The Qi Wireless Power Transfer System

Power Class 0 Specification

Part 4: Reference Designs

Version 1.2.4

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RELEASE HISTORY

Version	Release Date	Description
1.2.1	October 2015	Restructuring and renaming of Wireless Power Transfer System Descriptions.
1.2.2	April 2016	Added new PTx types A34, B7, and MP-A5; deprecated PTx types A1, A5, and A9. Addressed technical and editorial issues found in version 1.2.1. Made this document accessible to the general public.
1.2.3	February 2017	Added new Power Transmitter types MP-B1, MP-A6, MP-A7, and MP-A8. Relaxed requirements for Shielding materials in the reference designs, and addressed other change requests.
1.2.4	February 2018	New PTx types A11a, A28a, MP-A9, MP-A10 and MP-A13. Addressed technical and editorial issues found in version 1.2.3. See Annex A, History of Changes, for details.

Contents

1 General

1.1 Introduction

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 is wireless charging of low and medium power devices, such as mobile phones and tablet computers. The Wireless Power Consortium maintains the Qi logo for this application area.

1.2 Scope

This document, *Part 4: Reference Designs,* comprises reference designs for Power Class 0 Base Stations and Mobile Devices. Power Class 0 is the WPC designation for flat-surface devices, such as chargers, mobile phones, tablets, cameras, and battery packs, in the Baseline Power Profile (≤ 5 W) and Extended Power Profile (≤ 15 W).

1.2.1 Current Specification structure (introduced in version 1.2.1)

The Qi Wireless Power Transfer System for Power Class 0 Specification consists of the following documents.

- *Parts 1 and 2: Interface Definitions*
  - *Part 1: Primary Interface Definition*
  - *Part 2: Secondary Interface Definition*
- *Part 3: Compliance Testing*
- ***Part 4: Reference Designs*** (this document)

NOTE WPC publications prior to version 1.2.1 were structured differently, and are listed in Section 1.2.2 below. In particular, the Low Power and Medium Power publications were divided into separate System Description documents. Beginning with version 1.2.1, the Low Power and Medium Power System Descriptions have been merged into the Specification structure shown in this section. Additionally, the terms *Low Power* and *Medium Power* have been replaced in the current Specification by the terms *Baseline Power Profile* and *Extended Power Profile* respectively.

1.2.2 Earlier Specification structure (version 1.2.0 and below)

Before release 1.2.1, the Wireless Power Transfer Specification comprised the following documents.

- System Description, Wireless Power Transfer, Volume I: Low Power, Part 1: Interface Definition.
- System Description, Wireless Power Transfer, Volume I: Low Power, Part 2: Performance Requirements.
- System Description, Wireless Power Transfer, Volume I: Low Power, Part 3: Compliance Testing.
- System Description, Qi Wireless Power Transfer, Volume II: Medium Power.

1.3 Main features

- A method of contactless power transfer from a Base Station to a Mobile Device that is based on near field magnetic induction between coils.
- A Baseline Power Profile supporting transfer of up to about 5 W and an Extended Power Profile supporting transfer of up to about 15 W of power using an appropriate Secondary Coil (having a typical outer dimension of around 40 mm).
- Operation at frequencies in the 87…205 kHz range.
- Support for two methods of placing the Mobile Device on the surface of the Base Station:
  - Guided Positioning helps a user to properly place the Mobile Device on the surface of a Base Station that provides power through a single or a few fixed locations of that surface.
  - Free Positioning enables arbitrary placement of the Mobile Device on the surface of a Base Station that can provide power through any location of that surface.
- A simple communications protocol enabling the Mobile Device to take full control of the power transfer.
- Considerable design flexibility for integration of the system into a Mobile Device.
- Very low stand-by power achievable (implementation dependent).

1.4 Conformance and references

1.4.1 Conformance

All provisions in The Qi Wireless Power Transfer System, Power Class 0 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. For clarity, the word "**shall**" indicates a requirement that is to be followed strictly in order to conform to The Qi Wireless Power Transfer System, Power Class 0 Specification, and from which no deviation is permitted. The word "**should**" indicates that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others, or that a certain course of action is preferred but not necessarily required, or that in the negative form a certain possibility or course of action is deprecated but not prohibited. The word "**may**" indicates a course of action permissible within the limits of The Qi Wireless Power Transfer System, Power Class 0 Specification. The word "**can**" indicates a possibility or capability, whether material, physical, or causal.

1.4.2 References

For undated references, the most recently published Specification applies. The most recent WPC publications can be downloaded from http://www.wirelesspowerconsortium.com. (See Section 1.2.1 for a list of documents included in The Qi Wireless Power Transfer System for Power Class 0 Specification.) In addition, the following documents are referenced within The Qi Wireless Power Transfer System for Power Class 0 Specification.

- Product Registration Procedure Web page[1] (in the WPC Web site for members, navigate to the Testing & Registration section)
- Qi Product Registration Manual, Logo Licensee/Manufacturer[1]
- Qi Product Registration Manual, Authorized Test Lab[1]
- Power Receiver Manufacturer Codes[1], Wireless Power Consortium
- The International System of Units (SI), Bureau International des Poids et Mesures

[1] Access is restricted and requires signing in to the WPC Web site for members.

1.5 Definitions

Active Area: The part of the Interface Surface of a Base Station or Mobile Device through which a sufficiently high magnetic flux penetrates when the Base Station is providing power to the Mobile Device.

Base Station: A device that is able to provide near field inductive power as specified in The Qi Wireless Power Transfer System, Power Class 0 Specification. A Base Station carries a logo to visually indicate to a user that the Base Station complies with The Qi Wireless Power Transfer System, Power Class 0 Specification.

Baseline Power Profile: The minimum set of features applying to Power Transmitters and Power Receivers that can transfer no more than around 5 W of power.

Communications and Control Unit: The functional part of a Power Transmitter or Power Receiver that controls the power transfer.

NOTE With regard to implementation, the Communications and Control Unit may be distributed over multiple subsystems of the Base Station or Mobile Device.

Control Point: The combination of voltage and current provided at the output of the Power Receiver, and other parameters that are specific to a particular Power Receiver implementation.

Detection Unit: The functional part of a Power Transmitter that detects the presence of a Power Receiver on the Interface Surface.

Digital Ping: The application of a Power Signal in order to detect and identify a Power Receiver.

Extended Power Profile: The minimum set of features applying to Power Transmitters and Power Receivers that can transfer power above 5 W.

Free Positioning: A method of positioning a Mobile Device on the Interface Surface of a Base Station that does not require the user to align the Active Area of the Mobile Device to the Active Area of the Base Station.

Foreign Object: Any object that is positioned on the Interface Surface of a Base Station, but is not part of a Mobile Device.

Foreign Object Detection: A process that a Power Transmitter or Power Receiver executes in order to determine if a Foreign Object is present on the Interface Surface.

Friendly Metal	A part of a Base Station or a Mobile Device in which a Power Transmitter's magnetic field can generate eddy currents.
Guaranteed Power	The amount of output power of an appropriate reference Power Receiver that the Power Transmitter ensures is available at any time during the power transfer phase. For Power Transmitters that comply with the Baseline Power Profile, the reference is TPR#1A, which is defined in *Part 3: Compliance Testing*. For Power Transmitters that comply with the Extended Power Profile, the reference is TPR#MP1B, which is also defined in *Part 3: Compliance Testing*. Depending on the context, *Guaranteed Power* can refer to the Guaranteed Power value contained in the Power Transfer Contract, or it can refer to the Guaranteed Power Value field contained in the Power Transmitter Capability Packet.
Guided Positioning	A method of positioning a Mobile Device on the Interface Surface of a Base Station that provides the user with feedback to properly align the Active Area of the Mobile Device to the Active Area of the Base Station.
Interface Surface	The flat part of the surface of a Base Station that is closest to the Primary Coil(s), or the flat part of the surface of the Mobile Device that is closest to the Secondary Coil.
Maximum Power	The maximum amount of power that a Power Receiver expects to provide at its output throughout the power transfer phase. The Maximum Power serves as a scaling factor for the Received Power Values that a Power Receiver reports in its Received Power Packets.
Mobile Device	A device that is able to consume near field inductive power as specified in The Qi Wireless Power Transfer System, Power Class 0 Specification. A Mobile Device carries a logo to visually indicate to a user that the Mobile Device complies with the Specification.
Operating Frequency	The oscillation frequency of the Power Signal.
Operating Point	The combination of the frequency, duty cycle, and amplitude of the voltage that is applied to the Primary Cell.
Packet	A data structure for communicating a message from a Power Receiver to a Power Transmitter or vice versa. A Packet consists of a preamble, a header byte, a message, and a checksum. A Packet is named after the kind of message that it contains.

Potential Power	The amount of output power by an appropriate reference Power Receiver that the Power Transmitter can make available during the power transfer phase. For Power Transmitters that comply with the Baseline Power Profile, the reference is TPR#1A, which is defined in *Part 3: Compliance Testing*. For Power Transmitters that comply with the Extended Power Profile, the reference is TPR#MP1B, which is also defined in *Part 3: Compliance Testing*.
Power Conversion Unit	The functional part of a Power Transmitter that converts electrical energy to a Power Signal.
Power Factor	The ratio of the active power consumed and the apparent power drawn. The active power is expressed in watts. The apparent power typically is expressed in volt-amperes (VA).
Power Pick-up Unit	The functional part of a Power Receiver that converts a Power Signal to electrical energy.
Power Receiver	The subsystem of a Mobile Device that acquires near field inductive power and controls its availability at its output, as defined in The Qi Wireless Power Transfer System, Power Class 0 Specification. For this purpose, the Power Receiver communicates its power requirements to the Power Transmitter.
Power Signal	The oscillating magnetic flux that is enclosed by a Primary Cell and possibly a Secondary Coil.
Power Transfer Contract	A set of boundary conditions on the parameters that characterize the power transfer from a Power Transmitter to a Power Receiver. Violation of any of these boundary conditions causes the power transfer to abort.
Power Transmitter	The subsystem of a Base Station that generates near field inductive power and controls its transfer to a Power Receiver, as defined in The Qi Wireless Power Transfer System, Power Class 0 Specification.
Primary Cell	A single Primary Coil or a combination of Primary Coils that are used to provide a sufficiently high magnetic flux through the Active Area.
Primary Coil	A component of a Power Transmitter that converts electric current to magnetic flux.

Received Power — The total amount of power dissipated inside a Mobile Device, due to the magnetic field generated by a Power Transmitter. The Received Power includes the power that the Power Receiver makes available at its output for use by the Mobile Device, any power that the Power Receiver uses for its own purposes, as well as any power that is lost within the Mobile Device.

Reference Quality Factor — The quality-factor of Test Power Transmitter #MP1's Primary Coil at an Operating Frequency of 100 kHz, with a Power Receiver positioned on the Interface Surface and no Foreign Object nearby.

Response — A sequence of eight consecutive bi-phase modulated bits transmitted by a Power Transmitter in response to a request from a Power Receiver.

Secondary Coil — The component of a Power Receiver that converts magnetic flux to electromotive force.

Shielding — A component in the Power Transmitter that restricts magnetic fields to the appropriate parts of the Base Station, or a component in the Power Receiver that restricts magnetic fields to the appropriate parts of the Mobile Device.

Specification — The set of documents, Parts 1 through 4, that comprise The Qi Wireless Power Transfer System, Power Class 0 Specification (see Section 1.2.1).

Transmitted Power — The total amount of power generated by the Power Transmitter that is dissipated from the magnetic field outside the enclosure of the Base Station. The Power Transmitter typically determines the Transmitted Power by measuring the amount of power it draws from its power source and subtracting an estimate of the losses inside the enclosure of the Base Station.

WPID — A 48-bit number that uniquely identifies a Qi-compliant device.

1.6 Acronyms

AC	Alternating Current
ACK	Acknowledge
AWG	American Wire Gauge
BPP	Baseline Power Profile
BSUT	Base Station Under Test
CCU	Communications and Control Unit
CEP	Control Error Packet
DC	Direct Current
DCR	Direct Current Resistance
EM	Electro Magnetic
EMC	Electro Magnetic Compatibility
EMF	Electro Magnetic Fields
EPP	Extended Power Profile
EPT	End Power Transfer
ESR	Equivalent Series Resistance
FET	Field Effect Transistor
FOD	Foreign Object Detection
FSK	Frequency-Shift Keying
GPV	Guaranteed Power Value
LSB	Least Significant Bit
MSB	Most Significant Bit
MDUT	Mobile Device Under Test
N.A.	Not Applicable
NAK	Not-Acknowledge

ND	Not-Defined
NFC	Near Field Communication
NMD	NFC Mobile Device
PICC	Proximity Integrated Circuit Card
PID	Proportional Integral Differential
PRx	Power Receiver
PPV	Potential Power Value
PTC-GP	Power Transfer Contract – Guaranteed Power
PTx	Power Transmitter
RFID	Radio Frequency Identification
RMS	Root Mean Square
TP	Transmitter Power
TPR	Test Power Receiver
TPT	Test Power Transmitter
UART	Universal Asynchronous Receiver Transmitter
USB	Universal Serial Bus
WPID	Wireless Power Identifier

1.7 Symbols

C_d	Capacitance parallel to the Secondary Coil [nF]
C_m	Capacitance in the impedance matching network [nF]
C_P	Capacitance in series with the Primary Coil [nF]
C_S	Capacitance in series with the Secondary Coil [nF]
d	Duty cycle of the inverter in the Power Transmitter
d_s	Distance between a coil and its Shielding [mm]
d_z	Distance between a coil and the Interface Surface [mm]
f_CLK	Communications bit rate [kHz]
f_d	Resonant detection frequency [kHz]
f_op	Operating Frequency [kHz]
f_S	Secondary resonance frequency [kHz]
I_m	Primary Coil current modulation depth [mA]
I_o	Power Receiver output current [mA]
I_P	Primary Coil current [mA]
L_m	Inductance in the impedance matching network [μH]
L_P	Primary Coil self-inductance (Mobile Device away from Base Station) [μH]
L_S	Secondary Coil self-inductance (Mobile Device away from Base Station) [μH]
L'_S	Secondary Coil self-inductance (Mobile Device on top of Base Station) [μH]
P_FO	Power loss that results in heating of a Foreign Object [W]
P_PR	Total amount of power received through the Interface Surface [W]
P_PT	Total amount of power transmitted through the Interface Surface [W]
Q	Quality factor
t_delay	Power Control Hold-off Time [ms]

t_{CLK}	Communications clock period [μs]
t_{T}	Maximum transition time of the communications [μs]
V_{r}	Rectified voltage [V]
V_{o}	Power Receiver output voltage [V]

1.8 Conventions

This section defines the notations and conventions used in The Qi Wireless Power Transfer System, Power Class 0 Specification.

1.8.1 Cross references

Unless indicated otherwise, cross references to sections include the sub sections contained therein.

1.8.2 Informative text

Informative text is set in italics, unless the complete Section is marked as informative.

1.8.3 Terms in capitals

Terms having a specific meaning in the context of The Qi Wireless Power Transfer System, Power Class 0 Specification are capitalized and defined in Section ⍰.

1.8.4 Units of physical quantities

Physical quantities are expressed in units of the International System of Units.

1.8.5 Decimal separator

The decimal separator is a period.

1.8.6 Notation of numbers

- Real numbers are represented using the digits 0 to 9, a decimal point, and optionally an exponential part. In addition, a positive and/or negative tolerance indicator may follow a real number. Real numbers that do not include an explicit tolerance indicator, are accurate to half the least significant digit that is specified.

  EXAMPLE A specified value of $1.23^{+0.01}_{-0.02}$ comprises the range from 1.21 through 1.24; a specified value of $1.23^{+0.01}$ comprises the range from 1.23 through 1.24; a specified value of $1.23_{-0.02}$ comprises the range from 1.21 through 1.23; a specified value of 1.23 comprises the range from 1.225 through 1.234999…; and a specified value of $1.23^{\pm 10\%}$ comprises the range from 1.107 through 1.353.

- Integer numbers in decimal notation are represented using the digits 0 to 9.
- Integer numbers in hexadecimal notation are represented using the hexadecimal digits 0 to 9 and A to F, and are prefixed by "0x" unless explicitly indicated otherwise.
- Single bit values are represented using the words ZERO and ONE.
- Integer numbers in binary notation and bit patterns are represented using sequences of the digits 0 and 1, which are enclosed in single quotes (e.g. '01001'). In a sequence of *n* bits, the most significant bit (MSB) is bit b_{n-1} and the least significant bit (LSB) is bit b_0. The most significant bit is shown on the left-hand side.
- Numbers that are shown between parentheses are informative.

1.8.7 Bit ordering in a byte

The graphical representation of a byte is such that the most significant bit is on the left, and the least significant bit is on the right. Figure 1 defines the bit positions in a byte.

Figure 1. Bit positions in a byte

MSB							LSB
b7	b6	b5	b4	b3	b2	b1	b0

1.8.8 Byte numbering

The bytes in a sequence of n bytes are referred to as B_0, B_1, …, B_{n-1}. Byte B_0 corresponds to the first byte in the sequence; byte B_{n-1} corresponds to the last byte in the sequence. The graphical representation of a byte sequence is such that B_0 is at the upper left-hand side, and byte B_{n-1} is at the lower right-hand side.

1.8.9 Multiple-bit fields

Multiple-bit fields are used in the ID Packet. Unless indicated otherwise, a multiple-bit field in a data structure represents an unsigned integer value. In a multiple-bit field that spans multiple bytes, the MSB of the multiple-bit field is located in the byte with the lowest address, and the LSB of the multiple-bit field is located in the byte with the highest address.

NOTE Figure 2 provides an example of a 6-bit field that spans two bytes.

Figure 2. Example of multiple-bit field

						b_9	**b_8**		**b_7**	**b_6**	**b_5**	**b_4**	**b_3**	**b_2**	**b_1**	**b_0**

B_0 B_1

1.9 Operators

This section defines less-commonly used operators that are used in The Qi Wireless Power Transfer System, Power Class 0 Specification. The commonly used operators have their usual meaning.

1.9.1 Exclusive-OR

The symbol '⊕' represents the exclusive-OR operation.

1.9.2 Concatenation

The symbol '||' represents the concatenation of two bit strings. In the resulting concatenated bit string, the MSB of the right-hand side operand directly follows the LSB of the left-hand side operand.

1.10 Measurement equipment

All measurements shall be performed using equipment that has a resolution of at least one quarter of the precision of the quantity that is to be measured, unless indicated otherwise.

EXAMPLE "t_{start}=15 ms" means that the equipment shall be precise to 0.25 ms.

2 Power Transmitter reference designs

2.1 Introduction

The Power Transmitter designs that are defined in this *Part 4: Reference Designs*, are grouped in two basic types.

Type 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 Power Transmitter designs include means to realize proper alignment of the Primary Coil and Secondary Coil. Depending on this means, a type A Power Transmitter enables either Guided Positioning or Free Positioning.

Type B Power Transmitter designs have an array of Primary Coils. All type B Power Transmitters enable Free Positioning. For that purpose, type B 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 Base Station may contain several Power Transmitters in order to serve multiple Mobile Devices simultaneously. Note that multiple type B Power Transmitters may share (parts of) the multiplexer and array of Primary Coils (see Section 3.3.1.3).

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 part 4 of the Qi Power Class 0 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 *Part 4: Reference Designs.*

2.2 Baseline Power Profile designs that activate a single Primary Coil at a time

This Section 2.2 defines all type A Power Transmitter designs in the Baseline 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 *Power Transmitter to Power Receiver communications interface* section in *Parts 1 and 2: Interface Definitions*.

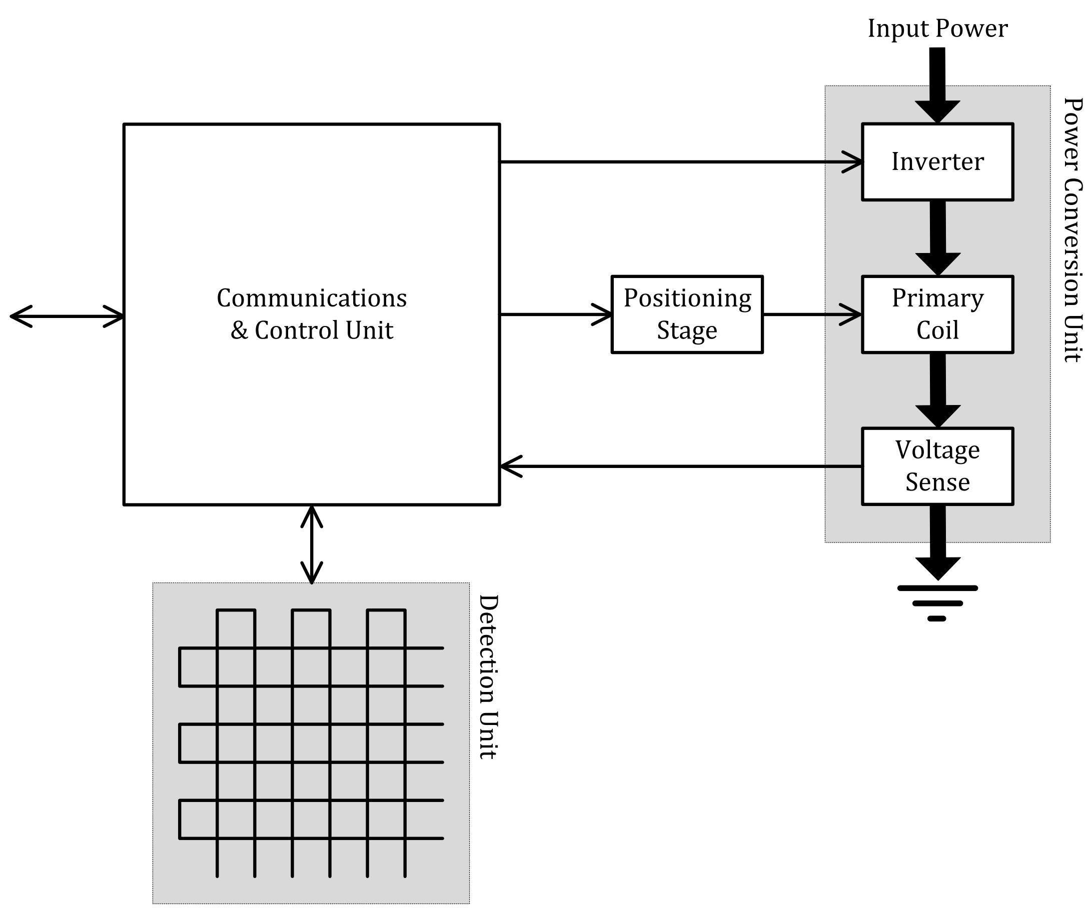
2.2.1 Power Transmitter design A1

Power Transmitter design A1 has been deprecated. For further information, see the note in Section 2.1.

2.2.2 Power Transmitter design A2

Power Transmitter design A2 enables Free Positioning. Figure 3 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 3. Functional block diagram of Power Transmitter design A2



The Power Conversion Unit on the right-hand side of Figure 3 and the Detection Unit of the bottom of Figure 3 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 Mobile Device. Finally, the voltage sense monitors the Primary Coil voltage.

The Communications and Control Unit on the left-hand side of Figure 3 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 Base Station, 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 *Part 4: 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 *Parts 1 and 2: Interface Definitions*). 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 *Moving Primary Coil based Free Positioning* section in *Parts 1 and 2: Interface Definitions* provides an example resonant detection method.

2.2.2.1 Mechanical details

Power Transmitter design A2 includes a single Primary Coil as defined in Section 2.2.2.1.1, Shielding as defined in Section 2.2.2.1.2, an Interface Surface as defined in Section 2.2.2.1.3, and a positioning stage as defined in Section 2.2.2.1.4

2.2.2.1.1 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 4, the Primary Coil has a circular shape and consists of multiple layers. All layers are stacked with the same polarity. Table 1 lists the dimensions of the Primary Coil.

Figure 4. Primary Coil of Power Transmitter design A2

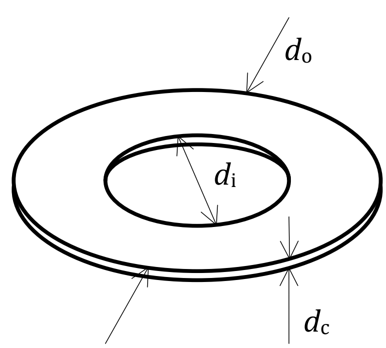


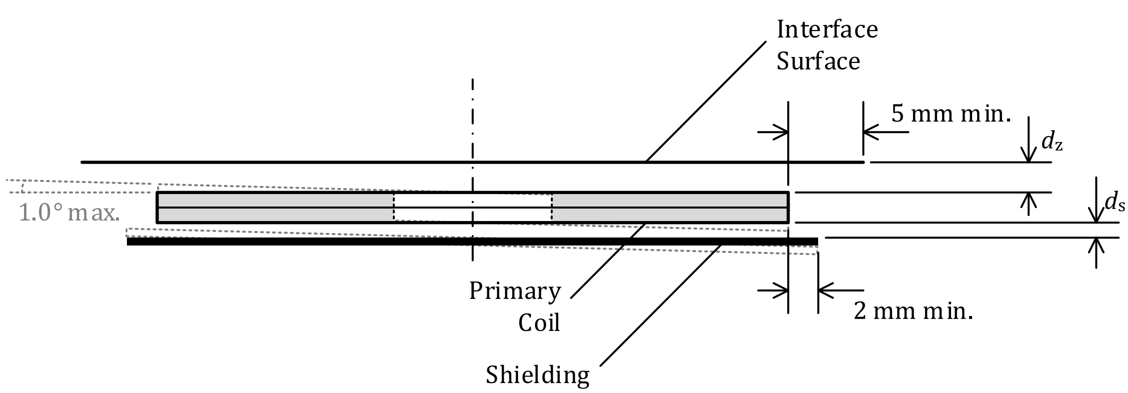
Table 1. Primary Coil parameters of Power Transmitter design A2

Parameter	Symbol	Value
Outer diameter	d_o	$40^{\pm 1}$ mm
Inner diameter	d_i	$19^{\pm 1}$ mm
Thickness	d_c	$2^{+0.2}$ mm
Number of turns per layer	N	10
Number of layers	–	2

2.2.2.1.2 Shielding

As shown in Figure 5, Shielding protects the Base Station 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 5. Primary Coil assembly of Power Transmitter design A2



2.2.2.1.3 Interface Surface

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

2.2.2.1.4 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.

2.2.2.2 Electrical details

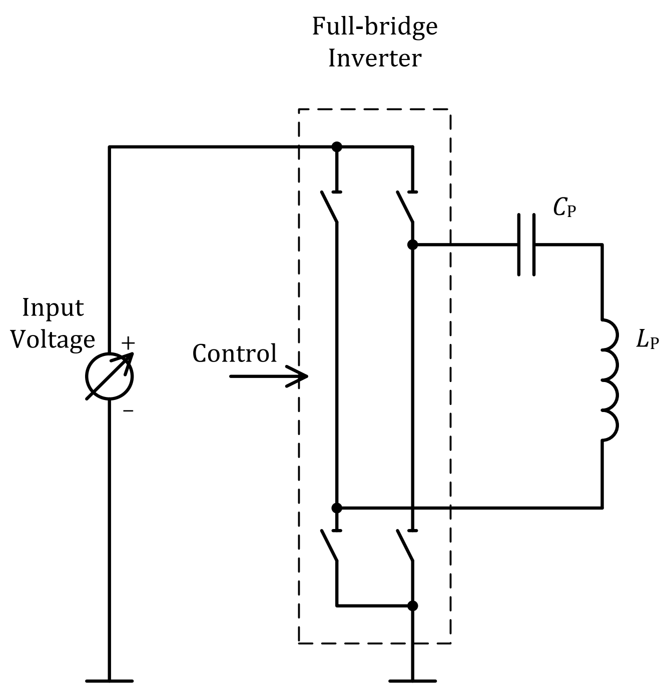
As shown in Figure 6, Power Transmitter design A2 uses a full-bridge inverter to drive the Primary Coil and a series capacitance. At the fixed Operating Frequency of 140 kHz, the assembly of Primary Coil and Shielding has a self-inductance $L_{\mathrm{P}} = 24^{\pm 1}$ μH. The value of the series capacitance 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 *Parts 1 and 2: Interface Definitions*), it shall use an initial input voltage of 8 V.

Figure 6. Electrical diagram (outline) of Power Transmitter design A2



Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Power transfer control* section in *Parts 1 and 2: Interface Definitions*. 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 2 provides the values of several parameters that are used in the PID algorithm.

Table 2. PID parameters for voltage control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	1	$\mathrm{mA^{-1}}$
Integral gain	K_i	0	$\mathrm{mA^{-1}ms^{-1}}$
Derivative gain	K_d	0	$\mathrm{mA^{-1}ms}$
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

2.2.3 Power Transmitter design A3

Power Transmitter design A3 enables Free Positioning, and has a design similar to Power Transmitter design A2. See Section 0 for an overview.

2.2.3.1 Mechanical details

Power Transmitter design A3 includes a single Primary Coil as defined in Section 2.2.3.1.1, Shielding as defined in Section 2.2.3.1.2, an Interface Surface as defined in Section 2.2.3.1.3, and a positioning stage as defined in Section 2.2.3.1.4.

2.2.3.1.1 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 7, the Primary Coil has a circular shape and consists of a single layer. Table 3 lists the dimensions of the Primary Coil.

Figure 7. Primary Coil of Power Transmitter design A3

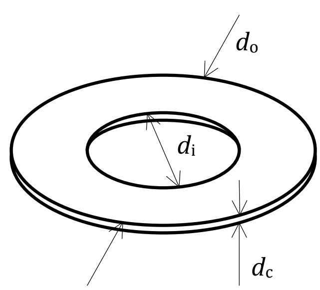


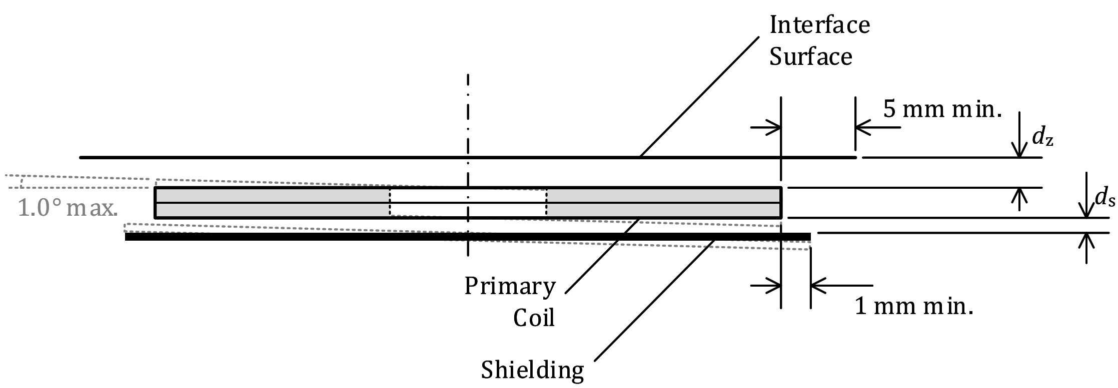
Table 3. Primary Coil parameters of Power Transmitter design A3

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

2.2.3.1.2 Shielding

As shown in Figure 8, Shielding protects the Base Station 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 8. Primary Coil assembly of Power Transmitter design A3



2.2.3.1.3 Interface Surface

As shown in Figure 8, the distance from the Primary Coil to the Interface Surface of the Base Station is $d_z = 2.5^{+0.5}_{-0}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Base Station extends at least 5 mm beyond the outer diameter of the Primary Coil.

2.2.3.1.4 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.

2.2.3.2 Electrical details

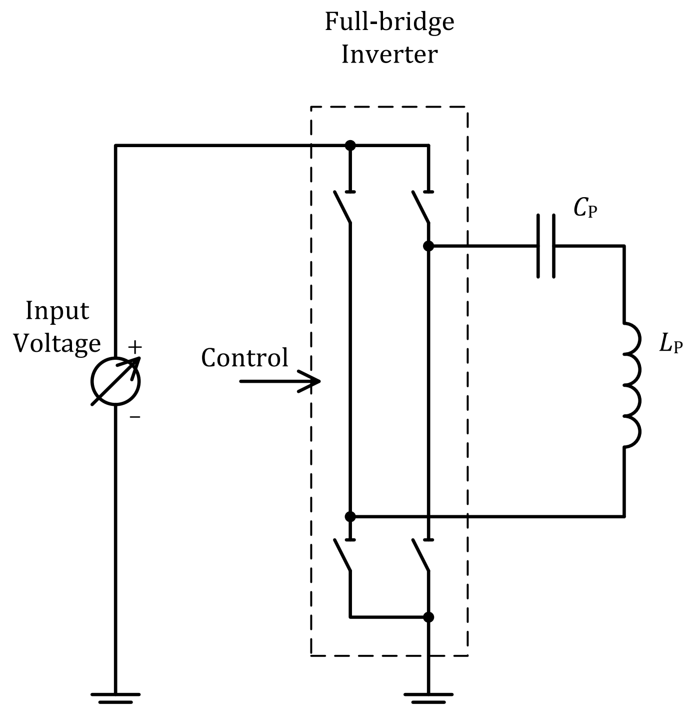
As shown in Figure 9, Power Transmitter design A3 uses a full-bridge inverter to drive the Primary Coil and a series capacitance. At an Operating Frequency range between 105 kHz and 140 kHz, the assembly of Primary Coil and Shielding has a self-inductance $L_{\mathrm{P}} = 16.5^{\pm 10\%}$ μH. The value 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 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 *Parts 1 and 2: Interface Definitions*), 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 Section *Parts 1 and 2: Interface Definitions*. 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 9. Electrical diagram (outline) of Power Transmitter design A3



Control of the power transfer shall proceed using the PID algorithm, which is defined in *Parts 1 and 2: Interface Definitions*. 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 4 provides the values of several parameters, which are used in the PID algorithm.

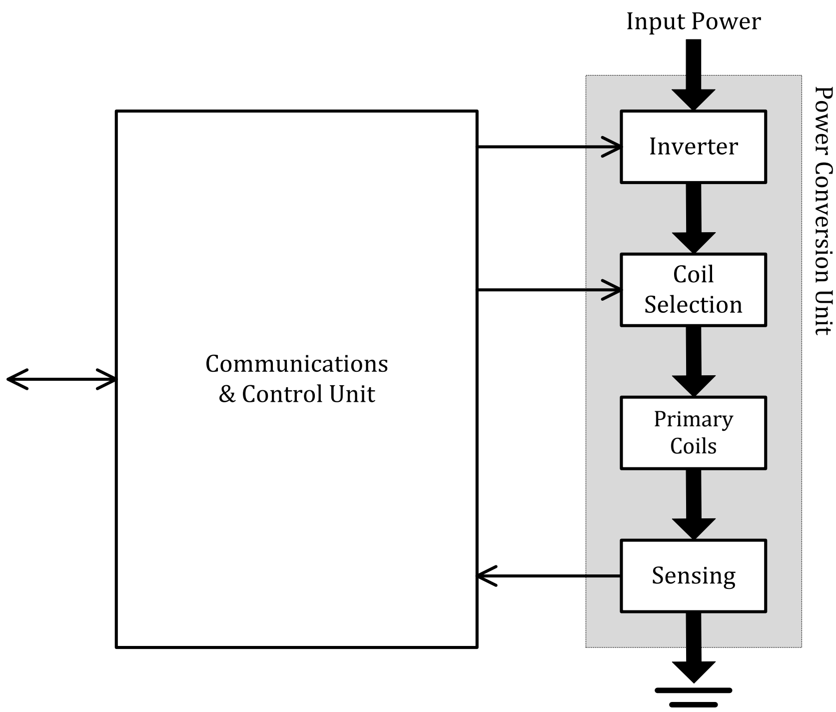
Table 4. PID parameters for voltage control

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

2.2.4 Power Transmitter design A4

Power Transmitter design A4 enables Free Positioning. Figure 10 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 10. Functional block diagram of Power Transmitter design A4



The Power Conversion Unit on the right-hand side of Figure 10 and the Detection Unit of the bottom of Figure 10 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 10 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 Base Station, e.g. for user interface purposes.

2.2.4.1 Mechanical details

Power Transmitter design A4 includes two Primary Coils as defined in Section 2.2.4.1.1, Shielding as defined in Section 2.2.4.1.2, and an Interface Surface as defined in Section 2.2.4.1.3.

2.2.4.1.1 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 11, a Primary Coil has a racetrack-like shape and consists of a single layer. Table 5 lists the dimensions of a Primary Coil.

Figure 11. Primary Coil of Power Transmitter design A4

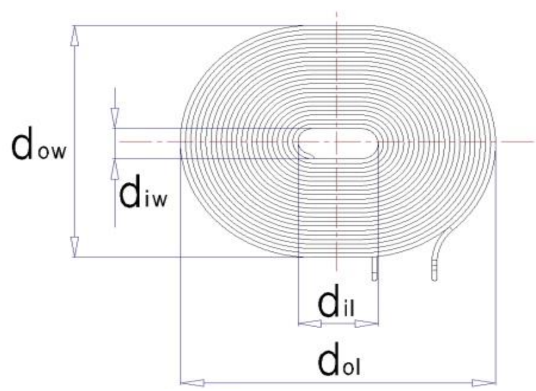
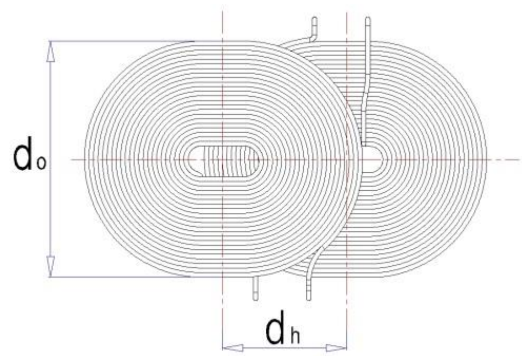


Table 5. Primary Coil parameters of Power Transmitter design A4

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}	$1.15^{\pm 0.05}$ 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 2.2.4.1.2) with their long axes coincident, and a displacement of $d_{\mathrm{h}} = 41^{\pm 0.5}$ mm between their centers. See Figure 12.

Figure 12. Dual Primary Coils (top view)

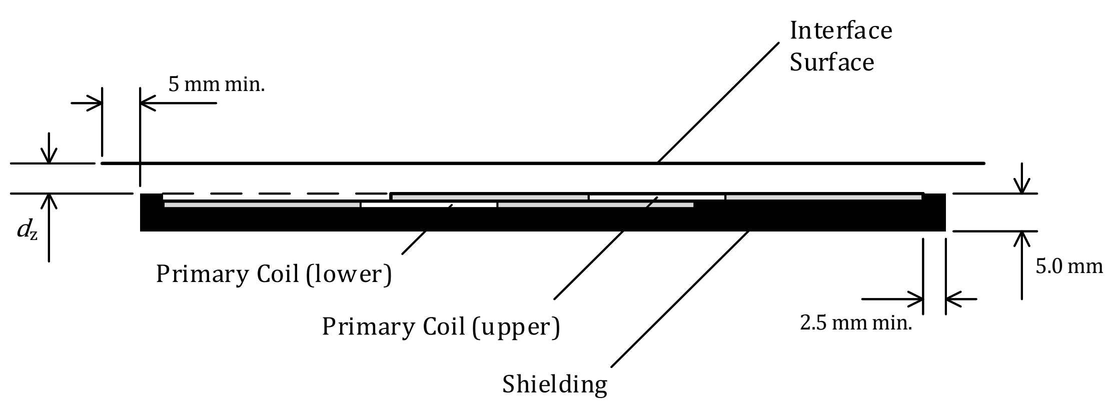


2.2.4.1.2 Shielding

As shown in Figure 13, Shielding protects the Base Station 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 13. Primary Coil assembly of Power Transmitter design A4



2.2.4.1.3 Interface Surface

As shown in Figure 13, the distance from the top face of the top Primary Coil to the Interface Surface of the Base Station 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 Base Station is $d_z = 3.15^{\pm 0.5}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Base Station extends at least 5 mm beyond the outer diameter of the Primary Coil.

2.2.4.1.4 Separation between multiple Power transmitters

In a Base Station 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 2.2.4.1.1.

2.2.4.2 Electrical details

As shown in Figure 14, 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.

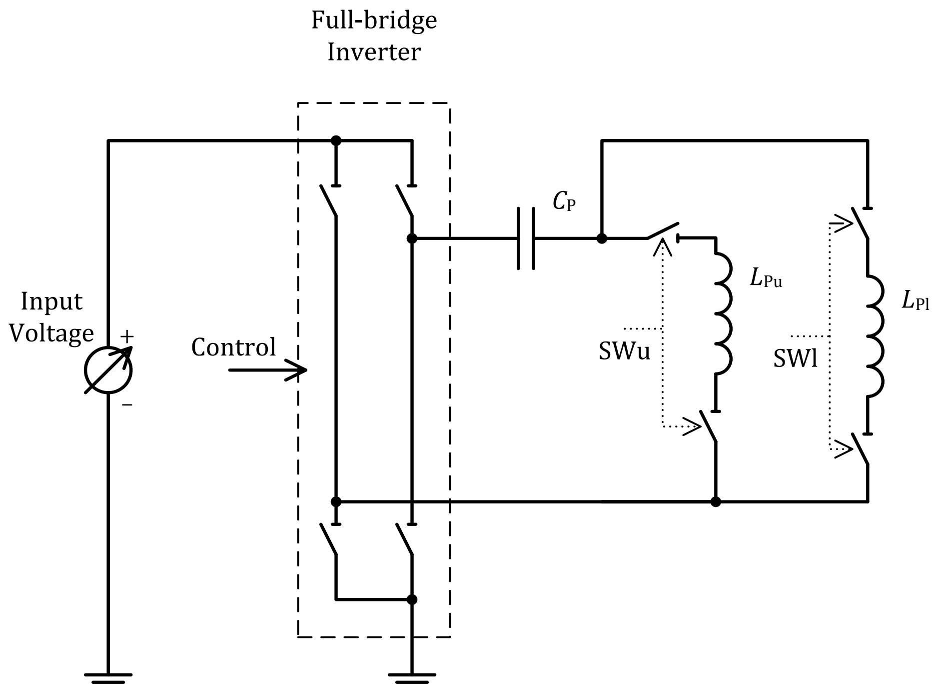
Within the Operating Frequency range of 110…180 kHz, each Primary Coil in the assembly of Primary Coils and Shielding has a self-inductance $L_{\mathrm{P}} = 24^{\pm 0.5}$ μH. The value of the series capacitance is $C_{\mathrm{P}} = 100^{\pm 5\%}$ nF. The input voltage to the full-bridge inverter is 5…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 *Part 4: Reference Designs*), 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 *Part 4: Reference Designs*. 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 14. Electrical diagram (outline) of Power Transmitter design A4



Control of the power transfer shall proceed using the PID algorithm, which is defined in *Parts 1 and 2: Interface Definitions*. 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 6 and Table 7 provide the values of several parameters, which are used in the PID algorithm.

Table 6. PID parameters for Operating Frequency 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}	20,000	N.A.
Scaling factor	S_{v}	1.0	Hz

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

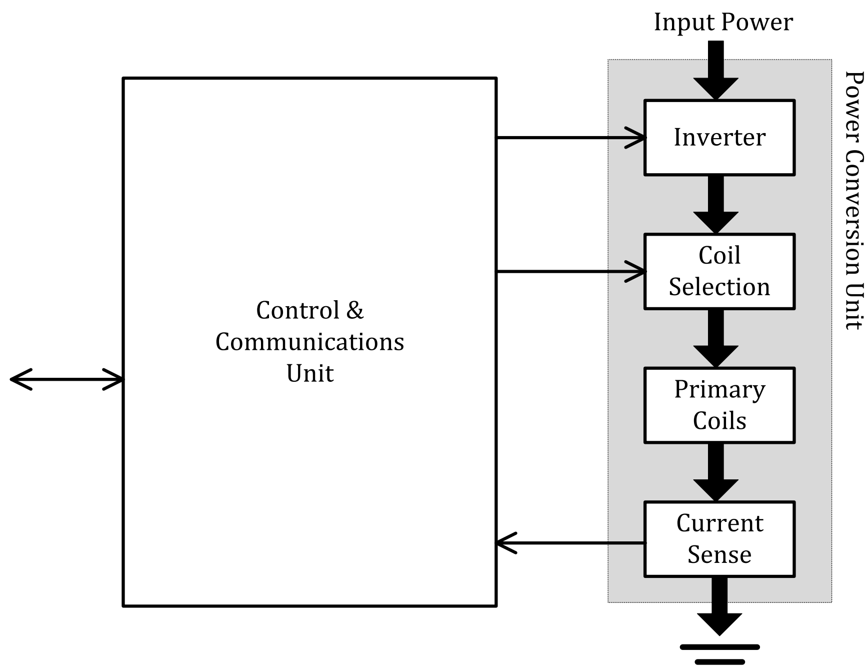
2.2.5 Power Transmitter design A5

Power Transmitter design A5 has been deprecated. For further information, see the note in Section 2.1.

2.2.6 Power Transmitter design A6

Figure 15 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 15. Functional block diagram of Power Transmitter design A6



The Power Conversion Unit on the right-hand side of Figure 15 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 15 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 Base Station, e.g. for user interface purposes.

2.2.6.1 Mechanical details

Power Transmitter design A6 includes one or more Primary Coils as defined in Section 2.2.6.1.1, Shielding as defined in Section 2.2.6.1.2, an Interface Surface as defined in Section 2.2.6.1.3.

2.2.6.1.1 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 16, the Primary Coil has a rectangular shape and consists of a single layer. Table 8 lists the dimensions of the Primary Coil.

Figure 16. Primary Coil of Power Transmitter design A6

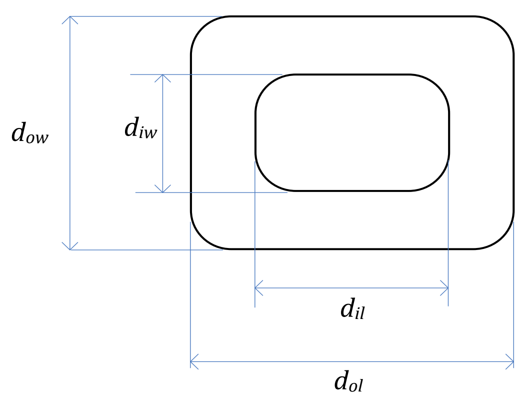
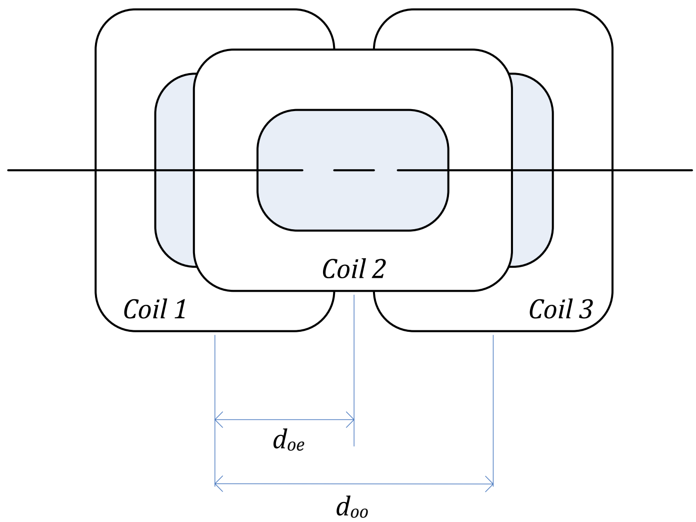


Table 8. Primary Coil parameters of Power Transmitter design A6

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 $d_{\mathrm{oo}} = 49.2^{\pm 4}$ mm between their centers. Even numbered coils are placed orthogonal to the odd numbered coils with a displacement of $d_{\mathrm{oe}} = 24.6^{\pm 2}$ mm between their centers. See Figure 17.

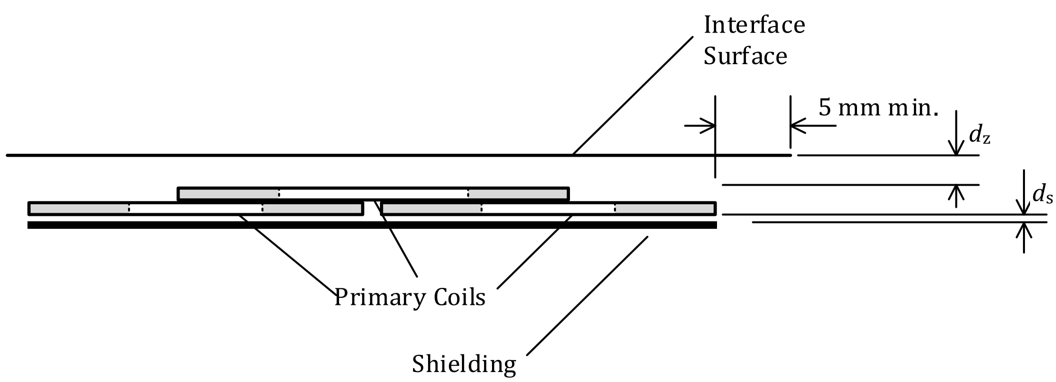
Figure 17. Primary Coils of Power Transmitter design A6



2.2.6.1.2 Shielding

As shown in Figure 18, Shielding protects the Base Station 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 18. Primary Coil assembly of Power Transmitter design A6



2.2.6.1.3 Interface Surface

As shown in Figure 18, the distance from the top face of the even-numbered Primary Coil to the Interface Surface of the Base Station 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 Base Station 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 Base Station extends at least 5 mm beyond the outer dimensions of the Primary Coils.

2.2.6.1.4 Inter coil separation

If the Base Station contains multiple type A6 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall have a center-to-center distance of at least $49.2^{\pm 4}$ mm.

2.2.6.2 Electrical details

As shown in Figure 19, 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 $f_{\mathrm{op}} = 115 \ldots 205$ 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 *Parts 1 and 2: Interface Definitions*), 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 *Parts 1 and 2: Interface Definitions*. 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 9, Table 10, and Table 11 provide the values of several parameters, which are used in the PID algorithm.

Figure 19. Electrical diagram (outline) of Power Transmitter design A6

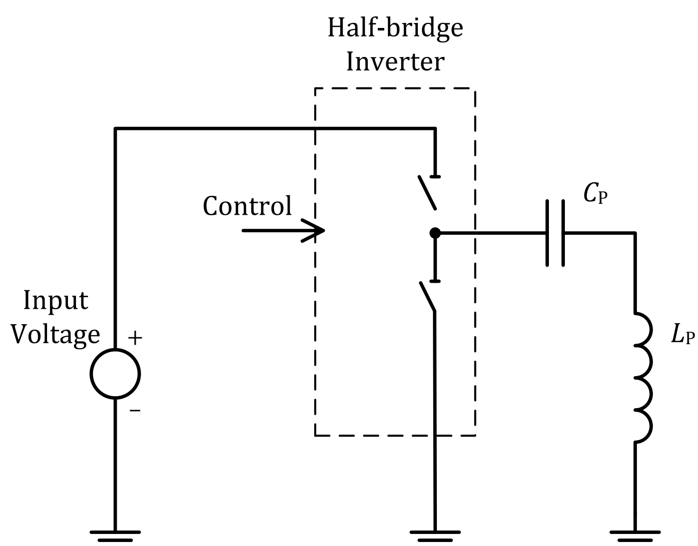


Table 9. PID parameters for Operating Frequency control

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 10. 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 11. 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	%

2.2.7 Power Transmitter design A7

Power Transmitter design A7 enables Free Positioning, and has a design similar to Power Transmitter design A2. See Section 0 for an overview.

2.2.7.1 Mechanical details

Power Transmitter design A7 includes a single Primary Coil as defined in Section 2.2.7.1.1, Shielding as defined in Section 2.2.7.1.2, an Interface Surface as defined in Section 2.2.7.1.3, and a positioning stage as defined in Section 2.2.7.1.4.

2.2.7.1.1 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 20, the Primary Coil has a circular shape and consists of a single layer. Table 12 lists the dimensions of the Primary Coil.

Figure 20. Primary Coil of Power Transmitter design A7

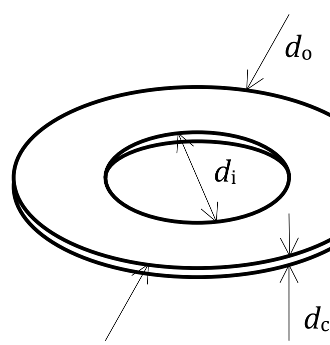


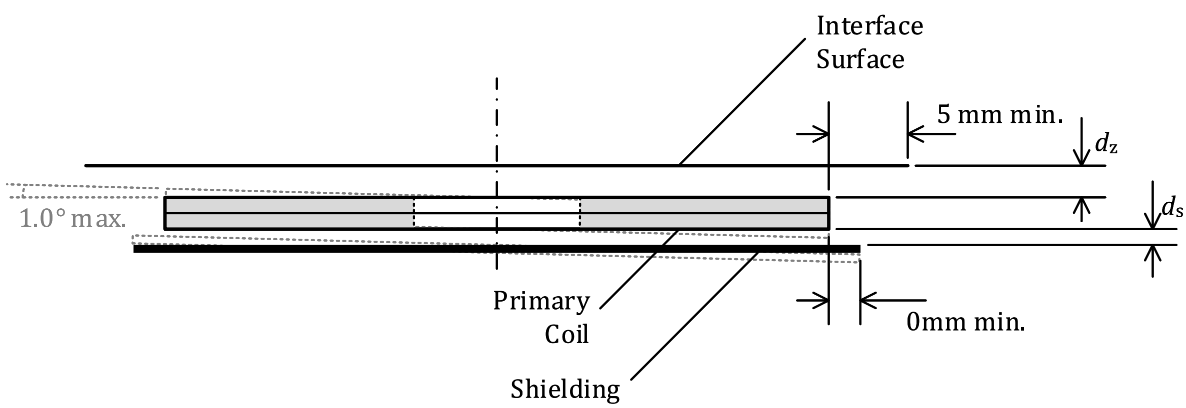
Table 12. Primary Coil parameters of Power Transmitter design A7

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

2.2.7.1.2 Shielding

As shown in Figure 21, Shielding protects the Base Station 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 21. Primary Coil assembly of Power Transmitter design A7



2.2.7.1.3 Interface Surface

As shown in Figure 21, the distance from the Primary Coil to the Interface Surface of the Base Station is $d_z = 3.0^{\pm 0.5}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Base Station extends at least 5mm beyond the outer diameter of the Primary Coil.

2.2.7.1.4 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.

2.2.7.2 Electrical details

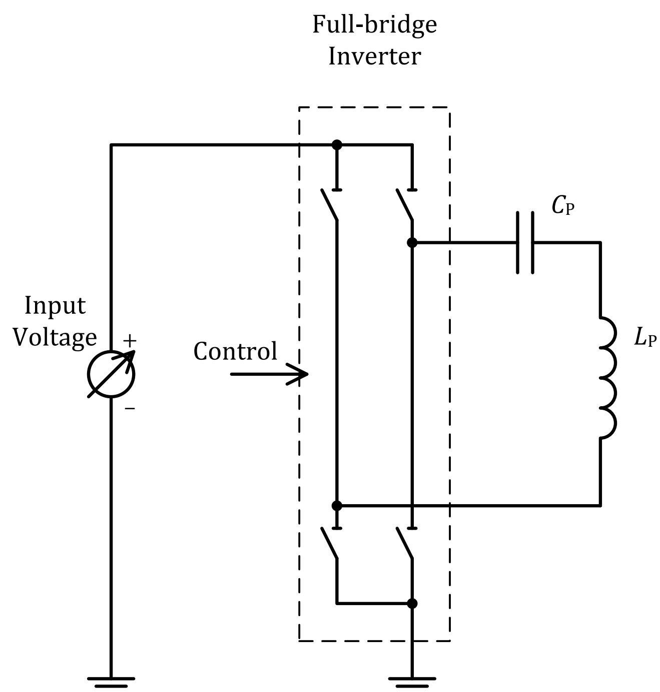
As shown in Figure 22, Power Transmitter design A7 uses a full-bridge inverter to drive the Primary Coil and a series capacitance. At an Operating Frequency range between 105 kHz and 140 kHz, the assembly of Primary Coil and Shielding has a self-inductance $L_P = 13.6^{\pm 10\%}$ μH. The value of the 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 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; see *Parts 1 and 2: Interface Definitions*), 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 *Parts 1 and 2: Interface Definitions*. 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 22. Electrical diagram (outline) of Power Transmitter design A7



Control of the power transfer shall proceed using the PID algorithm, which is defined in *Parts 1 and 2: Interface Definitions*. 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 13 provides the values of several parameters, which are used in the PID algorithm.

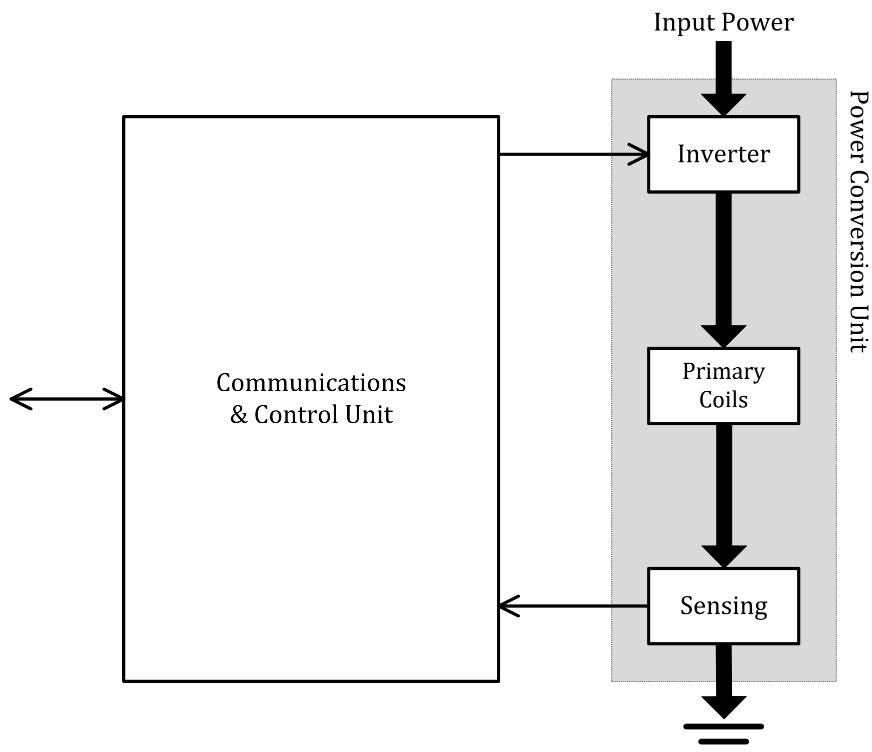
Table 13. PID parameters for voltage control

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

2.2.8 Power Transmitter design A8

Power Transmitter design A8 enables Free Positioning. Figure 23 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 23. Functional block diagram of Power Transmitter design A8



The Power Conversion Unit on the right-hand side of Figure 23 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 23 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 Base Station, e.g. for user interface purposes.

2.2.8.1 Mechanical details

Power Transmitter design A8 includes one Primary Coil as defined in Section 2.2.8.1.1, Shielding as defined in Section 2.2.8.1.2, and an Interface Surface as defined in Section 2.2.8.1.3.

2.2.8.1.1 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 24, a Primary Coil has a racetrack-like shape and consists of a single layer. Table 14 lists the dimensions of a Primary Coil.

Figure 24. Primary Coil of Power Transmitter design A8

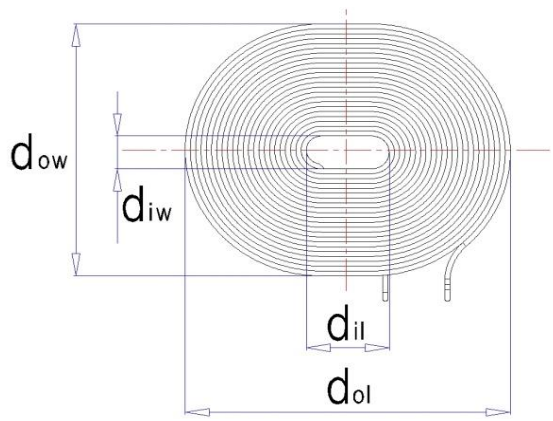


Table 14. Primary Coil parameters of Power Transmitter design A8

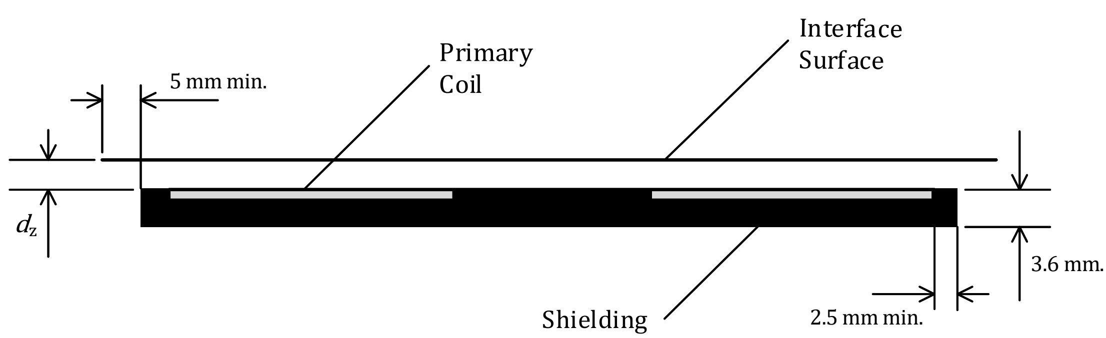
Parameter	Symbol	Value
Outer length	d_{ol}	$70^{\pm 0.5}$ mm
Inner length	d_{il}	$15^{\pm 0.5}$ mm
Outer width	d_{ow}	$59^{\pm 0.5}$ mm
Inner width	d_{iw}	$4^{\pm 0.5}$ mm
Thickness	d_{c}	$1.2^{\pm 0.15}$ mm
Number of turns per layer	N	23.5
Number of layers	–	1

2.2.8.1.2 Shielding

As shown in Figure 25, Shielding protects the Base Station 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 25. Primary Coil assembly of Power Transmitter design A8



2.2.8.1.3 Interface Surface

As shown in Figure 25, the distance from the Primary Coil to the Interface Surface of the Base Station is $d_z = 2.0^{\pm 0.5}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Base Station extends at least 5 mm beyond the outer diameter of the Primary Coil.

2.2.8.1.4 Separation between multiple Power transmitters

If the Base Station contains multiple type A8 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall have a center-to-center distance of at least 70 mm.

2.2.8.2 Electrical details

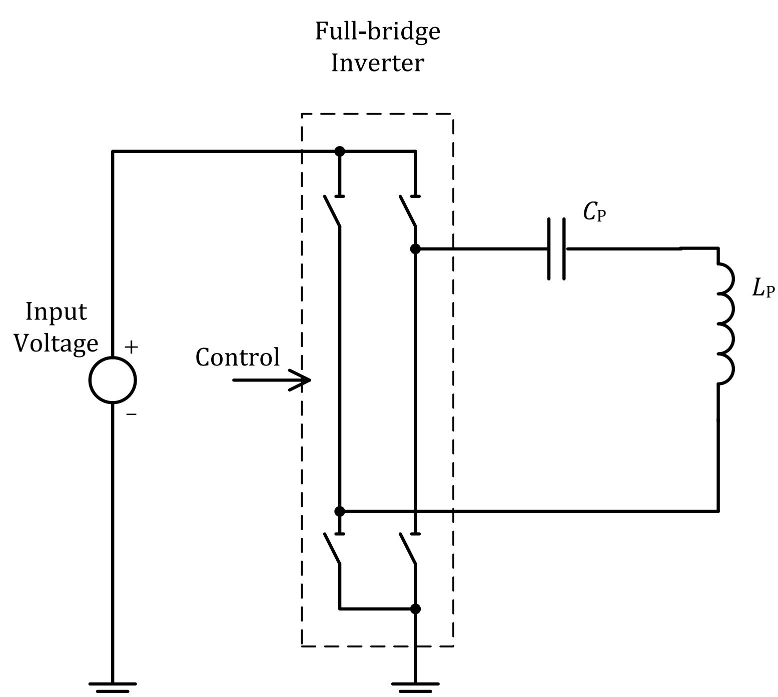
As shown in Figure 26, Power Transmitter design A8 uses a full-bridge inverter to drive the Primary Coil and a series capacitance. Within the Operating Frequency range of 110…180 kHz, the assembly of Primary Coil and Shielding has a self-inductance $L_{\mathrm{P}} = 24^{\pm 0.5}$ μH. The value of the 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 *Parts 1 and 2: Interface Definitions*), 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 *Parts 1 and 2: Interface Definitions*. 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 26. Electrical diagram (outline) of Power Transmitter design A8



Control of the power transfer shall proceed using the PID algorithm, which is defined in *Parts 1 and 2: Interface Definitions*. 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 15 and Table 16 provide the values of several parameters, which are used in the PID algorithm.

Table 15. PID parameters for Operating Frequency 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}	20,000	N.A.
Scaling factor	S_{v}	1.0	Hz

Table 16. 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

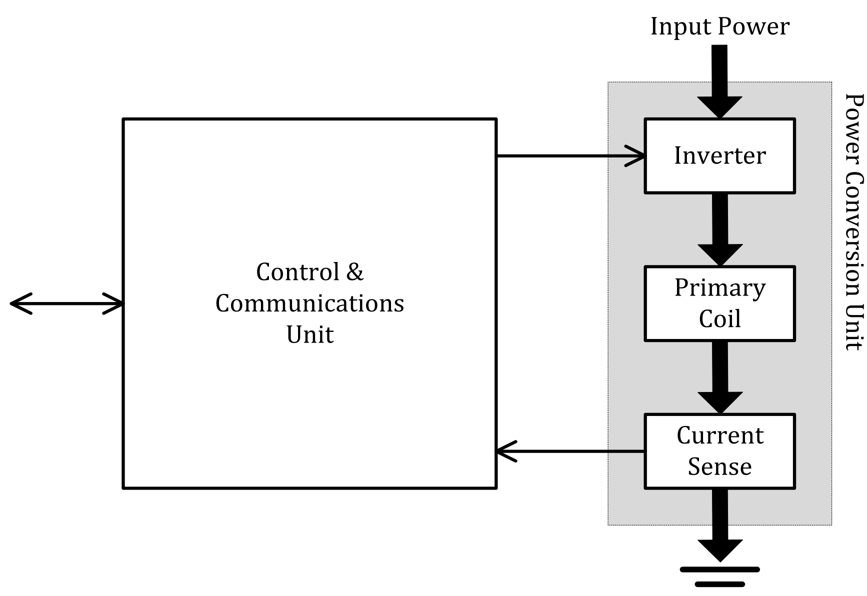
2.2.9 Power Transmitter design A9

Power Transmitter design A9 has been deprecated. For further information, see the note in Section 2.1.

2.2.10 Power Transmitter design A10

Power Transmitter design A10 enables Guided Positioning. Figure 27 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 27. Functional block diagram of Power Transmitter design A10



The Power Conversion Unit on the right-hand side of Figure 27 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 27 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 Base Station, e.g. for user interface purposes.

2.2.10.1 Mechanical details

Power Transmitter design A10 includes a single Primary Coil as defined in Section 2.2.10.1.1, Shielding as defined in Section 2.2.10.1.2, an Interface Surface as defined in Section 2.2.10.1.3, and an alignment aid as defined in Section 2.2.10.1.4.

2.2.10.1.1 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 28, the Primary Coil has a circular shape and consists of multiple layers. All layers are stacked with the same polarity. Table 17 lists the dimensions of the Primary Coil.

Figure 28. Primary Coil of Power Transmitter design A10

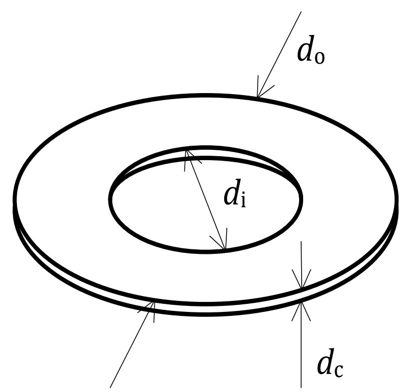


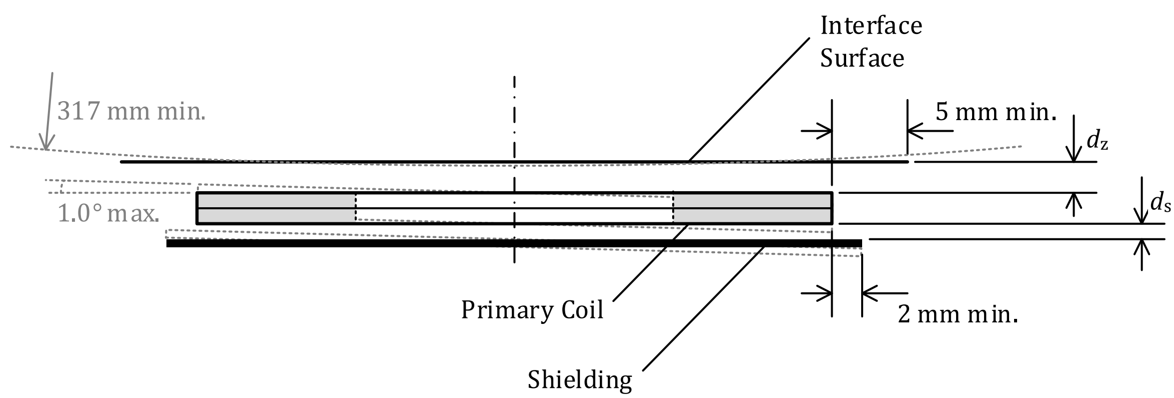
Table 17. Primary Coil parameters of Power Transmitter design A10

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

2.2.10.1.2 Shielding

As shown in Figure 29, Shielding protects the Base Station 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 29. Primary Coil assembly of Power Transmitter design A10



2.2.10.1.3 Interface Surface

As shown in Figure 29 the distance from the Primary Coil to the Interface Surface of the Base Station is $d_z = 2^{+0.5}_{-0.25}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Base Station 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 29.

2.2.10.1.4 Alignment aid

The user manual of the Base Station 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 Mobile Device positioning to help alignment.

NOTE Examples of Base Station alignment aids to assist the user positioning of the Mobile Device 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.

2.2.10.1.5 Inter coil separation

If the Base Station contains multiple type A10 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall have a center-to-center distance of at least 50 mm.

2.2.10.2 Electrical details

As shown in Figure 30, 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 $L_{\mathrm{P}} = 24^{\pm 10\%}$ μH. The value of the series capacitance is $C_{\mathrm{P}} = 100^{\pm 5\%}$ nF. The input voltage to the half-bridge inverter is $19^{\pm 1}$ 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 $f_{\mathrm{op}} = 110 \ldots 205$ 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

- $0.01 \times f_{\mathrm{op}} - 0.7$ 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 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 *Parts 1 and 2: Interface Definitions*), 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 *Parts 1 and 2: Interface Definitions*. 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 18, Table 19, and Table 20 provide the values of several parameters, which are used in the PID algorithm.

Figure 30. Electrical diagram (outline) of Power Transmitter design A10

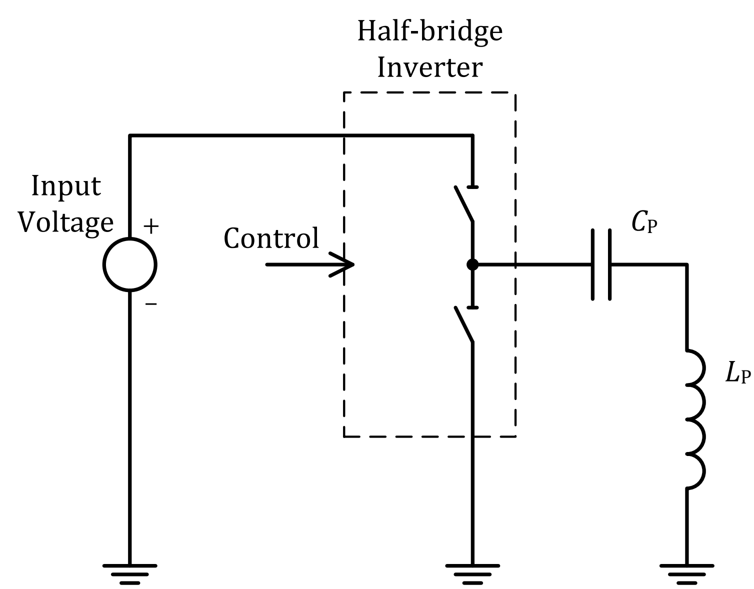


Table 18. PID parameters for Operating Frequency control

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 19. 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 20. PID parameters for duty cycle control

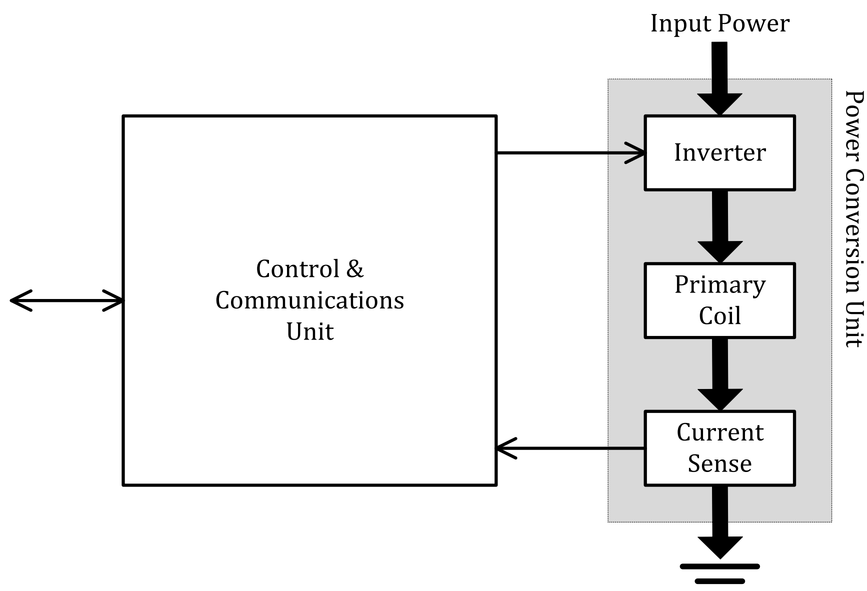
Parameter	Symbol	Value	Unit
Proportional gain	K_p	10	mA^{-1}
Integral gain	K_i	0.05	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	3,000	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_v	−0.01	%

2.2.11 Power Transmitter designs A11 and A11a

2.2.11.1 Power Transmitter design A11

Power Transmitter design A11 enables Guided Positioning. Figure 31 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 31. Functional block diagram of Power Transmitter design A11



The Power Conversion Unit on the right-hand side of Figure 31 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 31 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 Base Station, e.g. for user interface purposes.

2.2.11.1.1 Mechanical details

Power Transmitter design A11 includes a single Primary Coil as defined in Section 2.2.11.1.1.1, Shielding as defined in Section 2.2.11.1.1.2, an Interface Surface as defined in Section 2.2.11.1.1.3, and an alignment aid as defined in Section 2.2.11.1.1.4.

2.2.11.1.1.1 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 32, the Primary Coil has a circular shape and consists of one or two layers. Table 21 lists the dimensions of the Primary Coil.

Figure 32. Primary Coil of Power Transmitter design A11

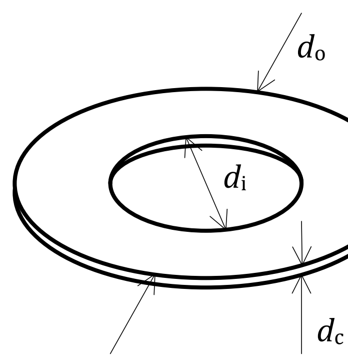


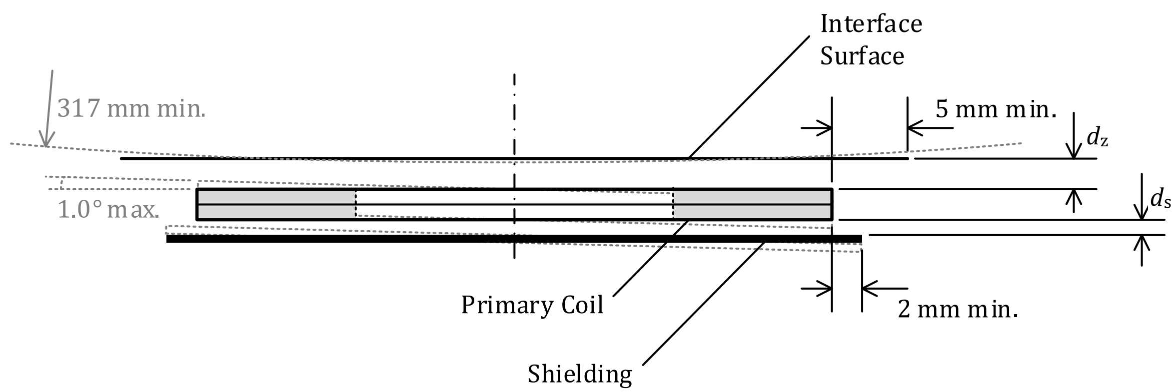
Table 21. Primary Coil parameters of Power Transmitter design A11

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

2.2.11.1.1.2 Shielding

As shown in Figure 33, Shielding protects the Base Station 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 33. Primary Coil assembly of Power Transmitter design A11



2.2.11.1.1.3 Interface Surface

As shown in Figure 33 the distance from the Primary Coil to the Interface Surface of the Base Station is $d_z = 2^{+0.5}_{-0.25}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Base Station 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 33.

2.2.11.1.1.4 Alignment aid

The user manual of the Base Station 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 Mobile Device positioning to help alignment.

NOTE Examples of Base Station alignment aids to assist the user positioning of the Mobile Device 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.

2.2.11.1.1.5 Inter coil separation

If the Base Station contains multiple type A11 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall have a center-to-center distance of at least 50 mm.

2.2.11.1.2 Electrical details

As shown in Figure 34, 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 $L_{\mathrm{P}} = 6.3^{\pm 10\%}$ 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 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 $f_{\mathrm{op}} = 110 \ldots 205$ 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

- $0.01 \times f_{\mathrm{op}} - 0.7$ 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 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 *Parts 1 and 2: Interface Definitions*), 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 *Parts 1 and 2: Interface Definitions*. 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 22, Table 23, and Table 24 provide the values of several parameters, which are used in the PID algorithm.

Figure 34. Electrical diagram (outline) of Power Transmitter design A11

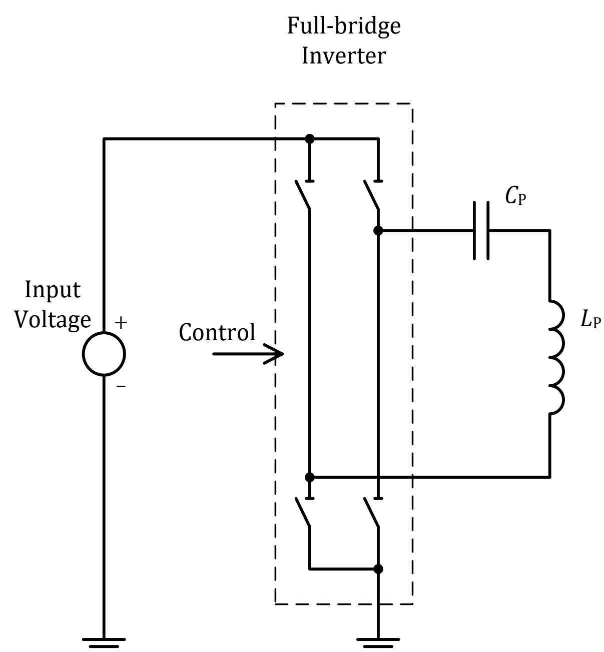


Table 22. PID parameters for Operating Frequency control

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 23. 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

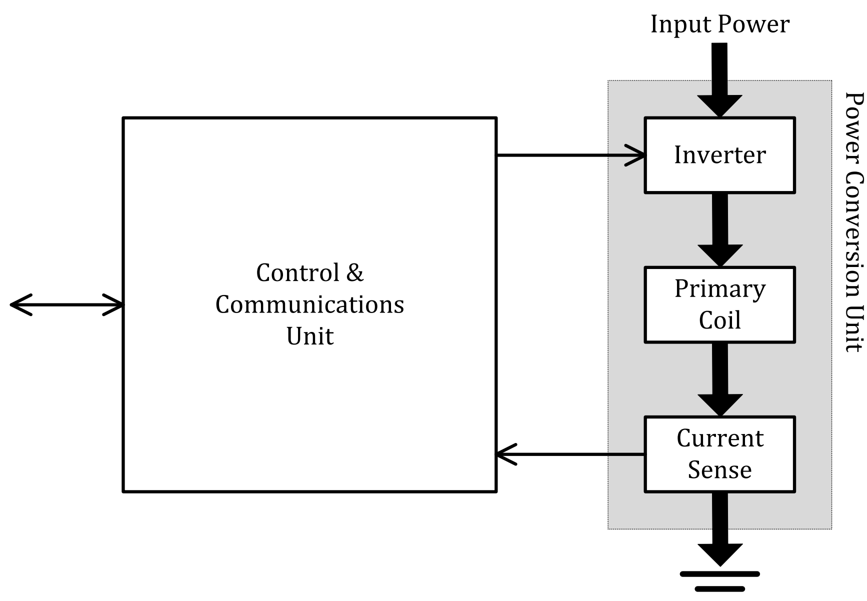
Table 24. PID parameters for duty cycle control

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	%

2.2.11.2 Power Transmitter design A11a

Power Transmitter design A11a enables Guided Positioning. Figure 35 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 35. Functional block diagram of Power Transmitter design A11a



The Power Conversion Unit on the right-hand side of Figure 35 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 35 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 Base Station, e.g. for user interface purposes.

2.2.11.2.1 Mechanical details

Power Transmitter design A11a includes a single Primary Coil as defined in Section 2.2.11.1.1.1, Shielding as defined in Section 2.2.11.1.1.2, an Interface Surface as defined in Section 2.2.11.1.1.3, and an alignment aid as defined in Section 2.2.11.1.1.4.

2.2.11.2.1.1 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 36, the Primary Coil has a circular shape and consists of one or two layers. Table 25 lists the dimensions of the Primary Coil.

Figure 36. Primary Coil of Power Transmitter design A11a

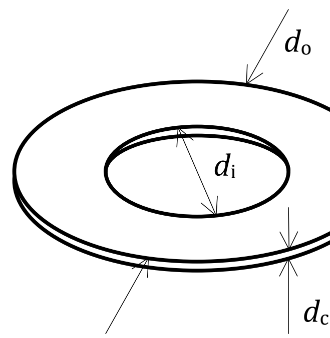


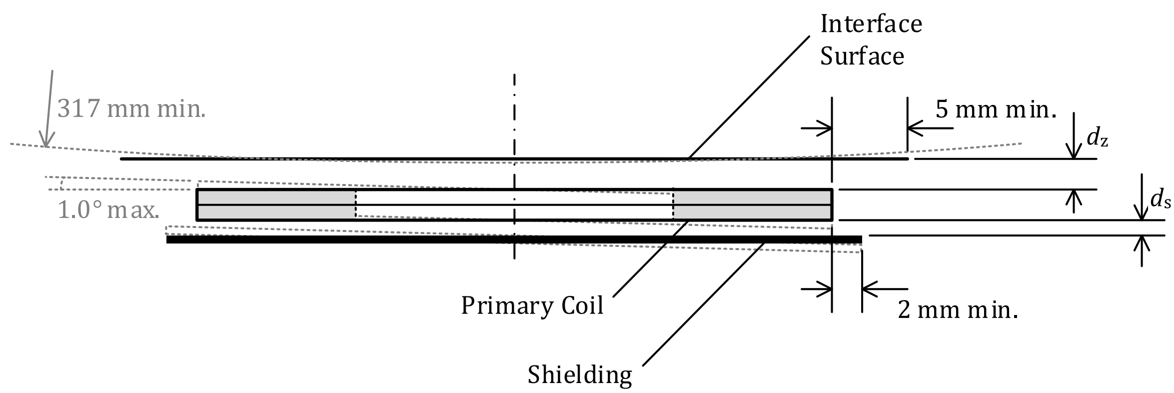
Table 25. Primary Coil parameters of Power Transmitter design A11a

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

2.2.11.2.1.2 Shielding

As shown in Figure 37, Shielding protects the Base Station 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 37. Primary Coil assembly of Power Transmitter design A11a



2.2.11.2.1.3 Interface Surface

As shown in Figure 37, the distance from the Primary Coil to the Interface Surface of the Base Station is $d_z = 2^{+0.5}_{-0.25}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Base Station 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 37.

2.2.11.2.1.4 Alignment aid

The user manual of the Base Station 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 Mobile Device positioning to help alignment.

NOTE Examples of Base Station alignment aids to assist the user positioning of the Mobile Device 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.

2.2.11.2.1.5 Inter coil separation

If the Base Station contains multiple type A11a Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall have a center-to-center distance of at least 50 mm.

2.2.11.2.2 Electrical details

As shown in Figure 38, 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 $f_{\mathrm{op}} = 110 \ldots 148$ 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 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 *Parts 1 and 2: Interface Definitions*), 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 *Parts 1 and 2: Interface Definitions*. 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 26, Table 27, and Table 28 provide the values of several parameters, which are used in the PID algorithm.

Figure 38. Electrical diagram (outline) of Power Transmitter design A11a

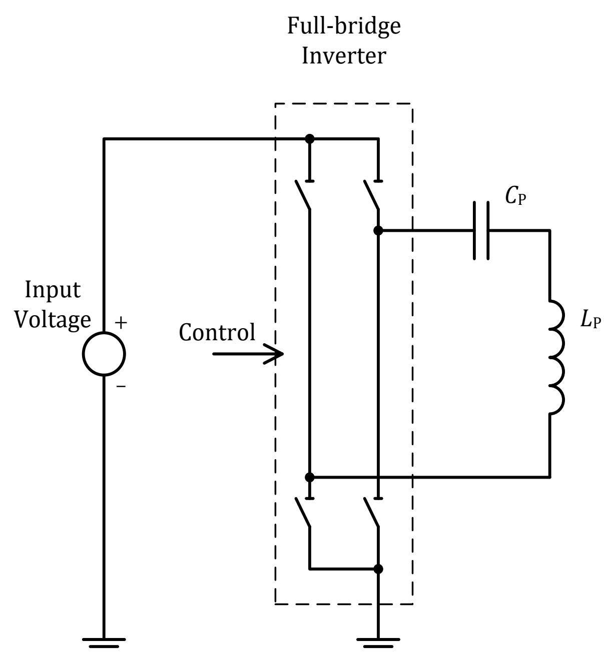


Table 26. PID parameters for Operating Frequency control

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 27. Operating Frequency dependent scaling factor

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

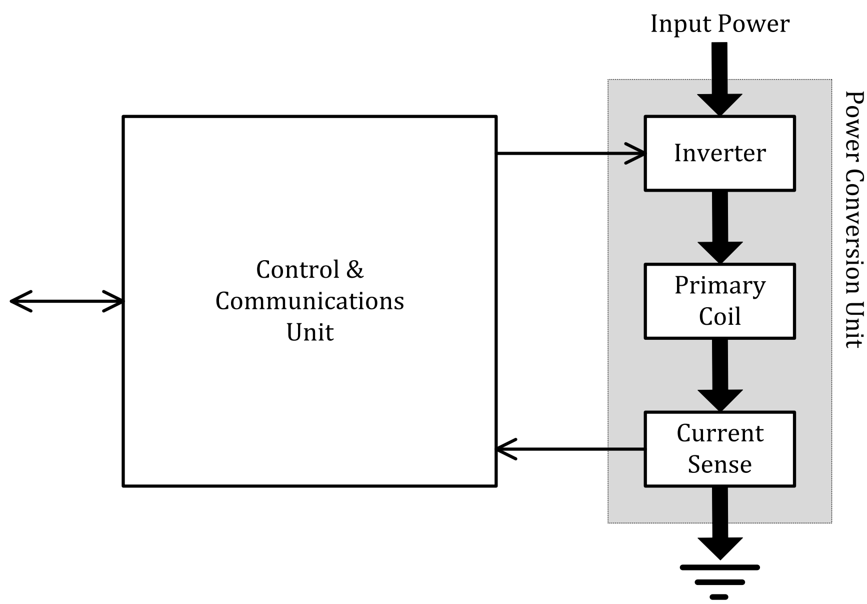
Table 28. PID parameters for duty cycle control

Parameter	Symbol	Value	Unit
Proportional gain	K_{p}	10	mA^{-1}
Integral gain	K_{i}	0.05	$\mathrm{mA}^{-1}\mathrm{ms}^{-1}$
Derivative gain	K_{d}	0	$\mathrm{mA}^{-1}\mathrm{ms}$
Integral term limit	M_{I}	3,000	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_{v}	−0.01	%

2.2.12 Power Transmitter design A12

Figure 39 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 39. Functional block diagram of Power Transmitter design A12



The Power Conversion Unit on the right-hand side of Figure 39 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 39 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 Base Station, e.g. for user interface purposes.

2.2.12.1 Mechanical details

Power Transmitter design A12 includes a single Primary Coil as defined in Section 2.2.12.1.1, Shielding as defined in Section 2.2.12.1.2, and an Interface Surface as defined in Section 2.2.12.1.3.

2.2.12.1.1 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 40, a Primary Coil has a racetrack-like shape and consists of a single layer. Table 29 lists the dimensions of a Primary Coil.

Figure 40. Primary Coil of Power Transmitter design A12

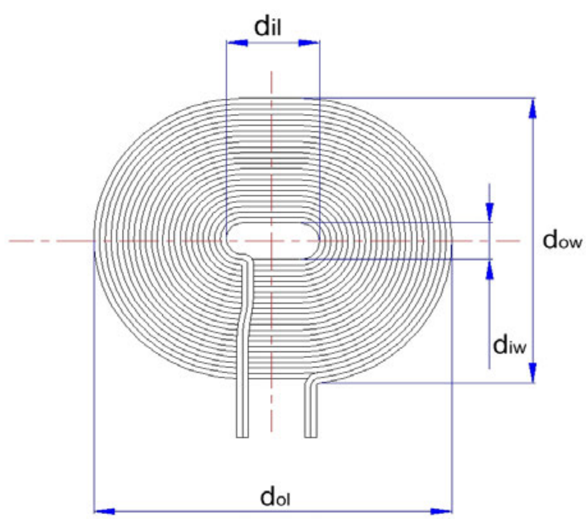


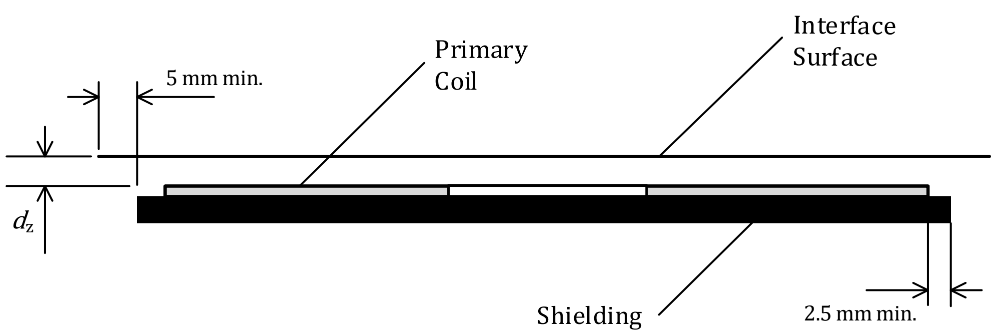
Table 29. Primary Coil parameters of Power Transmitter design A12

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

2.2.12.1.2 Shielding

As shown in Figure 41, Shielding protects the Base Station 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 41. Primary Coil assembly of Power Transmitter design A12



2.2.12.1.3 Interface Surface

As shown in Figure 41, the distance from the Primary Coil to the Interface Surface of the Base Station is $d_z = 2.0^{\pm 0.5}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Base Station extends at least 5 mm beyond the outer diameter of the Primary Coil.

2.2.12.1.4 Inter coil separation

If the Base Station contains multiple type A12 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall have a center-to-center distance of at least 65 mm.

2.2.12.2 Electrical details

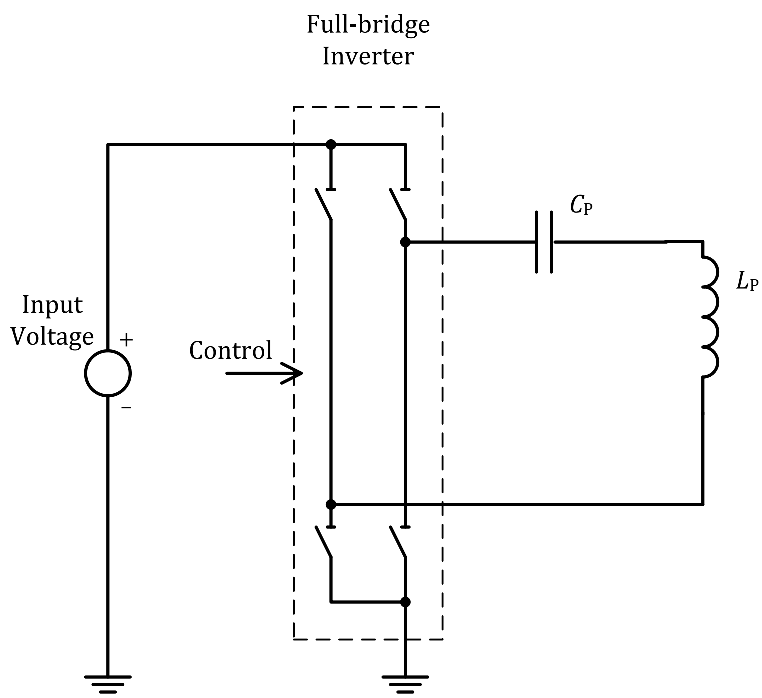
As shown in Figure 42, Power Transmitter design A12 uses a full-bridge inverter to drive the Primary Coil and a series capacitance. Within the Operating Frequency range specified below, the assembly of Primary Coil and Shielding has a self-inductance $L_{\mathrm{P}} = 7^{\pm 10\%}$ μH. The value of the series capacitance is $C_{\mathrm{P}} = 400^{\pm 5\%}$ 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 $f_{\mathrm{op}} = 110 \ldots 205$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 *Parts 1 and 2: Interface Definitions*), 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 *Parts 1 and 2: Interface Definitions*. 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 42. Electrical diagram (outline) of Power Transmitter design A12



Control of the power transfer shall proceed using the PID algorithm, which is defined in *Parts 1 and 2: Interface Definitions*. 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 30 and Table 31 provide the values of several parameters, which are used in the PID algorithm.

Table 30. PID parameters for Operating Frequency 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	20,000	N.A.
Scaling factor	S_v	1.0	Hz

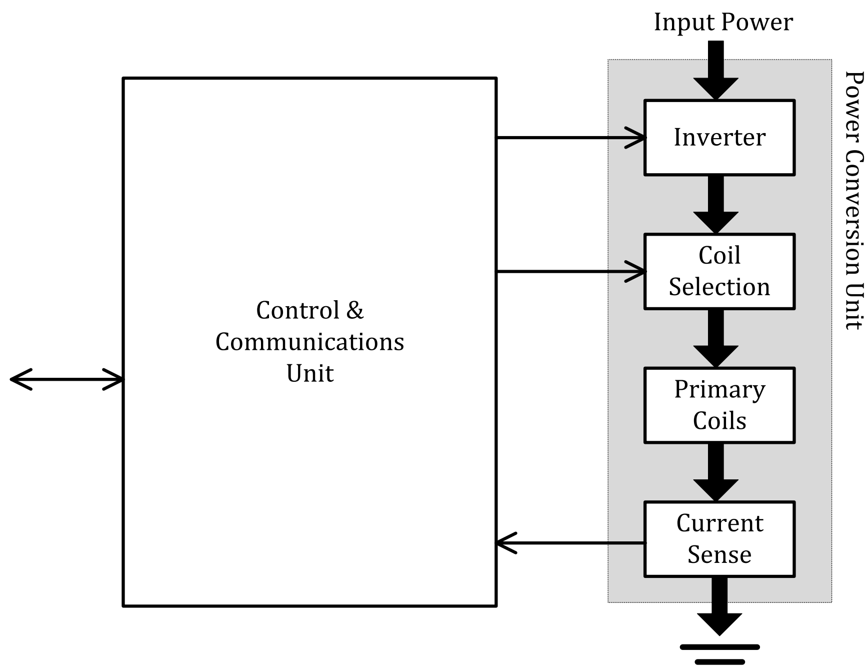
Table 31. PID parameters for duty cycle control

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}	20,000	N.A.
Scaling factor	S_{v}	0.1	%

2.2.13 Power Transmitter design A13

Figure 43 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 43. Functional block diagram of Power Transmitter design A13



The Power Conversion Unit on the right-hand side of Figure 43 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 43 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 Base Station, e.g. for user interface purposes.

2.2.13.1 Mechanical details

Power Transmitter design A13 includes one or more Primary Coils as defined in Section 2.2.13.1.1, Shielding as defined in Section 2.2.13.1.2, an Interface Surface as defined in Section 2.2.13.1.3.

2.2.13.1.1 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 44, the Primary Coil has a rectangular shape and consists of a single layer. Table 32 lists the dimensions of the Primary Coil.

Figure 44. Primary Coil of Power Transmitter design A13

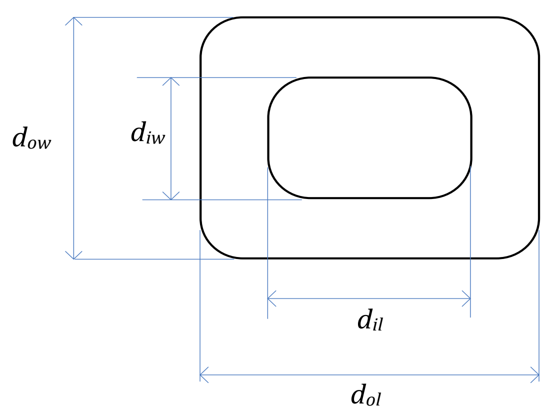
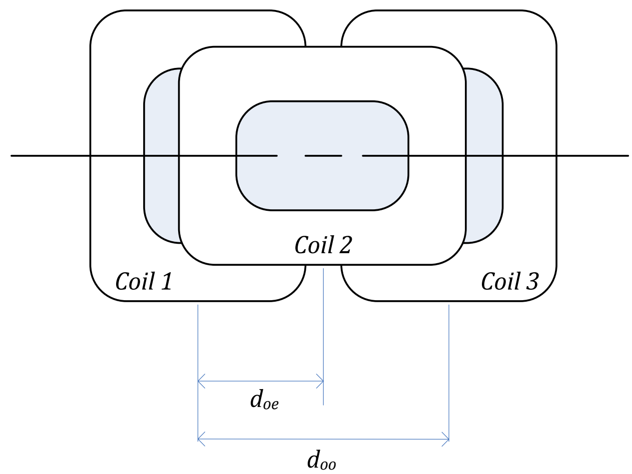


Table 32. Primary Coil parameters of Power Transmitter design A13

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 $d_{\mathrm{oo}} = 49.2^{\pm 4}$ mm between their centers. Even numbered coils are placed orthogonal to the odd numbered coils with a displacement of $d_{\mathrm{oe}} = 24.6^{\pm 2}$ mm between their centers. See Figure 45.

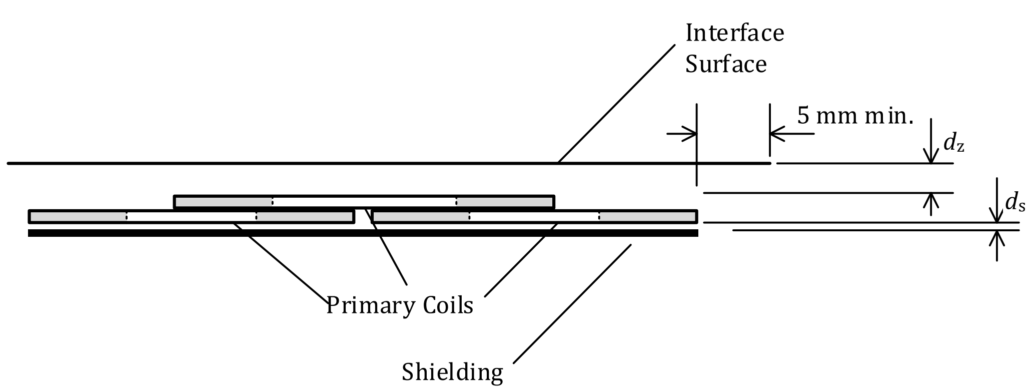
Figure 45. Primary Coils of Power Transmitter design A13



2.2.13.1.2 Shielding

As shown in Figure 46, Shielding protects the Base Station 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 $d_{\mathrm{s}} = 1.0$ mm.

Figure 46. Primary Coil assembly of Power Transmitter design A13



2.2.13.1.3 Interface Surface

As shown in Figure 46, the distance from the top face of the even-numbered Primary Coil to the Interface Surface of the Base Station 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 Base Station is $d_z = 4.5^{\pm 1}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Base Station extends at least 5 mm beyond the outer dimensions of the Primary Coils.

2.2.13.1.4 Inter coil separation

If the Base Station contains multiple type A13 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall have a center-to-center distance of at least $49.2^{\pm 4}$ mm.

2.2.13.2 Electrical details

As shown in Figure 47, 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 $L_\mathrm{P} = 11.5^{\pm 10\%}$ 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. 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 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 $f_\mathrm{op} = 105 \dots 115$ kHz, with a duty cycle of 50%.

When a type A13 Power Transmitter first applies a Power Signal (Digital Ping; see *Parts 1 and 2: Interface Definitions*), 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 *Parts 1 and 2: Interface Definitions*. 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 33 provides the values of several parameters, which are used in the PID algorithm.

Figure 47. Electrical diagram (outline) of Power Transmitter design A13

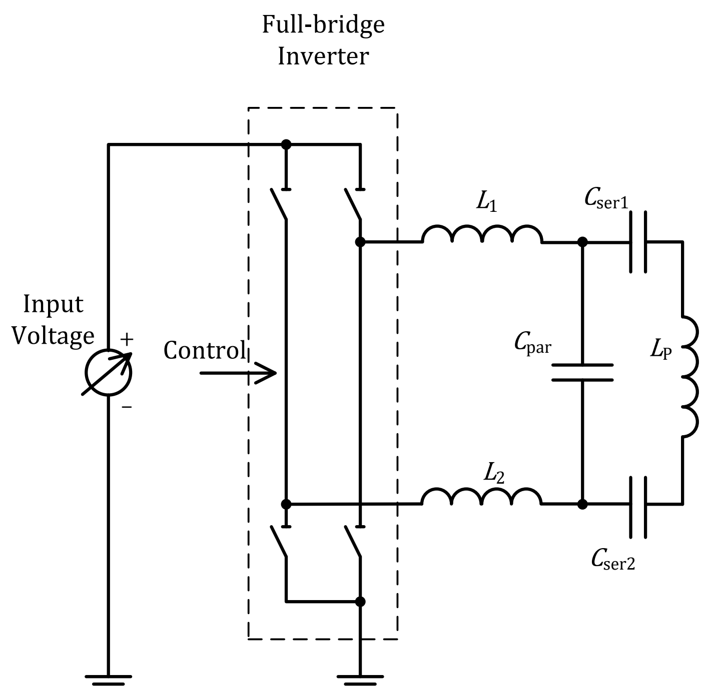


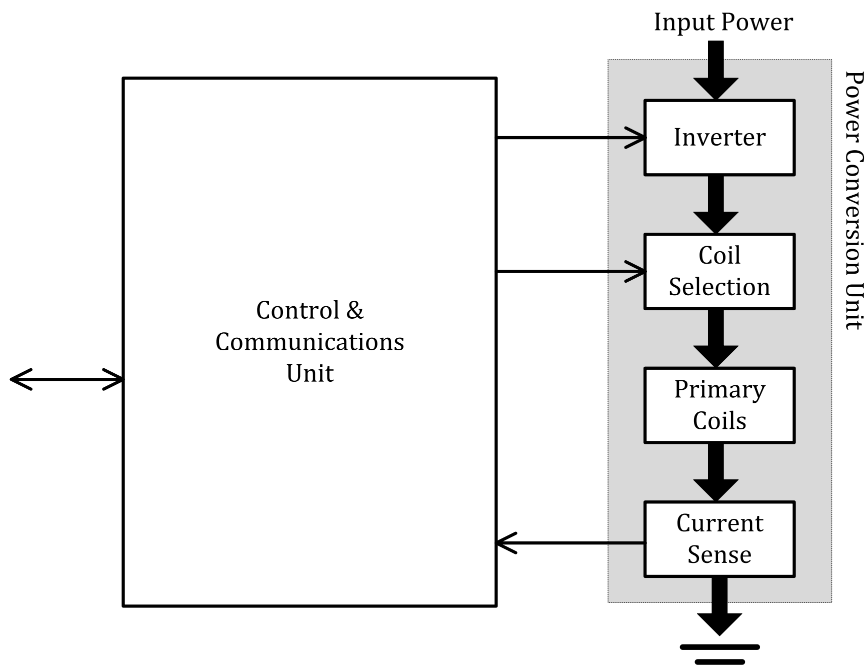
Table 33. PID parameters for voltage control

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

2.2.14 Power Transmitter design A14

Figure 48 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 48. Functional block diagram of Power Transmitter design A14



The Power Conversion Unit on the right-hand side of Figure 48 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 48 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 Base Station, e.g. for user interface purposes.

2.2.14.1 Mechanical details

Power Transmitter design A14 includes one or more Primary Coils as defined in Section 2.2.14.1.1, Shielding as defined in Section 2.2.14.1.2, an Interface Surface as defined in Section 2.2.14.1.3.

2.2.14.1.1 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 49, the Primary Coil has a racetrack-like shape and consists of a single layer. Table 34 lists the dimensions of the Primary Coil.

Figure 49. Primary Coil of Power Transmitter design A14

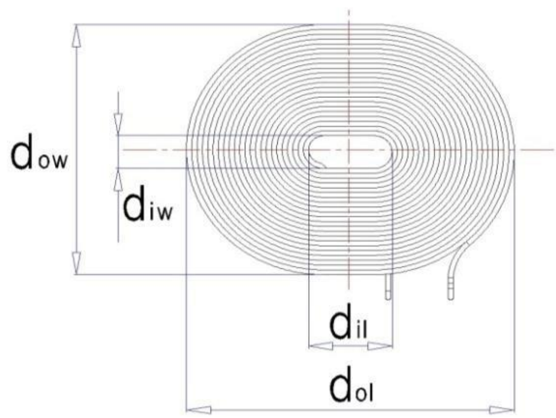
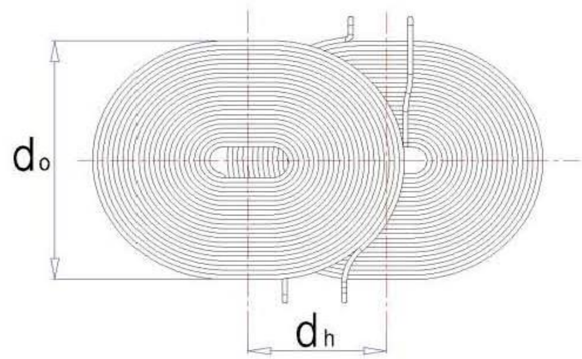


Table 34. Primary Coil parameters of Power Transmitter design A14

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 2.2.14.1.2) with their long axes coincident, and a displacement of $d_{\mathrm{h}} = 38^{\pm 0.5}$ mm between their centers. See Figure 50.

Figure 50. Primary Coils of Power Transmitter design A14

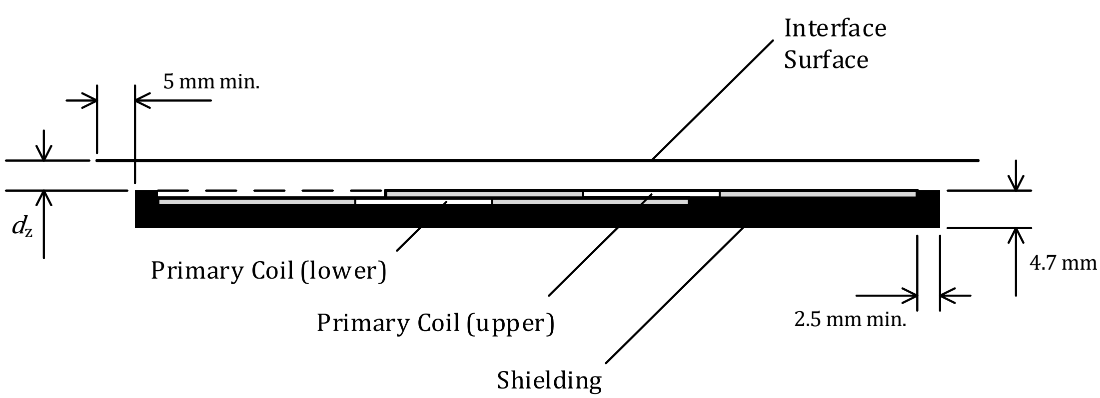


2.2.14.1.2 Shielding

As shown in Figure 51, Shielding protects the Base Station 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 51. Primary Coil assembly of Power Transmitter design A14



2.2.14.1.3 Interface Surface

As shown in Figure 51, the distance from the top face of the top Primary Coil to the Interface Surface of the Base Station 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 Base Station is $d_z = 3.3^{\pm 0.5}$ mm. In addition, the Interface Surface of the Base Station extends at least 5 mm beyond the outer edges of the Primary Coils.

2.2.14.1.4 Inter coil separation

If the Base Station contains multiple type A14 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall have a center-to-center distance of at least 70 mm.

2.2.14.2 Electrical details

As shown in Figure 52, 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.

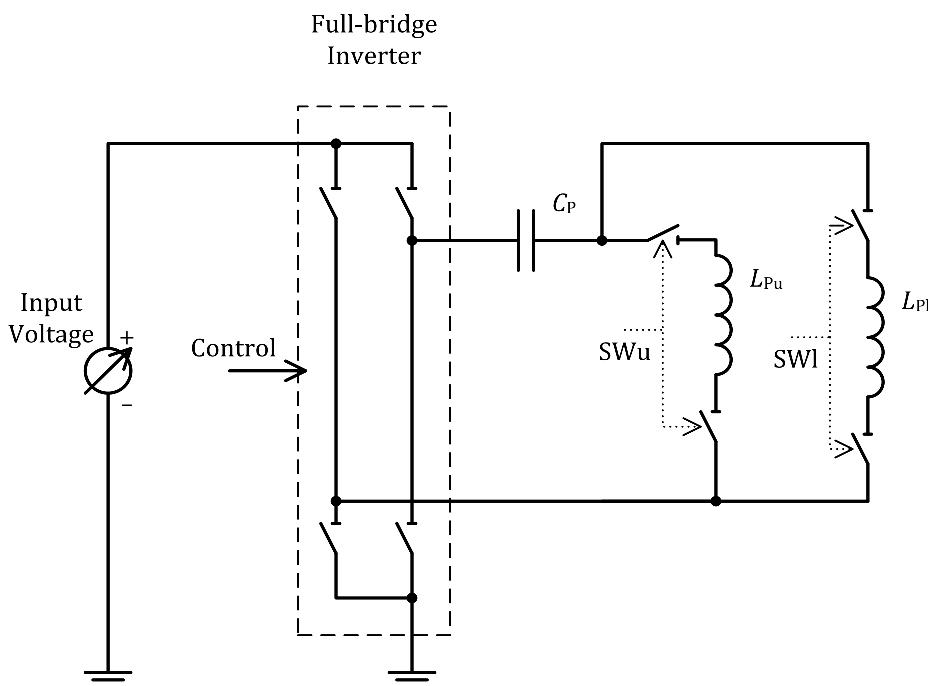
Within the Operating Frequency range specified below, the assembly of Primary Coils and Shielding has a self-inductance $L_{\mathrm{P}} = 24^{\pm 1.0}$ μH. The value of the series capacitance is $C_{\mathrm{P}} = 100^{\pm 5\%}$ nF. The input voltage to the full-bridge inverter is $12^{\pm 10\%}$ V.

NOTE Near resonance, the voltage developed across the series capacitance can reach levels up to 100 Vpk-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 $\mathrm{f_{op}} = 110 \ldots 205$ 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 *Parts 1 and 2: Interface Definitions*), 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 *Parts 1 and 2: Interface Definitions*. 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 52. Electrical diagram (outline) of Power Transmitter design A14



Control of the power transfer shall proceed using the PID algorithm, which is defined in Section *Parts 1 and 2: Interface Definitions*. 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 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 35 and Table 36 provide the values of several parameters, which are used in the PID algorithm.

Table 35. 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

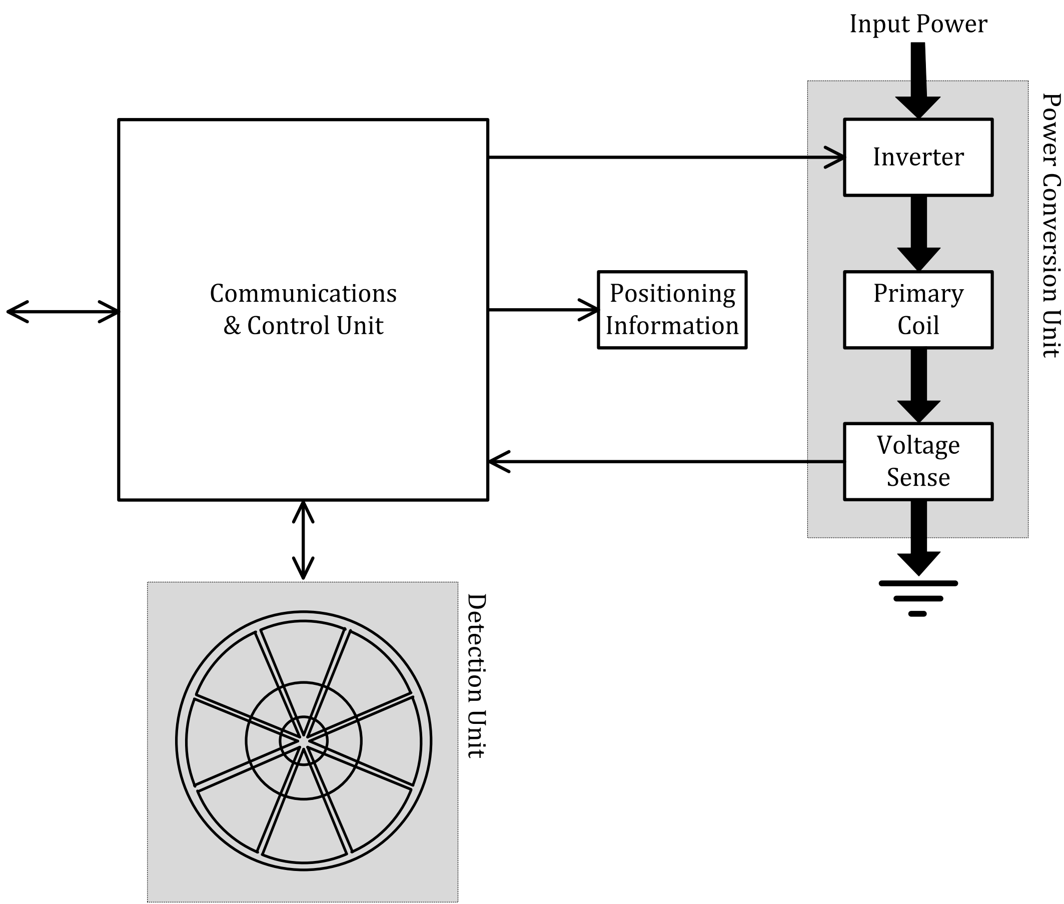
Table 36. PID parameters for duty cycle control

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}	20,000	N.A.
Scaling factor	S_{v}	0.1	%

2.2.15 Power Transmitter design A15

Figure 53 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 53. Functional block diagram of Power Transmitter design A15



The Power Conversion Unit on the right-hand side of Figure 53 and the Detection Unit at the bottom of Figure 53 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 53 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 Base Station, 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 *Part 4: 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 *Power Receiver Design Requirements* section in *Parts 1 and 2: Interface Definitions*). 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. *Parts 1 and 2: Interface Definitions* provides an example resonant detection method.

2.2.15.1 Mechanical details

Power Transmitter design A15 includes a single Primary Coil as defined in Section 2.2.15.1.1, Shielding as defined in Section 2.2.15.1.2, an Interface Surface as defined in Section 2.2.15.1.3, and an alignment aid as defined in Section 2.2.15.1.4.

2.2.15.1.1 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 54, the Primary Coil has a circular shape and consists of a single layer. Table 37 lists the dimensions of the Primary Coil.

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

Figure 54. Primary Coil of Power Transmitter design A15

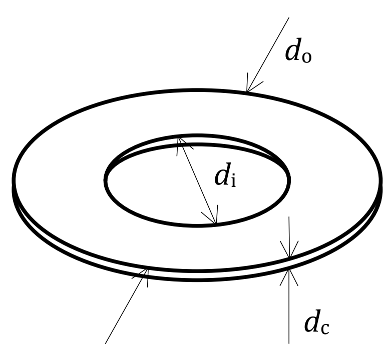


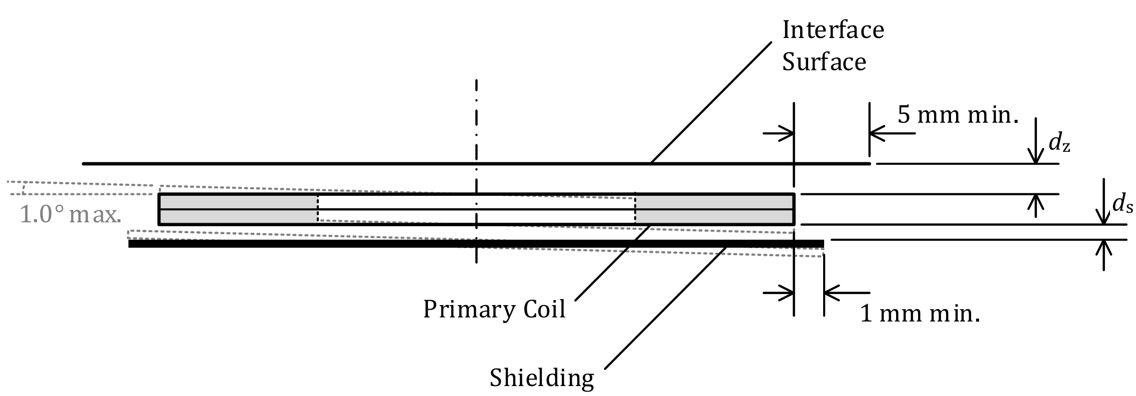
Table 37. Primary Coil parameters of Power Transmitter design A15

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

2.2.15.1.2 Shielding

As shown in Figure 55, Shielding protects the Base Station 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 $d_s = 1.5$mm.

Figure 55. Primary Coil assembly of Power Transmitter design A15



2.2.15.1.3 Interface Surface

As shown in Figure 55, the distance from the Primary Coil to the Interface Surface of the Base Station is $d_z = 3.0^{\pm 0.5}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Base Station extends at least 5 mm beyond the outer diameter of the Primary Coil.

2.2.15.1.4 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.*

2.2.15.2 Electrical details

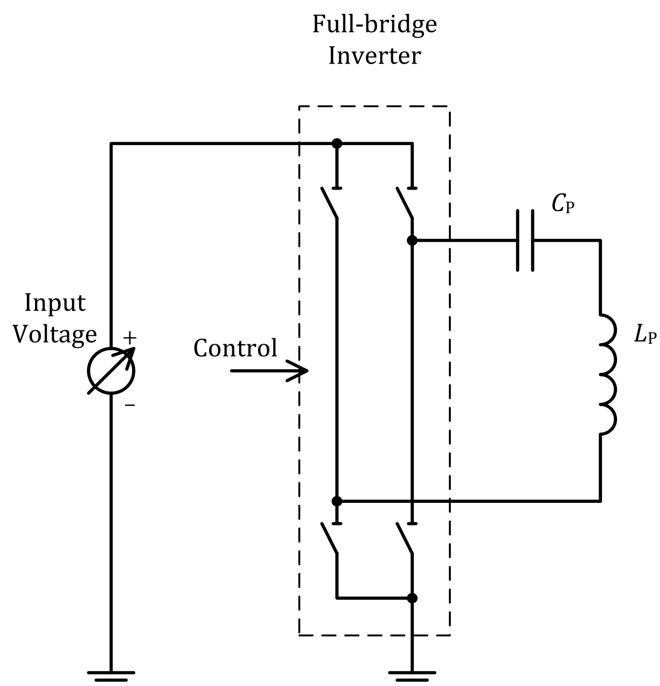
As shown in Figure 56, Power Transmitter design A15 uses a full-bridge inverter to drive the Primary Coil and a series capacitance. At an Operating Frequency range between 105 kHz and 140 kHz, the assembly of Primary Coil and Shielding has a self-inductance $L_{\mathrm{P}} = 13.6^{\pm 10\%}$ μH. The 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 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 *Parts 1 and 2: Interface Definitions*), 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 *Parts 1 and 2: Interface Definitions*. 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 56. Electrical diagram (outline) of Power Transmitter design A15



Control of the power transfer shall proceed using the PID algorithm, which is defined in Section *Parts 1 and 2: Interface Definitions*. 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 38 provides the values of several parameters, which are used in the PID algorithm.

Table 38. PID parameters for voltage control

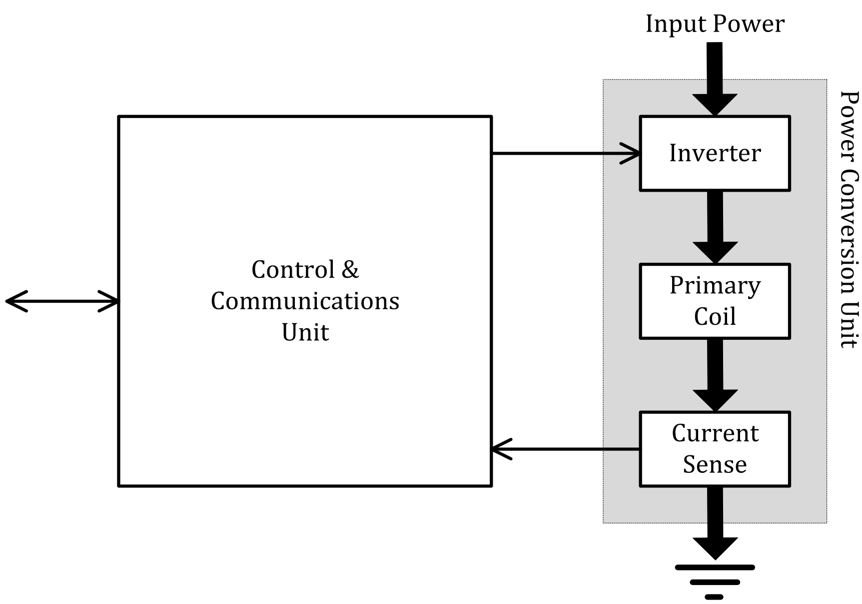
Parameter	Symbol	Value	Unit
Proportional gain	K_p	1	mA^{-1}
Integral gain	K_i	0	$\mathrm{mA}^{-1}\mathrm{ms}^{-1}$
Derivative gain	K_d	0	$\mathrm{mA}^{-1}\mathrm{ms}$
Integral term limit	M_I	N.A.	N.A.
PID output limit	M_PID	1,500	N.A.
Scaling factor	S_v	–0.5	mV

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.

2.2.16 Power Transmitter design A16

Figure 57 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 57. Functional block diagram of Power Transmitter design A16



The Power Conversion Unit on the right-hand side of Figure 57 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 57 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 Base Station, 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.

2.2.16.1 Mechanical details

Power Transmitter design A16 includes a single Primary Coil as defined in Section 2.2.16.1.1, Shielding as defined in Section 2.2.16.1.2, an Interface Surface as defined in Section 2.2.16.1.3, and an alignment aid as defined in Section 2.2.16.1.4.

2.2.16.1.1 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 58, the Primary Coil has a triangular shape and consists of a single layer. Table 39 lists the dimensions of the Primary Coil.

Figure 58. Primary Coil of Power Transmitter design A16

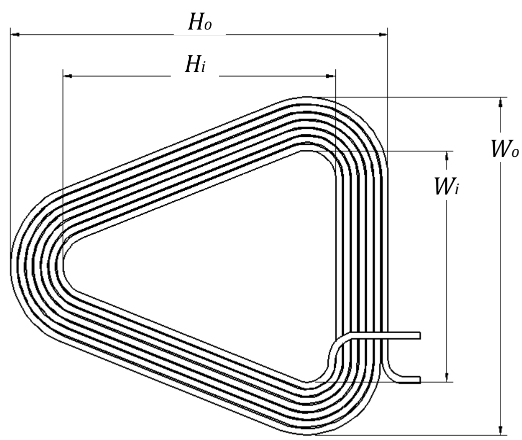


Table 39. Primary Coil parameters of Power Transmitter design A16

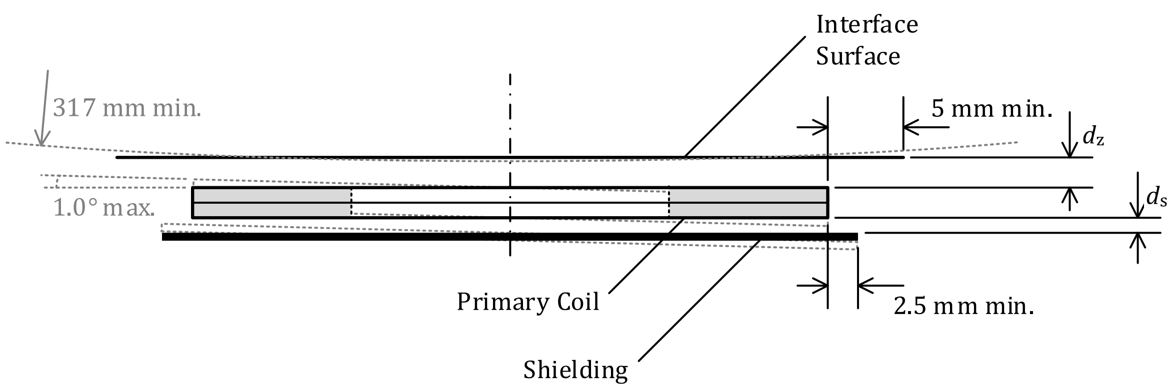
Parameter	Symbol	Value
Outer height	H_o	$59^{\pm 0.5}$ mm
Inner height	H_i	$43^{\pm 0.5}$ mm
Outer width	W_o	$52^{\pm 0.5}$ mm
Inner width	W_i	$36^{\pm 0.5}$ mm
Thickness	d_c	1.1+0.3 mm
Number of turns per layer	N	7
Number of layers	–	1

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.

2.2.16.1.2 Shielding

As shown in Figure 59, Shielding protects the Base Station 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 59. Primary Coil assembly of Power Transmitter design A16



2.2.16.1.3 Interface Surface

As shown in Figure 59, the distance from the Primary Coil to the Interface Surface of the Base Station is $d_z = 2^{+0.5}_{-0.5}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Base Station 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 59.

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.

2.2.16.1.4 Alignment aid

The user manual of the Base Station 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 Mobile Device positioning to help alignment.

NOTE Examples of Base Station alignment aids to assist the user positioning of the Mobile Device 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.

2.2.16.1.5 Inter coil separation

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

2.2.16.2 Electrical details

As shown in Figure 60, 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 $f_{\mathrm{op}} = 110 \ldots 205$ 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;

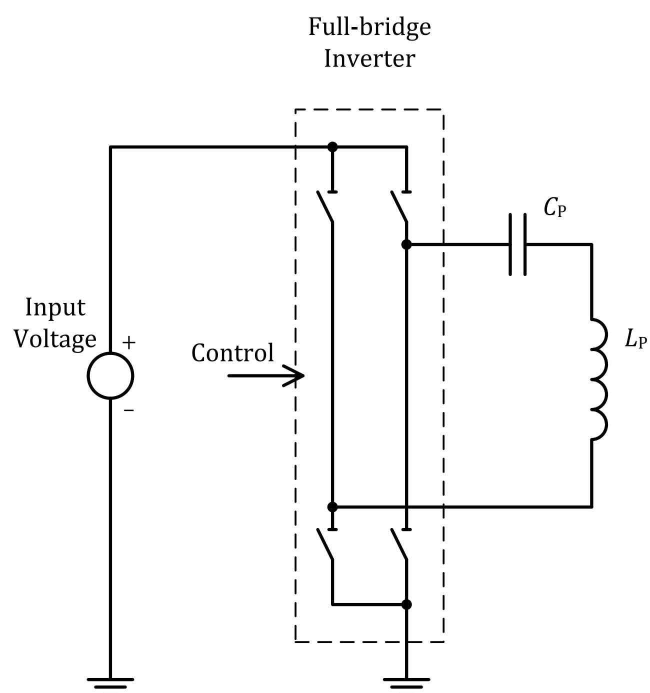
or better. In addition, a type A16 Power Transmitter shall control the duty cycle of the Power Signal with a resolution of 0.1% or better.

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.

When a type A16 Power Transmitter first applies a Power Signal (Digital Ping; see *Parts 1 and 2: Interface Definitions*), 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 *Parts 1 and 2: Interface Definitions*. 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 40, Table 41, and Table 42 provide the values of several parameters, which are used in the PID algorithm.

Figure 60. Electrical diagram (outline) of Power Transmitter design A16



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 40. PID parameters for Operating Frequency control

Parameter	Symbol	Value	Unit
Proportional gain	K_{p}	10	mA^{-1}
Integral gain	K_{i}	0.05	$\mathrm{mA}^{-1}\mathrm{ms}^{-1}$
Derivative gain	K_{d}	0	$\mathrm{mA}^{-1}\mathrm{ms}$
Integral term limit	M_{I}	3,000	N.A.
PID output limit	M_{PID}	20,000	N.A.

Table 41. 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

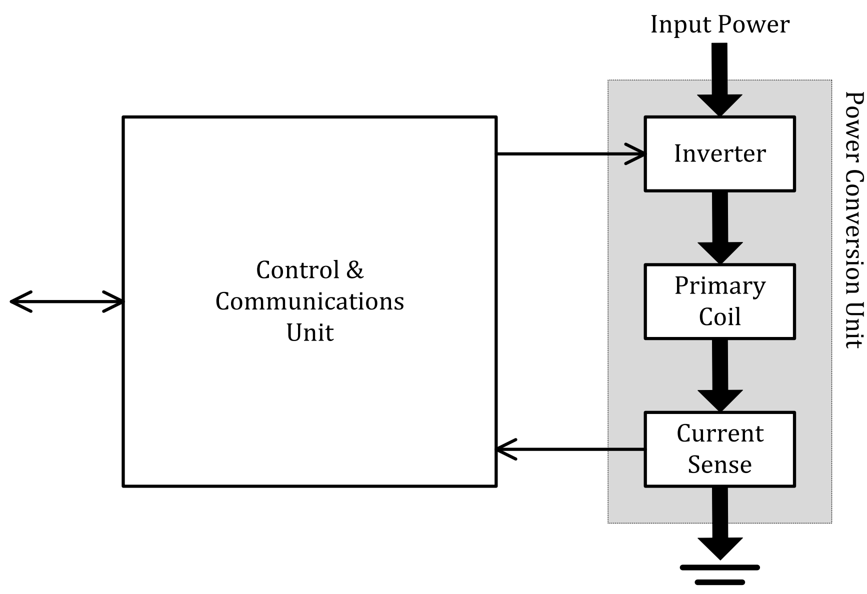
Table 42. PID parameters for duty cycle control

Parameter	Symbol	Value	Unit
Proportional gain	K_{p}	10	mA^{-1}
Integral gain	K_{i}	0.05	$\mathrm{mA}^{-1}\mathrm{ms}^{-1}$
Derivative gain	K_{d}	0	$\mathrm{mA}^{-1}\mathrm{ms}$
Integral term limit	M_{I}	3,000	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_{v}	−0.01	%

2.2.17 Power Transmitter design A17

Power Transmitter design A17 enables Guided Positioning. Figure 61 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 61. Functional block diagram of Power Transmitter design A17



The Power Conversion Unit on the right-hand side of Figure 61 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 61 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 Base Station, e.g. for user interface purposes.

2.2.17.1 Mechanical details

Power Transmitter design A17 includes a single Primary Coil as defined in Section 2.2.17.1.1, Shielding as defined in Section 2.2.17.1.2, an Interface Surface as defined in Section 2.2.17.1.3, and an alignment aid as defined in Section 2.2.17.1.4.

2.2.17.1.1 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 62, the Primary Coil has a circular shape and consists of multiple layers. All layers are stacked with the same polarity. Table 43 lists the dimensions of the Primary Coil.

Figure 62. Primary Coil of Power Transmitter design A17

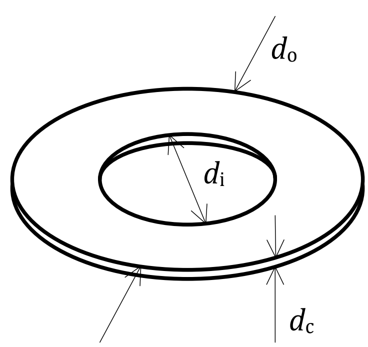


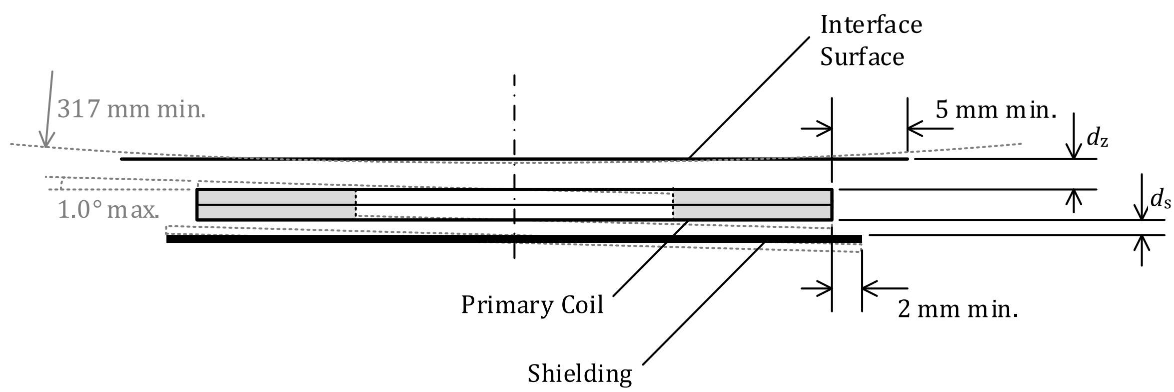
Table 43. Primary Coil parameters of Power Transmitter design A17

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

2.2.17.1.2 Shielding

As shown in Figure 63, Shielding protects the Base Station 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 63. Primary Coil assembly of Power Transmitter design A17



2.2.17.1.3 Interface Surface

As shown in Figure 63, the distance from the Primary Coil to the Interface Surface of the Base Station is $d_z = 7^{+0.5}_{-5.25}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Base Station 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 63.

2.2.17.1.4 Alignment aid

The user manual of the Base Station 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 Mobile Device positioning to help alignment.

NOTE Examples of Base Station alignment aids to assist the user positioning of the Mobile Device 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.

2.2.17.1.5 Inter coil separation

If the Base Station contains multiple type A17 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall have a center-to-center distance of at least 50 mm.

2.2.17.2 Electrical details

As shown in Figure 64, 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 $C_{par} = 200^{\pm 5\%}$ 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 $f_{\mathrm{op}} = 105 \ldots 116$ kHz with a duty cycle of 50%

When a type A17 Power Transmitter first applies a Power Signal (Digital Ping; see *Parts 1 and 2: Interface Definitions*), 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 *Parts 1 and 2: Interface Definitions*. 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 44 provides the values of several parameters, which are used in the PID algorithm.

Figure 64. Electrical diagram (outline) of Power Transmitter design A17

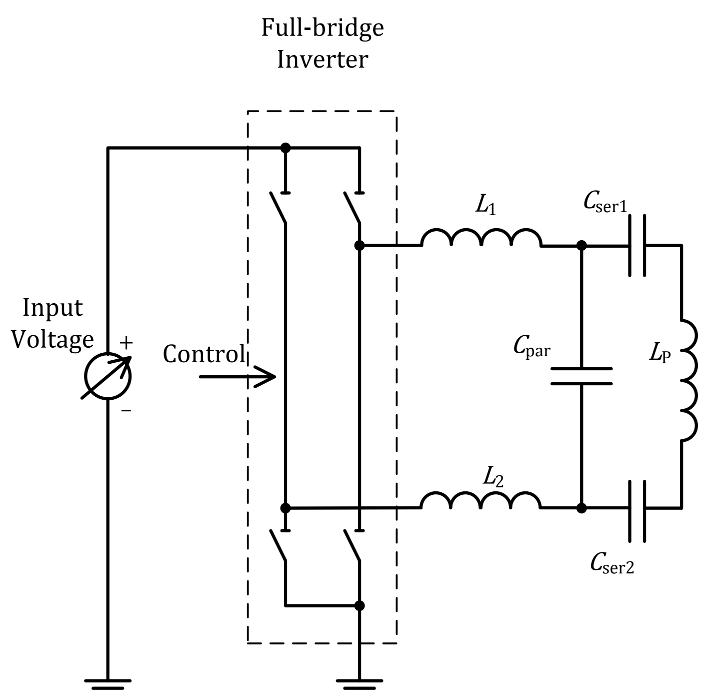


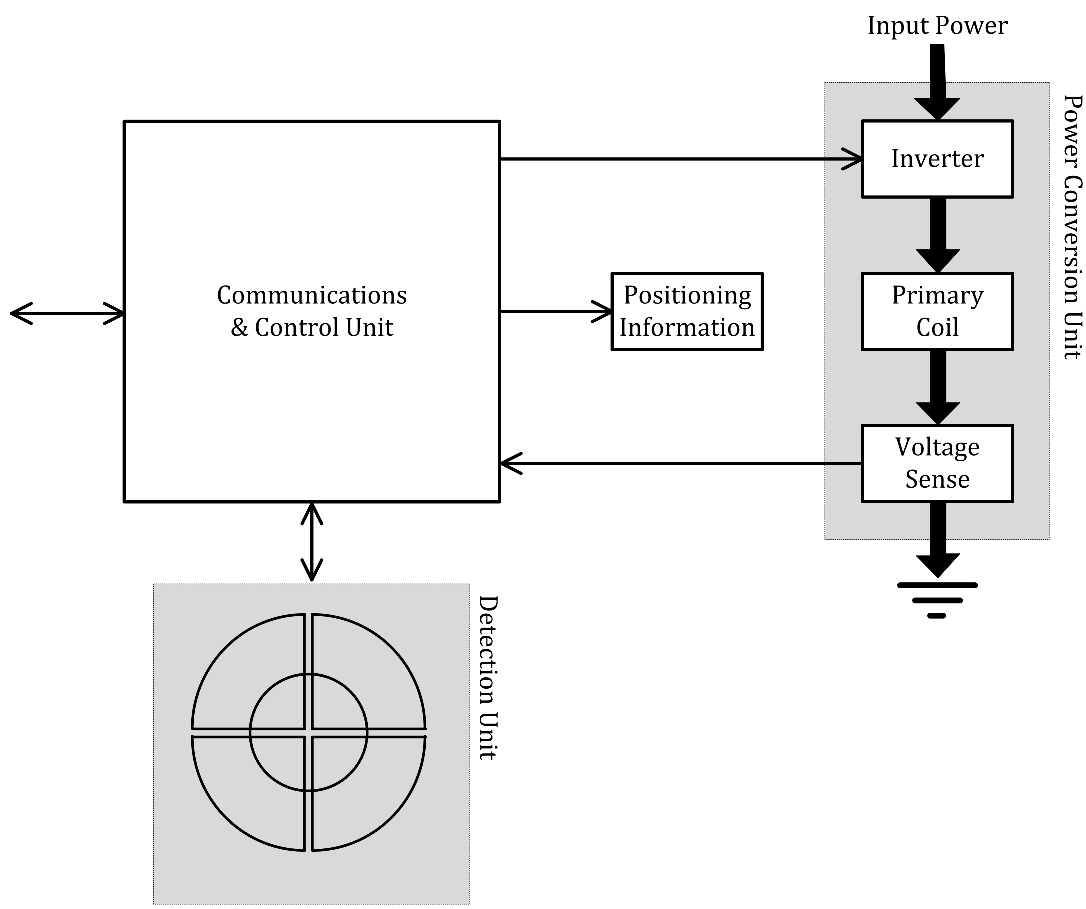
Table 44. PID parameters for voltage control

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

2.2.18 Power Transmitter design A18

Figure 65 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 65. Functional block diagram of Power Transmitter design A18



The Power Conversion Unit on the right-hand side of Figure 65 and the Detection Unit of the bottom of Figure 65 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 65 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 Base Station, 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 *Part 4: 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 *Power Receiver Design Requirements* section in *Parts 1 and 2: Interface Definitions*). 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. *Parts 1 and 2: Interface Definitions* provides an example resonant detection method.

2.2.18.1 Mechanical details

Power Transmitter design A18 includes a single Primary Coil as defined in Section 2.2.18.1.1, Shielding as defined in Section 2.2.18.1.2, an Interface Surface as defined in Section 2.2.18.1.3, and an alignment aid as defined in Section 2.2.18.1.4.

2.2.18.1.1 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 66, the Primary Coil has a circular shape and consists of a single layer. Table 45 lists the dimensions of the Primary Coil.

Figure 66. Primary Coil of Power Transmitter design A18

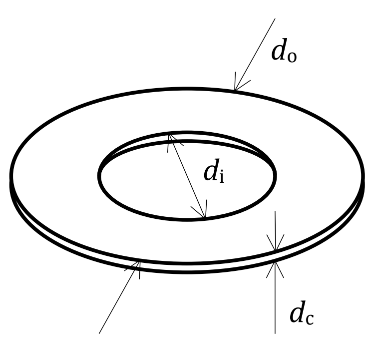


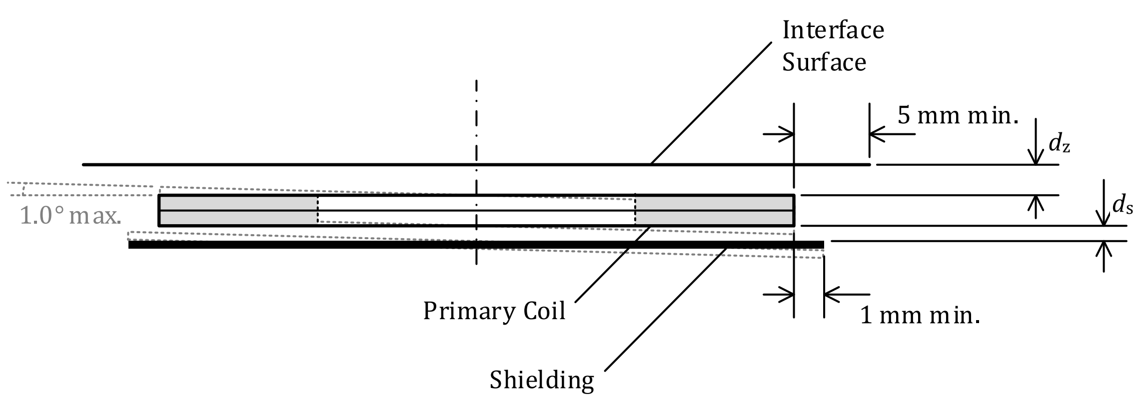
Table 45. Primary Coil parameters of Power Transmitter design A18

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

2.2.18.1.2 Shielding

As shown in Figure 67, Shielding protects the Base Station 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 $d_{\mathrm{s}} = 0.5$mm.

Figure 67. Primary Coil assembly of Power Transmitter design A18



2.2.18.1.3 Interface Surface

As shown in Figure 67, the distance from the Primary Coil to the Interface Surface of the Base Station is $d_{\mathrm{z}} = 2.0^{+1.5}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Base Station extends at least 5mm beyond the outer diameter of the Primary Coil.

2.2.18.1.4 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 or distance feedback.

2.2.18.2 Electrical details

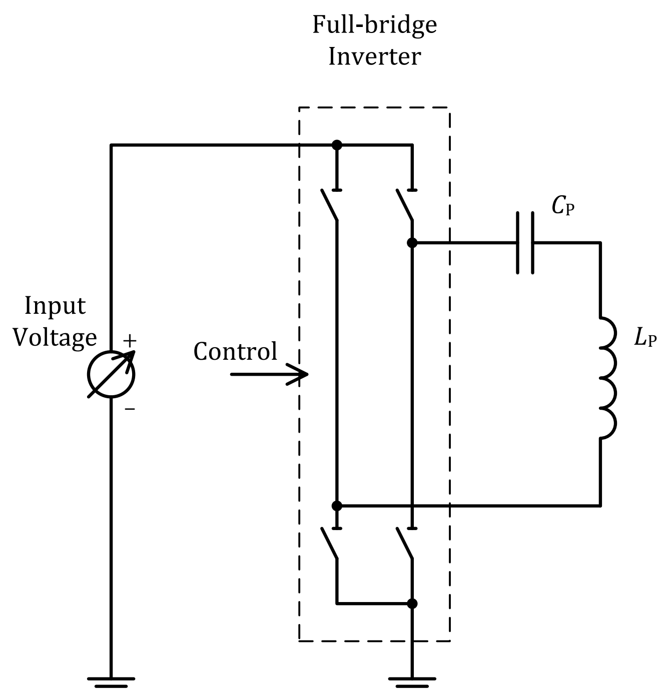
As shown in Figure 68, Power Transmitter design A18 uses a full-bridge inverter to drive the Primary Coil and a series capacitance. At an Operating Frequency range between 105 kHz and 140 kHz, the assembly of Primary Coil and Shielding has a self-inductance $L_{\mathrm{P}} = 13.6^{\pm 10\%}$ μH. The 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 *Parts 1 and 2: Interface Definitions*), 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 *Parts 1 and 2: Interface Definitions*. 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 68. Electrical diagram (outline) of Power Transmitter design A18



Control of the power transfer shall proceed using the PID algorithm, which is defined in *Parts 1 and 2: Interface Definitions*. 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 46 provides the values of several parameters, which are used in the PID algorithm.

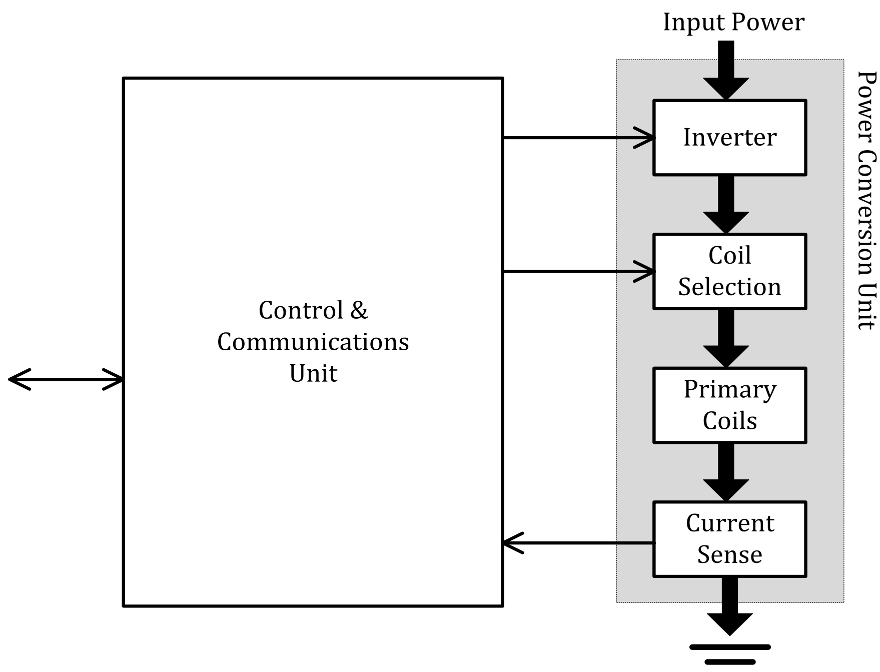
Table 46. PID parameters for voltage control

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

2.2.19 Power Transmitter design A19

Figure 69 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 69. Functional block diagram of Power Transmitter design A19



The Power Conversion Unit on the right-hand side of Figure 69 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 69 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 Base Station, e.g. for user interface purposes.

2.2.19.1 Mechanical details

Power Transmitter design A19 includes two Primary Coils as defined in Section 2.2.19.1.1, Shielding as defined in Section 2.2.19.1.2, and an Interface Surface as defined in Section 2.2.19.1.3.

2.2.19.1.1 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 70, the Primary Coil has a rectangular shape and consists of a single layer. Table 47 lists the dimensions of the Primary Coil.

Figure 70. Primary Coil of Power Transmitter design A19

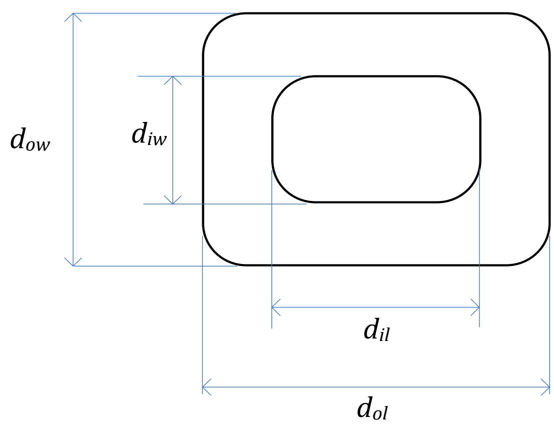
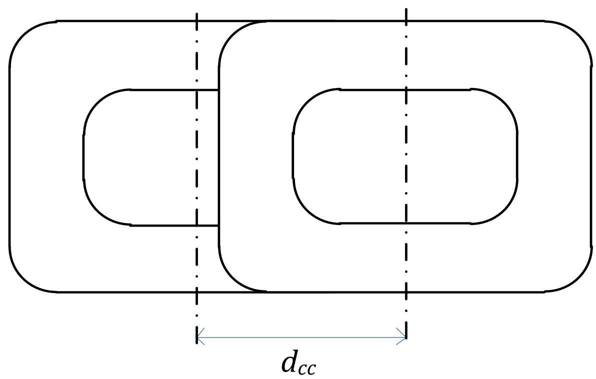


Table 47. Primary Coil parameters of Power Transmitter design A19

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 $d_{\mathrm{cc}} = 27^{\pm 4}$ mm. See Figure 71.

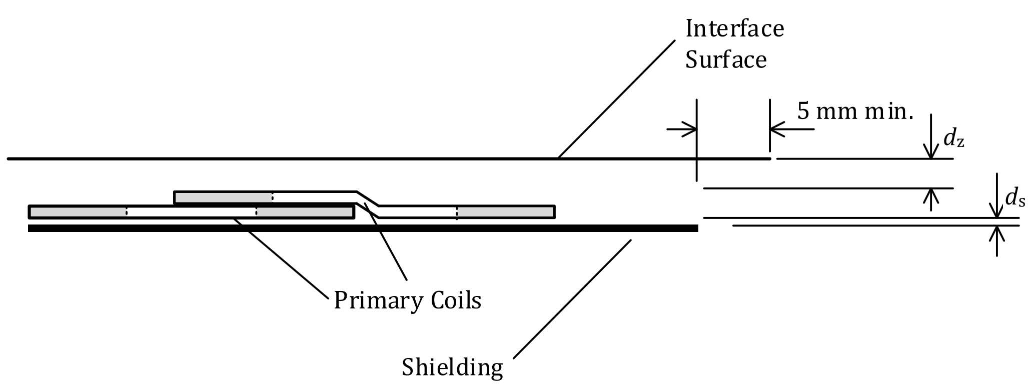
Figure 71. Primary Coils of Power Transmitter design A19



2.2.19.1.2 Shielding

As shown in Figure 72, Shielding protects the Base Station 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 72. Primary Coil assembly of Power Transmitter design A19



2.2.19.1.3 Interface Surface

As shown in Figure 72, the distance from the Primary Coil to the Interface Surface of the Base Station is $d_z = 2^{+0.5}_{-0.25}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Base Station extends at least 5 mm beyond the outer dimensions of the Primary Coils.

2.2.19.1.4 Inter coil separation

If the Base Station contains multiple type A19 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall have a center-to-center distance of at least $49.2^{\pm 4}$ mm.

2.2.19.2 Electrical details

As shown in Figure 73, 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 $f_{\mathrm{op}} = 115 \ldots 205$ 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 *Parts 1 and 2: Interface Definitions*), 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 *Parts 1 and 2: Interface Definitions*. 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 48, Table 49, and Table 50 provide the values of several parameters, which are used in the PID algorithm.

Figure 73. Electrical diagram (outline) of Power Transmitter design A19

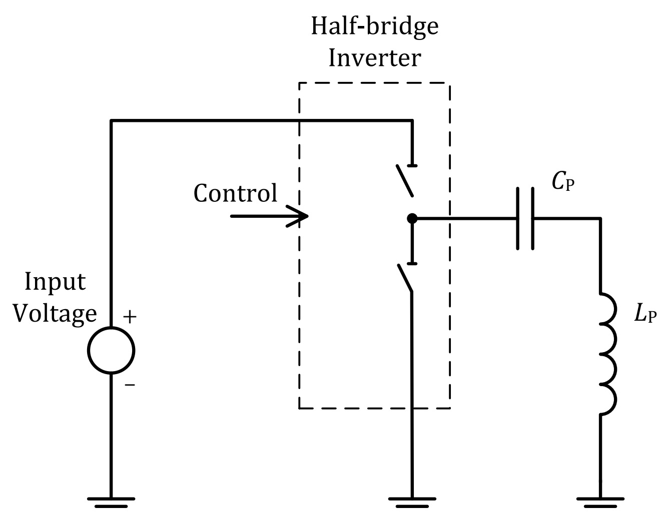


Table 48. PID parameters for Operating Frequency control

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 49. 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

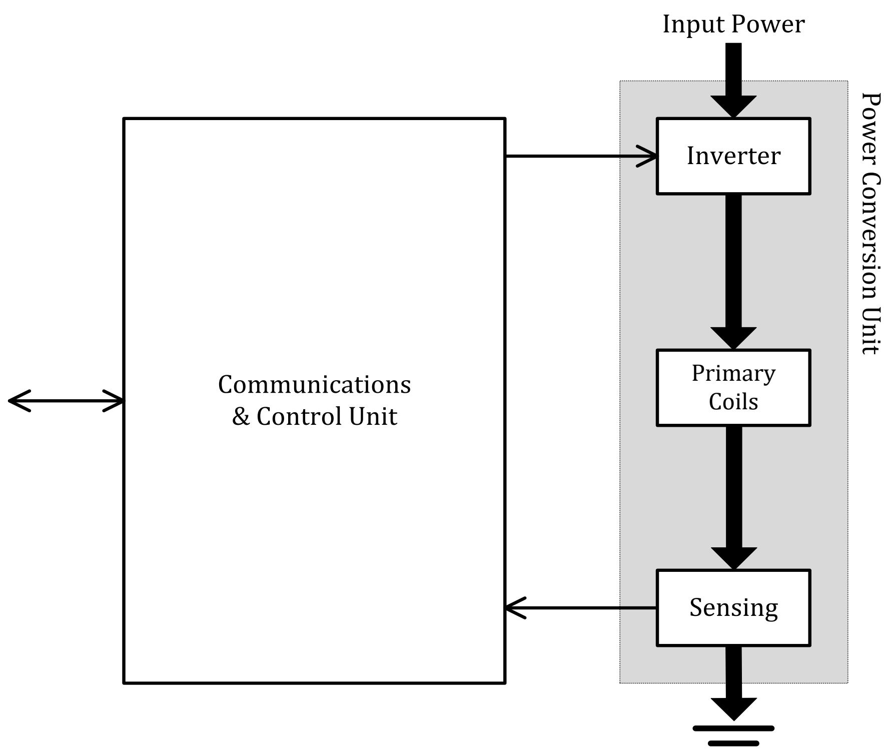
Table 50. PID parameters for duty cycle control

Parameter	Symbol	Value	Unit
Proportional gain	K_{p}	10	mA^{-1}
Integral gain	K_{i}	0.05	$\mathrm{mA}^{-1}\mathrm{ms}^{-1}$
Derivative gain	K_{d}	0	$\mathrm{mA}^{-1}\mathrm{ms}$
Integral term limit	M_{I}	3,000	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_{v}	−0.01	%

2.2.20 Power Transmitter design A20

Figure 74 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 74. Functional block diagram of Power Transmitter design A20



The Power Conversion Unit on the right-hand side of Figure 74 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 74 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 Base Station, e.g. for user interface purposes.

2.2.20.1 Mechanical details

Power Transmitter design A20 includes one Primary Coil as defined in Section 2.2.20.1.1, Shielding as defined in Section 2.2.20.1.2, and an Interface Surface as defined in Section 2.2.20.1.3.

2.2.20.1.1 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 75, a Primary Coil has a racetrack-like shape and consists of a single layer. Table 51 lists the dimensions of a Primary Coil.

Figure 75. Primary Coil of Power Transmitter design A20

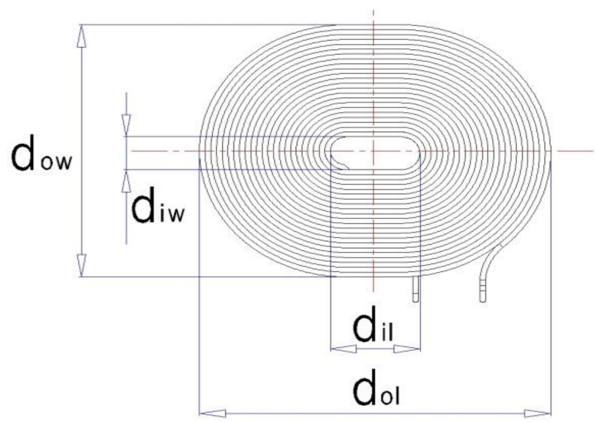


Table 51. Primary Coil parameters of Power Transmitter design A20

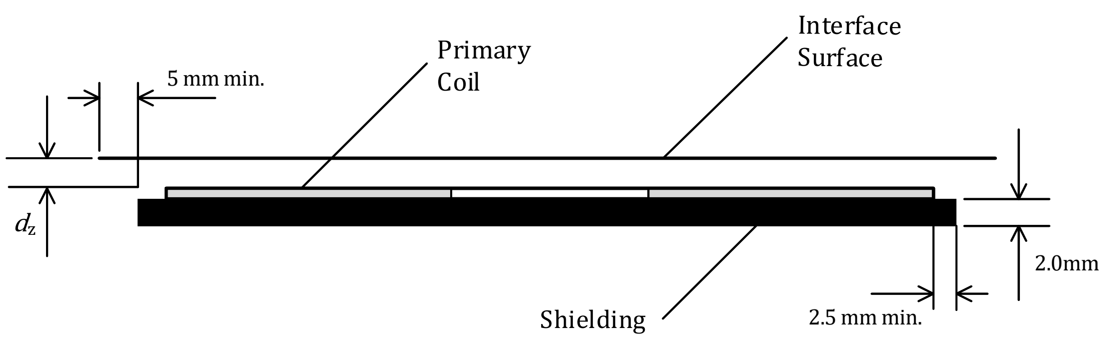
Parameter	Symbol	Value
Outer length	d_{ol}	$65.5^{\pm 0.5}$ mm
Inner length	d_{il}	$16.5^{\pm 0.5}$ mm
Outer width	d_{ow}	$57.1^{\pm 0.5}$ mm
Inner width	d_{iw}	$4.5^{\pm 0.5}$ mm
Thickness	d_{c}	$1.3^{\pm 0.15}$ mm
Number of turns per layer	N	22
Number of layers	–	1

2.2.20.1.2 Shielding

As shown in Figure 76, Shielding protects the Base Station 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 76. Primary Coil assembly of Power Transmitter design A20



2.2.20.1.3 Interface Surface

As shown in Figure 76, the distance from the Primary Coil to the Interface Surface of the Base Station is $d_z = 3.0^{\pm 0.5}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Base Station extends at least 5 mm beyond the outer diameter of the Primary Coil.

2.2.20.1.4 Separation between multiple Power transmitters

If the Base Station contains multiple type A20 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall have a center-to-center distance of at least $65.0^{\pm 0.5}$ mm.

2.2.20.2 Electrical details

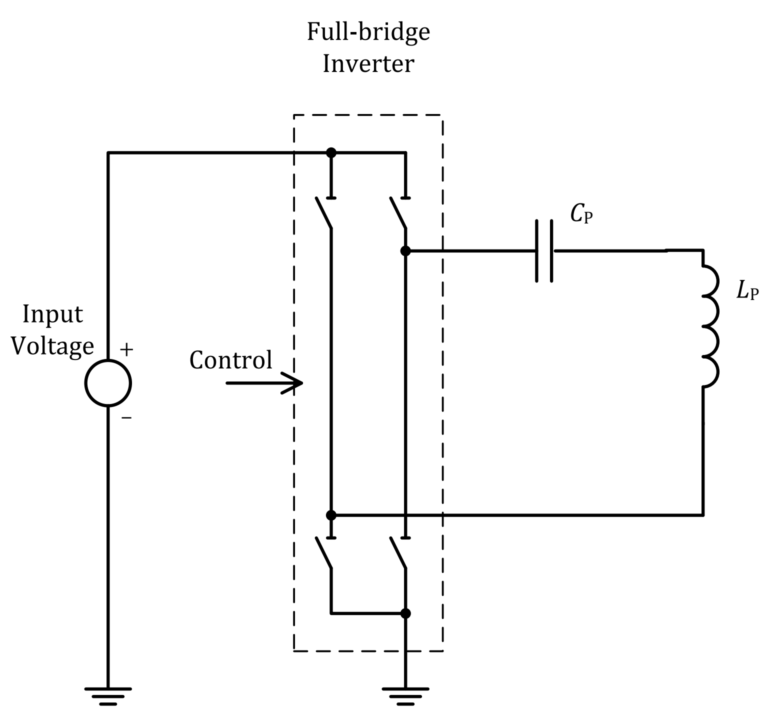
As shown in Figure 77, Power Transmitter design A20 uses a full-bridge inverter to drive the Primary Coil and a series capacitance. Within the Operating Frequency range specified below, the assembly of Primary Coil and Shielding has a self-inductance $L_{\mathrm{P}} = 24^{\pm 10\%}$ μH. The value of 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 $f_{\mathrm{op}} = 87 \ldots 110$ kHz.

When a type A20 Power Transmitter first applies a Power Signal (Digital Ping; see *Parts 1 and 2: Interface Definitions*), 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 *Parts 1 and 2: Interface Definitions*. 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 77. Electrical diagram (outline) of Power Transmitter design A20



Control of the power transfer shall proceed using the PID algorithm, which is defined in *Parts 1 and 2: Interface Definitions*. 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 52 and Table 53 provide the values of several parameters, which are used in the PID algorithm.

Table 52. PID parameters for Operating Frequency 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	20,000	N.A.
Scaling factor	S_v	1.0	Hz

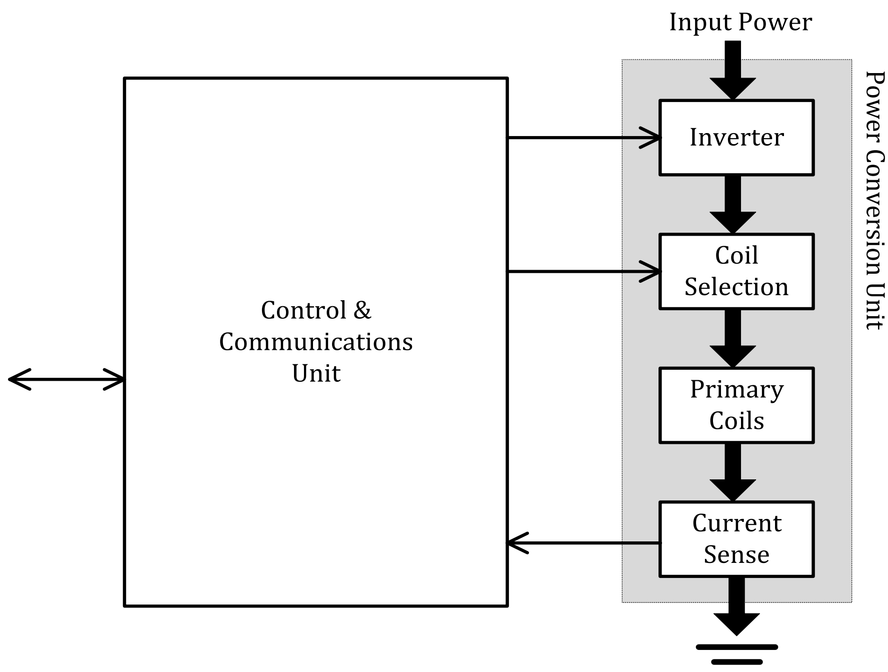
Table 53. PID parameters for voltage control

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

2.2.21 Power Transmitter design A21

Figure 78 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 78. Functional block diagram of Power Transmitter design A21



The Power Conversion Unit on the right-hand side of Figure 78 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 78 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 Base Station, e.g. for user interface purposes.

2.2.21.1 Mechanical details

Power Transmitter design A21 includes one or more Primary Coils as defined in Section 2.2.21.1.1, Shielding as defined in Section 2.2.21.1.2, an Interface Surface as defined in Section 2.2.21.1.3.

2.2.21.1.1 Primary Coil

The Primary Coil consists of at least one PCB coil. Figure 79 shows a view of a single Primary Coil. Table 54 lists the dimensions of the Primary Coil.

Figure 79. Primary Coil of Power Transmitter design A21

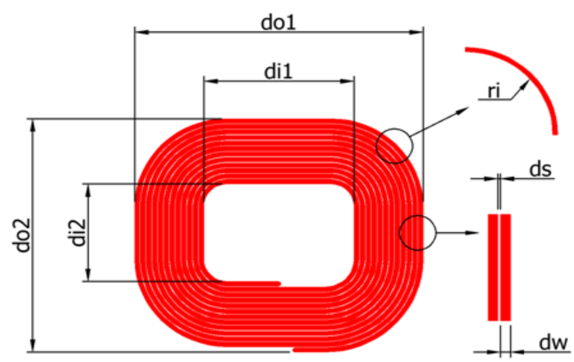


Table 54. Primary Coil parameters of Power Transmitter design A21

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 80.

Figure 80. Primary Coils of Power Transmitter design A21

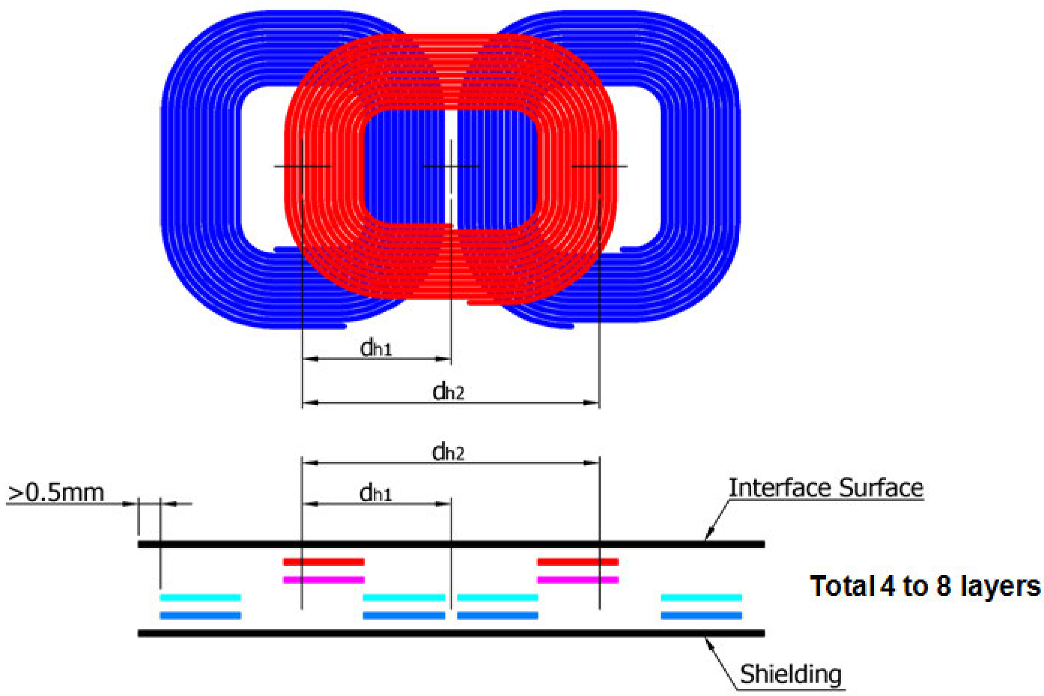


Figure 81. Primary Coils of Power Transmitter design A21

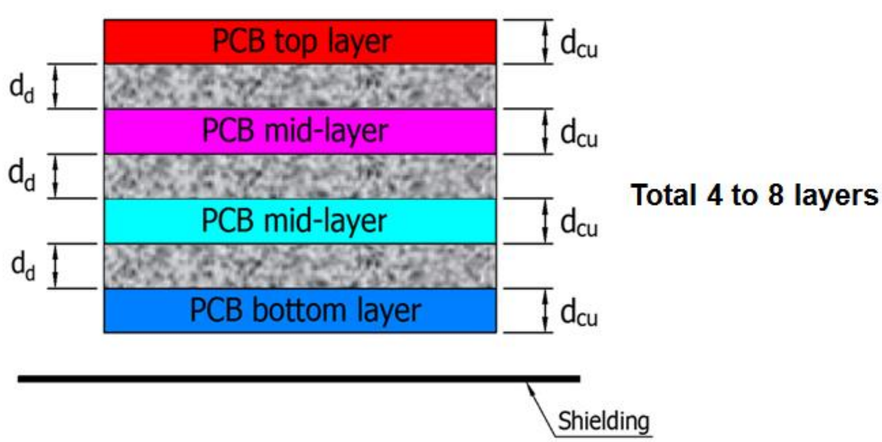


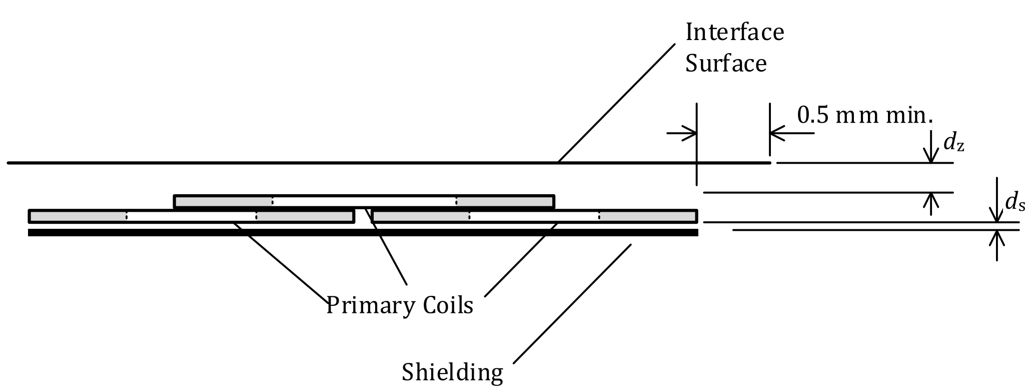
Table 55. Primary Coil parameters of Power Transmitter design A21

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

2.2.21.1.2 Shielding

As shown in Figure 82, Shielding protects the Base Station 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 $d_{\mathrm{s}} = 1.0$ mm.

Figure 82. Primary Coil assembly of Power Transmitter design A21



2.2.21.1.3 Interface Surface

As shown in Figure 82, the distance from the top face of the even-numbered Primary Coil to the Interface Surface of the Base Station 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 Base Station is also $d_{\mathrm{z}} = 2.75^{\pm 1}$ mm. In addition, the Interface Surface of the Base Station extends at least 0.5 mm beyond the outer dimensions of the Primary Coils.

2.2.21.1.4 Inter coil separation

If the Base Station contains multiple type A21 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall have a center-to-center distance of at least $49.2^{\pm 4}$ mm.

2.2.21.2 Electrical details

As shown in Figure 83, 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 $f_{\mathrm{op}} = 115 \ldots 205$ 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 *Parts 1 and 2: Interface Definitions*), 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 *Parts 1 and 2: Interface Definitions*. 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 56, Table 57, and Table 58 provide the values of several parameters, which are used in the PID algorithm.

Figure 83. Electrical diagram (outline) of Power Transmitter design A21

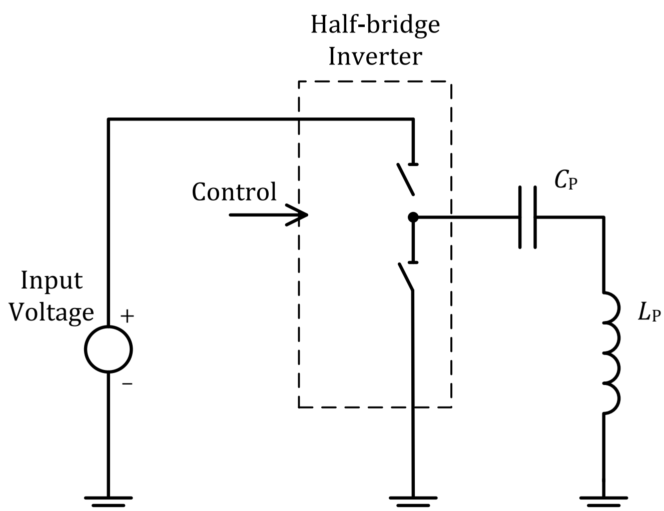


Table 56. PID parameters for Operating Frequency control

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 57. 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

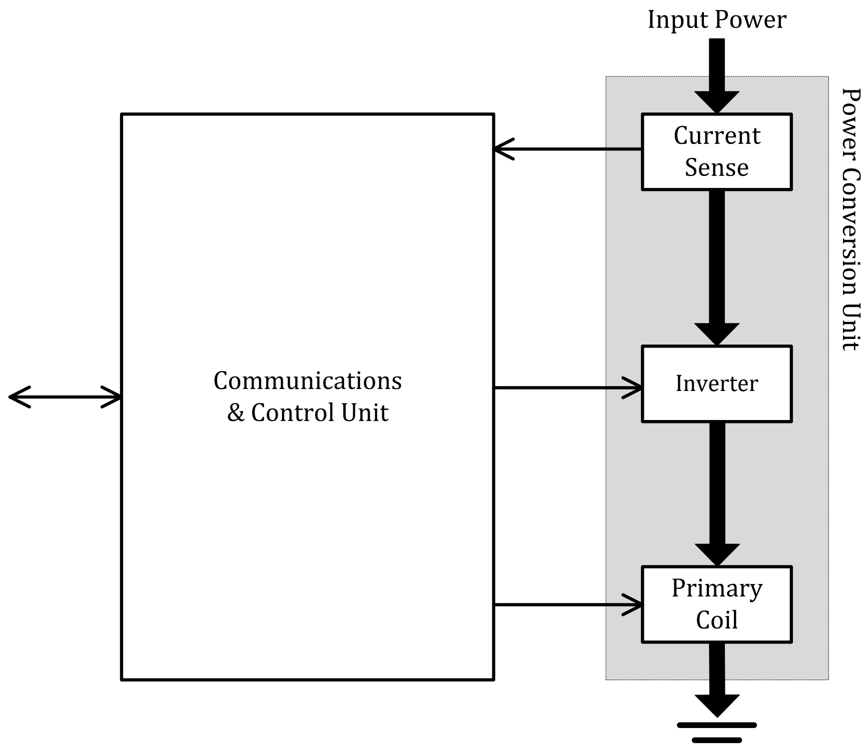
Table 58. PID parameters for duty cycle control

Parameter	Symbol	Value	Unit
Proportional gain	K_{p}	10	mA^{-1}
Integral gain	K_{i}	0.05	$\mathrm{mA}^{-1}\mathrm{ms}^{-1}$
Derivative gain	K_{d}	0	$\mathrm{mA}^{-1}\mathrm{ms}$
Integral term limit	M_{I}	3,000	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_{v}	−0.01	%

2.2.22 Power Transmitter design A22

Figure 84 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 84. Functional block diagram of Power Transmitter design A22



The Power Conversion Unit on the right-hand side of Figure 84 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 84 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 Base Station, e.g. for user interface purposes.

2.2.22.1 Mechanical details

Power Transmitter design A22 includes one Primary Coil as defined in Section 2.2.22.1.1, Shielding as defined in Section 2.2.22.1.2, and an Interface Surface as defined in Section 2.2.22.1.3.

2.2.22.1.1 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 85, a Primary Coil has a racetrack-like shape and consists of a single layer. Table 59 lists the dimensions of a Primary Coil.

Figure 85. Primary Coil of Power Transmitter design A22

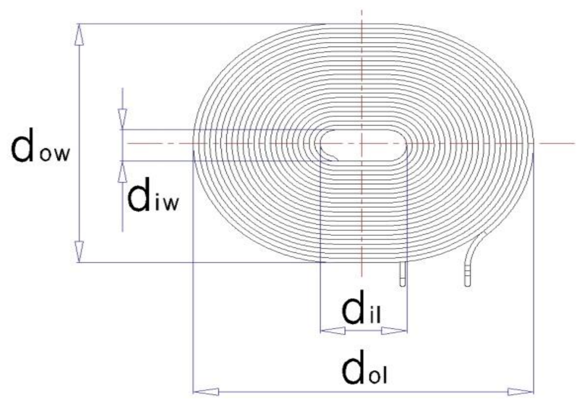


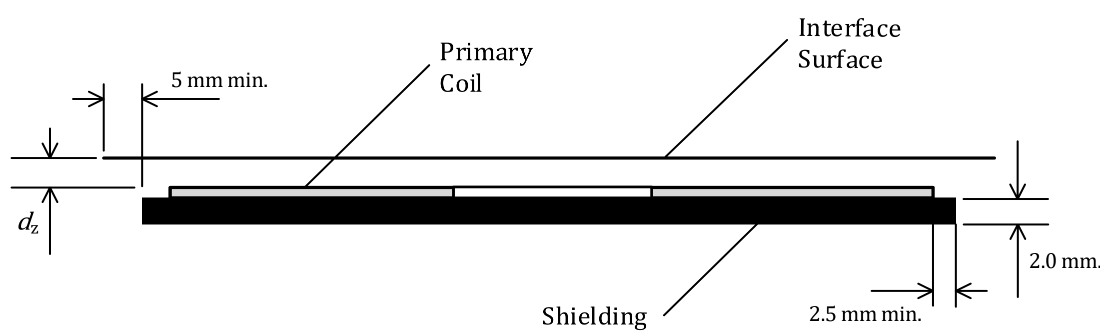
Table 59. Primary Coil parameters of Power Transmitter design A22

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

2.2.22.1.2 Shielding

As shown in Figure 86, Shielding protects the Base Station 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 86. Primary Coil assembly of Power Transmitter design A22



2.2.22.1.3 Interface Surface

As shown in Figure 86, the distance from the Primary Coil to the Interface Surface of the Base Station is $d_z = 2.5^{\pm 1.0}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Base Station extends at least 5 mm beyond the outer diameter of the Primary Coil.

2.2.22.1.4 Separation between multiple Power transmitters

If the Base Station contains multiple type A22 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall have a center-to-center distance of at least 66 mm.

2.2.22.2 Electrical details

As shown in Figure 87, 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 *Parts 1 and 2: Interface Definitions*), 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 *Parts 1 and 2: Interface Definitions.* 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 *Parts 1 and 2: Interface Definitions*. 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 60, Table 61, and Table 62 provide the values of several parameters, which are used in the PID algorithm.

Figure 87. Electrical diagram (outline) of Power Transmitter design A22

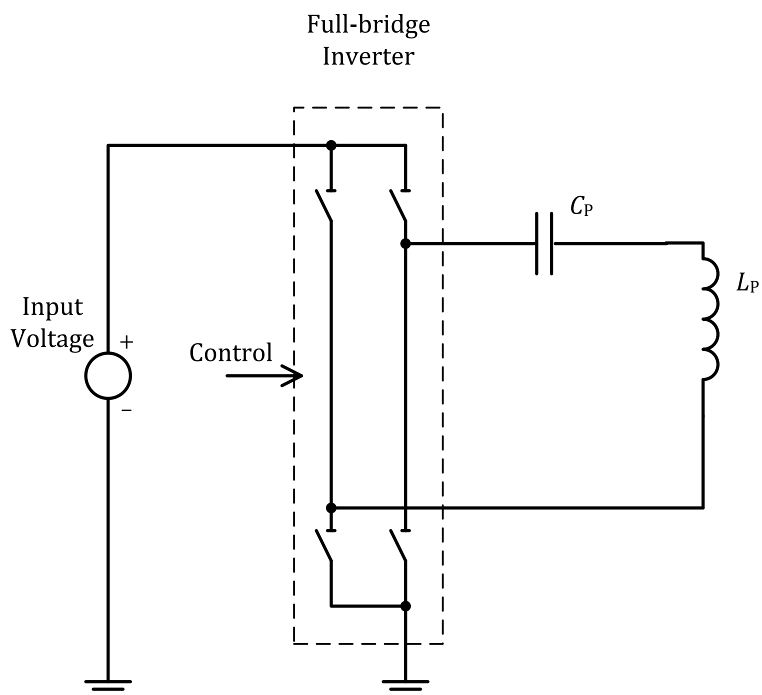


Table 60. PID parameters for voltage control

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 61. 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

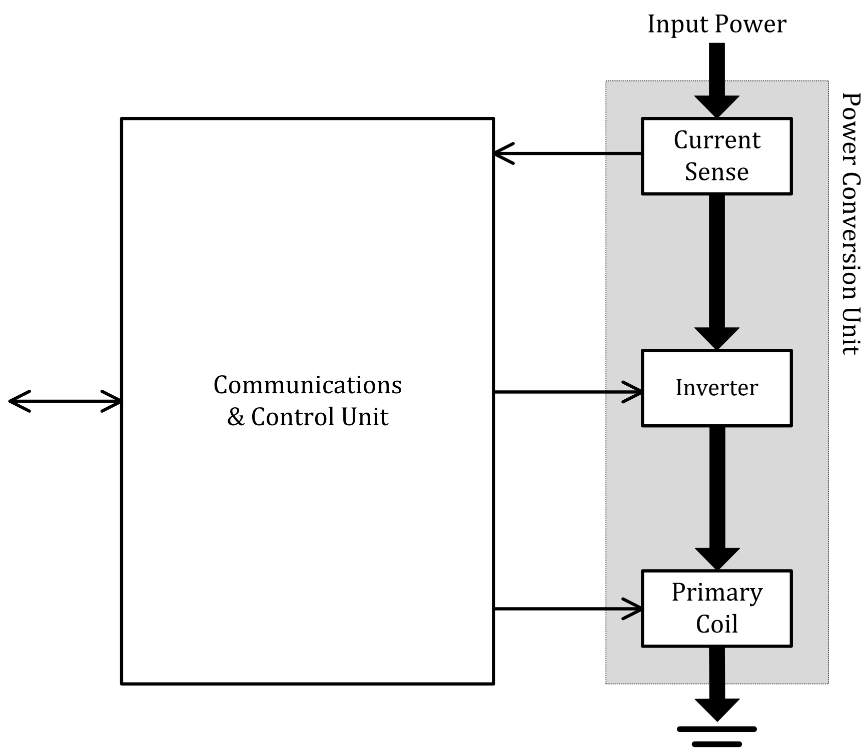
Table 62. PID parameters for duty control

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	°

2.2.23 Power Transmitter design A23

Figure 88 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 88. Functional block diagram of Power Transmitter design A23



The Power Conversion Unit on the right-hand side of Figure 88 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 88 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 Base Station, e.g. for user interface purposes.

2.2.23.1 Mechanical details

Power Transmitter design A23 includes one Primary Coil as defined in Section 2.2.23.1.1, Shielding as defined in Section 2.2.23.1.2, and an Interface Surface as defined in Section 2.2.23.1.3.

2.2.23.1.1 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 89, a Primary Coil has a racetrack-like shape and consists of a single layer. Table 63 lists the dimensions of a Primary Coil.

Figure 89. Primary Coil of Power Transmitter design A23

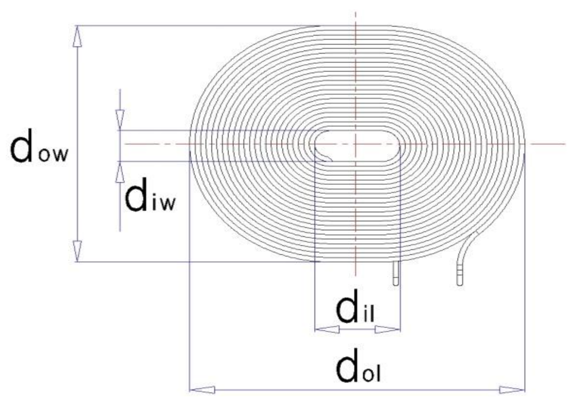


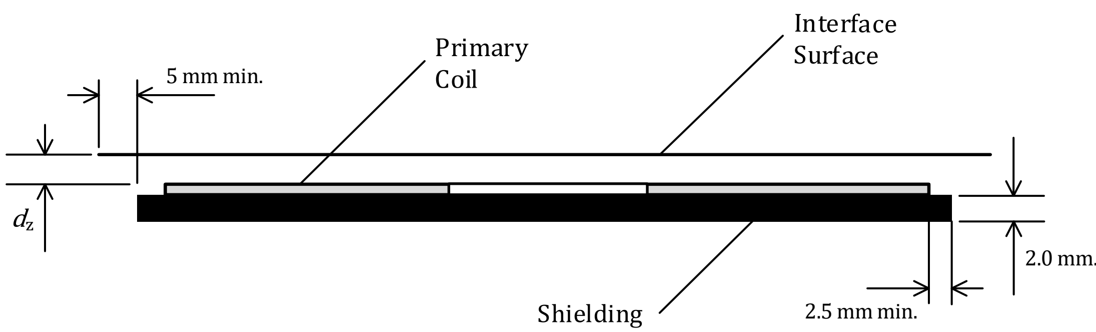
Table 63. Primary Coil parameters of Power Transmitter design A23

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

2.2.23.1.2 Shielding

As shown in Figure 90, Shielding protects the Base Station 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 90. Primary Coil assembly of Power Transmitter design A23



2.2.23.1.3 Interface Surface

As shown in Figure 90, the distance from the Primary Coil to the Interface Surface of the Base Station is $d_z = 2.5^{\pm 1.0}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Base Station extends at least 5 mm beyond the outer diameter of the Primary Coil.

2.2.23.1.4 Separation between multiple Power transmitters

If the Base Station contains multiple type A23 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall have a center-to-center distance of at least 66 mm.

2.2.23.2 Electrical details

As shown in Figure 91, 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 $L_{\mathrm{P}} = 19.0^{\pm10\%}$ μH. The value of the series capacitance is $C_{\mathrm{P}} = 168^{\pm10\%}$ 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 *Parts 1 and 2: Interface Definitions*), the Power Transmitter shall use an Operating Frequency of $108^{\pm5}$ 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 *Parts 1 and 2: Interface Definitions.* 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 *Parts 1 and 2: Interface Definitions*. 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 A23 Power Transmitter shall determine the amplitude of the Primary Coil current with a resolution of 5 mA or better. Finally, Table 64, Table 65, and Table 66 provide the values of several parameters, which are used in the PID algorithm.

Figure 91. Electrical diagram (outline) of Power Transmitter design A23

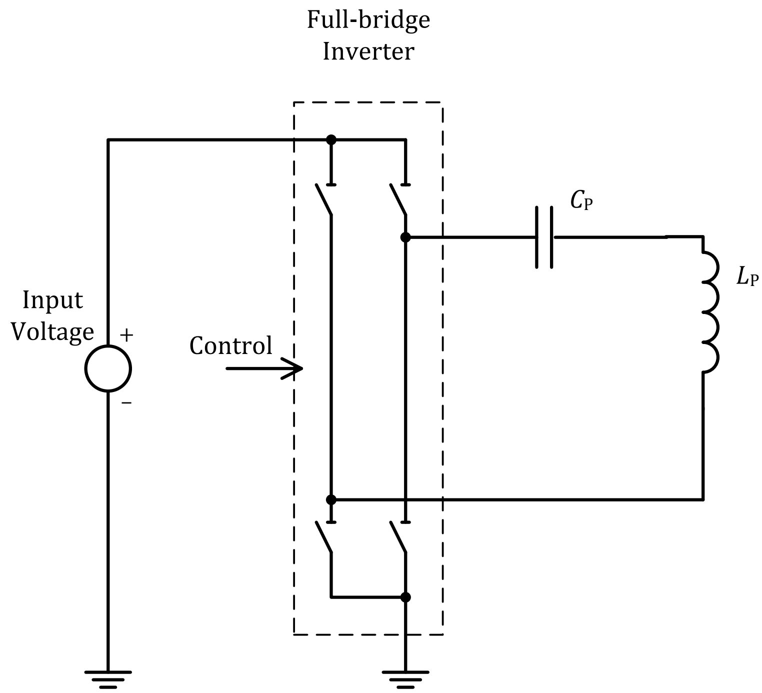


Table 64. PID parameters for voltage control

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 65. PID parameters for Operating Frequency 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	20,000	N.A.
Scaling factor	S_v	1.0	Hz

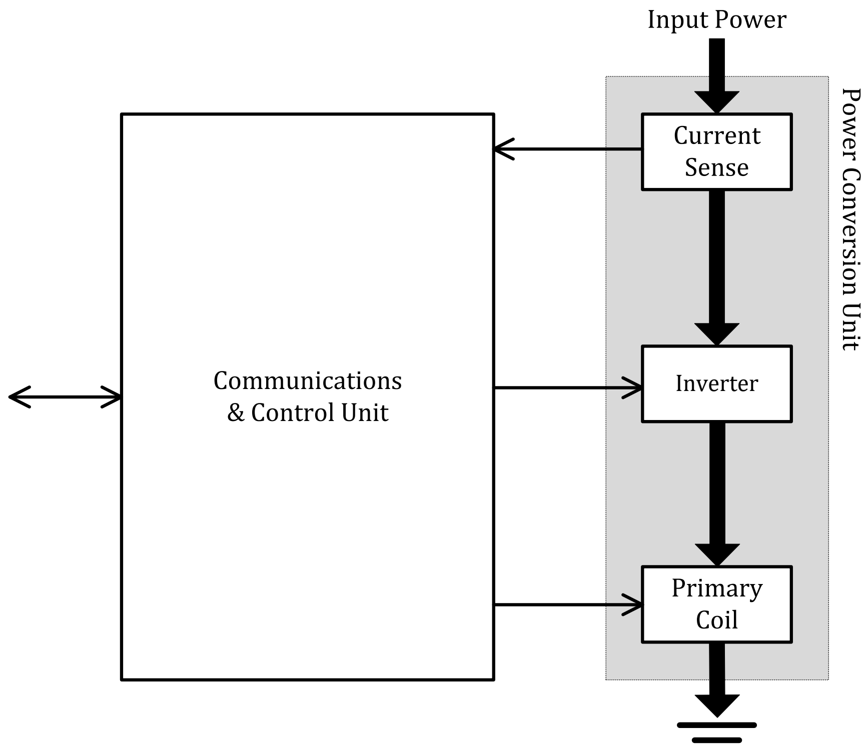
Table 66. PID parameters for duty control

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	20,000	N.A.
Scaling factor	S_v	-0.1	°

2.2.24 Power Transmitter design A24

Figure 92 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 92. Functional block diagram of Power Transmitter design A24



The Power Conversion Unit on the right-hand side of Figure 92 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 92 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 Base Station, e.g. for user interface purposes.

2.2.24.1 Mechanical details

Power Transmitter design A24 includes one Primary Coil as defined in Section 2.2.24.1.1, Shielding as defined in Section 2.4.3.1.2, and an Interface Surface as defined in Section 2.2.24.1.3.

2.2.24.1.1 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 93, a Primary Coil has a circular shape and consists of a single layer. Table 67 lists the dimensions of a Primary Coil.

Figure 93. Primary Coil of Power Transmitter design A24

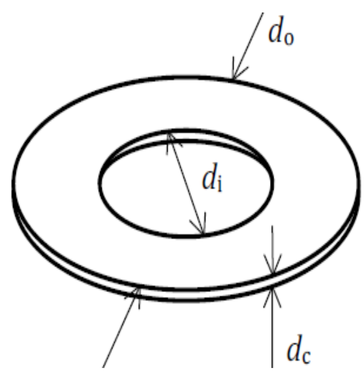


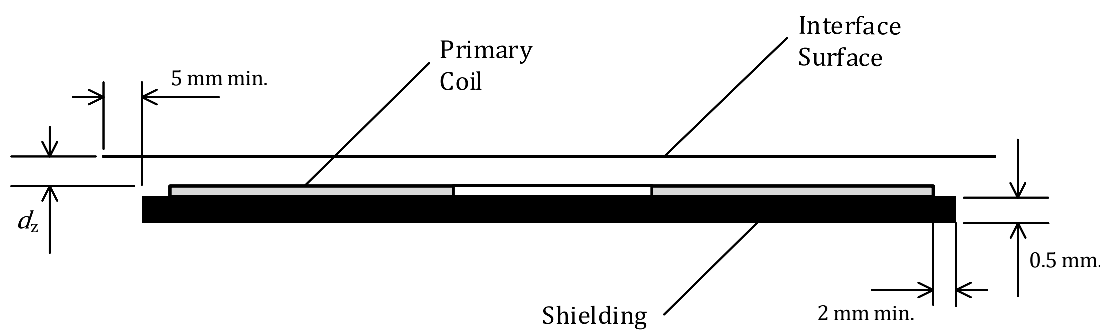
Table 67. Primary Coil parameters of Power Transmitter design A24

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

2.2.24.1.2 Shielding

As shown in Figure 94, Shielding protects the Base Station 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 94. Primary Coil assembly of Power Transmitter design A24



2.2.24.1.3 Interface Surface

As shown in Figure 94, the distance from the Primary Coil to the Interface Surface of the Base Station is $d_z = 3.0^{\pm 0.5}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Base Station extends at least 5 mm beyond the outer diameter of the Primary Coil.

2.2.24.1.4 Separation between multiple Power transmitters

If the Base Station contains multiple type A24 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall have a center-to-center distance of at least 50 mm.

2.2.24.2 Electrical details

As shown in Figure 95, 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 $f_{\mathrm{op}} = 110 \ldots 205$ 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 *Parts 1 and 2: Interface Definitions*), 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 *Parts 1 and 2: Interface Definitions.* 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 *Parts 1 and 2: Interface Definitions*. 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 68 and Table 69 provide the values of several parameters, which are used in the PID algorithm.

Figure 95. Electrical diagram (outline) of Power Transmitter design A24

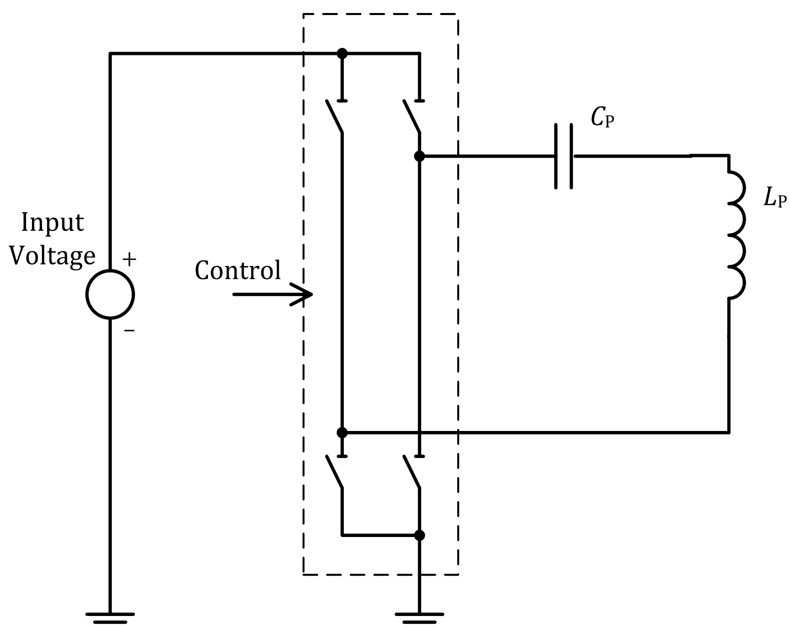


Table 68. PID parameters for Operating Frequency control

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

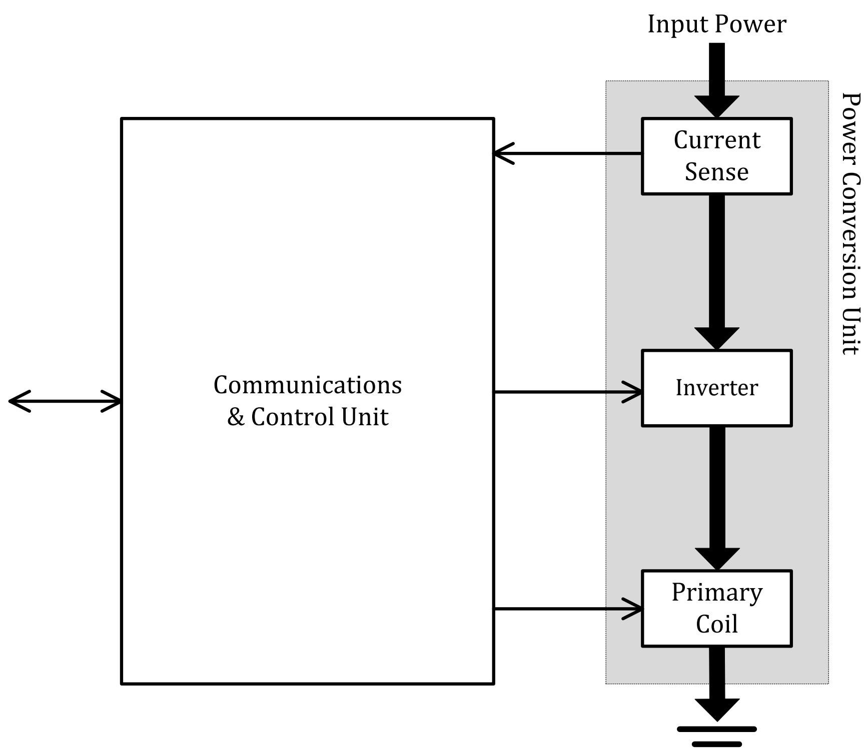
Table 69. PID parameters for duty cycle control

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}	20,000	N.A.
Scaling factor	S_{v}	-0.1	°

2.2.25 Power Transmitter design A25

Figure 96 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 96. Functional block diagram of Power Transmitter design A25



The Power Conversion Unit on the right-hand side of Figure 96 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 96 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 Base Station, e.g. for user interface purposes.

2.2.25.1 Mechanical details

Power Transmitter design A25 includes one Primary Coil as defined in Section 2.2.25.1.1, Shielding as defined in Section 2.2.25.1.2, and an Interface Surface as defined in Section 2.2.25.1.3.

2.2.25.1.1 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 97, a Primary Coil has a racetrack-like shape and consists of a single layer. Table 70 lists the dimensions of a Primary Coil.

Figure 97. Primary Coil of Power Transmitter design A25

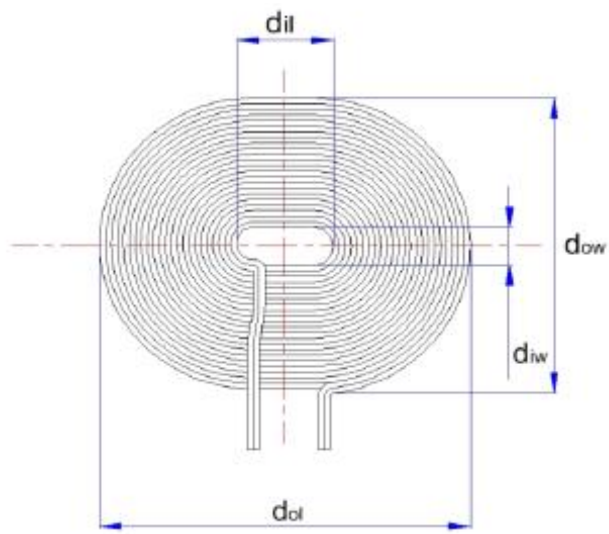


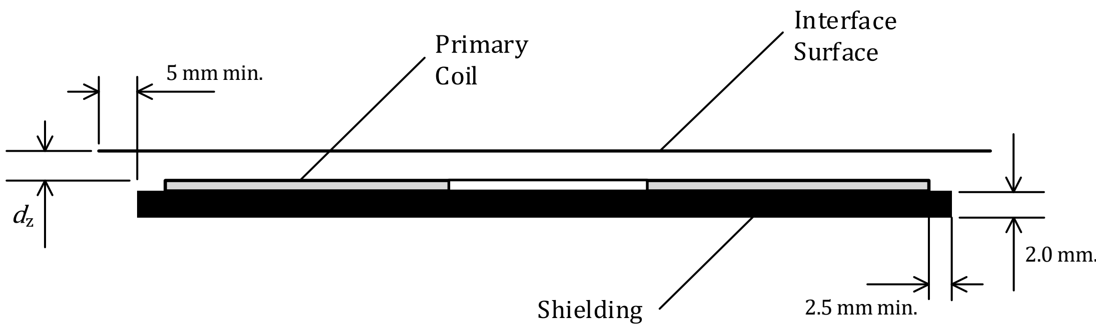
Table 70. Primary Coil parameters of Power Transmitter design A25

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

2.2.25.1.2 Shielding

As shown in Figure 98, Shielding protects the Base Station 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 98. Primary Coil assembly of Power Transmitter design A25



2.2.25.1.3 Interface Surface

As shown in Figure 98, the distance from the Primary Coil to the Interface Surface of the Base Station is $d_z = 2.5^{\pm 1.0}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Base Station extends at least 5 mm beyond the outer diameter of the Primary Coil.

2.2.25.1.4 Separation between multiple Power transmitters

If the Base Station contains multiple type A25 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall have a center-to-center distance of at least 67.2 mm.

2.2.25.2 Electrical details

As shown in Figure 99, 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 *Parts 1 and 2: Interface Definitions*), 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 *Parts 1 and 2: Interface Definitions.* 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 *Parts 1 and 2: Interface Definitions*. 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 71 and Table 72 provide the values of several parameters, which are used in the PID algorithm.

Figure 99. Electrical diagram (outline) of Power Transmitter design A25

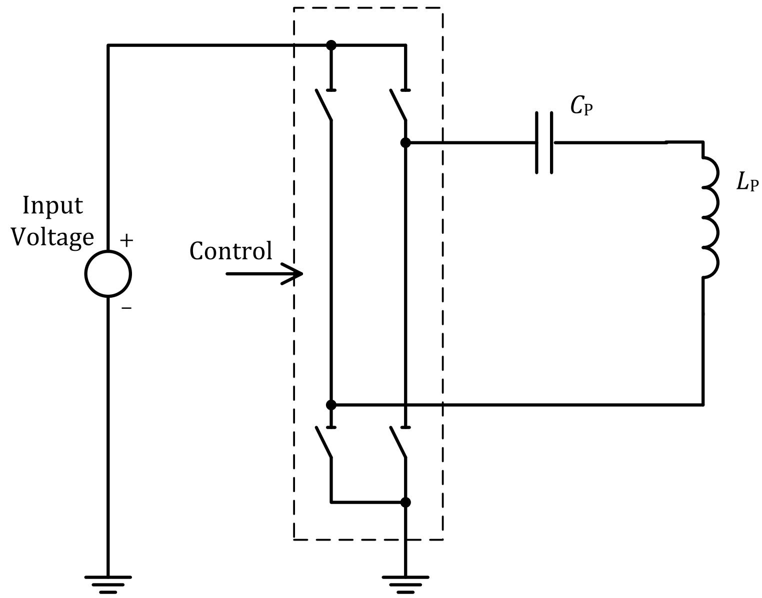


Table 71. PID parameters for Operating Frequency control

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

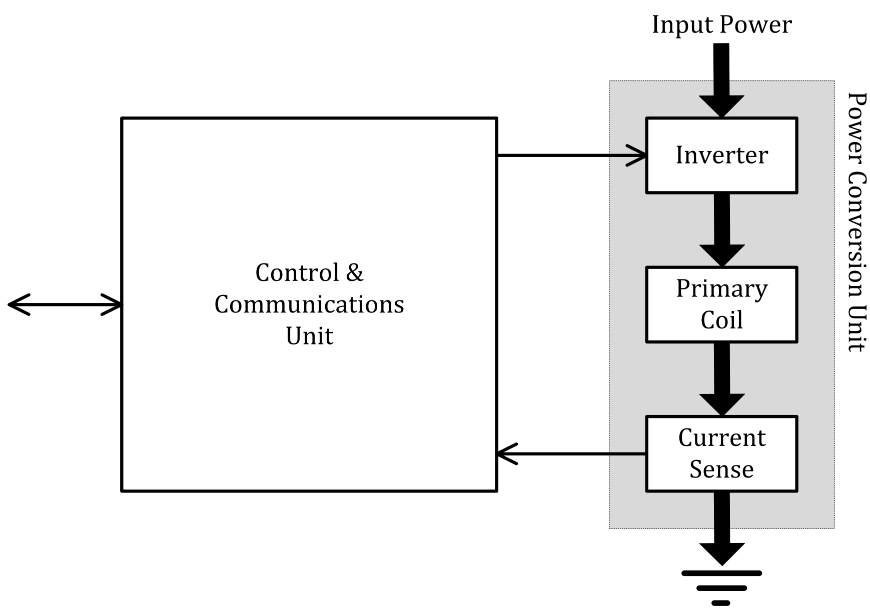
Table 72. PID parameters for duty cycle control

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	°

2.2.26 Power Transmitter design A26

Figure 100 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 100. Functional block diagram of Power Transmitter design A26



The Power Conversion Unit on the right-hand side of Figure 100 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 100comprises 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 Base Station, e.g. for user interface purposes.

2.2.26.1 Mechanical details

Power Transmitter design A26 includes a single Primary Coil as defined in Section 2.2.26.1.1, Shielding as defined in Section 2.2.26.1.2, an Interface Surface as defined in Section 2.2.26.1.3, and an alignment aid as defined in Section 2.2.26.1.4.

2.2.26.1.1 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 101, the Primary Coil has a triangular shape and consists of a single layer. Table 73 lists the dimensions of the Primary Coil.

Figure 101. Primary Coil of Power Transmitter design A26

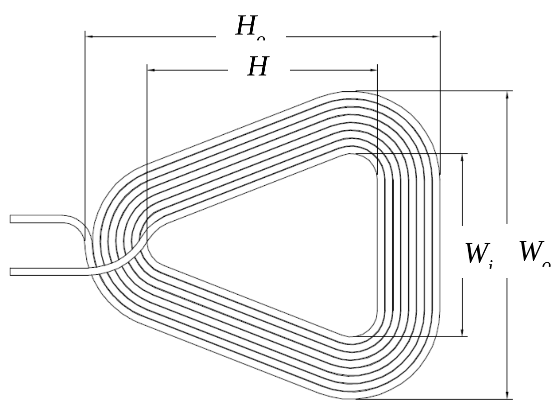


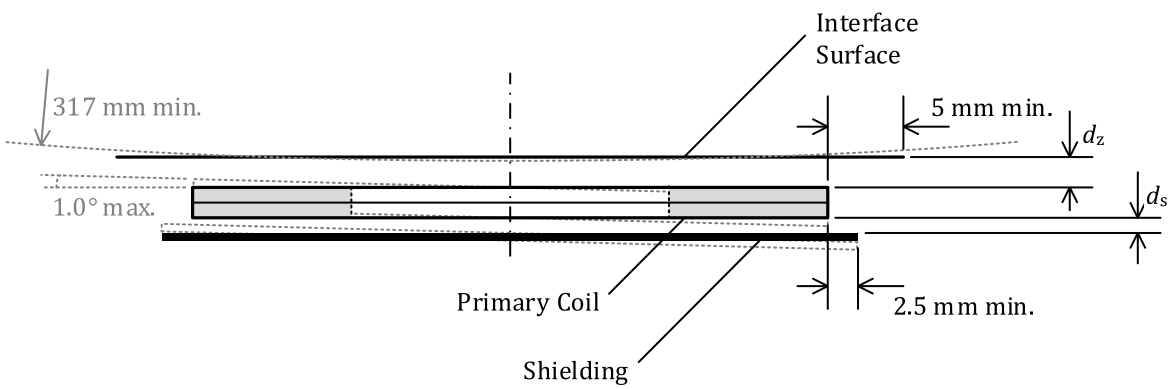
Table 73. Primary Coil parameters of Power Transmitter design A26

Parameter	Symbol	Value
Outer height	H_{o}	52±0.5 mm
Inner height	H_{i}	34±0.5 mm
Outer width	W_{o}	46±0.5 mm
Inner width	W_{i}	28±0.5 mm
Thickness	d_{c}	1.1+0.3 mm
Number of turns per layer	N	8
Number of layers	–	1

2.2.26.1.2 Shielding

As shown in Figure 102, Shielding protects the Base Station 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 $d_{\mathrm{s}} = 1.0$ mm.

Figure 102. Primary Coil assembly of Power Transmitter design A26



2.2.26.1.3 Interface Surface

As shown in Figure 102, the distance from the Primary Coil to the Interface Surface of the Base Station is $d_z = 2^{+0.5}_{-0.5}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Base Station 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 102.

2.2.26.1.4 Alignment aid

The user manual of the Base Station 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 Mobile Device positioning to help alignment.

NOTE Examples of Base Station alignment aids to assist the user positioning of the Mobile Device 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.

2.2.26.1.5 Inter coil separation

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

2.2.26.2 Electrical details

As shown in Figure 103, 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 $f_{\mathrm{op}} = 110 \ldots 205$ 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 (see *Parts 1 and 2: Interface Definitions*), 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 *Parts 1 and 2: Interface Definitions*. 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 74, Table 75, and Table 76 provide the values of several parameters, which are used in the PID algorithm.

Figure 103. Electrical diagram (outline) of Power Transmitter design A26

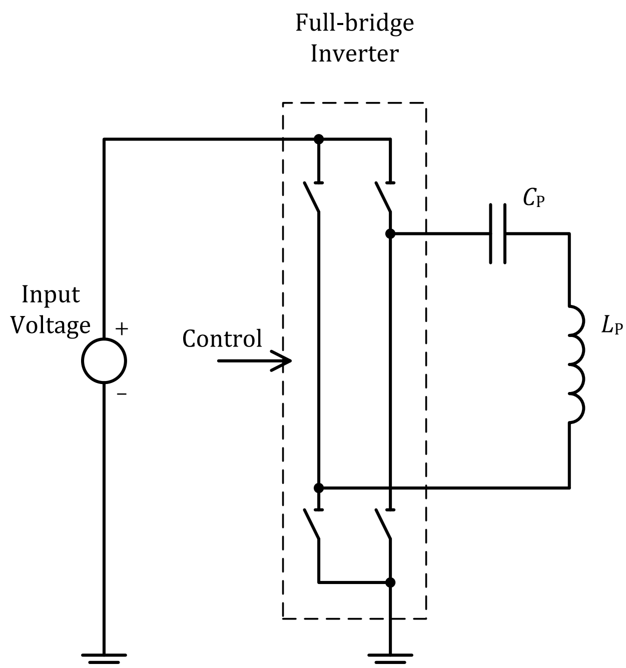


Table 74. PID parameters for Operating Frequency control

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 75. 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

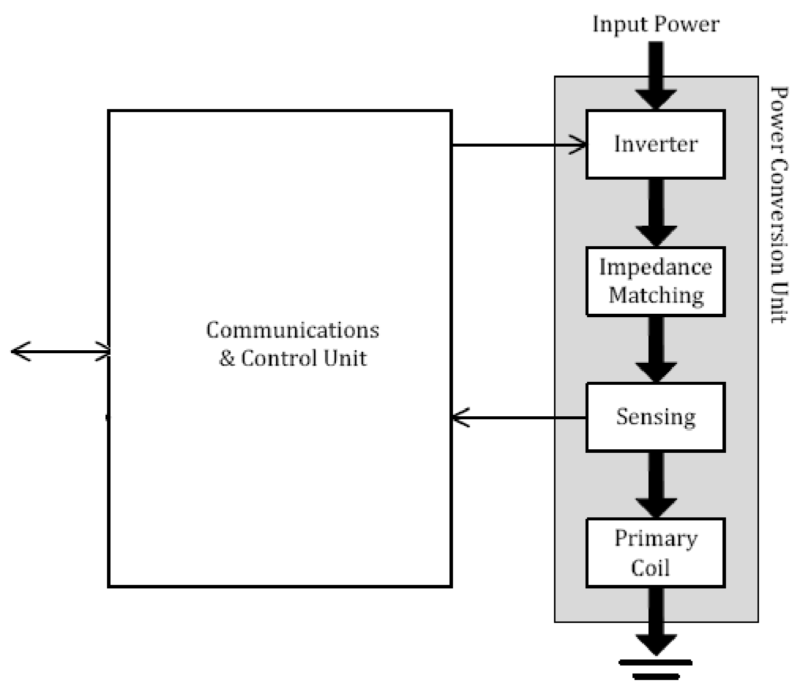
Table 76. PID parameters for duty cycle control

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

2.2.27 Power Transmitter design A27

Figure 104 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 104. Functional block diagram of Power Transmitter design A27



The Power Conversion Unit on the right-hand side of Figure 104 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 104 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 Base Station, e.g. for user interface purposes.

2.2.27.1 Mechanical details

Power Transmitter design A27 includes a Primary Coil array as defined in Section 2.2.27.1.1, Shielding as defined in Section 2.2.27.1.2, and an Interface Surface as defined in Section 2.2.27.1.3.

2.2.27.1.1 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 105, the Primary Coil has a circular shape and consists of one layer. Table 77 lists the dimensions of the Primary Coil.

Figure 105. Primary Coil of Power Transmitter design A27

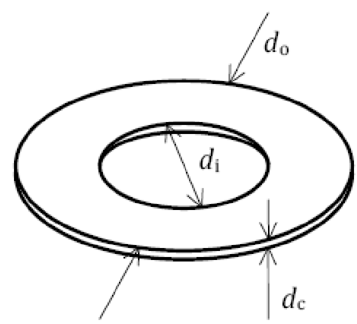


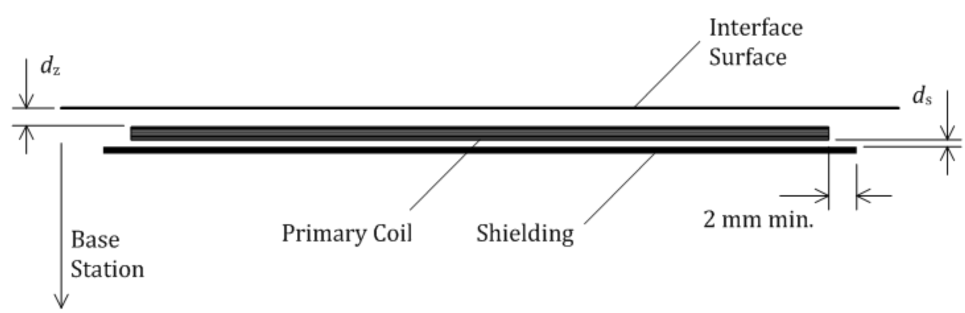
Table 77. Primary Coil parameters of Power Transmitter design A27

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

2.2.27.1.2 Shielding

As shown in Figure 106, Transmitter design A27 employs Shielding to protect the Base Station 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 106. Primary Coil array assembly of Power Transmitter design A27



2.2.27.1.3 Interface Surface

As shown in Figure 106, the distance from the Primary Coil to the Interface Surface of the Base Station 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.

2.2.27.1.4 Alignment aid

The user manual of the Base Station 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 Mobile Device positioning to help alignment.

NOTE Examples of Base Station alignment aids to assist the user positioning of the Mobile Device 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.

2.2.27.1.5 Inter coil separation

If the Base Station contains multiple type A27 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall have a center-to-center distance of at least 70 mm.

2.2.27.2 Electrical details

As shown in Figure 107, 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 $f_{\mathrm{op}} = 110 \ldots 120$ 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, $L_{\mathrm{m}} = 8.2^{\pm 20\%}$ μH, $C_{\mathrm{ser}} = 100^{\pm 5\%}$ nF and $C_{\mathrm{par}} = 100^{\pm 5\%}$ 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 108. 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 *Parts 1 and 2: Interface Definitions*), it shall use an initial phase difference of 120°.

Control of the power transfer shall proceed using the PID algorithm, which is defined in *Parts 1 and 2: Interface Definitions*. 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 A27 Transmitter shall determine the amplitude of the current into the Primary Coil with a resolution of 7 mA or better. Finally, Table 78 provides the values of several parameters, which are used in the PID algorithm.

Figure 107. Electrical diagram (outline) of Power Transmitter design A27

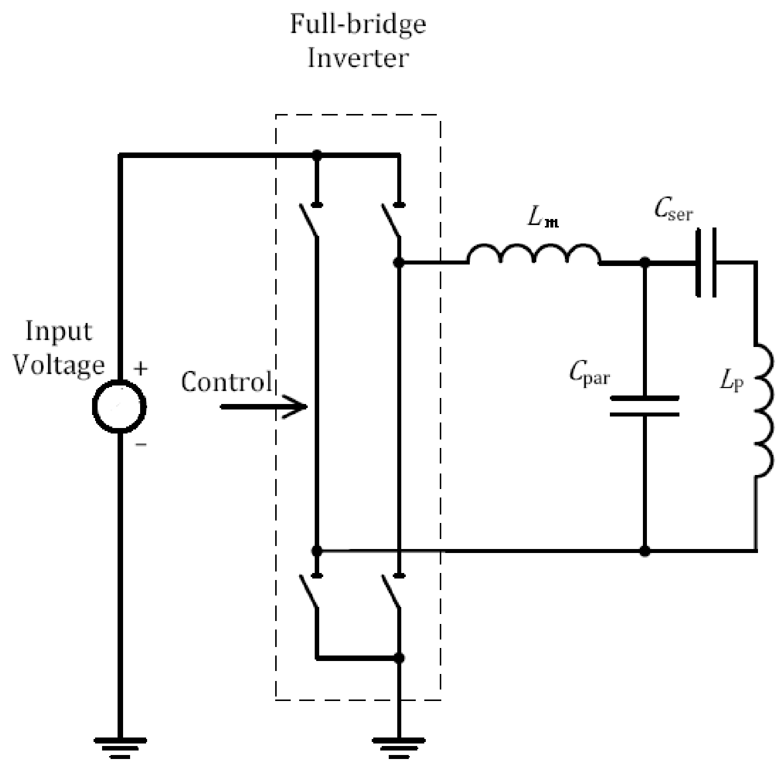


Figure 108. Control signals to the inverter

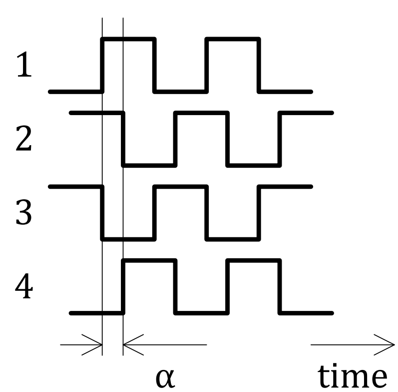


Table 78. Control parameters for power control

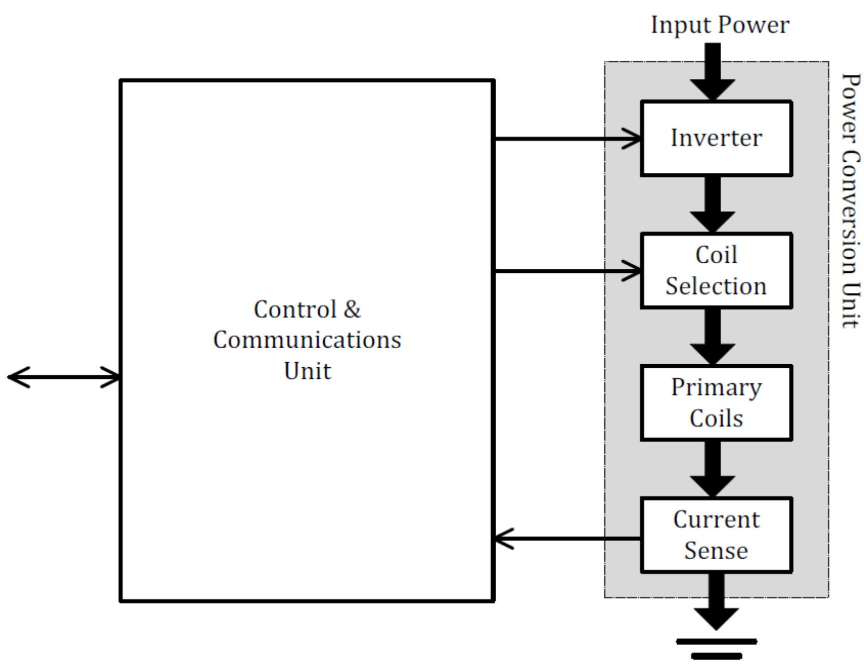
Parameter	Symbol	Value	Unit
Proportional gain	K_p	1	mA^{-1}
Integral gain	K_i	0	$mA^{-1}ms^{-1}$
Derivative gain	K_d	0	$mA^{-1}ms$
Integral term limit	M_I	N.A.	N.A.
PID output limit	M_{PID}	2,000	N.A.
Scaling factor	S_v	0.01	°

2.2.28 Power Transmitter designs A28 and A28a

2.2.28.1 Power Transmitter design A28

Figure 109 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 109. Functional block diagram of Power Transmitter design A28



The Power Conversion Unit on the right-hand side of Figure 109 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 109 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 Base Station, e.g. for user interface purposes.

2.2.28.1.1 Mechanical details

Power Transmitter design A28 includes one or more Primary Coils as defined in Section 2.2.28.1.1.1, Shielding as defined in Section 2.2.28.1.1.2, and Interface Surface as defined in Section 2.2.28.1.1.3.

2.2.28.1.1.1 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 110, the Primary Coil has a rectangular shape and consists of a single layer. Table 79 lists the dimensions of the Primary Coil.

Figure 110. Primary Coil of Power Transmitter design A28

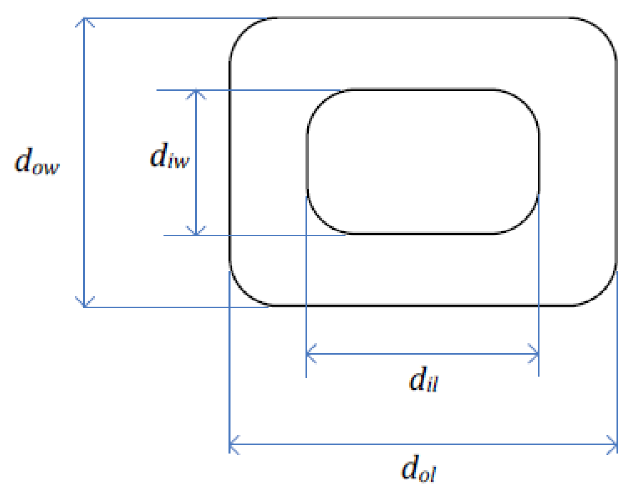
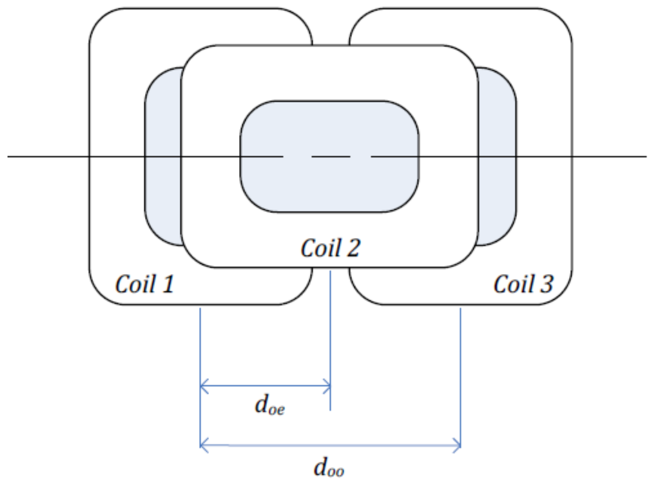


Table 79. Primary Coil parameters of Power Transmitter design A28

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 $d_{\mathrm{oo}} = 49.2^{\pm 4}$ mm between their centers. Even numbered coils are placed orthogonal to the odd numbered coils with a displacement of $d_{\mathrm{oe}} = 24.6^{\pm 2}$ mm between their centers. See Figure 111.

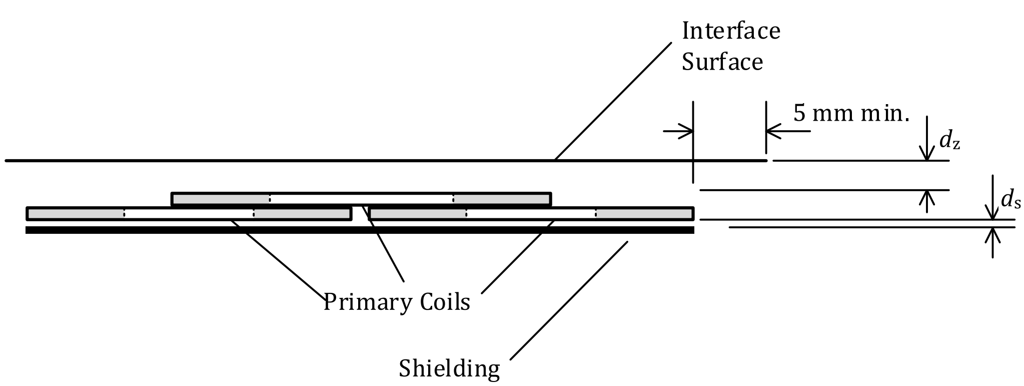
Figure 111. Primary Coils of Power Transmitter design A28



2.2.28.1.1.2 Shielding

As shown in Figure 112, Shielding protects the Base Station 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 $d_{\mathrm{s}} = 1.0$ mm.

Figure 112. Primary Coil assembly of Power Transmitter design A28



2.2.28.1.1.3 Interface Surface

As shown in Figure 112, the distance from the top face of the even-numbered Primary Coil to the Interface Surface of the Base Station is $\mathrm{d_z} = 2^{+0.5}_{-0.25}$ 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 Base Station extends at least 5 mm beyond the outer dimensions of the Primary Coils.

2.2.28.1.1.4 Inter coil separation

If the Base Station contains multiple type A28 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall have a center-to-center distance of at least $49.2^{\pm 4}$ mm.

2.2.28.1.2 Electrical details

As shown in Figure 113, 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 $f_{\mathrm{op}} = 115 \ldots 205$ 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

- $0.01 \times f_{\mathrm{op}} - 0.7$ 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 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 *Parts 1 and 2: Interface Definitions*), 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 *Parts 1 and 2: Interface Definitions*. 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 80, Table 81, and Table 82 provide the values of several parameters, which are used in the PID algorithm.

Figure 113. Electrical diagram (outline) of Power Transmitter design A28

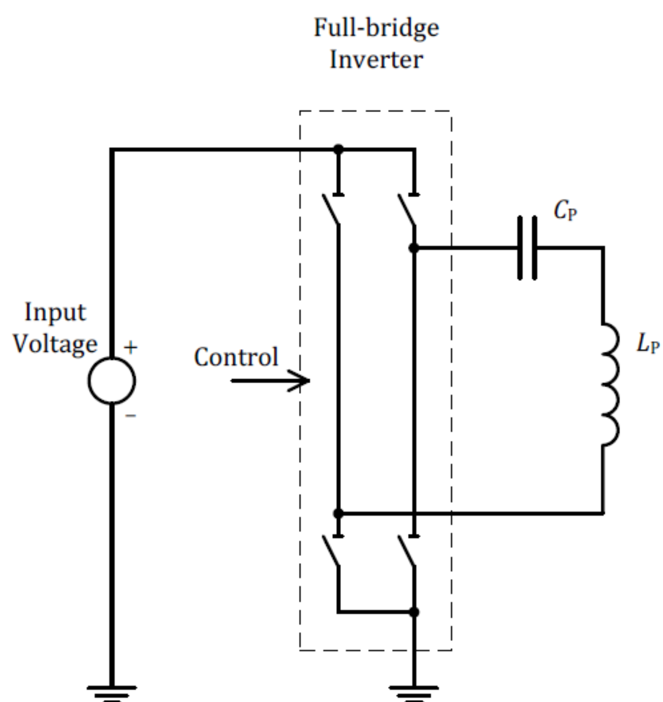


Table 80. PID parameters for Operating Frequency control

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

Table 81. 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

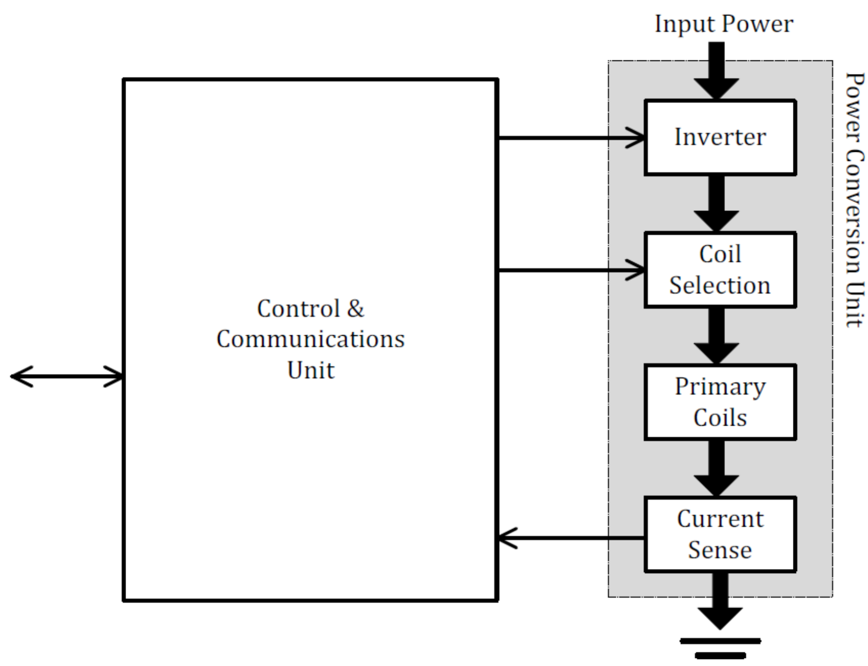
Table 82. PID parameters for duty cycle control

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

2.2.28.2 Power Transmitter design A28a

Figure 114 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 114. Functional block diagram of Power Transmitter design A28a



The Power Conversion Unit on the right-hand side of Figure 114 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 114 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 Base Station, e.g. for user interface purposes.

2.2.28.2.1 Mechanical details

Power Transmitter design A28a includes one or more Primary Coils as defined in Section 2.2.28.1.1.1, Shielding as defined in Section 2.2.28.1.1.2, and Interface Surface as defined in Section 2.2.28.1.1.3.

2.2.28.2.1.1 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 115, the Primary Coil has a rectangular shape and consists of a single layer. Table 83 lists the dimensions of the Primary Coil.

Figure 115. Primary Coil of Power Transmitter design A28a

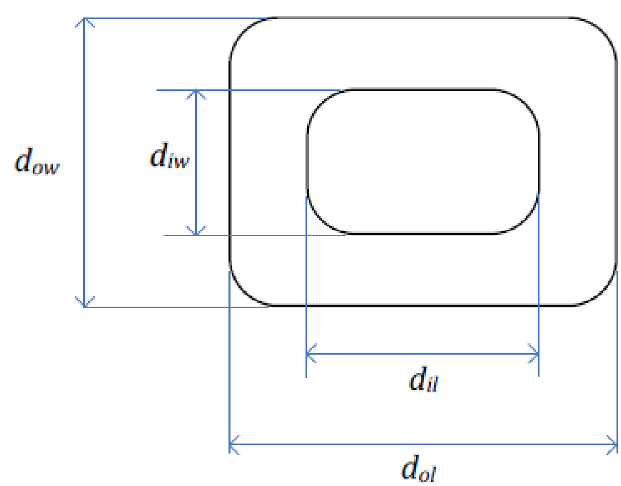
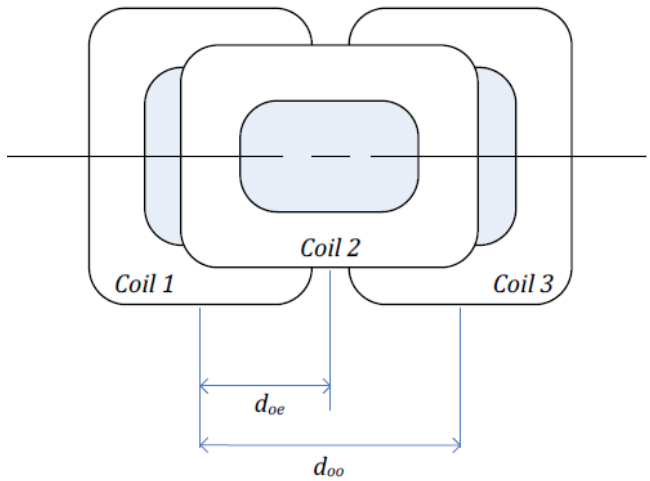


Table 83. Primary Coil parameters of Power Transmitter design A28a

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 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 $d_{\mathrm{oo}} = 49.2^{\pm 4}$ mm between their centers. Even numbered coils are placed orthogonal to the odd numbered coils with a displacement of $d_{\mathrm{oe}} = 24.6^{\pm 2}$ mm between their centers. See Figure 116.

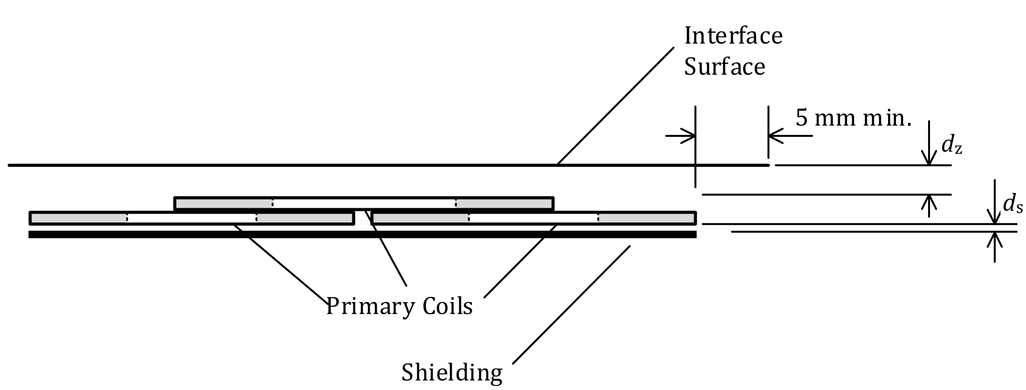
Figure 116. Primary Coils of Power Transmitter design A28a



2.2.28.2.1.2 *Shielding*

As shown in Figure 117, Shielding protects the Base Station 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 $d_{\mathrm{s}} = 1.0$ mm.

Figure 117. Primary Coil assembly of Power Transmitter design A28a



2.2.28.2.1.3 Interface Surface

As shown in Figure 117, the distance from the top face of the even-numbered Primary Coil to the Interface Surface of the Base Station is $\mathrm{d_z} = 2^{+0.5}_{-0.25}$ 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 Base Station is also $\mathrm{d_z} = 3.5^{+0.5}_{-0.25}$ mm. In addition, the Interface Surface of the Base Station extends at least 5 mm beyond the outer dimensions of the Primary Coils.

2.2.28.2.1.4 Inter coil separation

If the Base Station contains multiple type A28a Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall have a center-to-center distance of at least $49.2^{\pm 4}$ mm.

2.2.28.2.2 Electrical details

As shown in Figure 118, 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 $f_{\mathrm{op}} = 115 \ldots 148$ 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 $0.01 \times f_{\mathrm{op}} - 0.7$ 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 *Parts 1 and 2: Interface Definitions*), 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 *Parts 1 and 2: Interface Definitions*. 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 84, Table 85, and Table 86 provide the values of several parameters, which are used in the PID algorithm.

Figure 118. Electrical diagram (outline) of Power Transmitter design A28a

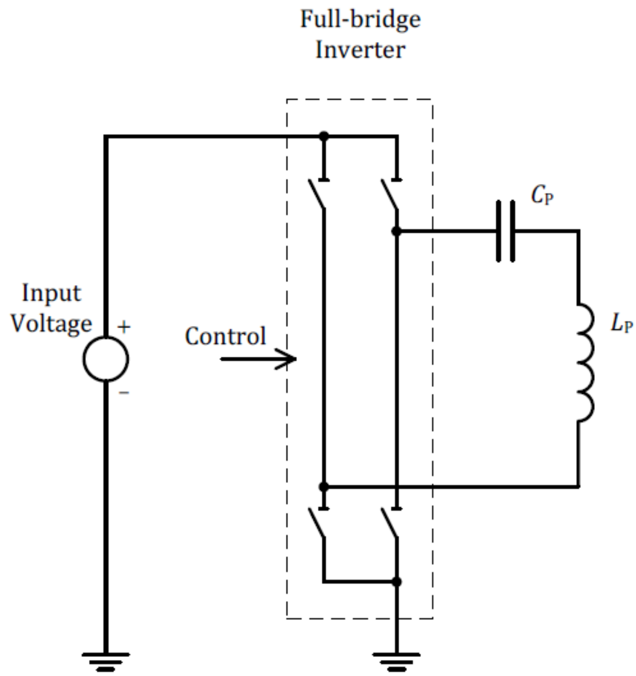


Table 84. PID parameters for Operating Frequency control

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

Table 85. Operating Frequency dependent scaling factor

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

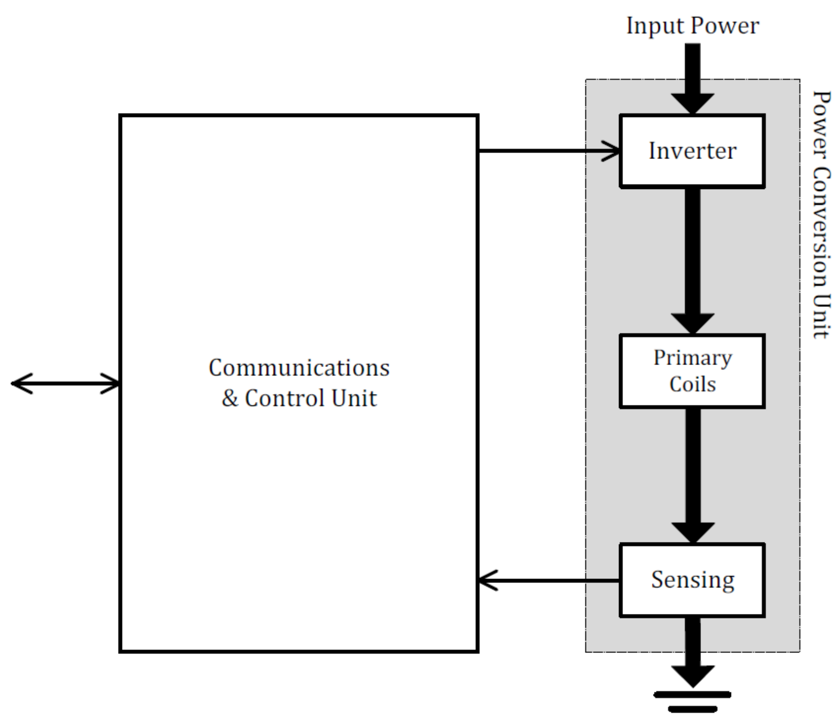
Table 86. PID parameters for duty cycle control

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

2.2.29 Power Transmitter design A29

Figure 119 illustrates the functional block diagram of Power Transmitter Design A29.

Figure 119. Functional block diagram of Power Transmitter A29



The Power Conversion Unit on the right-hand side of Figure 119 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 119 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 Base Station, e.g. for user interface purposes.

2.2.29.1 Mechanical details

Power Transmitter design A29 includes a Primary Coil array as defined in Section 2.2.29.1.1, Shielding as defined in Section 2.2.29.1.2, and an Interface Surface as defined in Section 2.2.29.1.3.

2.2.29.1.1 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 120 the Primary Coil has a circular shape and consists of two layers with a total of 13 turns. Table 87 lists the dimensions of the Primary Coil.

Figure 120. Primary Coil of Power Transmitter A29

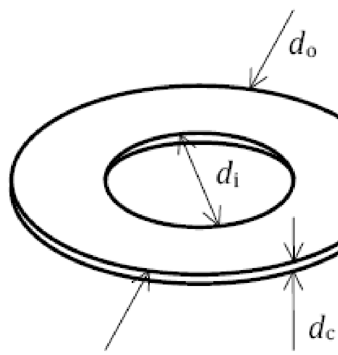


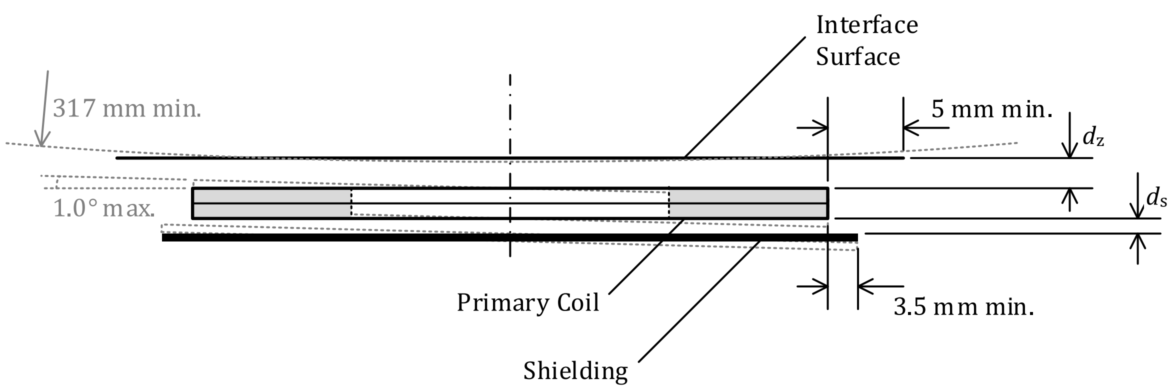
Table 87. Primary Coil parameters of Power Transmitter design A29

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

2.2.29.1.2 Shielding

As shown in Figure 121, Shielding protects the Base Station 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 121. Primary Coil assembly of Power Transmitter design A29



2.2.29.1.3 Interface Surface

As shown in Figure 121, the distance from the Primary Coil to the Interface Surface of the Base Station is $d_z = 2.5^{\pm 0.5}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Base Station 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 121.

2.2.29.1.4 Alignment Aid

The user manual of the Base Station 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 Mobile Device positioning to help alignment.

NOTE Examples of Base Station alignment aids to assist the user positioning of the Mobile Device 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.

2.2.29.1.4.1 Inter coil separation

If the Base Station contains multiple type A29 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall have a center-to-center distance of at least 70 mm.

2.2.29.2 Electrical Details

As shown in Figure 122, 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 $L_{\mathrm{p}} = 10^{\pm 10\%}$ μH. The value of the total series capacitance $C_{\mathrm{p}} = 247^{\pm 5\%}$ 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 *Parts 1 and 2: Interface Definitions*), 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 *Parts 1 and 2: Interface Definitions*. The controlled variable $v^{(i)}$ introduced in the definition of that algorithm represents the input voltage. Finally, Table 88 provides the values of several parameters, which are used in the PID algorithm.

Figure 122. Electrical diagram (outline) Primary Coil of Power Transmitter design A29

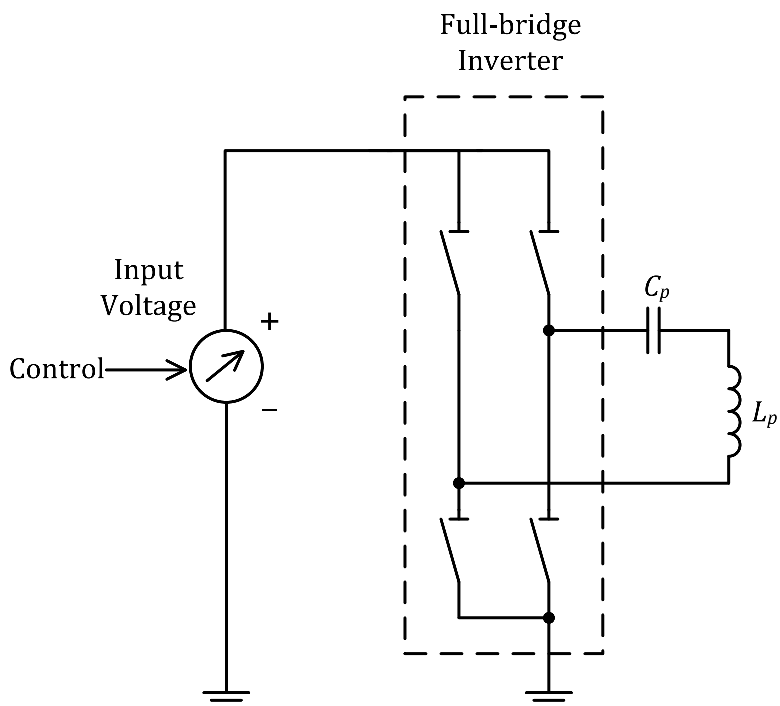


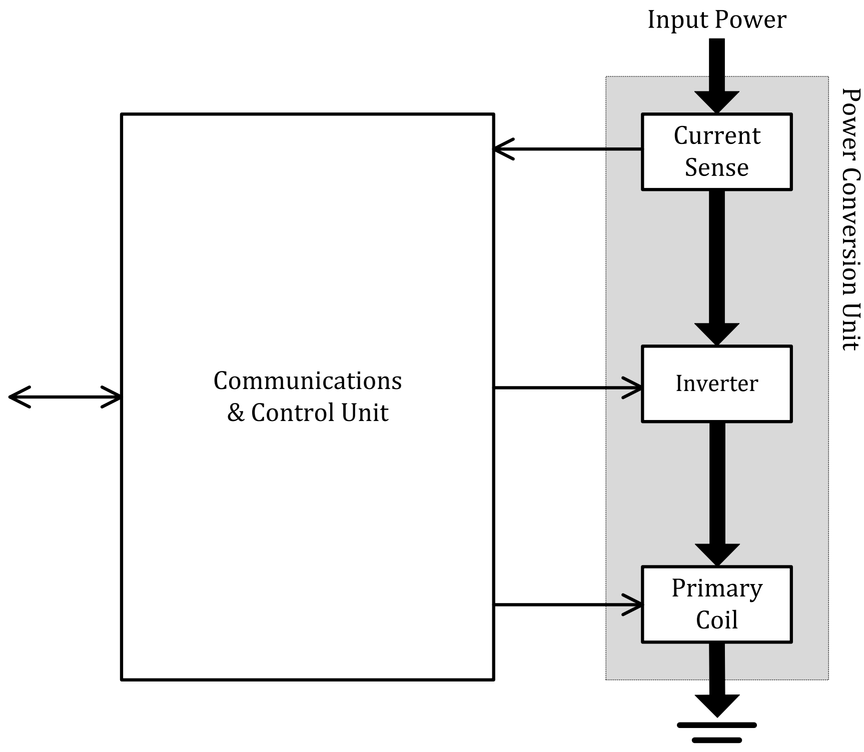
Table 88. PID parameters for voltage control

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

2.2.30 Power Transmitter design A30

Figure 123 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 123. Functional block diagram of Power Transmitter design A30



The Power Conversion Unit on the right-hand side of Figure 123 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 123 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 Base Station, e.g. for user interface purposes.

2.2.30.1 Mechanical details

Power Transmitter design A30 includes one Primary Coil as defined in Section 2.2.30.1.1, Shielding as defined in Section 2.2.30.1.2, and an Interface Surface as defined in Section 2.2.30.1.3.

2.2.30.1.1 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 124, a Primary Coil has a racetrack-like shape and consists of a single layer. Table 89 lists the dimensions of a Primary Coil.

Figure 124. Primary Coil of Power Transmitter design A30

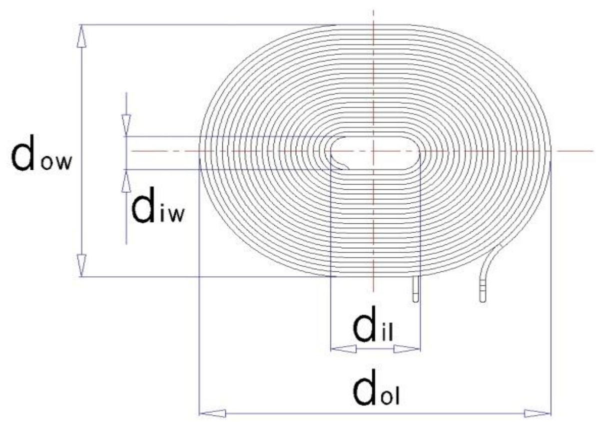


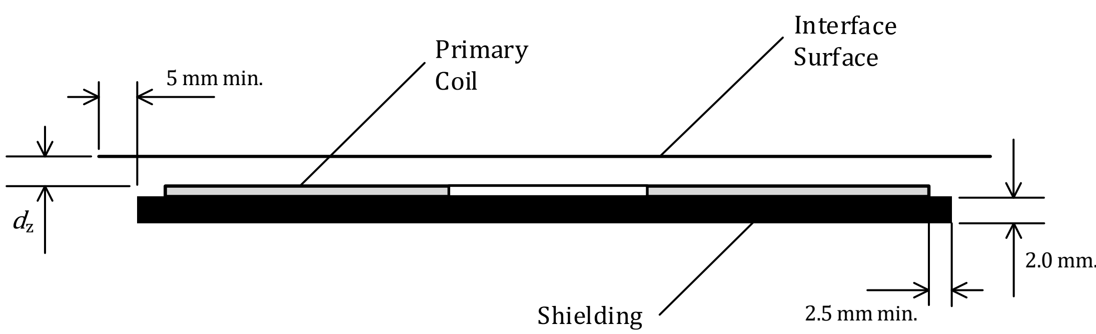
Table 89. Primary Coil parameters of Power Transmitter design A30

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

2.2.30.1.2 Shielding

As shown in Figure 125, Shielding protects the Base Station 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 125. Primary Coil assembly of Power Transmitter design A30



2.2.30.1.3 Interface Surface

As shown in Figure 125, the distance from the Primary Coil to the Interface Surface of the Base Station is $d_z = 5^{\pm 1.0}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Base Station extends at least 5 mm beyond the outer diameter of the Primary Coil.

2.2.30.1.4 Separation between multiple Power transmitters

If the Base Station contains multiple type A30 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall have a center-to-center distance of at least 80 mm.

2.2.30.2 Electrical details

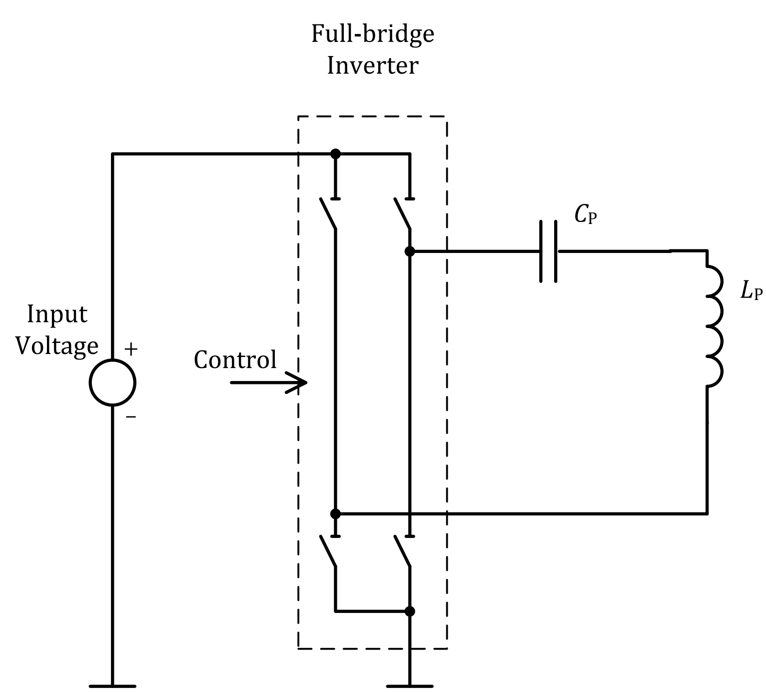
As shown in Figure 126, Power Transmitter design A30 uses a full-bridge inverter to drive the Primary Coil and a series capacitance. Within the Operating Frequency range specified below, the assembly of Primary Coil and Shielding has a self-inductance $L_{\mathrm{P}} = 24.0^{\pm 10\%}$ μH. The input voltage to the full-bridge inverter is $12^{\pm 5\%}$ V. The value of the series capacitance is $C_{\mathrm{P}} = 100^{\pm 10\%}$ 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 $f_{\mathrm{op}} =$ 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 *Parts 1 and 2: Interface Definitions*), 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 *Parts 1 and 2: Interface Definitions*. 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 126. Electrical diagram (outline) of Power Transmitter design A30



Control of the power transfer shall proceed using the PID algorithm, which is defined in *Parts 1 and 2: Interface Definitions*. 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 90 and Table 91 provide the value of several parameters, which are used in the PID algorithm.

Table 90. PID parameters for Operating Frequency 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	20,000	N.A.
Scaling factor	S_v	1.0	Hz

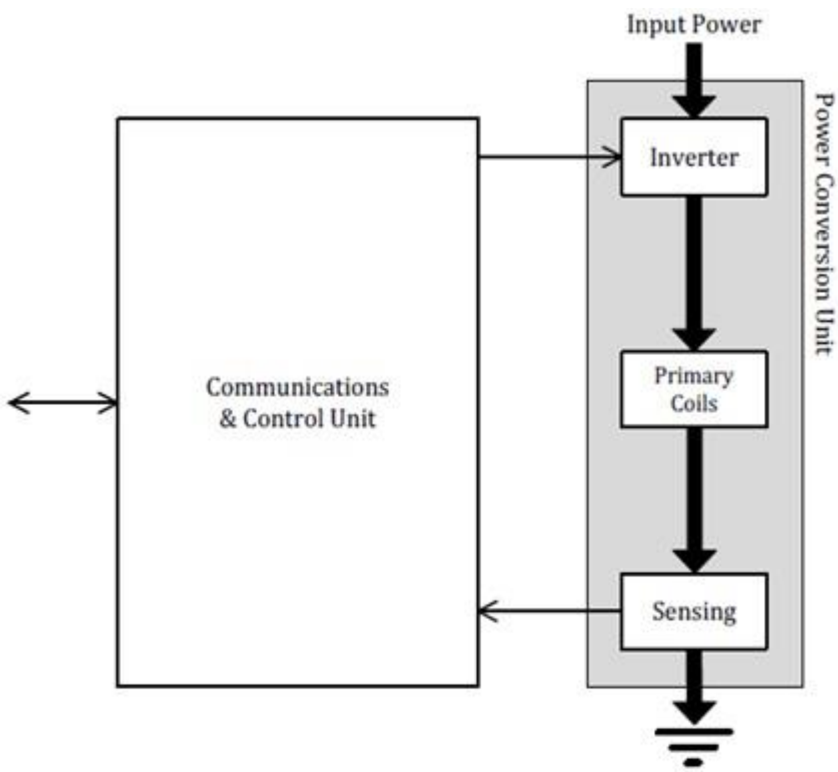
Table 91. PID parameters for duty cycle control

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	20,000	N.A.
Scaling factor	S_v	-0.1	°

2.2.31 Power Transmitter design A31

Figure 127 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 127. Functional block diagram of Power Transmitter design A31



The Power Conversion Unit on the right-hand side of Figure 127 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 127 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 Base Station, e.g. for user interface purposes.

2.2.31.1 Mechanical details

Power Transmitter design A31 includes one Primary Coil as defined in Section 2.2.31.1.1, Shielding as defined in Section 2.2.31.1.2, and an Interface Surface as defined in Section 2.2.31.1.3.

2.2.31.1.1 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 128, a Primary Coil has a racetrack-like shape and consists of a single layer. Table 92 lists the dimensions of a Primary Coil.

Figure 128. Primary Coil of Power Transmitter design A31

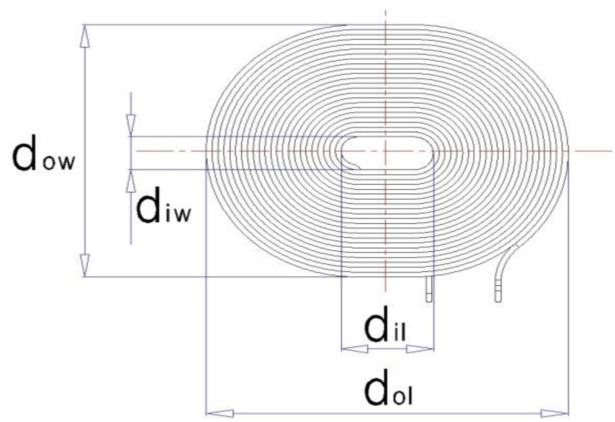


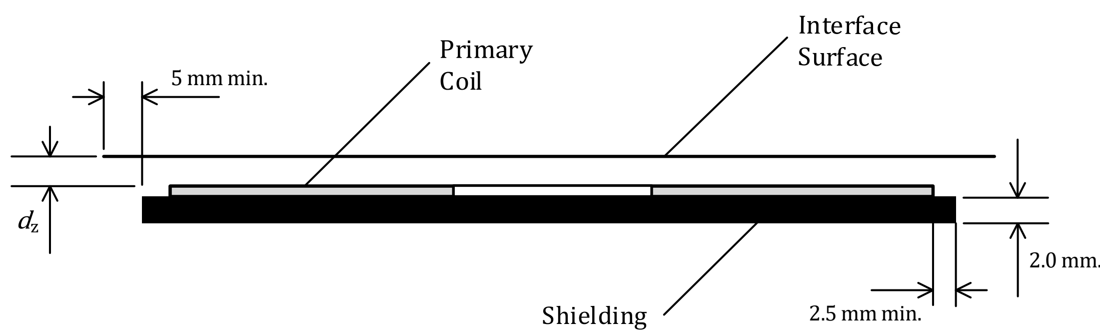
Table 92. Primary Coil parameters of Power Transmitter design A31

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

2.2.31.1.2 Shielding

As shown in Figure 129, Shielding protects the Base Station 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 129. Primary Coil assembly of Power Transmitter design A31



2.2.31.1.3 Interface Surface

As shown in Figure 129, the distance from the Primary Coil to the Interface Surface of the Base Station is $d_z = 3.0^{\pm 0.5}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Base Station extends at least 5.0 mm beyond the outer diameter of the Primary Coil.

2.2.31.1.4 Separation between multiple Power transmitters

If the Base Station contains multiple type A31Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall have a center-to-center distance of at least 71.0 mm.

2.2.31.2 Electrical details

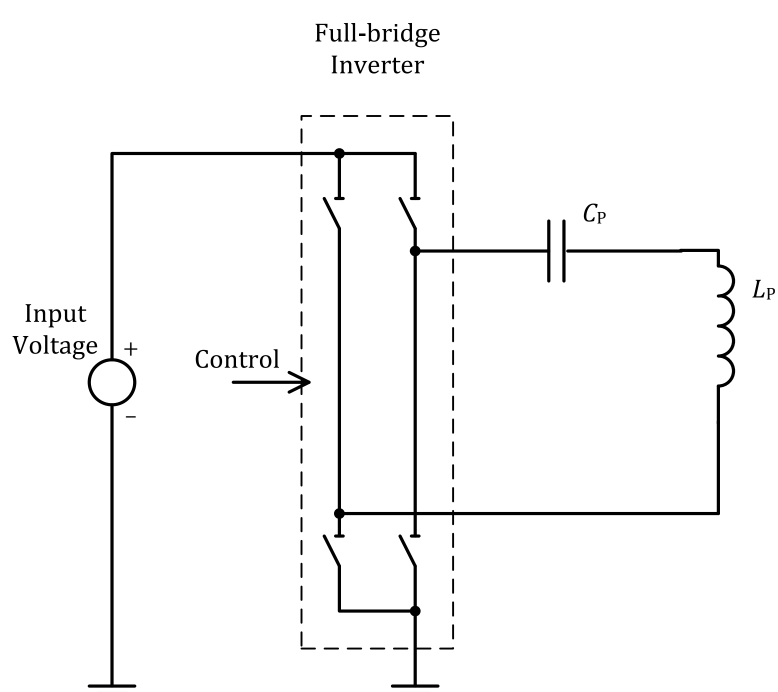
As shown in Figure 130, Power Transmitter design A31 uses a full-bridge inverter to drive the Primary Coil and a series capacitance. Within the Operating Frequency range specified below, the assembly of Primary Coil and Shielding has a self-inductance $L_{\mathrm{P}} = 24^{\pm 10\%}$ μH. The input voltage to the full-bridge inverter is $12^{\pm 5\%}$ V. The value of the series capacitance is $C_{\mathrm{P}} = 148^{\pm 5\%}$ nF.

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

Power Transmitter design 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 $f_{\mathrm{op}} =$ 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 *Parts 1 and 2: Interface Definitions*), the Power Transmitter shall use an Operating Frequency of $98^{\pm 10.0}$ kHz, and a duty cycle of $25^{\pm 10.0}$%. 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 *Parts 1 and 2: Interface Definitions*. 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 130. Electrical diagram (outline) of Power Transmitter design A31



Control of the power transfer shall proceed using the PID algorithm, which is defined in *Parts 1 and 2: Interface Definitions*. The controlled variable $v^{(i)}$ 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 93 and Table 94 provide the values 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	$\mathrm{mA}^{-1}\mathrm{ms}^{-1}$
Derivative gain	K_d	0	$\mathrm{mA}^{-1}\mathrm{ms}$
Integral term limit	M_I	N.A.	N.A.
PID output limit	M_PID	20,000	N.A.
Scaling factor	S_v	1.0	Hz

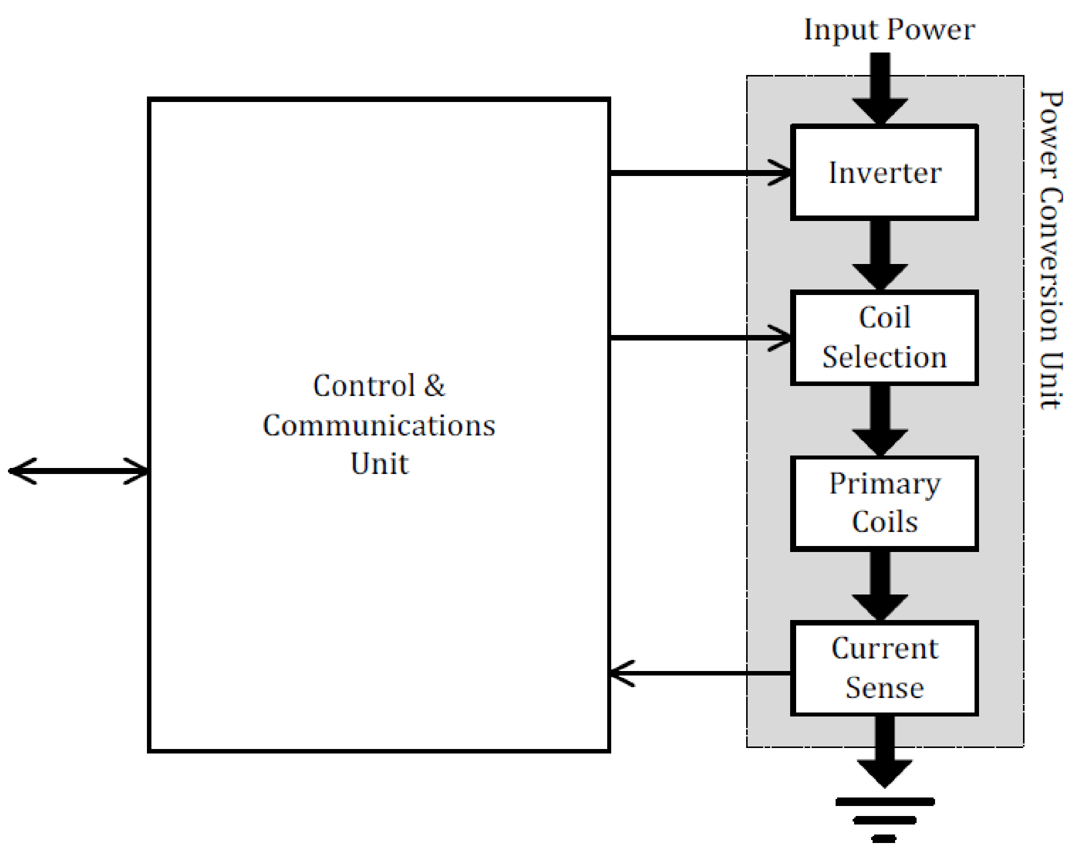
Table 94. PID parameters for duty control

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	20,000	N.A.
Scaling factor	S_v	−0.1	°

2.2.32 Power Transmitter design A32

Figure 131 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 131. Functional block diagram of Power Transmitter design A32



The Power Conversion Unit on the right-hand side of Figure 131 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 131 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 Base Station, e.g. for user interface purposes.

2.2.32.1 Mechanical details

Power Transmitter design A32 includes at least one Primary Coil as defined in Section 2.2.32.1.1, Shielding as defined in Section 2.2.32.1.2, and an Interface Surface as defined in Section 2.2.32.1.3.

2.2.32.1.1 Primary coil

The Primary Coil consists of at least one PCB coil. Figure 132 shows a view of a single Primary Coil. Table 95 lists the dimensions of the Primary Coil.

Figure 132. Primary Coil of Power Transmitter design A32

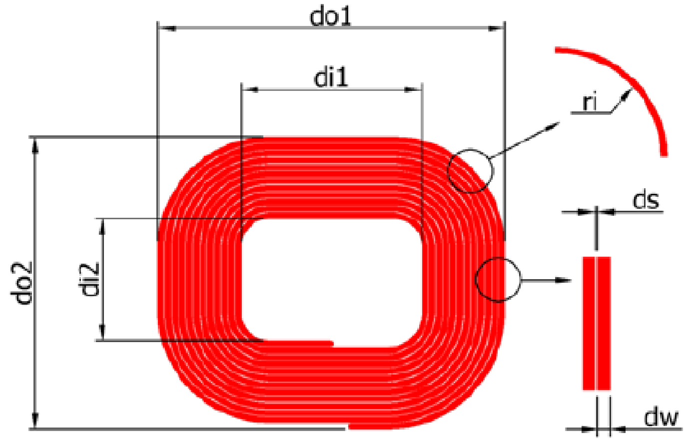
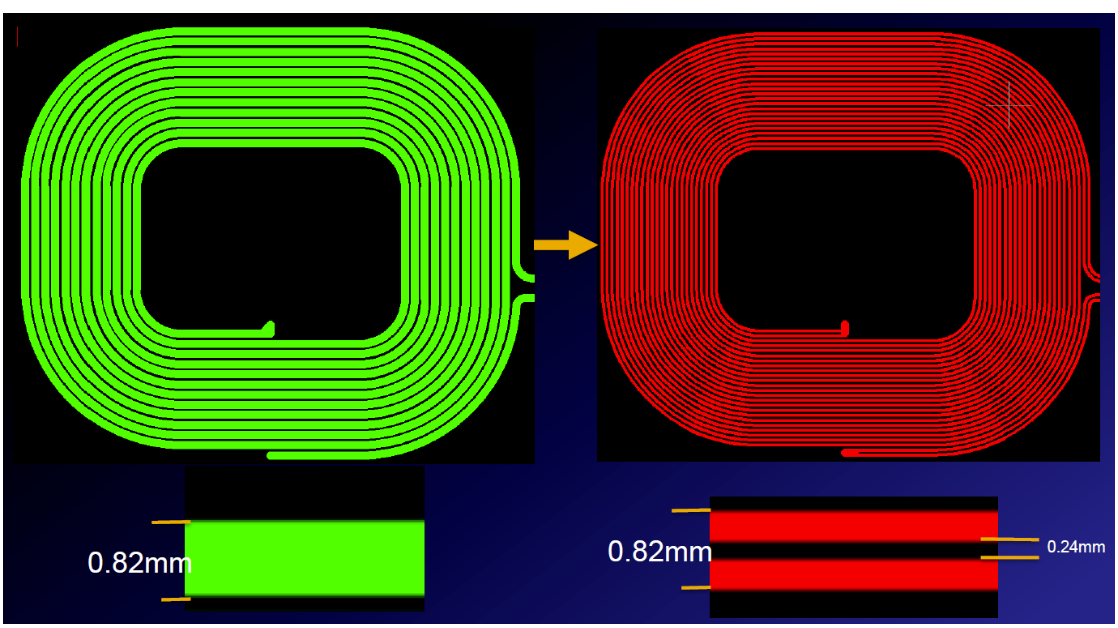


Table 95. Primary Coil parameters of Power Transmitter design A32

Parameter	Symbol	Value
Outer length	$do1$	$53.4^{\pm0.7}$ mm
Inner length	$di1$	$27.5^{\pm0.7}$ mm
Outer width	$do2$	$45.8^{\pm0.7}$ mm
Inner width	$di2$	$19.5^{\pm075}$ 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 133

Figure 133. 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 134.

Figure 134. Primary Coils of Power Transmitter design A32

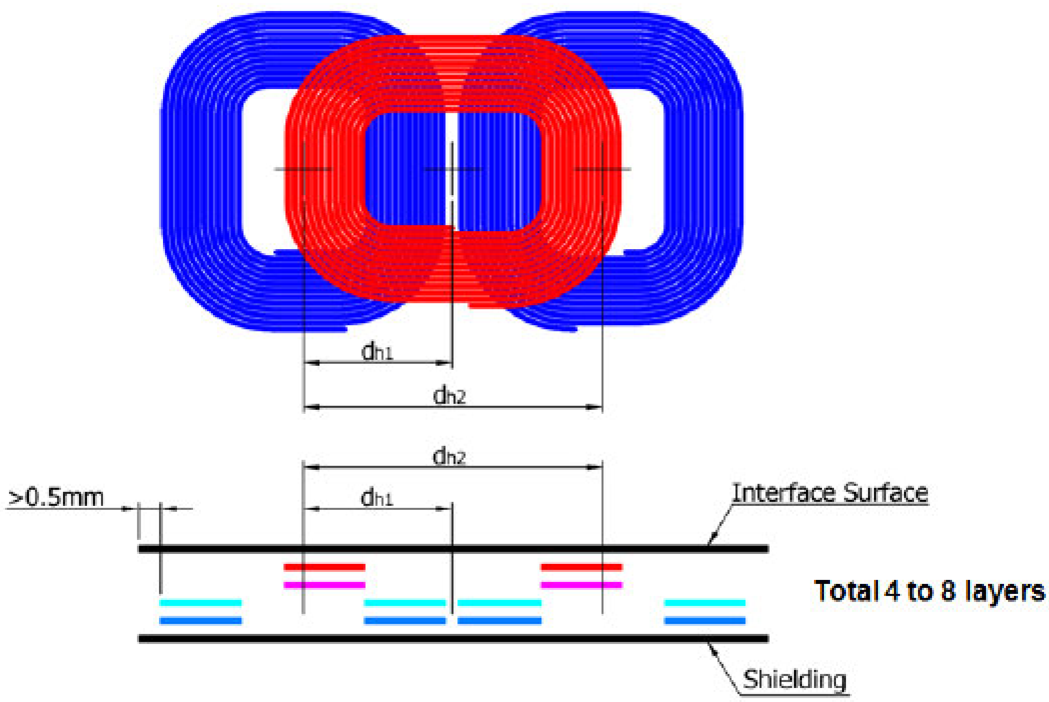


Figure 135. Primary Coils of Power Transmitter design A32

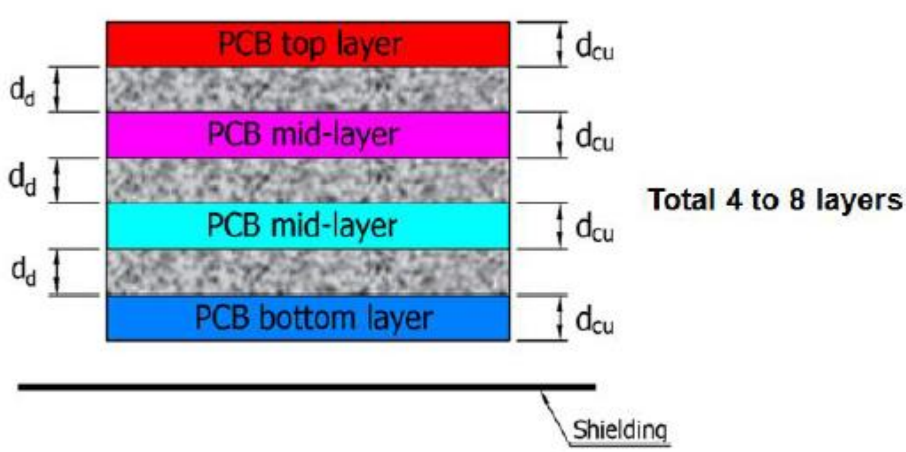


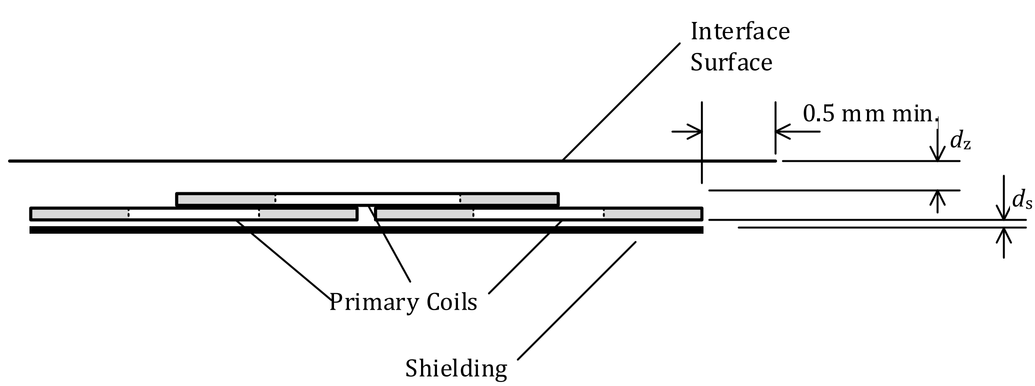
Table 96. Primary Coil parameters of Power Transmitter design A32

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

2.2.32.1.2 Shielding

As shown in Figure 136, Shielding protects the Base Station 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 136. Primary Coil assembly of Power Transmitter design A32



2.2.32.1.3 Interface Surface

As shown in Figure 136, the distance from the top face of the even-numbered Primary Coil to the Interface Surface of the Base Station 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 Base Station is also $d_z = 2.75^{\pm 1}$ mm. In addition, the Interface Surface of the Base Station extends at least 0.5 mm beyond the outer dimensions of the Primary Coils.

2.2.32.1.4 Separation between multiple Power transmitters

If the Base Station contains multiple type A32 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall have a center-to-center distance of at least $49.2_{\pm 4}$ mm.

2.2.32.2 Electrical details

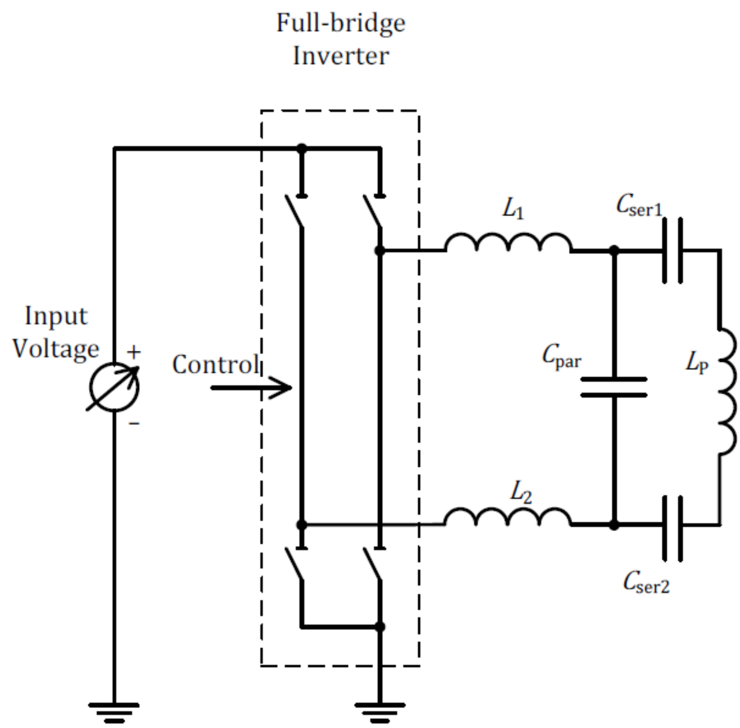
As shown in Figure 126, Power Transmitter design A32 uses a full-bridge inverter to drive an individual Primary Coil and a series capacitance. Within the Operating Frequency range specified below, the assembly of Primary Coil and Shielding has a self-inductance $L_{\mathrm{P}} = 11.5^{\pm 10\%}$ μH for coils closest to the Interface Surface, and inductance $L_{\mathrm{P}} = 12.5^{\pm 10\%}$ 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 $1/C_{\mathrm{ser1}} + 1/C_{\mathrm{ser2}} = 1/200^{\pm 10\%}$ 1/nF. 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

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 $f_{\mathrm{op}} = 105 \ldots 115$ kHz, with a duty cycle of 50%.

When a type A32 Power Transmitter first applies a Power Signal (Digital Ping; see *Parts 1 and 2: Interface Definitions*), it shall use an initial voltage of 3.5±0.5 V for a bottom Primary Coil, and 3.0±0.5 V for a top Primary Coil, and a recommended Operating Frequency of 110 kHz.

Figure 137. Electrical diagram (outline) of Power Transmitter design A32



Control of the power transfer shall proceed using the PID algorithm, which is defined in *Parts 1 and 2: Interface Definitions*. 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 97 provides the values of several parameters, which are used in the PID algorithm.

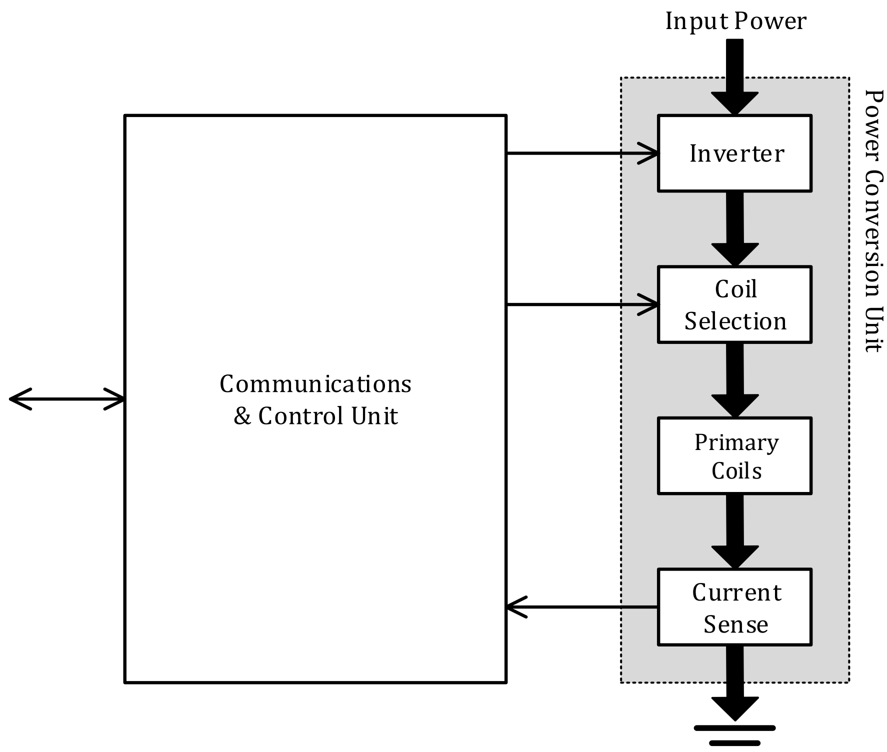
Table 97. PID parameters for voltage control

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

2.2.33 Power Transmitter design A33

Power Transmitter design A33 enables Free Positioning of Power Receiver. Figure 138 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 138. Functional block diagram of Power Transmitter design A33



The Power Conversion Unit on the right-hand side of Figure 138 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 138 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 Base Station, e.g. for user interface purposes.

2.2.33.1 Mechanical details

Power Transmitter design A33 includes one or more Primary Coils as defined in Section 2.2.33.1.1, Shielding as defined in Section 2.2.33.1.2, an Interface Surface as defined in Section 2.2.33.1.3.

2.2.33.1.1 Primary coil

The Primary Coil consists of at least one PCB coil. Figure 139 shows a view of a single Primary Coil. Table 98 lists the dimensions of the Primary Coil.

Figure 139. Primary Coil of Power Transmitter design A33

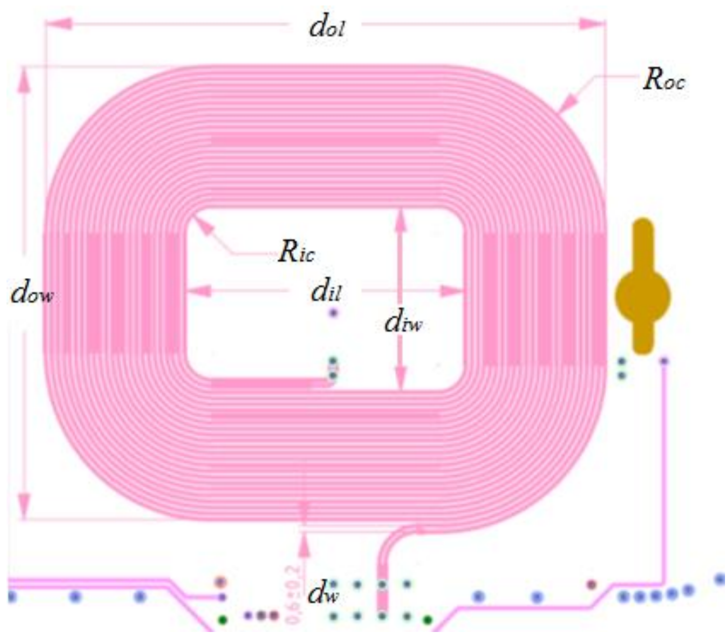


Table 98. Primary Coil parameters of Power Transmitter design A33

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 140 and Figure 141. Table 99 lists the dimensions of the Primary Coils.

Figure 140. Three Primary Coils of Power Transmitter design A33

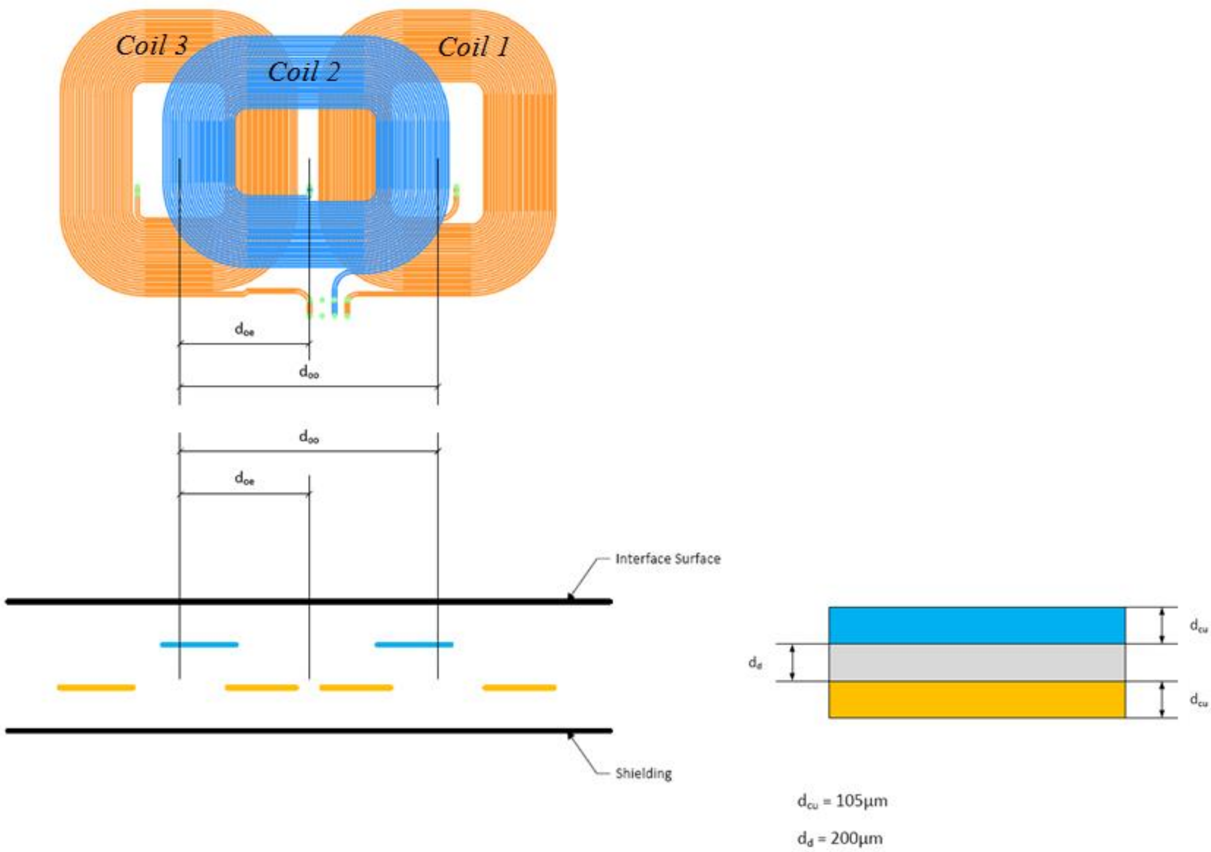


Figure 141. Four Primary Coils of Power Transmitter design A33

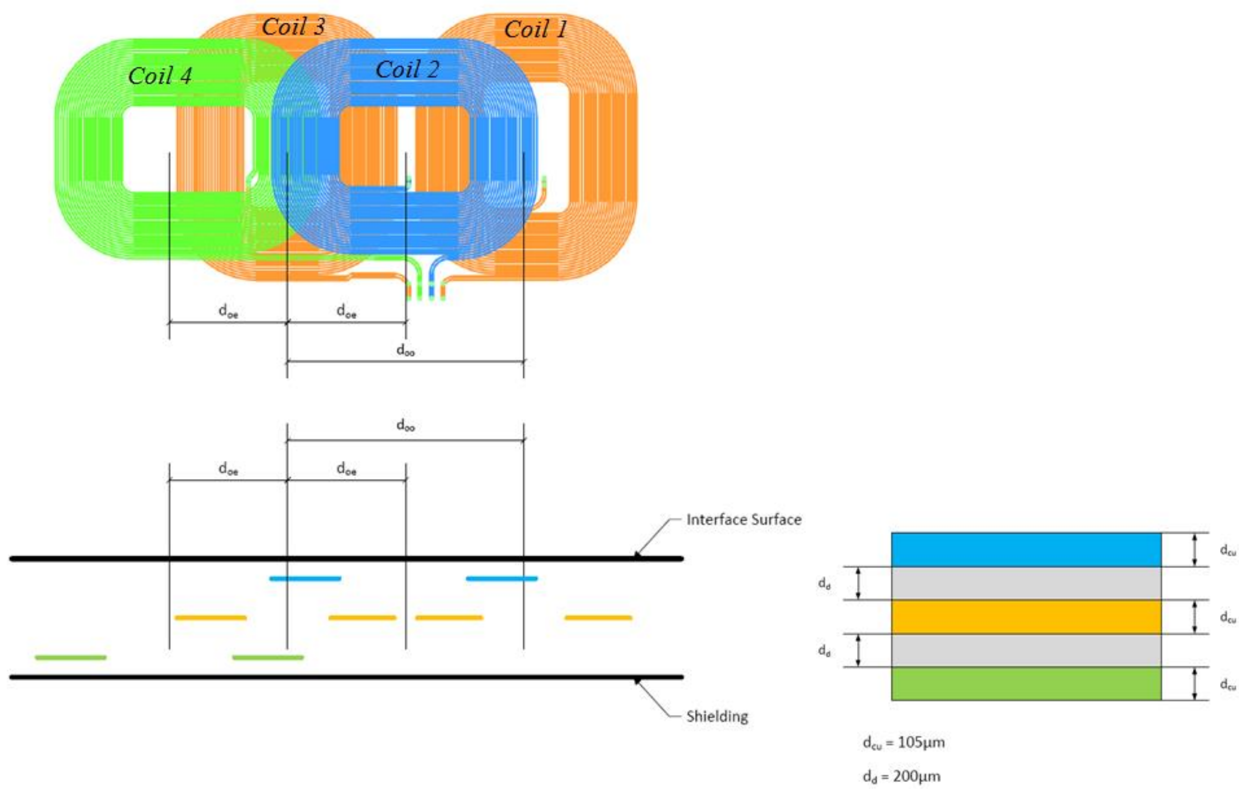
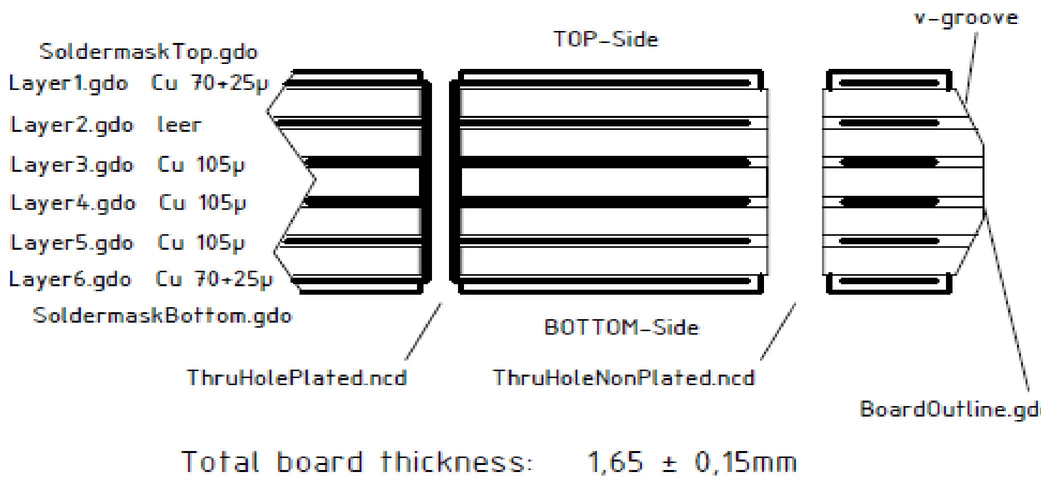


Table 99. Primary Coil parameters of Power Transmitter design A33

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 142 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.

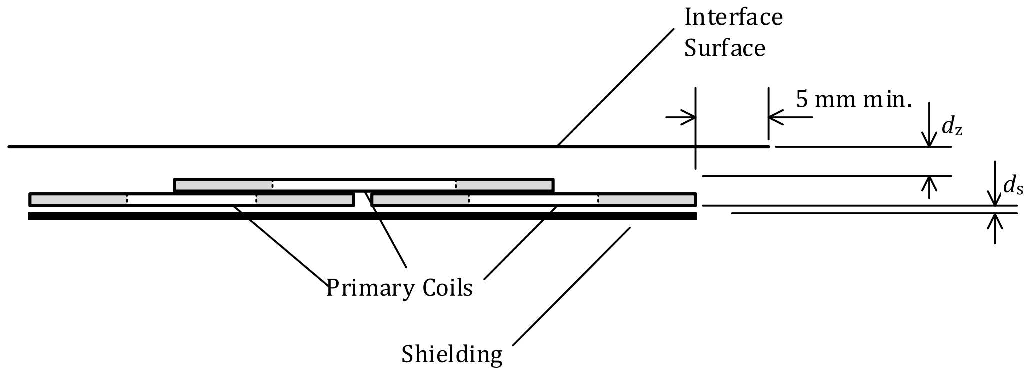
Figure 142. Layered structure of the Primary Coils of Power Transmitter design A33



2.2.33.1.2 Shielding

As shown in Figure 143, Shielding protects the Base Station 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 143. Primary Coil assembly of Power Transmitter design A33



2.2.33.1.3 Interface Surface

As shown in Figure 143, the distance from the top face of the even-numbered Primary Coil to the Interface Surface of the Base Station is $\mathrm{d_z} = 3^{\pm 1}$ 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 Base Station is $\mathrm{d_z} = 4.5^{\pm 1}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Base Station extends at least 5 mm beyond the outer dimensions of the Primary Coils.

2.2.33.1.4 Inter coil separation

If the Base Station contains multiple type A33 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall have a center-to-center distance of at least $49.2^{\pm 4}$ mm.

2.2.33.2 Electrical details

As shown in Figure 144, 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 *Parts 1 and 2: Interface Definitions*), 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 *Parts 1 and 2: Interface Definitions*. 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 100 provides the values of several parameters, which are used in the PID algorithm.

Figure 144. Electrical diagram (outline) of Power Transmitter design A33

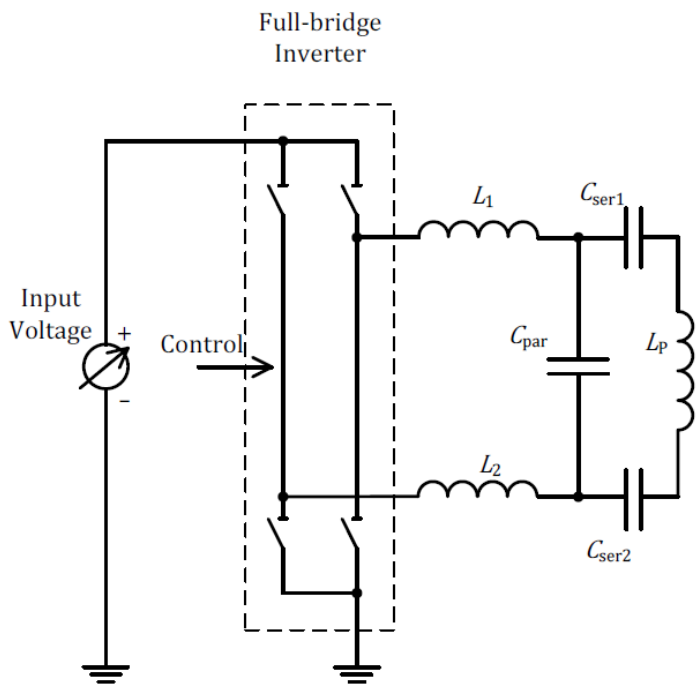


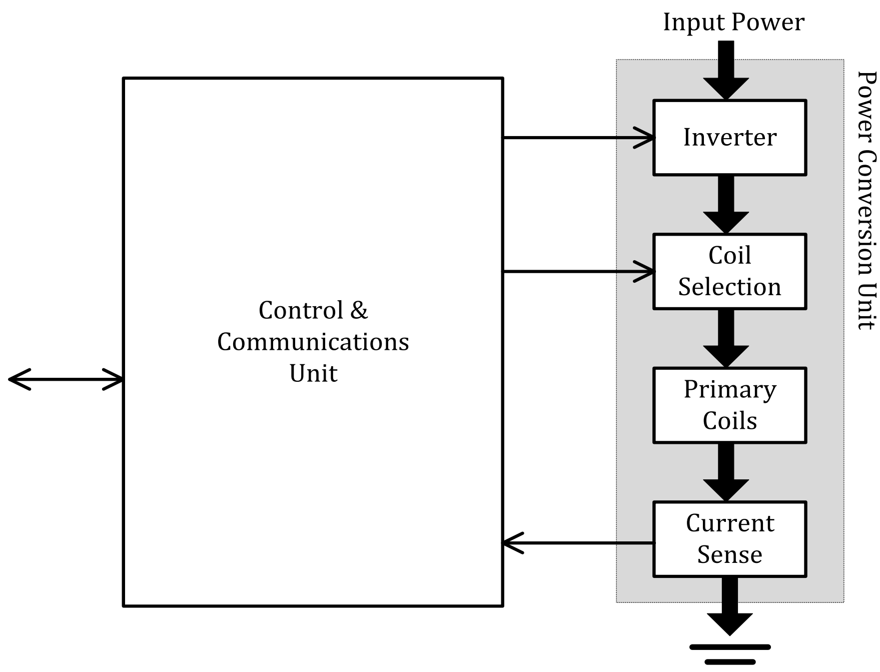
Table 100. PID parameters for voltage control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	0.03	mA^{-1}
Integral gain	K_i	0.01	$\text{mA}^{-1}\text{ms}^{-1}$
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

2.2.34 Power Transmitter design A34

Figure 145 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 145. Functional block diagram of Power Transmitter design A34



The Power Conversion Unit on the right-hand side of Figure 145 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 145 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 Base Station, e.g. for user interface purposes.

2.2.34.1 Mechanical details

Power Transmitter design A34 includes one or more Primary Coils as defined in Section 2.2.34.1.1, Shielding as defined in Section 2.2.34.1.2, an Interface Surface as defined in Section 2.2.34.1.3.

2.2.34.1.1 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 146, the Primary Coil has a rectangular shape and consists of a single layer. Table 101 lists the dimensions of the Primary Coil.

Figure 146. Primary Coil of Power Transmitter design A34

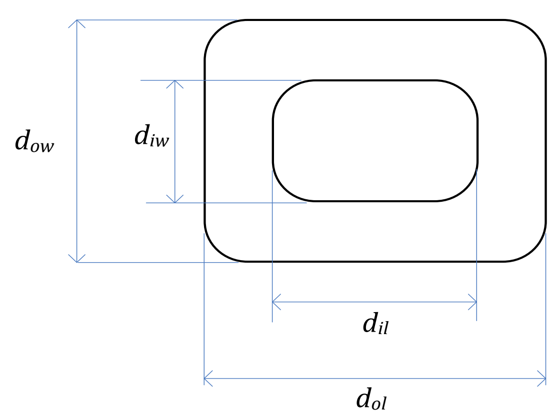
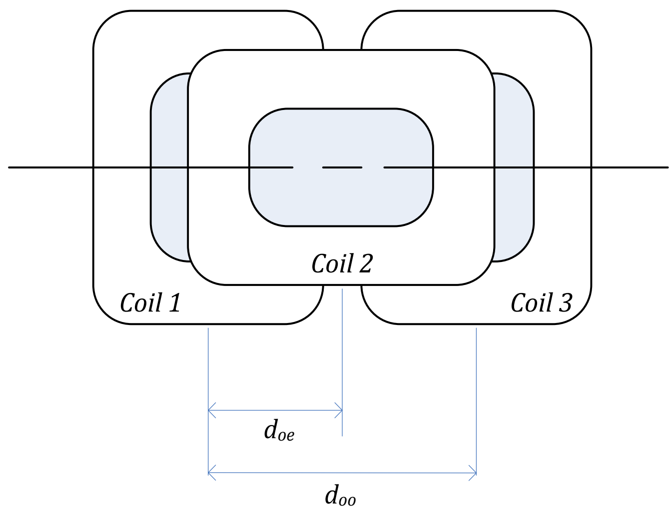


Table 101. Primary Coil parameters of Power Transmitter design A34

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 $d_{\mathrm{oo}} = 49.2^{\pm 4}$ mm between their centers. Even numbered coils are placed orthogonal to the odd numbered coils with a displacement of $d_{\mathrm{oe}} = 24.6^{\pm 2}$ mm between their centers. See Figure 147.

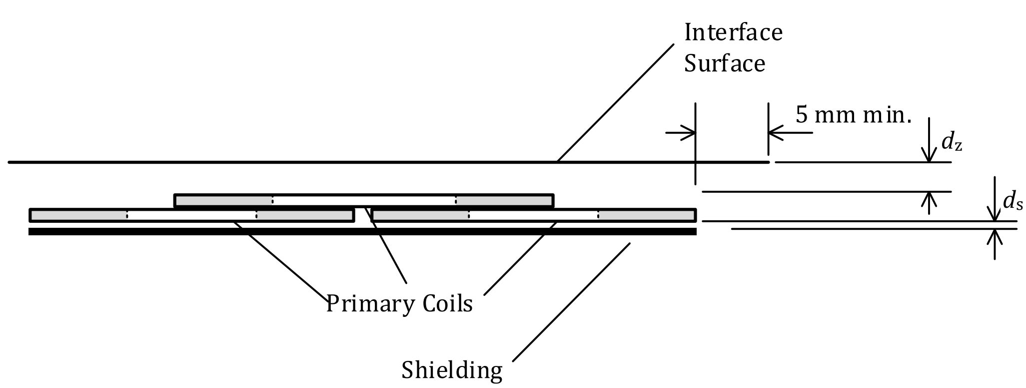
Figure 147. Primary Coils of Power Transmitter design A34



2.2.34.1.2 Shielding

As shown in Figure 148, Shielding protects the Base Station 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 $d_{\mathrm{s}} = 1.0$ mm.

Figure 148. Primary Coil assembly of Power Transmitter design A34



2.2.34.1.3 Interface Surface

As shown in Figure 148, the distance from the top face of the even-numbered Primary Coil to the Interface Surface of the Base Station 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 Base Station is $d_z = 4.5^{\pm 1}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Base Station extends at least 5 mm beyond the outer dimensions of the Primary Coils.

2.2.34.1.4 Inter coil separation

If the Base Station contains multiple type A34 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall have a center-to-center distance of at least $49.2^{\pm 4}$ mm.

2.2.34.2 Electrical details

As shown in Figure 149, 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 $L_{\mathrm{P}} = 11.5^{\pm 10\%}$ 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 inductance L is $3.3^{\pm 20\%}$ μH. The value of series capacitance is $C_{\mathrm{ser}} = 168^{\pm 10\%}$ nF. 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 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 $f_{\mathrm{op}} = 105 \ldots 115$ kHz, with a duty cycle of 50%.

When a type A34 Power Transmitter first applies a Power Signal (Digital Ping; see *Parts 1 and 2: Interface Definitions*), 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 *Parts 1 and 2: Interface Definitions*. 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 102 provides the values of several parameters, which are used in the PID algorithm.

Figure 149. Electrical diagram (outline) of Power Transmitter design A34

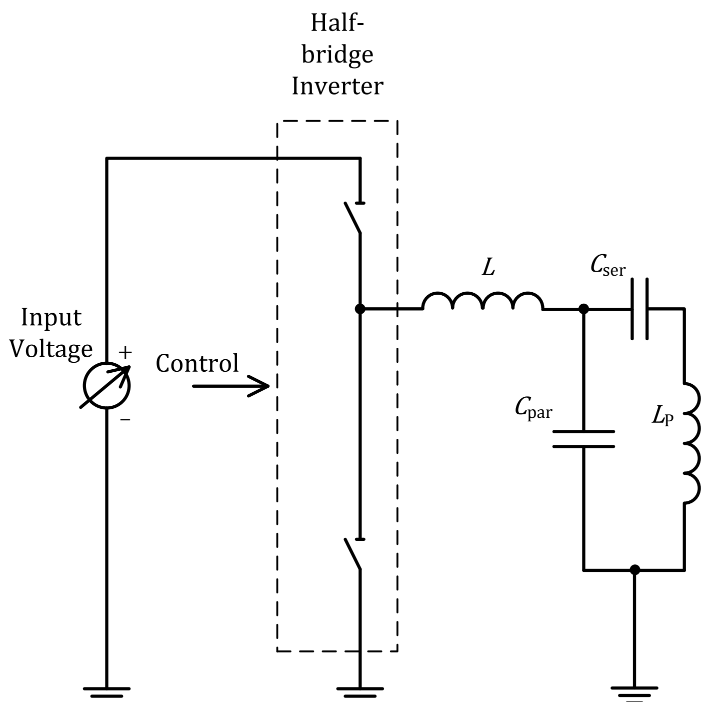


Table 102. PID parameters for voltage control

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	-2	mV

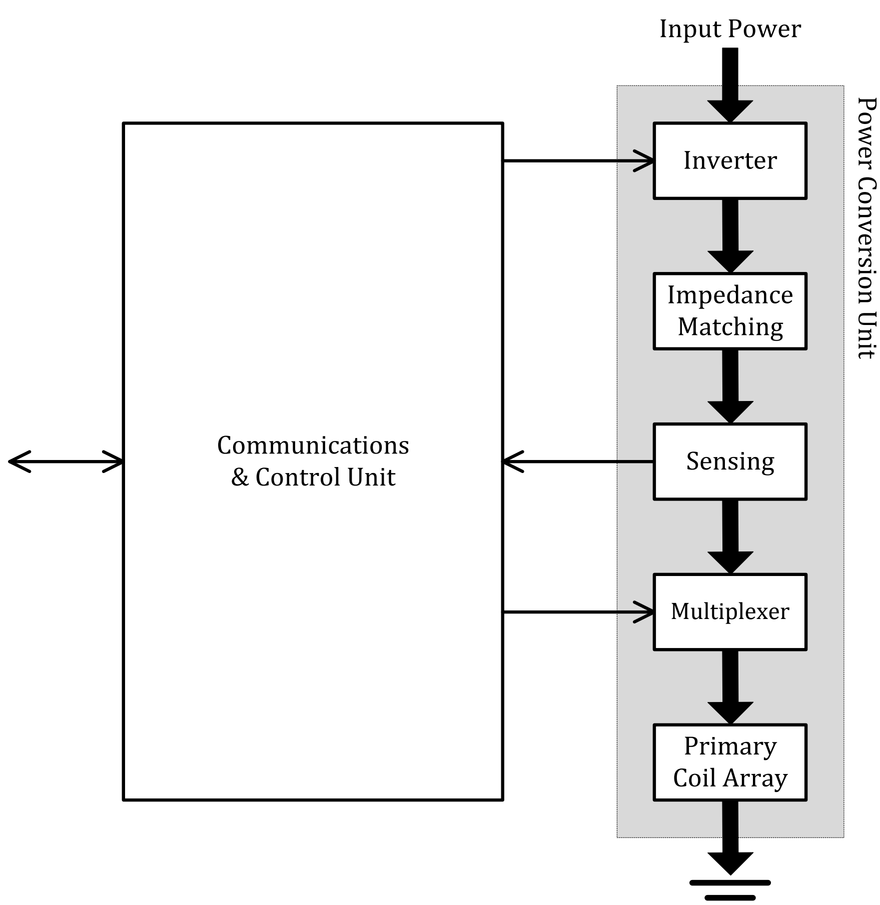
2.3 Baseline Power Profile designs that activate multiple Primary Coils simultaneously

This Section 2.2.34 defines all type B Power Transmitter designs in the Baseline Power Profile. In addition to the definitions in this section, each Power Transmitter design shall implement the relevant parts of the protocols and communications interface defined in *Parts 1 and 2: Interface Definitions*.

2.3.1 Power Transmitter design B1

Power Transmitter design B1 enables Free Positioning. Figure 150 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 150. Functional block diagram of Power Transmitter design B1



The Power Conversion Unit on the right-hand side of Figure 150 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 150 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 Base Station, e.g. for user interface purposes.

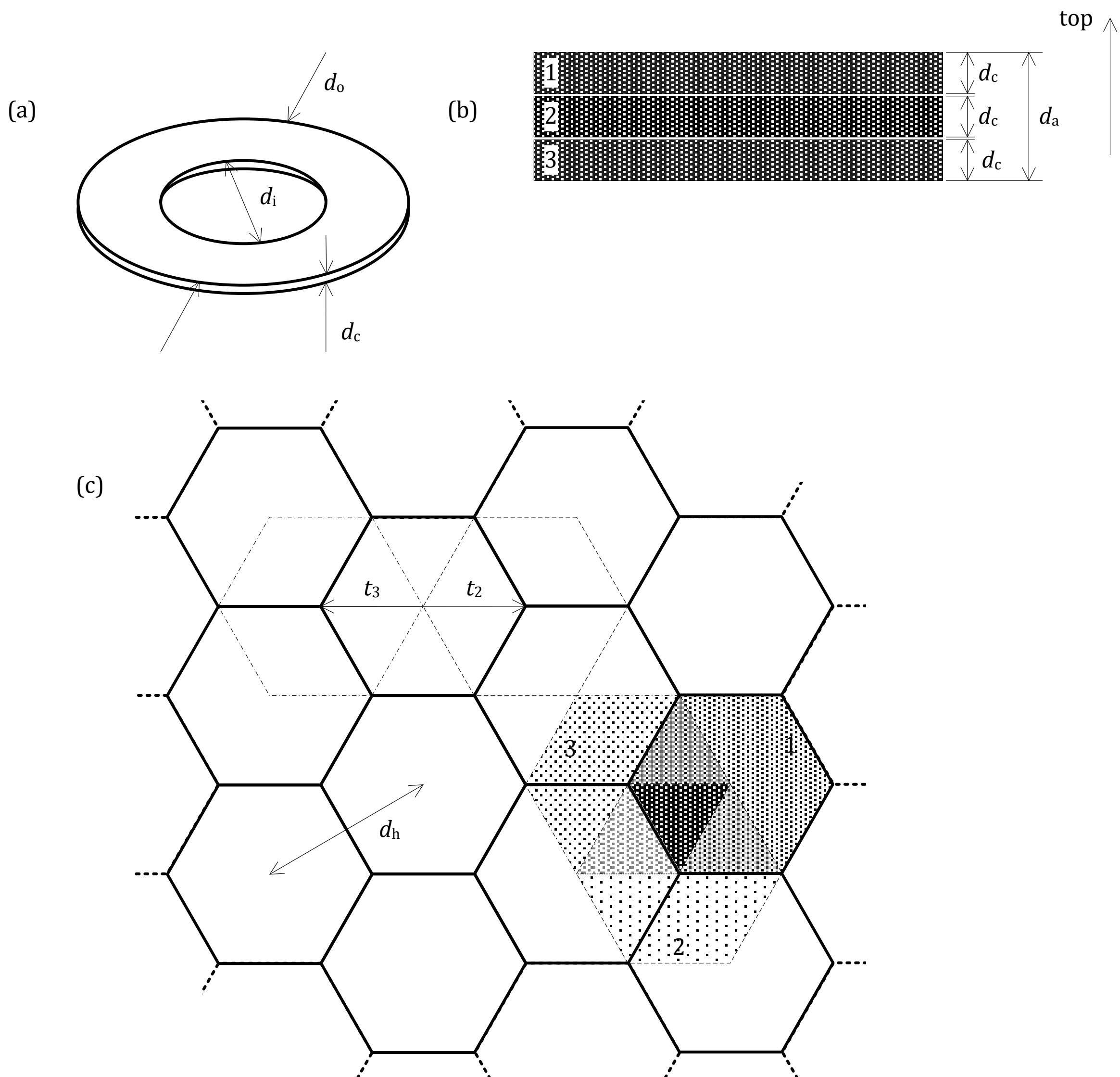
2.3.1.1 Mechanical details

Power Transmitter design B1 includes a Primary Coil array as defined in Section 2.3.1.1.1, Shielding as defined in Section 2.3.1.1.2, and an Interface Surface as defined in Section 2.3.1.1.3.

2.3.1.1.1 Primary Coil array

The Primary Coil array consists of 3 layers. Figure 151(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 151. Primary Coil array of Power Transmitter design B1



As shown in Figure 151(a), the Primary Coil has a circular shape and consists of a single layer. Figure 151(b) shows a side view of the layer structure of the Primary Coil array. Figure 151(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 2.3.1.2 for the meaning of the shaded hexagons.

Table 103 lists the relevant parameters of the Primary Coil array.

Table 103. Primary Coil array parameters of Power Transmitter design B1

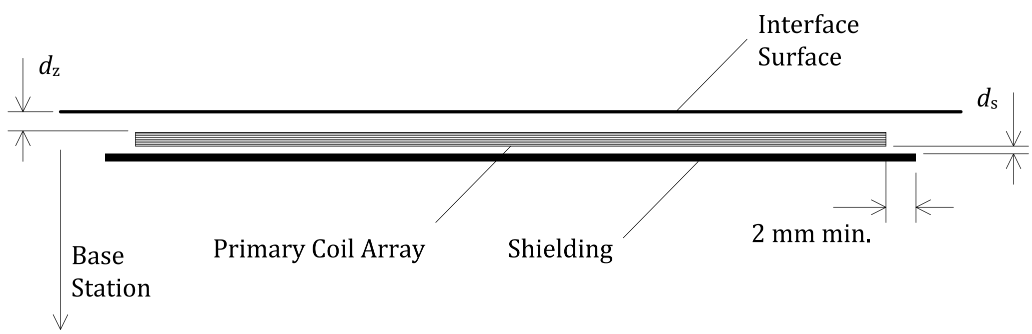
Parameter	Symbol	Value
Outer diameter	d_{o}	$28.5_{-0.7}$ mm
Inner diameter	d_{i}	$10.5^{\pm 0.3}$ mm
Layer thickness*	d_{c}	$0.6^{+0.05}_{-0.1}$ mm
Number of turns	N	16
Array thickness	d_{a}	$1.9^{+0.3}_{-0.2}$ mm
Center-to-center distance	d_{h}	28.6^{+1} mm
Offset 2nd layer array	t_2	$16.5^{+0.6}$ mm
Offset 3rd layer array	t_3	$16.5^{+0.6}$ mm

* Value includes thickness of connection wires.

2.3.1.1.2 Shielding

As shown in Figure 152, Transmitter design B1 employs Shielding to protect the Base Station 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 $d_{\mathrm{s}} = 0.5$ mm below the Primary Coil array.

Figure 152. Primary Coil array assembly of Power Transmitter design B1



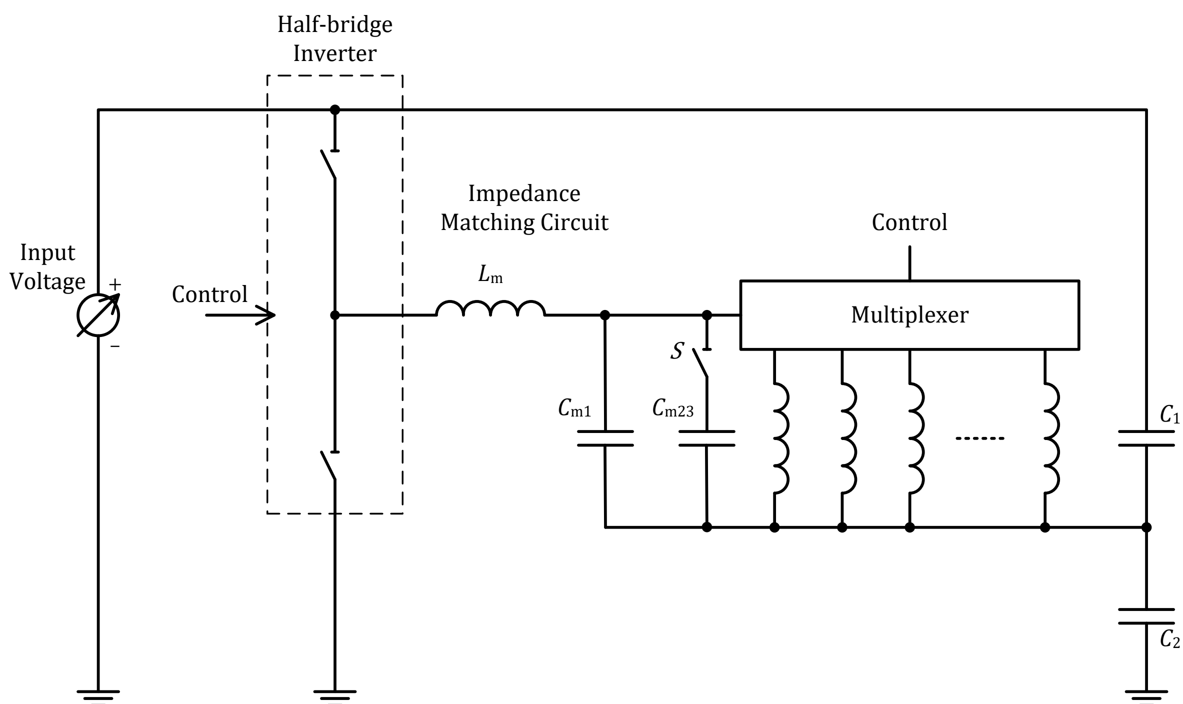
2.3.1.1.3 Interface Surface

As shown in Figure 152, the distance from the Primary Coil array to the Interface Surface of the Base Station is $d_{\mathrm{z}} = 2^{+0.5}_{-0.25}$ 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.

2.3.1.2 Electrical details

As shown in Figure 153, 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 150(c) for an example.

Figure 153. Electrical diagram (outline) of Power Transmitter design B1



Within the Operating Frequency range $f_{op} = 105 \ldots 113$ 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 swich 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 (see the *Digital Ping* section in *Parts 1 and 2: Interface Definitions*), 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 *Power transfer control* section in *Parts 1 and 2: Interface Definitions*. 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 104 provides the values of several parameters, which are used in the PID algorithm.

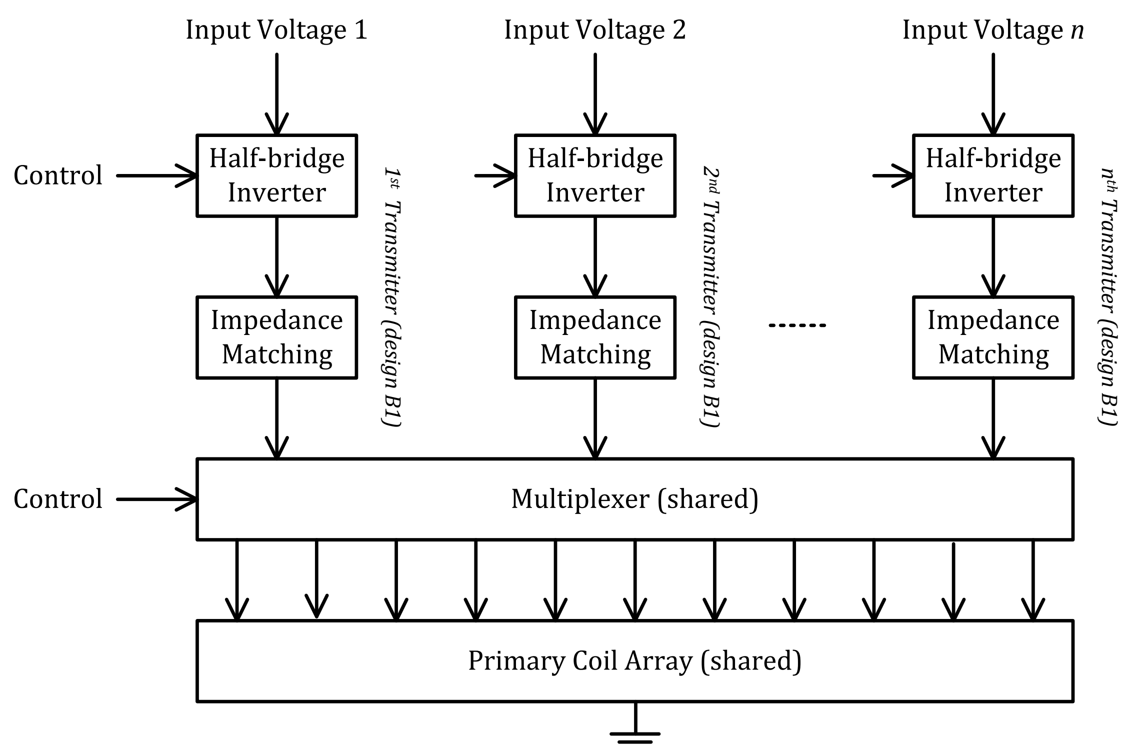
Table 104. PID parameters for voltage control

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}	2,000	N.A.
Scaling factor	S_{v}	–1	mV

2.3.1.3 Scalability

Sections 2.3.1.1 and 2.3.1.2 define the mechanical and electrical details of Power Transmitter design B1. As defined in Section 2.1, a type B1 Power Transmitter serves a single Power Receiver only. In order to serve multiple Power Receivers simultaneously, a Base Station may contain multiple type B1 Power Transmitters. As shown in Figure 154, 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 2.3.1.2. In addition, the multiplexer shall ensure that it does not connect multiple inverters to any individual Primary Coil.

Figure 154. Multiple type B1 Power Transmitters sharing a multiplexer and Primary Coil array



2.3.2 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 150 and the descriptive text in Section 2.3.1.

2.3.2.1 Mechanical details

Power Transmitter design B2 includes a Primary Coil array as defined in Section 2.3.2.1.1, Shielding as defined in Section 2.3.2.1.2, and an Interface Surface as defined in Section 2.3.2.1.3.

2.3.2.1.1 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 155(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 155(a), the corners of this hexagonal shape are rounded. The bottom inset of Figure 155(a) shows the width of the trace as well as the distance between two adjacent turns. Figure 155(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 155(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 2.3.2.2 for the meaning of the shaded hexagons.

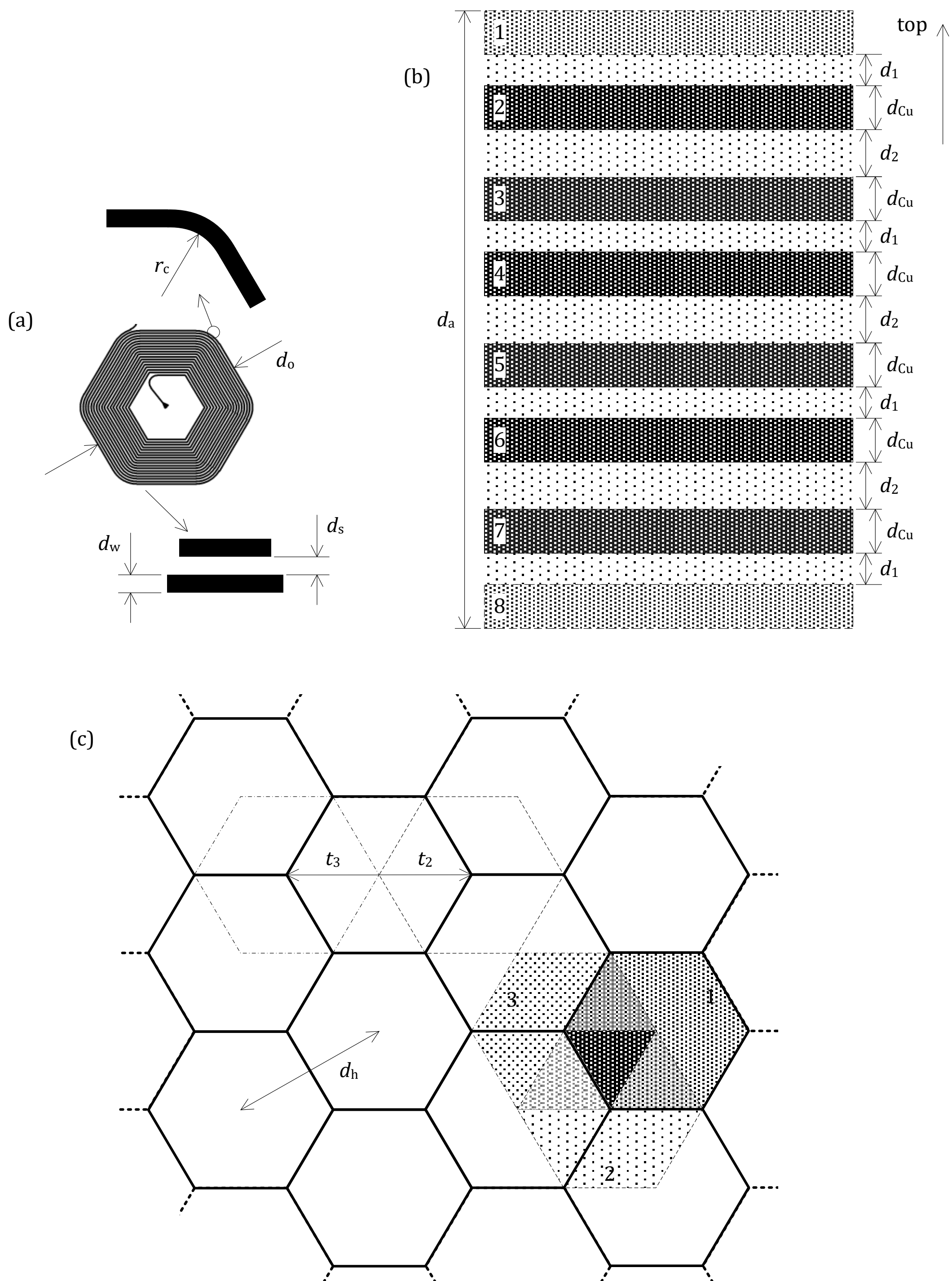
Table 105. Primary Coil array parameters of Power Transmitter design B2

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	$d_{\mathrm{w}} + d_{\mathrm{s}}$	$0.6^{\pm 0.03}$ 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.

Table 105 lists the relevant parameters of the Primary Coil array. The finished PCB thickness is $1.3^{\pm 10\%}$ mm.

Figure 155. Primary Coil array of Power Transmitter design B2



2.3.2.1.2 Shielding

Power Transmitter design B2 employs Shielding that is identical to the Shielding of Power Transmitter design B1. See Section 2.3.1.1.2.

2.3.2.1.3 Interface Surface

The distance from the Primary Coil array to the Interface Surface of the Base Station is $d_{\mathrm{z}} = 2^{+0.1}_{-0.5}$ mm, across the top face of the Primary Coil array. See also Figure 152 in Section 2.3.1.1.3. In addition, the Interface Surface extends at least 5 mm beyond the outer edges of the Primary Coil array.

2.3.2.2 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 153 in Section 2.3.1.2.

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 155(c) for an example.

Within the Operating Frequency range $f_{\mathrm{op}} = 105 \ldots 113$ kHz, the assembly of Primary Coil array and Shielding has an inductance of $11.7^{\pm 1}$ μH for each set of Primary Coils in layer 2 and layer 7 (connected in parallel), $11.8^{\pm 1}$ μH for each set of Primary Coils in layer 3 and layer 6 (connected in parallel), and $12.3^{\pm 1}$ 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 153) are, respectively, $C_{\mathrm{m1}} = 256^{\pm 5\%}$ nF, $C_{\mathrm{m23}} = 147^{\pm 5\%}$ nF and $L_{\mathrm{m}} = 3.8^{\pm 5\%}$ 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 swich 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 (see the *Digital Ping* section in *Parts 1 and 2: Interface Definitions*), 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 *Power transfer control* section in *Parts 1 and 2: Interface Definitions*. 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 104 in Section 2.3.1.2 provides the values of several parameters, which are used in the PID algorithm.

2.3.2.3 Scalability

Power Transmitter Design B2 offers the same scalability options as Power Transmitter design B1. See Section 2.3.1.3.

2.3.3 Power Transmitter design B3

Power Transmitter design B3 enables Free Positioning, and has a design similar to Power Transmitter design B1. See Section 2.3.1 for an overview.

2.3.3.1 Mechanical details

Power Transmitter design B3 includes a Primary Coil array as defined in Section 2.3.3.1.1, Shielding as defined in Section 2.3.3.1.2, and an Interface Surface as defined in Section 2.3.3.1.3.

2.3.3.1.1 Primary Coil array

The Primary Coil array consists of a hybrid PCB/wire wound coil structure. As shown Figure 156(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 156(b).

Each Primary Coil inside the PCB consists of a trace that runs through 18 hexagonal turns as shown in Figure 156(c), and are identical to the Primary Coils of Power Transmitter design B2 defined in Section 2.3.2.1.1.

Figure 156(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 2.3.3.2 for the meaning of the shaded hexagons.

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

Figure 156. Primary Coil array of Power Transmitter design B3

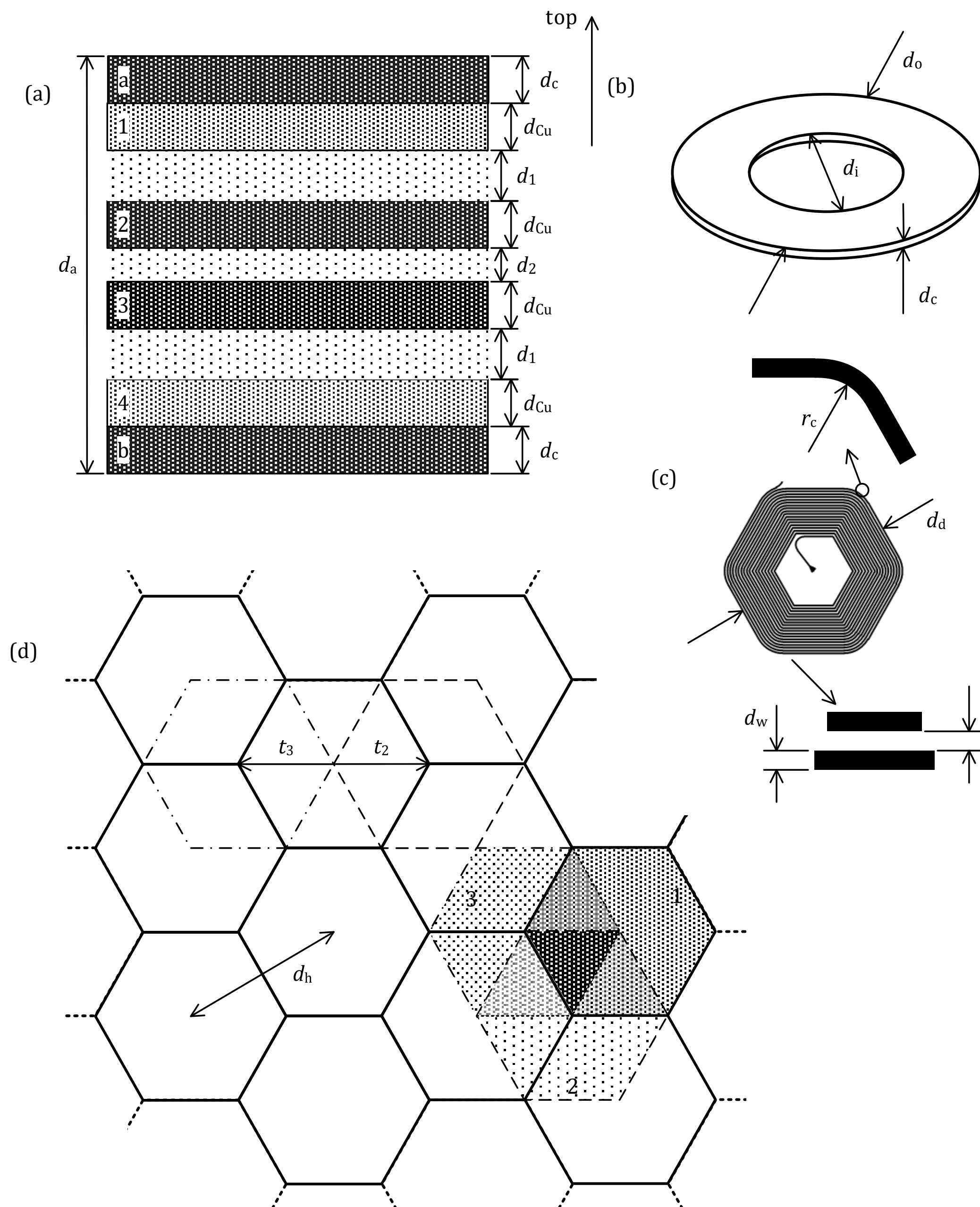


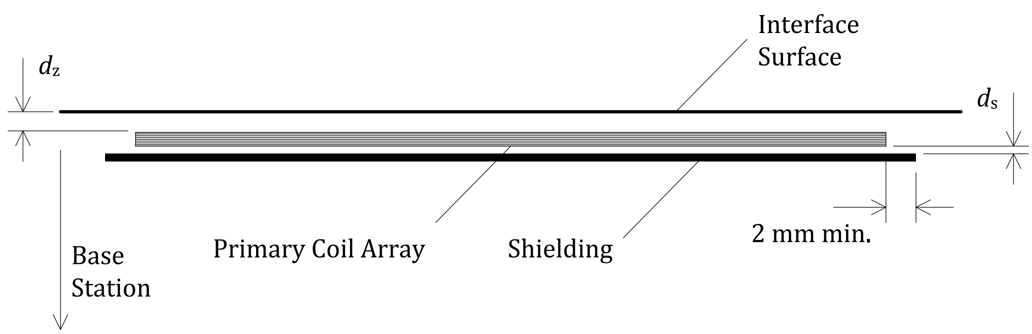
Table 106. Primary Coil array parameters of Power Transmitter design B3

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	$d_{\mathrm{w}} + d_{\mathrm{s}}$	$0.6^{\pm 0.03}$ 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

2.3.3.1.2 Shielding

As shown in Figure 157, Transmitter design B3 employs Shielding to protect the Base Station 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 $d_\mathrm{s} = 0.5$ mm below the Primary Coil array.

Figure 157. Primary Coil array assembly of Power Transmitter design B3



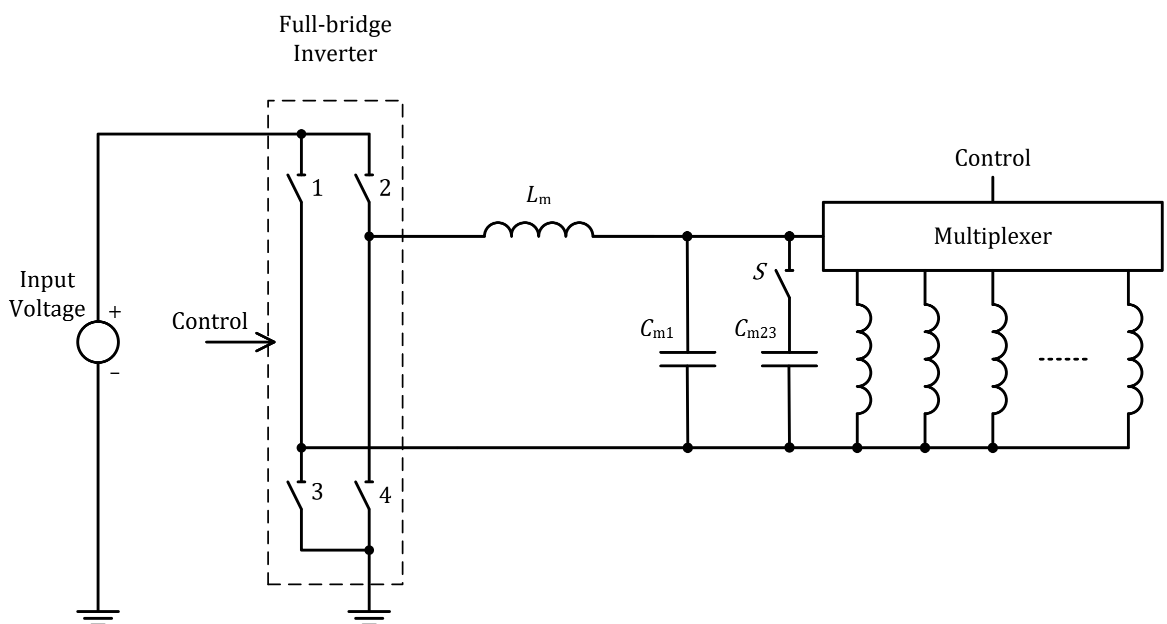
2.3.3.1.3 Interface Surface

As shown in Figure 157, the distance from the Primary Coil array to the Interface Surface of the Base Station is $d_\mathrm{z} = 2^{+0.1}_{-0.5}$ 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.

2.3.3.2 Electrical details

As shown in Figure 158, 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 156(d) for an example.

Figure 158. Electrical diagram (outline) of Power Transmitter design B3

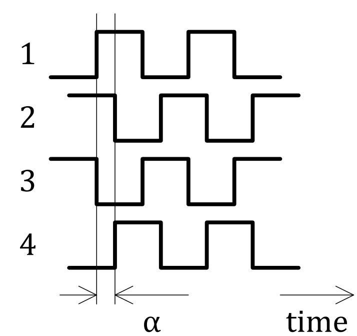


Within the Operating Frequency range $f_{op} = 105 \ldots 113$ kHz, the assembly of Primary Coil array and Shielding has an inductance of $11.6^{\pm 1}$ μH for each individual Primary Coil in layer (a) (closest to the Interface Surface), $12.4^{\pm 1}$ μH for each individual Primary Coil in PCB layers 2 and 3, and $13.5^{\pm 1.5}$ μH for each individual Primary Coil in layer (b). The capacitances and inductance in the impedance matching circuit are, respectively, $C_{m1} = 222^{\pm 5\%}$ nF, $C_{m23} = 133^{\pm 5\%}$ nF, and $L_m = 3.8^{\pm 5\%}$ μH. The switch S is open if the Primary Cell consists of a single Primary Coil; otherwise, the swich S is closed. The input voltage to the full-bridge inverter is $12^{\pm 5\%}$ 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 159. 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 (see the *Digital Ping* section in *Parts 1 and 2: Interface Definitions*), it shall use an initial phase difference of 120°.

Figure 159. Control signals to the inverter



Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Power transfer control* section in *Parts 1 and 2: Interface Definitions*. 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 107 provides the values of several parameters that 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	$\mathrm{mA}^{-1}\mathrm{ms}^{-1}$
Derivative gain	K_d	0	$\mathrm{mA}^{-1}\mathrm{ms}$
Integral term limit	M_I	N.A.	N.A.
PID output limit	M_PID	2,000	N.A.
Scaling factor	S_v	0.01	°

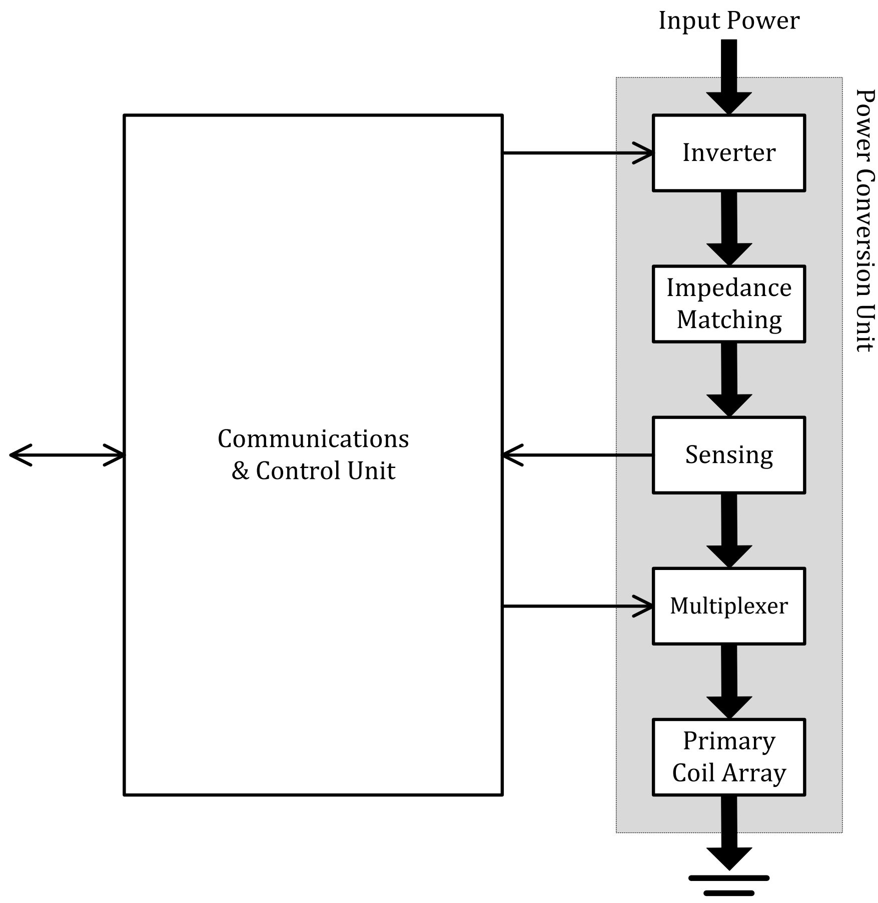
2.3.3.3 Scalability

Power Transmitter Design B3 offers the same scalability options as Power Transmitter design B1. See Section 2.3.1.3.

2.3.4 Power Transmitter design B4

Power Transmitter design B4 enables Free Positioning. Figure 160 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 160. Functional block diagram of Power Transmitter design B4



The Power Conversion Unit on the right-hand side of Figure 160 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 160 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 Base Station, e.g. for user interface purposes.

2.3.4.1 Mechanical details

Power Transmitter design B4 includes a Primary Coil array as defined in Section 2.3.4.1.1, Shielding as defined in Section 2.3.4.1.2, and an Interface Surface as defined in Section 2.3.4.1.3.

2.3.4.1.1 Primary Coil array

The Primary Coil array consists of partly overlapping square shaped planar coils. Figure 161(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 161(b) shows a top view of such wire-wound Primary Coil. Table 108 lists the relevant parameters of the coils shown in Figure 161.

Figure 161. Top view of PCB and wire-wound Primary Coil of Power Transmitter design B4

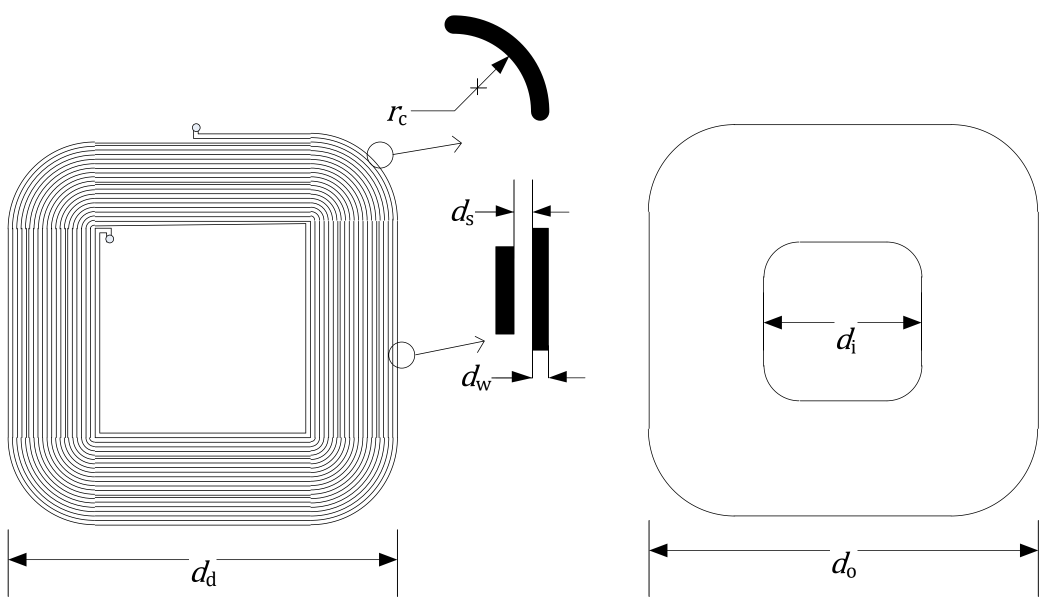


Table 108. Primary Coil parameters of Power Transmitter design B4

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	$d_{\mathrm{w}} + d_{\mathrm{s}}$	$0.6^{\pm 0.03}$ 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 162 shows the layout of the Primary Coil array. Figure 163 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 109 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 162. Top view (a) and cross section (b) of the Primary Coil array of Power Transmitter design B4.

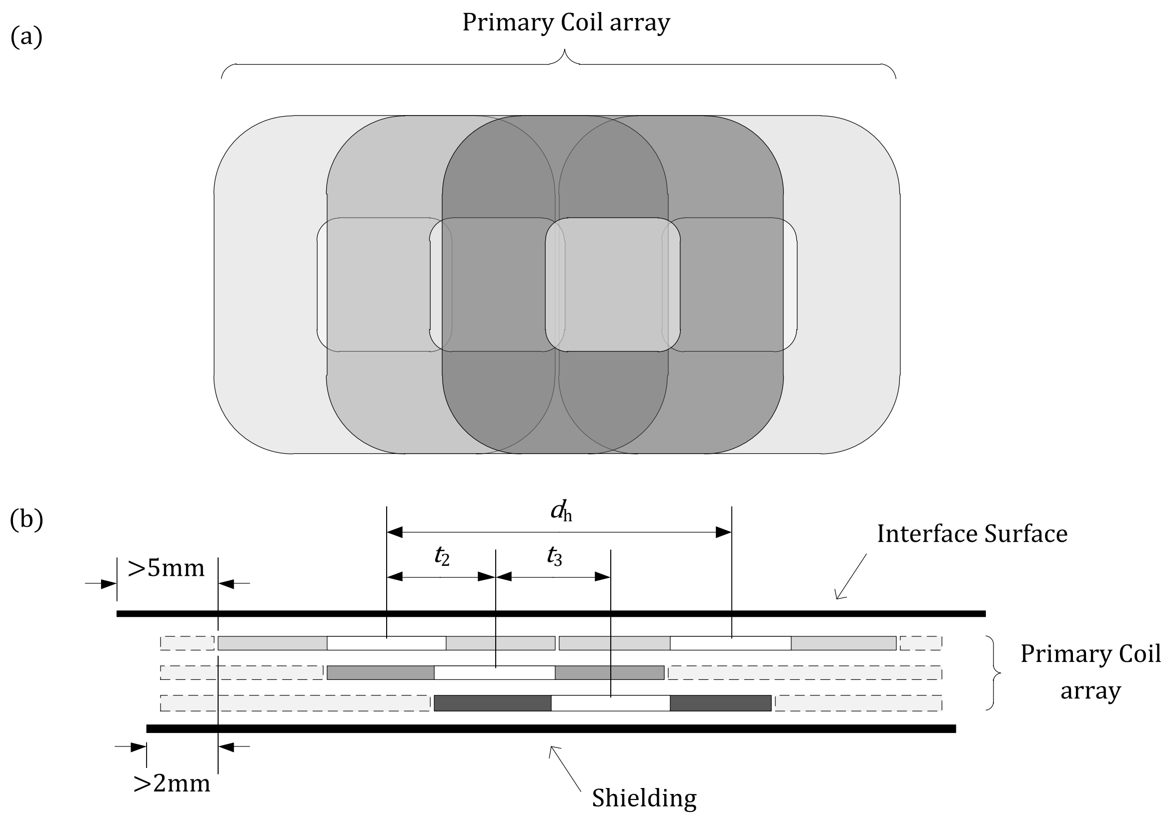


Figure 163. Layered structure of the Primary Coil array

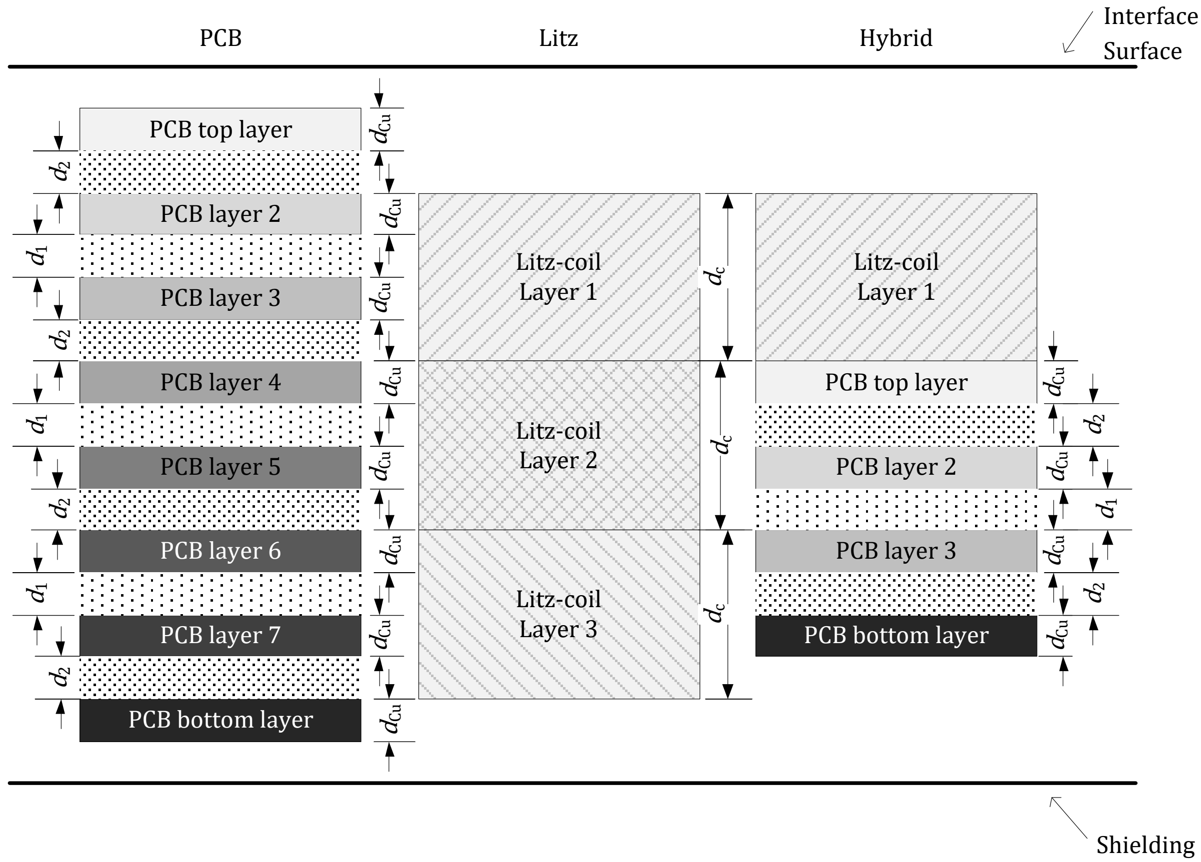


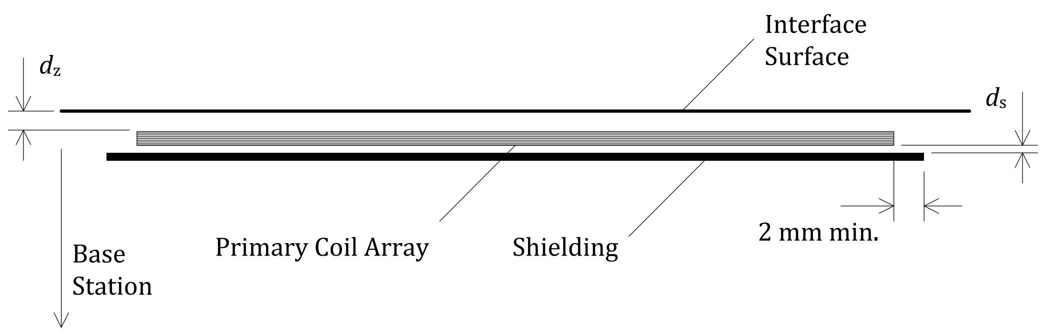
Table 109. Primary Coil array parameters of Power Transmitter design B4

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

2.3.4.1.2 Shielding

As shown in Figure 163, Transmitter design B4 employs Shielding to protect the Base Station 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 $d_{\mathrm{s}} = 0.5$ mm below the Primary Coil array.

Figure 164. Primary Coil array assembly of Power Transmitter design B4



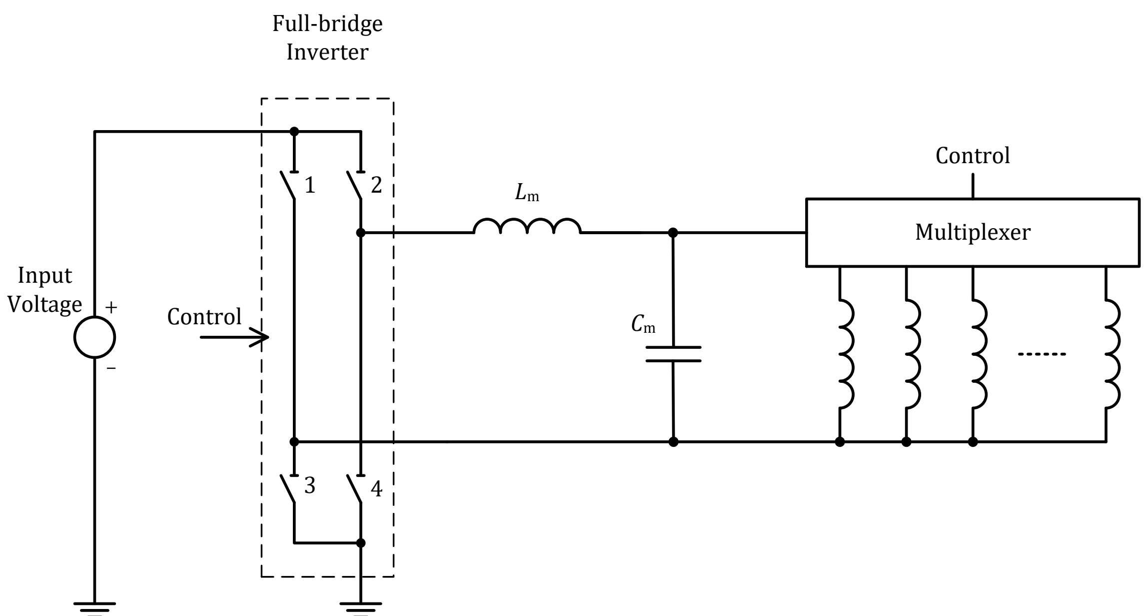
2.3.4.1.3 Interface Surface

As shown in Figure 164, the distance from the Primary Coil array to the Interface Surface of the Base Station is $d_{\mathrm{z}} = 2^{\pm 0.5}$ 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.

2.3.4.2 Electrical details

As shown in Figure 165, 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 165. Electrical diagram (outline) of Power Transmitter design B4

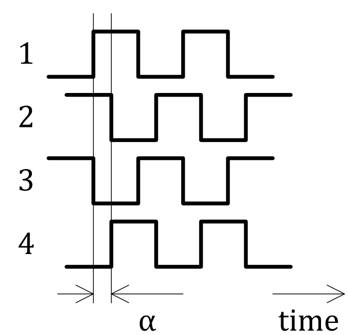


Within the Operating Frequency range $f_{\mathrm{op}} = 105 \ldots 113$ kHz, the assembly of Primary Coil array and Shielding has an inductance of $8.8^{\pm 1}$ μH for each individual Primary Coil in layer (a) (closest to the Interface Surface), $9.1^{\pm 1}$ μH for each individual Primary Coil in layer (b), and $9.5^{\pm 1}$ μH for each individual Primary Coil in layer (c) (closest to the Shielding). The capacitances and inductance in the impedance matching circuit are, respectively, $C_{\mathrm{m}} = 300^{\pm 5\%}$ nF, and $L_{\mathrm{m}} = 3.8^{\pm 5\%}$ μH. The input voltage to the full-bridge inverter is $12^{\pm 5\%}$ 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 166. 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 (see the *Digital Ping* section in *Parts 1 and 2: Interface Definitions*), it shall use an initial phase difference of 120°.

Figure 166. Control signals to the inverter



Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Power transfer control* section in *Parts 1 and 2: Interface Definitions*. 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 110 provides the values of several parameters, which are used in the PID algorithm.

Table 110. Control parameters for power control

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

2.3.4.3 Scalability

Power Transmitter Design B4 offers the same scalability options as Power Transmitter design B1. See Section 2.3.1.3.

2.3.5 Power Transmitter design B5

Figure 167 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.

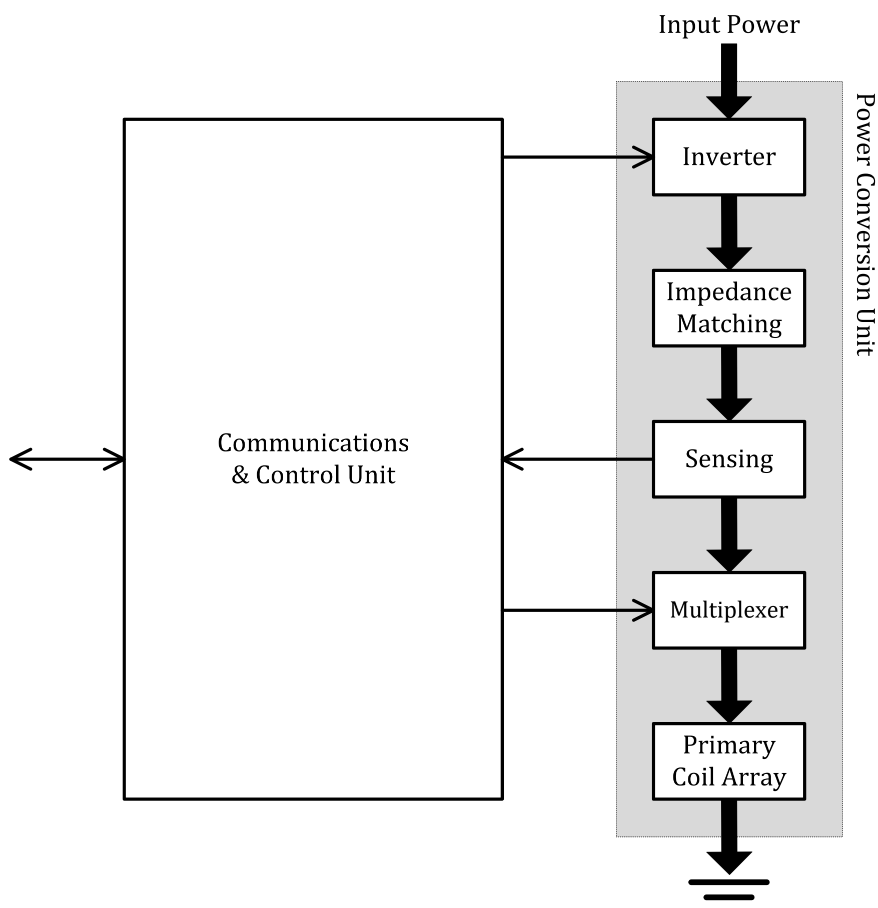


Figure 167. Functional block diagram of Power Transmitter design B5

The Power Conversion Unit on the right-hand side of Figure 167 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 167 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 Base Station, e.g. for user interface purposes.

2.3.5.1 Mechanical details

Power Transmitter design B5 includes a Primary Coil array as defined in Section 2.3.5.1.1, Shielding as defined in Section 2.3.5.1.2, and an Interface Surface as defined in Section 2.3.5.1.3.

2.3.5.1.1 Primary Coil array

The Primary Coil array consists of partly overlapping square shaped planar coils. Figure 168(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 168(b) shows a top view of such wire-wound Primary Coil. Table 111 lists the relevant parameters of the coils shown in Figure 168.

Figure 168. Top view of PCB and wire-wound Primary Coil of Power Transmitter design B5

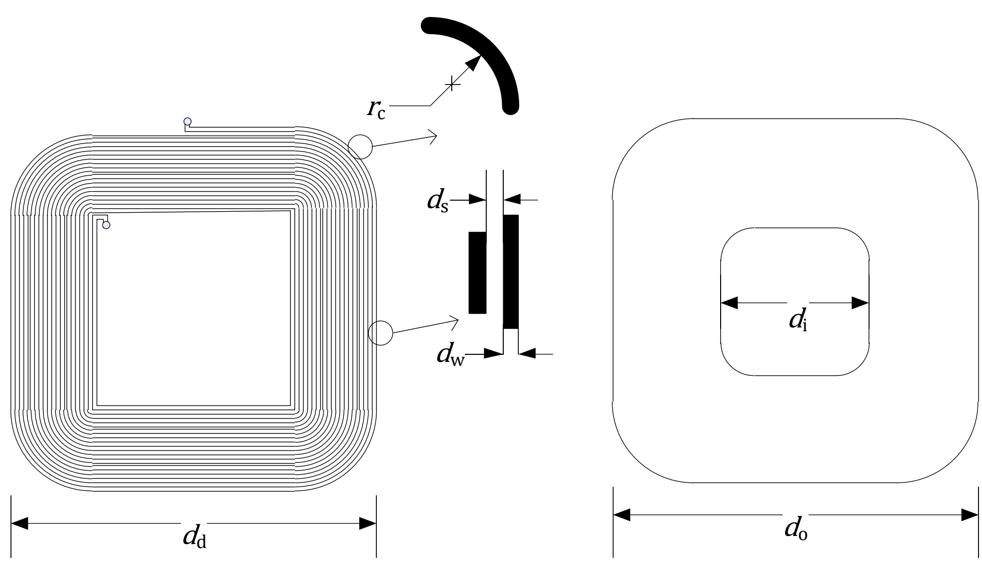


Table 111. Primary Coil parameters of Power Transmitter design B5

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	$d_{\mathrm{w}} + d_{\mathrm{s}}$	$0.6^{\pm 0.03}$ 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 169 shows the layout of the Primary Coil array. Figure 170 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 169. Top view (a) and cross section (b) of the Primary Coil array of Power Transmitter design B5.

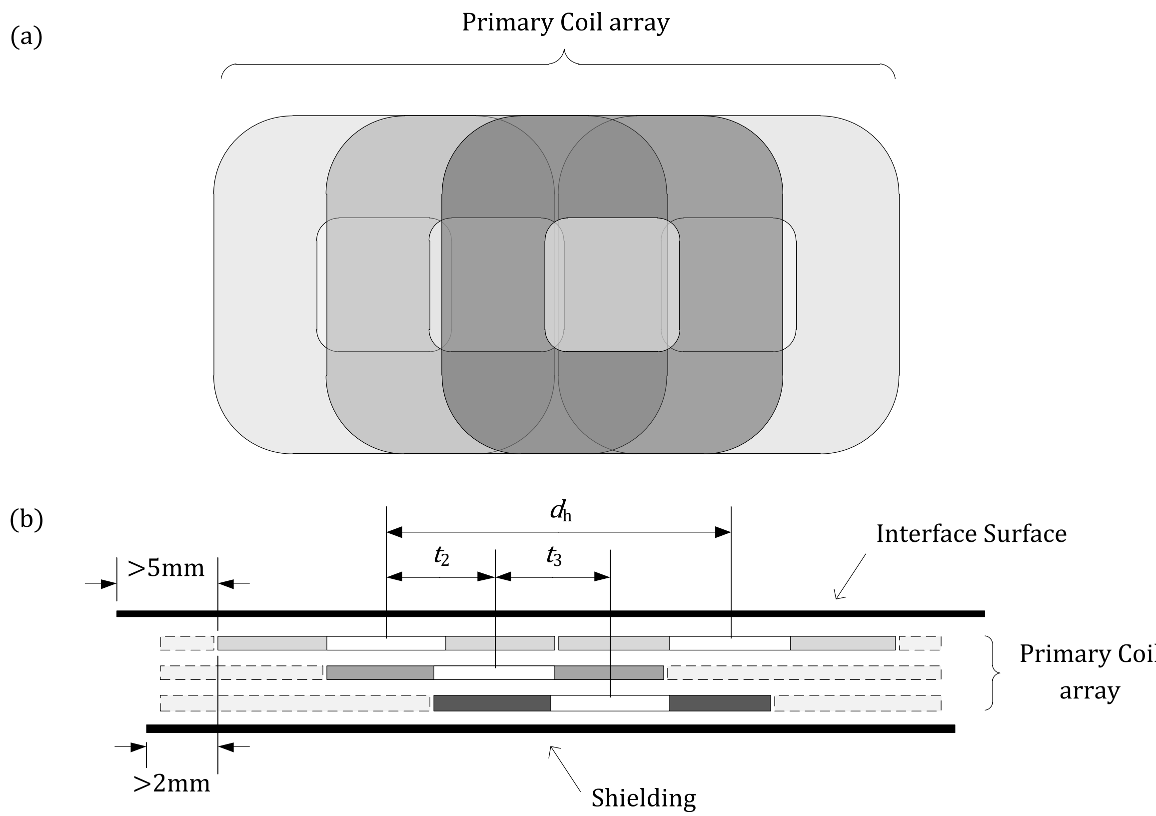


Figure 170. Layered structure of the Primary Coil array

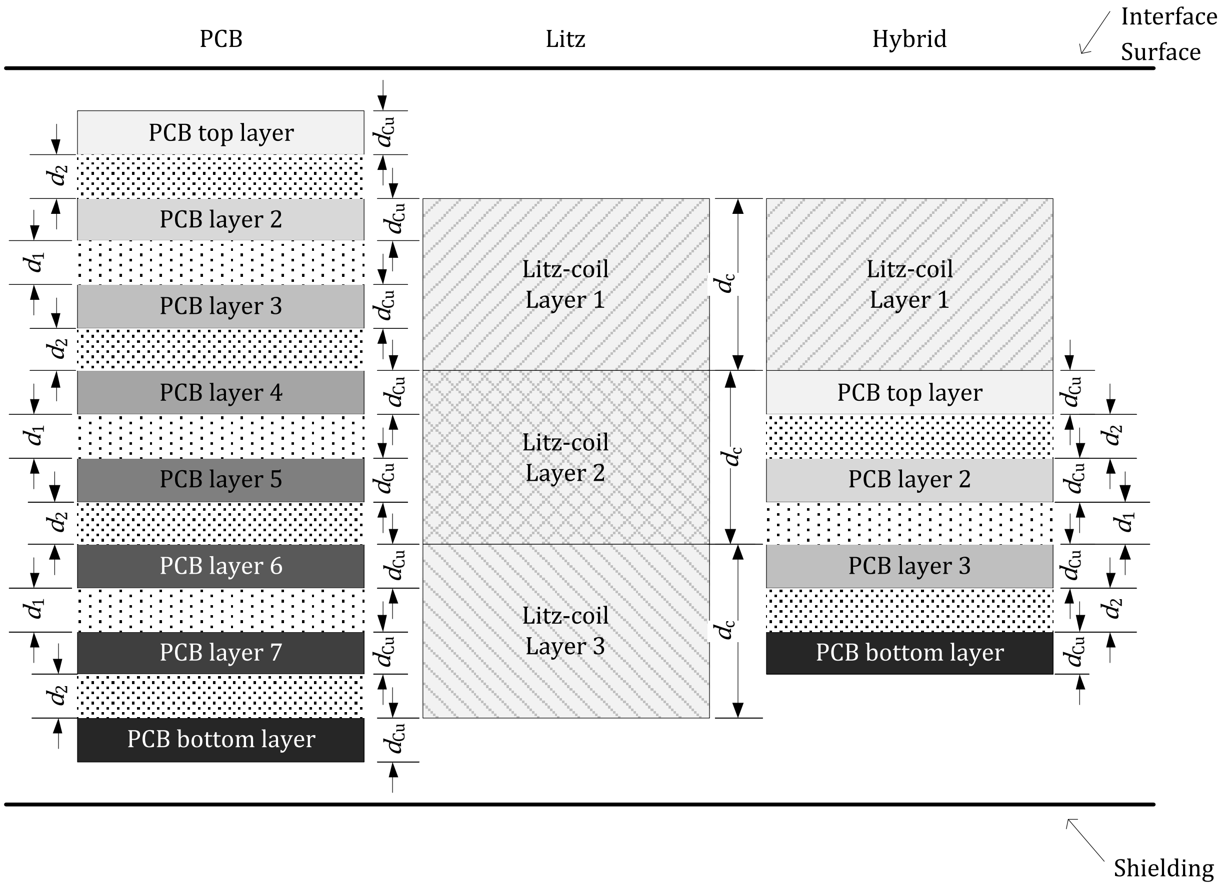


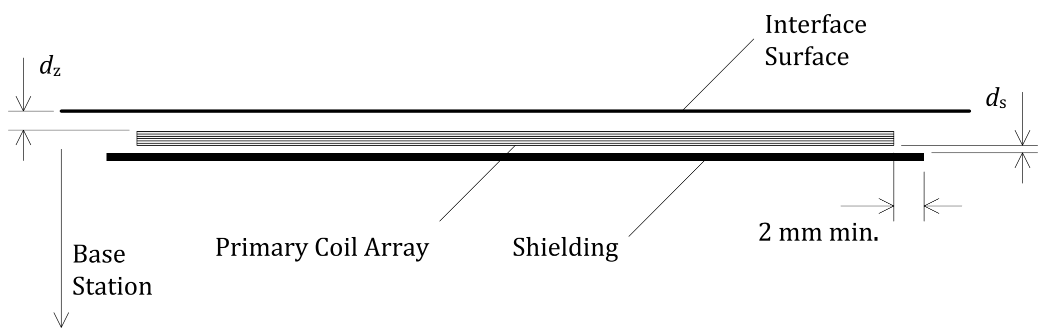
Table 112. Primary Coil array parameters of Power Transmitter design B5

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

2.3.5.1.2 Shielding

As shown in Figure 169, Transmitter design B5 employs Shielding to protect the Base Station 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 $d_\mathrm{s} = 0.5$ mm below the Primary Coil array.

Figure 171. Primary Coil array assembly of Power Transmitter design B5



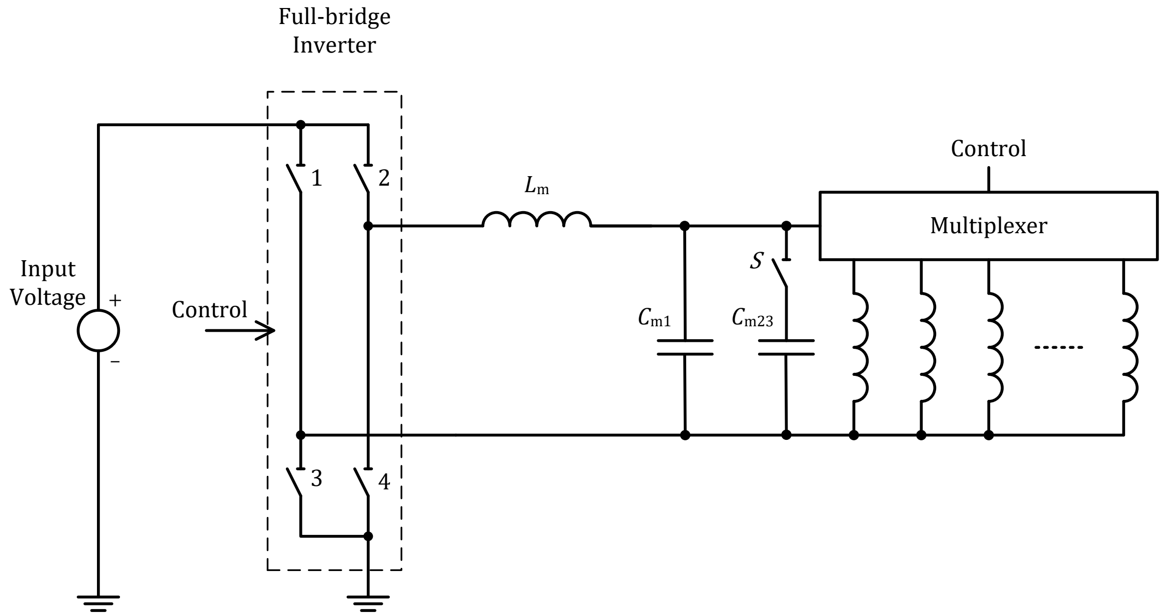
2.3.5.1.3 Interface Surface

As shown in Figure 171, the distance from the Primary Coil array to the Interface Surface of the Base Station is $d_\mathrm{z} = 2^{+0.5}_{-0.25}$ 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.

2.3.5.2 Electrical details

As shown in Figure 172, 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 172. Electrical diagram (outline) of Power Transmitter design B5

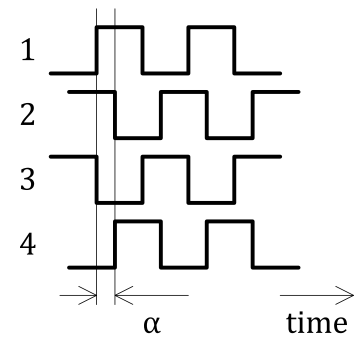


Within the Operating Frequency range $f_{\text{op}} = 96 \pm 2$ kHz, the assembly of Primary Coil array and Shielding has an inductance of $8.8^{\pm 1}$ μH for each individual Primary Coil in layer (a) (closest to the Interface Surface), $9.1^{\pm 1}$ μH for each individual Primary Coil in layer (b), and $9.5^{\pm 1}$ μH for each individual Primary Coil in layer (c) (closest to the Shielding). The capacitances and inductance in the impedance matching circuit are, respectively, $C_{\text{m1}} = 356^{\pm 5\%}$ nF, $C_{\text{m23}} = 82^{\pm 5\%}$ nF, and $L_{\text{m}} = 3.8^{\pm 5\%}$ μH. The switch S is open if the Primary Cell consists of a single Primary Coil; otherwise, the swich S is closed. The input voltage to the full-bridge inverter is $12^{\pm 5\%}$ 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 173. 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 (see the *Digital Ping* section in *Parts 1 and 2: Interface Definitions*), it shall use an initial phase difference of 120°.

Figure 173. Control signals to the inverter



Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Power transfer control* section in *Parts 1 and 2: Interface Definitions*. 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 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	$\mathrm{mA}^{-1}\mathrm{ms}^{-1}$
Derivative gain	K_{d}	0	$\mathrm{mA}^{-1}\mathrm{ms}$
Integral term limit	M_{I}	N.A.	N.A.
PID output limit	M_{PID}	2,000	N.A.
Scaling factor	S_{v}	0.01	°

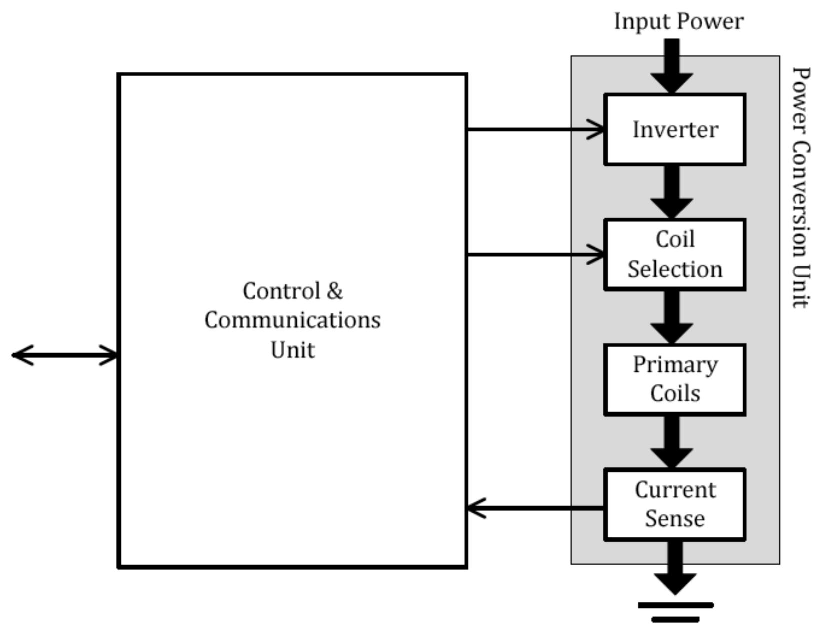
2.3.5.3 Scalability

Power Transmitter Design B5 offers the same scalability options as Power Transmitter design B1. See Section 2.3.1.3.

2.3.6 Power Transmitter design B6

Figure 174 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 174. Functional block diagram of Power Transmitter design B6



The Power Conversion Unit on the right-hand side of Figure 174 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 174 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 Base Station, e.g. for user interface purposes.

2.3.6.1 Mechanical details

Power Transmitter design B6 includes a Primary Coil array as defined in Section 2.3.6.1.1, Shielding as defined in Section 2.3.6.1.2, and an Interface Surface as defined in Section 2.3.6.1.3.

2.3.6.1.1 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[2]. As shown in Figure 175, the Primary Coil has an oval shape and consists of a single layer. Table 114 lists the dimensions of the Primary Coil.

Figure 175. Primary coil of Power Transmitter design B6

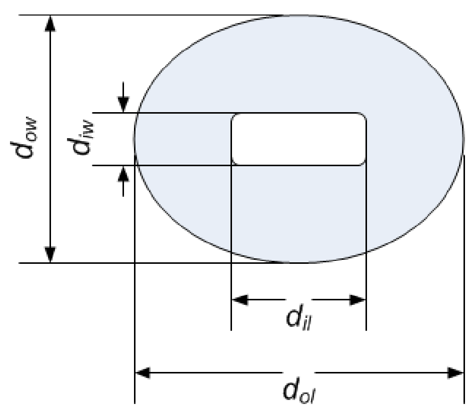


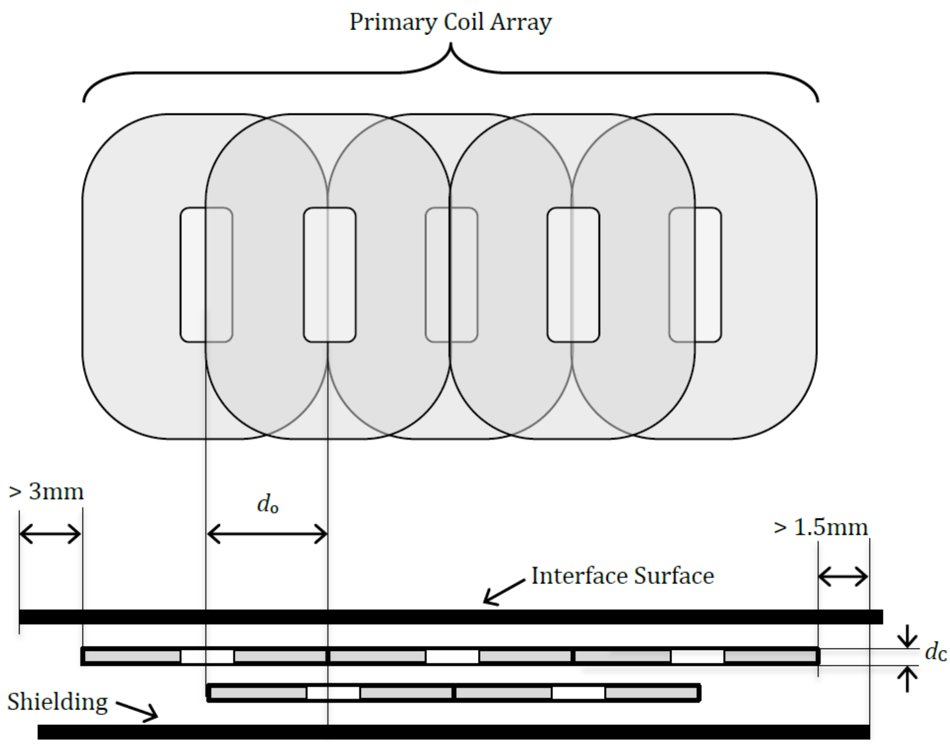
Table 114. Design parameters for Primary Coil array of Power Transmitter B6

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	dC	$0.65^{\pm 0.3}$ mm
Number of turns per layer	N	11 turns
Number of layers	-	1

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 $d_{\mathrm{o}} = 17.0^{+2.0}_{-0.0}$ mm between their centers, such that there is an overlap of about 50% of the area. Figure 176 shows the functional arrangement of coils in the Primary Coil array. See also Table 114 for details of the parameters.

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

Figure 176. Arrangement of coils in the Primary Coil array of Power Transmitter B6

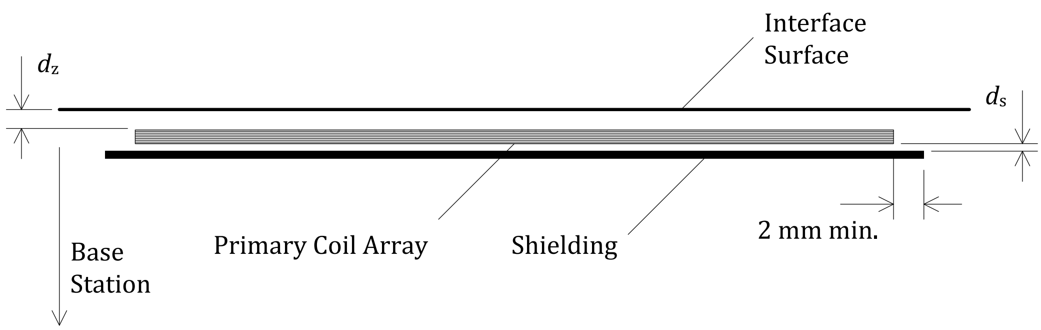


The Communications & Control Unit of a single Power Transmitter selects 1 or 2 coils from the array to form a Primary Cell for power transfer when a Power Receiver is positioned on the Active Area. In the case where 2 coils are selected, these 2 coils shall have an overlap.

2.3.6.1.2 Shielding

As shown in Figure 176, Transmitter design B6 employs Shielding to protect the Base Station 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 177. Primary Coil array assembly of Power Transmitter design B6



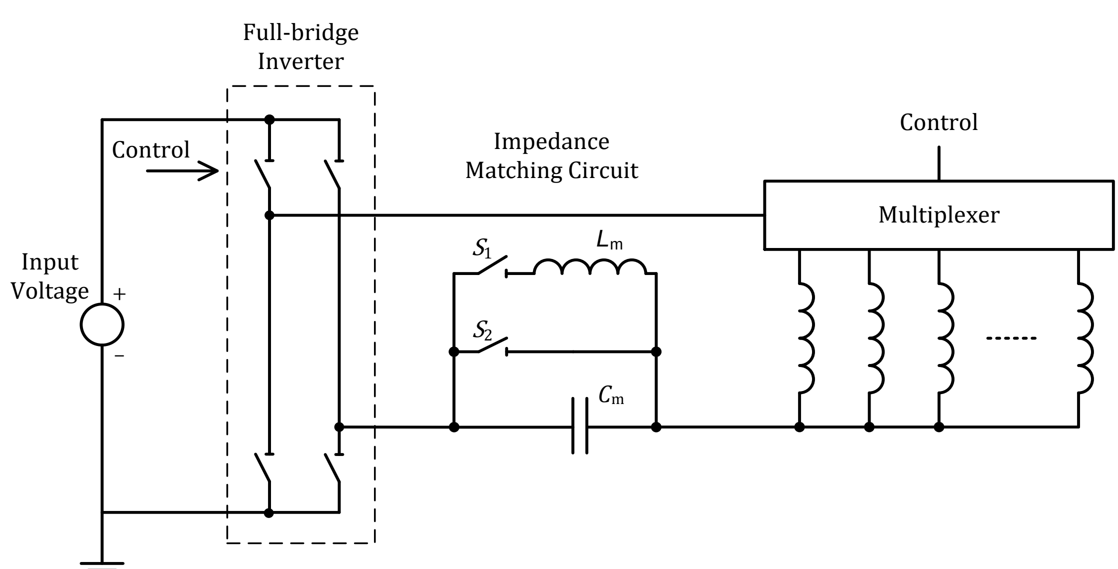
2.3.6.1.3 Interface Surface

As shown in Figure 177, the distance from the Primary Coil array to the Interface Surface of the Base Station 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.

2.3.6.2 Electrical details

As shown in Figure 178, 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 2.3.6.1.1) Primary Coils are connected—in parallel—to the driving circuit. The connected Primary Coil(s) together constitute a Primary Cell.

Figure 178. Electrical diagram (outline) of Power Transmitter design B6



Within the Operating Frequency range $f_{\mathrm{op}} = 125 \ldots 135$ kHz, the assembly of Primary Coil array and Shielding has an inductance of $5.8^{\pm0.5}$ μH for each individual Primary Coil in layer (a) (closest to the Interface Surface), and $6.2^{\pm0.5}$ μH for each individual Primary Coil in layer (b) (closest to the Shielding). The capacitance in the impedance matching circuit is $C_{\mathrm{m}} = 1000^{\pm5\%}$ nF. The inductance in the impedance matching circuit is $L_{\mathrm{m}} = 1$ μH. The input voltage to the full-bridge inverter is $5^{\pm5\%}$ V.

NOTE The voltage across the capacitance C_{m} can reach levels exceeding 25V pk-pk.

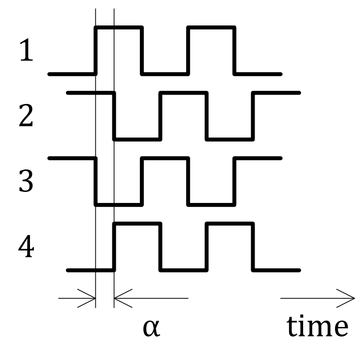
Switches S_1 and S_2 may be used to change the impedance the inverter sees when driving the Primary Cell, allowing the inverter to drive the Primary Cell at Operating Points that are more efficient (i.e. requiring less current). During normal operation both switches should be open. However, during a 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 115 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 115. 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 179. 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 (see the *Digital Ping* section in *Parts 1 and 2: Interface Definitions*), it shall use an initial phase difference of 180° and switch S_1 closed and switch S_2 open.

Figure 179. Control signals to the inverter



Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Power transfer control* section in *Parts 1 and 2: Interface Definitions*. 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 116 provides the values of several parameters, which are used in the PID algorithm.

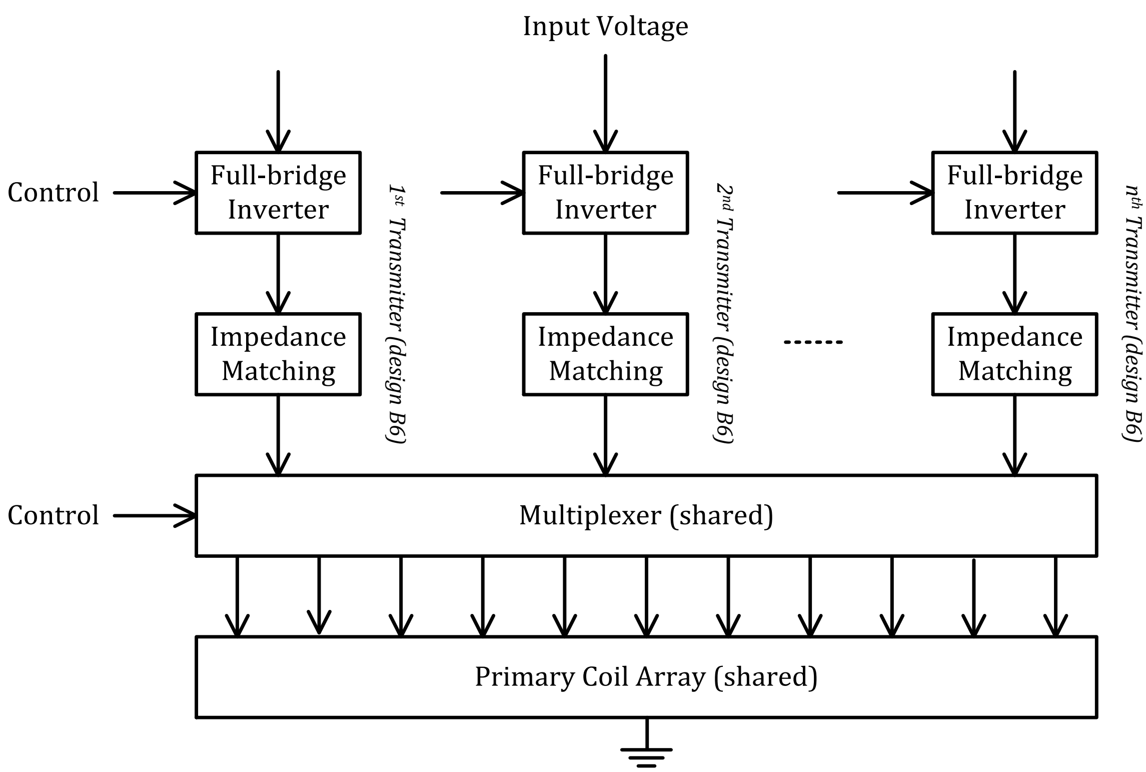
Table 116. Control parameters for power control

Parameter	Symbol	Value	Unit
Proportional gain	K_{p}	1	$\mathrm{mA^{-1}}$
Integral gain	K_{i}	0	$\mathrm{mA^{-1}ms^{-1}}$
Derivative gain	K_{d}	0	$\mathrm{mA^{-1}ms}$
Integral term limit	M_{I}	N.A.	N.A.
PID output limit	M_{PID}	2,000	N.A.
Scaling factor	S_{v}	0.01	°

2.3.6.3 Scalability

Sections 2.3.6.1 and 2.3.6.2 define the mechanical and electrical details of Power Transmitter design B6. As defined in Section 2.1, a type B6 Power Transmitter serves a single Power Receiver only. In order to serve multiple Power Receivers simultaneously, a Base Station may contain multiple type B6 Power Transmitters. As shown in Figure 180, 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 2.3.6.2. In addition, the multiplexer shall ensure that it does not connect multiple inverters to any individual Primary Coil.

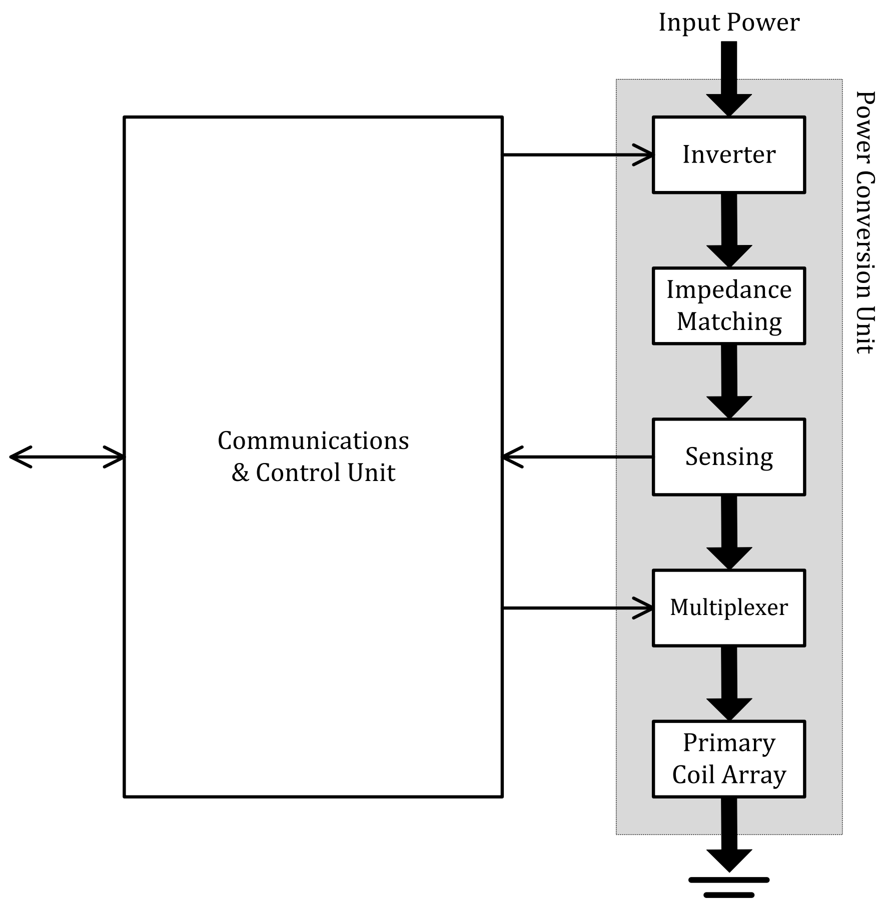
Figure 180. Multiple type B6 Power Transmitters sharing a multiplexer and Primary Coil array



2.3.7 Power Transmitter design B7

Figure 181 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 181. Functional block diagram of Power Transmitter design B7



The Power Conversion Unit on the right-hand side of Figure 181 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 181 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 Base Station, e.g. for user interface purposes.

2.3.7.1 Mechanical details

Power Transmitter design B7 includes a Primary Coil array as defined in Section 2.3.7.1.1, Shielding as defined in Section 2.3.7.1.2, and an Interface Surface as defined in Section 2.3.7.1.3.

2.3.7.1.1 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 182 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 117 lists the relevant parameters of the coils shown in Figure 182.

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 182. Top view of Primary Coil A (left) and Primary Coil B (right) of Power Transmitter design B7

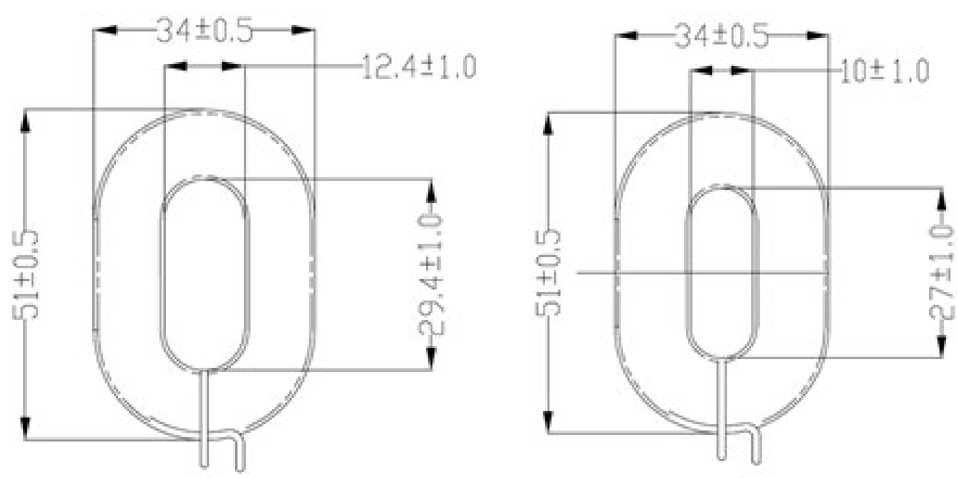


Table 117. Primary Coil parameters of Power Transmitter design B7

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 183 shows the layout of an example execution of the Primary Coil array using four Primary Coils. Table 118 lists the relevant parameters of the Primary Coil array.

Figure 183. Example of Power Transmitter design B7 in a 4-coil execution

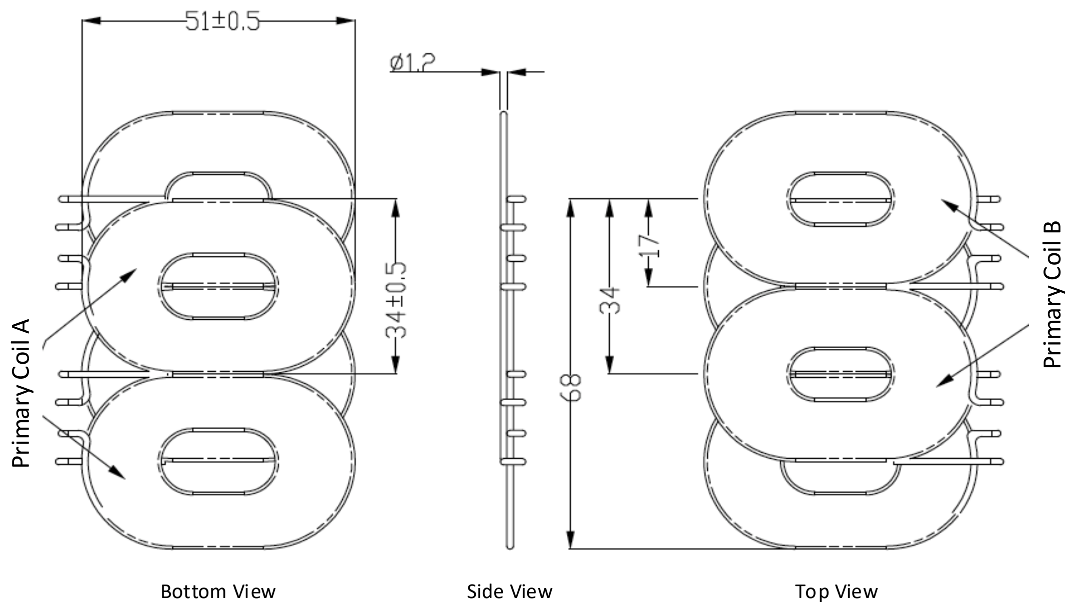


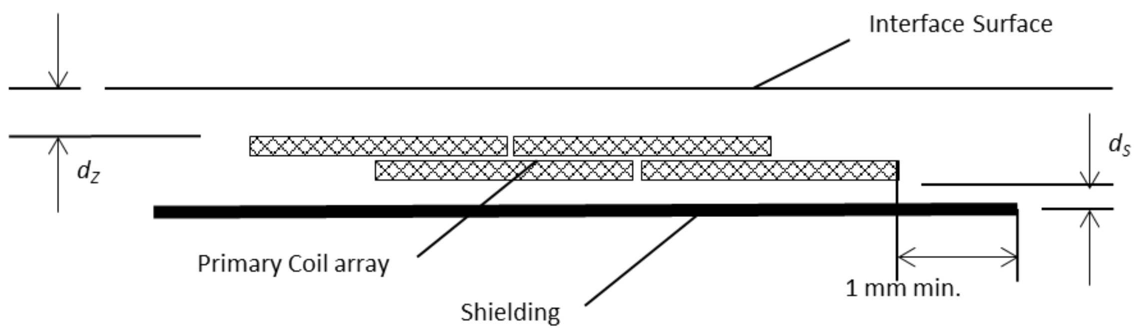
Table 118. Primary Coil array parameters of Power Transmitter design B7

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

2.3.7.1.2 Shielding

As shown in Figure 184, Transmitter design B7 employs Shielding to protect the Base Station 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 184. Primary Coil array assembly of Power Transmitter design B7



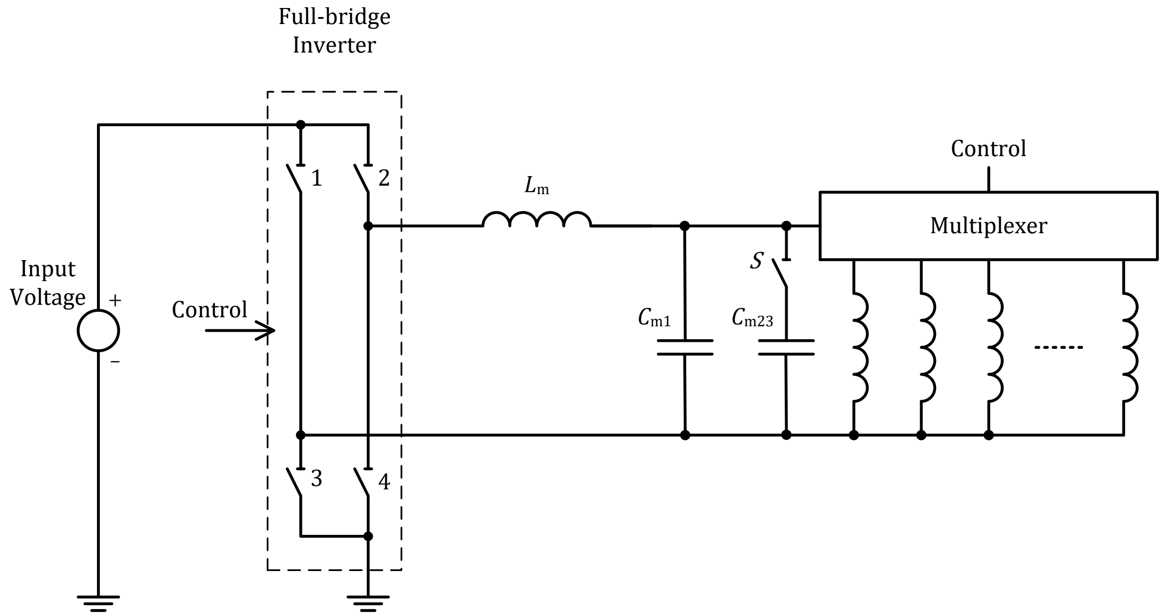
2.3.7.1.3 Interface Surface

As shown in Figure 184, the distance from the Primary Coil array to the Interface Surface of the Base Station 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.

2.3.7.2 Electrical details

As shown in Figure 185, 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 185. Electrical diagram (outline) of Power Transmitter design B7

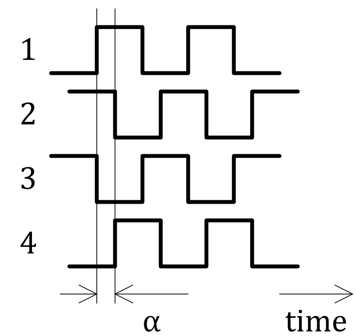


Within the Operating Frequency range $f_{Op} = 115^{\pm 5}$ kHz, the assembly of Primary Coil array and Shielding has an inductance of $6.1^{\pm 0.6}$μH for each individual Primary Coil. The capacitances and inductance in the impedance matching circuit are, respectively, $C_{m1} = 300^{\pm 5\%}$ nF, $C_{m23} = 100^{\pm 5\%} - 300^{\pm 5\%}$ 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 186. 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 (see the *Digital Ping* section in *Parts 1 and 2: Interface Definitions*), it shall use an initial phase difference of 150°.

Figure 186. Control signals to the inverter



Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Power transfer control* section in *Parts 1 and 2: Interface Definitions*. 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 119 provides the values of several parameters that are used in the PID algorithm.

Table 119. Power control parameters for Power Transmitter design B7

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}	2,000	N.A.
Scaling factor	S_{v}	0.01	°

2.3.7.3 Scalability

Power Transmitter Design B7 offers the same scalability options as Power Transmitter design B1. See Section 2.3.1.3.

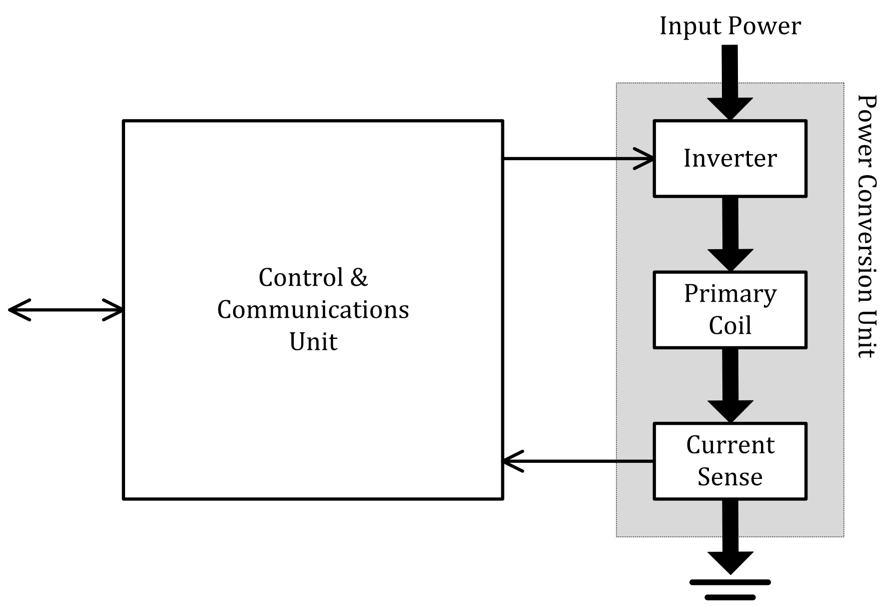
2.4 Extended Power Profile Power Transmitter designs

This Section 2.4 defines all type MP-A 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 and communications interface defined in *Parts 1 and 2: Interface Definitions*.

2.4.1 Power Transmitter design MP-A1

Figure 187 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 187. Functional block diagram of Power Transmitter design MP-A1



The Power Conversion Unit on the right-hand side of Figure 187 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 187 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 Base Station, e.g. for user interface purposes.

2.4.1.1 Mechanical details

This section defines the Primary Coil, the Shielding, the Interface Surface, and the alignment aid for Power Transmitter design MP-A1.

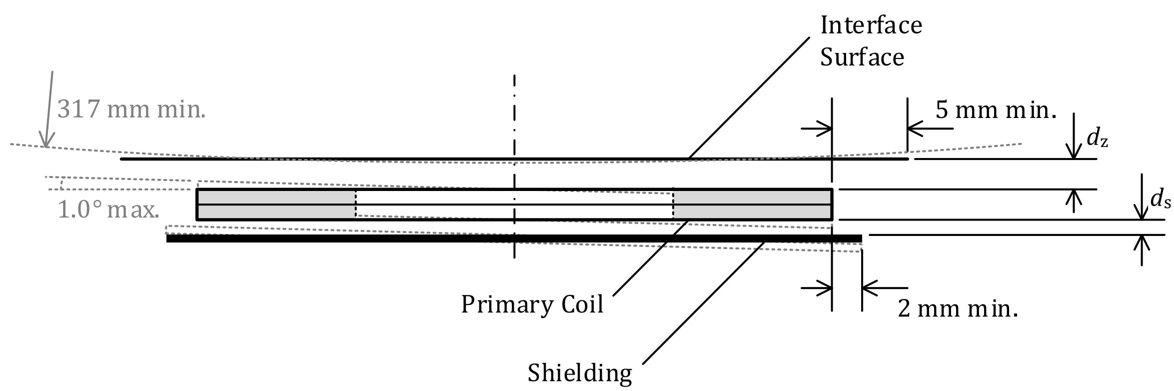
2.4.1.1.1 Primary Coil

The Primary Coil of the MP-A1 design is identical to the Primary Coil of the type A10 Power Transmitter defined in Section 0.

2.4.1.1.2 Shielding

As shown in Figure 188, Shielding protects the Base Station 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 188. Primary Coil assembly of Power Transmitter design MP-A1



2.4.1.1.3 Interface Surface

As shown in Figure 188, the distance from the Primary Coil to the Interface Surface of the Base Station is $d_z = 2^{+0.5}_{-0.25}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Base Station 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 188.

2.4.1.1.4 Alignment aid

The user manual of a Base Station 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 Mobile Device positioning to help alignment.

NOTE Examples of Base Station alignment aids to assist the user positioning of the Mobile Device 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.

2.4.1.1.5 Inter-coil separation

If the Base Station contains multiple type MP-A1 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall have a center-to-center distance of at least 50 mm.

2.4.1.2 Electrical details

As shown in Figure 189, 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 190), or uses the Operating Frequency and duty cycle of the half-bridge inverter's driving signals (see Figure 191) in order to control the amount of power that is transferred. For this purpose, the Operating Frequency range of the inverter is $f_{\mathrm{op}} = 110$ kHz to 205 kHz with a driving signal phase difference of $\alpha = 0°$ 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:

- $0.01 \cdot f_{\mathrm{op}} - 0.7$ kHz for f_{op} in the 110 kHz to 175 kHz range;
- $0.015 \cdot f_{\mathrm{op}} - 1.58$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 *Parts 1 and 2: Interface Definitions*. 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 120, Table 121, Table 122, and Table 123 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 189. Electrical diagram (outline) of Power Transmitter design MP-A1

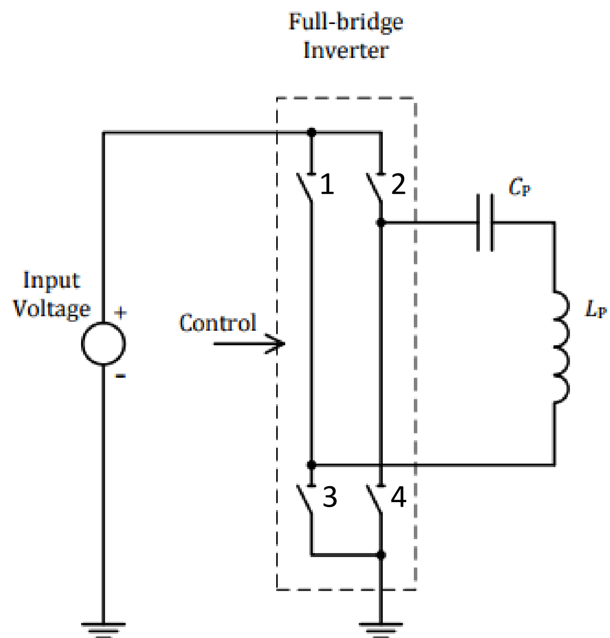


Table 120. PID parameters for Operating Frequency control

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

Figure 190. Phase control signals to Full Bridge inverter

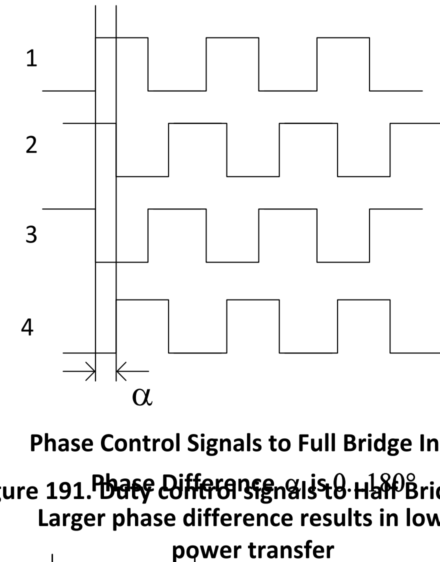


Figure 191. Duty control signals to Half Bridge inverter

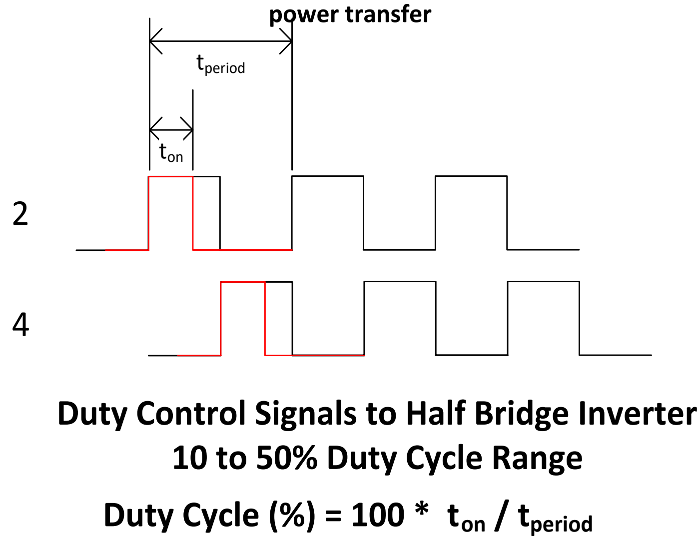


Table 121. Operating Frequency dependent scaling factor

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 122. 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 123. 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	%

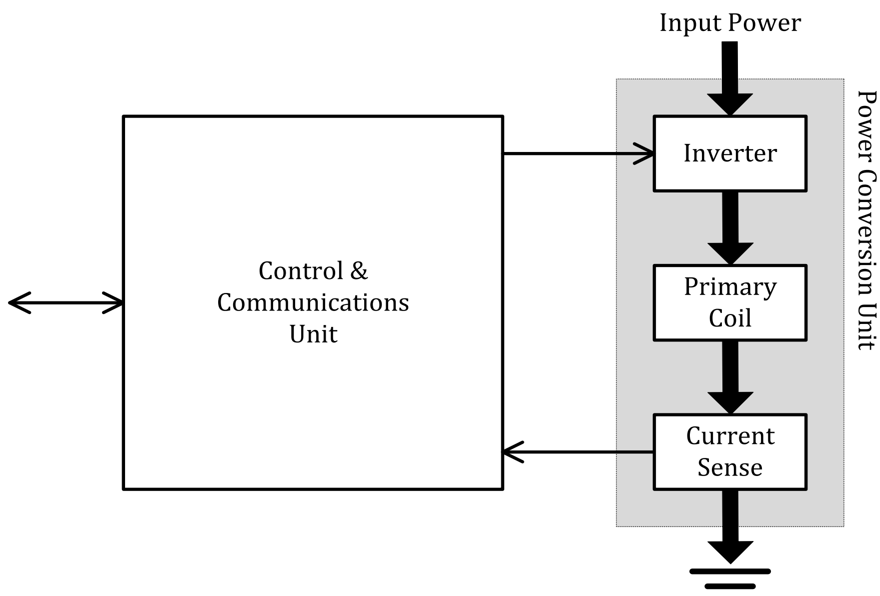
2.4.1.3 Information interface

The Not Res Sens Bit in the Power Transmitter Capability Packet shall be set to ZERO.

2.4.2 Power Transmitter design MP-A2

Figure 192 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 192. Functional block diagram of Power Transmitter design MP-A2



The Power Conversion Unit on the right-hand side of Figure 192 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 192 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 Base Station, e.g. for user interface purposes.

2.4.2.1 Mechanical details

This section defines the single Primary Coil, the Shielding, the Interface Surface and the alignment aid for Power Transmitter design MP-A2.

2.4.2.1.1 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 193 the Primary Coil has a rectangular shape and consists of a single layer. Table 124 lists the dimensions and other parameters of the Primary Coil.

Figure 193. Primary Coil parameters of Power Transmitter design MP-A2

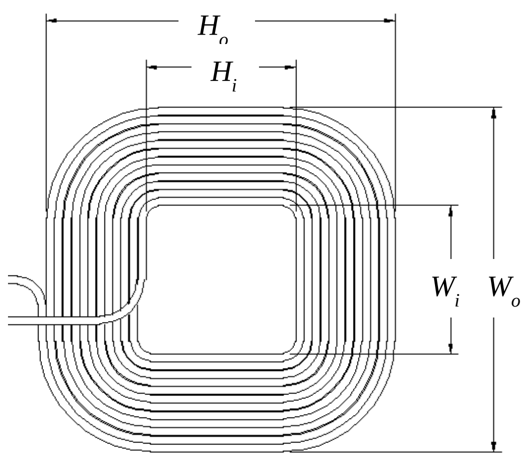


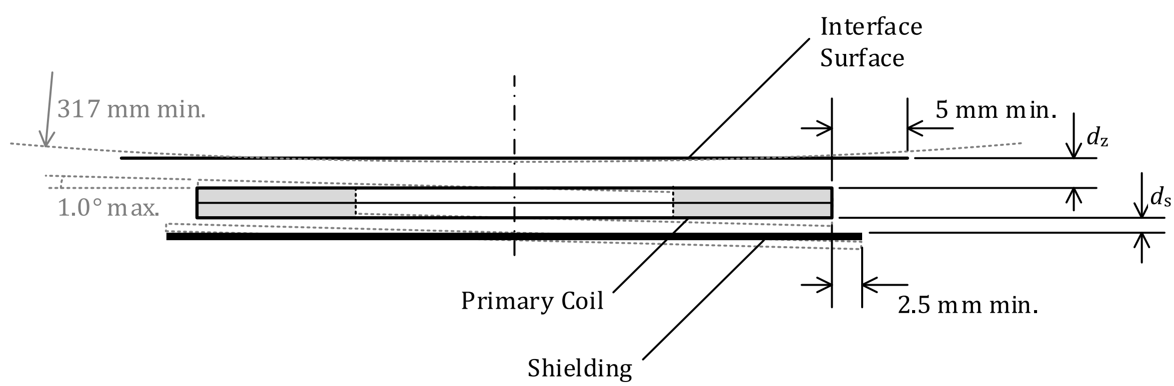
Table 124. Primary Coil parameters of Power Transmitter design MP-A2

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

2.4.2.1.2 Shielding

As shown in Figure 194, a soft-magnetic material protects the Base Station 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 194. Primary Coil assembly of Power Transmitter design MP-A2



2.4.2.1.3 Interface Surface

As shown in Figure 194, the distance from the Primary Coil to the Interface Surface of the Base Station 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 Base Station 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 194.

2.4.2.1.4 Alignment aid

The user manual of a Base Station 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 Mobile Device placement to help alignment.

NOTE Examples of Base Station alignment aids to assist the user placement of the Mobile Device 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.

2.4.2.1.5 Inter-coil separation

If the Base Station contains multiple type MP-A2 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall not overlap.

2.4.2.2 Electrical details

As shown in Figure 195 and Figure 196, 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 $L_{\mathrm{P}} = 10.0^{\pm 10\%}$ μH. The value of the series capacitance is $C_{\mathrm{P}} = 247^{\pm 5\%}$ 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 $f_{\mathrm{op}} = 110$ kHz to 145 kHz. The duty cycle of the full-bridge inverter is 40% to 50% if $f_{\mathrm{op}} = 110$ kHz to 145 kHz and is 5% to 50% at $f_{\mathrm{op}} = 145$ 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 $0.007 \cdot f_{\mathrm{op}} - 0.5$ 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 $12^{\pm1}$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 *Power Transmitter perspective* section in *Parts 1 and 2: Interface Definitions*) 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 *Parts 1 and 2: Interface Definitions*. 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 125, Table 126, and Table 127 provide the values of the parameters that are used in the PID algorithm for the full-bridge inverter topology; Table 128, Table 129, and Table 130 provide the same parameters for the half-bridge inverter topology.

Figure 195. Electrical diagram (outline) of Power Transmitter design MP-A2 (full-bridge topology)

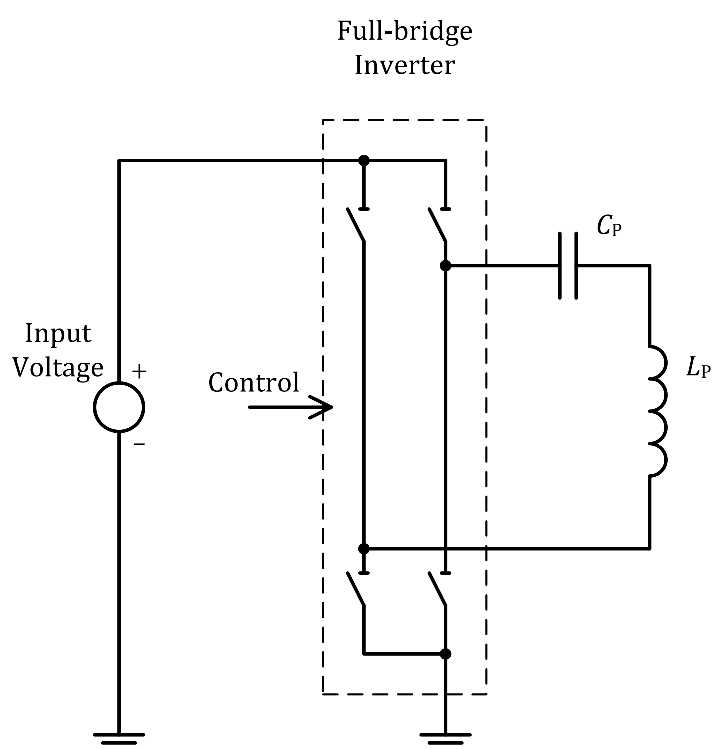


Table 125. PID parameters for Operating Frequency control design MP-A2 (full-bridge topology)

Parameter	Symbol	Value	Unit
Proportional gain	K_{p}	2	mA^{-1}
Integral gain	K_{i}	0.01	$\mathrm{mA}^{-1}\mathrm{ms}^{-1}$
Derivative gain	K_{d}	0	$\mathrm{mA}^{-1}\mathrm{ms}$
Integral term limit	M_{I}	500	N.A.
PID output limit	M_{PID}	5,000	N.A.

Table 126. 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 127. 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	$\mathrm{mA}^{-1}\mathrm{ms}^{-1}$
Derivative gain	K_{d}	0	$\mathrm{mA}^{-1}\mathrm{ms}$
Integral term limit	M_{I}	500	N.A.
PID output limit	M_{PID}	5,000	N.A.
Scaling factor	S_{V}	-0.01	%

Table 128. Electrical diagram of Power Transmitter design MP-A2 (half-bridge topology)

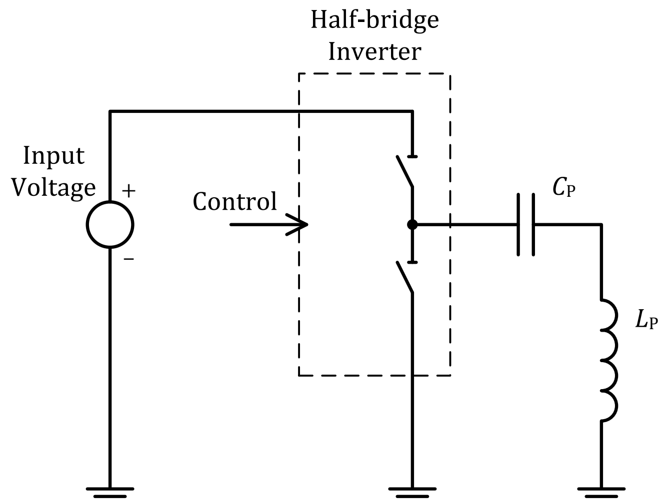


Table 129. PID parameters for Operating Frequency control (half-bridge topology)

Parameter	Symbol	Value	Unit
Proportional gain	K_p	5	mA^{-1}
Integral gain	K_i	0.02	$\mathrm{mA}^{-1}\mathrm{ms}^{-1}$
Derivative gain	K_d	0	$\mathrm{mA}^{-1}\mathrm{ms}$
Integral term limit	M_I	1,000	N.A.
PID output limit	M_PID	10,000	N.A.

Table 130. 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 131. 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	$\mathrm{mA}^{-1}\mathrm{ms}^{-1}$
Derivative gain	K_{d}	0	$\mathrm{mA}^{-1}\mathrm{ms}$
Integral term limit	M_{I}	1,000	N.A.
PID output limit	M_{PID}	10,000	N.A.
Scaling factor	S_{V}	-0.01	%

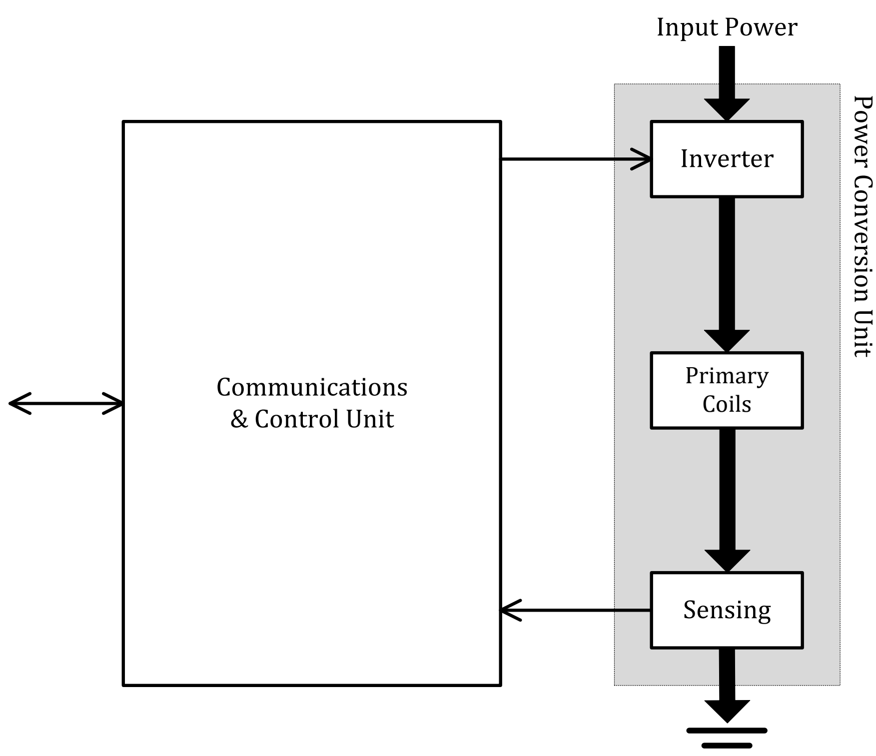
2.4.2.3 Information interface

The Not Res Sens Bit in the Power Transmitter Capability Packet shall be set to ZERO.

2.4.3 Power Transmitter design MP-A3

Figure 196 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 196. Functional block diagram of Power Transmitter design MP-A3



The Power Conversion Unit on the right-hand side of Figure 196 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 196 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 Base Station, e.g. for user interface purposes.

2.4.3.1 Mechanical details

Power Transmitter design MP-A3 includes one Primary Coil, Shielding, and an Interface Surface as defined in the subsections below.

2.4.3.1.1 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 197, 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 132.

Figure 197. Primary Coil of Power Transmitter design MP-A3

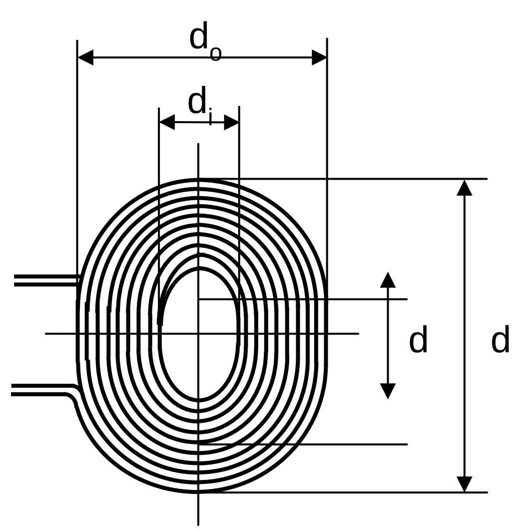


Table 132. Primary Coil parameters of Power Transmitter design MP-A3

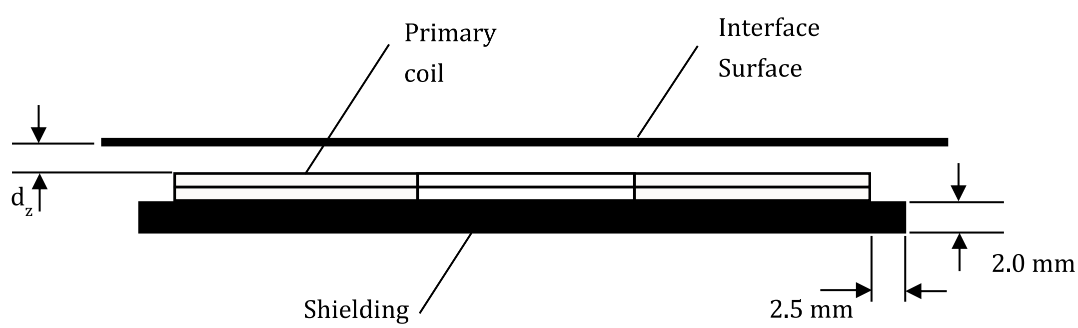
Parameter	Symbol	Value
Outer length	d_{ol}	$42.8^{\pm 2.0}$ mm
Inner length	d_{il}	$17.2^{\pm 1.0}$ mm
Outer width	d_{ow}	$36.2^{\pm 2.0}$ mm
Inner width	d_{iw}	$9.3^{\pm 1.0}$ mm
Thickness	d_{c}	$3.8^{\pm 0.5}$ mm
Number of turns per layer	N	8
Number of layers	–	2

2.4.3.1.2 Shielding

As shown in Figure 197, Shielding protects the Base Station 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 133. Primary Coil assembly of Power Transmitter design MP-A3



2.4.3.1.3 Interface Surface

As shown in Figure 197, the distance from the Primary Coil to the Interface Surface of the Base Station is $d_z = 3.0^{\pm 0.5}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Base Station extends at least 5 mm beyond the outer diameter of the Primary Coil.

2.4.3.1.4 Inter-coil separation

If the Base Station contains multiple type MP-A3 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall have a center-to-center distance of at least $55.0^{\pm 0.5}$ mm.

2.4.3.2 Electrical details

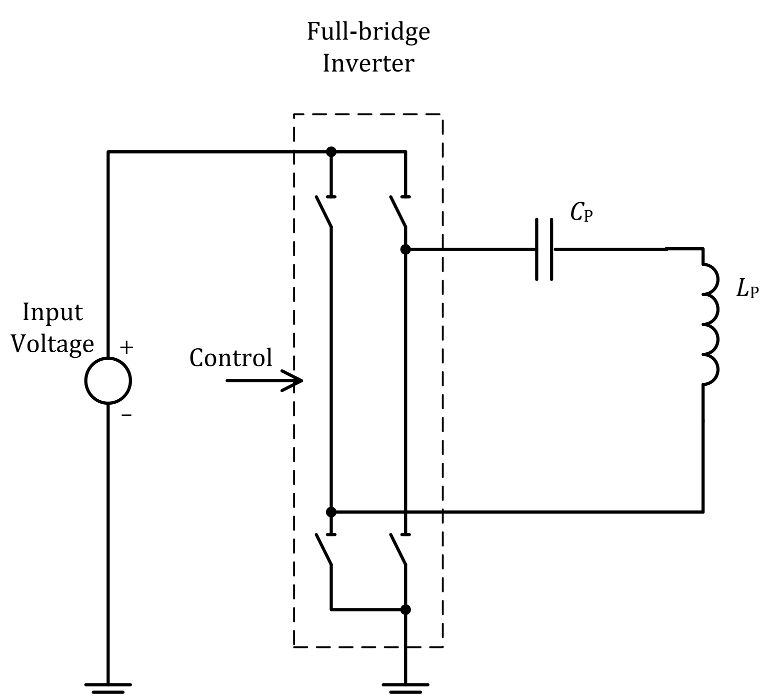
As shown in Figure 198, Power Transmitter design MP-A3 uses a full-bridge inverter topology to drive the Primary Coil and a series capacitance. Within the Operating Frequency range specified in this section, the Primary Coil and Shielding assembly has a self-inductance value of $L_\mathrm{P} = 10.1^{\pm 5\%}$ 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 $f_\mathrm{op} = 110$ 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 198. Electrical diagram (outline) of Power Transmitter design MP-A3



Control of the power transfer shall proceed using the PID algorithm that is defined in *Parts 1 and 2: Interface Definitions*. The controlled variable $\boldsymbol{v}^{(i)}$ 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 134, Table 135, and Table 136 provide the values of the parameters that are used in the PID algorithm.

Table 134. PID parameters for Operating Frequency 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	20,000	N.A.
Scaling factor	S_v	1.0	Hz

Table 135. 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

Table 136. PID parameters for duty cycle 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	20,000	N.A.
Scaling factor	S_v	0.1	%

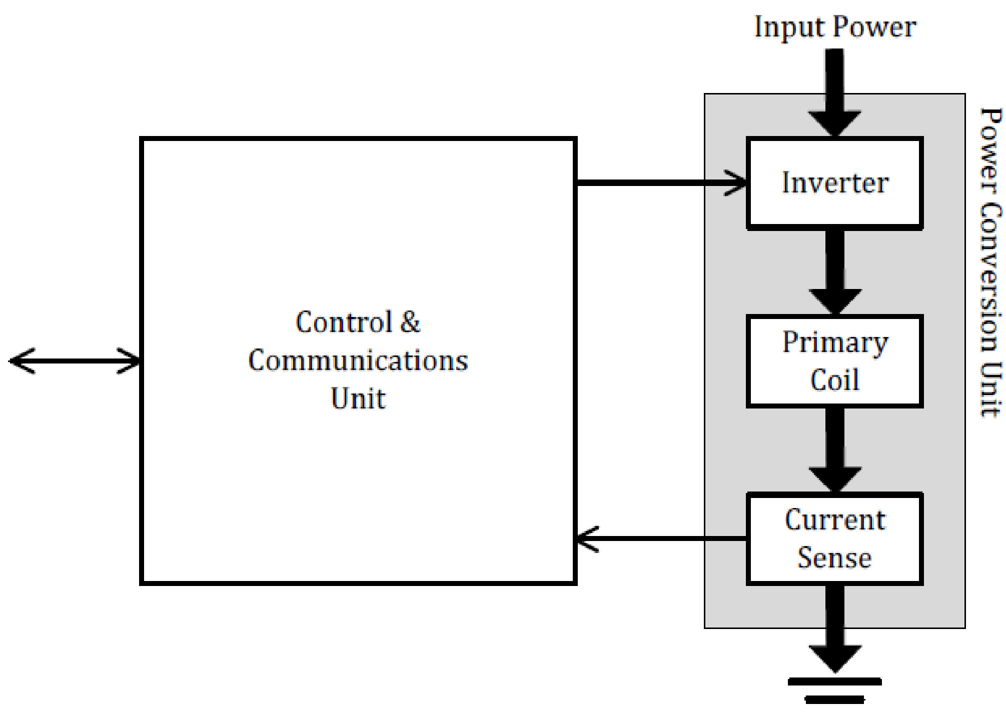
2.4.3.3 Information interface

The Not Res Sens Bit in the Power Transmitter Capability Packet shall be set to ZERO.

2.4.4 Power Transmitter design MP-A4

Figure 199 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 199. Functional block diagram of Power Transmitter design MP-A4



The Power Conversion Unit on the right-hand side of Figure 199 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 199 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 Base Station, e.g. for user interface purposes.

2.4.4.1 Mechanical details

This section defines the Primary Coil, the Shielding, the Interface Surface, and the alignment aid for Power Transmitter design MP-A4.

2.4.4.1.1 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 200 the Primary Coil has a round shape and consists of a single layer. Table 137 lists the dimensions and other parameters of the Primary Coil.

Figure 200. Primary Coil of Power Transmitter design MP-A4

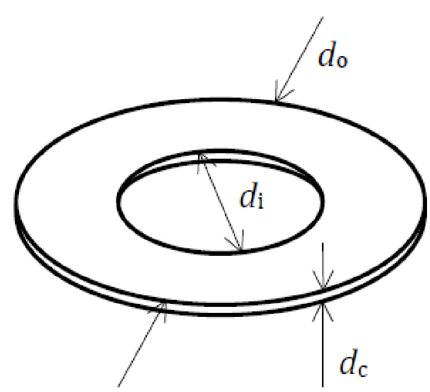


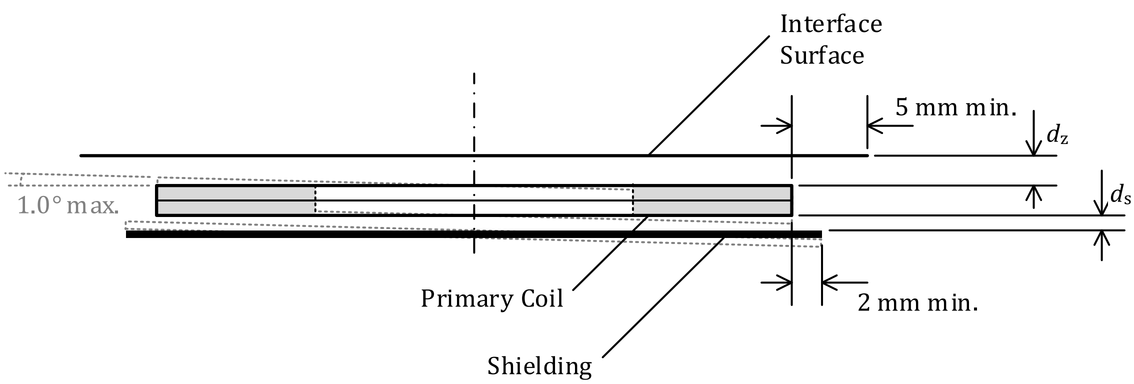
Table 137. Primary Coil parameters of Power Transmitter design MP-A4

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

2.4.4.1.2 Shielding

As shown in Figure 201, Shielding protects the Base Station 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 201. Primary Coil assembly of Power Transmitter design MP-A4



2.4.4.1.3 Interface surface

As shown in Figure 201, the distance from the Primary Coil to the Interface Surface of the Base Station is $d_z = 2^{\pm 1}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Base Station extends at least 5 mm beyond the outer dimensions of the Primary Coils.

2.4.4.1.4 Alignment aid

The user manual of a Base Station 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 Mobile Device positioning to help alignment.

NOTE Examples of Base Station alignment aids to assist the user positioning of the Mobile Device 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.

2.4.4.1.5 Inter-coil separation

If the Base Station contains multiple type MP-A4 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall have a center-to-center distance of at least 56 mm.

2.4.4.2 Electrical details

As shown in Figure 202, 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 $L_{\mathrm{P}} = 8.9^{\pm 10\%}\,\mu H$. The value of the series capacitance is $C_{\mathrm{P}} = 276^{\pm 5\%}\,\mathrm{n}F$.

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 203), or uses the Operating Frequency and duty cycle of the half-bridge inverter's driving signals (see Figure 204) 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:

- $0.01 \cdot f_{\mathrm{op}} - 0.7$ kHz for f_{op} in the 110 kHz to 175 kHz range;
- $0.015 \cdot f_{\mathrm{op}} - 1.58$ 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 *Parts 1 and 2: Interface Definitions*. The controlled variable $^{(i)}$ 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 138, Table 139, Table 140, Table 141, and Table 142 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 202. Electrical diagram (outline) of Power Transmitter design MP-A4

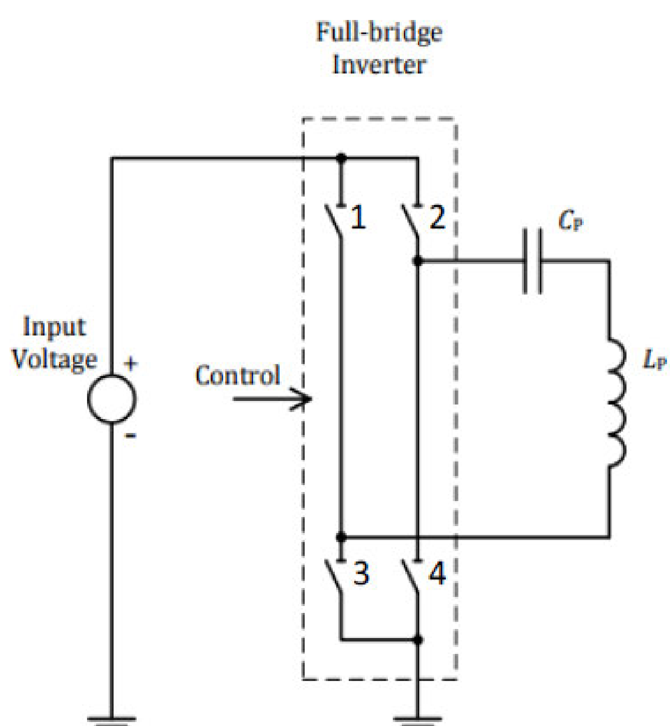


Figure 203. Phase control signals to Full Bridge inverter

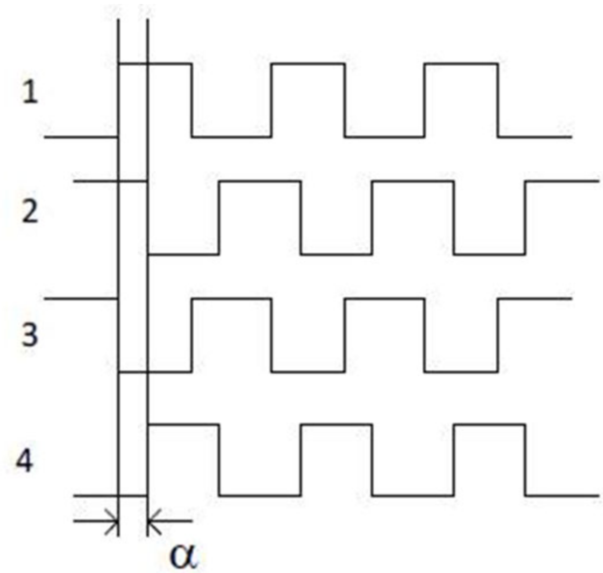


Figure 204. Duty control signals to Half Bridge inverter

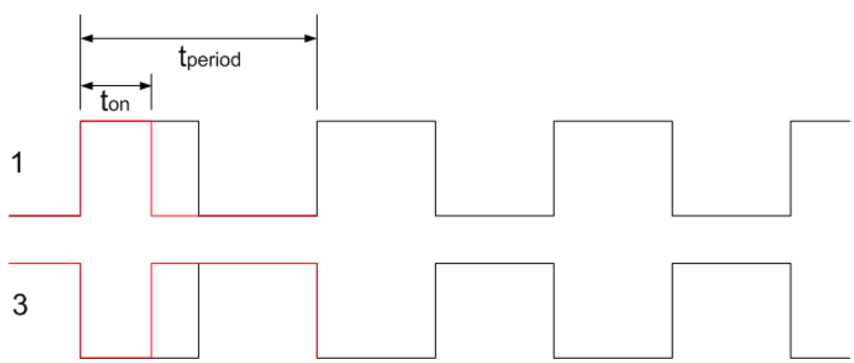


Table 138. PID parameters for Operating Frequency control (half bridge)

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

Table 139. PID parameters for Operating Frequency control (full bridge)

Parameter	Symbol	Value	Unit
Proportional gain	K_p	5	mA^{-1}
Integral gain	K_i	1	$\mathrm{mA}^{-1}\mathrm{ms}^{-1}$
Derivative gain	K_d	1	$\mathrm{mA}^{-1}\mathrm{ms}$
Integral term limit	M_I	3,000	N.A.
PID output limit	M_{PID}	20,000	N.A.

Table 140. 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 141. PID parameters for phase control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	1	mA^{-1}
Integral gain	K_i	1	$\mathrm{mA}^{-1}\mathrm{ms}^{-1}$
Derivative gain	K_d	0	$\mathrm{mA}^{-1}\mathrm{ms}$
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 142. PID parameters for duty cycle control

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

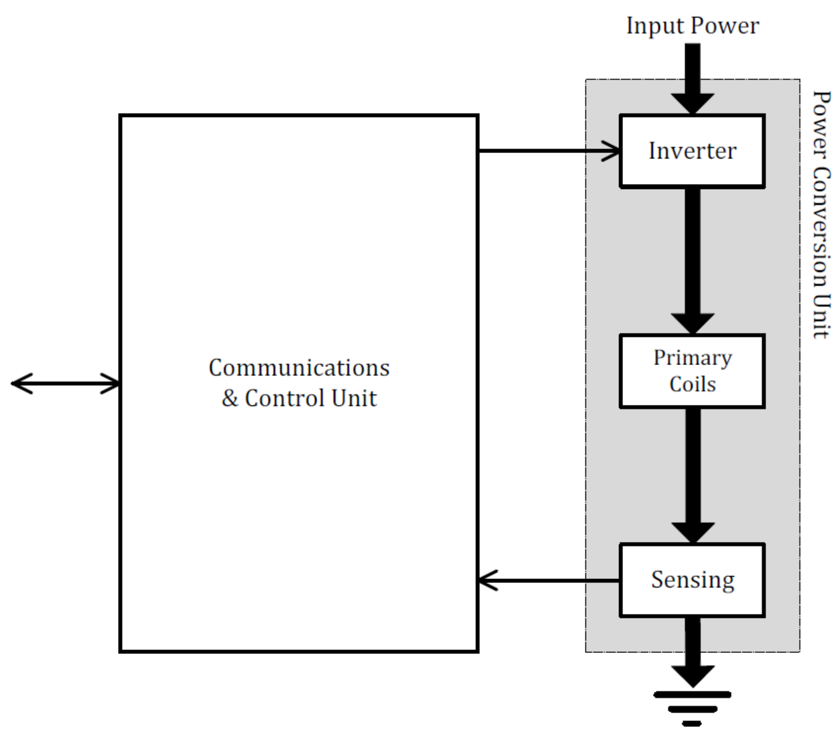
2.4.4.3 Information interface

The Not Res Sens Bit in the Power Transmitter Capability Packet shall be set to ZERO.

2.4.5 Power Transmitter design MP-A5

Figure 205 illustrates the functional block diagram of Power Transmitter Design MP-A5.

Figure 205. Functional block diagram of Power Transmitter MP-A5



The Power Conversion Unit on the right-hand side of Figure 205 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 205 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 Base Station, e.g. for user interface purposes.

2.4.5.1 Mechanical details

Power Transmitter design MP-A5 includes a Primary Coil array as defined in Section 2.4.5.1.1, Shielding as defined in Section 2.4.5.1.2, and an Interface Surface as defined in Section 2.4.5.1.3.

2.4.5.1.1 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 206 the Primary Coil has a circular shape and consists of two layers with a total of 13 turns. Table 143 lists the dimensions of the Primary Coil.

Figure 206.Primary Coil of Power Transmitter MP-A5

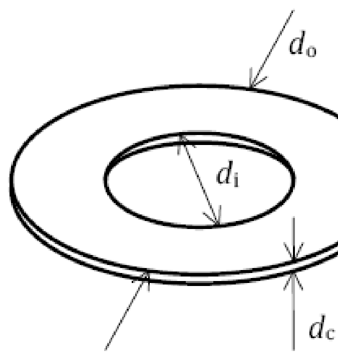


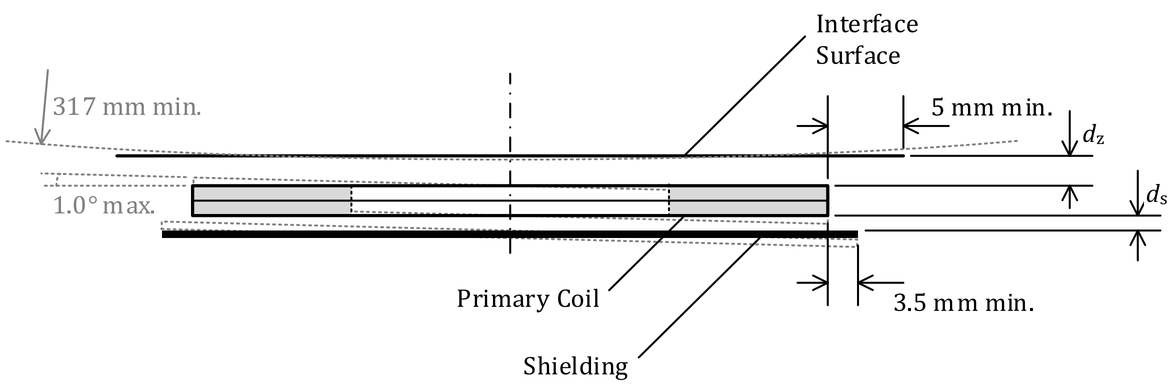
Table 143. Primary Coil of Power Transmitter MP-A5

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

2.4.5.1.2 Shielding

As shown in Figure 207, Shielding protects the Base Station 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 207. Primary Coil assembly of Power Transmitter design MP-A5



2.4.5.1.3 Interface Surface

As shown in Figure 207, the distance from the Primary Coil to the Interface Surface of the Base Station is $d_z = 2.5^{\pm 0.5}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Base Station 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 207.

2.4.5.1.4 Alignment Aid

The user manual of the Base Station 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 Mobile Device positioning to help alignment.

NOTE Examples of Base Station alignment aids to assist the user positioning of the Mobile Device 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.

2.4.5.1.5 Inter coil separation

If the Base Station contains multiple type MP-A5 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall have a center-to-center distance of at least 70 mm.

2.4.5.2 Electrical Details

As shown in Figure 208, 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 $L_{\mathrm{p}} = 10^{\pm 10\%}$ μH. The value of the total series capacitance $C_{\mathrm{p}} = 247^{\pm 5\%}$ 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 *Parts 1 and 2: Interface Definitions*), 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 *Parts 1 and 2: Interface Definitions*. The controlled variable $v^{(i)}$ introduced in the definition of that algorithm represents the input voltage. Finally, Table 144 provides the values of several parameters that are used in the PID algorithm.

Figure 208. Electrical diagram (outline) Primary Coil of Power Transmitter design MP-A5

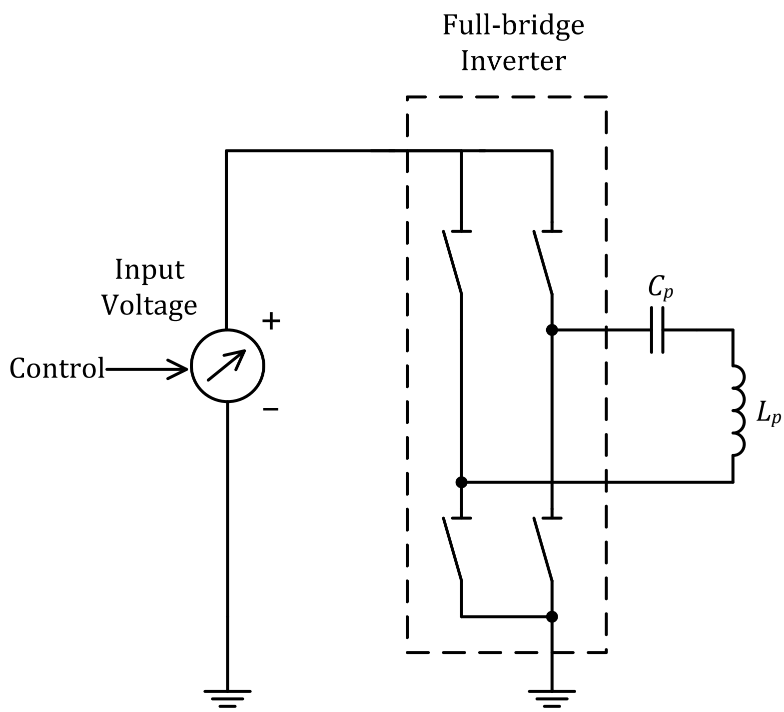


Table 144. PID parameters for voltage control

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	%

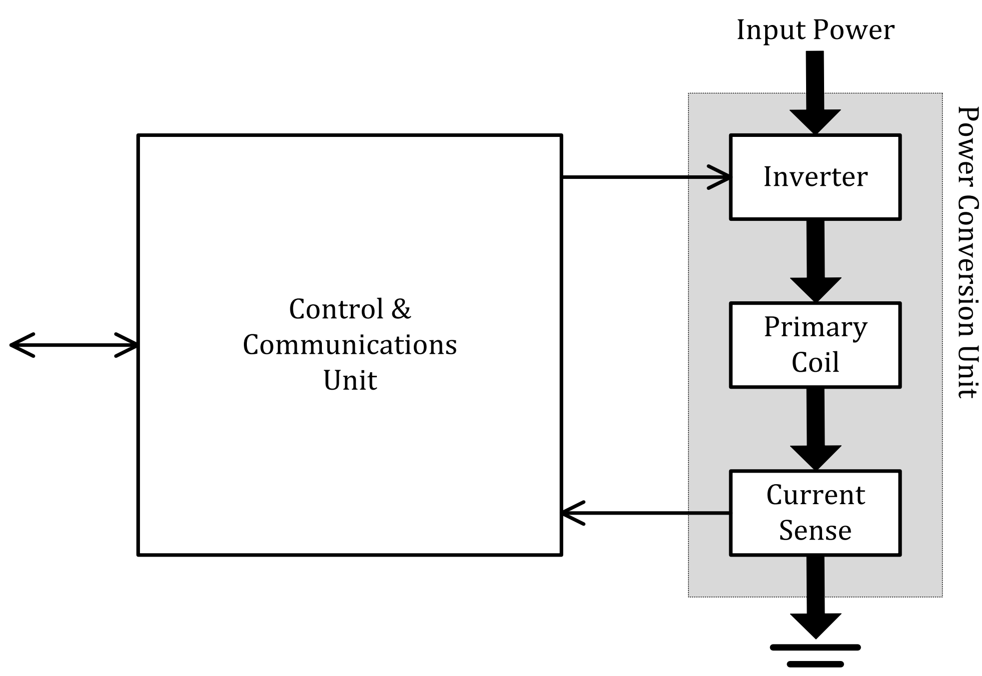
2.4.5.3 Information interface

The Not Res Sens Bit in the Power Transmitter Capability Packet shall be set to ONE.

2.4.6 Power Transmitter design MP-A6

Figure 209 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 209. Functional block diagram of Power Transmitter design MP-A6



The Power Conversion Unit on the right-hand side of Figure 209 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 209 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 Base Station, e.g. for user interface purposes.

2.4.6.1 Mechanical details

This section defines the Primary Coils, the Shielding, and the Interface Surface for Power Transmitter design MP-A6.

2.4.6.1.1 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 210, the Primary Coils have two types of rectangular shape and each coil consists of a single layer. Table 145 and Table 146 list the dimensions of both bottom (close to ferrite) and top (close to interface) Primary Coil.

Figure 210. Bottom and Top Primary Coils of Power Transmitter design MP-A6

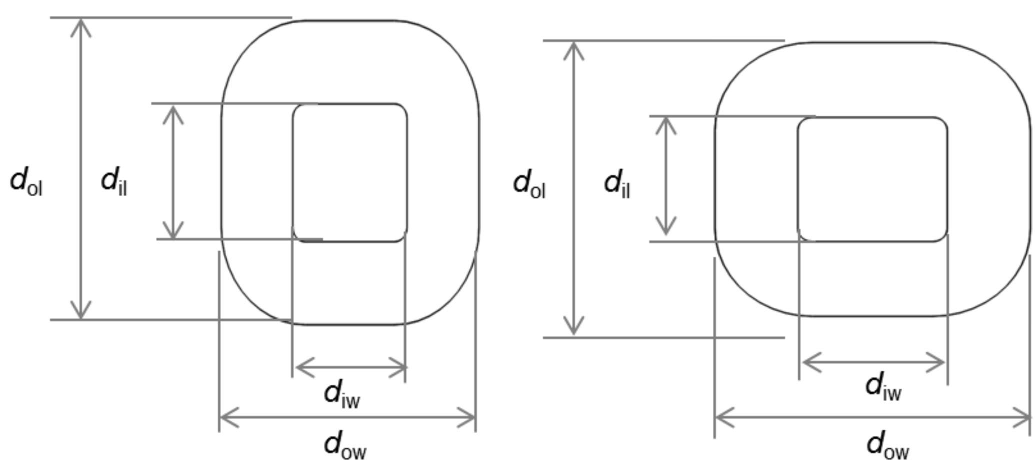


Table 145. Bottom Primary Coil parameters of Power Transmitter design MP-A6

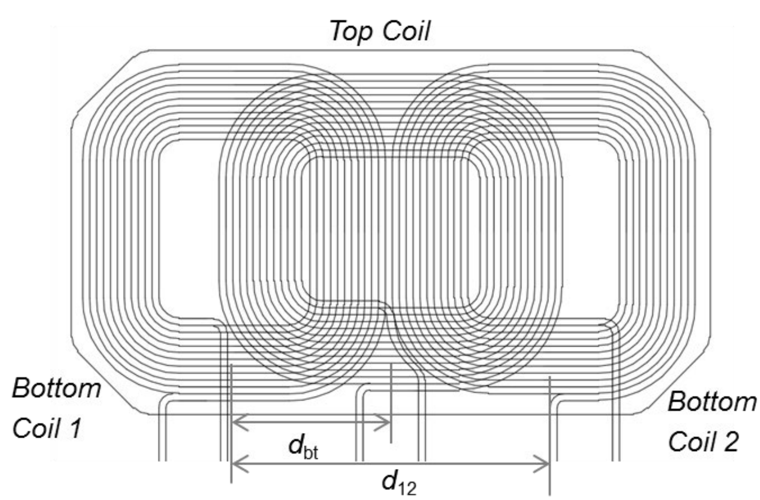
Parameter	Symbol	Value
Outer height	d_{ol}	$49.0^{\pm 1.0}$ mm
Inner height	d_{il}	$26.0^{\pm 1.0}$ mm
Outer width	d_{ow}	$44.0^{\pm 1.0}$ mm
Inner width	d_{iw}	$22.0^{\pm 1.0}$ mm
Thickness	d_c	$1.1^{\pm 0.2}$ mm
Number of turns per layer	N	11
Number of layers	–	1

Table 146. 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 211.

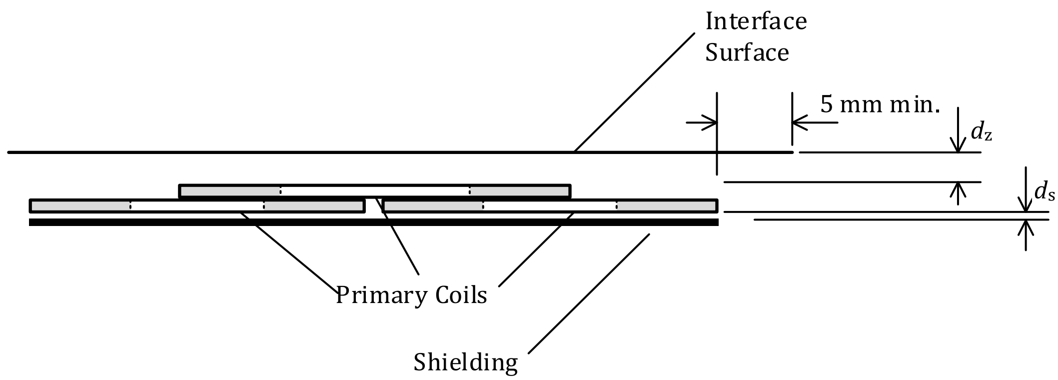
Figure 211. Bottom and Top Primary Coils of Power Transmitter design MP-A6



2.4.6.1.2 Shielding

As shown in Figure 212, a soft-magnetic material protects the Base Station 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 *Part 4: Reference Designs* limits the composition of the Shielding to any Mn-Zn (for example, PM12 from TODAISU).

Figure 212. Primary Coil assembly of Power Transmitter design MP-A6



2.4.6.1.3 Interface Surface

As shown in Figure 212, the distance from the top face of the top Primary Coil to the Interface Surface of the Base Station is $d_z = 5.5^{\pm 1.5}$ 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 Base Station extends at least 5 mm beyond the outer dimensions of the Primary Coils.

2.4.6.1.4 Alignment aid

The user manual of the Base Station 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 Mobile Device placement to help alignment.

NOTE Examples of Base Station alignment aids to assist the user placement of the Mobile Device 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.

2.4.6.1.5 Inter coil separation

If the Base Station contains multiple type MP-A6 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall have a center-to-center distance of at least $49.2^{\pm 4}$ mm.

2.4.6.2 Electrical details

As shown in Figure 213, 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 $L_P = 11.3^{\pm 0.7}$ μH. The value of the series capacitance is $C_P = 139^{\pm 6\%}$ 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 *Parts 1 and 2: Interface Definitions*. 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 147 provides the values of several parameters, which are used in the PID algorithm.

Figure 213. Electrical diagram (outline) of Power Transmitter design MP-A6

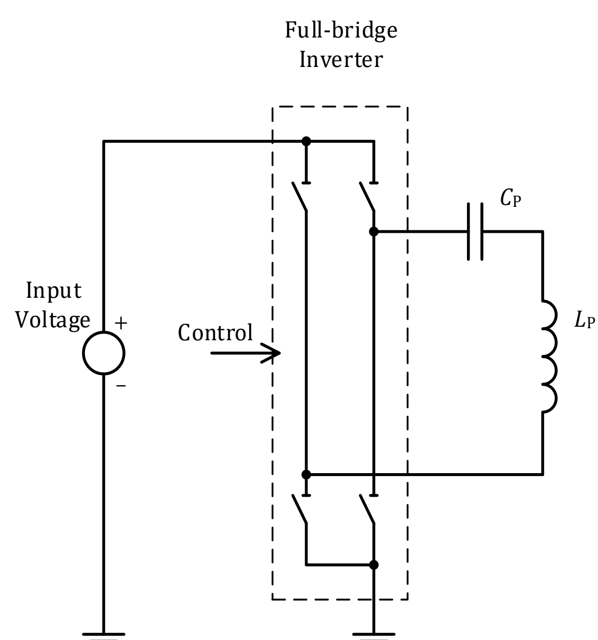


Table 147. PID parameters for Voltage control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	10	mA^{-1}
Integral gain	K_i	1	$\mathrm{mA}^{-1}\mathrm{ms}^{-1}$
Derivative gain	K_d	0	$\mathrm{mA}^{-1}\mathrm{ms}$
Integral term limit	M_I	3,000	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_V	100	mV

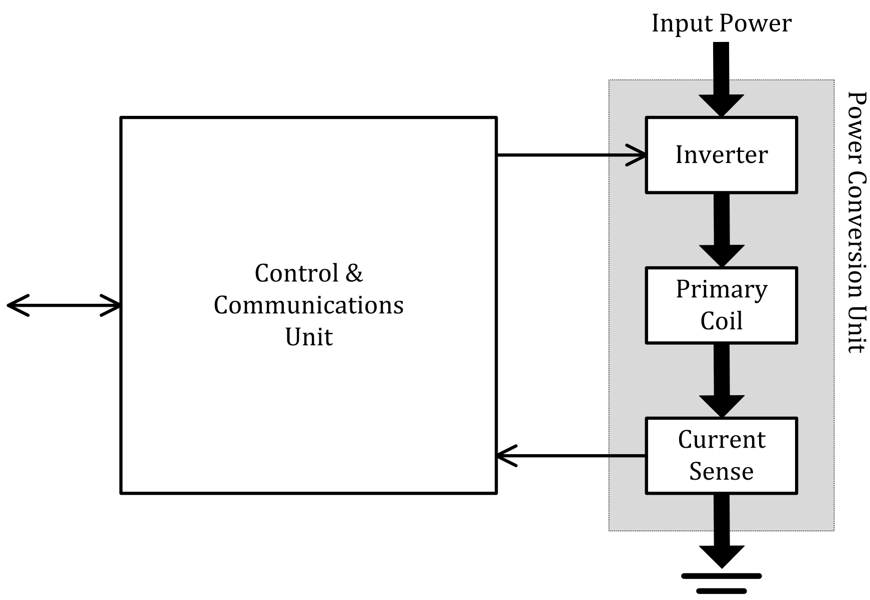
2.4.6.3 Information interface

The Not Res Sens Bit in the Power Transmitter Capability Packet shall be set to ONE.

2.4.7 Power Transmitter design MP-A7

Figure 214 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 214. Functional block diagram of Power Transmitter design MP-A7



The Power Conversion Unit on the right-hand side of Figure 214 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 214 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 Base Station, e.g. for user interface purposes.

2.4.7.1 Mechanical details

This section defines the Primary Coil, the Shielding, the Interface Surface, and the alignment aid for Power Transmitter design MP-A7.

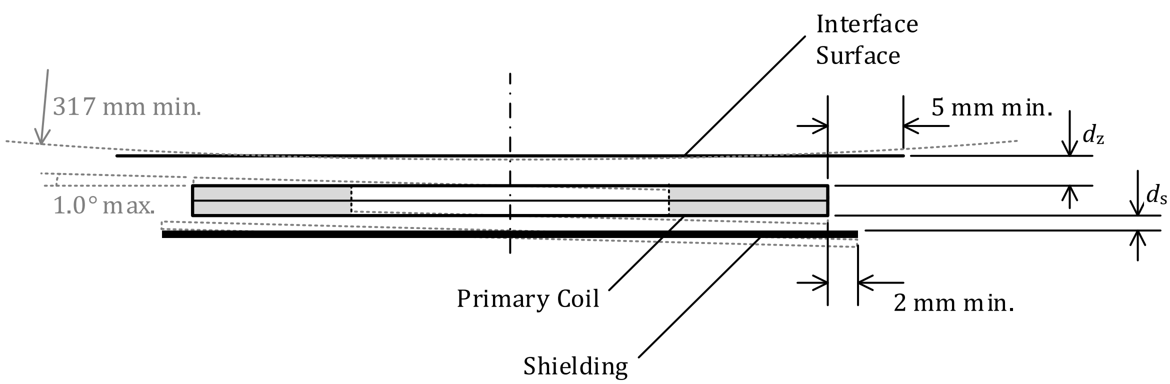
2.4.7.1.1 Primary Coil

The Primary Coil of the MP-A7 design is identical to the Primary Coil of the type A10 Power Transmitter.

2.4.7.1.2 Shielding

As shown in Figure 215, Shielding protects the Base Station 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 215. Primary Coil assembly of Power Transmitter design MP-A7



2.4.7.1.3 Interface Surface

As shown in Figure 215, the distance from the Primary Coil to the Interface Surface of the Base Station is $d_z = 2^{+0.5}_{-0.25}$ mm, across the top face of the Primary Coil. In addition, the Interface Surface of the Base Station 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 215.

2.4.7.1.4 Alignment aid

The user manual of a Base Station 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 Mobile Device positioning to help alignment.

NOTE Examples of Base Station alignment aids to assist the user positioning of the Mobile Device 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.

2.4.7.1.5 Inter-coil separation

If the Base Station contains multiple type A7 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall have a center-to-center distance of at least 50 mm.

2.4.7.2 Electrical details

As shown in Figure 218, 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 219), or uses the Operating Frequency and duty cycle of the half-bridge inverter's driving signals (see Figure 220) in order to control the amount of power that is transferred. For this purpose, the Operating Frequency range of the inverter is $f_{\mathrm{op}} = 110$ kHz to 205 kHz with a driving signal phase difference of $\alpha = 0°$ 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:

- $0.01 \cdot f_{\mathrm{op}} - 0.7$ kHz for f_{op} in the 110 kHz to 175 kHz range;
- $0.015 \cdot f_{\mathrm{op}} - 1.58$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 *Parts 1 and 2: Interface Definitions*. 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 150, Table 151, Table 152, and Table 153 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 216 and Figure 217 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 216. Increasing power

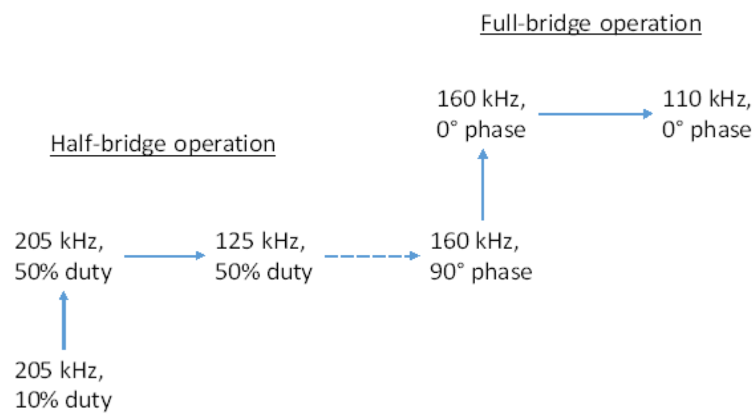


Table 148. Control parameter requirements for increasing power

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 217. Decreasing power

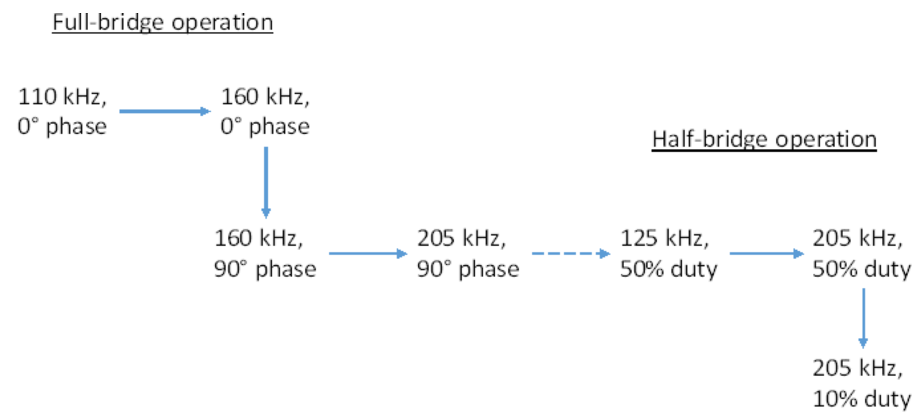


Table 149. Control parameter requirements for decreasing power

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 218. Electrical diagram (outline) of Power Transmitter design MP-A7

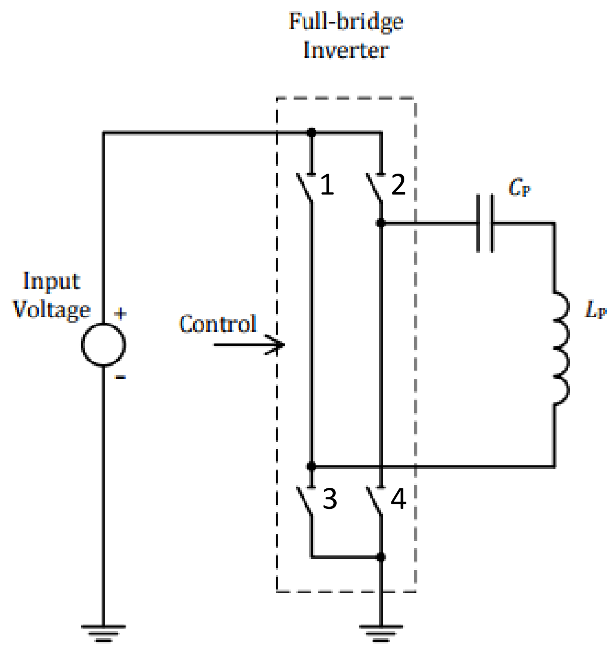


Table 150. PID parameters for Operating Frequency control

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 219. Phase control signals to Full Bridge inverter

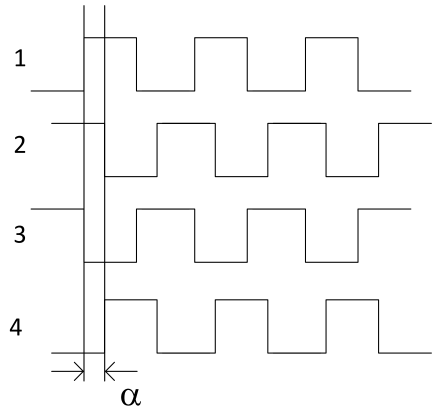


Figure 220. Duty control signals to Half Bridge inverter

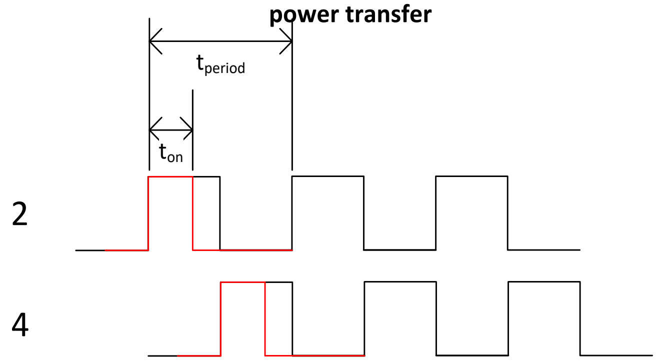


Table 151. Operating Frequency dependent scaling factor

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 152. PID parameters for phase control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	1	mA^{-1}

Parameter	Symbol	Value	Unit
Integral gain	K_{i}	0.01	$\mathrm{mA}^{-1}\mathrm{ms}^{-1}$
Derivative gain	K_{d}	0	$\mathrm{mA}^{-1}\mathrm{ms}$
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 153. PID parameters for duty cycle control

Parameter	Symbol	Value	Unit
Proportional gain	K_{p}	1	mA^{-1}
Integral gain	K_{i}	0.01	$\mathrm{mA}^{-1}\mathrm{ms}^{-1}$
Derivative gain	K_{d}	0	$\mathrm{mA}^{-1}\mathrm{ms}$
Integral term limit	M_{I}	3,000	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_{V}	-0.002	%

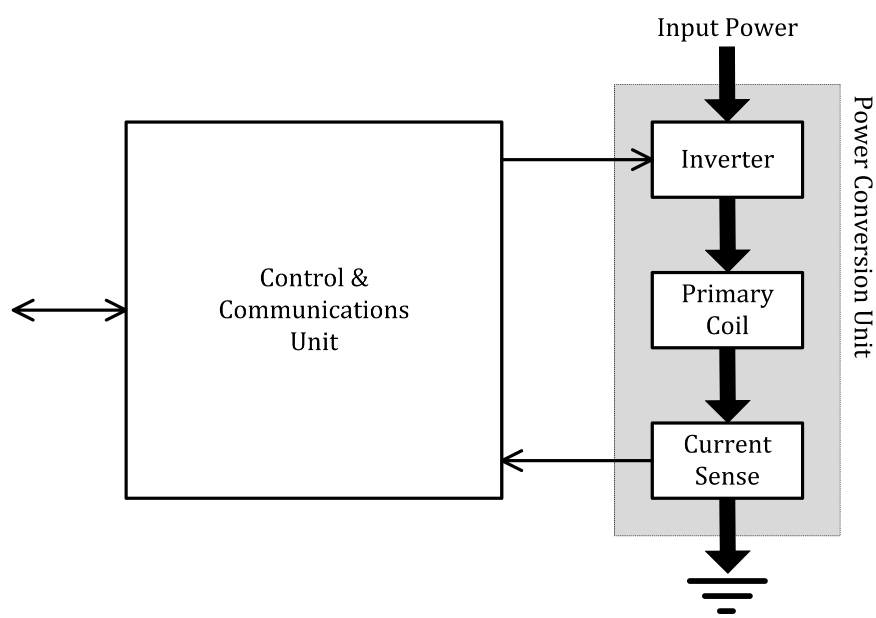
2.4.7.3 Information interface

The Not Res Sens Bit in the Power Transmitter Capability Packet shall be set to ZERO.

2.4.8 Power Transmitter design MP-A8

Figure 221 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 221. Functional block diagram of Power Transmitter design MP-A8



The Power Conversion Unit on the right-hand side of Figure 221 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 221 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 Base Station, e.g. for user interface purposes.

2.4.8.1 Mechanical details

This section defines the Primary Coil, the Shielding, the Interface Surface, and the alignment aid for Power Transmitter design MP-A8.

2.4.8.1.1 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 222. Primary Coil of Power Transmitter design MP-A8

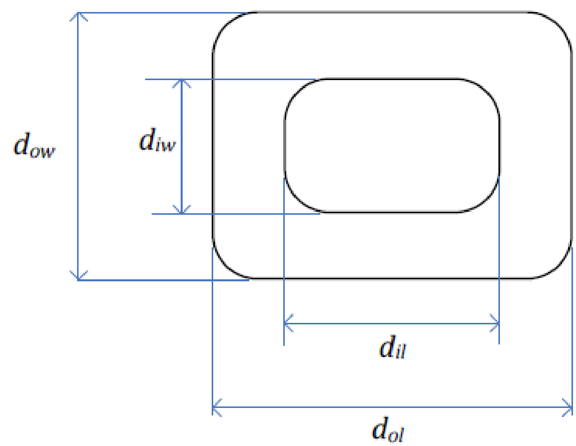
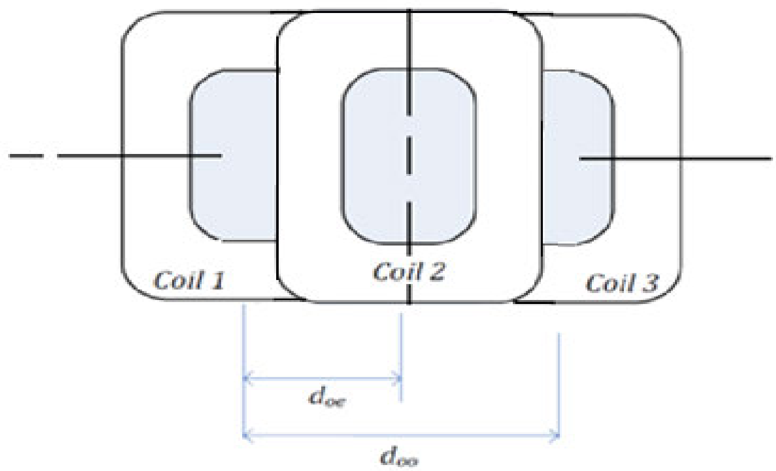


Table 154. Primary Coil parameters of Power Transmitter design MP-A8

Parameter	Symbol	Value
Outer length	d_{ol}	$51.0^{\pm 1.0}$ mm
Inner length	d_{il}	$27.5^{\pm 0.5}$ mm
Outer width	d_{ow}	$43.0^{\pm 1.0}$ 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	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 $d_{oo} = 44.0^{\pm 1.0}$ 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 $d_{oe} = 22.0^{\pm 1.0}$ mm. Figure 223 shows this arrangement using three Primary Coils.

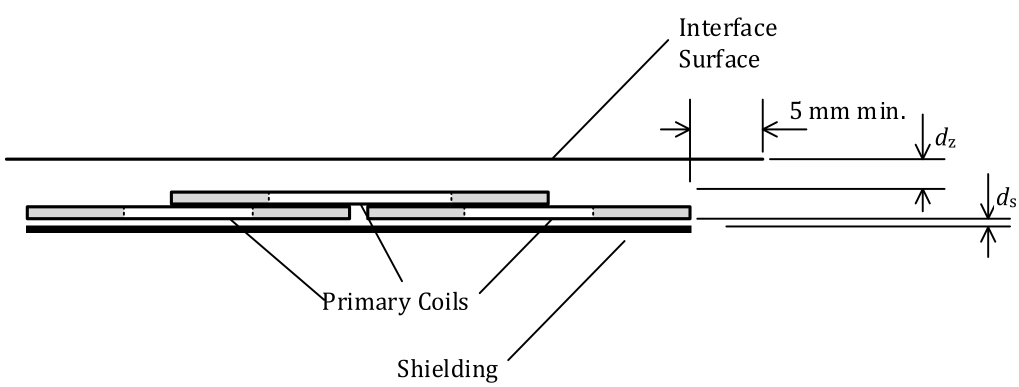
Figure 223. Primary Coil of Power Transmitter design MP-A8



2.4.8.1.2 Shielding

As shown in Figure 224, soft-magnetic material protects the Base Station 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 $d_s = 1.0$ mm. This version of *Part 4: Reference Designs* limits the composition of the Shielding to a Ni-Zn or Mn-Zn ferrite core from any supplier.

Figure 224. Primary Coil assembly of Power Transmitter design MP-A8



2.4.8.1.3 Interface Surface

As shown in Figure 224, the distance from the top face of the even-numbered Primary Coil to the Interface Surface of the Base Station 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 Base Station is $d_z = 3.6^{+0.5}_{-0.25}$ mm. In addition, the Interface Surface of the Base Station 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 224.

2.4.8.1.4 Alignment aid

The user manual of a Base Station 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 Mobile Device positioning to help alignment.

NOTE Examples of Base Station alignment aids to assist the user positioning of the Mobile Device 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.

2.4.8.1.5 Inter-coil separation

If the Base Station contains multiple type MP-A8 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall have a center-to-center distance of at least 50 mm.

2.4.8.2 Electrical details

As shown in Figure 225, 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 $7.5^{\pm 10\%}$ μH for cells closest to the Interface Surface and an inductance of $8.5^{\pm 10\%}$ μH for cells furthest from the Interface Surface. The value of the series capacitance is $420^{\pm 5\%}$ nF for cells closest to the Interface Surface and $400^{\pm 5\%}$ nF for cells farthest from the Interface Surface. The input voltage to the full bridge 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-A8 uses the Operating Frequency and the phase difference of the full-bridge inverter's driving signals (see Figure 226), or uses the Operating Frequency and duty cycle of the half-bridge inverter's driving signals (see Figure 227) in order to control the amount of power that is transferred. For this purpose, the Operating Frequency range of the inverter is $f_{\mathrm{op}} = 110$ kHz to 205 kHz with a driving signal phase difference of $\alpha = 0°$ 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:

- $0.01 \cdot f_{\mathrm{op}} - 0.7$ kHz for f_{op} in the 110 kHz to 175 kHz range;
- $0.015 \cdot f_{\mathrm{op}} - 1.58$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 $12^{\pm 1}$ 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 *Parts 1 and 2: Interface Definitions*. 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 155, Table 156, Table 157, Table 158, and Table 159 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 225. Electrical diagram (outline) of Power Transmitter design MP-A8

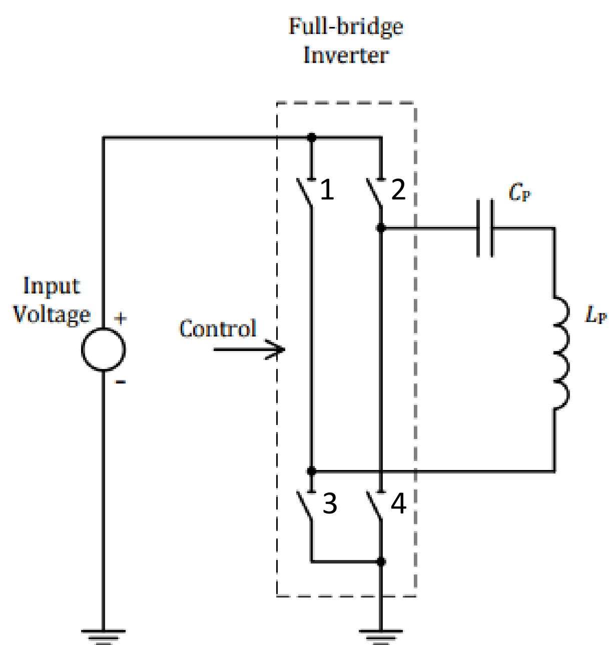


Table 155. PID parameters for Operating Frequency control (half bridge)

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 156. 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 226. Phase difference control signals to full bridge inverter

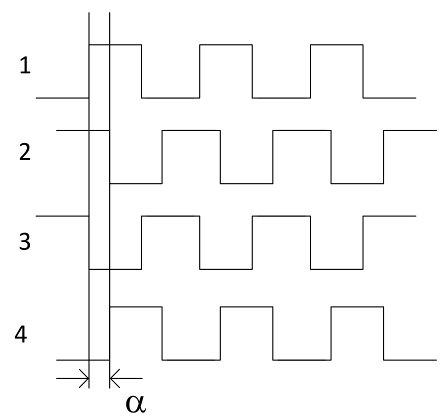


Figure 227. Duty cycle control signals to half bridge inverter

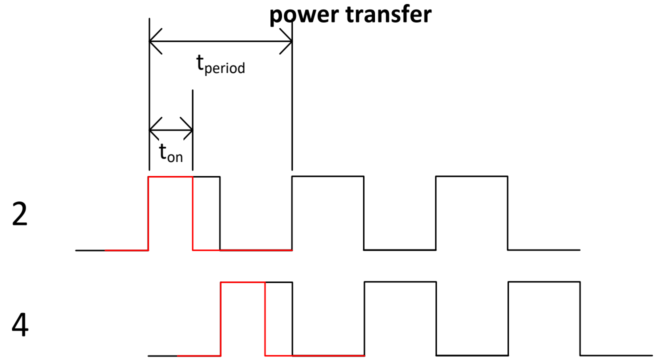


Table 157. Operating Frequency dependent scaling factor

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 158. PID parameters for phase difference control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	1	mA^{-1}
Integral gain	K_i	1	$\mathrm{mA}^{-1}\mathrm{ms}^{-1}$
Derivative gain	K_d	0	$\mathrm{mA}^{-1}\mathrm{ms}$
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 159. PID parameters for duty cycle control

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

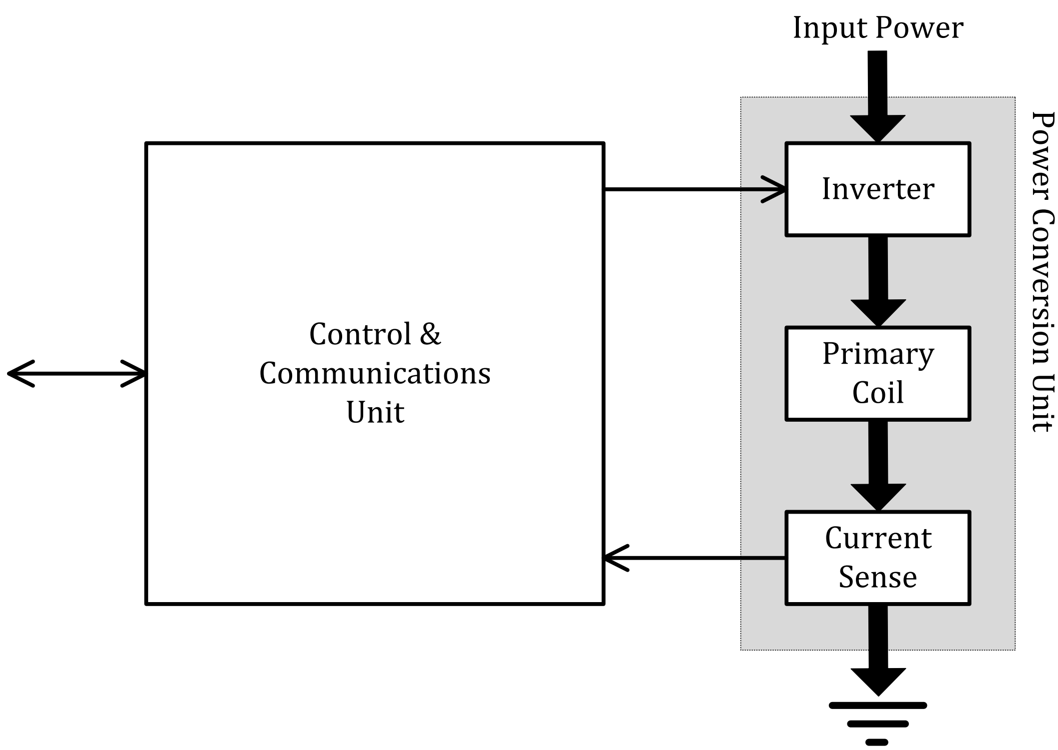
2.4.8.3 Information interface

The Not Res Sens Bit in the Power Transmitter Capability Packet shall be set to ZERO.

2.4.9 Power Transmitter design MP-A9

Figure 228 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 228. Functional block diagram of Power Transmitter design MP-A9



The Power Conversion Unit on the right-hand side of Figure 228 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 228 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 Base Station, e.g. for user interface purposes.

2.4.9.1 Mechanical details

This section defines the Primary Coil, the Shielding, the Interface Surface, and the alignment aid for Power Transmitter design MP-A9.

2.4.9.1.1 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 229, the Primary Coil has a racetrack-like shape and consists of a single layer. Table 160 and Table 161 list the dimensions of the bottom Primary Coil and the top Primary Coil respectively.

Figure 229. Primary Coil of Power Transmitter design MP-A9

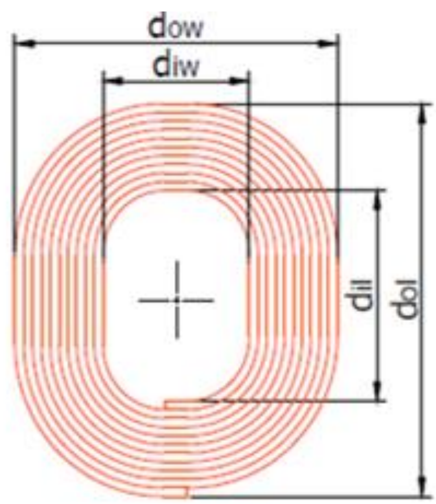


Table 160. Bottom Primary Coil parameters of Power Transmitter design MP-A9

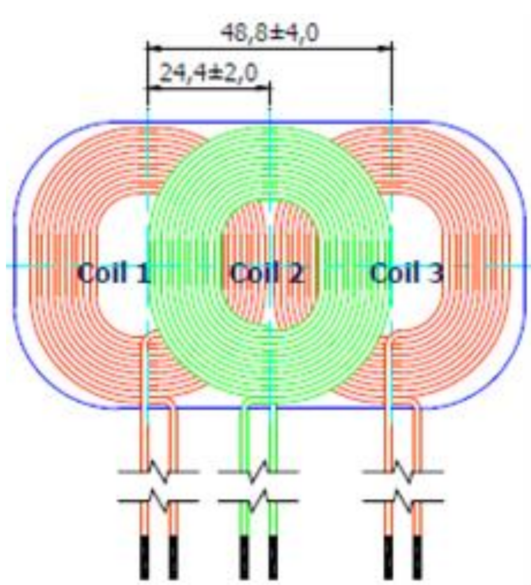
Parameter	Symbol	Value
Outer length	d_{ol}	$53.0^{\pm 1.5}$ mm
Inner length	d_{il}	$27.5^{\pm 0.5}$ mm
Outer width	d_{ow}	$46.7^{\pm 1.5}$ mm
Inner width	d_{iw}	$20.5^{\pm 0.5}$ mm
Thickness	d_c	$1.6^{\pm 0.5}$ mm
Number of turns per layer	N	11
Number of layers	–	1

Table 161. 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 230 shows this arrangement using three Primary Coils.

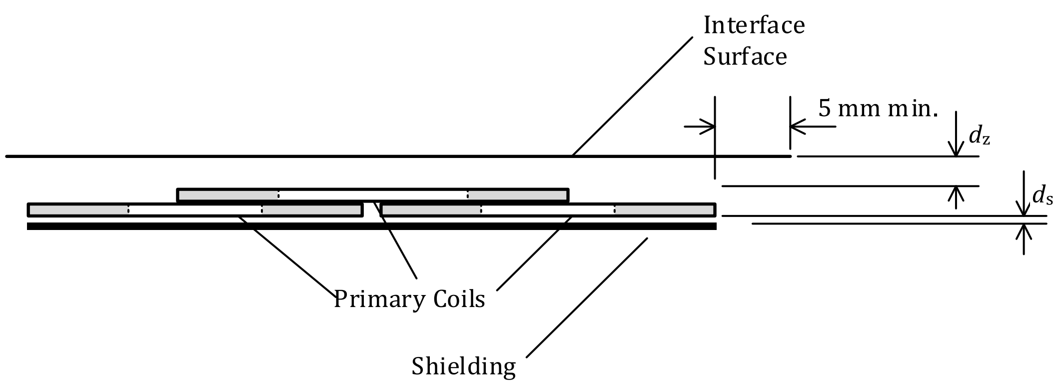
Figure 230. Primary Coils of Power Transmitter design MP-A9



2.4.9.1.2 Shielding

As shown in Figure 231, soft-magnetic material protects the Base Station 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 *Part 4: Reference Designs* limits the composition of the Shielding to a Ni-Zn or Mn-Zn ferrite core from any supplier.

Figure 231. Primary Coil assembly of Power Transmitter design MP-A9



2.4.9.1.3 Interface Surface

As shown in Figure 231, the distance from the top face of the even-numbered Primary Coil to the Interface Surface of the Base Station 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 Base Station ($d_s = 5.6^{\pm 1.0}$ mm). In addition, the Interface Surface of the Base Station extends at least 5.0 mm beyond the outer dimensions of the Primary Coil.

2.4.9.1.4 Alignment aid

The user manual of a Base Station 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 Mobile Device positioning to help alignment.

NOTE Examples of Base Station alignment aids to assist the user positioning of the Mobile Device 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.

2.4.9.1.5 Inter-coil separation

If the Base Station contains multiple type MP-A9 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall have a center-to-center distance of at least 57 mm.

2.4.9.2 Electrical details

As shown in Figure 232, 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 $L_p = 9.8^{\pm 10\%}$ μH for cells furthest from the Interface Surface and an inductance of $L_p = 10.2^{\pm 10\%}$ μH for cells closest to the Interface Surface. The value of the series capacitance is $C_p = 400^{\pm 5\%}$ 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 $f_{\mathrm{op}} = 120 \ldots 130$ kHz with a duty cycle of 50%.

When a type MP-A9 Power Transmitter first applies a Power Signal (see Digital Ping in *Parts 1 and 2: Interface Definitions*), 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 *Parts 1 and 2: Interface Definitions*. 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 162 provides the values of several parameters that are used in the PID algorithm.

Figure 232. Electrical diagram (outline) of Power Transmitter design MP-A9

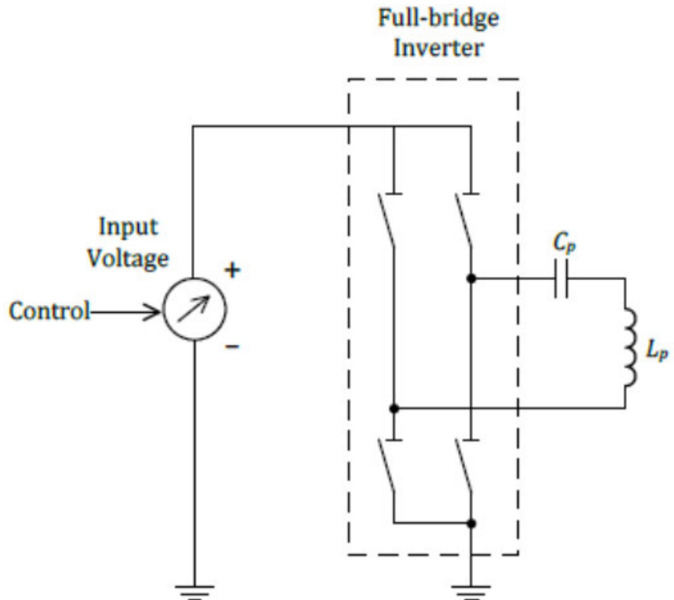


Table 162. PID parameters for voltage control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	5	mA^{-1}
Integral gain	K_i	1	$\mathrm{mA}^{-1}\mathrm{ms}^{-1}$
Derivative gain	K_d	0	$\mathrm{mA}^{-1}\mathrm{ms}$
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

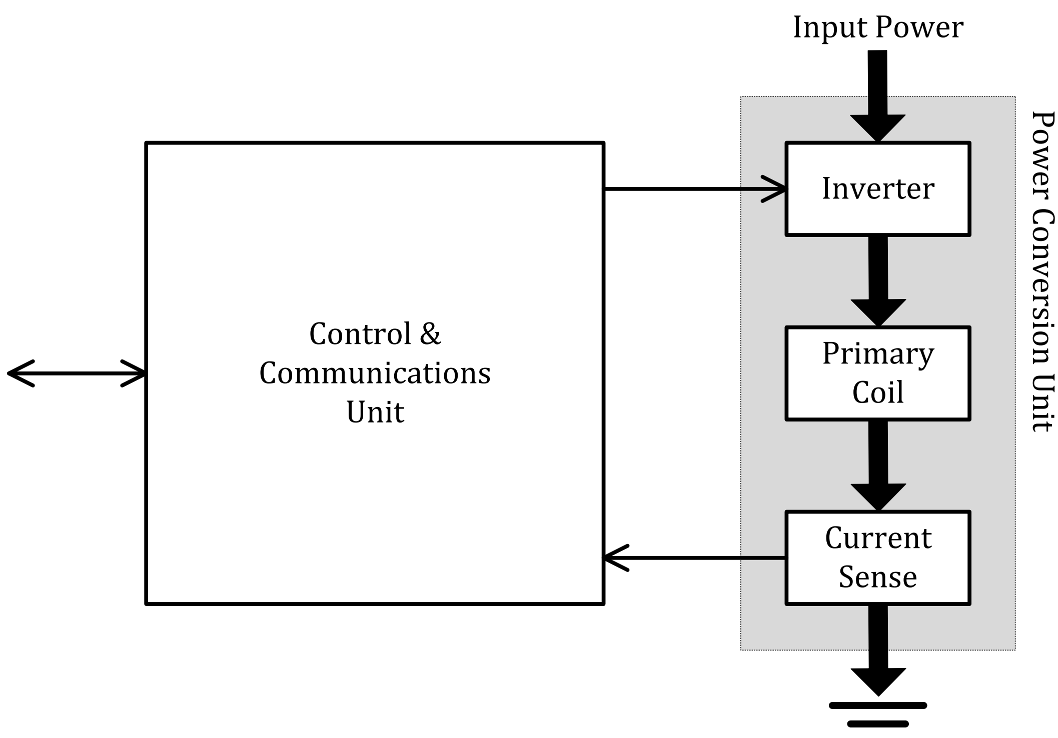
2.4.9.3 Information Interface

The Not Res Sens Bit in the Power Transmitter Capability Packet shall be set to ONE.

2.4.10 Power Transmitter design MP-A10

Figure 233 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 233. Functional block diagram of Power Transmitter design MP-A10



The Power Conversion Unit on the right-hand side of Figure 233 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 233 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 Base Station, e.g. for user interface purposes.

2.4.10.1 Mechanical details

This section defines the single Primary Coil, the Shielding, the Interface Surface and the alignment aid for Power Transmitter design MP-A10.

2.4.10.1.1 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 234, the Primary Coil has a rectangular shape and consists of a single layer. Table 163 lists the dimensions of the Primary Coil.

Figure 234. Primary Coil of Power Transmitter design MP-A10

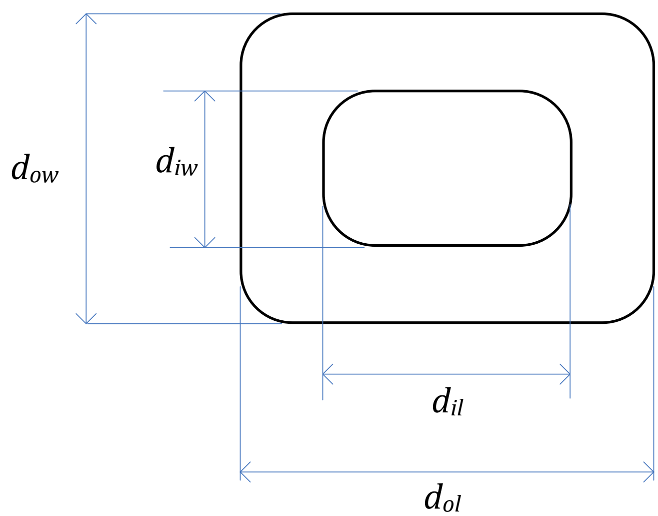


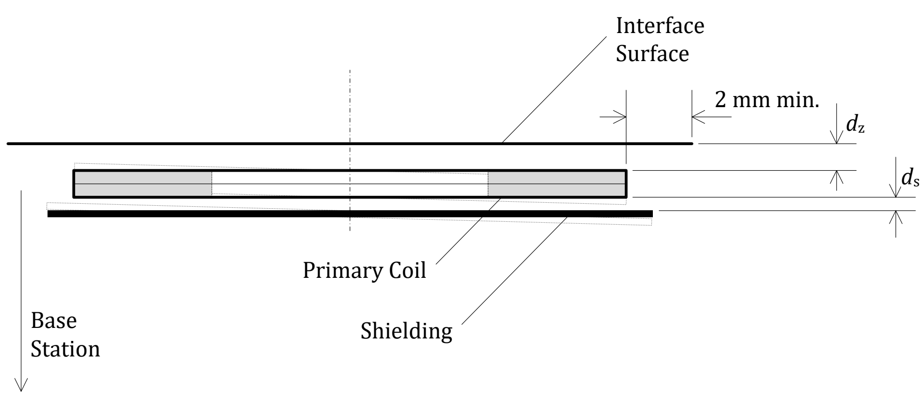
Table 163. Primary Coil parameters of Power Transmitter design MP-A10

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

2.4.10.1.2 Shielding

As shown in Figure 235, soft-magnetic material protects the Base Station 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 235. Primary Coil assembly of Power Transmitter design MP-A10



2.4.10.1.3 Interface Surface

As shown in Figure 235, the distance from the Primary Coil to the Interface Surface of the Base Station 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 Base Station extends at least 2 mm beyond the outer diameter of the Primary Coil.

2.4.10.1.4 Alignment aid

The user manual of a Base Station 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 Mobile Device positioning to help alignment.

NOTE Examples of Base Station alignment aids to assist the user positioning of the Mobile Device 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.

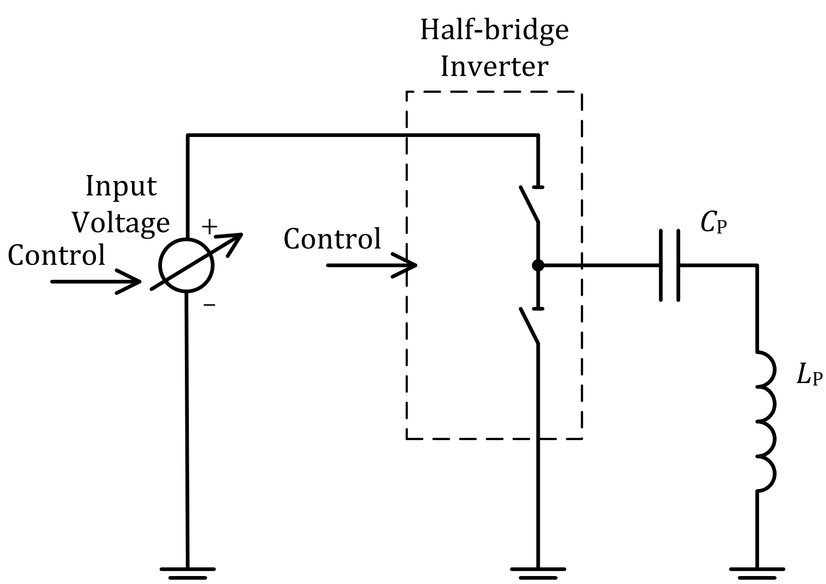
2.4.10.1.5 Inter coil separation

If the Base Station contains multiple type MP-A10 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall not overlap.

2.4.10.2 Electrical details

As shown in Figure 236, 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 236. 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 $f_{\mathrm{op}} = 110$ 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 $f_{\mathrm{op}} = 110$ kHz to 180 kHz and is 10% to 50% at $f_{\mathrm{op}} = 180$ 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 $0.007 \cdot f_{\mathrm{op}} - 0.5$ 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:

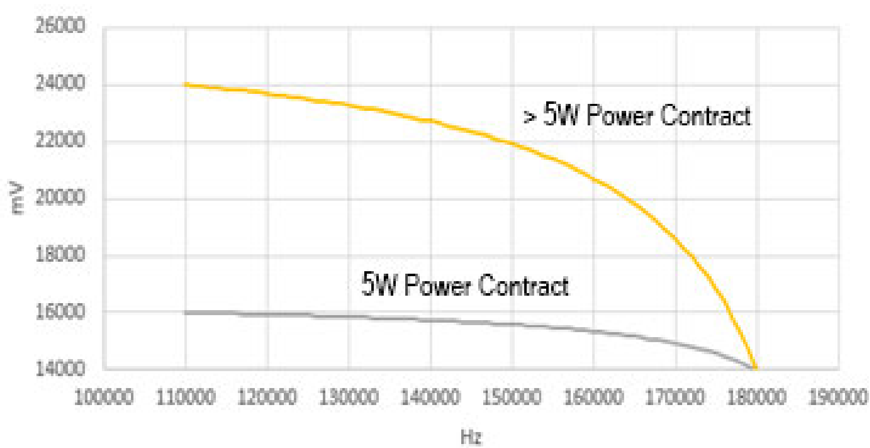
$$V_{mV} = V_{fmin} - \left(\left(\frac{2548000}{4096.\frac{f_{max} - f}{f_{max} - f_{min}} + 1000} \right) - 500 \right) . \frac{V_{fmin} - V_{fmax}}{2048}$$

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 237 shows graphically the Inverter Input Voltage as a function of Operating Frequency.

Figure 237. 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 *Parts 1 and 2: Interface Definitions*. 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 164, Table 165, and Table 166 provide the values of the parameters that are used in the PID algorithm.

Table 164. 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	$\mathrm{mA}^{-1}\mathrm{ms}^{-1}$
Derivative gain	K_{d}	0.5	$\mathrm{mA}^{-1}\mathrm{ms}$
Integral term limit	M_{I}	N.A.	N.A.
PID output limit	M_{PID}	20,000	N.A.

Table 165. Operating Frequency dependent scaling factor

Frequency Range [kHz]	Scaling Factor S_V [Hz]
110 to 125	1.0
125 to 180	2.0

Table 166. PID parameters for duty cycle control

Parameter	Symbol	Value	Unit
Proportional gain	K_{p}	1.0	mA^{-1}
Integral gain	K_{i}	0	$\mathrm{mA}^{-1}\mathrm{ms}^{-1}$
Derivative gain	K_{d}	-0.4	$\mathrm{mA}^{-1}\mathrm{ms}$
Integral term limit	M_{I}	N.A.	N.A.
PID output limit	M_{PID}	10,000	N.A.
Scaling factor	S_{V}	0.1	%

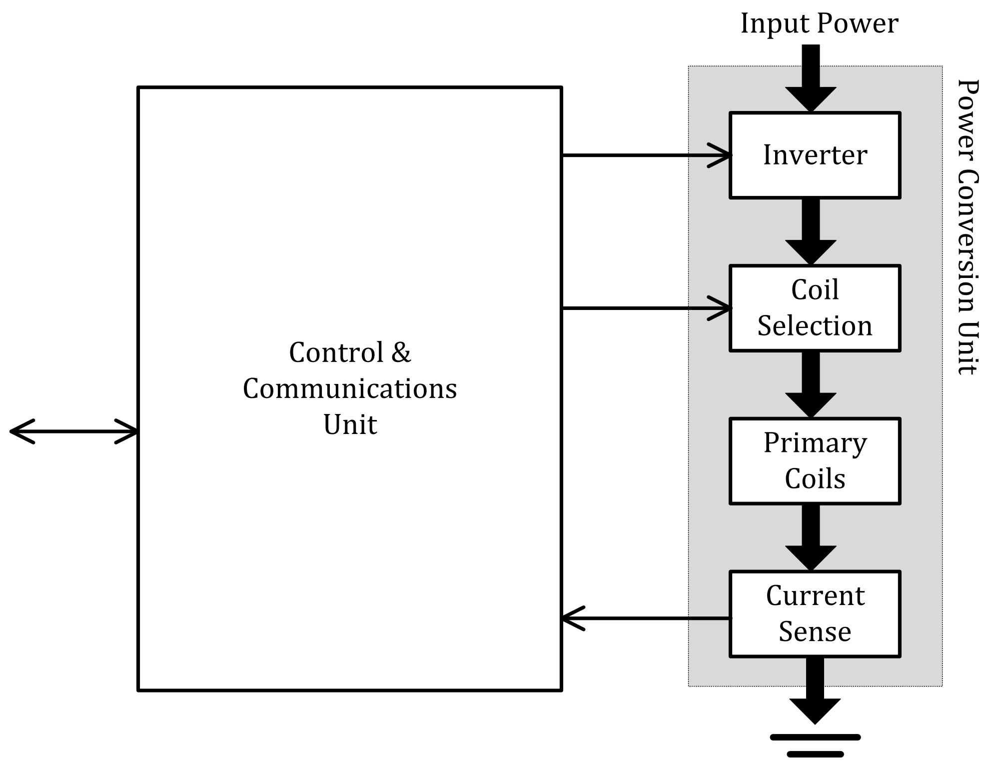
2.4.10.3 Information interface

The Not Res Sens Bit in the Power Transmitter Capability Packet shall be set to ZERO.

2.4.11 Power Transmitter design MP-A13

Figure 238 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 238. Functional block diagram of Power Transmitter design MP-A13



The Power Conversion Unit on the right-hand side of Figure 238 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 238 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 Base Station, e.g. for user interface purposes.

2.4.11.1 Mechanical details

Power Transmitter design A13 includes one or more Primary Coils as defined in Section 2.4.11.1.1, Shielding as defined in Section 2.4.11.1.2, an Interface Surface as defined in Section 2.2.28.1.1.3.

2.4.11.1.1 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 rectangular shape and consists of a single layer. Table 167 lists the dimensions of the Primary Coil.

Figure 239. Primary Coil of Power Transmitter design MP-A13

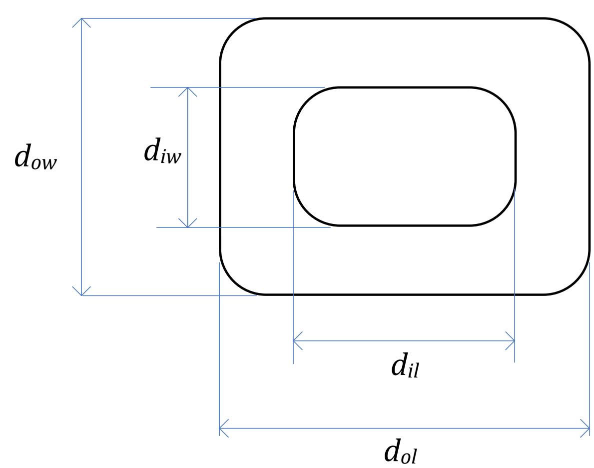
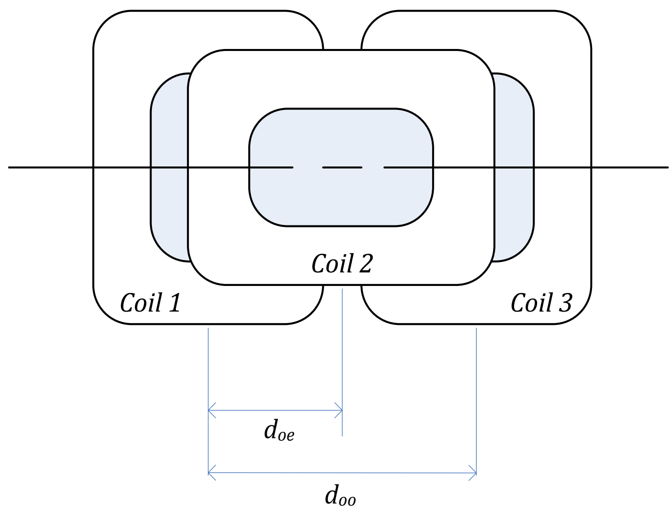


Table 167. Primary Coil parameters of Power Transmitter design MP-A13

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 $d_{\text{oo}} = 49.2^{\pm 4}$ mm between their centers. Even numbered coils are placed orthogonal to the odd numbered coils with a displacement of $d_{\text{oe}} = 24.6^{\pm 2}$ mm between their centers. See Figure 240.

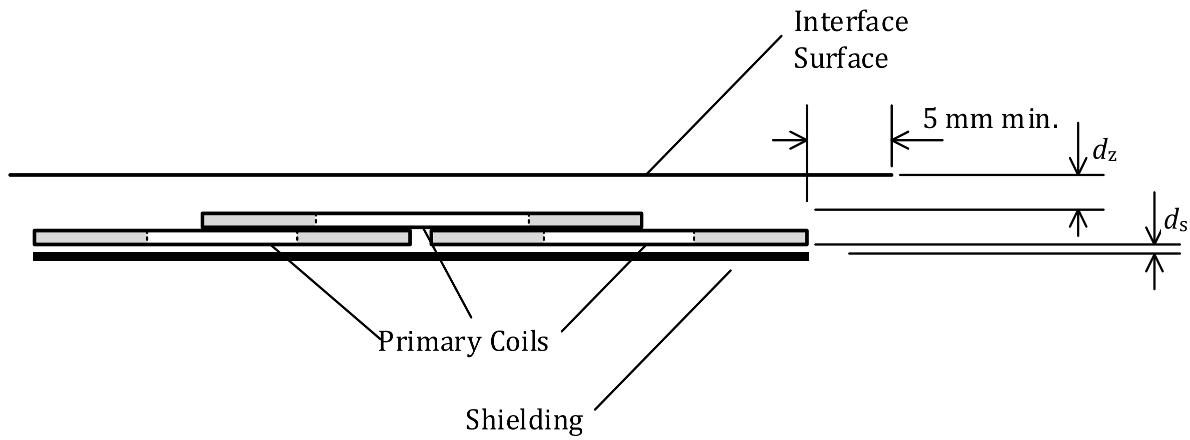
Figure 240. Primary Coils of Power Transmitter design MP-A13



2.4.11.1.2 Shielding

As shown in Figure 241, soft-magnetic material protects the Base Station 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 $d_{\text{s}} = 1.0$ mm.

Figure 241. Primary Coil assembly of Power Transmitter design MP-A13



2.4.11.1.3 Interface Surface

As shown in Figure 241, the distance from the top face of the even-numbered Primary Coil to the Interface Surface of the Base Station 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 Base Station is $d_z = 4.5^{\pm 1}$ mm. In addition, the Interface Surface of the Base Station extends at least 5 mm beyond the outer dimensions of the Primary Coils.

2.4.11.1.4 Alignment aid

The user manual of a Base Station 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 Mobile Device positioning to help alignment.

NOTE Examples of Base Station alignment aids to assist the user positioning of the Mobile Device 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.

2.4.11.1.5 Inter coil separation

If the Base Station contains multiple type MP-A13 Power Transmitters, the Primary Coils of any pair of those Power Transmitters shall have a center-to-center distance of at least $49.2^{\pm 4}$ mm.

2.4.11.2 Electrical details

As shown in Figure 242, 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 $L_{\mathrm{P}} = 11.5^{\pm 10\%}$ 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. The value of the parallel capacitance is $C_{\mathrm{par}} = 400^{\pm 10\%}$ nF. Splitting the series capacitance is optional, affecting only high frequency electromagnetic emissions, and it is permissible to eliminate C_{ser2}, in which case $C_{\mathrm{ser1}} = 200^{\pm 10\%}$ 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 *Parts 1 and 2: Interface Definitions*), 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 *Parts 1 and 2: Interface Definitions*. 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 168 and Table 169 provide the values of several parameters, which are used in the PID algorithm.

Figure 242. Electrical diagram (outline) of Power Transmitter design MP-A13

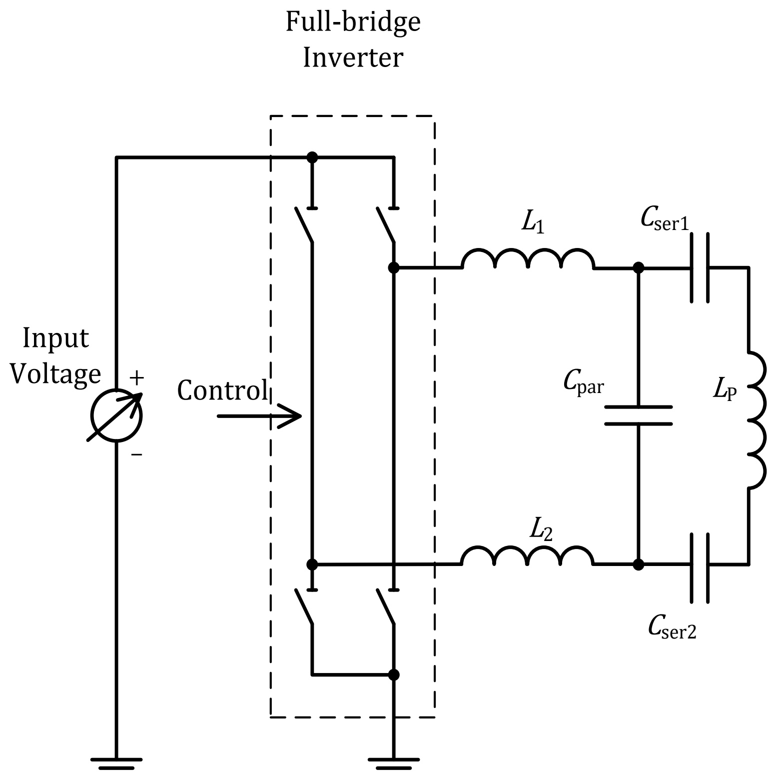


Table 168. PID parameters for voltage control

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 169. PID parameters for duty cycle control

Parameter	Symbol	Value	Unit
Proportional gain	K_{p}	0.03	mA^{-1}
Integral gain	K_{i}	0.01	$\mathrm{mA}^{-1}\mathrm{ms}^{-1}$
Derivative gain	K_{d}	0	$\mathrm{mA}^{-1}\mathrm{ms}$
Integral term limit	M_{I}	3,000	N.A.
PID output limit	M_{PID}	20,000	N.A.
Scaling factor	S_{v}	-0.01	%

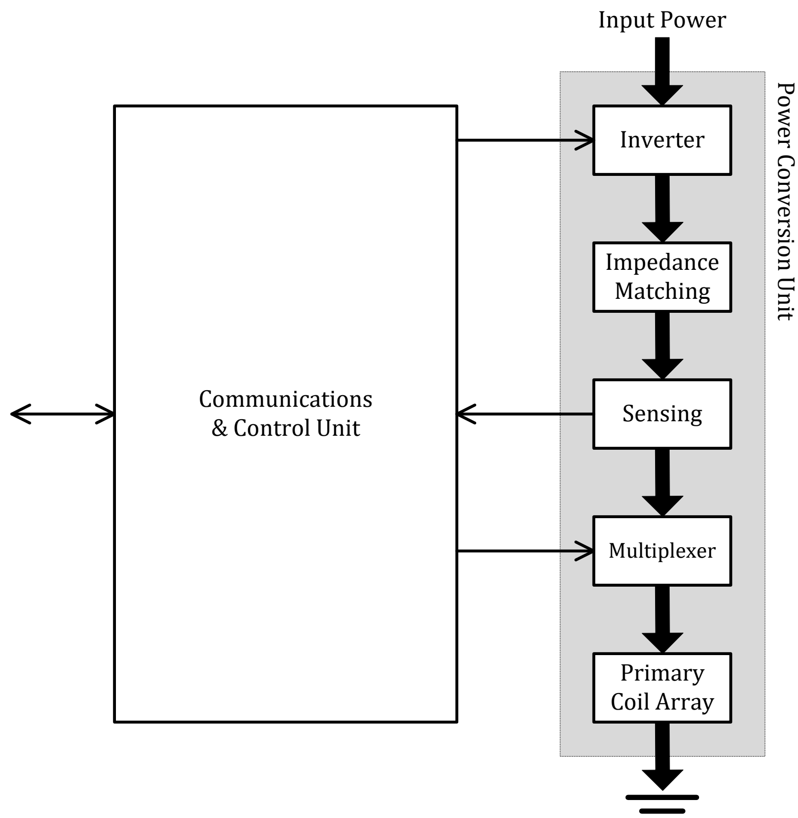
2.4.11.3 Information interface

The Not Res Sens Bit in the Power Transmitter Capability Packet shall be set to ZERO.

2.4.12 Power Transmitter design MP-B1

Figure 243 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 243. Functional block diagram of Power Transmitter design MP-B1



The Power Conversion Unit on the right-hand side of Figure 243 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 243 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 Base Station, e.g. for user interface purposes.

2.4.12.1 Mechanical details

Power Transmitter design MP-B1 includes a Primary Coil array as defined in Section 2.3.7.1.1, Shielding as defined in Section 2.3.7.1.2, and an Interface Surface as defined in Section 2.3.7.1.3.

2.4.12.1.1 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 244 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 170 lists the relevant parameters of the coils shown in Figure 244.

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 244. Top view of Primary Coil A (left) and Primary Coil B (right) of Power Transmitter design MP-B1

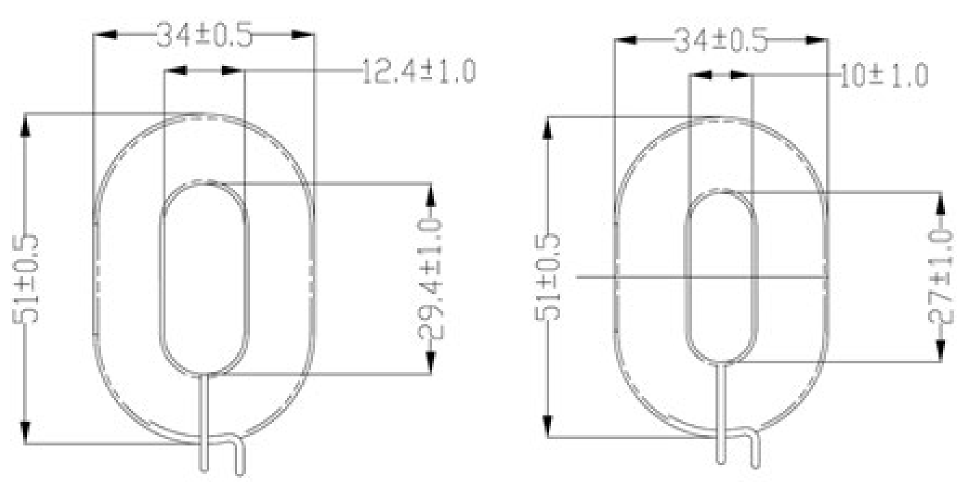


Table 170. Primary Coil parameters of Power Transmitter design MP-B1

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 245 shows the layout of an example execution of the Primary Coil array using four Primary Coils. Table 171 lists the relevant parameters of the Primary Coil array.

Figure 245. Example of Power Transmitter design MP-B1 in a 4-coil execution

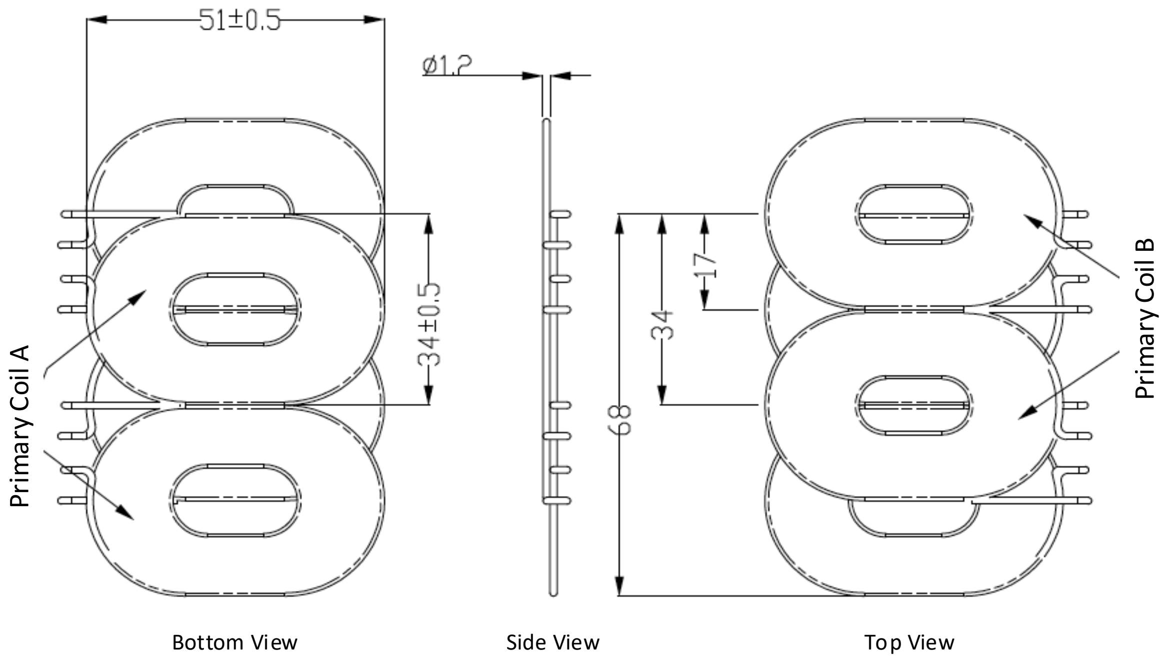


Table 171. Primary Coil array parameters of Power Transmitter design MP-B1

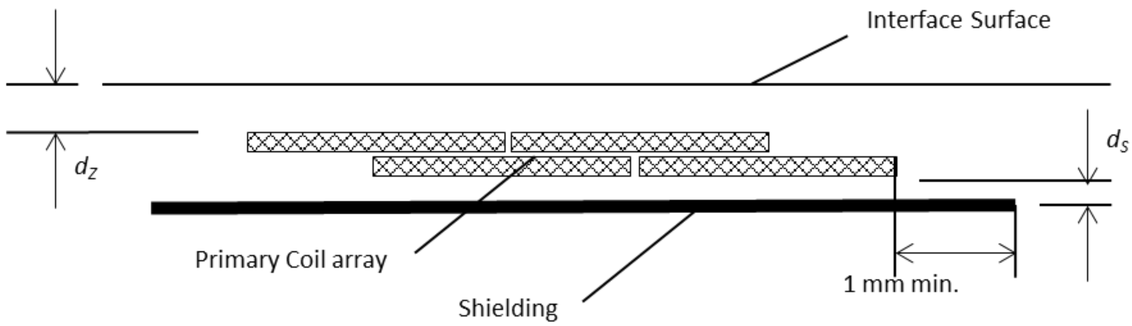
Parameter	Symbol	Value
Center-to-center distance	d_h	$34.0^{\pm 0.5}$ mm
Offset 2nd layer array	t_2	$17.0^{\pm 0.5}$ mm
Litz-layer thickness	d_c	$1.2^{\pm 0.5}$ mm

2.4.12.1.2 Shielding

As shown in Figure 246, Transmitter design MP-B1 employs Shielding to protect the Base Station 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 $d_\mathrm{s} = 0.5$ 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 *Part 4: Reference Designs* limits the composition of the Shielding to any Mn-Zn (for example, PC44 from TDK Corporation).

Figure 246. Primary Coil array assembly of Power Transmitter design MP-B1, cross-sectional view



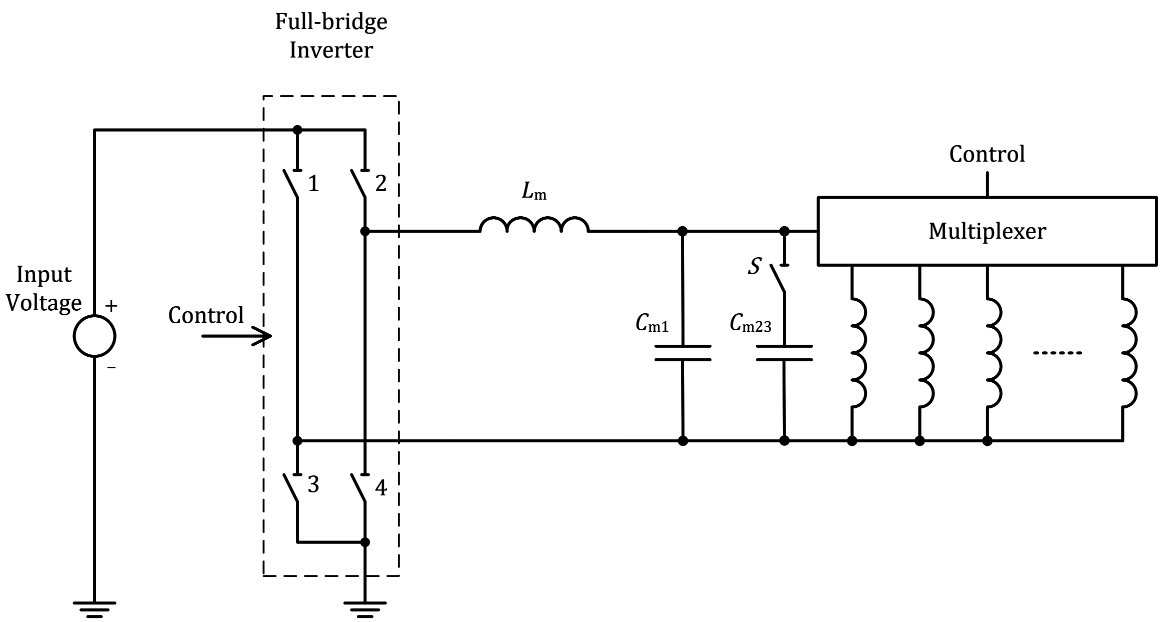
2.4.12.1.3 Interface Surface

As shown in Figure 246, the distance from the top face of the top Primary Coil array to the Interface Surface of the Base Station 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.

2.4.12.2 Electrical details

As shown in Figure 247, 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 247. Electrical diagram (outline) of Power Transmitter design MP-B1

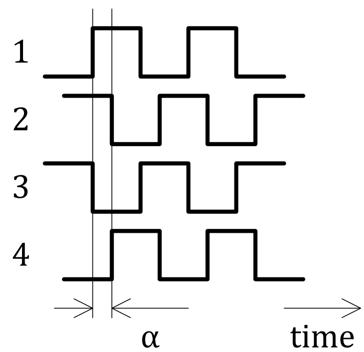


Within the Operating Frequency range $f_{Op} = 115^{\pm 5}$ kHz, the assembly of Primary Coil array and Shielding has an inductance of $6.1^{\pm 0.6}$ μH for each individual Primary Coil. The capacitances in the impedance-matching circuit are $C_{m1} = 300^{\pm 5\%}$nF and C_{m23} is in the range of $100^{-5\%}$ 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 248). 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 (see the *Digital Ping* section in *Parts 1 and 2: Interface Definitions*), it shall use an initial phase difference of 150°.

Figure 248. Control signals to the inverter



Control of the power transfer shall proceed using the PID algorithm, which is defined in the *Power transfer control* section in *Parts 1 and 2: Interface Definitions*. 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 172 provides the values of several parameters that are used in the PID algorithm.

Table 172. Power control parameters for Power Transmitter design MP-B1

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

2.4.12.3 Scalability

Power Transmitter Design MP-B1 offers the same scalability options as Power Transmitter design B1. See Section 2.3.1, *Power Transmitter design B1*.

3 Power Receiver reference designs (Informative)

3.1 Power Receiver example 1 (5W)

The design of Power Receiver example 1 is optimized to directly charge a single cell lithium-ion battery at constant current or voltage.

3.1.1 Mechanical details

This Section 3.1.1 provides the mechanical details of Power Receiver example 1.

3.1.1.1 Secondary Coil

The Secondary Coil of Receiver example 1 is of the wire-wound type, and consists of no. 26 AWG (0.41 mm diameter) litz wire having 26 strands of no. 40 AWG (0.08 mm diameter). As shown in Figure 249, the Secondary Coil has a rectangular shape and consists of a single layer. Table 173 lists the dimensions of the Secondary Coil.

Figure 249. Secondary Coil of Power Receiver example 1

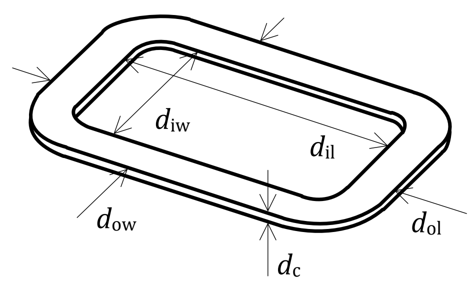


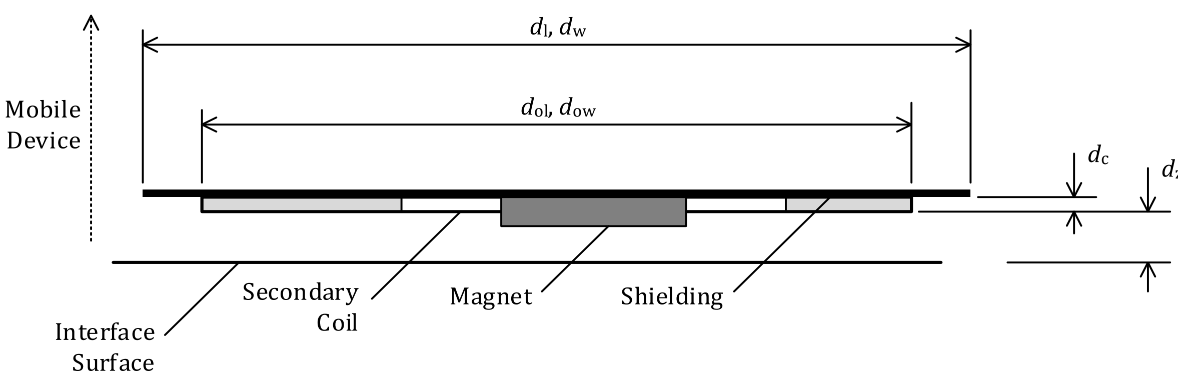
Table 173. Secondary Coil parameters of Power Receiver example 1

Parameter	Symbol	Value
Outer length	d_{ol}	$44.25^{\pm 0.25}$ mm
Inner length	d_{il}	$28.75^{\pm 0.25}$ mm
Outer width	d_{ow}	$30.25^{\pm 0.25}$ mm
Inner width	d_{iw}	$14.75^{\pm 0.25}$ mm
Thickness	d_c	0.6 mm
Number of turns per layer	N	14
Number of layers	–	1

3.1.1.2 Shielding

As shown in Figure 250, Power Receiver example 1 employs Shielding. The Shielding should be Ni-Zn or Mn-Zn ferrite and should be at least 1.0 mm thick. The Shielding has a size of $d_\mathrm{l} \times d_\mathrm{w} = 52^{\pm 1} \times 35^{\pm 1}$ mm², and is centered directly on the top face of the Secondary Coil such that the long side of the Secondary Coil and the Shielding are aligned.

Figure 250. Secondary Coil and Shielding assembly of Power Receiver example 1



3.1.1.3 Interface Surface

The distance from the Secondary Coil to the Interface Surface of the Mobile Device is $d_\mathrm{z} = 2.5$ mm, uniform across the bottom face of the Secondary Coil.

3.1.1.4 Alignment aid

Power Receiver example 1 employs a bonded Neodymium magnet,[3] which has its south pole oriented towards the Interface Surface. The diameter of the magnet is 15 mm, and its thickness is 1.2 mm.

[3] The purpose of the magnet—providing an alignment aid to the user—has disappeared with the deprecation of magnets in Power Transmitter designs.

3.1.2 Electrical details

At the secondary resonance frequency $f_S = 100$ kHz, the assembly of Secondary Coil and Shielding has inductance values $L_s = 15.3^{\pm 1}$ μH and $L'_s = 20.0^{\pm 1}$ μH. The capacitance values in the dual resonant circuit are $C_S = 127^{\pm 1\%}$ nF and $C_d = 1.6^{\pm 5\%}$ nF.

As shown in Figure 251, the rectification circuit consists of four diodes in a full bridge configuration and a low-pass filtering capacitance $C = 20$ μF.

The communications modulator consists of two equal capacitances $C_{cm} = 22^{\pm 5\%}$ nF in series with two switches. The resistance value $R = 10^{\pm 5\%}$ kΩ.

The subsystem connected to the output of Power Receiver example 1 is expected to consist of a single cell lithium-ion battery. This Power Receiver example 1 controls the output current and output voltage into the battery according to the common constant current to constant voltage charging profile. An example profile is indicated in Figure 252. The maximum output power to the battery is controlled to a 5 W level.

Figure 251. Electrical details of Power Receiver example 1

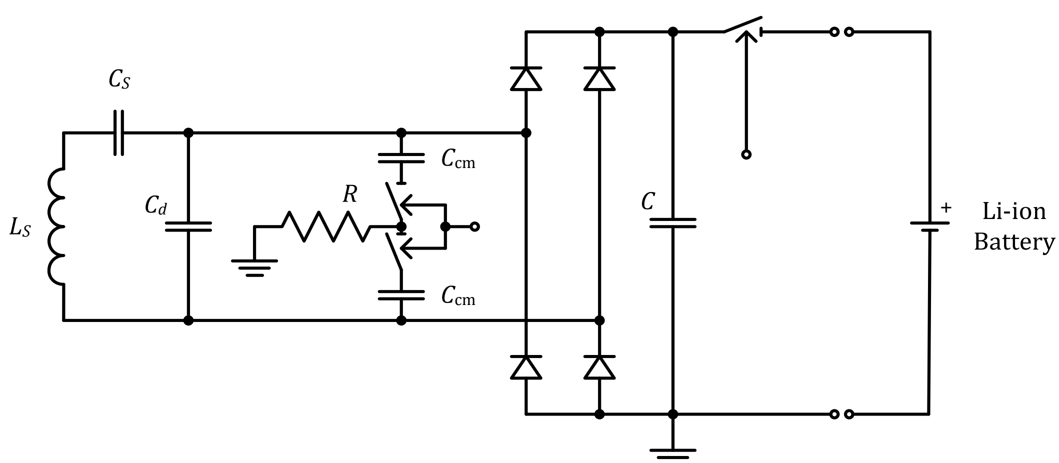
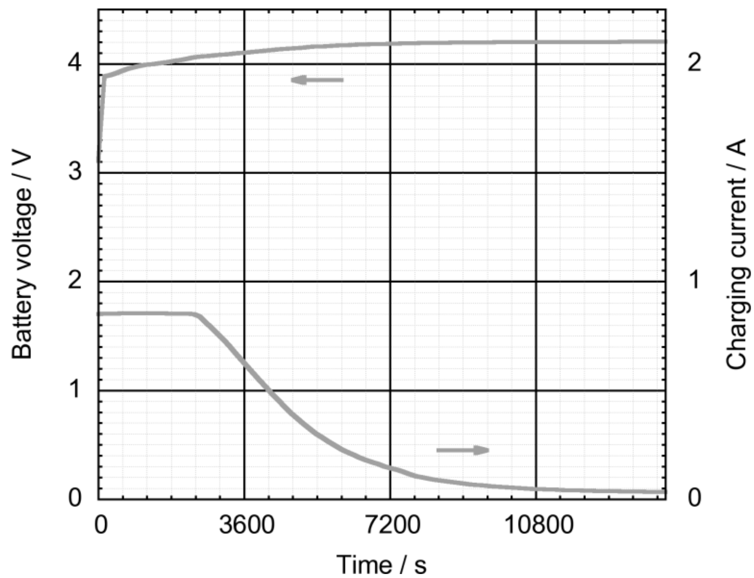


Figure 252. Li-ion battery charging profile



3.2 Power Receiver example 2 (5W)

The design of Power Receiver example 2 uses post-regulation to create a voltage source at the output of the Power Receiver.

3.2.1 Mechanical details

This section 3.2.1 provides the mechanical details of Power Receiver example 2.

3.2.1.1 Secondary Coil

The Secondary Coil of Power Receiver example 2 is of the wire-wound type, and consists of litz wire having 24 strands of no. 40 AWG (0.08 mm diameter). As shown in Figure 253, the Secondary Coil has a circular shape and consists of multiple layers. All layers are stacked with the same polarity. Table 174 lists the dimensions of the Secondary Coil.

Figure 253. Secondary Coil of Power Receiver example 2

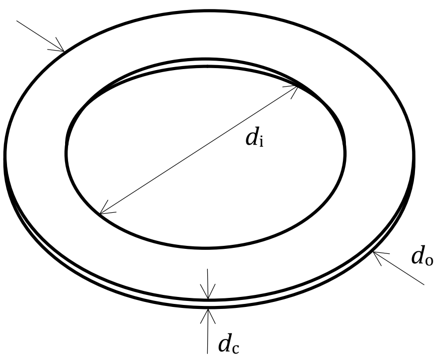


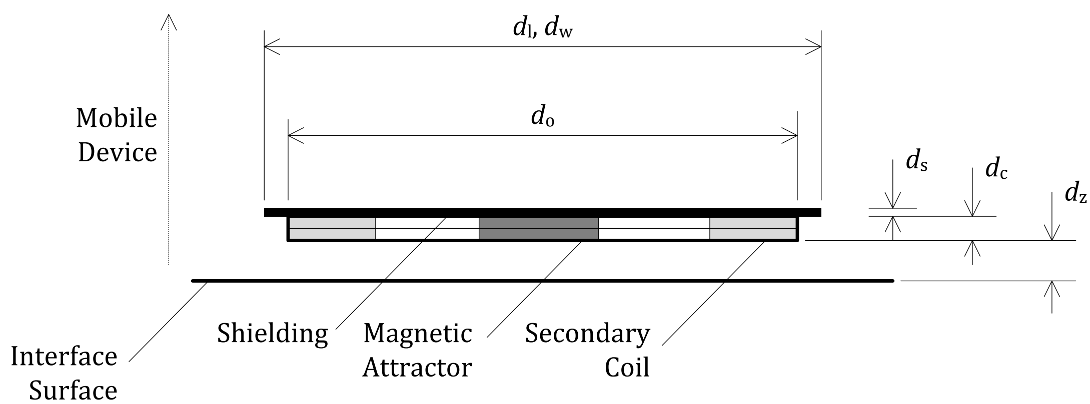
Table 174. Parameters of the Secondary Coil of Power Receiver example 2

Parameter	Symbol	Value
Outer diameter	d_o	$32^{\pm 0.25}$ mm
Inner diameter	d_i	$21.7^{\pm 0.6}$ mm
Thickness	d_c	$0.9^{\pm 0.2}$ mm
Number of turns per layer	N	9
Number of layers	–	2

3.2.1.2 Shielding

As shown in Figure 254, Power Receiver example 2 employs Shielding. The Shielding should be Ni-Zn or Mn-Zn ferrite and should be at least 0.8 mm thick. The Shielding has a size of $d_l \times d_w = 35^{\pm 1} \times 35^{\pm 1}$ mm², and is centered directly on the top face of the Secondary Coil.

Figure 254. Secondary Coil and Shielding assembly of Power Receiver example 2



3.2.1.3 Interface Surface

The distance from the Secondary Coil to the Interface Surface of the Mobile Device is $d_z = 2$ mm, uniform across the bottom face of the Secondary Coil.

3.2.1.4 Alignment aid

Power Receiver example 2 employs Shielding material (see section 3.2.1.2) as an alignment aid[4] (see *Parts 1 and 2: Interface Definitions*). The diameter of this Shielding material is 10 mm, and its thickness is 0.8 mm.

[4] The purpose of the additional Shielding material—providing an alignment aid to the user—has disappeared with the deprecation of magnets in Power Transmitter designs.

3.2.2 Electrical details

At the secondary resonance frequency $f_\mathrm{S} = 100$ kHz, the assembly of Secondary Coil and Shielding has inductance values $L_\mathrm{S} = 23.8^{\pm 1}$ μH and $L'_\mathrm{s} = 30.8^{\pm 1}$ μH. The capacitance values in the dual resonant circuit are $C_\mathrm{S} = 82^{\pm 5\%}$ nF and $C_\mathrm{d} = 1.0^{\pm 5\%}$ nF.

As shown in Figure 255, the rectification circuit consists of four diodes in a full bridge configuration and a low-pass filtering capacitance $C = 20^{\pm 20\%}$ μF.

The communications modulator consists of a $R_\mathrm{cm} = 33^{\pm 5\%}$ Ω resistance in series with a switch.

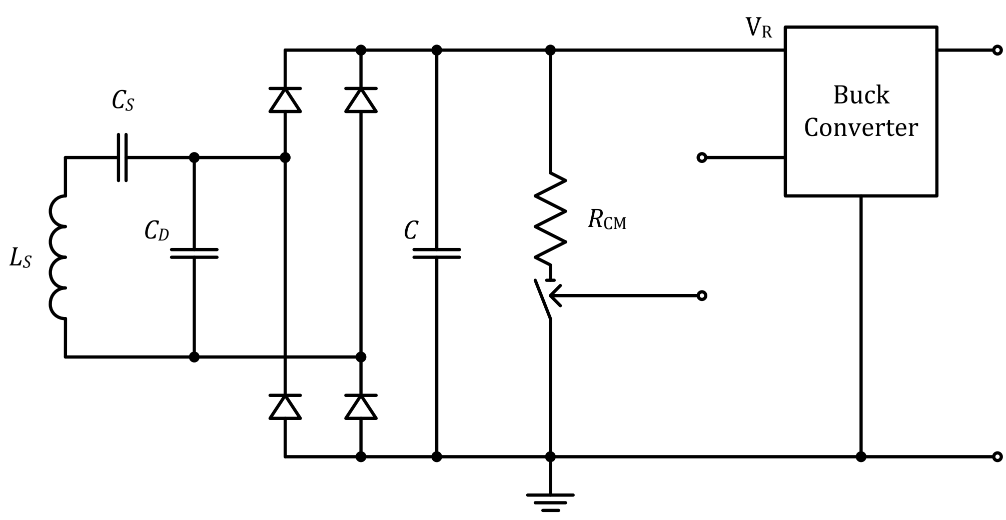
The buck converter comprises the post-regulation stage of Power Receiver example 2. The Control and Communications Unit of the Power Receiver can disable the buck converter. This provides the output disconnect functionality. In addition, the Control and Communications Unit controls the input voltage V_r to the buck converter, such that $V_\mathrm{r} = 7$ V.

The buck converter has a constant output voltage of 5 V and an output current

$$I_\mathrm{buck} = \frac{\eta(P) \cdot P}{5\ \mathrm{V}},$$

Where P is the output power of the buck converter, and $\eta(P)$ is the power dependent efficiency of the buck converter.

Figure 255. Electrical details of Power Receiver example 2



3.3 Power Receiver example 3 (8 W)

The design of Power Receiver example 3 uses post-regulation to create a voltage source at the output of the Power Receiver.

3.3.1 Mechanical details

This section provides the mechanical details of Power Receiver example 3.

3.3.1.1 Secondary Coil

The Secondary Coil of Power Receiver example 3 is of the wire-wound type, and consists of litz wire having 66 strands of no. 40 AWG (0.08 mm diameter). As shown in Figure 256, the Secondary Coil has a circular shape and consists of a single layer. Table 175 lists the dimensions and other parameters of the Secondary Coil.

Figure 256. Secondary Coil of Power Receiver example 3

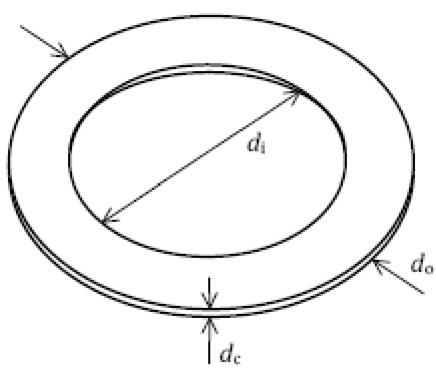


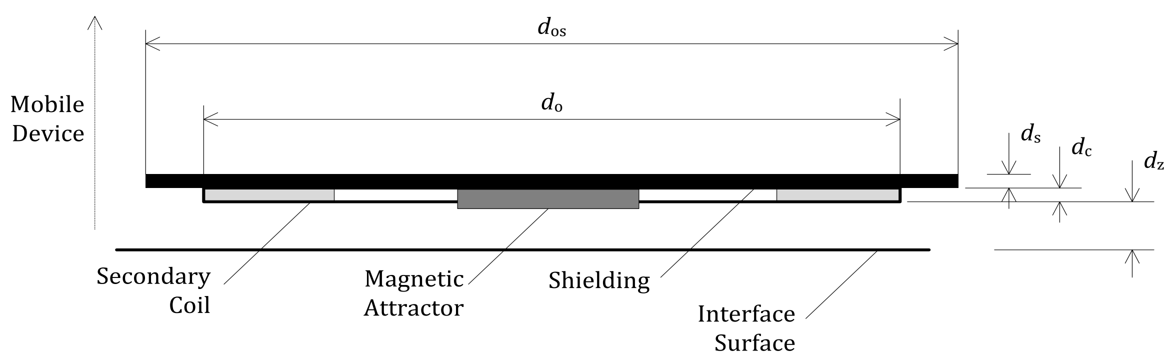
Table 175. Secondary Coil parameters of Power Receiver example 3

Parameter	Symbol	Value
Outer diameter	d_o	$47^{\pm 2}$ mm
Inner diameter	d_i	$24.25^{\pm 0.25}$ mm
Thickness	d_c	$0.9^{\pm 0.1}$ mm
Number of turns per layer	N	12
Number of layers	–	1

3.3.1.2 Shielding

As shown in Figure 257, Power Receiver example 3 employs Shielding. The Shielding should be Ni-Zn or Mn-Zn ferrite and should be $d_s = 1.0^{\pm 0.25}$ mm thick. The Shielding has a size of $d_{os} = 50^{\pm 0.25}$ mm, and is centered directly on the top face of the Secondary Coil.

Figure 257. Secondary Coil and Shielding assembly of Power Receiver example 3



3.3.1.3 Interface Surface

The distance from the Secondary Coil to the Interface Surface of the Mobile Device is $d_z = 2.5$ mm, uniform across the bottom face of the Secondary Coil.

3.3.1.4 Alignment aid

Power Receiver example 3 employs Shielding material as a magnetic attractor.[5] The diameter of this Shielding material is $20.0^{\pm 0.25}$ mm and its thickness is $1.27^{\pm 0.1}$ mm.

[5] The purpose of the additional Shielding material—providing an alignment aid to the user—has disappeared with the deprecation of magnets in Power Transmitter designs.

3.3.2 Electrical details

At the secondary resonance frequency $f_S = 100$ kHz, the assembly of Secondary Coil and Shielding has inductance values $L_S = 11.5^{\pm 1}$ μH and $L_S{}' = 15.7^{\pm 1}$ μH. The capacitance values in the dual resonant circuit are $C_S = 160^{\pm 5\%}$ nF and $C_d = 2.2^{\pm 5\%}$ nF.

As shown in Figure 258, the rectification circuit consists of four diodes in a full-bridge configuration with a low-pass filtering capacitance of $C = 33^{\pm 20\%}$ μF.

The communications modulator consists of two capacitors in series with two switches, each with a capacitance of $C_{cm} = 22^{\pm 10\%}$ nF.

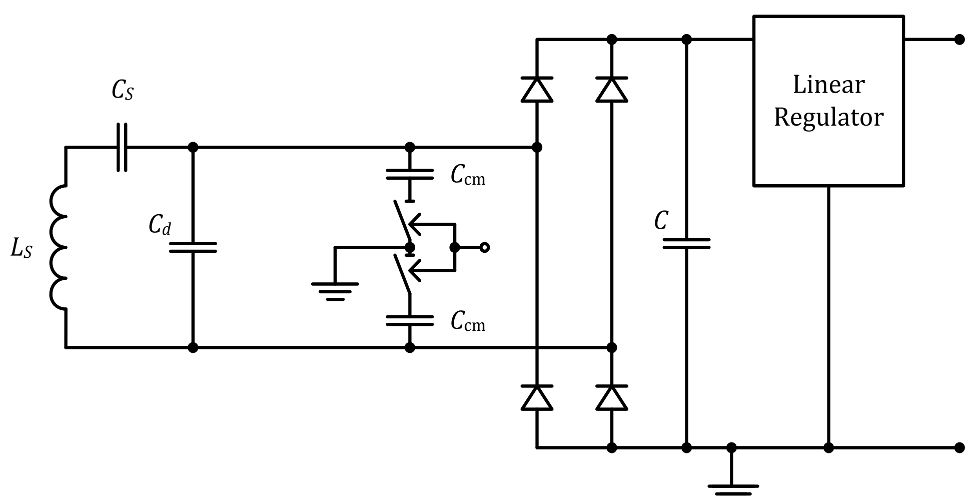
The linear regulator comprises the post-regulation stage of Power Receiver example 3. The Control and Communications Unit of the Power Receiver can disable the regulator to provide output disconnect functionality. In addition, the Control and Communications Unit controls the input voltage to the regulator, such that $V_r = 5.8$ V.

The linear regulator has a constant output voltage of 5 V. The output current is

$$I_{reg} = \frac{P}{5\text{ V}}$$

where P is the output power of the regulator. In this example, the output power is up to 8 W.

Figure 258. Electrical details of Power Receiver example 3



3.4 Power Receiver example 4 (15 W)

The design of Power Receiver example 4 uses post-regulation to create a voltage source at the output of the Power Receiver.

3.4.1 Mechanical details

This section provides the mechanical details of Power Receiver example 4.

3.4.1.1 Secondary Coil

The Secondary Coil of Power Receiver example 4 is of the wire-wound type, and consists of litz wire having 66 strands of no. 40 AWG (0.08 mm diameter). As shown in Figure 259, the Secondary Coil has a circular shape and consists of multiple layers. All layers are stacked with the same polarity. Table 176 lists the dimensions and other parameters of the Secondary Coil.

Figure 259. Secondary Coil of Power Receiver example 4

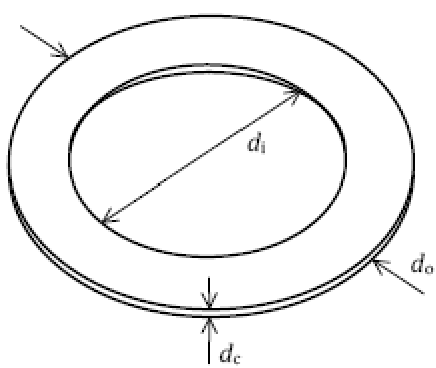


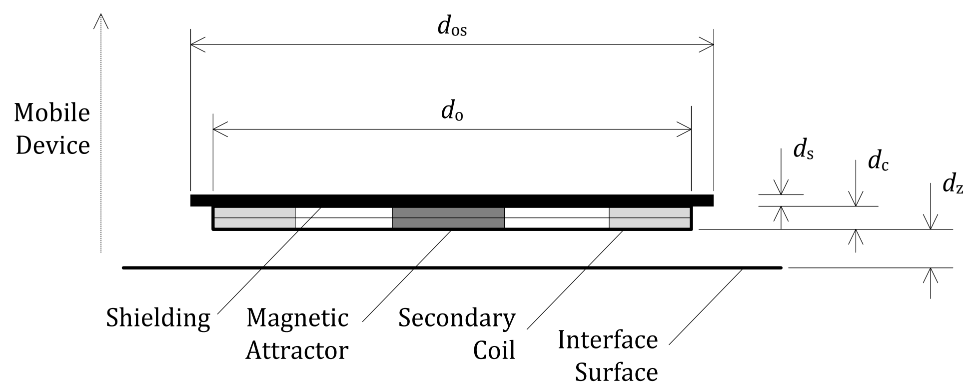
Table 176. Secondary Coil parameters of Power Receiver example 4

Parameter	Symbol	Value
Outer diameter	d_o	$47.0^{\pm 2}$ mm
Inner diameter	d_i	$28.0^{\pm 0.25}$ mm
Thickness	d_c	$1.8^{\pm 0.1}$ mm
Number of turns per layer	N	10
Number of layers	–	2

3.4.1.2 Shielding

As shown in Figure 260, Power Receiver example 4 employs Shielding. The Shielding should be Ni-Zn or Mn-Zn ferrite and should be $d_{\mathrm{s}} = 1.0^{\pm 0.25}$ mm thick. The Shielding has a size of $d_{\mathrm{os}} = 50^{\pm 0.25}$ mm, and is centered directly on the top face of the Secondary Coil.

Figure 260. Secondary Coil and Shielding assembly of Power Receiver example 4



3.4.1.3 Interface Surface

The distance from the Secondary Coil to the Interface Surface of the Mobile Device is $d_{\mathrm{z}} = 2.5$ mm, uniform across the bottom face of the Secondary Coil.

3.4.1.4 Alignment aid

Power Receiver example 4 employs Shielding material as a magnetic attractor.[6] The diameter of this Shielding material is $20.0^{\pm 0.25}$ mm and its thickness is $1.91^{\pm 0.1}$ mm.

[6] The purpose of the additional Shielding material—providing an alignment aid to the user—has disappeared with the deprecation of magnets in Power Transmitter designs.

3.4.2 Electrical details

At the secondary resonance frequency $f_{\mathrm{S}} = 100$ kHz, the assembly of Secondary Coil and Shielding has inductance values of $L_{\mathrm{S}} = 33.6^{\pm 1}$ μH and $L_{\mathrm{S}}' = 44.8^{\pm 1}$ μH. The capacitance values in the dual resonant circuit are $C_{\mathrm{S}} = 56^{\pm 5\%}$ nF and $C_{\mathrm{d}} = 0.8^{\pm 5\%}$ nF.

As shown in Figure 261, the rectification circuit consists of four diodes in a full-bridge configuration with a low-pass filtering capacitance of $C = 33^{\pm 20\%}$ μF.

The communications modulator consists of two capacitors in series with two switches, each with a capacitance of $R_{\mathrm{cm}} = 30^{\pm 5\%}\ \Omega$

The buck converter comprises the post-regulation stage of Power Receiver example 4. The Control and Communications Unit of the Power Receiver can disable the buck converter to provide output disconnect functionality. In addition, the Control and Communications Unit controls the input voltage to the buck converter, such that $V_{\mathrm{r}} = 12$ V.

The buck converter has a constant output voltage of 5 V. The output current is

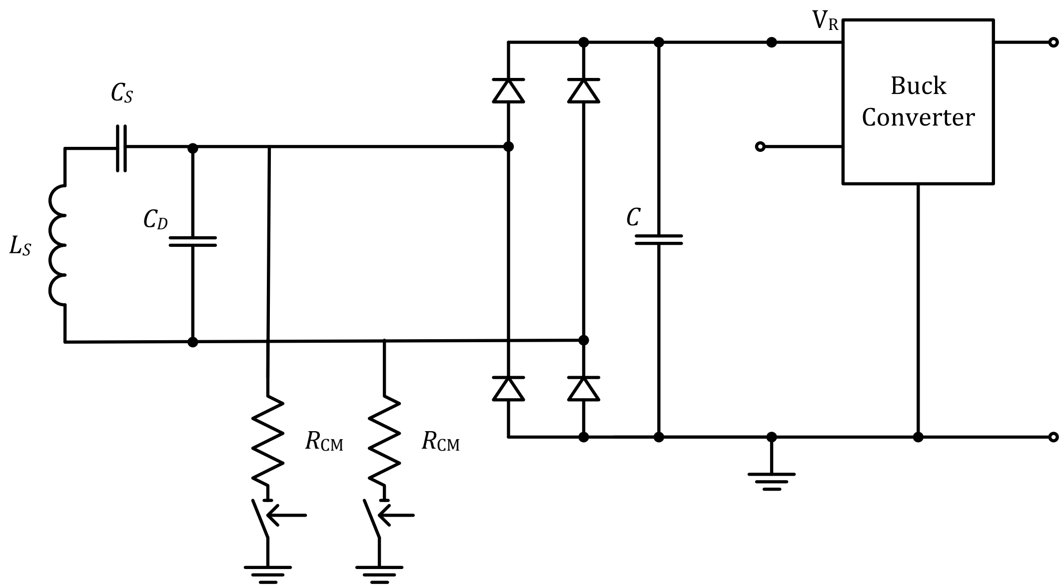
$$I_{\mathrm{out}} = \frac{P}{5\ \mathrm{V}}$$

and the input current is

$$I_{\mathrm{buck}} = \frac{P}{\eta(P)\ \cdot\ 12\ \mathrm{V}}$$

where P is the output power of the buck converter, and $\eta(P)$ is the power-dependent efficiency of the buck converter. For this example, P may be as large as 15 W.

Figure 261. Electrical details of Power Receiver example 4



3.5 Power Receiver example 5 (12 W)

The design of Power Receiver example 5 uses post-regulation to create a voltage source at the output of the Power Receiver.

3.5.1 Mechanical details

This section provides the mechanical details of Power Receiver example 5.

3.5.1.1 Secondary Coil

The Secondary Coil of Power Receiver example 5 is of the wire-wound type, and consists of 30 AWG (0.26 mm diameter) bifilar wire. As shown in Figure 262, the Secondary Coil has a circular shape and consists of a single layer. Table 177 lists the dimensions and other parameters of the Secondary Coil.

Figure 262. Secondary Coil of Power Receiver example 5

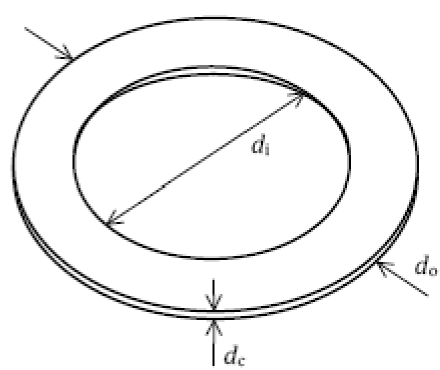


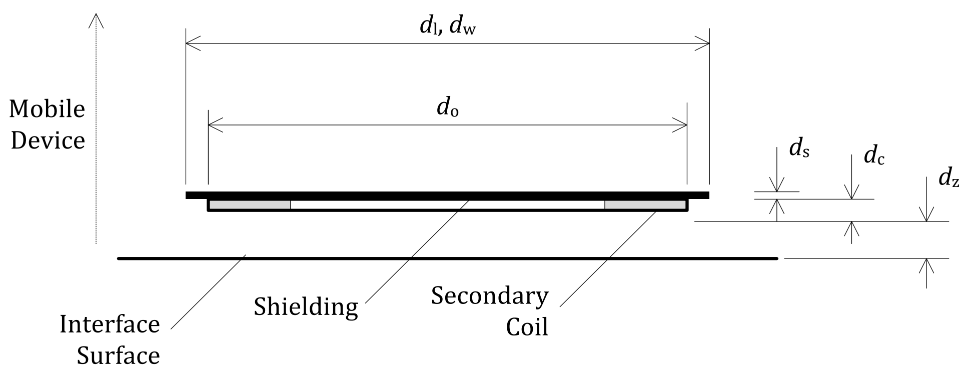
Table 177. Secondary Coil parameters of Power Receiver example 5

Parameter	Symbol	Value
Outer diameter	d_o	$40.0^{\pm 0.25}$ mm
Inner diameter	d_i	$22.0^{\pm 0.25}$ mm
Thickness	d_c	$0.29^{\pm 0.1}$ mm
Number of turns per layer	N	15
Number of layers	–	1

3.5.1.2 Shielding

As shown in Figure 263, Power Receiver example 5 employs Shielding. The Shielding should be Ni-Zn or Mn-Zn ferrite and should be $0.6^{\pm 0.25}$ mm thick. The Shielding has a size of $d_\mathrm{l} \times d_\mathrm{w} = 50.0^{\pm 0.25} \times 50.0^{\pm 0.25}$ mm² and is centered directly on the top face of the Secondary Coil.

Figure 263. Secondary Coil and Shielding assembly of Power Receiver example 5



3.5.1.3 Interface Surface

The distance from the Secondary Coil to the Interface Surface of the Mobile Device is $d_\mathrm{z} = 1.0$ mm, uniform across the bottom face of the Secondary Coil.

3.5.2 Electrical details

At the secondary resonance frequency $f_\mathrm{S} = 100$ kHz, the Secondary Coil and Shielding assembly has inductance values of $L_\mathrm{s} = 15.4^{\pm 1}$ μH and $L'_\mathrm{s} = 23.0^{\pm 1}$ μH. The capacitance values in the dual resonant circuit are $C_\mathrm{S} = 110^{\pm 5\%}$ nF and $C_\mathrm{d} = 1.6^{\pm 5\%}$ nF.

As shown in Figure 264, the rectification circuit consists of four diodes in a full-bridge configuration with a low-pass filtering capacitance of $C = 10^{\pm 20\%}$ μF.

The communications modulator consists of two capacitors in series with two switches, each with a capacitance of $C_\mathrm{m} = 22^{\pm 10\%}$ nF.

The buck converter comprises the post-regulation stage of Power Receiver example 5. The Control and Communications Unit of the Power Receiver can disable the buck converter to provide output disconnect functionality. In addition, the Control and Communications Unit controls the input voltage to the buck converter, such that $V_\mathrm{r} = 12$ V.

The buck converter has a constant output voltage of 5 V. The output current is

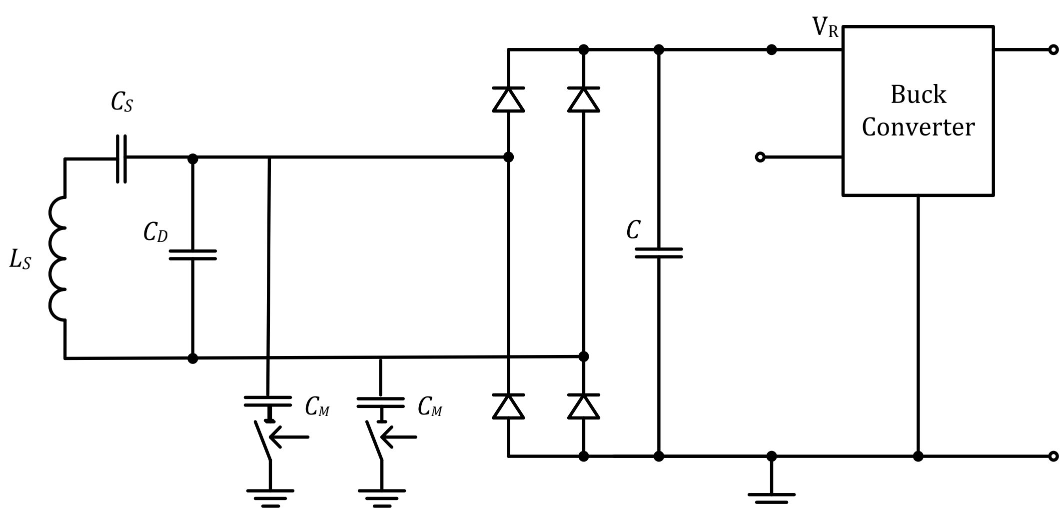
$$I_{\text{out}} = \frac{P}{5\ \text{V}}$$

and the input current is

$$I_{buck} = \frac{P}{\eta(P)\ \cdot\ 12\ \text{V}}$$

where P is the output power of the buck converter, and $\eta(P)$ is the power-dependent efficiency of the buck converter.

Figure 264. Electrical details of Power Receiver example 5



Annex A History of Changes

NOTE The changes listed in Table 178 are limited to technical updates and other changes of significance made in version 1.2.4. The table does not identify minor editorial changes such as typographical errors.

Table 178. Changes from version 1.2.3 to 1.2.4

Location	Old	New	Reason
Throughout, Interface Surface sections	[Only the distance from the top coil in multi-coil designs to the BSUT Interface Surface is provided.]	[Added the distance (where available) from a single coil to the BSUT Interface Surface.]	Change request #428
Section 2.2.11, Power Transmitter design A11	Power Transmitter design A11	Moved Power Transmitter design A11 to section 2.2.11.1 and added Power Transmitter design A11a to section 2.2.11.2	Change request #399
Section 2.2.28, Power Transmitter design A28	Power Transmitter design A28	Moved Power Transmitter design A28 to section 2.2.28.1 and added Power Transmitter design A28a to section 2.2.28.2	Change request #399
Section 2.2.32.1.1, Primary Coil	—	Added a note to Table 95 regarding the track width parameter: “**The trace may be divided, as shown in Figure 133.” Also added Figure 133, “Coil trace examples…”	Change request #413
Section 2.4.9, Power Transmitter design MP-A9	Power Transmitter design MP-B1	Moved Power Transmitter design MP-B1 to section 2.4.10 and added Power Transmitter design MP-A9 to section 2.4.9.	Change request #381
Section 2.4.10, Power Transmitter design MP-A10	—	New Power Transmitter design MP-A10	Change request #419
Section 2.4.11, Power Transmitter design MP-A13	—	New Power Transmitter design MP-A13	Change request #426