



BSI Standards Publication

The Qi wireless power transfer system - Power class 0 specification

Part 2: Reference Designs Version.1.1.2

National foreword

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PUBLICLY AVAILABLE SPECIFICATION PRE-STANDARD



**The Qi wireless power transfer system – Power class 0 specification –
Part 2: Reference Designs Version.1.1.2**

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 29.240.99; 33.160.99; 35.200

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

THE QI WIRELESS POWER TRANSFER SYSTEM – POWER CLASS 0 SPECIFICATION –

Part 2: Reference Designs Version.1.1.2

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The text of this PAS is based on the following document:

This PAS was approved for publication by the P-members of the committee concerned as indicated in the following document

Draft PAS	Report on voting
100/2827/PAS	100/2862/RVDPAS

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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 Annex H of 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 (WPC Web site for members, Testing & Registration section)
- Qi Product Registration Manual, Logo Licensee/Manufacturer
- Qi Product Registration Manual, Authorized Test Lab
- Power Receiver Manufacturer Codes, Wireless Power Consortium
- The International System of Units (SI), Bureau International des Poids et Mesures

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*.

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 <i>Part 3: Compliance Testing</i> . For Power Transmitters that comply with the Extended Power Profile, the reference is TPR#MP1B, which is also defined in <i>Part 3: Compliance Testing</i> .
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 dissipated outside the Interface Surface of a Base Station, due to the magnetic field generated by the Power Transmitter.
WPID	A 48-bit number that uniquely identifies a Qi-compliant device.

1.6 Acronyms

AC	Alternating Current
ACK	Acknowledge
AWG	American Wire Gauge
BSUT	Base Station Under Test
CEP	Control Error Packet
DC	Direct Current
DCR	Direct Current Resistance

EM	Electro Magnetic
EMC	Electro Magnetic Compatibility
EMF	Electro Magnetic Fields
EPT	End Power Transfer
ESR	Equivalent Series Resistance
FET	Field Effect Transistor
FOD	Foreign Object Detection
FSK	Frequency-Shift Keying
LSB	Least Significant Bit
MSB	Most Significant Bit
MDUT	Mobile Device Under Test
N.A.	Not Applicable
NAK	Not-Acknowledge
ND	Not-Defined
PID	Proportional Integral Differential
PRx	Power Receiver
PTx	Power Transmitter
RMS	Root Mean Square
TPR	Test Power Receiver
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 [μ H]
L_p	Primary Coil self inductance [μ H]
L_s	Secondary Coil self inductance (Mobile Device away from Base Station) [μ H]
L'_s	Secondary Coil self inductance (Mobile Device on top of Base Station) [μ H]
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 1.5.

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

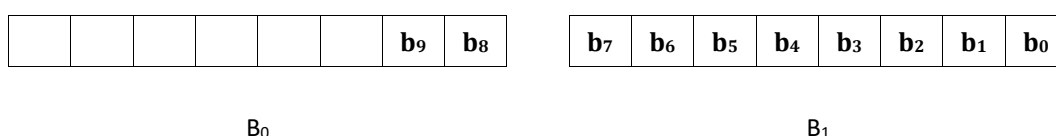
The bytes in a sequence of n bytes are referred to as $B_0, B_1, \dots, B_{n-1}$. Byte B_0 corresponds to the first byte in the sequence; byte B_{n-1} corresponds to the last byte in the sequence. The graphical representation of a byte sequence is such that B_0 is at the upper left-hand side, and byte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



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 ' $\oplus$ ' 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 " $t_{\text{start}}=15 \text{ ms}$ " 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.

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

This Section 0 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*.

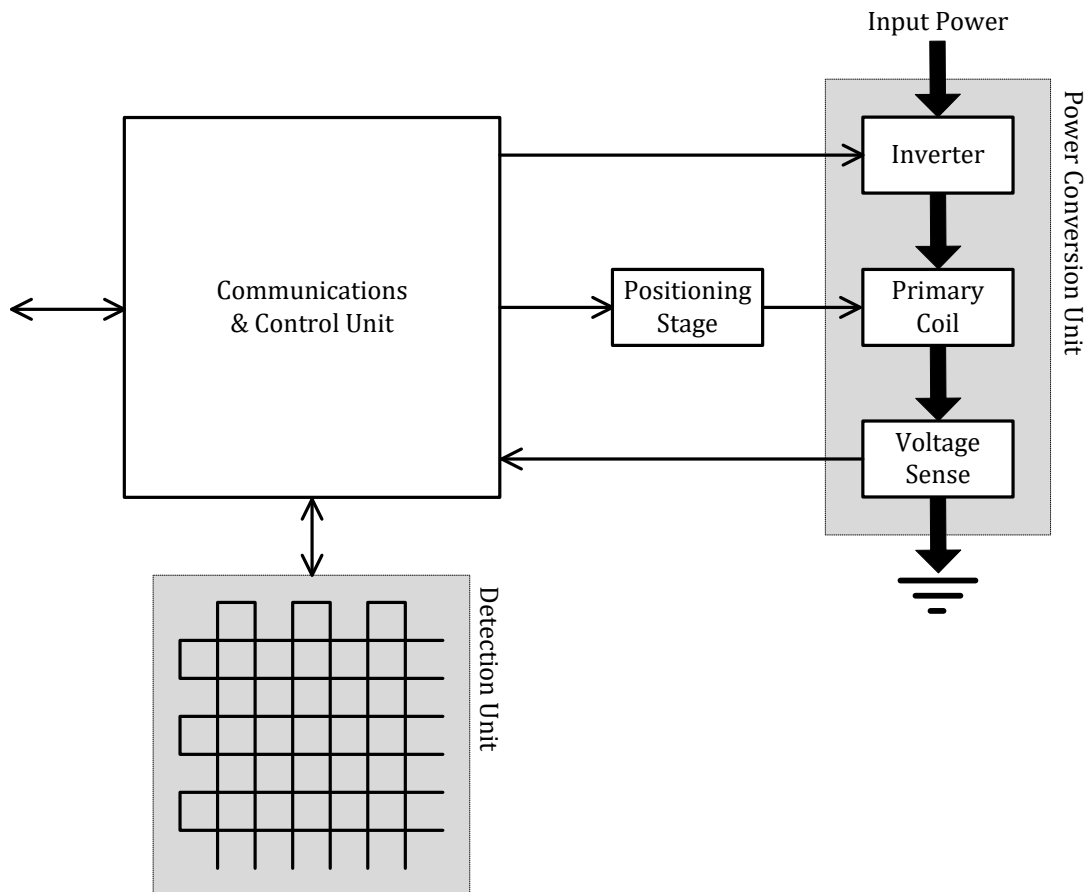
2.2.1 Power Transmitter design A1

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 A1. 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 A1.

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. Primary Coil of Power Transmitter design A2, 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

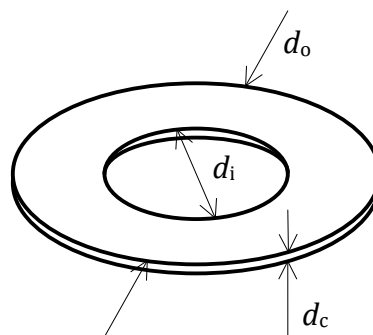


Table 1. Primary Coil parameters of Power Transmitter design A2

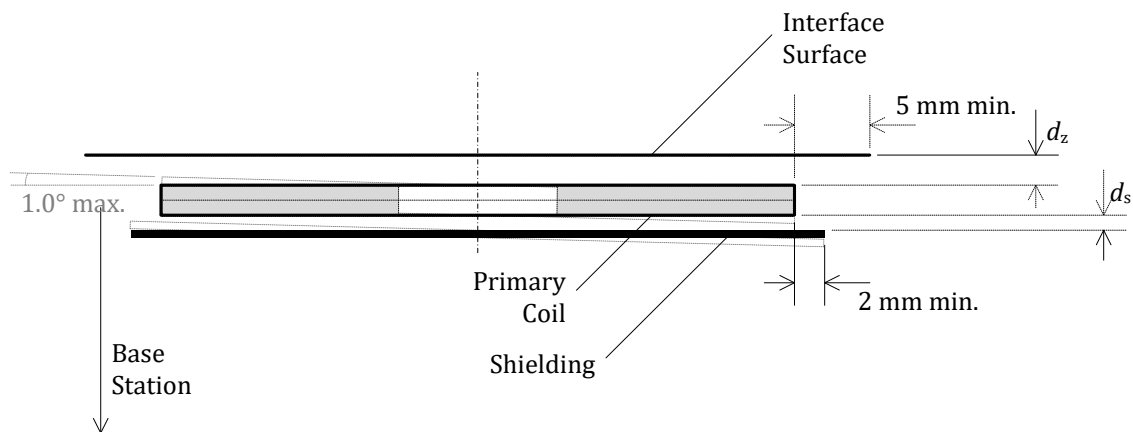
Parameter	Symbol	Value
Outer diameter	d_o	$40^{\pm 1}$ mm
Inner diameter	d_i	$19^{\pm 1}$ mm
Thickness	d_c	$2^{+0.2}$ mm
Number of turns per layer	N	10
Number of layers	–	2

2.2.2.1.2 Shielding

As shown in Figure 5, 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 0.20 mm and is placed below the Primary Coil at a distance of at most $d_s = 0.1$ mm. This version of *Part 4: Reference Designs* limits the composition of the Shielding to a choice from the following list of materials:

- DPR-MF3 — Daido Steel
- HS13-H — Daido Steel

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

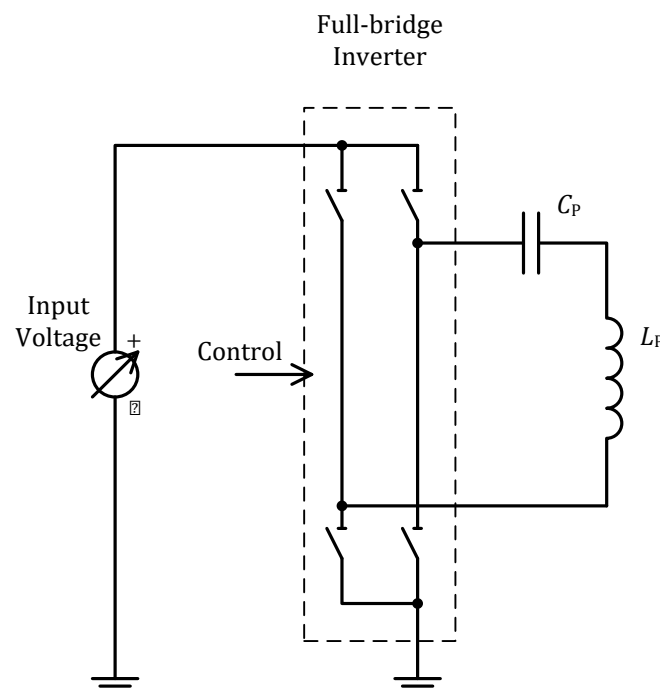
As shown in Figure 6, Power Transmitter design A2 uses a full-bridge inverter to drive the Primary Coil and a series capacitance. At the fixed Operating Frequency of 140 kHz, the assembly of Primary Coil and Shielding has a self inductance $L_P = 24^{\pm 1} \mu\text{H}$. The value of the series capacitance is $C_P = 200^{\pm 5\%} \text{ nF}$.

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	mA ⁻¹
Integral gain	K_i	0	mA ⁻¹ ms ⁻¹
Derivative gain	K_d	0	mA ⁻¹ ms
Integral term limit	M_I	N.A.	N.A.
PID output limit	M_{PID}	1,500	N.A.
Scaling factor	S_v	–0.5	mV

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

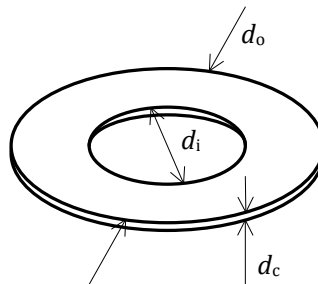


Table 3. Primary Coil parameters of Power Transmitter design A3

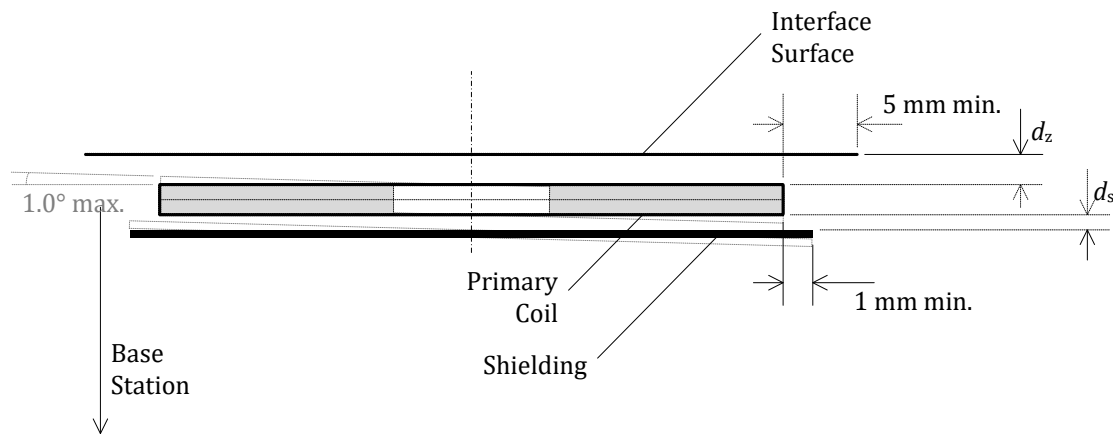
Parameter	Symbol	Value
Outer diameter	d_o	$33^{\pm 1}$ mm
Inner diameter	d_i	$10^{\pm 0.2}$ mm
Thickness	d_c	$1.8^{\pm 0.4}$ mm
Number of turns per layer	N	25
Number of layers	–	1

2.2.3.1.2 Shielding

As shown in Figure 8, soft-magnetic material protects the Base Station from the magnetic field that is generated in the Primary Coil. The Shielding extends to at least 1 mm beyond the outer diameter of the Primary Coil, has a thickness of at least 0.60 mm and is placed below the Primary Coil at a distance of at most $d_s = 0.4$ mm. This version of *Part 4: Reference Designs* limits the composition of the Shielding to a choice from the following list of materials:

- HS13-H — Daido Steel
- KNZWA20B356 — Panasonic

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

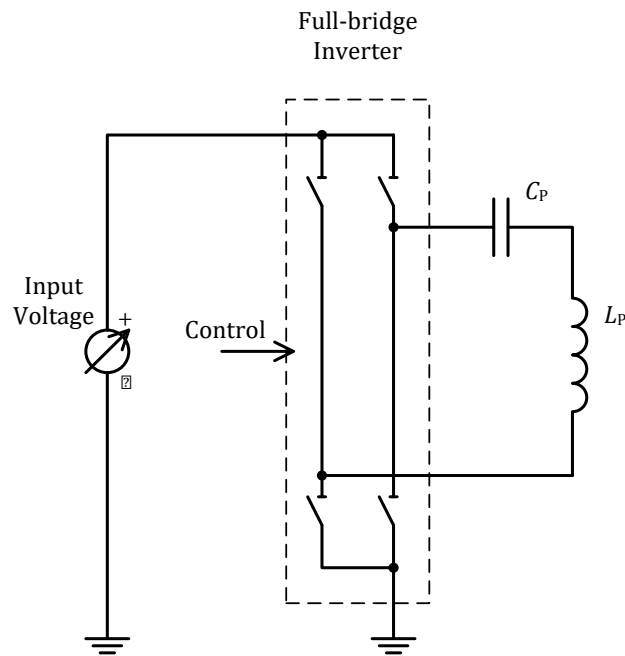
As shown in Figure 9, Power Transmitter design A3 uses a full-bridge inverter to drive the Primary Coil and a series capacitance. At an Operating Frequency range between 105 kHz and 140 kHz, the assembly of Primary Coil and Shielding has a self inductance $L_p = 16.5^{\pm 10\%}$ μH . The value of the 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 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.

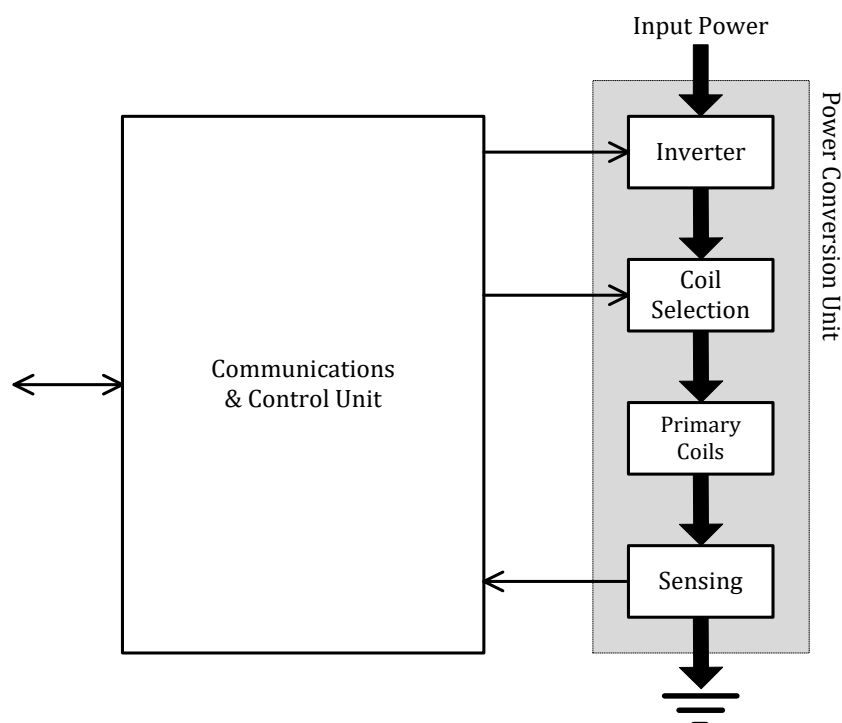
Table 4. PID parameters for voltage control

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

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

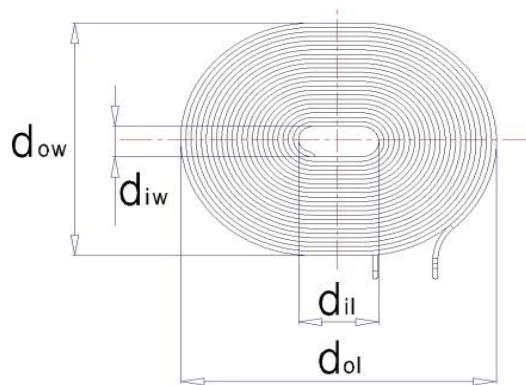
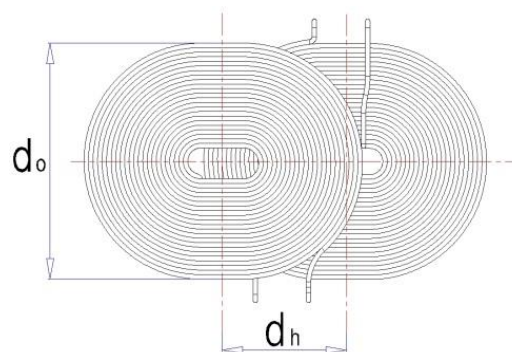


Table 5. Primary Coil parameters of Power Transmitter design A4

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 $d_h = 41^{\pm 0.5}$ mm between their centers. See Figure 12.

Figure 12. Dual Primary Coils (top view)

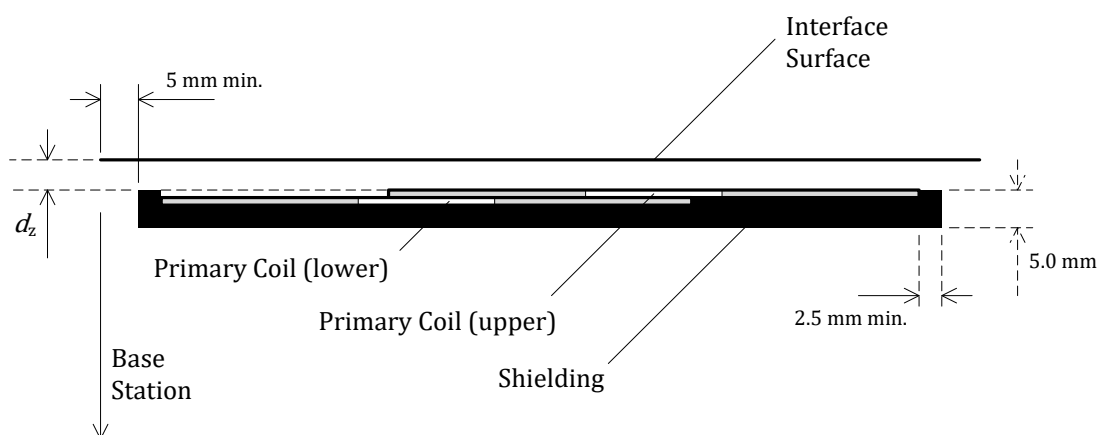


2.2.4.1.2 Shielding

As shown in Figure 13, soft-magnetic material protects the Base Station from the magnetic field that is generated in the Primary Coils. 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, and has a thickness of at least 5 mm. This version of *Part 4: Reference Designs* limits the composition of the Shielding to a choice from the following list of materials:

- Mn-Zn-Ferrite Dust Core — any supplier

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 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.

2.2.4.1.4 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.

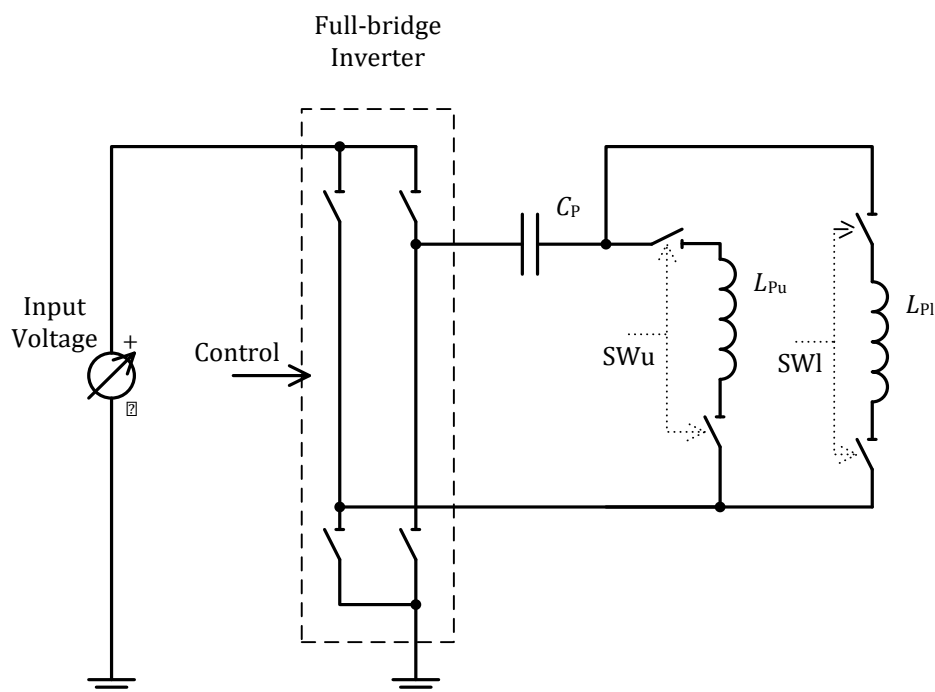
Within the Operating Frequency range of 110...180 kHz, each Primary Coil in the assembly of Primary Coils and Shielding has a self inductance $L_p = 24^{\pm 0.5}$ μ H. The value of the series capacitance is $C_p = 100^{\pm 5\%}$ nF. The input voltage to the full-bridge inverter is 5...11 V.

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

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

When a type A4 Power Transmitter first applies a Power Signal (Digital Ping; see *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 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	$\text{mA}^{-1}\text{ms}^{-1}$
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 7. PID parameters for voltage control

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

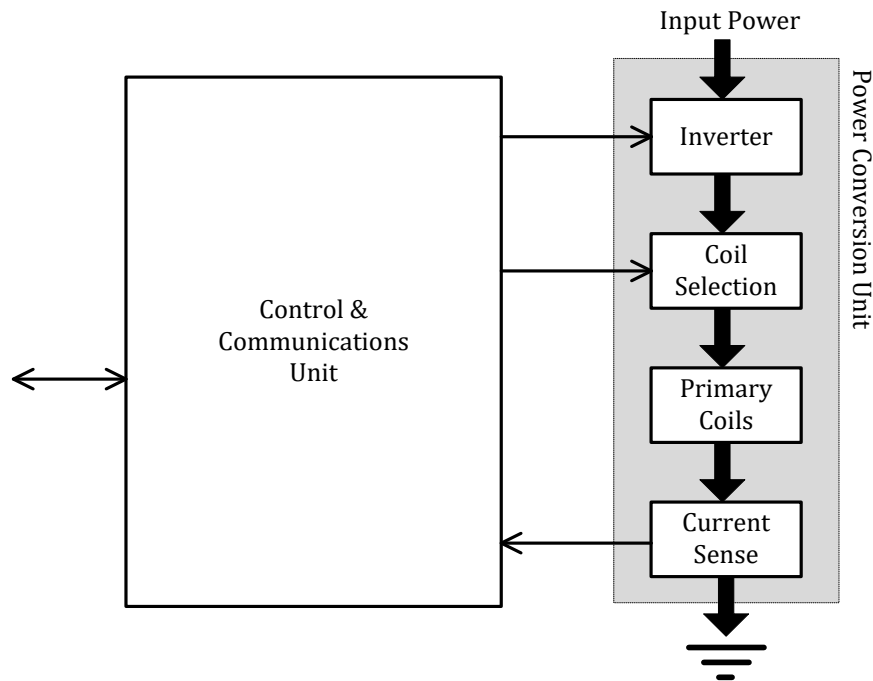
2.2.5 Power Transmitter design A5

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

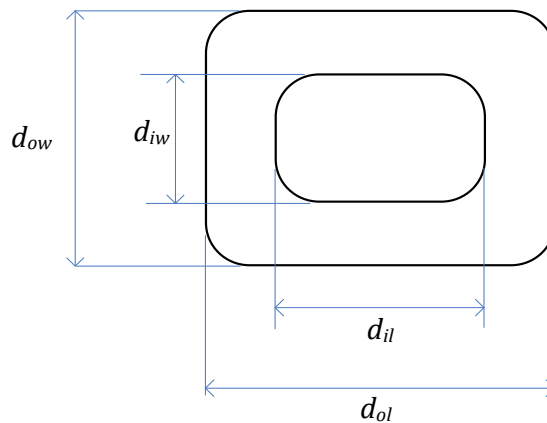
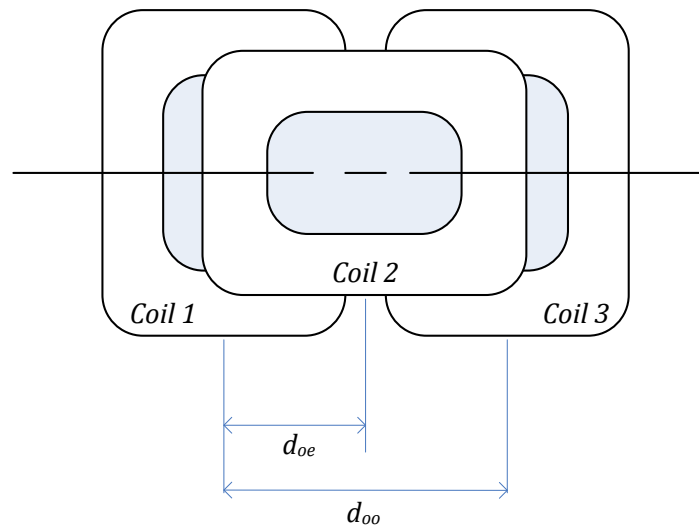


Table 8. Primary Coil parameters of Power Transmitter design A6

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

Power Transmitter design A6 contains at least one Primary Coil. Odd numbered coils are placed alongside each other with a displacement of $d_{oo} = 49.2^{+4}$ mm between their centers. Even numbered coils are placed orthogonal to the odd numbered coils with a displacement of $d_{oe} = 24.6^{+2}$ mm between their centers. See Figure 17.

Figure 17. Primary Coils of Power Transmitter design A6

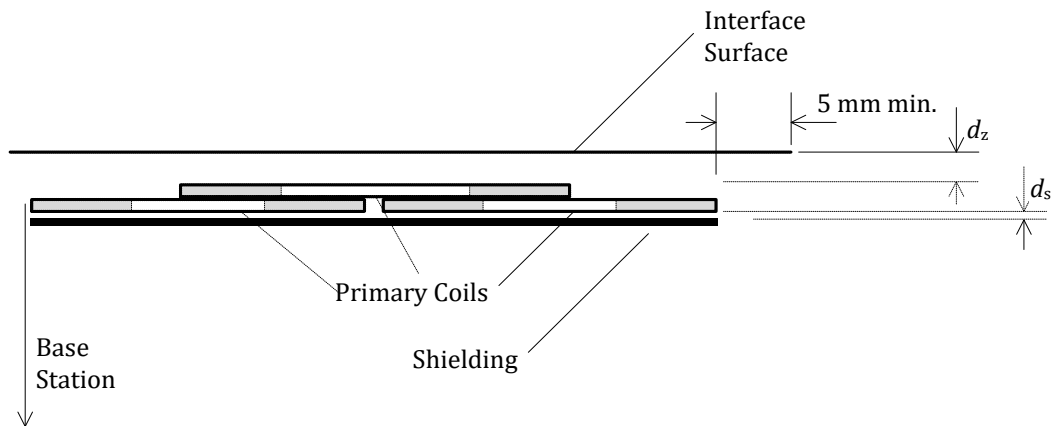


2.2.6.1.2 Shielding

As shown in Figure 18, soft-magnetic material protects the Base Station from the magnetic field that is generated in the Primary Coil. The Shielding extends to at least the outer dimensions of the Primary Coils, has a thickness of at least 0.5 mm, and is placed below the Primary Coil at a distance of at most $d_s = 1.0$ mm. This version of *Part 4: Reference Designs* limits the composition of the Shielding to a choice from the following list of materials:

- Material 44 — Fair Rite Corporation.
- Material 28 — Steward, Inc.
- CMG22G — Ceramic Magnetics, Inc.
- Kolektor 22G — Kolektor.
- LeaderTech SB28B2100-1 — LeaderTech Inc.
- TopFlux “A” — TopFlux.
- TopFlux “B” — TopFlux.
- ACME K081 — Acme Electronics.
- L7H — TDK Corporation.
- PE22 — TDK Corporation.
- FK2 — TDK Corporation.
- 68 — EMICORE Corp.
- M79 — EMICORE Corp.

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 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 the case of a single Primary Coil, the distance from the Primary Coil to the Interface Surface of the Base Station is $d_z = 3^{+0.5}_{-0.25}$ 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^{+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 $L_p = 11.5^{\pm 10\%} \mu\text{H}$ for coils closest to the Interface Surface and inductance $L_p = 12.5^{\pm 10\%} \mu\text{H}$ for coils furthest from the Interface Surface. The value of the series capacitance is $C_p = 0.147^{\pm 5\%} \mu\text{F}$ for coils closest to the Interface Surface and $C_p = 0.136^{\pm 5\%} \mu\text{F}$ for coils furthest from the Interface Surface. The input voltage to the half-bridge inverter is $12^{\pm 5\%} \text{ V}$.

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

Power Transmitter design A6 uses the Operating Frequency and duty cycle of the Power Signal in order to control the amount of power that is transferred. For this purpose, the Operating Frequency range of the half-bridge inverter is $f_{op} = 115 \dots 205 \text{ kHz}$ 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

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

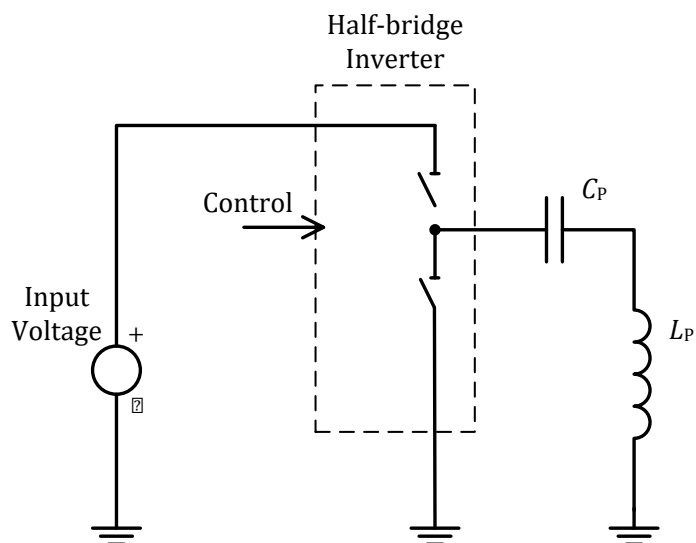


Table 9. PID parameters for Operating Frequency control

Parameter	Symbol	Value	Unit
Proportional gain	K_p	10	mA^{-1}
Integral gain	K_i	0.05	$\text{mA}^{-1}\text{ms}^{-1}$
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.

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	$\text{mA}^{-1}\text{ms}^{-1}$
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	–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

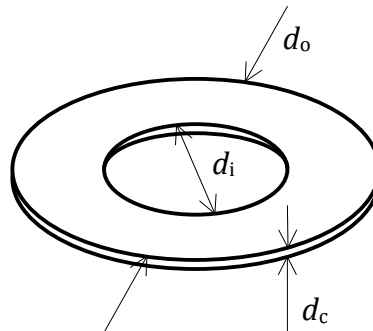


Table 12. Primary Coil parameters of Power Transmitter design A7

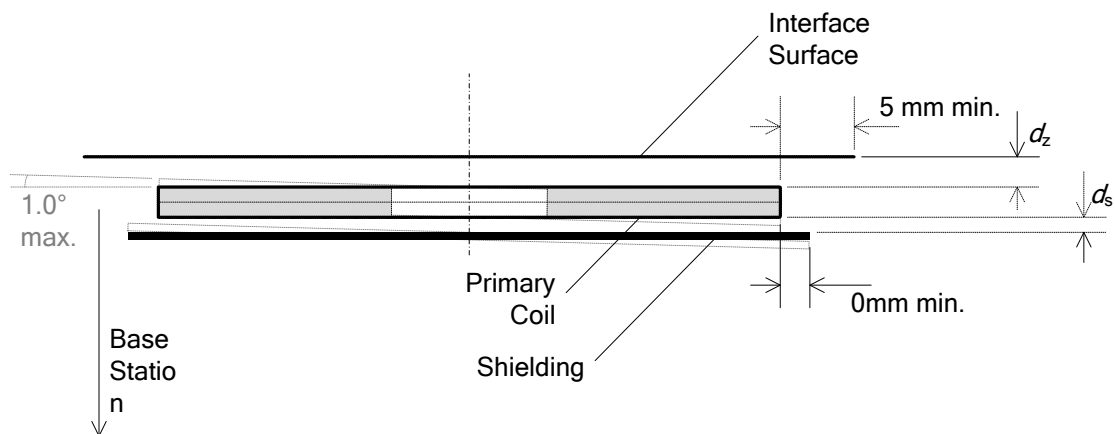
Parameter	Symbol	Value
Outer diameter	d_o	$39^{\pm 2}$ mm
Inner diameter	d_i	$12^{\pm 0.2}$ mm
Thickness	d_c	$1.9^{\pm 0.2}$ mm
Number of turns per layer	N	20
Number of layers	–	1

2.2.7.1.2 Shielding

As shown in Figure 21, soft-magnetic material protects the Base Station from the magnetic field that is generated in the Primary Coil. The Shielding extends to at least the edges of the Primary Coil, has a thickness of at least 0.60 mm and is placed below the Primary Coil at a distance of at most $d_s = 0.5\text{mm}$. This version of *Part 4: Reference Designs* limits the composition of the Shielding to a choice from the following list of materials:

- KNZWAB – Panasonic
- KNZWAC – Panasonic
- FK2 – TDK Corporation
- FK5 – TDK Corporation
- PF600F – FDK Corporation

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 $d_z = 3.0^{+0.5}_{-0.5}\text{ mm}$, 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

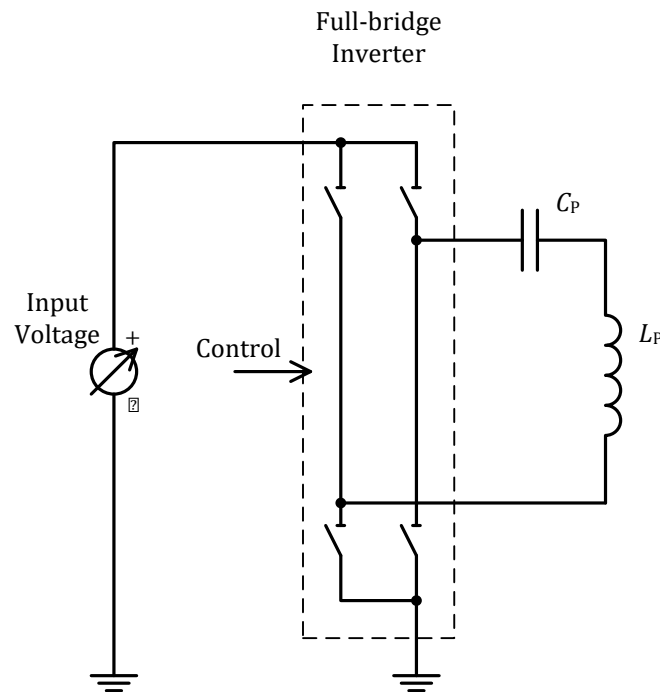
As shown in Figure 22, Power Transmitter design A7 uses a full-bridge inverter to drive the Primary Coil and a series capacitance. At an Operating Frequency range between 105 kHz and 140 kHz, the assembly of Primary Coil and Shielding has a self inductance $L_p = 13.6^{\pm 10\%}$ μH . The value of the 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 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.

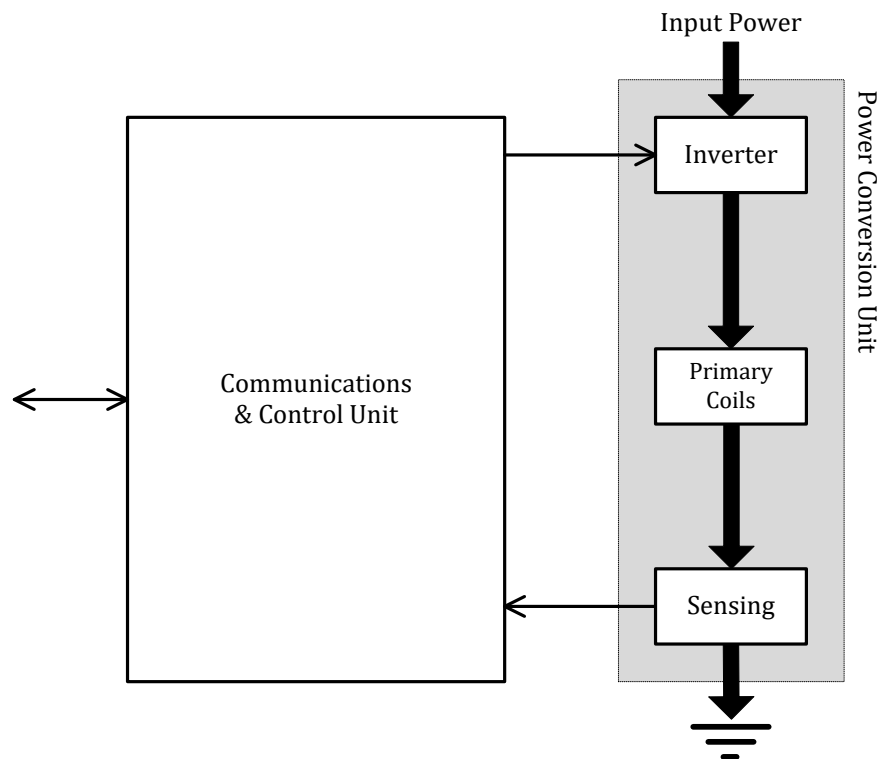
Table 13. PID parameters for voltage control

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

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.