WIRELESS POWER
CONSORTIUM

Qi Specification

Power Receiver Design Examples

Version 1.3

January 2021

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RELEASE HISTORY

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

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1 General

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

1.1 Structure of the Qi Specification

General documents

- Introduction
- Glossary, Acronyms, and Symbols

System description documents

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

Reference design documents

- Power Transmitter Reference Designs
- Power Receiver Design Examples

Compliance testing documents

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

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

1.2 Scope

The *Qi Specification, Power Receiver Design Examples* (this document) includes several examples of Power Receiver designs using different power levels. The designs focus on basic mechanical and electrical considerations in each design without requirements or guidelines.

1.3 Compliance

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

Table 1: Verbal forms for expressions of provisions

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

1.4 References

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

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

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

1.5 Conventions

1.5.1 Notation of numbers

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

1.5.2 Tolerances

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

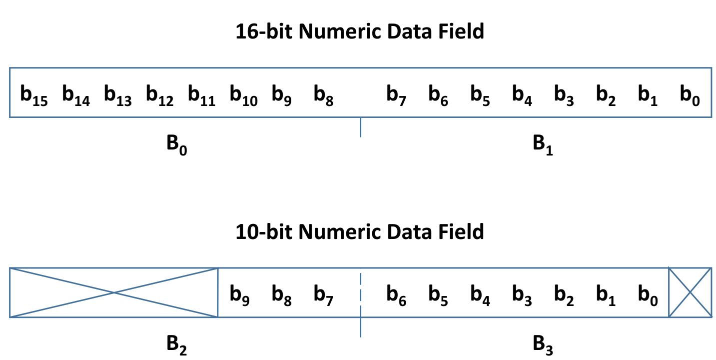
1.5.3 Fields in a data packet

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

Table 2: Example of fields in a data packet

<table>
<tr><th></th><th>b_7</th><th>b_6</th><th>b_5</th><th>b_4</th><th>b_3</th><th>b_2</th><th>b_1</th><th>b_0</th></tr>
<tr><td>B_0</td><td colspan="8" rowspan="2">(msb)
16-bit Numeric Data Field
(lsb)</td></tr>
<tr><td>B_1</td></tr>
<tr><td>B_2</td><td colspan="5">Other Field</td><td colspan="3">(msb)</td></tr>
<tr><td>B_3</td><td colspan="7">10-bit Numeric Data Field (lsb)</td><td>Field</td></tr>
</table>

Figure 1. Examples of fields in a data packet



1.5.4 Notation of text strings

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

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

1.5.5 Short-hand notation for data packets

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

<MNEMONIC>/<modifier>

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

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

1.6 Power Profiles

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

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

Table 3: Capabilities included in a Power Profile

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

2 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.

2.1 Mechanical details

This section provides the mechanical details of Power Receiver example 1.

2.1.1 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 2, the Secondary Coil has a rectangular shape and consists of a single layer. Table 4 lists the dimensions of the Secondary Coil.

Figure 2. Secondary Coil of Power Receiver example 1

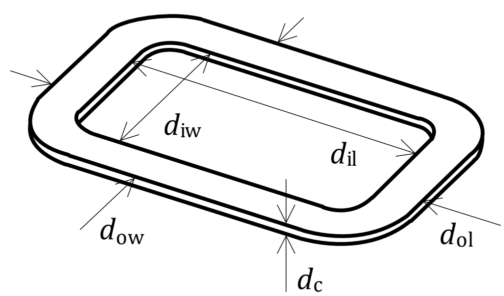


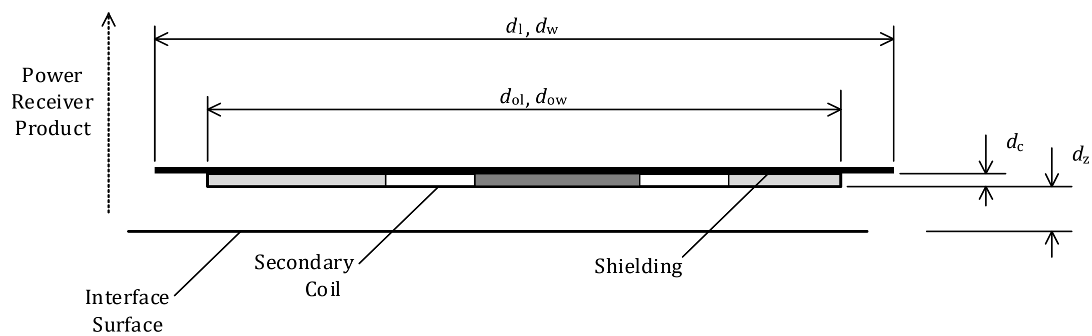
Table 4: Secondary Coil parameters of Power Receiver example 1

Parameter	Symbol	Value	Tolerance	Unit
Outer length	d_{ol}	44.25	±0.25	mm
Inner length	d_{il}	28.75	±0.25	mm
Outer width	d_{ow}	30.25	±0.25	mm
Inner width	d_{iw}	14.75	±0.25	mm
Thickness	d_c	0.6	±0.1	N/A
Number of turns per layer	N	14	±0.2	N/A
Number of layers	–	1	N/A	N/A

2.1.2 Shielding

As shown in Figure 3, 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 $d_l \times d_w = (52 \pm 1) \times (35 \pm 1)\ \text{mm}^2$, 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 3. Secondary Coil and Shielding assembly of Power Receiver example 1



2.1.3 Interface Surface

The distance from the Secondary Coil to the Interface Surface of the Power Receiver Product is d_z = 2.5 mm, uniform across the bottom face of the Secondary Coil.

2.2 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 ± 1) μH and L'_s = (20 ± 1) μH. The capacitance values in the dual resonant circuit are C_s = (127 ± 1%) nF and C_d = (1.6 ± 5%) nF.

As shown in Figure 4, 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 ± 5%) nF in series with two switches. The resistance value R = (10 ± 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 5. The maximum output power to the battery is controlled to a 5 W level.

Figure 4. Electrical details of Power Receiver example 1

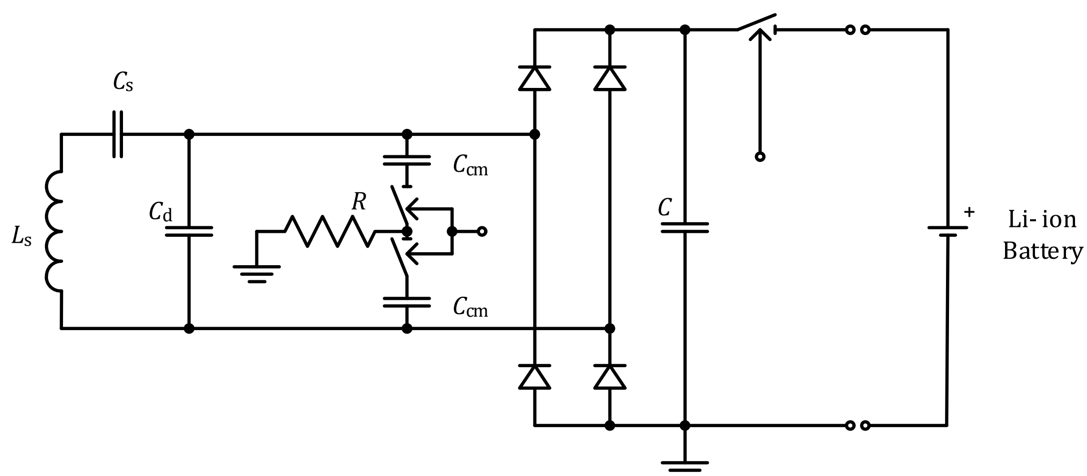
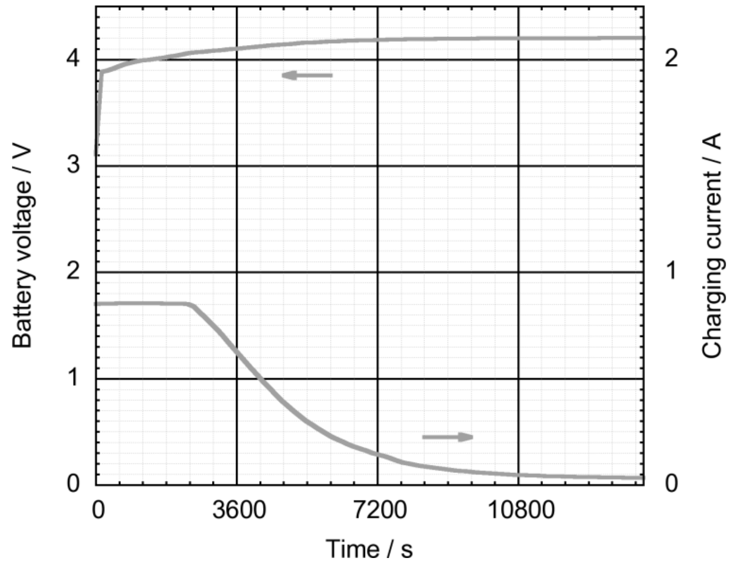


Figure 5. Li-ion battery charging profile



3 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.

3.1 Mechanical details

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

3.1.1 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 6, the Secondary Coil has a circular shape and consists of multiple layers. All layers are stacked with the same polarity. Table 5 lists the dimensions of the Secondary Coil.

Figure 6. Secondary Coil of Power Receiver example 2

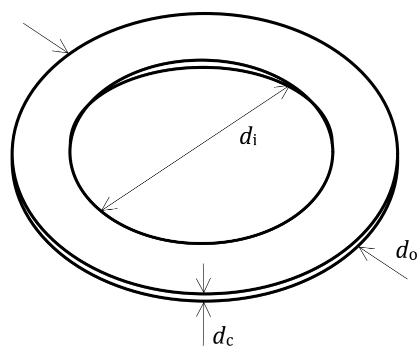


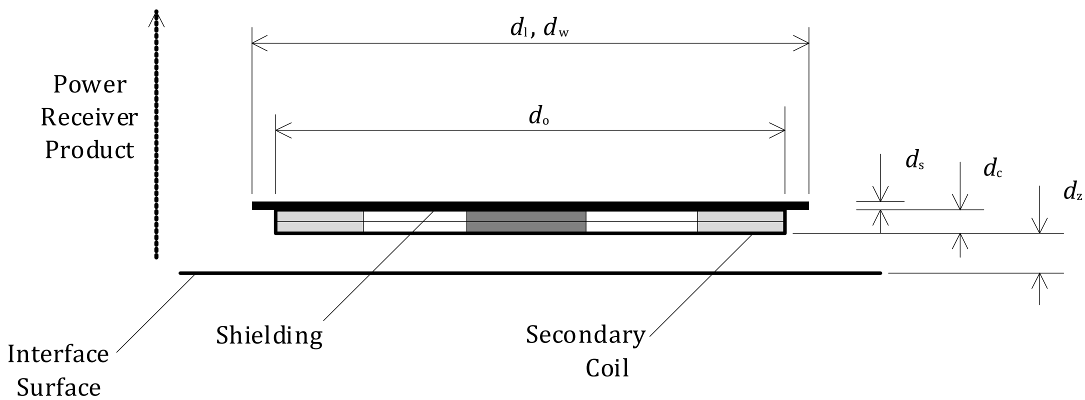
Table 5: Parameters of the Secondary Coil of Power Receiver example 2

Parameter	Symbol	Value	Tolerance	Unit
Outer diameter	d_o	32	±0.25	mm
Inner diameter	d_i	21.7	±0.6	mm
Thickness	d_c	0.9	±0.1	mm
Number of turns per layer	N	9	±0.2	N/A
Number of layers	–	2	N/A	N/A

3.1.2 Shielding

As shown in Figure 7, 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 $d_l \times d_w = (35 \pm 1) \times (35 \pm 1)\ \mathrm{mm}^2$, and is centered directly on the top face of the Secondary Coil.

Figure 7. Secondary Coil and Shielding assembly of Power Receiver example 2



3.1.3 Interface Surface

The distance from the Secondary Coil to the Interface Surface of the Power Receiver Product is d_z = 2 mm, uniform across the bottom face of the Secondary Coil.

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 = (23.8 ± 1) μH and L'_s = (30.8 ± 1) μH. The capacitance values in the dual resonant circuit are C_s = (82 ± 5%) nF and C_d = (1 ± 5%) nF.

As shown in Figure 8, the rectification circuit consists of four diodes in a full bridge configuration and a low-pass filtering capacitance C = (20 ± 20%) μF.

The communications modulator consists of a R_{cm} = (33 ± 5%) Ω resistance in series with a switch.

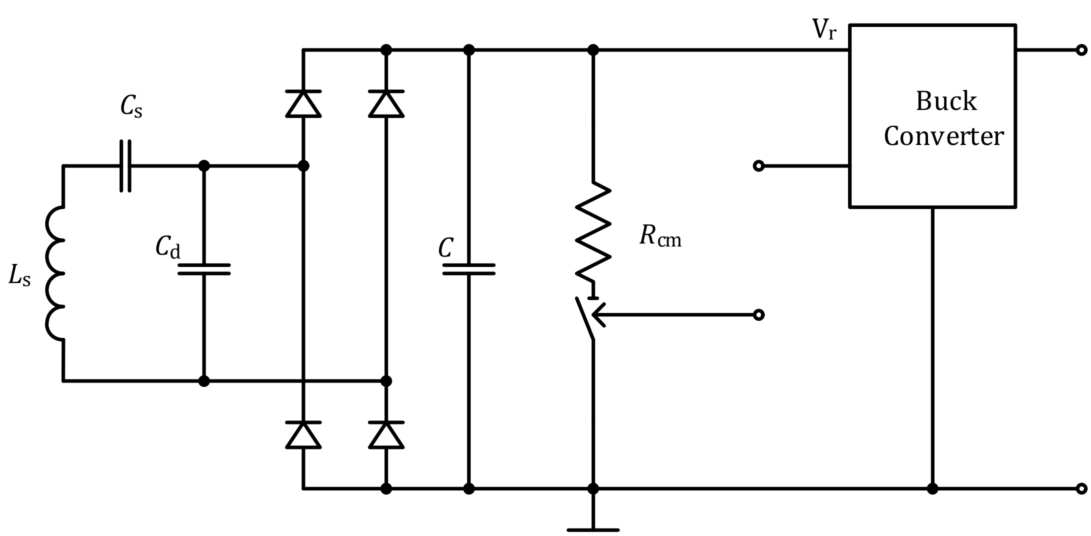
The buck converter comprises the post-regulation stage of Power Receiver example 2. The Control and Communications Unit of the Power Receiver can disable the buck converter. This provides the output disconnect functionality. In addition, the Control and Communications Unit controls the input voltage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

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

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

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

Figure 8. Electrical details of Power Receiver example 2



4 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.

4.1 Mechanical details

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

4.1.1 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 9, the Secondary Coil has a circular shape and consists of a single layer. Table 6 lists the dimensions and other parameters of the Secondary Coil.

Figure 9. Secondary Coil of Power Receiver example 3

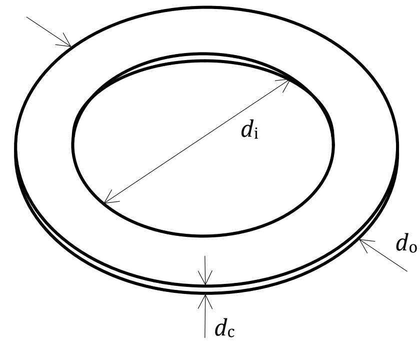


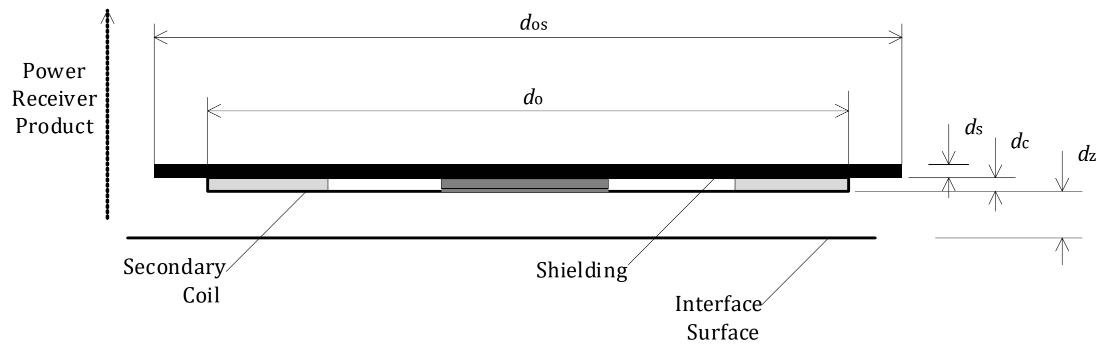
Table 6: Secondary Coil parameters of Power Receiver example 3

Parameter	Symbol	Value	Tolerance	Unit
Outer diameter	d_o	47	±2	mm
Inner diameter	d_i	24.25	±0.25	mm
Thickness	d_c	0.9	±0.1	mm
Number of turns per layer	N	12	±0.2	N/A
Number of layers	–	1	N/A	N/A

4.1.2 Shielding

As shown in Figure 10, Power Receiver example 3 employs Shielding. The Shielding should be Ni-Zn or Mn-Zn ferrite and should be d_s = (1 ± 0.25) mm thick. The Shielding has a size of d_{os} = (50 ± 0.25) mm, and is centered directly on the top face of the Secondary Coil.

Figure 10. Secondary Coil and Shielding assembly of Power Receiver example 3



4.1.3 Interface Surface

The distance from the Secondary Coil to the Interface Surface of the Power Receiver Product is d_z = 2.5 mm, uniform across the bottom face of the Secondary Coil.

4.2 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 ± 1) µH and L'_s = (15.7 ± 1) µH. The capacitance values in the dual resonant circuit are C_s = (160 ± 5%) nF and C_d = (2.2 ± 5%) nF.

As shown in Figure 11, the rectification circuit consists of four diodes in a full-bridge configuration with a low-pass filtering capacitance of C = (33 ± 20%) µF.

The communications modulator consists of two capacitors in series with two switches, each with a capacitance of C_{cm} = (22 ± 10%) nF.

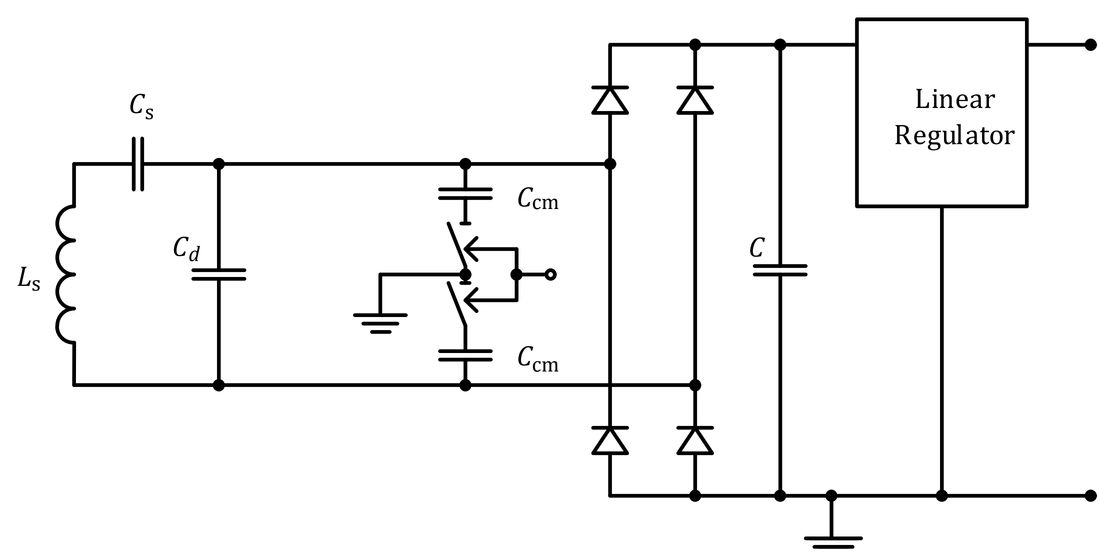
The linear regulator comprises the post-regulation stage of Power Receiver example 3. The Control and Communications Unit of the Power Receiver can disable the regulator to provide output disconnect functionality. In addition, the Control and Communications Unit controls the input voltage to the regulator,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

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

$$I_{\mathrm{reg}} = \frac{P}{5\ \mathrm{V}}$$

where P is the output power of the regulator. In this example, the output power is up to 8 W.

Figure 11. Electrical details of Power Receiver example 3



5 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.

5.1 Mechanical details

This section provides the mechanical details of Power Receiver example 4.

5.1.1 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 12, the Secondary Coil has a circular shape and consists of multiple layers. All layers are stacked with the same polarity. Table 7 lists the dimensions and other parameters of the Secondary Coil.

Figure 12. Secondary Coil of Power Receiver example 4

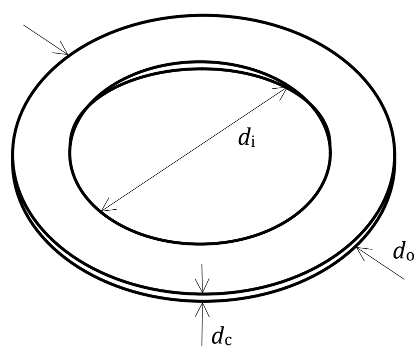


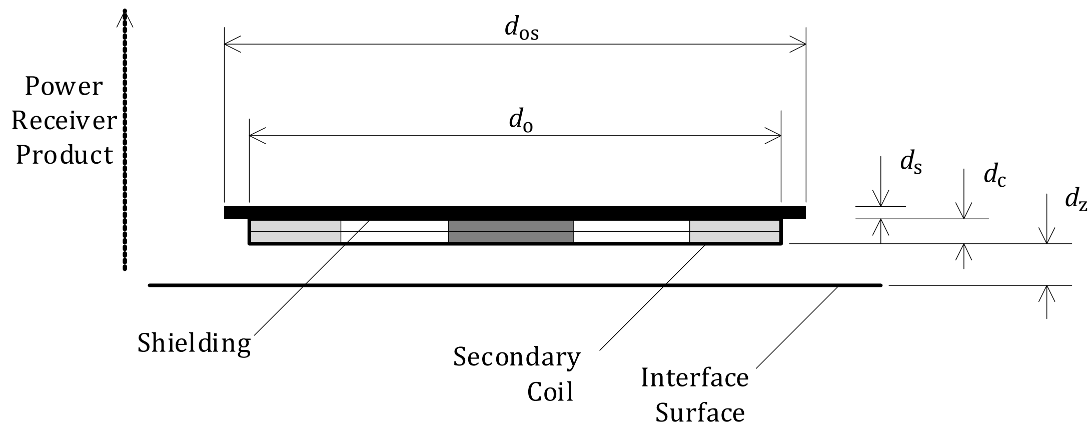
Table 7: Secondary Coil parameters of Power Receiver example 4

Parameter	Symbol	Value	Tolerance	Unit
Outer diameter	d_o	47	±2	mm
Inner diameter	d_i	28	±0.25	mm
Thickness	d_c	1.8	±0.1	mm
Number of turns per layer	N	10	±0.2	N/A
Number of layers	–	2	N/A	N/A

5.1.2 Shielding

As shown in Figure 13, Power Receiver example 4 employs Shielding. The Shielding should be Ni-Zn or Mn-Zn ferrite and should be d_s = (1 ± 0.25) mm thick. The Shielding has a size of d_{os} = (50 ± 0.25) mm, and is centered directly on the top face of the Secondary Coil.

Figure 13. Secondary Coil and Shielding assembly of Power Receiver example 4



5.1.3 Interface Surface

The distance from the Secondary Coil to the Interface Surface of the Power Receiver Product is d_z = 2.5 mm, uniform across the bottom face of the Secondary Coil.

5.2 Electrical details

At the secondary resonance frequency f_s = 100 kHz, the assembly of Secondary Coil and Shielding has inductance values of L_s = (33.6 ± 1) μH and L'_s = (44.8 ± 1) μH. The capacitance values in the dual resonant circuit are C_s = (56 ± 5%) nF and C_d = (0.8 ± 5%) nF.

As shown in Figure 14, the rectification circuit consists of four diodes in a full-bridge configuration with a low-pass filtering capacitance of C = (33 ± 20%) μF.

The communications modulator consists of two resistors in series with two switches, each with a resistance of R_{cm} = (30 ± 5%) Ω.

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_r = 12 V.

The buck converter has a constant output voltage of 5 V. The output current is

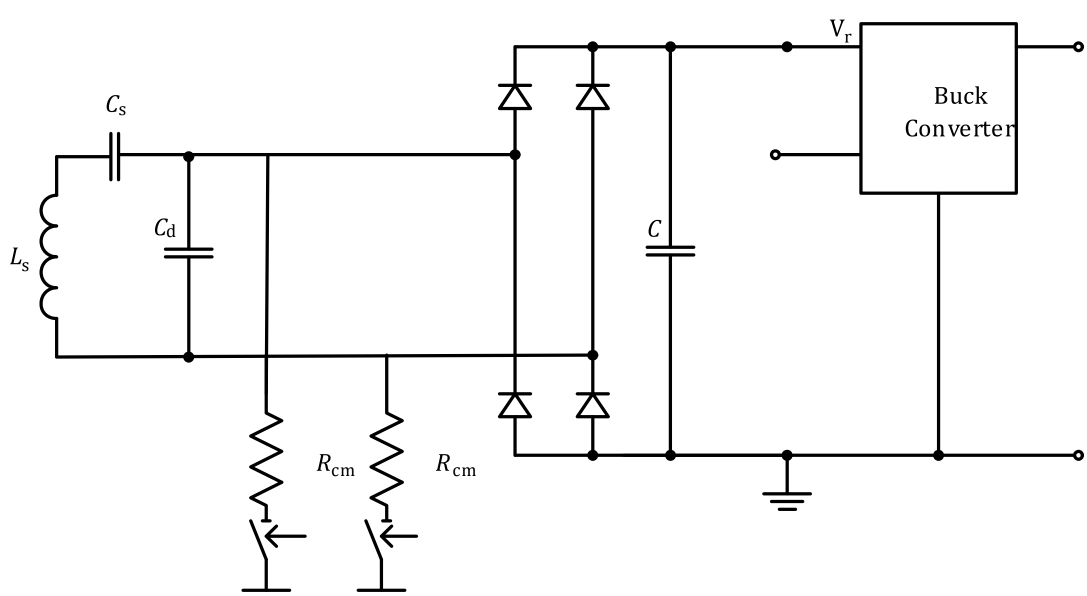
$$I_{\text{out}} = \frac{P}{5\ \text{V}}$$

and the input current is

$$I_{\text{buck}} = \frac{P}{\eta(P) \cdot 12\ \text{V}}$$

where P is the output power of the buck converter, and $\eta(P)$ is the power-dependent efficiency of the buck converter. For this example, P may be as large as 15 W.

Figure 14. Electrical details of Power Receiver example 4



6 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.

6.1 Mechanical details

This section provides the mechanical details of Power Receiver example 5.

6.1.1 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 15, the Secondary Coil has a circular shape and consists of a single layer. Table 8 lists the dimensions and other parameters of the Secondary Coil.

Figure 15. Secondary Coil of Power Receiver example 5

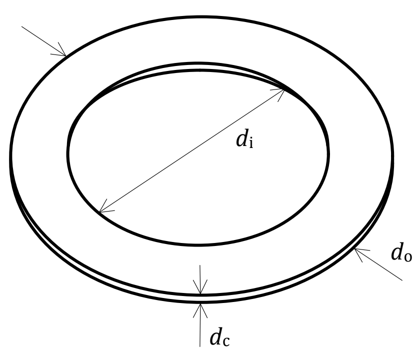


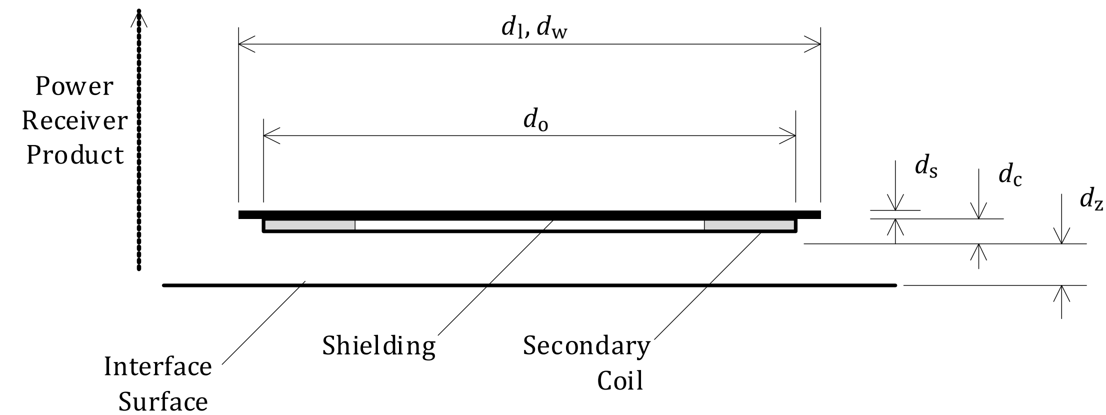
Table 8: Secondary Coil parameters of Power Receiver example 5

Parameter	Symbol	Value	Tolerance	Unit
Outer diameter	d_o	40	±0.25	mm
Inner diameter	d_i	22	±0.25	mm
Thickness	d_c	0.29	±0.1	mm
Number of turns per layer	N	15	±0.2	N/A
Number of layers	–	1	N/A	N/A

6.1.2 Shielding

As shown in Figure 16, Power Receiver example 5 employs Shielding. The Shielding should be Ni-Zn or Mn-Zn ferrite and should be (0.6 ± 0.25) mm thick. The Shielding has a size of $d_l \times d_w$ = (50 ± 0.25) × (50 ± 0.25) mm^2 and is centered directly on the top face of the Secondary Coil.

Figure 16. Secondary Coil and Shielding assembly of Power Receiver example 5



6.1.3 Interface Surface

The distance from the Secondary Coil to the Interface Surface of the Power Receiver Product is d_z = 1 mm, uniform across the bottom face of the Secondary Coil.

6.2 Electrical details

At the secondary resonance frequency f_s = 100 kHz, the Secondary Coil and Shielding assembly has inductance values of L_s = (15.4 ± 1) μH and L'_s = (23 ± 1) μH. The capacitance values in the dual resonant circuit are C_s = (110 ± 5%) nF and C_d = (1.6 ± 5%) nF.

As shown in Figure 17, the rectification circuit consists of four diodes in a full-bridge configuration with a low-pass filtering capacitance of C = (10 ± 20%) μF.

The communications modulator consists of two capacitors in series with two switches, each with a capacitance of C_m = (22 ± 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_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

$$I_{\text{buck}} = \frac{P}{\eta(P) \cdot 12\ \text{V}}$$

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

Figure 17. Electrical details of Power Receiver example 5