are used in the PID algorithm.

The type MP-A8 Power Transmitter shall handle the different control methodologies as follows.

- At an Operating Frequency of 205 kHz, the Power Transmitter shall operate in half-bridge mode, using duty cycle control with a range of 10% to 50%.
- At Operating Frequencies between 172 kHz and 205 kHz, the Power Transmitter shall operate in half-bridge mode at 50% duty cycle, using Operating Frequency control.

- At an Operating Frequency of 172 kHz, the Power Transmitter shall operate in full-bridge mode with a phase difference of 0° to 133°.
- At Operating Frequencies below 172 kHz, the Power Transmitter shall operate in full-bridge mode with a phase difference of 0° using Operating Frequency control.

When the Power Transmitter reaches the 172-kHz transition point, it shall

- switch from half-bridge mode to full-bridge mode at a 133° phase difference if moving down in Operating Frequency, or
- switch from full-bridge mode at a 133° phase difference to half-bridge mode if moving up in Operating Frequency.

If the Power Transmitter reaches the 172-kHz transition point in the middle of a PID control loop, the Power Transmitter shall terminate the control loop and wait for subsequent Control Error Packets.

Figure 224. Electrical diagram (outline) of Power Transmitter design MP-A8

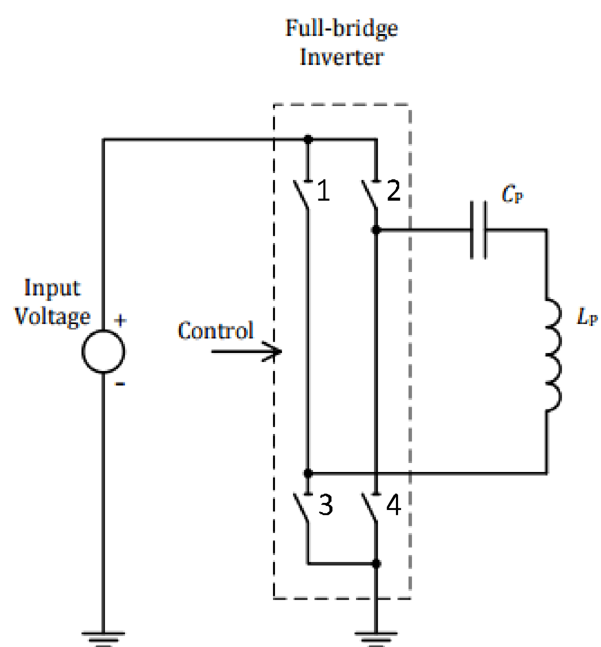


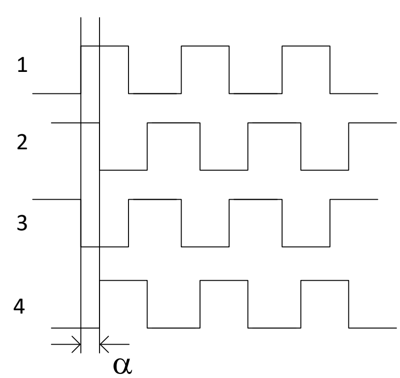
Table 158: PID parameters for Operating Frequency control (half bridge)

Parameter	Symbol	Value	Unit
Proportional gain	K_p	10	mA^{-1}
Integral gain	K_i	1	$mA^{-1}ms^{-1}$
Derivative gain	K_d	1	$mA^{-1}ms$
Integral term limit	M_I	3,000	N.A.
PID output limit	M_{PID}	20,000	N.A.

Table 159: PID parameters for Operating Frequency control (full bridge)

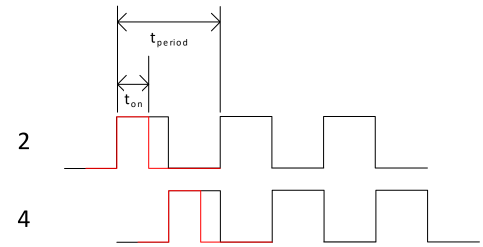
Parameter	Symbol	Value	Unit
Proportional gain	K_p	5	mA^{-1}
Integral gain	K_i	1	$mA^{-1}ms^{-1}$
Derivative gain	K_d	1	$mA^{-1}ms$
Integral term limit	M_I	3,000	N.A.
PID output limit	M_{PID}	20,000	N.A.

Figure 225. Phase difference control signals to full bridge inverter



Phase Control Signals to Full Bridge Inverter
Phase Difference α is 0...180°
Larger phase difference results in lower power transfer

Figure 226. Duty cycle control signals to half bridge inverter



Duty Control Signals to Half Bridge Inverter
10 to 50% Duty Cycle Range

Duty Cycle (%) = 100 * t_{on} / t_{period}

Table 160: Operating Frequency dependent scaling factor

Frequency Range [kHz]	Scaling Factor S_v [Hz]
110 to 140	1.5
140 to 160	2
160 to 180	3
180 to 205	5

Table 161: PID parameters for phase difference control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	1	mA^{-1}
Integral gain	K_i	1	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	3,000	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_v	0.009	°

Table 162: PID parameters for duty cycle control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	10	mA^{-1}
Integral gain	K_i	1	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	3,000	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_v	-0.01	%

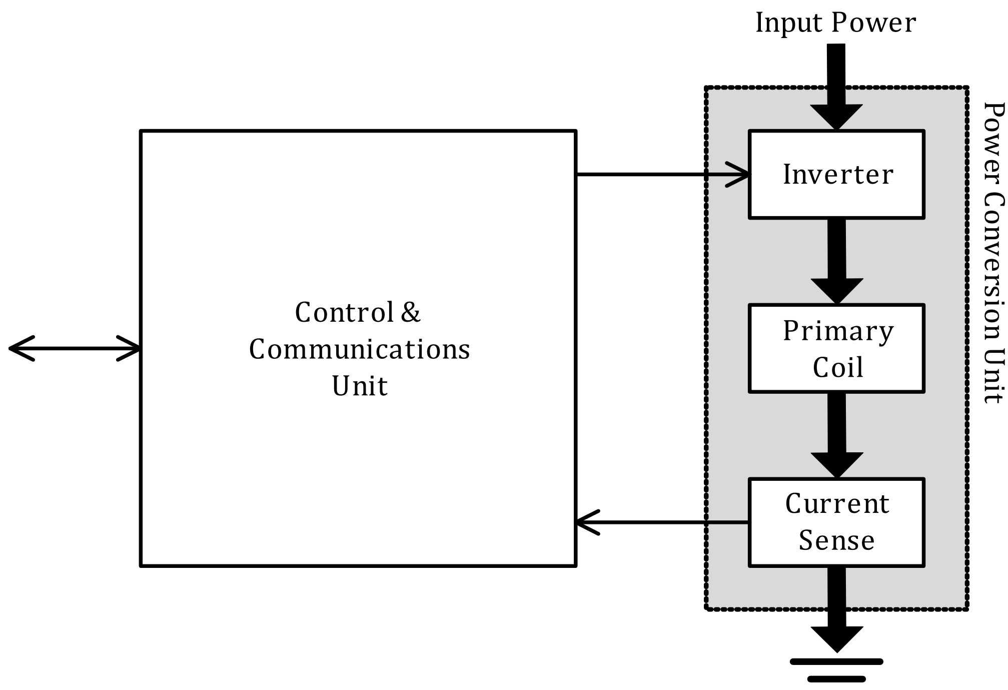
53.2.1 Information interface

The Not Res Sens Bit in the Power Transmitter Capability Packet shall be set to ZERO.

54 Power Transmitter design MP-A9

Figure 227 illustrates the functional block diagram of Power Transmitter design MP-A9. This design consists of two major functional units, namely a Power Conversion Unit and a Communications and Control Unit.

Figure 227. Functional block diagram of Power Transmitter design MP-A9



The Power Conversion Unit on the right-hand side of Figure 227 comprises the analog parts of the design. The inverter converts the DC input to an AC waveform that drives a resonant circuit consisting of the Primary Coil plus a series capacitor. Finally, the current sense monitors the Primary Coil current.

The Communications and Control Unit on the left-hand side of Figure 227 comprises the digital logic part of the design. This unit receives and decodes messages from the Power Receiver, executes the relevant power control algorithms and protocols, and drives the frequency of the AC waveform to control the power transfer. The Communications and Control Unit also interfaces with other subsystems of the Power Transmitter Product, e.g. for user interface purposes.

54.1 Mechanical details

This section defines the Primary Coil, the Shielding, the Interface Surface, and the alignment aid for Power Transmitter design MP-A9.

54.1.1 Primary Coil

The Primary Coil is of the wire-wound type, and consists of type 2 litz wire having 200 strands of no. 42 AWG (0.06 mm diameter), or equivalent. As shown in Figure 228, the Primary Coil has a racetrack-like shape and consists of a single layer. Table 163 and Table 164 list the dimensions of the bottom Primary Coil and the top Primary Coil respectively.

Figure 228. Primary Coil of Power Transmitter design MP-A9

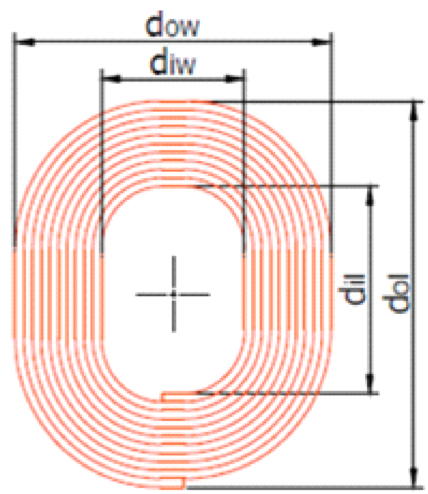


Table 163: Bottom Primary Coil parameters of Power Transmitter design MP-A9

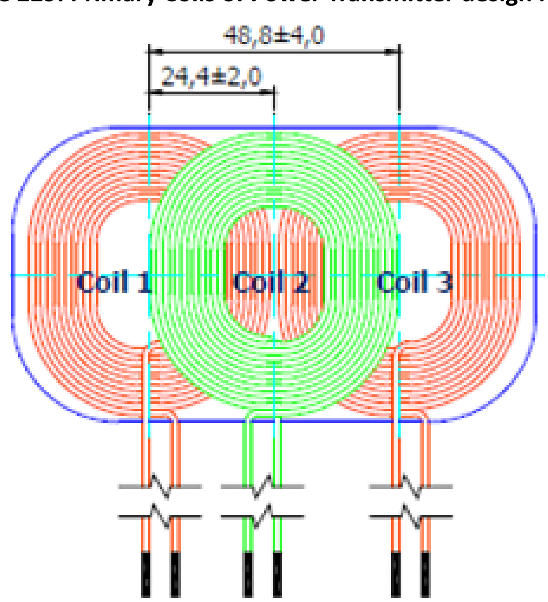
Parameter	Symbol	Value
Outer length	d_{ol}	$53.0^{\pm 1.5}$ mm
Inner length	d_{il}	$27.5^{\pm 0.5}$ mm
Outer width	d_{ow}	$46.7^{\pm 1.5}$ mm
Inner width	d_{iw}	$20.5^{\pm 0.5}$ mm
Thickness	d_c	$1.6^{\pm 0.5}$ mm
Number of turns per layer	N	11
Number of layers	–	1

Table 164: Top Primary Coil parameters of Power Transmitter design MP-A9

Parameter	Symbol	Value
Outer length	d_{ol}	$53.0^{\pm 1.5}$ mm
Inner length	d_{il}	$25.2^{\pm 0.5}$ mm
Outer width	d_{ow}	$48.1^{\pm 1.5}$ mm
Inner width	d_{iw}	$19.5^{\pm 0.5}$ mm
Thickness	d_{c}	$1.6^{\pm 0.5}$ mm
Number of turns per layer	N	12
Number of layers	–	1

Power Transmitter design MP-A9 contains at least one Primary Coil. The use of multiple Primary Coils enables one-dimensional freedom of positioning. For that purpose, odd-numbered Primary Coils are placed in a row with a typical displacement of 48.8 mm between their centers. Even-numbered Primary Coils are placed in a similar row on top of the odd numbered Primary Coils with a typical displacement of 24.4 mm between their centers. Figure 229 shows this arrangement using three Primary Coils.

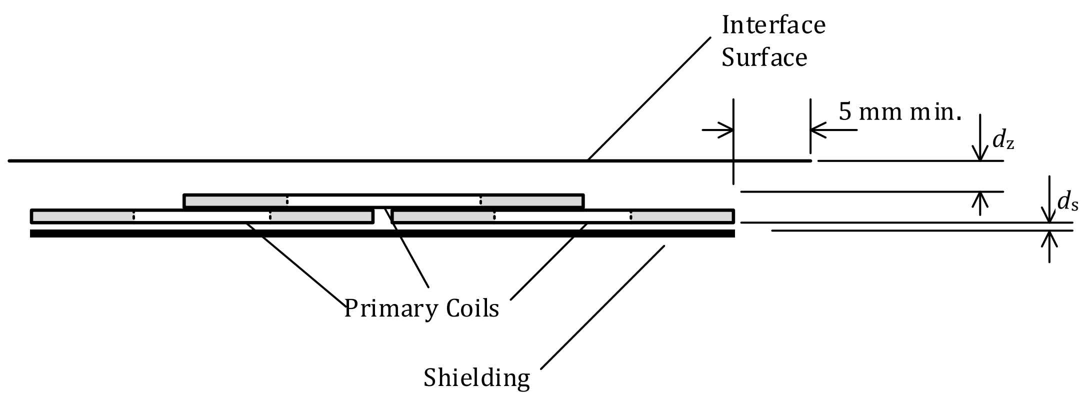
Figure 229. Primary Coils of Power Transmitter design MP-A9



54.1.2 Shielding

As shown in Figure 230, soft-magnetic material protects the Power Transmitter Product from the magnetic field that is generated in the Primary Coils. The Shielding extends to at least 2 mm beyond the outer diameter of the Primary Coil, has a thickness of at least 0.9 mm, and is placed below the Primary Coil at a distance of at most d_s = 1.0 mm. This version of *Power Transmitter Reference Designs* limits the composition of the Shielding to a Ni-Zn or Mn-Zn ferrite core from any supplier.

Figure 230. Primary Coil assembly of Power Transmitter design MP-A9



54.1.3 Interface Surface

As shown in Figure 230, the distance from the top face of the even-numbered Primary Coil to the Interface Surface of the Power Transmitter Product is $d_z = 4^{\pm 1.0}$ mm, across the top face of the Primary Coil array. The odd-numbered Primary Coils are mounted flush to the bottom face of the even-numbered Primary Coils. If the Power Transmitter contains only one Primary Coil, the distance from the top face of the Primary Coil to the Interface Surface of the Power Transmitter Product ($d_s = 5.6^{\pm 1.0}$ mm). In addition, the Interface Surface of the Power Transmitter Product extends at least 5.0 mm beyond the outer dimensions of the Primary Coil.

54.1.4 Alignment aid

The user manual of a Power Transmitter Product containing a type MP-A9 Power Transmitter shall provide information about the location of its Active Area(s).

For the best user experience, it is recommended to employ at least one user feedback mechanism during Power Receiver Product positioning to help alignment.

Examples of Power Transmitter Product alignment aids to assist the user positioning of the Power Receiver Product include:

- A marked Interface Surface to indicate the location of the Active Area(s)—e.g. a logo or other visual marking, lighting, etc.
- A visual feedback display—e.g. by means of illuminating an LED to indicate proper alignment.
- An audible or tactile feedback mechanism.

54.1.5 Inter-coil separation

If the Power Transmitter Product contains multiple type MP-A9 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall not overlap.

54.2 Electrical details

As shown in Figure 231, Power Transmitter design MP-A9 uses a full-bridge inverter to drive an individual Primary Coil and a series capacitor. Within the Operating Frequency range specified below, the assembly of Primary Coil and Shielding has an inductance $L_{\mathrm{p}} = 9.8^{\pm 10\%}$ μH for cells furthest from the Interface Surface and an inductance of $L_{\mathrm{p}} = 10.2^{\pm 10\%}$ μH for cells closest to the Interface Surface. The value of the series capacitance is $C_{\mathrm{p}} = 400^{\pm 5\%}$ nF.

NOTE: Near resonance, the voltage developed across the series capacitance can reach levels exceeding 200 V pk-pk.

Power Transmitter design MP-A9 uses the input voltage of the inverter in order to control the amount of power that is transferred. For this purpose, the input voltage has a range of 1 V to 25 V with a resolution of 25 mV or better. The Operating Frequency is $f_{\mathrm{op}} = 120...130$ kHz with a duty cycle of 50%.

When a type MP-A9 Power Transmitter first applies a Power Signal (see Digital Ping; the *Qi Specification, Communications Protocol*), it shall use an initial input voltage to the full-bridge inverter of $7.0^{\pm 0.5}$ V and an initial Operating Frequency of 125 kHz.

Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Qi Specification, Power Delivery*. The controlled variable $v^{(i)}$ introduced in the definition of that algorithm represents the input voltage to the inverter. In order to guarantee sufficiently accurate power control, a type MP-A9 Power Transmitter shall determine the amplitude of the Primary Cell current—which is equal to the Primary Coil current—with a resolution of 7 mA or better. Finally, Table 165 provides the values of several parameters that are used in the PID algorithm.

Figure 231. Electrical diagram (outline) of Power Transmitter design MP-A9

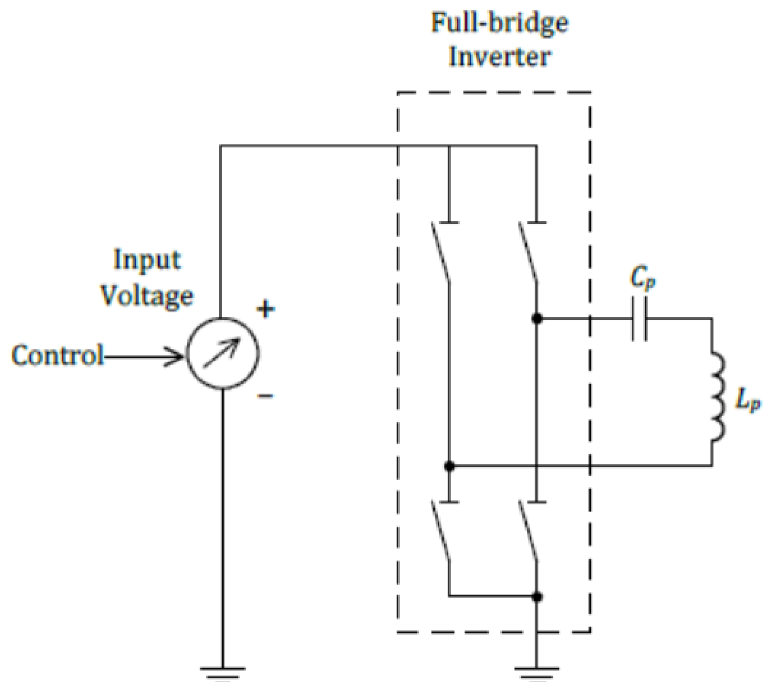


Table 165: PID parameters for voltage control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	5	mA^{-1}
Integral gain	K_i	1	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	3,000	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_v	-0.1	mV

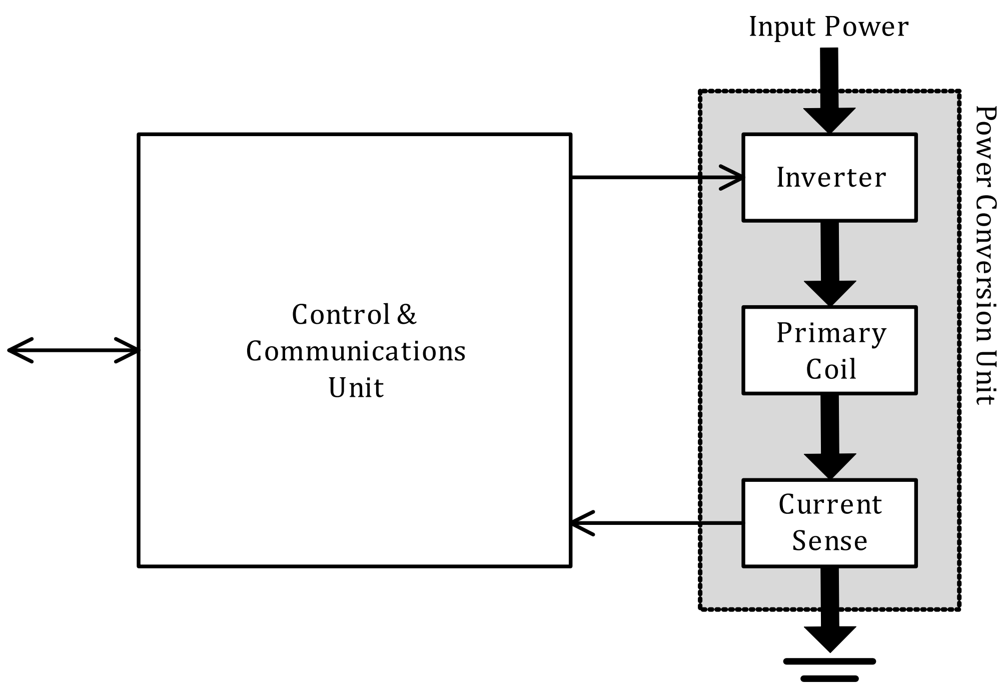
54.2.1 Information Interface

The Not Res Sens Bit in the Power Transmitter Capability Packet shall be set to ONE.

55 Power Transmitter design MP-A10

Figure 232 illustrates the functional block diagram of Power Transmitter design MP-A10. This design consists of two major functional units, namely a Power Conversion Unit and a Communications and Control Unit.

Figure 232. Functional block diagram of Power Transmitter design MP-A10



The Power Conversion Unit on the right-hand side of Figure 232 comprises the analog parts of the design. The inverter converts the DC input to an AC waveform that drives a resonant circuit consisting of the Primary Coil plus a series capacitor. Finally, the current sense monitors the Primary Coil current.

The Communications and Control Unit on the left-hand side of Figure 232 comprises the digital logic part of the design. This unit receives and decodes messages from the Power Receiver, executes the relevant power control algorithms and protocols, and drives the frequency of the AC waveform to control the power transfer. The Communications and Control Unit also interfaces with other subsystems of the Power Transmitter Product, e.g. for user interface purposes.

55.1 Mechanical details

This section defines the single Primary Coil, the Shielding, the Interface Surface and the alignment aid for Power Transmitter design MP-A10.

55.1.1 Primary Coil

The Primary Coil is of the wire-wound type, and consists of no. 17 AWG (1.15 mm diameter) type 2 litz wire having 105 strands of no. 40 AWG (0.08 mm diameter), or equivalent. As shown in Figure 233, the Primary Coil has a rectangular shape and consists of a single layer. Table 166 lists the dimensions of the Primary Coil.

Figure 233. Primary Coil of Power Transmitter design MP-A10

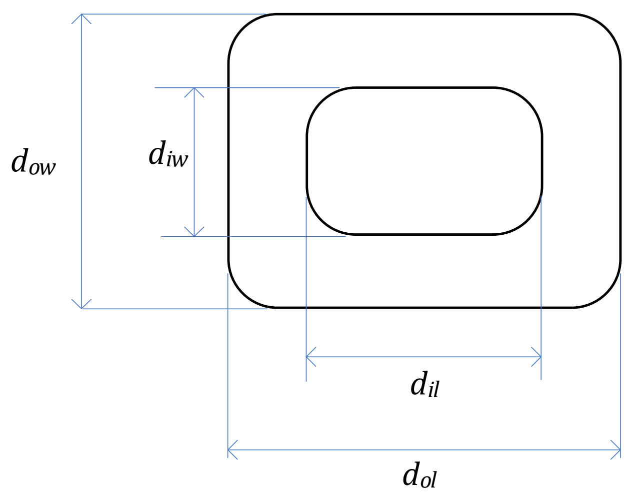


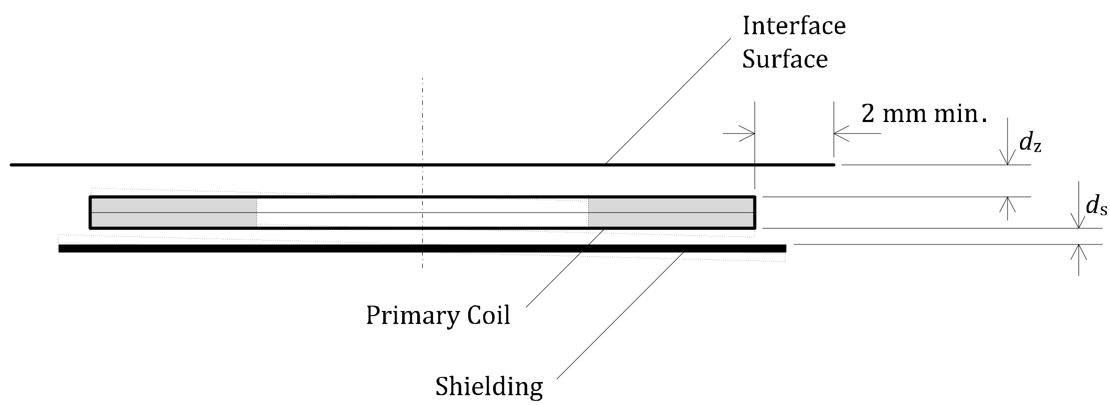
Table 166: Primary Coil parameters of Power Transmitter design MP-A10

Parameter	Symbol	Value
Outer length	d_{ol}	$53.2^{\pm 0.5}$ mm
Inner length	d_{il}	$27.5^{\pm 0.5}$ mm
Outer width	d_{ow}	$45.2^{\pm 0.5}$ mm
Inner width	d_{iw}	$19.5^{\pm 0.5}$ mm
Thickness	d_c	$1.5^{\pm 0.5}$ mm
Number of turns per layer	N	12
Number of layers	–	1

55.1.2 Shielding

As shown in Figure 234, soft-magnetic material protects the Power Transmitter Product from the magnetic field that is generated in the Primary Coil. The Shielding should be Ni-Zn or Mn-Zn ferrite and should be at least 0.5 mm thick. The Shielding extends to at least to the outer dimensions of the Primary Coil, and is placed below the Primary Coil at a distance of at most d_s = 1.0 mm.

Figure 234. Primary Coil assembly of Power Transmitter design MP-A10



55.1.3 Interface Surface

As shown in Figure 234, the distance from the Primary Coil to the Interface Surface of the Power Transmitter Product is $d_z = 3.0^{+0.5}_{-0.25}$ mm across the top face of the Primary Coil. In addition, the Interface Surface of the Power Transmitter Product extends at least 2 mm beyond the outer diameter of the Primary Coil.

55.1.4 Alignment aid

The user manual of a Power Transmitter Product containing a type MP-A10 Power Transmitter shall provide information about the location of its Active Area(s).

For the best user experience, it is recommended to employ at least one user feedback mechanism during Power Receiver Product positioning to help alignment.

Examples of Power Transmitter Product alignment aids to assist the user positioning of the Power Receiver Product include:

- A marked Interface Surface to indicate the location of the Active Area(s)—e.g. a logo or other visual marking, lighting, etc.
- A visual feedback display—e.g. by means of illuminating an LED to indicate proper alignment.
- An audible or tactile feedback mechanism.

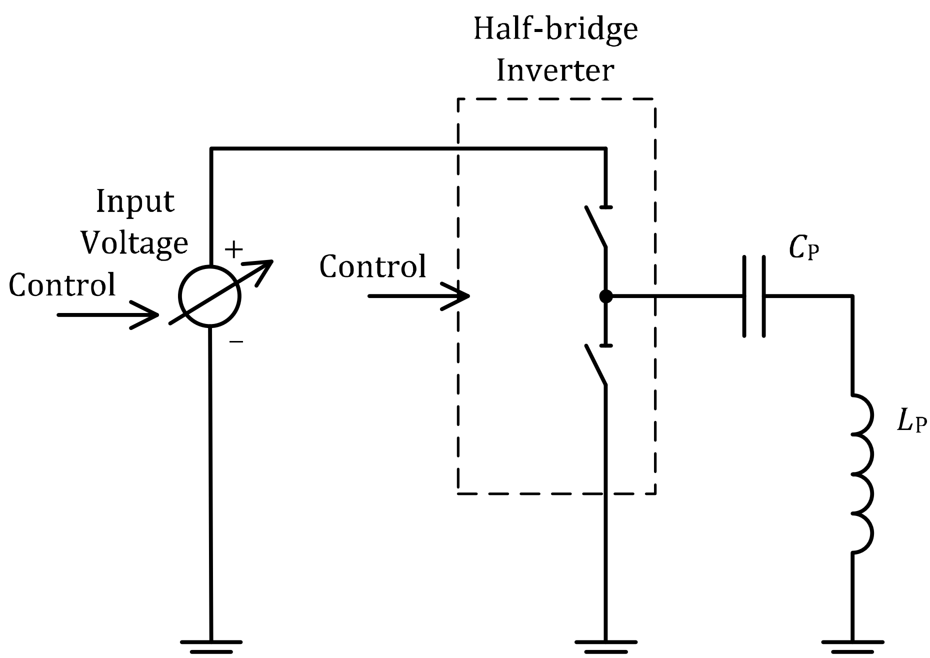
55.1.5 Inter coil separation

If the Power Transmitter Product contains multiple type MP-A10 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall not overlap.

55.2 Electrical details

As shown in Figure 235, Power Transmitter design MP-A10 uses half-bridge inverter topology to drive the Primary Coil and a series capacitance. Within the Operating Frequency range specified below, the assembly of Primary Coil and Shielding has a self-inductance $L_{\mathrm{P}} = 12.5^{\pm 10\%}$ μH. The value of the series capacitance is $C_{\mathrm{P}} = 200^{\pm 10\%}$ nF.

Figure 235. Electrical diagram of Power Transmitter design MP-A10



Power Transmitter design MP-A10 uses a combination of the Operating Frequency, Inverter Input Voltage, and the duty cycle of the Power Signal to control the amount of power that is transferred. For this purpose, the Operating Frequency range of the inverter is f_{op} = 110 kHz to 180 kHz. The Inverter Input Voltage is a direct function of the Operating Frequency. The Inverter Input Voltage to the inverter varies from $14^{\pm 0.1}$ V to $16^{\pm 0.1}$ V when a 5W power contract is negotiated with Power Receiver and it varies from $14^{\pm 0.1}$ V to $24^{\pm 0.1}$ V when a power contract above 5W is negotiated with Power Receiver. The duty cycle of the half-bridge inverter is 50% if f_{op} = 110 kHz to 180 kHz and is 10% to 50% at f_{op} = 180 kHz. A higher Operating Frequency or a lower Inverter Input Voltage or a lower duty cycle will result in the transfer of a lower amount of power. In order to achieve a sufficiently accurate adjustment of the amount of power that is transferred, a type MP-A10 Power Transmitter shall control the Operating Frequency with a minimum resolution of $0.007 \times f_{\mathrm{op}} - 0.5$kHz for f_{op} in the 110 kHz to 180 kHz range. In addition, a Type MP-A10 Power Transmitter shall control the duty cycle of the Power Signal with a resolution of 0.1% or better.

The Inverter Input Voltage follows the following mathematical law:

$$V_{\mathrm{mV}} = V_{\mathrm{fmin}} - \left(\left(\frac{2548000}{4096.\frac{f_{\max} - f}{f_{\max} - f_{\min}} + 1000} \right) - 500 \right) . \frac{V_{\mathrm{fmin}} - V_{\mathrm{fmax}}}{2048}$$

Where:

- V_{mV} is the Inverter Input Voltage in mV
- V_{fmin}=16000mV for 5W power contract and 24000mV for >5W power contract
- V_{fmax}=14000mV
- f_{max}=180000Hz
- f_{min}=110000Hz
- f = Operating Frequency of bridge in Hz

Figure 236 shows graphically the Inverter Input Voltage as a function of Operating Frequency.

Figure 236. Inverter Input Voltage function of Operating Frequency

When a type MP-A10 Power Transmitter first applies a Power Signal (Digital Ping), it shall use an initial Inverter Input Voltage of $15.1^{\pm 10\%}$ V and an initial Operating Frequency of $163^{\pm 5\%}$ kHz and a duty cycle of 50%.

Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Qi Specification, Power Delivery*. The controlled variable $v^{(i)}$ introduced in the definition of that algorithm represents Operating Frequency or the duty cycle. In order to guarantee sufficiently accurate power control, a type MP-A10 Power Transmitter shall determine the amplitude of the Primary Cell current with a resolution of 7 mA or better. Finally, Table 167, Table 168, and Table 169 provide the values of the parameters that are used in the PID algorithm.

Table 167: PID parameters for Operating Frequency control design MP-A10

Parameter	Symbol	Value	Unit
Proportional gain	K_p	1	mA^{-1}
Integral gain	K_i	0	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0.5	$mA^{-1}ms$
Integral term limit	M_I	N.A.	N.A.
PID output limit	M_{PID}	20,000	N.A.

Table 168: Operating Frequency dependent scaling factor

Frequency Range [kHz]	Scaling Factor S_v [Hz]
110 to 125	1.0
125 to 180	2.0

Table 169: PID parameters for duty cycle control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	1.0	mA^{-1}
Integral gain	K_i	0	$mA^{-1}ms^{-1}$
Derivative gain	K_d	-0.4	$mA^{-1}ms$
Integral term limit	M_I	N.A.	N.A.
PID output limit	M_{PID}	10,000	N.A.
Scaling factor	S_v	0.1	%

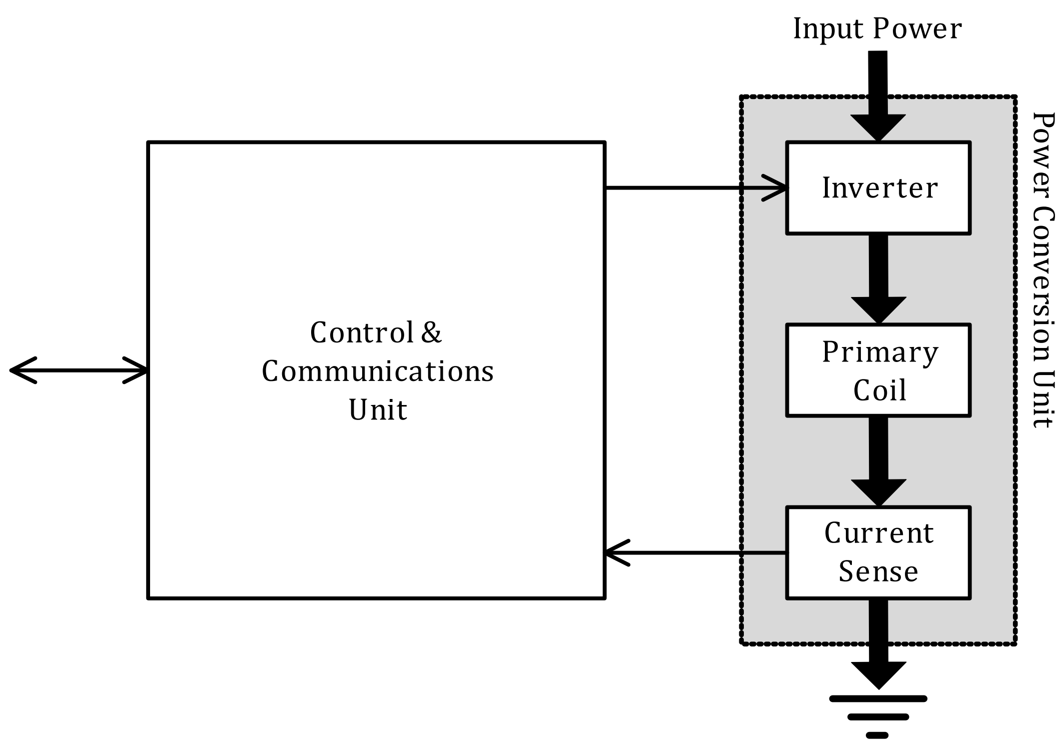
55.2.1 Information interface

The Not Res Sens Bit in the Power Transmitter Capability Packet shall be set to ZERO.

56 Power Transmitter design MP-A11

Figure 237 illustrates the functional block diagram of Power Transmitter design MP-A11. This design consists of two major functional units, namely a Power Conversion Unit and a Communications and Control Unit.

Figure 237. Functional block diagram of Power Transmitter design MP-A11



The Power Conversion Unit on the right-hand side of Figure 237 comprises the analog parts of the design. The inverter converts the DC input to an AC waveform that drives a resonant circuit consisting of the Primary Coil plus a series capacitor.

The Communications and Control Unit on the left-hand side of Figure 237 comprises the digital logic part of the design. This unit receives and decodes messages from the Power Receiver, executes the relevant power control algorithms and protocols, and drives the frequency of the AC waveform to control the power transfer. The Communications and Control Unit also interfaces with other subsystems of the Power Transmitter Product, e.g. for user interface purposes.

56.1 Mechanical details

This section defines the Primary Coil, the Shielding, the Interface Surface, and the alignment aid for Power Transmitter design MP-A11.

56.1.1 Primary Coil

The Primary Coil is of the wire-wound type and consists of no. 17 AWG (1.15 mm diameter) type 2 litz wire having 105 strands of no. 40 AWG (0.08 mm diameter), or equivalent. As shown in Figure 239, the Primary Coil has a circular shape and consists of one or two layers. Table 167 lists the dimensions of the Primary Coil.

Figure 238. Primary Coil of Power Transmitter design MP-A11

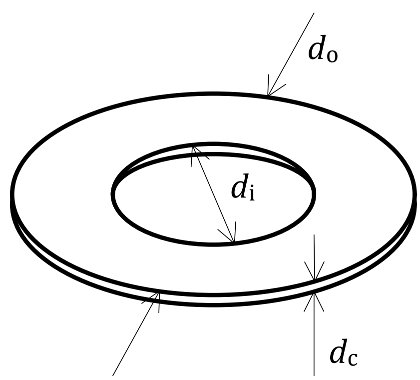


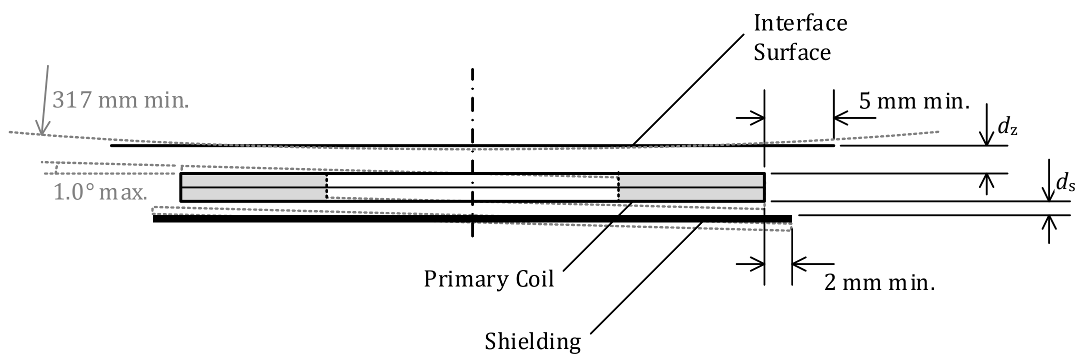
Table 170: Primary Coil parameters of Power Transmitter design MP-A11

Parameter	Symbol	Value
Outer length	d_o	$44.0^{\pm 1.5}$ mm
Inner length	d_i	$20.5^{\pm 0.5}$ mm
Thickness	d_c	$2.1^{\pm 0.5}$ mm
Number of turns per layer	N	10 (5 bifilar turns)
Number of layers	–	1 or 2

56.1.2 Shielding

As shown in Figure 239, soft-magnetic material protects the Power Transmitter Product from the magnetic field that is generated in the Primary Coil. The Shielding extends to at least 2 mm beyond the outer diameter of the Primary Coil, has a thickness of at least 0.5 mm, and is placed below the Primary Coil at a distance of at most d_s = 1.0 mm. This version of *Power Transmitter Reference Designs* limits the composition of the Shielding to a Ni-Zn or Mn-Zn ferrite core from any supplier.

Figure 239. Primary Coil assembly of Power Transmitter design MP-A11



56.1.3 Interface Surface

As shown in Figure 239, the distance from the top face of the even-numbered Primary Coil to the Interface Surface of the Power Transmitter Product is $d_z = 3.5^{\pm 1.0}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Power Transmitter Product extends at least 5.0 mm beyond the outer dimensions of the Primary Coil.

NOTE: This Primary-Coil-to-Interface-Surface distance implies that the tilt angle between the Primary Coil and a flat Interface Surface is at most 1.0°. Alternatively, in case of a non-flat Interface Surface, this Primary-Coil-to-Interface-Surface distance implies a radius of curvature of the Interface Surface of at least 317 mm, centered on the Primary Coil. See Figure 239.

56.1.4 Alignment aid

The user manual of a Power Transmitter Product containing a type MP-A11 Power Transmitter shall provide information about the location of its Active Area(s).

For the best user experience, it is recommended to employ at least one user feedback mechanism during Power Receiver Product positioning to help alignment.

NOTE: Examples of Power Transmitter Product alignment aids to assist the user positioning of the Power Receiver Product include:

- A marked Interface Surface to indicate the location of the Active Area(s)—e.g. a logo or other visual marking, lighting, etc.
- A visual feedback display—e.g. by means of illuminating an LED to indicate proper alignment.
- An audible or tactile feedback mechanism.

56.1.5 Inter coil separation

If the Power Transmitter Product contains multiple type MP-A11 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall not overlap.

56.2 Electrical details

As shown in Figure 240, Power Transmitter design MP-A11 uses a full-bridge inverter to drive an individual Primary Coil and a series capacitance. Within the Operating Frequency range specified below, the assembly of Primary Coil and Shielding has a self-inductance $L_\mathrm{P} = 6.3^{\pm 10\%}$ μH. The value of the series capacitance is $C_\mathrm{p} = 500^{\pm 5\%}$.

NOTE: Near resonance, the voltage developed across the series capacitance can reach levels exceeding 200 V pk-pk.

Power Transmitter design MP-A11 uses the input voltage of the inverter in order to control the amount of power that is transferred. For this purpose, the input voltage has a range of 1 V to 19 V with a resolution of 15 mV or better. The Operating Frequency is $f_\mathrm{op} = 120...130$ kHz.

When a type MP-A11 Power Transmitter first applies a Power Signal (Digital Ping; see the *Qi Specification, Communications Protocol*), it shall use an initial voltage of $4.0^{\pm 0.5}$ V and an initial Operating Frequency of $125^{\pm 4}$ kHz.

Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Qi Specification, Power Delivery*. The controlled variable $v^{(i)}$ introduced in the definition of that algorithm represents the input voltage to the inverter. In order to guarantee sufficiently accurate power control, a type MP-A11 Power Transmitter shall determine the amplitude of the Primary Cell current—which is equal to the Primary Coil current—with a resolution of 7 mA or better. Finally, Table 171 provides the values of several parameters, which are used in the PID algorithm.

Figure 240. Electrical diagram (outline) of Power Transmitter design MP-A11

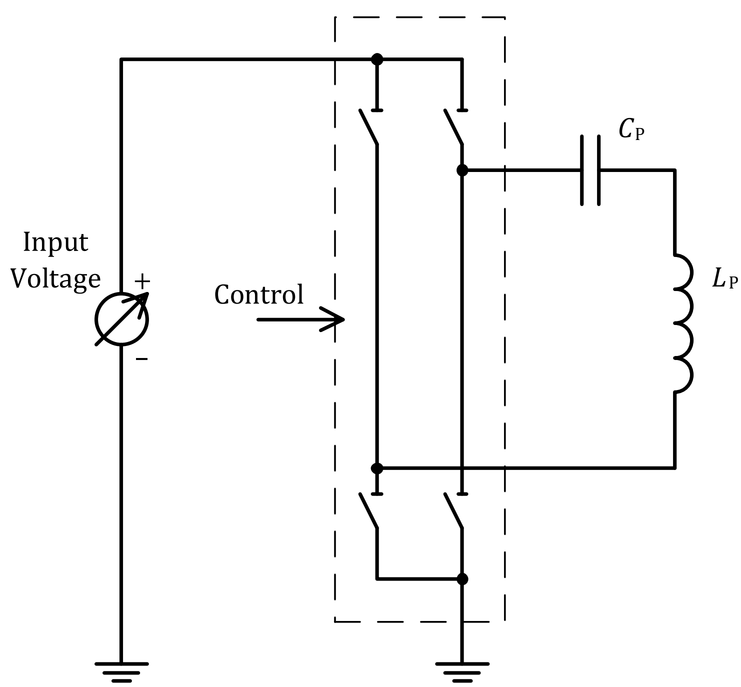


Table 171: PID parameters for voltage control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	5	mA^{-1}
Integral gain	K_i	1	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	3,000	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_v	-0.1	mV

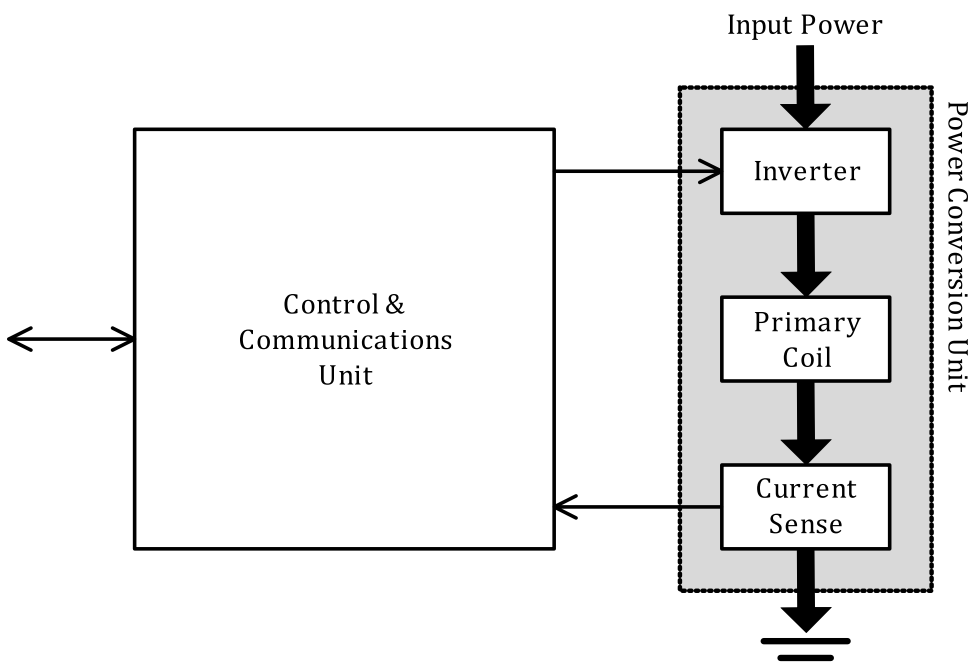
56.2.1 Information interface

The Not Res Sens Bit in the Power Transmitter Capability Packet shall be set to ONE.

57 Power Transmitter design MP-A12

Figure 241 illustrates the functional block diagram of Power Transmitter design MP-A12. This design consists of two major functional units, namely a Power Conversion Unit and a Communications and Control Unit.

Figure 241. Functional block diagram of Power Transmitter design MP-A12



The Power Conversion Unit on the right-hand side of Figure 241 comprises the analog parts of the design. The inverter converts the DC input to an AC waveform that drives a resonant circuit, which consists of the Primary Coil plus a series capacitor. Finally, the current sense monitors the Primary Coil current.

The Communications and Control Unit on the left-hand side of Figure 241 comprises the digital logic part of the design. This unit receives and decodes messages from the Power Receiver, executes the relevant power control algorithms and protocols, and drives the frequency of the AC waveform to control the power transfer. The Communications and Control Unit also interfaces with other subsystems of the Power Transmitter Product, e.g. for user interface purposes.

57.1 Mechanical details

This section defines the Primary Coil, the Shielding, the Interface Surface, and the alignment aid for Power Transmitter design MP-A12.

57.1.1 Primary Coil

The Primary Coil is of the wire-wound type, and consists of no. 17 AWG litz wire having 105 strands of no. 40 AWG (0.08 mm diameter), or equivalent. As shown in Figure 242, the Primary Coils have two types of rectangular shape and each coil consists of a single layer. Table 172 and Table 173 list the dimensions of both bottom (close to ferrite) and top (close to interface) Primary Coil.

Figure 242. Bottom and Top Primary Coils of Power Transmitter design MP-A12

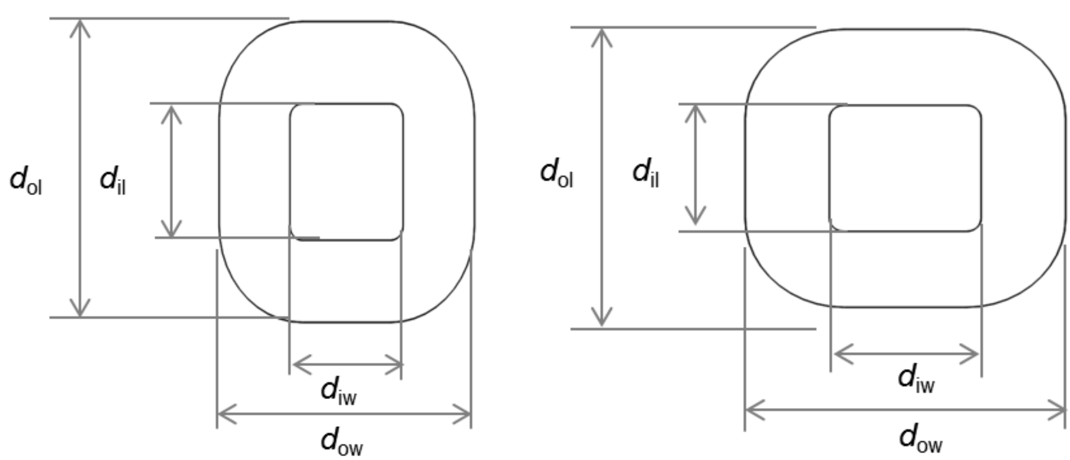


Table 172: Bottom Primary Coil parameters of Power Transmitter design MP-A12

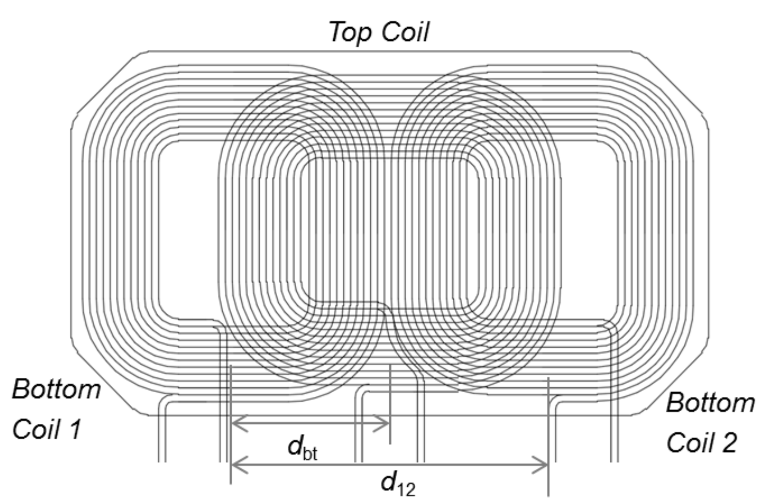
Parameter	Symbol	Value
Outer height	d_{ol}	$49.0^{\pm1.0}$ mm
Inner height	d_{il}	$26.0^{\pm1.0}$ mm
Outer width	d_{ow}	$44.0^{\pm1.0}$ mm
Inner width	d_{iw}	$22.0^{\pm1.0}$ mm
Thickness	d_c	$1.1^{\pm0.2}$ mm
Number of turns per layer	N	11
Number of layers	—	1

Table 173: Top Primary Coil parameters of Power Transmitter design MP-A12

Parameter	Symbol	Value
Outer height	d_{ol}	$46.0^{\pm 1.0}$ mm
Inner height	d_{il}	$21.0^{\pm 1.0}$ mm
Outer width	d_{ow}	$49.5^{\pm 1.0}$ mm
Inner width	d_{iw}	$25.5^{\pm 1.0}$ mm
Thickness	d_c	$1.1^{\pm 0.2}$ mm
Number of turns per layer	N	12
Number of layers	—	1

Power Transmitter design MP-A12 contains three Primary Coils. Bottom Primary Coil #1 and bottom Primary Coil #2 are placed alongside each other with a displacement of $d_{12} = 46^{\pm 4}$ mm between their centers. The top Primary Coil is placed orthogonal to the bottom Primary Coils, with a displacement of $d_{bt} = 23^{\pm 2}$ mm between their centers. See Figure 243.

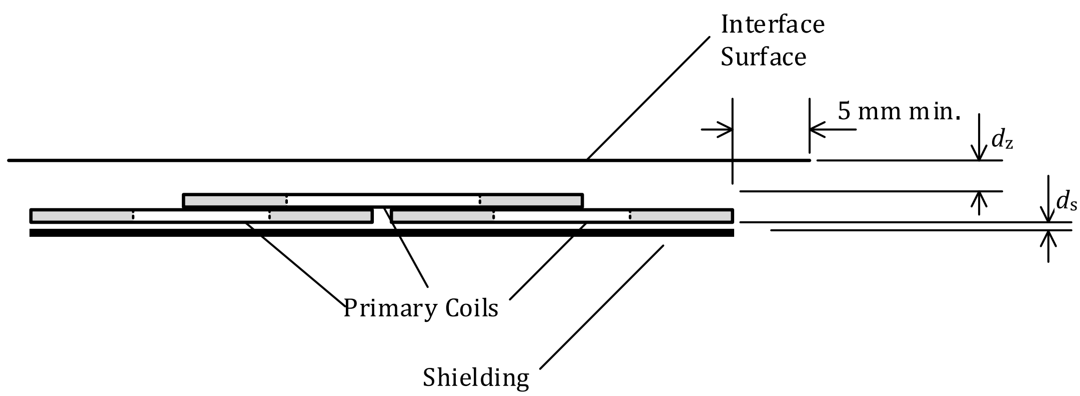
Figure 243. Bottom and Top Primary Coils of Power Transmitter design MP-A12



57.1.2 Shielding

As shown in Figure 244, a soft-magnetic material protects the Power Transmitter Product from the magnetic field that is generated in the Primary Coils. The Shielding extends to at least 2 mm beyond the outer dimensions of the Primary Coils, has a thickness of at least 1.5 mm, and is placed below the Primary Coil at a distance of at most d_s = 1.0 mm. This version of *Power Transmitter Reference Designs* limits the composition of the Shielding to a Ni-Zn or Mn-Zn ferrite core from any supplier.

Figure 244. Primary Coil assembly of Power Transmitter design MP-A12



57.1.3 Interface Surface

As shown in Figure 244, the distance from the top face of the top Primary Coil to the Interface Surface of the Power Transmitter Product is $d_z = 7.0^{\pm 1.0}$ mm, across the top face of the Primary Coil. The odd-numbered Primary Coils are mounted flush to the bottom face of the even-numbered Primary Coils. If the Power Transmitter contains only one Primary Coil, the distance from the top face of the bottom Primary Coil to the Interface Surface of the Power Transmitter Product ($d_s = 8.1^{\pm 0.4}$ mm). In addition, the Interface Surface of the Power Transmitter Product extends at least 5.0 mm beyond the outer dimensions of the Primary Coil.

NOTE: This Primary-Coil-to-Interface-Surface distance implies that the tilt angle between the Primary Coil and a flat Interface Surface is at most 1.0°. See Figure 244.

57.1.4 Alignment aid

The user manual of the Power Transmitter Product containing type MP-A12 Power Transmitter shall provide information about the location of its Active Area(s).

For the best user experience, it is recommended to employ at least one user feedback mechanism during Power Receiver Product placement to help alignment.

Examples of Power Transmitter Product alignment aids to assist the user placement of the Power Receiver Product include:

- A marked Interface Surface to indicate the location of its Active Area(s)—e.g. a logo or other visual marking, lighting, etc.
- A visual feedback display—e.g. by means of illuminating an LED to indicate proper alignment.
- An audible or haptic feedback mechanism.

57.1.5 Inter coil separation

If the Power Transmitter Product contains multiple type MP-A12 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall not overlap.

57.2 Electrical details

As shown in Figure 245, Power Transmitter design MP-A12 uses a full-bridge inverter to drive an individual Primary Coil and a series capacitance. Within the Operating Frequency range specified below, the assembly of Primary Coils and Shielding has a self-inductance $L_{\mathrm{P}} = 11.3^{\pm 0.7}$ μH. The value of the series capacitance is $C_{\mathrm{p}} = 300^{\pm 5\%}$ nF.

NOTE: Near resonance, the voltage developed across the series capacitance can reach levels exceeding 200 V pk-pk.

Power Transmitter design MP-A12 uses the input voltage of the inverter to control the amount of power that is transferred. For this purpose, the input voltage has a range of 1 to 20 V with a resolution of 10 mV or better. The Operating Frequency is $f_{\mathrm{op}} = 108 \ldots 114$ kHz with a duty cycle of 50%.

When Power Transmitter design MP-A12 first applies a Power Signal (see the *Qi Specification, Communications Protocol*), it shall use an initial voltage of $7.0^{\pm 0.5}$ V for bottom and top Primary Coils, and a recommended Operating Frequency of 111 kHz.

Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Qi Specification, Power Delivery*. The controlled variable $v^{(i)}$ introduced in the definition of that algorithm represents the input voltage to the inverter. In order to guarantee sufficiently accurate power control, Power Transmitter design MP-A12 shall determine the amplitude of the Primary Cell current—which is equal to the Primary Coil current—with a resolution of 7 mA or better. Finally, Table 174 provides the values of several parameters, which are used in the PID algorithm.

Figure 245. Electrical diagram (outline) of Power Transmitter design MP-A12

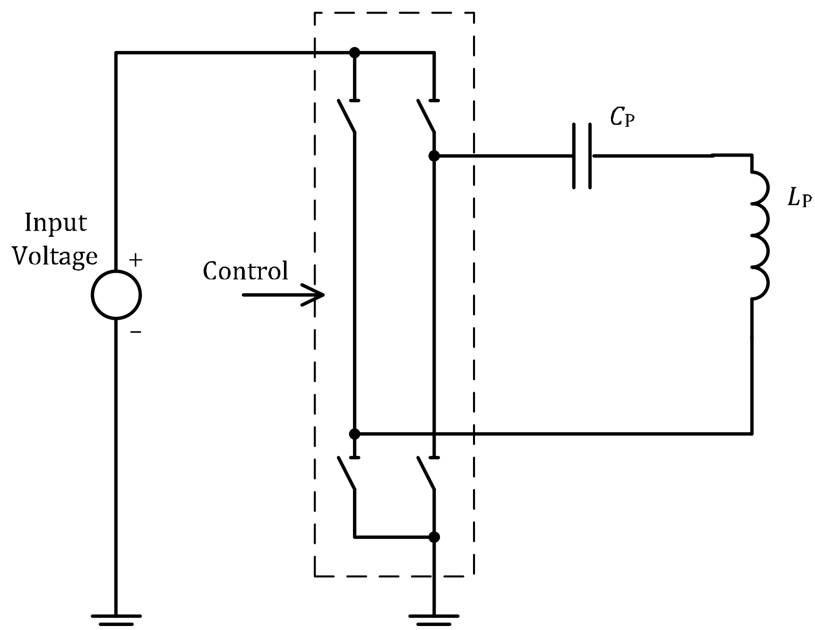


Table 174: PID parameters for Voltage control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	10	mA^{-1}
Integral gain	K_i	1	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	3,000	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_v	100	mV

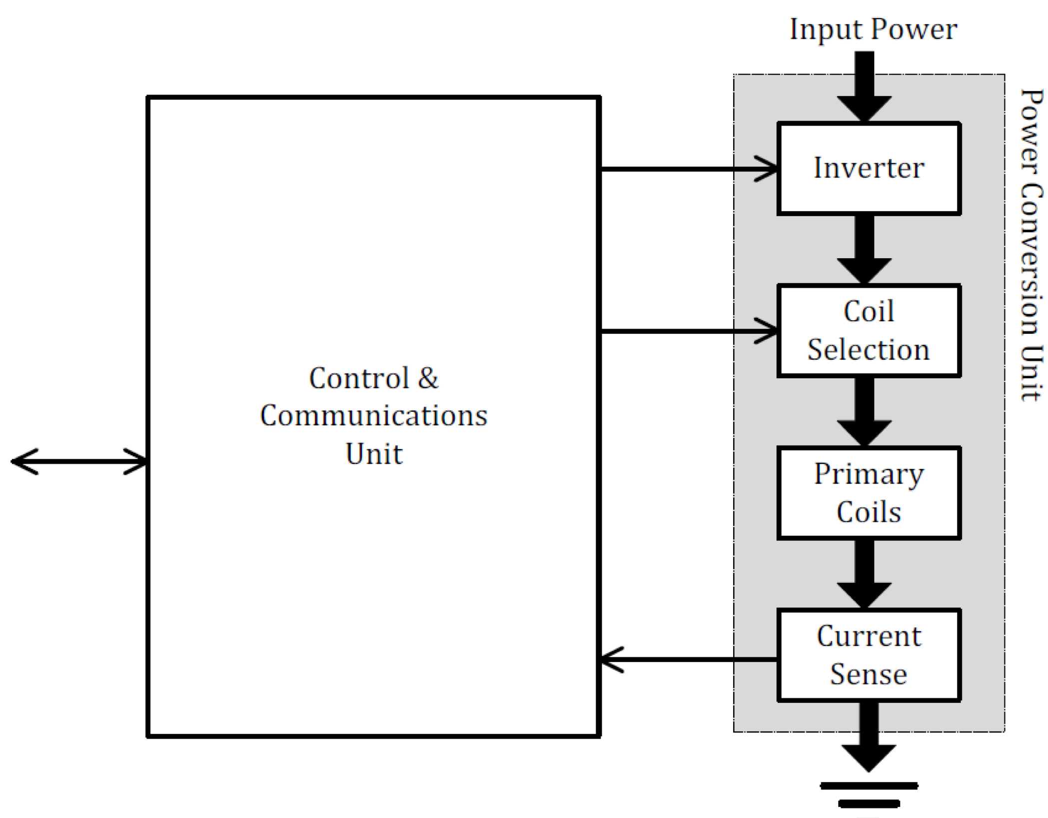
57.2.1 Information interface

The Not Res Sens Bit in the Power Transmitter Capability Packet shall be set to ONE.

58 Power Transmitter design MP-A13

Figure 246 illustrates the functional block diagram of Power Transmitter design MP-A13. This design consists of two major functional units, namely a Power Conversion Unit and a Communications and Control Unit.

Figure 246. Functional block diagram of Power Transmitter design MP-A13



The Power Conversion Unit on the right-hand side of Figure 246 comprises the analog parts of the design. The inverter converts the DC input to an AC waveform that drives a resonant circuit, which consists of the selected Primary Coil plus a series capacitor. The selected Primary Coil is one from a linear array of partially overlapping Primary Coils, as appropriate for the position of the Power Receiver relative to the Primary Coils. Selection of the Primary Coil proceeds by the Power Transmitter attempting to establish communication with a Power Receiver using any of the Primary Coils. Note that the array may consist of a single Primary Coil only, in which case the selection is trivial. Finally, the current sense monitors the Primary Coil current.

The Communications and Control Unit on the left-hand side of Figure 246 comprises the digital logic part of the design. This unit receives and decodes messages from the Power Receiver, configures the Coil Selection block to connect the appropriate Primary Coil, executes the relevant power control algorithms and protocols, and drives the frequency of the AC waveform to control the power transfer. The Communications and Control Unit also interfaces with other subsystems of the Power Transmitter Product, e.g. for user interface purposes.

58.1 Mechanical details

Power Transmitter design A13 includes one or more Primary Coils as defined in Section 58.1.1, *Primary Coil*, Shielding as defined in Section 58.1.2, *Shielding*, an Interface Surface as defined in Section 58.1.3, *Interface Surface*.

58.1.1 Primary Coil

The Primary Coil is of the wire-wound type, and consists of no. 17 AWG (1.15 mm diameter) type 2 litz wire having 105 strands of no. 40 AWG (0.08 mm diameter), or equivalent. As shown in Figure 247, the Primary Coil has a rectangular shape and consists of a single layer. Table 175 lists the dimensions of the Primary Coil.

Figure 247. Primary Coil of Power Transmitter design MP-A13

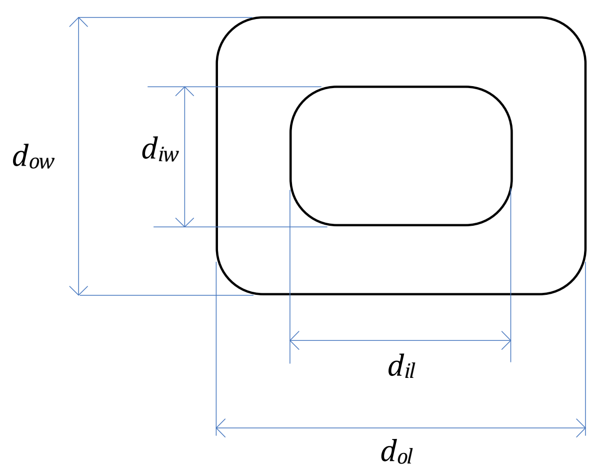
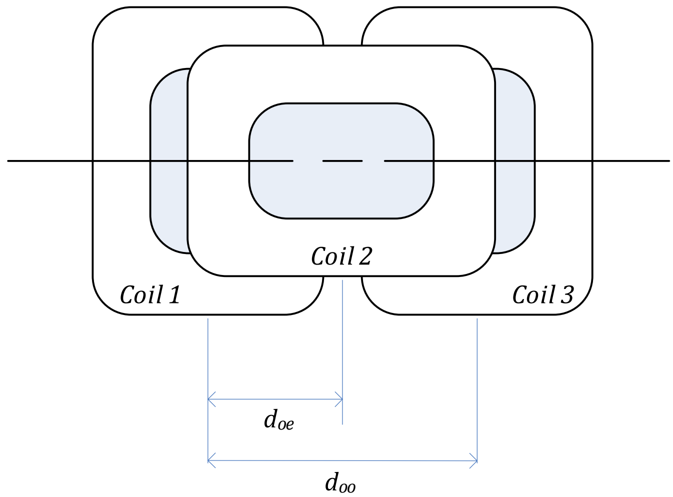


Table 175: Primary Coil parameters of Power Transmitter design MP-A13

Parameter	Symbol	Value
Outer length	d_{ol}	$53.2^{\pm 0.5}$ mm
Inner length	d_{il}	$27.5^{\pm 0.5}$ mm
Outer width	d_{ow}	$45.2^{\pm 0.5}$ mm
Inner width	d_{iw}	$19.5^{\pm 0.5}$ mm
Thickness	d_c	$1.5^{\pm 0.5}$ mm
Number of turns per layer	N	12
Number of layers	–	1

Power Transmitter design A13 contains at least one Primary Coil. Odd numbered coils are placed alongside each other with a displacement of $d_{oo} = 49.2^{\pm 4}$ mm between their centers. Even numbered coils are placed orthogonal to the odd numbered coils with a displacement of $d_{oe} = 24.6^{\pm 2}$ mm between their centers. See Figure 248.

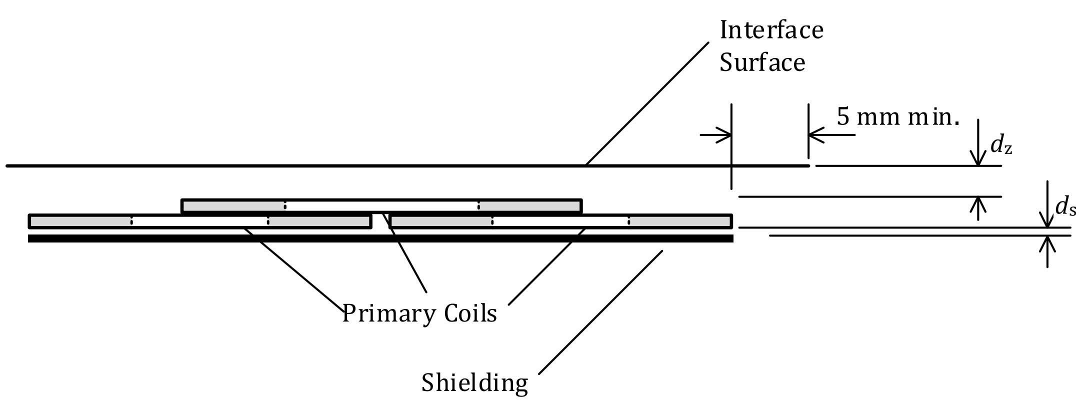
Figure 248. Primary Coils of Power Transmitter design MP-A13



58.1.2 Shielding

As shown in Figure 249, soft-magnetic material protects the Power Transmitter Product from the magnetic field that is generated in the Primary Coil. The Shielding should be Ni-Zn or Mn-Zn ferrite and should be at least 0.5 mm thick. The Shielding extends to at least to the outer dimensions of the Primary Coil, and is placed below the Primary Coil at a distance of at most $d_s = 1.0$ mm.

Figure 249. Primary Coil assembly of Power Transmitter design MP-A13



58.1.3 Interface Surface

As shown in Figure 249, the distance from the top face of the even-numbered Primary Coil to the Interface Surface of the Power Transmitter Product is $d_z = 3^{\pm 1}$ mm, across the top face of the Primary Coil. The odd-numbered Primary Coils are mounted flush to the bottom face of the even-numbered Primary Coils. If the Power Transmitter contains only one Primary Coil, the distance from the top face of the Primary Coil to the Interface Surface of the Power Transmitter Product is $d_z = 4.5^{\pm 1}$ mm. In addition, the Interface Surface of the Power Transmitter Product extends at least 5 mm beyond the outer dimensions of the Primary Coils.

58.1.4 Alignment aid

The user manual of a Power Transmitter Product containing a type MP-A13 Power Transmitter shall provide information about the location of its Active Area(s).

For the best user experience, it is recommended to employ at least one user feedback mechanism during Power Receiver Product positioning to help alignment.

Examples of Power Transmitter Product alignment aids to assist the user positioning of the Power Receiver Product include:

- A marked Interface Surface to indicate the location of the Active Area(s)—e.g. a logo or other visual marking, lighting, etc.
- A visual feedback display—e.g. by means of illuminating an LED to indicate proper alignment.
- An audible or tactile feedback mechanism.

58.1.4.1 Inter coil separation

If the Power Transmitter Product contains multiple type MP-A13 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall not overlap.

58.2 Electrical details

As shown in Figure 250, Power Transmitter design MP-A13 uses a full-bridge inverter to drive an individual Primary Coil and a series capacitance. Within the Operating Frequency range specified below, the assembly of Primary Coils and Shielding has a self-inductance $L_P = 11.5^{\pm 10\%}$ µH for coils closest to the Interface Surface and inductance $L_P = 12.5^{\pm 10\%}$ µH for coils furthest from the Interface Surface. The value of inductances L_1 and L_2 is $1^{\pm 20\%}$ µH. The value of the total series capacitance is $1 / C_{ser1} + 1 / C_{ser2} = 1 / 200^{\pm 10\%}$ 1/nF. The value of the parallel capacitance is $C_{par} = 400^{\pm 10\%}$ nF. Splitting the series capacitance is optional, affecting only high frequency electromagnetic emissions, and it is permissible to eliminate C_{ser2}, in which case $C_{ser1} = 200^{\pm 10\%}$ nF.

NOTE: Near resonance, the voltage developed across the series capacitance can reach levels exceeding 100 V pk-pk.

Power Transmitter design MP-A13 uses the input voltage of the inverter to control the amount of power that is transferred. For this purpose, the input voltage has a range of 1…12 V, with a resolution of 10 mV or better with a duty cycle of 50%. Below 1V input voltage, the duty cycle may be reduced to a minimum of 20% for lower power operation. The Operating Frequency f_{op} is fixed with a target frequency of 120kHz but may be set within 112kHz – 128kHz to optimize for component variation.

When a type MP-A13 Power Transmitter first applies a Power Signal (Digital Ping; see the *Qi Specification, Communications Protocol*), it shall use an initial voltage of $4.0^{\pm 0.5}$ V for a bottom Primary Coil, and $3.5^{\pm 0.5}$ V for a top Primary Coil, and a recommended target Operating Frequency of 120 kHz.

Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Qi Specification, Power Delivery*. The controlled variable $v^{(i)}$ introduced in the definition of that algorithm represents the input voltage to the inverter. In order to guarantee sufficiently accurate power control, a type MP-A13 Power Transmitter shall determine the amplitude of the Primary Cell current—which is equal to the Primary Coil current—with a resolution of 7 mA or better. Finally, Table 176 and Table 177 provide the values of several parameters, which are used in the PID algorithm.

Figure 250. Electrical diagram (outline) of Power Transmitter design MP-A13

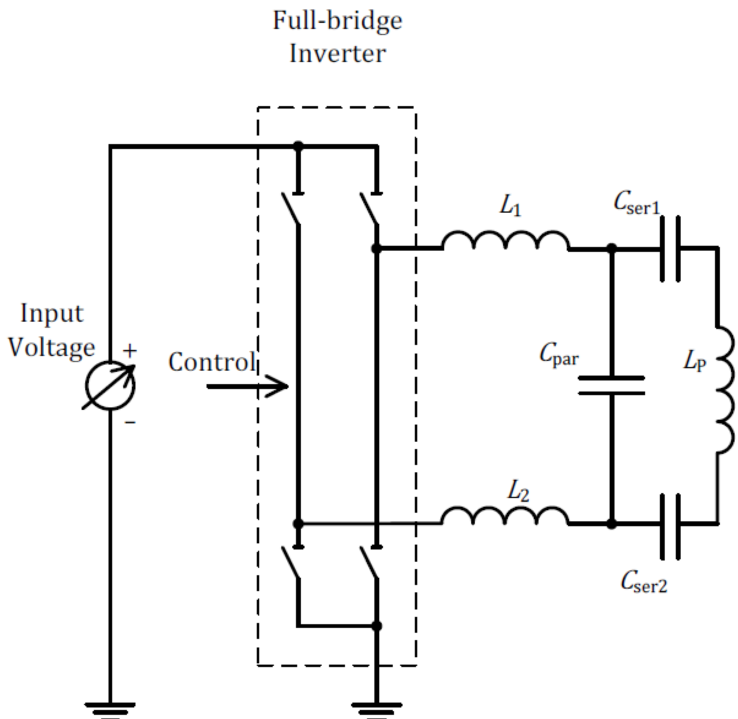


Table 176: PID parameters for voltage control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	0.03	mA^{-1}
Integral gain	K_i	0.01	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	3,000	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_v	-2	mV

Table 177: PID parameters for duty cycle control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	0.03	mA^{-1}
Integral gain	K_i	0.01	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	3,000	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_v	-0.01	%

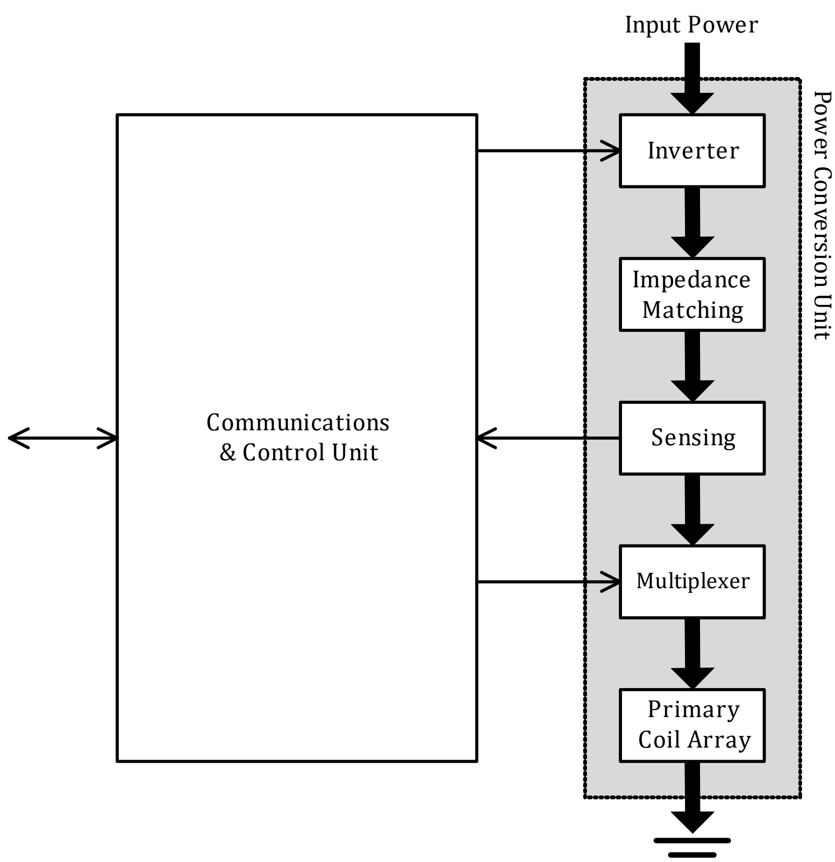
58.2.1 Information interface

The Not Res Sens Bit in the Power Transmitter Capability Packet shall be set to ZERO.

59 Power Transmitter design MP-B1

Figure 251 illustrates the functional block diagram of Power Transmitter design MP-B1, which consists of two major functional units, namely a Power Conversion Unit and a Communications and Control Unit.

Figure 251. Functional block diagram of Power Transmitter design MP-B1



The Power Conversion Unit on the right-hand side of Figure 251 comprises the analog parts of the design. The design uses an array of partly overlapping Primary Coils to provide for Free Positioning. Depending on the position of the Power Receiver, the multiplexer connects and/or disconnects the appropriate Primary Coil(s). The impedance matching network forms a resonant circuit with the parts of the Primary Coil array that are connected. The sensing circuits monitor (amongst others) the Primary Cell current and voltage, and the inverter converts the DC input to an AC waveform that drives the Primary Coil array.

The Communications and Control Unit on the left-hand side of Figure 251 comprises the digital logic part of the design. This unit receives and decodes messages from the Power Receiver, configures the multiplexer to connect the appropriate parts of the Primary Coil array, executes the relevant power control algorithms and protocols, and drives the inverter to control the amount of power provided to the Power Receiver. The Communications and Control Unit also interfaces with the other subsystems of the Power Transmitter Product, e.g. for user interface purposes.

59.1 Mechanical details

Power Transmitter design MP-B1 includes a Primary Coil array as defined in Section 59.1.1, *Primary Coil array*, Shielding as defined in Section 59.1.2, *Shielding*, and an Interface Surface as defined in Section 59.1.3, *Interface Surface*.

59.1.1 Primary Coil array

The Primary Coil design of the MP-B1 is identical to the Primary Coil array of the type B7 Power Transmitter array and consists of partly-overlapping, rectangular-shaped planar coils. In order to keep the inductance of each coil similar in the final assembly there are two coils specified for this transmitter type, Primary Coil A and Primary Coil B. On the left side of Figure 252 is a top view of Primary Coil A (left), which consists of a 17 AWG (1.2 mm diameter) wire that runs through 9 rectangular-shaped turns in a single layer. On the right is a top view of Primary Coil B, which consists of a 17 AWG (1.2 mm diameter) wire that runs through 10 rectangular-shaped turns in a single layer. Another realization of a single Primary Coil A or B is to construct it from litz wire having 105 strands of no. 40 AWG (0.08 mm diameter), or equivalent. Table 178 lists the relevant parameters of the coils shown in Figure 252.

NOTE: Primary Coil B can be constructed from Primary Coil A by adding one inner turn, conversely, Primary Coil A can be constructed from Primary Coil B by removing one inner turn.

In this Primary Coil array, the coils closest to the Shielding shall be according to Primary Coil A, and the coils closest to the Interface Surface shall be according to Primary Coil B. Moreover, a transmitter execution that uses only one Primary Coil shall use Primary Coil A.

Figure 252. Top view of Primary Coil A (left) and Primary Coil B (right) of Power Transmitter design MP-B1

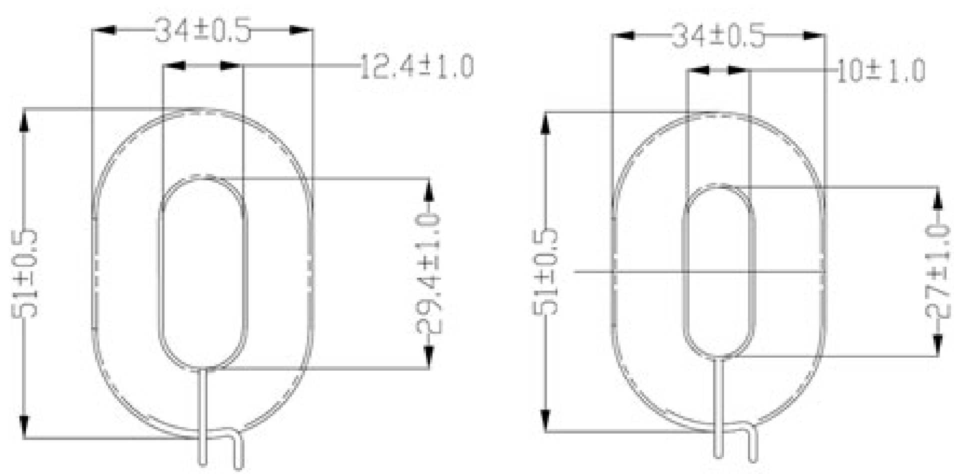


Table 178: Primary Coil parameters of Power Transmitter design MP-B1

Parameter	**Symbol**	**Value**
Primary Coil A (closest to the Shielding)		
Outer width	w_o	$34.0^{+0.5}_{0.5}$ mm
Outer length	l_o	$51.0^{+0.5}_{0.5}$ mm
Inner width	w_i	$12.4^{+1.0}_{1.0}$ mm
Inner length	l_i	$29.4^{+1.0}_{1.0}$ mm
Number of turns	N	9
Primary Coil B (closest to Interface Surface)		
Outer width	w_o	$34.0^{+0.5}_{0.5}$ mm
Outer length	l_o	$51.0^{+0.5}_{0.5}$ mm
Inner width	w_i	$10.0^{+1.0}_{1.0}$ mm
Inner length	l_i	$27.0^{+1.0}_{1.0}$ mm
Number of turns	N	10

Power Transmitter design MP-B1 enables one-dimensional freedom of positioning. For that purpose, the Primary Coils are placed in a row, such that there is an overlap of approximately 50% of the area. Each Primary Coil (except for an execution that uses only one Primary Coil) overlaps with one other Primary Coils in a different layer. Figure 253 shows the layout of an example execution of the Primary Coil array using four Primary Coils. Table 179 lists the relevant parameters of the Primary Coil array.

Figure 253. Example of Power Transmitter design MP-B1 in a 4-coil execution

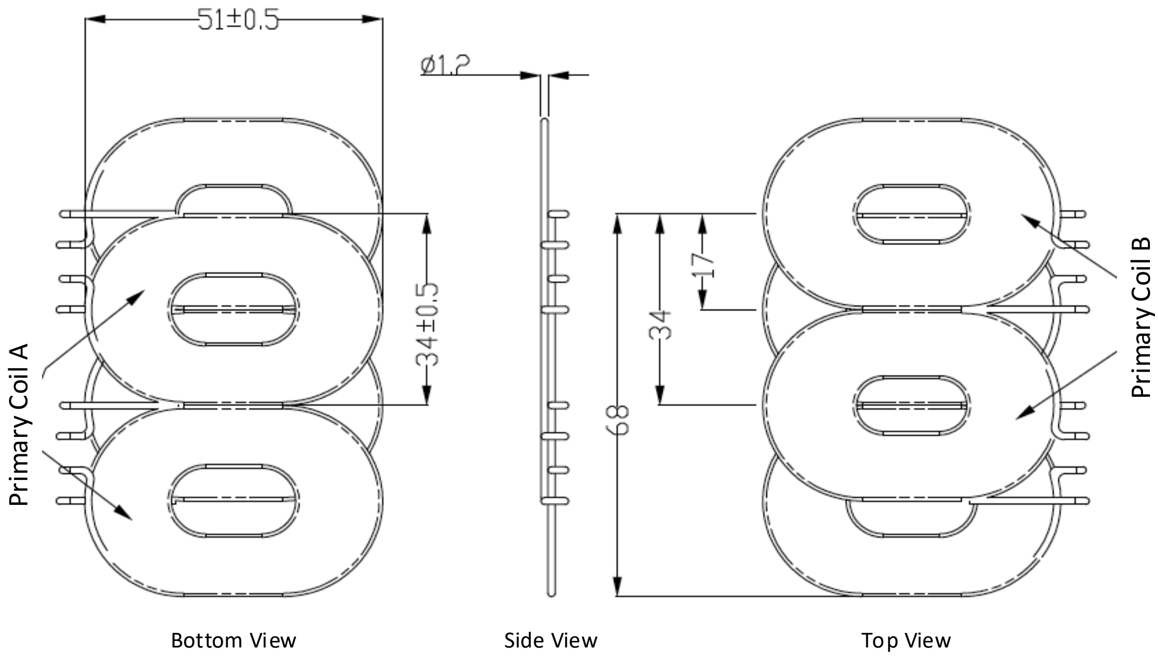


Table 179: Primary Coil array parameters of Power Transmitter design MP-B1

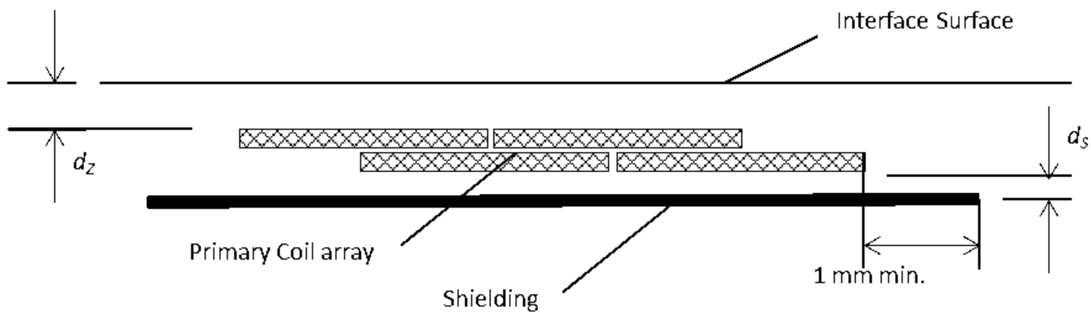
Parameter	Symbol	Value
Center-to-center distance	d_h	$34.0^{\pm 0.5}$ mm
Offset 2nd layer array	t_2	$17.0^{\pm 0.5}$ mm
Litz-layer thickness	d_c	$1.2^{\pm 0.5}$ mm

59.1.2 Shielding

As shown in Figure 254, Transmitter design MP-B1 employs Shielding to protect the Power Transmitter Product from the magnetic field that is generated in the Primary Coil array. The Shielding extends to at least 1 mm beyond the outer edges of the Primary Coil array, and is placed at a distance of at most d_s = 0.5 mm below the Primary Coil array.

The Shielding consists of soft magnetic material that has a thickness of at least 0.5 mm. This version of *Power Transmitter Reference Designs* limits the composition of the Shielding to any Mn-Zn (for example, PC44 from TDK Corporation).

Figure 254. Primary Coil array assembly of Power Transmitter design MP-B1, cross-sectional view



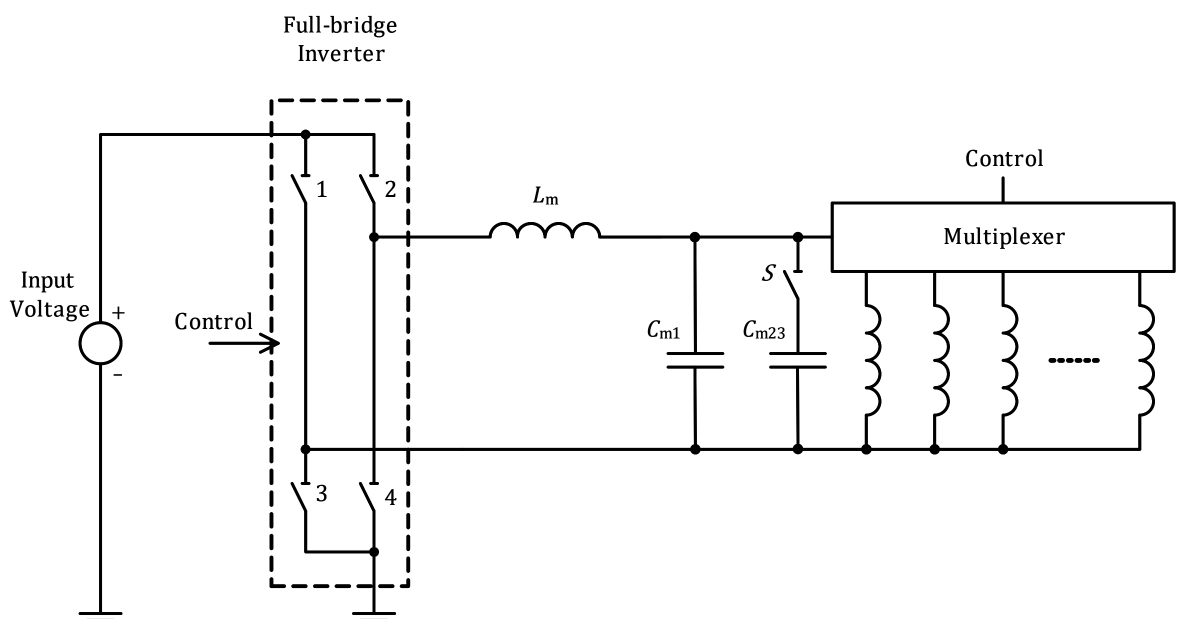
59.1.3 Interface Surface

As shown in Figure 254, the distance from the top face of the top Primary Coil array to the Interface Surface of the Power Transmitter Product is $d_Z = 2^{\pm 0.5}$ mm, across the top face of the Primary Coil array. The bottom Primary Coil array is mounted flush to the bottom face of the top Primary Coil array. In addition, the Interface Surface extends at least 2 mm beyond the outer edges of the Primary Coil array.

59.2 Electrical details

As shown in Figure 255, Power Transmitter design MP-B1 uses a full-bridge inverter to drive the Primary Coil array. In addition, Power Transmitter design MP-B1 uses a multiplexer to select the position of the Active Area. The multiplexer shall configure the Primary Coil array in such a way that one or two Primary Coils are connected—in parallel—to the driving circuit. The connected Primary Coils together constitute a Primary Cell. In the case that two Primary Coils are selected, these two Primary Coils shall have an overlap of approximately 50% of the area of a single Primary Coil.

Figure 255. Electrical diagram (outline) of Power Transmitter design MP-B1

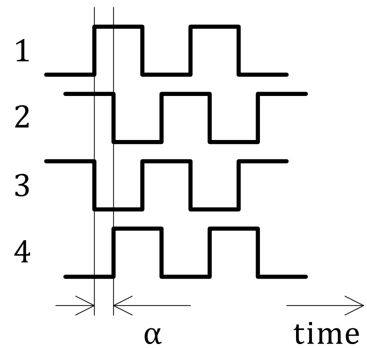


Within the Operating Frequency range $f_{0p} = 115^{\pm 5}$ kHz, the assembly of Primary Coil array and Shielding has an inductance of $6.1^{\pm 0.6}$ μH for each individual Primary Coil. The capacitances in the impedance-matching circuit are $C_{m1} = 300^{\pm 5\%}$ nF and C_{m23} is in the range of $100^{-5\%}$ to $300^{+5\%}$ nF. The inductance in the impedance-matching circuit is $L_m = 3.8^{\pm 5\%}$ μH. Switch S is open if the Primary Cell consists of a single Primary Coil; otherwise, switch S is closed. The input voltage to the full-bridge inverter is $15^{\pm 5\%}$ V.

NOTE: The voltage across the capacitance C_m can reach levels exceeding 40 V pk-pk.

Power Transmitter design MP-B1 uses the phase difference between the control signals to two halves of the full-bridge inverter to control the amount of power that is transferred (see Figure 256). For this purpose, the range of the phase difference α is 0…180°—with a larger phase difference resulting in a lower power transfer. In order to achieve a sufficient accurate adjustment of the power that is transferred, a type MP-B1 Power Transmitter shall be able to control the phase difference with a resolution of 0.42° or better. When a type MP-B1 Power Transmitter first applies a Power Signal (Digital Ping; see the *Qi Specification, Communications Protocol*), it shall use an initial phase difference of 150°.

Figure 256. Control signals to the inverter



Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Qi Specification, Power Delivery*. The controlled variable $v^{(i)}$ introduced in the definition of that algorithm represents the phase difference between the two halves of the full-bridge inverter. In order to guarantee sufficiently accurate power control, a type MP-B1 Transmitter shall determine the amplitude of the current into the Primary Cell with a resolution of 5 mA or better. In addition to the PID algorithm, a type MP-B1 Power Transmitter shall limit the current into the Primary Cell to at most 4 A RMS in the case that the Primary Cell consists of two Primary Coils, or at most 3 A RMS in the case that the Primary Cell consists of one Primary Coil. Finally, Table 180 provides the values of several parameters that are used in the PID algorithm.

Table 180: Power control parameters for Power Transmitter design MP-B1

Parameter	Symbol	Value	Unit
Proportional gain	K_p	1	mA^{-1}
Integral gain	K_i	0	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	N.A.	N.A.
PID output limit	M_{PID}	2,000	N.A.
Scaling factor	S_v	0.01	°

59.2.1 Scalability

Power Transmitter Design MP-B1 offers the same scalability options as Power Transmitter design B1. See Section 39, *Power Transmitter design B1*.