ENGLISH TRANSLATION

WIRELESS POWER TRANSMISSION SYSTEMS

ARIB STANDARD

ARIB STD-T113 Version 1. 1

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Association of Radio Industries and Businesses

Foreword

The Association of Radio Industries and Businesses (ARIB) investigates and summarizes the basic technical requirements for various radio systems in the form of "ARIB Standards". These standards are developed with the participation of and through discussions amongst radio equipment manufacturers, telecommunication operators, broadcasting equipment manufacturers, broadcasters and users.

ARIB Standards include "government technical regulations" (mandatory standard) that are set for the purpose of encouraging effective use of frequency and preventing interference with other spectrum users, and "private technical standards" (voluntary standards) that are defined in order to ensure compatibility and adequate quality of radio equipment and broadcasting equipment as well as to offer greater convenience to radio equipment manufacturers, telecommunication operators, broadcasting equipment manufacturers, broadcasters and users.

This ARIB Standard is developed for Wireless Power Transmission Systems. In order to ensure fairness and transparency in the defining stage, the standard was set by consensus at the ARIB Standard Assembly with the participation of both domestic and foreign interested parties from radio equipment manufacturers, telecommunication operators, broadcasting equipment manufacturers, broadcasters and users.

ARIB sincerely hopes that this ARIB Standard will be widely used by radio equipment manufacturers, telecommunication operators, broadcasting equipment manufacturers, broadcasters and users.

NOTE:

Although this ARIB Standard contains no specific reference to any Essential Industrial Property Rights relating thereto, the holders of such Essential Industrial Property Rights state to the effect that the rights listed in the Attachment 1 and 2, which are the Industrial Property Rights relating to this standard, are held by the parties also listed therein, and that to the users of this standard, in the case of Attachment 1, such holders shall not assert any rights and shall unconditionally grant a license to practice such Industrial Property Rights contained therein, and in the case of Attachment 2, the holders shall grant, under reasonable terms and conditions, a non-exclusive and non-discriminatory license to practice the Industrial Property Rights contained therein. However, this does not apply to anyone who uses this ARIB Standard and also owns and lays claim to any other Essential Industrial Property Rights of which is covered in whole or part in the contents of the provisions of this ARIB Standard.

Attachment 1 (selection of option 1)

(N/A)

Attachment 2 (selection of option 2)

Patent Holder	Name Of Patent	Registration No. / Application No.	Remarks
Murata Manufacturing Co., Ltd.	Device for transporting energy by partial influence through a dielectric medium *1	JP04962560	JP
Murata Manufacturing Co., Ltd.	Power transfer system and noncontact charging device *1	JP05035477	JP
Murata Manufacturing Co., Ltd.	Power transmitting apparatus and power transmission system *1	JP05093386	JP
Murata Manufacturing Co., Ltd.	Power transfer system *1	JP05304930	JP
Murata Manufacturing Co., Ltd.	Wireless power transmission system*1	JP05454748	JP
Murata Manufacturing Co., Ltd.	Power transmission device and power transmission control method *1	JP05541422	JP
Murata Manufacturing Co., Ltd.	Wireless power transmission system *1	JP05482967	JP
Murata Manufacturing Co., Ltd.	Power transmission device and transmission control method *1	JP2014-168377	JP
Murata Manufacturing Co., Ltd.	Frequency characteristic measuring method*1	WO2015/072374	—
CANON Inc.	Charging apparatus and charging method *1	JP5188211	JP,US,CN
CANON Inc.	Charging apparatus and control method *1)	JP5597022	JP,US,EP,CN,KR ,WO
QUALCOMM Incorporated	Wireless power transfer for appliances and equipments *1	JP5379221	US8,487,478; US20130300358; JP; CN; EP; IN; KR
QUALCOMM Incorporated	Signaling charging in wireless power environment *1	JP2011-525097	US20090286475; JP; CN; EP; IN; KR; TW
QUALCOMM Incorporated	Transmit power control for a wireless charging system *1	JP5341180	US20090284369; JP; CN; EP; IN; KR; TW

QUALCOMM Incorporated	Optimization of wireless power devices for charging batteries *1	JP5743226	US8,803,474; CN; DE; EP; GB; IN; KR
QUALCOMM Incorporated	Wireless power bridge *1	JP2011-508578	US8,729,734; US20140183969; JP; CN; EP; IN; KR
QUALCOMM Incorporated	Passive receivers for wireless power transmission *1	JP2012-501160	US8,432,070; JP; CN; DE; EP; GB; IN; KR
QUALCOMM Incorporated	Power management for electronic devices *1	JP5539528	US20110115432; JP; BR; CN; EP; IN; KR; TW
QUALCOMM Incorporated	Detection and protection of devices within a wireless power system *1	JP2013-523067	US20110221388; JP; CN; EP; IN; KR
QUALCOMM Incorporated	Low power detection of wireless power devices *1	JP2013-521913	US20120025624; CN; EP; IN; KR
QUALCOMM Incorporated	Apparatus and method for implementing a differential drive amplifier and a coil arrangement *1	JP5393898	US8,772,975; US20120228959; CN; DE; EP; ES; FR; GB; IN; IT; KR; NL; TW
QUALCOMM Incorporated	Wireless charging of devices *1	JP2013-536882	US20120104867; CN; EP; IN; KR
QUALCOMM Incorporated	System and method for low loss wireless power transmission *1	JP2014-547440	US20130154383; CN; EP; IN; KR
QUALCOMM Incorporated	Systems and methods for limiting voltage in wireless power receivers *1	JP2014-537178	US20130099585; CN; EP; IN; KR
QUALCOMM Incorporated	System and method for wireless power control communication using bluetooth low energy *1	JP2015-504621	US20130257365; BR; CN; EP; IN; KR
QUALCOMM Incorporated	System and method for wireless power control communication using bluetooth low energy *1	JP2015-504622	US20130257364; BR; CN; EP; IN; KR
QUALCOMM Incorporated	Protection device and method for power transmitter *1	US20140071571*	JP; CN; EP; IN; KR
QUALCOMM Incorporated	Resolving communcations in a wireless power system with co-located transmitters *1	WO2014093172*	US20140159651; JP; CN; IN
QUALCOMM Incorporated	System and method for facilitating avoidance of wireless charging cross connection *1	WO2014093160*	US20140159653; EP; IN
QUALCOMM Incorporated	Multi spiral inductor *1	WO2015073209*	US20150130579
The University of Tokyo CELLCROSS Co., Ltd.	COMMUNICATION SYSTEM, INTERFACE DEVICE, AND SIGNAL CARRYING APPARATUS *2	JP4565579	JP

The University of Tokyo CELLCROSS Co., Ltd.	SIGNAL CARRYING SYSTEM *2	JP4538594	JP
CELLCROSS Co., Ltd.	SIGNAL CARRYING APPARATUS, INTERFACE DEVICE, AND COMMUNICATION SYSTEM *2	JP4650906	JP
TEIJIN FIBERS LTD	SHEET STRUCTURE FOR COMMUNICATION *2	JP2010-517654	JP

* The deadline for filing of a Japan counterpart of this patent application has not yet passed. Therefore a Japanese counterpart may still be filed or granted in Japan.

*1 Applied for the content described in ARIB STD-T113 v1.0

*2 Applied for the content amended in ARIB STD-T113 v1.1

(Reference: Not applied in Japan)

Patent Holder	Name Of Patent	Registration No. / Application No.)	Remarks
QUALCOMM Incorporated	Antennas and their coupling characteristics for wireless power transfer via magnetic coupling*1	US8,344,552	US8,710,701
QUALCOMM Incorporated	Tuning and gain control in electro-magnetic power systems *1	US8,629,576	
QUALCOMM Incorporated	Systems and methods for controlling output power of a wireless power transmitter *1	US20120242160	
QUALCOMM Incorporated	Waking up a wireless power transmitter from beacon mode *1	US20120223589	
QUALCOMM Incorporated	Reducing heat dissipation in a wireless power receiver*1	US20120223590	

*1 Applied for the content described in ARIB STD-T113 v1.0

Contents

Part 1

400 kHz-Band

Capacitive Coupling Wireless Power Transmission Systems

for Mobile Devices

Contents

Chapter 1 General Descriptions

1.1 Outline

This ARIB STANDARD (hereinafter referred to as “Standard”) specifies the wireless interface between the power transmitting and power receiving units of a wireless power transmission (WPT) system (hereinafter referred to as “Capacitive Coupling WPT System” or “System”), which transmits electric power wirelessly by means of capacitive coupling (in other words, electric field coupling) using 400 kHz electromagnetic waves for the purpose of electrical power charging or electrical power feeding to mobile devices.

This System is operated at transmission power not exceeding the limitation allowed without permission in the “Other Equipment” category stipulated in “Article 45, Item (3) of the Regulations for Enforcement of the Radio Act” and the “Equipment Utilizing High Frequency Current” stipulated in “Article 100, Paragraph (1), Item (ii) of the Radio Act”.

1.2 Scope of the Standard

The configuration of the Capacitive Coupling WPT System is shown in Figure 1-1.

The WPT System consists of a power transmitting unit (PTU) which transmits electrical power fed from an external device and a power receiving unit (PRU) which receives the transmitted electric power and feeds it to an external device. Electrostatic capacitance is formed between the power transmitting electrodes of the PTU and the power receiving electrodes of the PRU, and the electric power is wirelessly transmitted. In general, the external device connected to the PTU is assumed to be the power supply, and the external device connected to the PRU is assumed to be the load device.

This Standard, which is applied to the constituent elements of the Capacitive Coupling WPT System as shown in Figure 1-1, specifies a wireless interface between the PTU and PRU. The “specified interface point” shown in Figure 1-1 is the location of the wireless interface.

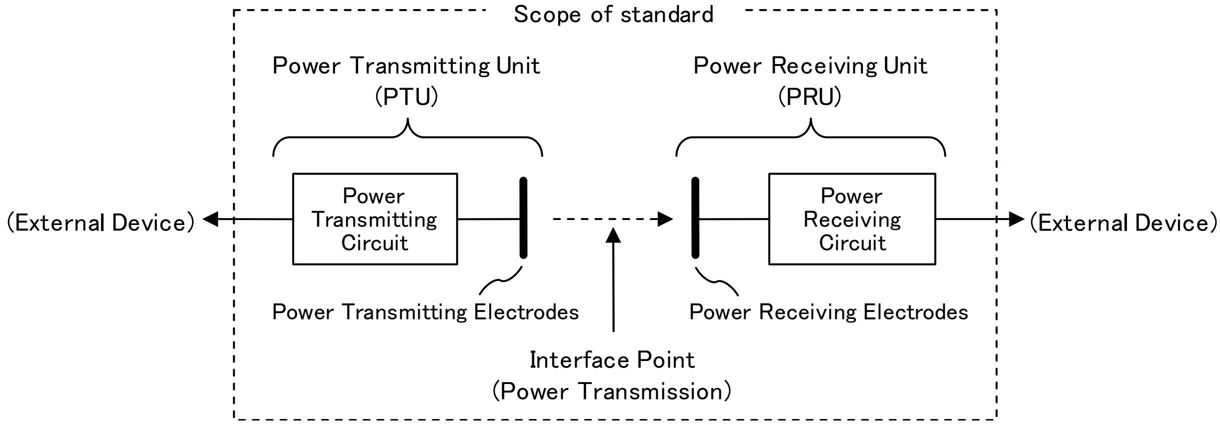

Figure 1-1 Configuration of the Capacitive Coupling WPT System

1.3 Normative References

The terms used in this Standard follow the definitions specified in the Radio Act and other related regulations unless otherwise noted. In addition, “RERA” in Chapter 3 means “Regulations for Enforcement of the Radio Act”.

Furthermore, this Standard refers to the following documents as needed and uses the corresponding reference numbers:

[1] “Technical Requirements on 6 MHz-band Magnetic Induction Coupled Wireless Power Transmission System and 400 kHz-band Capacitive Coupling Wireless Power Transmission System”, Report of the Information Communication Council of the Ministry of Internal Affairs and Communications, January 2015.

[2] CISPR32 Edition1.0, January 2012.

[3] IEC 60950-1 ed2.2, Consol. with am 1 & 2: Information technology equipment - Safety - Part 1: General requirements, May 2013.

[4] Information and Communications Council Report No. 2035, “Protection from the Radio Waves (10 kHz to 10 MHz) on the Human Body”, March 2015

Chapter 2 System Overview

2.1 System Characteristics

The Capacitive Coupling WPT System assumes indoor use primarily at home or the office and realizes the following functions.

・Direct supply of electricity to operate mobile devices

・Charge the battery in mobile devices

The Capacitive Coupling WPT System assumes the distance between the power transmitting and the power receiving electrodes is less than 10mm or in that proximity. It provides the benefits of high power transmission efficiency and low radiated emission.

2.2 System Architecture

The basic configuration of the power transmitting and receiving units of the Capacitive Coupling WPT System is shown in Figure 2-1. As shown in the figure, the power transmitting unit (PTU) and power receiving unit (PRU) conform "1 to 1" configuration. A power supply is connected to the PTU and a receiving load is connected to the PRU.

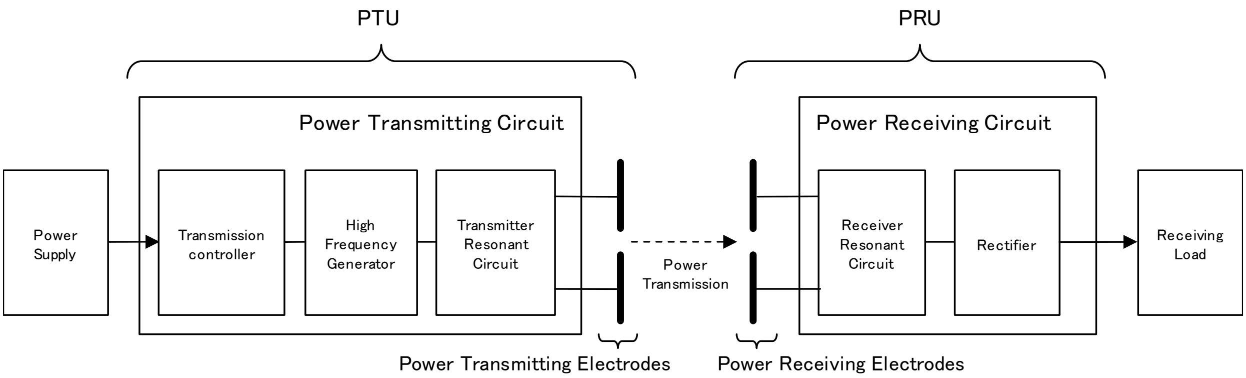

Figure 2-1 Basic configuration of the Capacitive Coupling WPT System

The PTU consists of a power transmitting circuit and power transmitting electrodes. The power transmitting circuit consists of a transmission controller, high frequency generator and transmitter resonant circuit. The DC input power is converted to AC power in the power transmitting circuit, and the AC power is sent to the PRU through the coupling between the power transmitting electrodes and power receiving electrodes. The PRU consists of a power receiving circuit and power receiving electrodes. The power receiving circuit consists of a receiver resonant circuit and a rectifier, and converts the AC power received from the PTU to DC power and supplies it to the receiving load.

Each type of power at the input at the various points is defined as shown in Figure 2-2. The power that is input from the power supply to the power transmitting circuit is defined as the "PTU in power", and the power that is output from the power transmitting circuit to the power transmitting electrodes is defined as the "Transmitting power". The power that is input from the power receiving electrodes to the power receiving circuit is defined as the "Receiving power", and the power that is output from the power receiving circuit to the receiving load is defined as the "PRU out power".

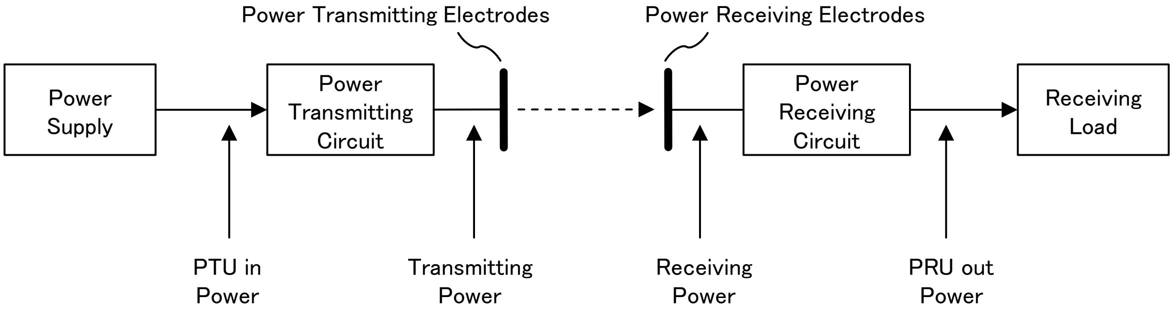

Figure 2-2 Definition of each type of power at the various points

2.3 Requirements of the System

The specific parameters of the Capacitive Coupling WPT System shall meet the criteria specified in this Standard for maintaining interconnectivity of PTU and PRU. The parameters for interconnectivity are listed below.

Coupling coefficient: k
Q factor of the transmitter resonant circuit: Q_T
Q factor of the receiver resonant circuit: Q_R
Resonant frequency of the transmitter resonant circuit: f_T
Resonant frequency of the receiver resonant circuit: f_R
Receiving voltage: V_R

2.3.1 Power transmitting unit (PTU)

The functions and requirements of the PTU are explained below.

The block diagram is shown in Figure 2-1. The high frequency generator generates AC power from the DC power supply. The transmitter resonant circuit increases the amplitude of the AC power and feeds it to the power transmitting electrodes. The transmission controller can detect presence of the PRU and control the start or stop of power transfer to the PRU by monitoring voltage changes of the transmitter resonant circuit.

Q_T and f_T of the transmitter resonant circuit are critical parameters for maintaining interconnectivity and are defined in Figure 2-3. f_T is the peak frequency that maximizes the absolute value of the impedance of the transmitter resonant circuit. Q_T is calculated by equation (1) using the peak frequency (f_T) and the bandwidth (Δf_T) where the drop in the (absolute value of) impedance is 3dB from the peak.

$$Q_T = f_T/\Delta f_T \qquad (1)$$

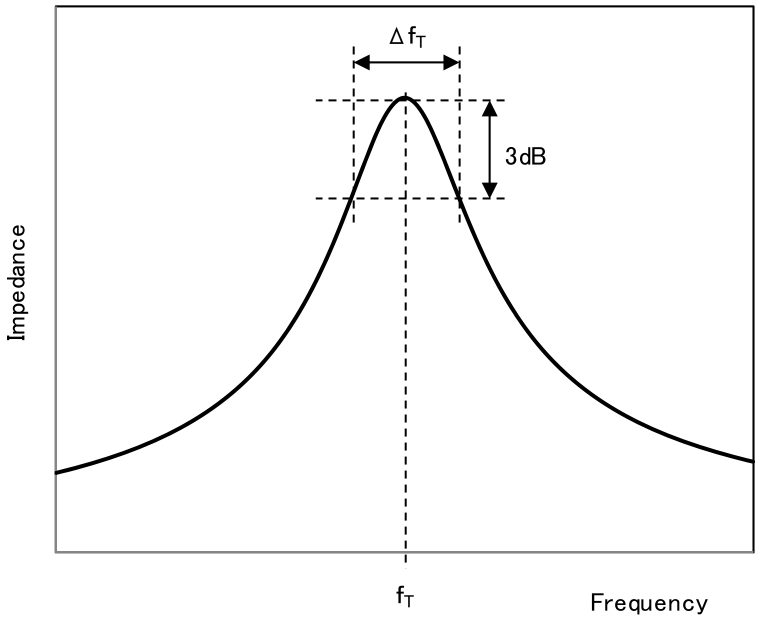

Figure 2-3 Impedance properties of the transmitter resonant circuit

2.3.2 Power receiving unit (PRU)

The functions and requirements of the PRU are explained below.

The receiver resonant circuit decreases the amplitude of the receiving AC voltage (V_R) at the power receiving electrodes, and the rectifier converts the AC voltage to DC voltage (shown in Figure 2-1).

Q_R and f_R of the receiver resonant circuit and the receiving AC voltage (V_R) are critical parameters for maintaining interconnectivity and are defined in Figure 2-4. f_R is the peak frequency that maximizes the absolute value of the impedance of the receiver resonant circuit. Q_R is calculated by equation (2) using the peak frequency (f_R) and the bandwidth (Δf_R) where the drop in the (absolute value of) impedance is 3dB from the peak.

$$Q_R = f_R / \Delta f_R \qquad (2)$$

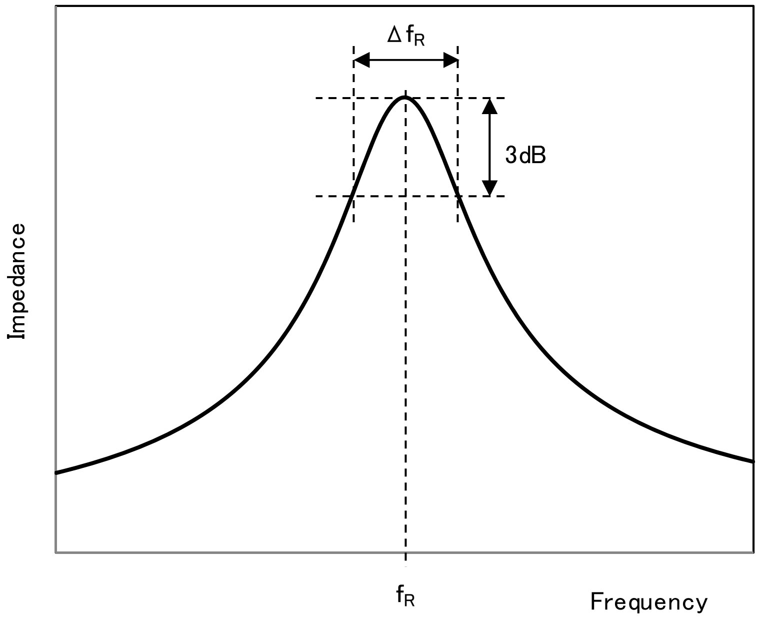

Figure 2-4 Impedance properties of the receiver resonant circuit

The receiving voltage (V_R) shown in Figure 2-5 is the input AC voltage to the receiver resonant circuit, and it is one of the critical parameters for maintaining interconnectivity.

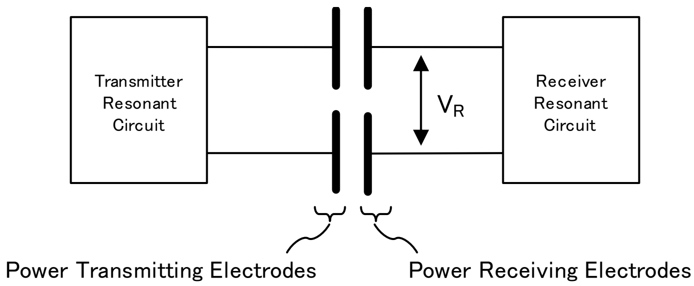

Figure 2-5 Receiving voltage: Origin point of V_R

2.3.3 Coupling coefficient between the PTU and PRU

In this Standard, the coupling coefficient between the power transmitting electrodes and power receiving electrodes is determined by the equivalent electrical circuit of the capacitive coupling part shown in Figure 2-6.

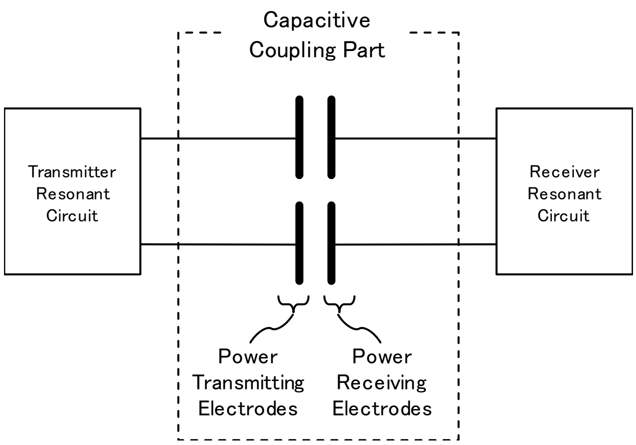

Figure 2-6 Schematic diagram of the capacitive coupling

Capacitive coupling between the power transmitting electrodes and power receiving electrodes is described with a Π type equivalent circuit that consists of C_C, C_1 and C_2. C_C is the equivalent coupling capacitance, and C_1 and C_2 are the equivalent parallel capacitances of the power transmitting electrodes and power receiving electrodes, respectively.

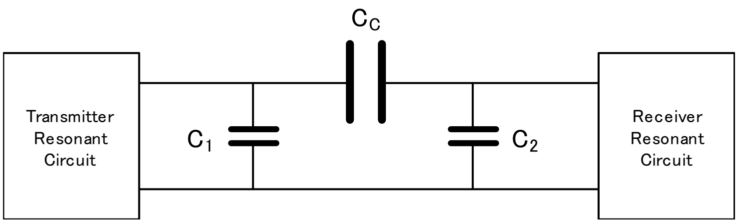

Figure 2-7 Π type equivalent circuit at the capacitive coupling

Using a Π type equivalent circuit, the coupling coefficient (k) is defined by equation (3).

$$k = \frac{C_C}{\sqrt{(C_1 + C_C)(C_2 + C_C)}} \quad , \quad 0 \le k \le 1 \qquad (3)$$

C_C, C_1, C_2, are derived from the following equation.

$$C_C = \sqrt{C_{2S}(C_{1S} - C_{1O})}$$
$$C_1 = C_{1S} - C_C$$
$$C_2 = C_{2S} - C_C$$

C_{1S} : Capacitance at the input of the power transmitting electrodes when the power receiving electrodes are shorted.

C_{1O} : Capacitance at the input of the power transmitting electrodes when the power receiving electrodes are opened.

C_{2S} : Capacitance at the input of the power receiving electrodes when the power transmitting electrodes are shorted.

2.3.4 Control system

In the Capacitive Coupling WPT System, the control functions which control the power transmission are necessary for achieving safe and reliable wireless power transfer. Such functions include a mechanism for starting the power transfer after recognition of the PRU. The control functions also include the recognition of the PRU; one is to recognize the PRU by detecting coupling between the PTU and the PRU and the other is by data-communication between the PTU and the PRU.

The Capacitive Coupling WPT System adopts the former method as the means of detecting coupling between the PTU and the PRU without data-communication. The details of the system control are described in Chapter 4.

Chapter 3 Technical Requirements of the System

3.1 General Requirements

3.1.1 Power transmission method

The power transmission method shall use non-modulated and continuous waves.

3.1.2 Power transmission frequency ranges

The power transmission frequency shall be in one of the following ranges;

- Greater than or equal to 425 kHz, and less than or equal to 471 kHz
- Greater than or equal to 480 kHz, and less than or equal to 489 kHz
- Greater than or equal to 491 kHz, and less than or equal to 494 kHz
- Greater than or equal to 506 kHz, and less than or equal to 517 kHz
- Greater than or equal to 519 kHz, and less than or equal to 524 kHz

3.1.3 Radiated emission limits

Radiated emission limits shall refer to “Section 2.2 Limitation on 400 kHz band capacitive coupling wireless power transmission systems” in [1] for each frequency range as follows.

(1) In-band Emission Limits

In the frequency ranges for power transmission, radiated emission shall not exceed the values shown in Table 3-1.

Table 3-1 Radiated emission limits in the power transmission frequency band

Frequency (f) range	Measurement distance	Limit (quasi-peak)
425 kHz ≤ f ≤ 471 kHz	10m	14.5 - (15.6451 x Log(frequency [MHz]/0.15)) dBμA/m
480 kHz ≤ f ≤ 489 kHz		
491 kHz ≤ f ≤ 494 kHz		
506 kHz ≤ f ≤ 517 kHz		
519 kHz ≤ f ≤ 524 kHz		

(2) Out-of-band Emission Limits

Out-of-band radiated emission shall not exceed the values shown in Table 3-2.

Table 3-2 Out-of-band radiated emission limits

Frequency (f) range	Measurement distance	Limit (quasi-peak)
150 kHz ≤ f < 425 kHz	10m	14.5 - (15.6451 x Log(frequency [MHz]/0.15)) dBμA/m
471 kHz < f < 480 kHz		
489 kHz < f < 491 kHz		
494 kHz < f < 506 kHz		
517 kHz < f < 519 kHz		
524 kHz < f < 526.5 kHz		
526.5 kHz ≤ f ≤ 1605.5 kHz		-2.0 dBμA/m
1605.5 kHz < f < 4 MHz		14.5 - (15.6451 x Log(frequency [MHz]/0.15)) dBμA/m
4 MHz < f ≤ 11 MHz		-32.5635+(17.3595 x Log (frequency [MHz]/0.15)) dBμA/m
11 MHz < f ≤ 30 MHz		29 - (15.6451 x Log (frequency [MHz]/0.15)) dBμA/m
30 MHz < f ≤ 80.872 MHz		30 dBμV/m
80.872 MHz < f < 81.88 MHz		50 dBμV/m
81.88 MHz ≤ f ≤ 134.786 MHz		30 dBμV/m
134.786 MHz < f ≤ 136.414 MHz		50 dBμV/m
136.414 MHz < f ≤ 230 MHz		30 dBμV/m
230 MHz < f ≤ 1000 MHz		37 dBμV/m

Table 3-3 and Table 3-4 shall be applied to frequencies greater than or equal to 30MHz. If the PTU is embedded in a multimedia device, the limits in [2] should be applied.

Table 3-3 Radiated emission limits for frequencies greater than 30MHz up to 1GHz

Frequency (f) range	Measurement		Limit
	Distance	Detector/Bandwidth	
30 MHz < f ≤ 230 MHz	10m	Quasi-peak /120 kHz	30 MHz < f ≤ 230 MHz
230 MHz < f ≤ 1000 MHz			230 MHz < f ≤ 1000 MHz
30 MHz < f ≤ 230 MHz	3m		30 MHz < f ≤ 230 MHz
230 MHz < f ≤ 1000 MHz			230 MHz < f ≤ 1000 MHz

Table 3-4 Radiated emission limits for frequencies greater than 1GHz up to 6GHz

Frequency (f) range	Measurement		Limit
	Distance	Detector/Bandwidth	
1000 MHz < f ≤ 3000 MHz	3m	Average/1 MHz	1000 MHz < f ≤ 3000 MHz
3000 MHz < f ≤ 6000 MHz			3000 MHz < f ≤ 6000 MHz
1000 MHz < f ≤ 3000 MHz		Peak/1 MHz	1000 MHz < f ≤ 3000 MHz
3000 MHz < f ≤ 6000 MHz			3000 MHz < f ≤ 6000 MHz

3.1.4 Coupling coefficient

The coupling coefficient (k) shall be at least 0.2.

3.1.5 Protecting the human body from electric shock

Protection from electric shock shall be ensured in accordance with "Section 2.1 Protection from electric shock and energy hazards" in [3]. In addition, the power transmitting electrodes and power receiving electrodes shall not be exposed as a protection against electric shock. Furthermore, the high frequency generator and transmitter resonant circuit in the power transmitting circuit shall be insulated.

3.1.6 RF exposure level for the human body

The RF exposure level for the human body shall comply with "Section 3.2 RF exposure limits applied to Wireless Power Transmission Systems" in [1]. Regarding the electro-magnetic field intensity level in general environments (average value over 6 minutes), the values in Table 3 (a) in [4] shall be applied. Regarding to stimulating effect, the guideline and guideline values in [4] shall be applied.

3.2 Power Transmitting Unit (PTU)

3.2.1 Output power

The output power shall be less than or equal to 50W.

(RERA: Article 45 (iii))

3.2.2 Frequency variation range

The frequency variation range, which is defined as the frequency fluctuation range for stabilizing the power transmission at the start of the power transfer, shall be within ±2 kHz from the stable frequency.

3.2.3 Q factor of the transmitter resonant circuit

The Q factor of the transmitter resonant circuit (Q_T) shall be at least 20.

3.2.4 Resonant frequency of the transmitter resonant circuit

The resonant frequency of the transmitter resonant circuit (f_T) shall be at least 427 kHz and not more than 522 kHz.

3.2.5 Power transmitting electrodes

The PTU shall have two power transmitting electrodes, and the structure shall comply with Appendix 1.

3.2.6 Detection of the power receiving unit (PRU)

The PTU shall have a function for recognizing the PRU. The PTU shall not transmit power until a PRU is recognized.

3.3 Power Receiving Unit (PRU)

3.3.1 Q factor of the receiver resonant circuit

The Q factor of the receiver resonant circuit (Q_R) shall be at least 20.

3.3.2 Resonant frequency of the receiver resonant circuit

The resonant frequency of the receiver resonant circuit (f_R) shall be greater than or equal 427 kHz and less than or equal 522 kHz.

3.3.3 Power receiving electrodes

The PRU shall have two power receiving electrodes, and the structure shall comply with Appendix 1.

3.3.4 Receiving voltage and reference receiver resonant circuit

The receiving voltage (V_R) shall be greater than or equal 1.2 $kV_{P\text{-}P}$ and less than or equal 2.4 $kV_{P\text{-}P}$ when the receiving load is consuming 30 W. The details of the reference receiver resonant circuit are specified in Chapter 4.

3.3.5 Load characteristics of the PRU

The PRU shall receive the maximum demanded power for the receiving load when the receiving voltage (V_R) is 1.2 $kV_{P\text{-}P}$.

Chapter 4 System Control Requirements

4.1 Overview

Figure 4-1 shows the functional block diagram for the power transmission control of the Capacitive Coupling WPT System. The transmission controller realizes the control function for safely and securely transferring power in the Capacitive Coupling WPT System. The transmission controller consists of a current and voltage detection circuit, a switch and a controller, and it detects presence of a PRU and monitors the power transmission condition. The circuit configuration of the transmission controller shall comply with the specification in 4.3.2.1

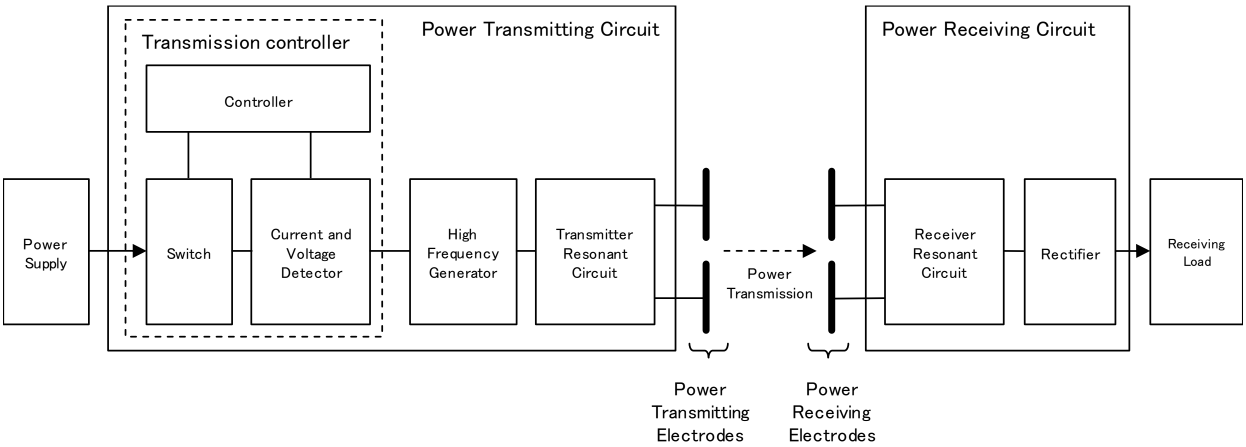

Figure 4-1 Function block diagram of the Capacitive Coupling WPT System.

4.2 Equivalent Circuits of the PTU and PRU and their Parameters

Figure 4-2 shows the parameters required for interconnectivity of the PTU and the PRU.

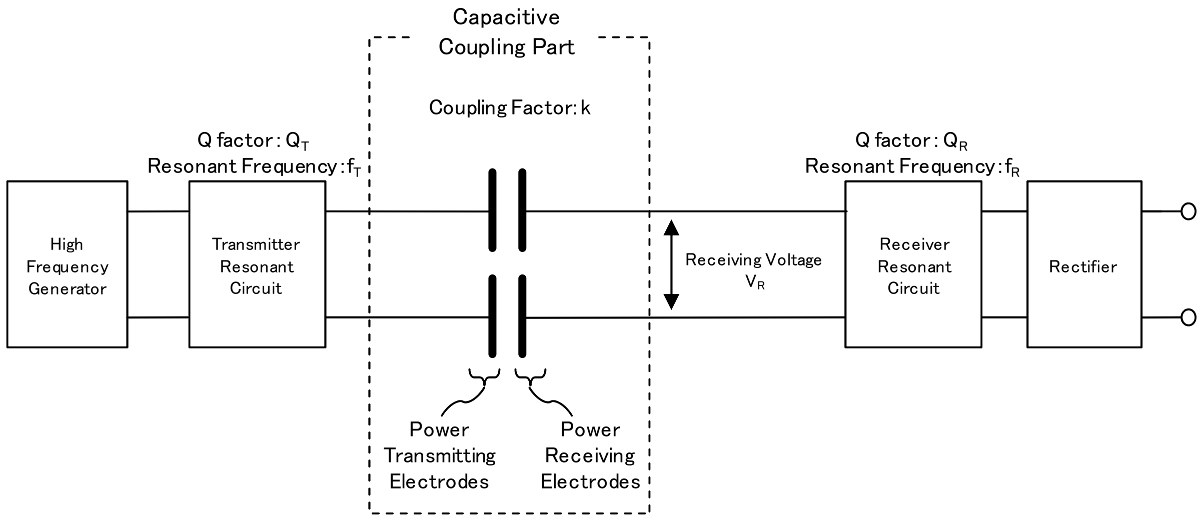

Figure 4-2 Parameters required for maintaining interconnectivity.

In the control of the Capacitive Coupling WPT System, the parameters of the receiver resonant circuit may affect the voltage wave form of the high frequency generator and are measured by the frequency search function (See 4.3.2.2). Verify that the parameters meet the requirements shown in Table 4-1.

Also, the parameters Q_T and f_T of the transmitter resonant circuit are critical parameters for maintaining the power transmission characteristics. If these parameters do not satisfy the conditions set forth in Chapter 3, the criteria for detecting the PRU in the frequency search cannot be satisfied. Interconnectivity is maintained by the frequency search procedure, which checks the voltage value V_T of the high frequency generator in the prescribed range, and the Q_T and f_T of the transmitter resonant circuit must satisfy the conditions in Chapter 3.

Table 4-1 Parameters and requirements verified during the frequency search.

Parameters related to power transmission	Requirements
Q_R	V_T must have a positive peak.
f_R	Frequency f_R for the maximum V_T must be within the specified range.
k	V_T at f_R must be within the specified range.

The PTU is designed to provide 30W of power to the reference model of receiver resonant circuit within the prescribed receiving voltage (V_R) range indicated in 3.3.4. The configuration of the reference model of receiver resonant circuit is specified as follows.

Requirements for the reference model of receiver resonant circuit

- The resonant frequency shall be 457±3 kHz.
- The Q factor shall be greater than or equal to 20.
- The circuit shall be the parallel resonant circuit type.

The receiving voltage (V_R) shall be measured using the reference model of receiver resonant circuit described above and the measurement method specified in Chapter 5.

The PRU shall be designed to be capable of outputting maximum power to the receiving load at a receiving voltage (V_R) of 1.2 $kV_{P\text{-}P}$. The PTU shall be designed to transfer at least 30W in the receiving voltage (V_R) range of 1.2kVpp to 2.4kVpp in order to maintain interconnectivity.

This standard does not specify the output voltage from the rectifier, which depends on the specifications of the target devices and is out of the scope of this specification.

4.3 Power Transmission Control Function

4.3.1 State transition

Figure 4-3 shows the state transition diagram. The transmission control circuit shall be capable of judging the presence of a PRU, a foreign object or other failure, and it shall control the state of power transmission by detecting the voltage V_T and the current i_T at the high frequency generator.

In this Standard, 6 states are specified: “Standby 1”, “Stop”, “Power transmission”, “Standby 2”, “Shutdown” and “Power Off”.

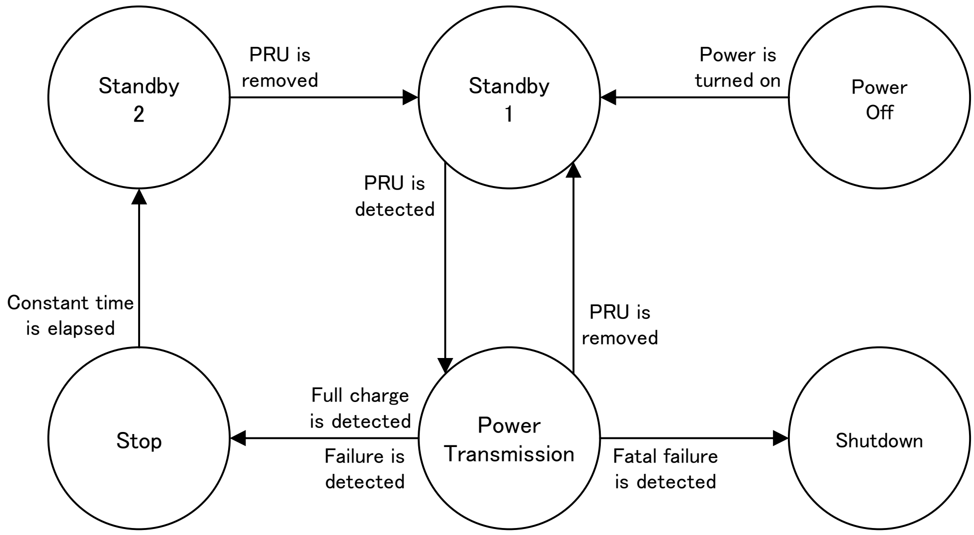

Figure 4-3 State transition diagram of the power transmission control (PTU)

Table 4-2 shows the relationship between the states of the PTU and PRU.

Table 4-2 Relationship between the states of the PTU and PRU.

State of system	State of PTU	State of PRU
Power Off	All stop	No load
Standby 1	Frequency search and judgment	No load
Power Transmission	Power transmission and monitoring specified parameters	Receiving power
Stop	Only the controller functions	No load
Standby 2	Frequency search and judgment	No load
Shutdown	All stop	No load

Explanations and requirements of each state are provided below.

(1) Power Off

- In the “Power Off” state, the PTU is not fully functional. Therefore, the PRU cannot receive power.
- If the power supply is turned on, the state shall change to “Standby 1”. In other cases, the state will not change.

(2) Standby 1

・A frequency search shall be performed in the "Standby 1" state.

・If the PTU detects a normal PRU, the state shall change to "Power transmission".

The method of the frequency search and details of the criteria to detect a normal PRU are specified in 4.3.2.2.

(3) Power Transmission

・The PTU shall transfer power to the PRU while monitoring V_T and i_T. The detecting circuits for measuring V_T and i_T are described in 4.3.2.1.

・The PTU shall be able to detect "Fatal Failure", "Failure", "Full Charge" and "PRU Removal" using the transmission control function. Table 4-3 shows the detection criteria for each event.

Table 4-3 Judgment criteria for each event.

Event	Parameter	Criteria
"Full Charge"	i_T	The following condition continues for 10 minutes or more. i_T is less than or equal to 400 mA and stays within 5% deviation.
"PRU Removal"	i_T	i_T decreases 30 % or more within 100 ms, and i_T becomes less than 100 mA after that.
"Failure"	i_T	i_T exceeds the rated value defined by each manufacturer.
"Fatal Failure"	V_T	V_T exceeds the rated value defined by each manufacturer.

・If "Full Charge" is detected, the state shall change to "Stop".

・If "PRU Removal" is detected, the state shall change to "Standby 1".

・If "Failure" is detected, the state shall change to "Stop".

・If "Fatal Failure" is detected, the state shall change to "Shutdown".

(4) Stop

・In the "Stop" state, only the controller functions, and no power is transmitted.

・After at least 100 ms from the transition to the "Stop" state, the state shall change to "Standby 2".

(5) Standby 2

・A frequency search shall be performed in the "Standby 2" state to confirm "PRU Removal".

・When the PTU does not detect a PRU, the PTU shall change from “Standby 2” to “Standby 1” and judge that the PRU has been removed from the charging area.

The details of the determination criteria for PRU detection are described in 4.3.2.2

(6) Shutdown

・In the “Shutdown” state, the PTU shall stop supplying power to the high frequency generator.

・The PTU never transmits power in the “Shutdown” state, and a power-cycle does not exist. Without the power-cycle, the state shall not change to “Standby 1”.

4.3.2 Control function

4.3.2.1 Configuration of the transmission controller and high frequency generator

Figure 4-4 shows the configuration of the transmission controller. V_T and i_T shall be evaluated by using this circuit.

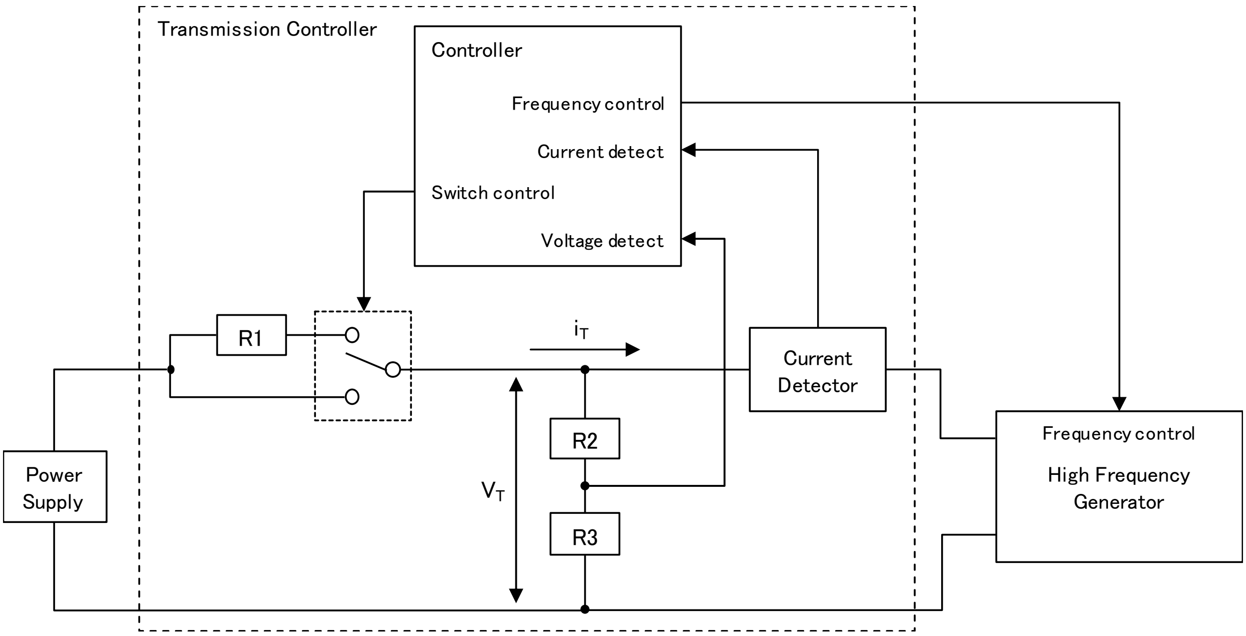

Figure 4-4 Configuration of the transmission control circuit.

The circuit and system components are specified as follows.

In the frequency search procedure, the circuit shall switch to the route that passes through R1 to restrict the input current to the high frequency generator. In the power transmission state, the circuit shall switch to the bypass route that does not run through R1. In addition, the high frequency generator shall be capable of varying the frequency by means of control by the controller.

Resistance values:

R1 shall be set to a value that can limit the input power during the frequency search to 1W or less. R2 and R3 shall be set to the division ratio that can satisfy the rated input voltage to the controller.

Current detection circuit:

The controller shall be capable of detecting the current amplitude.

Controller:

The controller shall consist of a voltage detection function, memory function and digital output function (to switch peripherals).

High frequency generation circuit:

The circuit shall be capable sweeping the transmission frequency.

4.3.2.2 Frequency search

Methods for controlling the hardware and detecting a PRU by the frequency search procedure in the “Standby 1” and “Standby 2” states are specified as follows. The interconnectivity between the PTU and the PRU can be confirmed by the frequency search procedure stated in 4.2. The frequency characteristic of V_T is correlated with the impedance characteristic, which is affected by the coupling condition between the PTU and PRU, as well as by the presence of a PRU. Therefore, this control system detects the presence of a PRU by measuring the frequency response of V_T. The procedure for the frequency search is as follows.

(1) Use the circuit in Figure 4-4 to measure V_T.

(2) Change the frequency and measure V_T repeatedly.

(3) Record V_T.

(4) If the recorded frequency characteristics of V_T satisfy all of the following conditions, the controller judges that a PRU exists in the charging area and shall start power transmission at the peak frequency with the maximum V_T.

Criteria for judging the presence of a PRU

- The maximum value of V_T is detected.
- The peak frequency where maximum V_T is obtained is in the range from 427 kHz to 522 Hz.
- The maximum value of V_T is in the following range:

Upper limit value: Input voltage x 0.5 (V)

Lower limit value: Input voltage x 0.05 (V)

In the "Standby 1" state, the controller shall continue to perform frequency searches until the above criteria are satisfied. In the "Standby 2" state, if the above conditions are satisfied, the controller judge that the PRU is still in charging area and continues performing the frequency searches.

Figure 4-5 shows an example of the relationship between the frequency and V_T when a PRU is placed on a PTU. If the PRU is placed on the PTU correctly, a resonant waveform is observed in the frequency band.

Here, the following requirements shall be specified.

・The frequency band of the frequency search shall be from 425 kHz to 524 kHz.

・The frequency interval of the frequency search shall be 10 kHz or less.

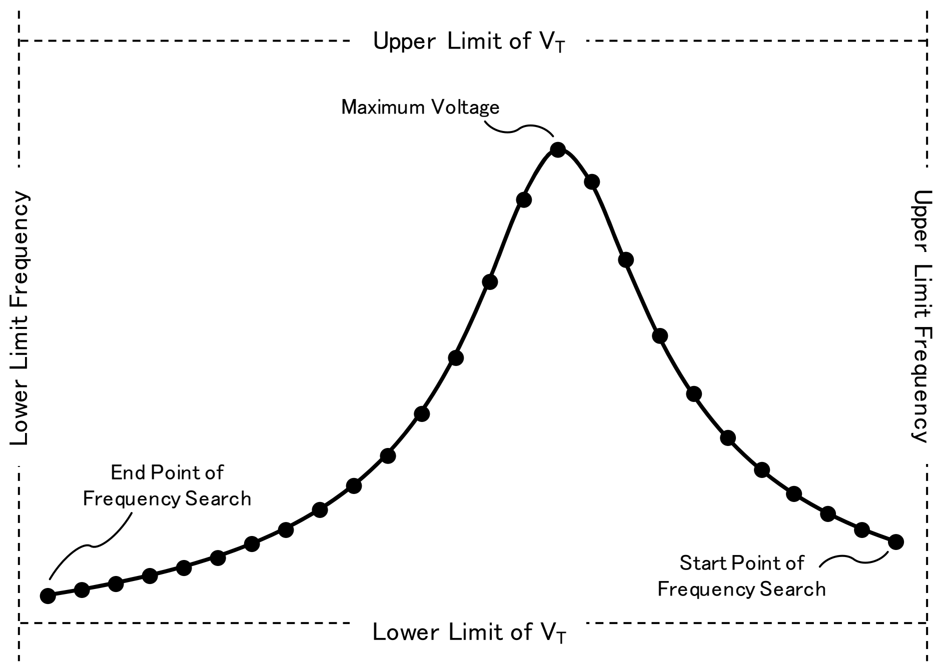

Figure 4-5 Relationship between the frequency in the frequency search and V_T.

Figure 4-6 shows the timing of the frequency searches. The Frequency Search indicates the duration of a complete edge-to-edge frequency search performed one-time from the lower limit to the upper limit. The Interval is the time duration from the end of Frequency Search to the beginning of the next Frequency Search.

Figure 4-6 Timing of the frequency searches.

The Frequency Search and the Interval are specified as follows:

- The Frequency Search shall be 1 second or less per search.
- The Interval shall be 5 seconds or less.

4.3.2.3 Control of the transmission state

In the “Power transmission” state, the controller shall measure V_T periodically using the transmission controller shown in Figure 4-4. The details of the measurement are specified as follows:

- The measurement interval of V_T shall be 100 milliseconds or less.
- Power transmission shall be stopped within 1 second after detecting a failure.

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Chapter 5　Measurement Methods

In this chapter, the measurement methods are stipulated for confirming that the system meets the requirements in “Chapter 3: Technical requirements of the system”.

5.1　Test Conditions

5.1.1　Humidity and temperature of the measurement location

(1)　Measurements shall be performed in the temperature range of 5 - 35°C.

(2)　Measurements shall be performed in the humidity range of 45 - 85%.

5.1.2　Load

The load used for the measurements described in 5.2 shall be a resistance load or an electronic load device.

5.2　Measurement Conditions

5.2.1　Power transmission frequency ranges

The frequency on the power transmission shall be measured after 15 minutes from the start of power transmission. The highest frequency and lowest frequency in frequency search shall be measured, as well in the frequency search performed in the “Standby 1” state as specified in Chapter 4.

5.2.2　Frequency variation range

The highest frequency and lowest frequency of the signal for power transfer corresponding “5.2.1 Power transmission frequency ranges” shall be measured for 15 minutes after the start of power transmission.

5.2.3　Output power

The measurement system for the output power from the PTU is shown in Figure 5-1. The output power shall be measured using a load that emulates the maximum power transmission without the presence of a PRU on the PTU.

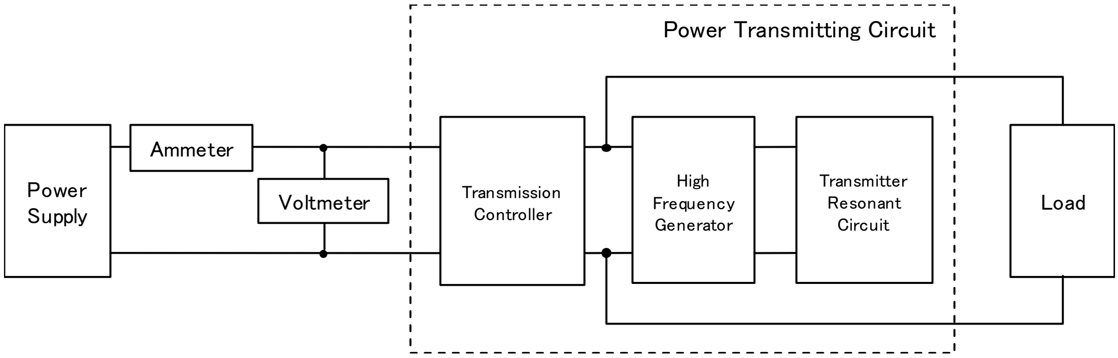
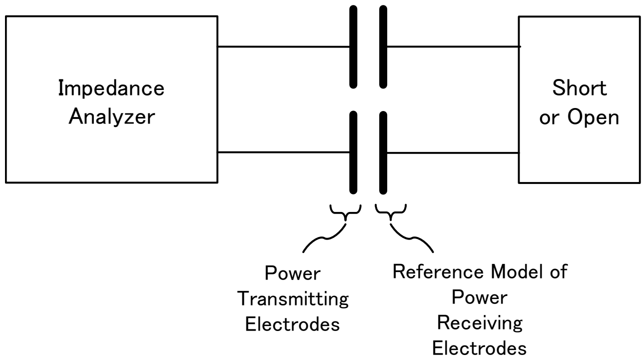


Figure 5-1 Measurement system for output power

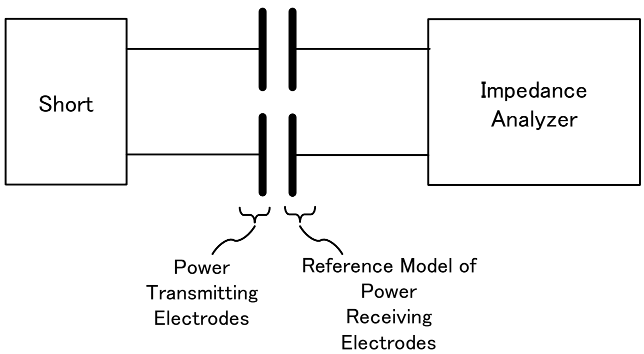
The output power is defined as the power calculated from the measurement results of a voltmeter and ammeter at the power input point of the PTU.

5.2.4 Coupling coefficient

The measurement system for measuring the capacitances of the electrodes when designing the PTU is shown in Figure 5-2. The coupling coefficient [k] between the power transmitting electrodes and reference model of power receiving electrodes shall be measured by the measurement system shown in Figure 5-2 using the standard power receiving electrodes as specified in Appendix 2.



(1) Measurement system for the power transmitting side capacitance (when designing the PTU)



(2) Measurement system for the power receiving side capacitance (when designing the PTU)

Figure 5-2 Measurement system for the capacitance parameters of the electrodes when designing the PTU

The coupling coefficient is calculated by equation (3) in 2.3.3 using the measured capacitance parameters in the following conditions. The measuring frequency is set at 457 kHz.

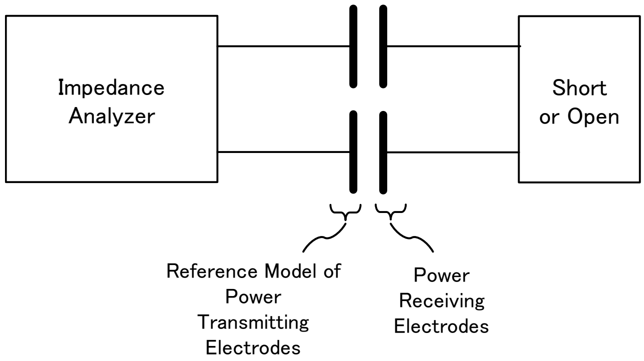
C_{1S} : Power transmitting side capacitance when the standard power receiving electrodes are electrically shorted

C_{1O} : Power transmitting side capacitance when the standard power receiving electrodes are electrically opened

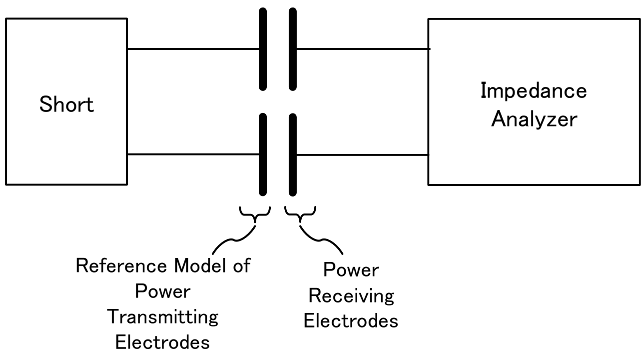
C_{2S} : Power receiving side capacitance when the power transmitting electrodes are electrically shorted

The measuring circuit for the capacitance parameters when designing the PRU is shown in Figure 5-3.

The coupling coefficient [k] between the power receiving electrodes and reference model of power transmitting electrodes shall be measured by the measuring circuit in Figure 5-3. Herein, the standard power transmitting electrodes are specified in Appendix 2.



(1) Measurement system for the power transmitting side capacitance (when designing the PRU)



(2) Measurement system for the power receiving side capacitance (when designing the PRU)

Figure 5-3 Measurement system for the capacitance parameters of electrodes when designing the PRU

The coupling coefficient is calculated by equation (3) in 2.3.3 using the measured capacitance parameters in the following conditions. The measuring frequency is set at 457 kHz.

C_{1S} : Power transmitting side capacitance when the power receiving electrodes are electrically shorted

C_{1O} : Power transmitting side capacitance when the power receiving electrodes are electrically opened

C_{2S} : Power receiving side capacitance when the standard power transmitting electrodes are electrically shorted

5.2.5 Resonant frequency and Q factor

(1) Measurement of the characteristics of the transmitter resonant circuit

The power receiving electrodes shall be coupled with the power transmitting electrodes. The input terminals of the transmitter resonant circuit shall be shorted electrically as shown in Figure 5-4.

The reference model of power receiving electrodes specified in Appendix 2 shall be used as the power receiving electrodes, and the impedance shall be measured by an impedance analyzer connected to the reference model of power receiving electrodes.

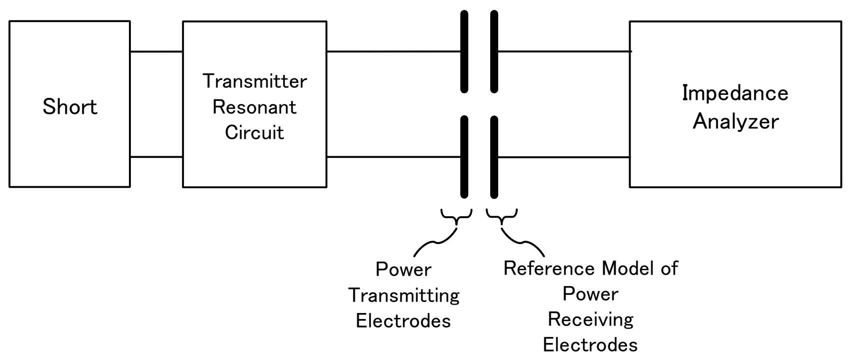


Figure 5-4 Measurement system for the transmitter resonant circuit characteristics

f_T shall be obtained from the impedance measurement result, and Q_T shall be calculated.

Refer to equation (1) in 2.3.1 for the method of calculating Q_T.

(2) Measurement for the characteristics of the receiver resonant circuit

The power transmitting electrodes shall be coupled with the PRU as shown in Figure 5-4.

The reference model of power transmitting electrodes specified in Appendix 2 shall be used as the power transmitting electrodes, and the impedance shall be measured by an impedance analyzer connected to the standard power transmitting electrodes.

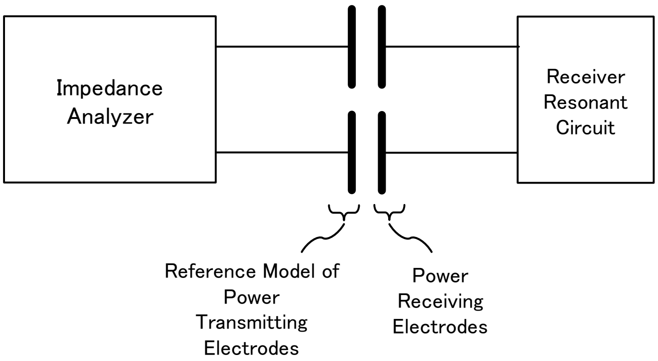


Figure 5-5 Measurement system for the receiver resonant circuit characteristics

f_R shall be obtained from the impedance measurement result, and Q_R shall be calculated. Refer to equation (2) in 2.3.1 for the method of calculating Q_R.

5.2.6 Receiving voltage and reference receiver resonant circuit

Receiving voltage (V_R) shall be measured using the reference model of receiver resonant circuit specified in Chapter 4, in the power transmission state, and in accordance with the measurement system shown in Figure 5-6. The transmission frequency shall be set at 457 kH ± 3 kHz. The load condition shall be set at 30W.

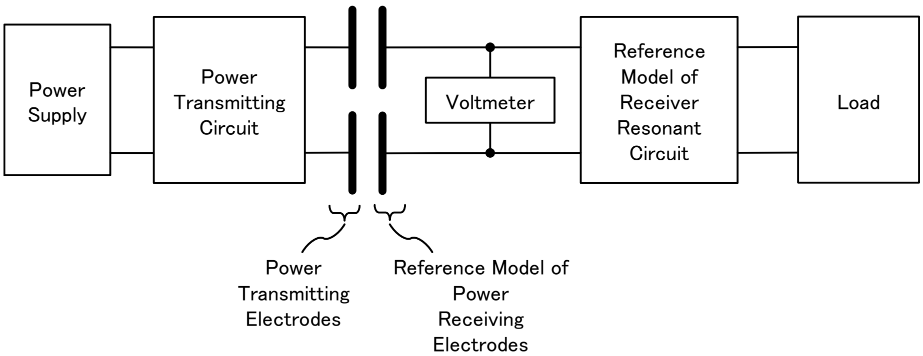


Figure 5-6 Measurement system for the receiving voltage (V_R)

5.2.7 Load characteristics of the PRU

The maximum load is measured at an input of 1.2 $kV_{P\text{-}P}$ to the Rx resonator. The measurement system for the load characteristics of the PRU is shown in Figure 5-7.

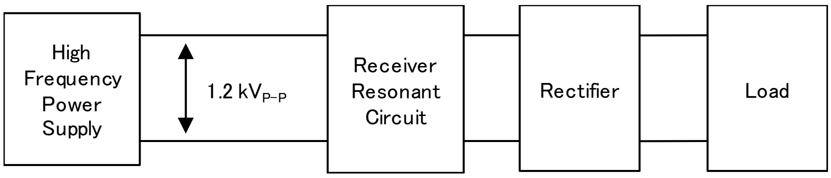


Figure 5-7 Measurement system for load characteristics of the PRU

5.2.8 Radiated emission intensity

Radiated emission intensity shall be measured based on following clauses in [1]: “2.3 Measurement equipment”, “2.4 Configuration and arrangement of the devices being tested”, “2.5 Operational requirements of the devices being tested” and “2.6 Measurement method”. The measurement shall be performed when the PTU is transferring power at the maximum level.

5.2.9 RF Exposure level for the human body

The measurement shall be performed based on “3.3 The evaluation methods for verifying the guideline pattern and values to be applied in wireless power transmission systems” in [1] under the condition that the PTU is transferring power at the maximum level.

5.2.10 Confirmation of the power transmission stop function

The failure detection function as specified in Chapter 4 shall be confirmed to function appropriately.

The measurement system for confirming the power transmission stop function is shown in Figure 5-8.

The measurement system is composed of a power supply, ammeter, PTU, load and measurement circuit. The measurement circuit shall measure the input current of the PTU while changing the load resistance.

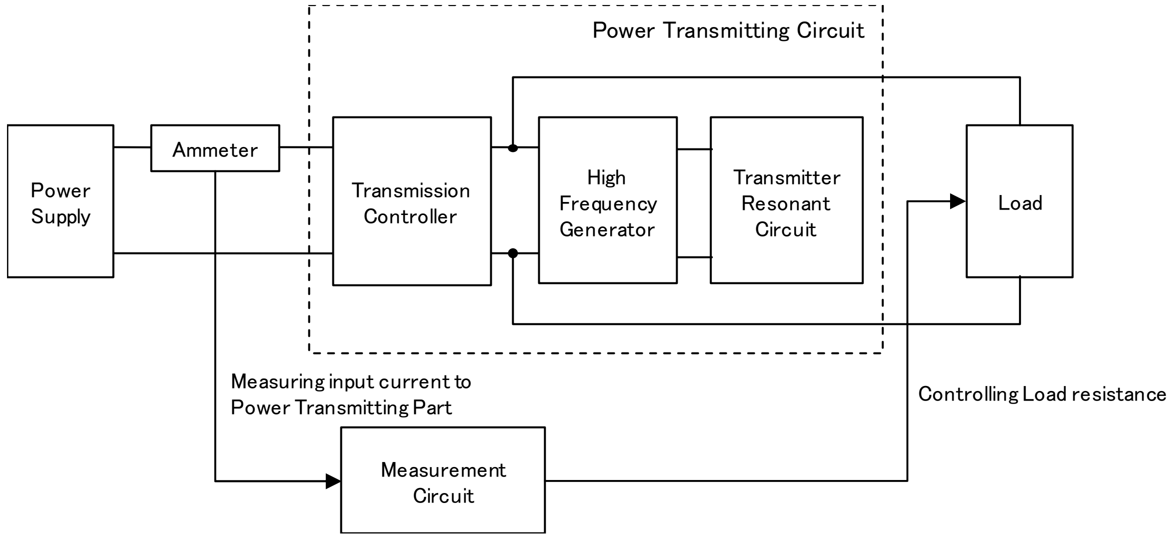


Figure 5-8 Measurement system for confirming the power transmission stop function

The measurement shall be performed in accordance with the procedure below after determining the number of measurements required for stable operation and confirming the environmental conditions.

(1) Set the resistance of the load so that the input current does not exceed the rated value.

(2) In the power transmission state, decrease the load resistance to an over-rated value of the input current to the PTU. The rated value of the input current is determined by the manufacturer, depending on the power supply specification of the PTU.

(3) Confirm the power transmission stops at the rated current. Measure the transition time from over-current detection until the power transmission stops.

Chapter 6 Terms and Definitions

6.1 Terms and Definitions

The terms used in this Standard are defined as follows:

[Capacitance]

Quantity of electric charge when a unit voltage is applied to a capacitor. Capacitance C is calculated as C=Q/V [F] from the voltage V [V] and electric charge Q [C].

[Capacitive Coupling WPT System]

One wireless power transmission technology that operates on the principle that power is transferred wirelessly using electrostatic induction generated by capacitive coupling between the countered electrodes.

[Coupling Coefficient]

A coefficient calculated from the capacitances generated by the power transmitting electrodes and power receiving electrodes in the capacitive coupling WPT System. It is correlated with efficiency.

[High-Frequency-Based Equipment]

A category of equipment that utilizes high frequency current of 10 kHz or greater, which is stipulated in Article 100, Paragraph 1 of the Japan Radio Law.

[High Frequency Generator]

An electrical circuit that converts DC power to a desired RF power signal.

[Input Current]

Input power current from the power supply to the PTU.

[Input Voltage]

Input power voltage from the power supply to the PTU.

[Load Device]

A device receiving power in the wireless power transmission system.

[Other Equipment]

Equipment categorized as high-frequency-based equipment with no communication function and is used for directly providing high frequency energy to the load, or is otherwise used for heating, ionization, etc.

[Output Power]

Electrical power transmitted via a power line conducting high frequency current at a frequency of 10 kHz or greater. In the capacitive coupling WPT System, it is defined as the "PTU in power" to the power transmitting circuit.

[Power Receiving Circuit]

In the capacitive coupling WPT System, it is composed of the receiver resonant circuit and rectifier.

[Power Receiving Electrodes]

In the capacitive coupling WPT System, it is the portion of the coupled conductor unit for generating static capacitance, and it is connected to the power receiving circuit.

[Power Receiving Unit: PRU]

In the capacitive coupling WPT System, it is a whole unit of power receiving that is composed of a power receiving circuit and power receiving electrodes.

[Power Supply]

A device that supplies electric power.

[Power Transmitting]

Power transmission by the transmitting unit.

[Power Transmitting Circuit]

In the capacitive coupling WPT System, it is composed of the high-frequency generator, transmitter resonant circuit and transmission controller.

[Power Transmitting Electrodes]

In the capacitive coupling WPT System, they are the portion of the coupled conductor unit for generating static capacitance and are connected to the power transmitting circuit.

[Power Transmitting Unit: PTU]

In the capacitive coupling WPT System, it is a whole unit that is composed of a power transmitting circuit and power transmitting electrodes.

[Q Factor]

The Q factor describes the sharpness of the resonance. When the Q factor is high, the resonator bandwidth is narrow.

[Receiver Resonant Circuit]

In the capacitive coupling WPT System, it is an electrical circuit consisting of a resonant circuit with power receiving electrodes.

[Receiving Power]

Input power applied to the power receiving electrodes in the capacitive coupling WPT system. In this Standard, input power to the power receiving electrode and output power from the power receiving electrode are treated as the same because there is almost no loss at the electrode.

[Receiving Voltage]

Input AC voltage to the power receiving resonant circuit in the capacitive coupling WPT

System.

[Rectifier]

An electrical circuit that converts the received high-frequency current into DC.

[State Transition Diagram]

Drawings describing the combination of transition states in the systems.

[Transmission Controller]

In the capacitive coupling WPT System, it is a circuit for safely controlling the power transmission.

[Transmission Frequency]

Frequency of the electromagnetic field that transmits the electrical energy during wireless power transmission.

[Transmitter Resonant Circuit]

In the capacitive coupling WPT System, it is an electrical circuit consisting of a resonant circuit with power transmitting electrodes.

[Transmitting Power]

Input power applied to the power transmitting electrodes in the capacitive coupling WPT System. In this Standard, input power to the power transmitting electrode and output power from the power transmitting electrode are treated as the same because there is almost no loss at the electrode.

6.2 Abbreviations

The following abbreviated terms are used in this Standard.

[P]

PRU	Power receiving unit
PTU	Power transmitting unit

[W]

WPT	Wireless Power Transmission

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Appendix 1 Design Specifications for the Electrodes

1 Overview of Electrode Design

This appendix describes the specifications for designing the power transmitting electrodes and power receiving electrodes. The electrodes shall meet the requirements for k, f_T, f_R, Q_T and Q_R described in Chapter 3. The following is the detailed specification for electrode design.

2 Layout of the Electrodes

The basic layout of the electrodes is shown in Figure A1-1. This layout is applied to both the power transmitting electrodes and power receiving electrodes. The power transmitting / power receiving electrodes consist of two (2) electrodes, an inner electrode named E_{TA} or E_{RA} and an outer electrode named E_{TP} or E_{RP}. E_{TA} and E_{TP} are the names of the power transmitting electrodes, and E_{RA} and E_{RP} are the names of the power receiving electrodes. The PTU and PRU have a ground electrode named GND_T (for the PTU) or GND_R (for the PRU) that is connected to the electrical ground of the PTU and PRU, respectively. The ground electrode is larger than the outer electrode, and it fully covers the outer electrode. The “center point” of the power transmitting electrodes or the power receiving electrodes is defined as the gravity point of E_{TA} or E_{RA}.

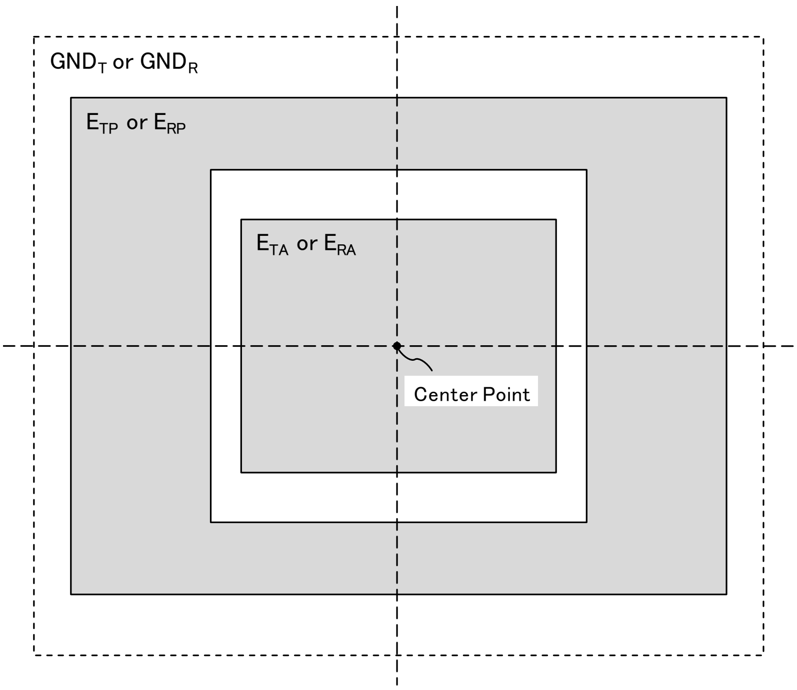
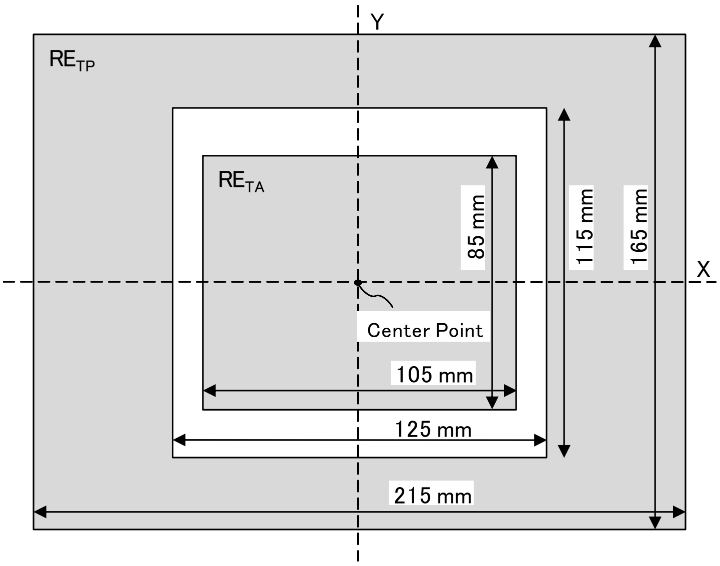


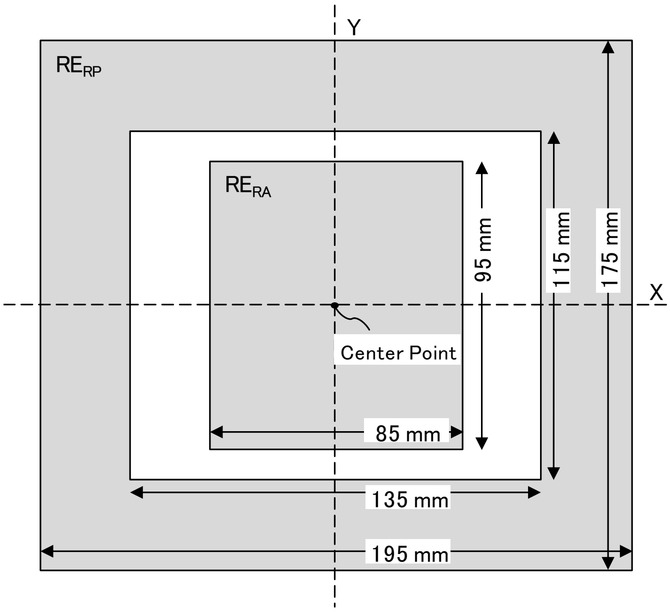
Figure A1-1 Layout of the electrodes

In the Figure A1-1, each electrode has a rectangular shape, but this design specification places no restrictions on the shape. However, the following conditions shall be satisfied when designing the electrodes.

- When the center point of the power transmitting electrodes is placed on the center point of the reference power receiving electrodes specified in Figure A1-2 (2), the power transmitting electrodes shall be designed so that the overlap of E_{TA} and RE_{RA} is at least 70% of RE_{RA} and the overlap of E_{TP} and RE_{RP} is at least 70% of RE_{RP}.
- When the center point of the power receiving electrodes is placed on the center point of the reference power transmitting electrodes specified in Figure A1-2 (1), the power receiving electrodes shall be designed so that the overlap of E_{RA} and RE_{TA} is at least 70 % of RE_{TA} and the overlap of E_{RP} and RE_{TP} is at least 70% of RE_{TP}.
- When the center point of the power transmitting electrodes is placed on the center point of the reference power receiving electrodes, the power transmitting electrodes shall be designed to avoid overlapping between E_{TA} and RE_{RP} and between E_{TP} and RE_{RA}.
- When the center point of the power receiving electrodes is placed on the center point of the reference power transmitting electrodes, the power receiving electrodes shall be designed to avoid overlapping between E_{RA} and RE_{TP} and between E_{RP} and RE_{TA}.
- The PTU ground electrode GND_T shall be designed to cover the whole of E_{TP}, and the PRU ground electrode GND_R shall be designed to cover the whole of E_{RP}.



(1) Reference power transmitting electrodes



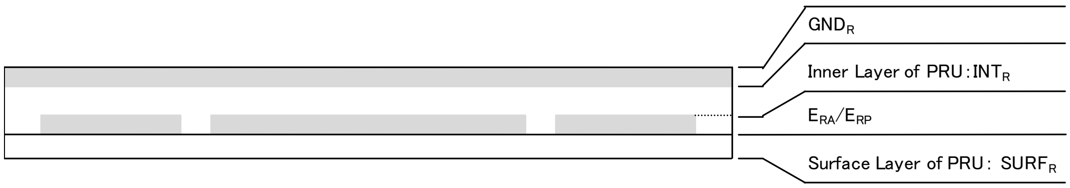
(2) Reference power receiving electrodes

Figure A1-2 Layout and the dimensions of the reference electrodes

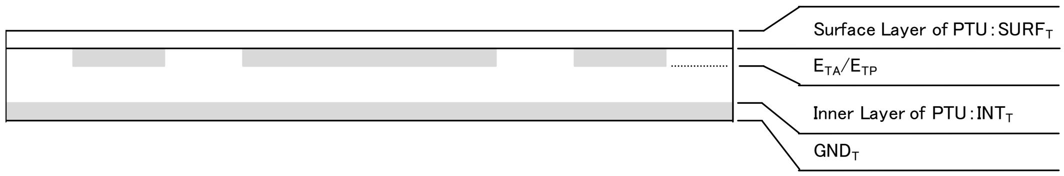
3 Cross-Sectional Structure of the Electrodes

Figure A1-3 (1) and (2) show a cross section of the power receiving electrodes and power transmitting electrodes, respectively. On the PTU side, E_{TA} and E_{TP} are placed on the same plane, and GND_T is located on the side opposite to the E_{TA} and E_{TP} of the inner insulating layer INT_T. On the PRU side, E_{RA} and E_{RP} are placed on the same plane, and GND_R is located on the side opposite to the E_{RA} and E_{RP} of the inner insulating layer INT_R. E_{TA} and E_{TP} are covered with a surface insulation layer $SURF_T$, and E_{RA} and E_{RP} are covered with a surface insulation layer $SURF_R$.

The actual materials and thickness of the electrodes and insulating layer are not specified.



(1) Power receiving electrodes



(2) Power transmitting electrodes

Figure A1-3 Cross section of the electrodes

Appendix 2　Reference Model of Electrode Design

This appendix describes the specifications for the reference models of Power Transmitting Electrodes and Power Receiving Electrodes. These reference models of Electrodes are used to measure each parameter set forth in Chapter 5.

1　Layout and Dimensions of the Electrodes

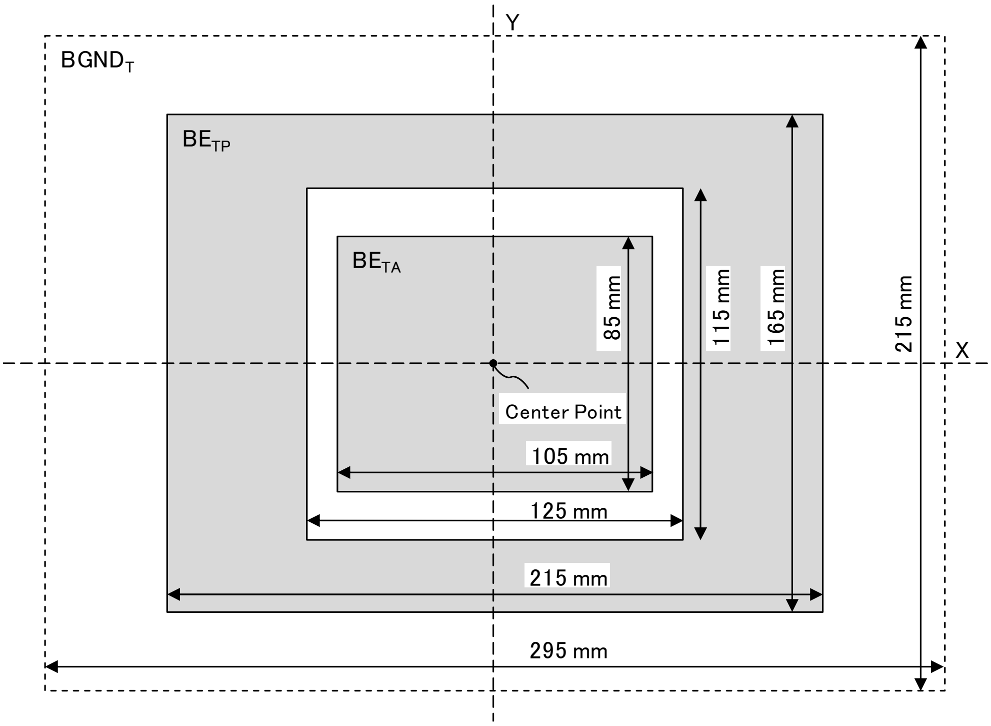
The layout of the Power Transmitting Electrodes and the Power Receiving Electrodes is shown in Figure A2-1 (1) and (2), respectively.

The Power Transmitting Electrodes and Power Receiving Electrodes have same configuration consisting of an inner electrode, BE_{TA} or BE_{RA}, and an outer electrode, BE_{TP} or BE_{RP}. BE_{TA} and BE_{TP} are the names of the Power Transmitting Electrodes, and BE_{RA} and BE_{RP} are the names of the Power Receiving Electrodes. There are also ground electrodes for the PTU and PRU respectively called $BGND_T$ and $BGND_R$.

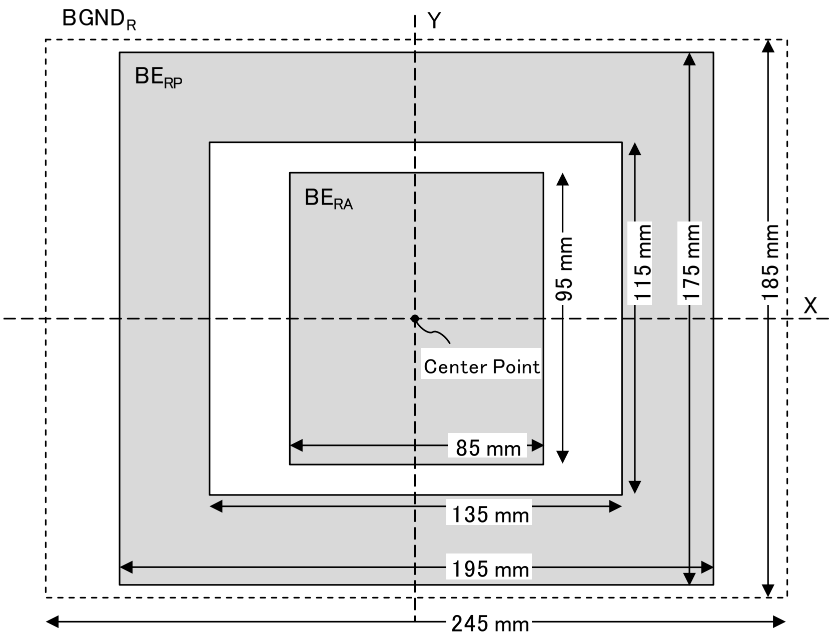
The "center point" of the power transmitting electrodes or the power receiving electrodes is defined as the gravity point of BE_{TA} or BE_{RA}.

The dimensional tolerance of the electrodes shall be within ±0.5 mm.

The wiring point on the electrodes for each measurement is not specified. The wire length shall be 200 mm or less.



(1) Reference model of power transmitting electrodes



(2) Reference model of power receiving electrodes

Figure A2-1 Layout of the reference model of electrodes

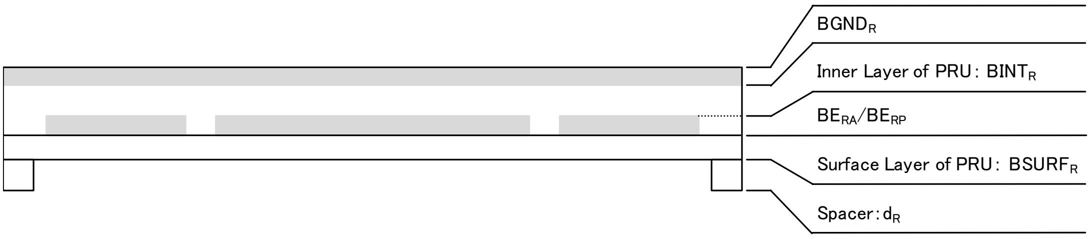
2 Cross-sectional Structure of the Electrodes

Figure A2-2 shows a cross section of the power receiving electrodes and power transmitting electrodes. On the PTU side, BE_{TA} and BE_{TP} are placed on the same plane, and $BGND_T$ is located on the side opposite to the BE_{TA} and BE_{TP} of the inner insulating layer $BINT_T$. On the PRU side, BE_{RA} and BE_{RP} are placed on the same plane, and the $BGND_R$ is located on the side opposite to the BE_{RA} and BE_{RP} of the inner insulating layer $BINT_R$. BE_{TA} and BE_{TP} are covered with a surface insulation layer $BSURF_T$, and the BE_{RA} and BE_{RP} are covered with a surface insulation layer $BSURF_R$. The thickness of the power transmitting electrodes, power receiving electrodes and ground electrodes shall be 0.2 mm or less. The electrode materials should be common metals such as copper and aluminum.

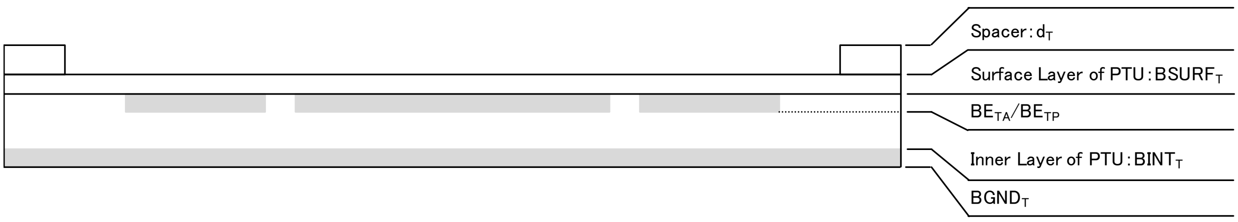
An air gap shall be created between the Tx-Rx counter electrodes using holding spacers d_R (PRU side) and d_T (PTU side). The spacers shall be placed to avoid overlapping with BE_{TA}, BE_{TP}, BE_{RA} and BE_{RP}.

The cross-sectional dimensions are shown in Figure A2-1 (1) and (2).

Dielectric insulating material should be a common dielectric resin listed in Table A2-1.



(1) Reference model of power receiving electrodes



(2) Reference model of power transmitting electrodes

Figure A2-2 Cross section of the reference model of electrodes

Table A2-1 Dimensions and materials of the reference model of electrodes

(1) Reference model of receiving electrode

<table>
<tr><th>Items</th><th>Relative permittivity</th><th>Thickness (mm)</th><th>Recommended Materials</th></tr>
<tr><td>$BINT_R$</td><td rowspan="3">2.9±0.1</td><td>1.0±0.2</td><td rowspan="3">Polycarbonate, ABS Resin and polyethylene terephthalate</td></tr>
<tr><td>$BSURF_R$</td><td>0.6±0.1</td></tr>
<tr><td>d_R</td><td>0.5±0.1</td></tr>
</table>

(2) Reference model of transmitting electrodes

<table>
<tr><th>Items</th><th>Relative permittivity</th><th>Thickness (mm)</th><th>Recommended Materials</th></tr>
<tr><td>d_T</td><td rowspan="3">2.9±0.1</td><td>0.5±0.1</td><td rowspan="3">Polycarbonate, ABS Resin and polyethylene terephthalate</td></tr>
<tr><td>$BSURF_T$</td><td>0.6±0.1</td></tr>
<tr><td>$BINT_T$</td><td>4.0±0.2</td></tr>
</table>

Part 2

6.78 MHz

Magnetic Coupling Wireless Power Transmission Systems

for Mobile Devices

Contents

Chapter 1 General Descriptions

1.1 Outline

This ARIB STANDARD (hereinafter referred to as “Standard”) covers the supply of electric power to or charging the batteries of mobile devices, and it specifies the wireless interfaces for power transmission and control communications between the power transmitting unit (PTU) and power receiving unit (PRU) of a “wireless power transmission system which transmits electric power wirelessly by means of magnetic resonance technology using 6.78 MHz electromagnetic waves” (hereinafter referred to as “6.78 MHz Magnetic Coupling Wireless Power Transmission (WPT) System” or “System”).

This System is operated at transmission power not exceeding the limitations allowed without permission in the "Other Equipment" category stipulated in “Article 45, Item (3) of the Regulations for Enforcement of the Radio Act” and “Equipment Utilizing High Frequency Current” stipulated in “Article 100, Paragraph (1), Item (ii) of the Radio Act”.

Also, this Standard refers to the “A4WP Wireless Power Transfer System Specification (BSS) Version 1.2.1.” (Appendix 1).

1.2 Scope of the Standard

The configuration of the 6.78 MHz Magnetic Coupling WPT System is shown in Figure 1-1. The 6.78 MHz Magnetic Coupling WPT System consists of a PTU which transmits electrical power fed from an external device and a PRU which receives electric power transmitted by the PTU and feeds the power to the external device. A magnetic coupling is formed between the PTU’s transmitter resonator and the PRU’s receiver resonator, and the electric power is wirelessly transferred. Communication is performed for controlling the power transmission through communication between the PTU’s transmitter communication unit and PRU’s receiver communication unit. In general, the “external device” at the PTU is assumed to be the power supply, and the “external device” at the PRU is assumed to be the device receiving power.

This Standard is applied to the framework of the 6.78 MHz Magnetic Coupling WPT System shown in Figure 1-1, and this Standard specifies the wireless interface between the PTU and PRU. As shown in Figure 1-1, an “interface point” defines the wireless section interface, and there are two interface points: one for power transmission and the other for control signaling.

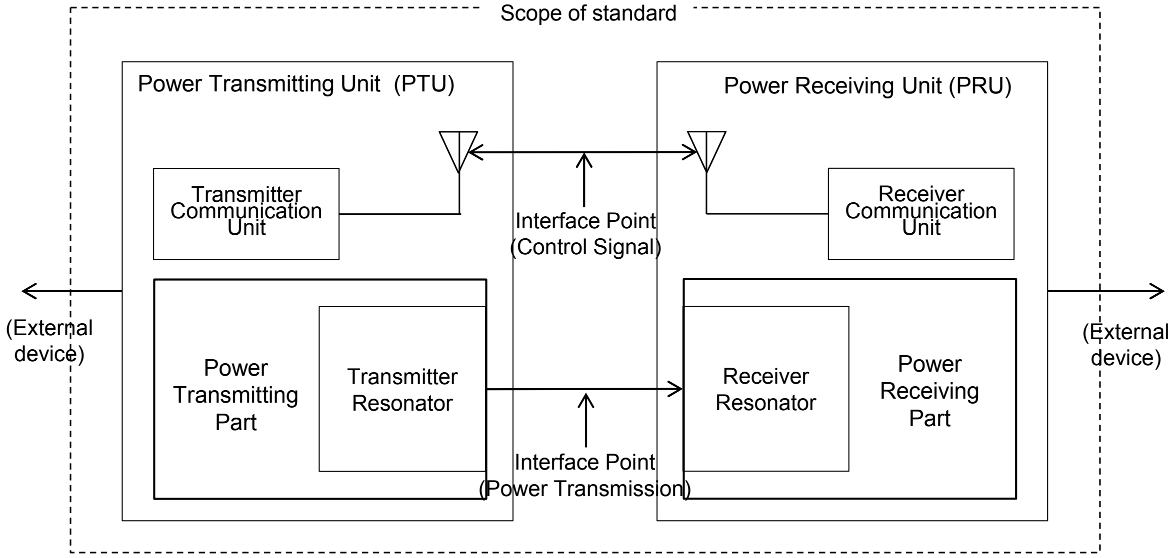


Figure 1-1 Configuration of the Magnetic Coupling WPT System

1.3 Normative References

The terms used in this Standard follow the definitions specified in the Radio Act and other related regulations unless otherwise noted. In addition, "RERA" in the Chapter 3 means the "Regulations for Enforcement of the Radio Act."

Furthermore, this Standard refers to the following documents as needed, and uses the corresponding reference numbers:

[1] ARIB STD-T66 "Second Generation Low Power Data Communication System/ Wireless LAN System "

[2] Technical requirements on 6 MHz-band Magnetic Resonance Coupling Wireless Power Transmission Systems and 400 kHz-band Capacitive Coupling Wireless Power Transmission Systems", The MIC Information Communication Council Report, January 2015.

[3] CISPR 32 Edition 1.0, January 2012.

[4] Information and Communications Council Report No. 2035, "Protection from the Radio Waves (10 kHz to 10 MHz) on the Human Body", March 2015.

Chapter 2 System Overview

2.1 System Characteristics

This System provides mobile device users a wireless power transfer function based on magnetic resonance coupling utilizing 6.78 MHz radio wave. The 6.78 MHz Magnetic Coupling WPT System applies a star topology network consisting of one PTU and one or more PRUs. This network allows one PTU to transmit power to multiple PRUs simultaneously. In addition, the device placement of the PRUs on the PTU is flexible (rotational invariance, horizontal and vertical displacement tolerance and angular displacement tolerance).

2.2 System Architecture

A WPT System consisting of a PTU and a PRU is shown in Figure 2-1. The PTU consists of a power delivery unit, power amplifier, matching circuit, power transmitter resonator, transmitter control unit and transmitter communication unit. A PRU consists of a power receiver resonator, rectifier, DC-DC converter, receiver control unit and receiver communication unit.

Power is transferred from the DC output of the power delivery unit in the PTU to the load device in the PRU. Regarding the control communications between PTU and PRU, the 2.4 GHz-band wireless communication system specified in [1] shall be applied.

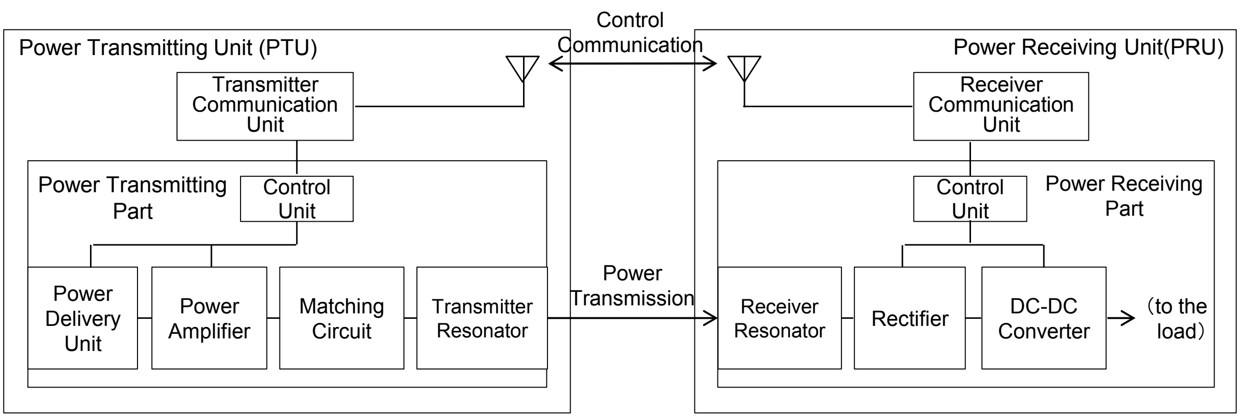


Figure 2-1 WPT System configuration

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Chapter 3 Technical Requirements of the System

3.1 Power Transmission Method

The power transmission method shall be a method using non-modulated continuous waves.

3.2 Power Transmission Frequency Range

The power transmission frequency shall be in the following range:

Higher than or equal to 6.765 MHz and lower than or equal to 6.795 MHz

3.3 Output Power

The output power shall be less than or equal to 50 W.

(RERA: Article 45(iii))

3.4 Radiated Emission Limits

The radiated emission limits shall confirm to "Section 2.1 Limitation on 6 MHz-band magnetic resonance coupling wireless power transmission systems" in [2] for each frequency range below.

(1) In-band emission limits

In the frequency ranges for power transmission, radiated emission shall not exceed the values shown in Table 3-1.

Table 3-1 In-band radiated emission limits

Frequency (f) range	Measurement distance	Limit (quasi-peak)
6.765 MH ≤ f ≤ 6.776 MHz	10 m	44 dBμA/m
6.776 MHz < f ≤ 6.795 MHz		64 dBμA/m

(2) Out-of-band emission limits

Out-of-band radiated emissions shall not exceed the values shown in Table 3-2.

Table 3-2 Out-of-band radiated emission limits

Frequency (f) range	Measure-ment distance	Limit (quasi-peak measurement value)
150 kHz ≤ f < 526.5 kHz	10 m	14.5-15.6451xLog(frequency[MHz]/0.15) dBμA/m
526.5 kHz ≤ f ≤ 1605.5 kHz		-2.0 dBμA/m

1605.5 kHz < f < 4 MHz		14.5-15.6451xLog(frequency[MHz]/0.15) dBμA/m
4 MHz ≤ f < 6.765 MHz		-32.5635+17.3595xLog(frequency[MHz]/0.15) dBμA/m
6.795 MHz < f < 11 MHz		-32.5635+17.3595xLog(frequency[MHz]/0.15) dBμA/m
11 MHz ≤ f ≤ 13.553 MHz		29-15.6451xLog(frequency[MHz]/0.15) dBμA/m
13.567 MHz ≤ f ≤ 20.295 MHz		29-15.6451xLog(frequency[MHz]/0.15) dBμA/m
20.295 MHz < f < 20.385 MHz		4.0 dBμA/m
20.385 MHz ≤ f ≤ 26.957 MHz		29-15.6451xLog(frequency[MHz]/0.15) dBμA/m
27.283 MHz ≤ f ≤ 30 MHz		29-15.6451xLog(frequency[MHz]/0.15) dBμA/m
30 MHz < f ≤ 33.825 MHz		30 dBμV/m
33.825 MHz < f < 33.975 MHz		49.5 dBμV/m
33.975 MHz ≤ f ≤ 40.66 MHz		30 dBμV/m
40.70 MHz ≤ f ≤ 80.872 MHz		30 dBμV/m
80.872 MHz < f < 81.88 MHz		50 dBμV/m
81.88 MHz ≤ f ≤ 134.786 MHz		30 dBμV/m
134.786 MHz < f < 136.414 MHz		50 dBμV/m
136.414 MHz ≤ f ≤ 230 MHz		30 dBμV/m
230 MHz < f ≤ 1000 MHz		37 dBμV/m

When a PTU is embedded in a multimedia device and the limits in [3] are applicable, Table 3-3 and Table 3-4 shall be applied to frequencies higher than or equal to 30 MHz.

Table 3-3 Radiated emission limits for frequencies at least 30 MHz and not more than 1 GHz

Frequency (f) range	Measurement		Limit
	Distance	Detector/Bandwidth	OATS/5-wall anechoic chamber (refer Table A1 in [3])
30 MHz < f ≤ 33.825 MHz	10 m	Quasi-Peak / 120 kHz	30 dBμV/m
33.825 MHz < f ≤ 33.975 MHz			49.5 dBμV/m
33.975 MHz ≤ f ≤ 40.66 MHz			30 dBμV/m
40.70 MHz ≤ f ≤ 230 MHz			30 dBμV/m
230 MHz < f ≤ 1000 MHz			37 dBμV/m
30 MHz < f ≤ 33.825 MHz	3 m		40 dBμV/m
33.825 MHz < f < 33.975 MHz			59.5 dBμV/m

33.975 MHz ≤ f ≤ 40.66 MHz			40 dBμV/m
40.70 MHz ≤ f ≤ 230 MHz			40 dBμV/m
230 MHz < f ≤ 1000 MHz			47 dBμV/m

Table 3-4 Radiated emission limits for frequencies at least 1 GHz and not more than 6 GHz

Frequency (f) range	Measurement		Limit
	Distance	Detector/Bandwidth	OATS/5-wall anechoic chamber (refer Table A1 in [3])
1000 MHz < f ≤ 3000 MHz	3 m	Average / 1 MHz	30 dBμV/m
3000 MHz < f ≤ 6000 MHz			37 dBμV/m
1000 MHz < f ≤ 3000 MHz		Peak / 1 MHz	40 dBμV/m
3000 MHz < f ≤ 6000 MHz			47 dBμV/m

3.5 RF Exposure Limits for the Human Body

RF exposure limits for the human body shall comply with “Section 3.2 RF exposure limits applied to Wireless Power Transmission Systems” in [2]. Regarding the electro-magnetic field intensity limits in common environments (average value over 6 minutes), the values in Table 3 (a) in [4] shall be applied. Regarding the stimulating effect, the guideline and guideline values in [4] shall be applied.

3.6 Requirements for Control Communications

Refer to [1] for the control communication system requirements.

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Chapter 4 System Requirements for Interoperability

This chapter stipulates the technical specifications for interoperability between 6.78 MHz-Magnetic Coupling WPT Systems with reference to Appendix 1.

4.1 Description of the System and System Components

Refer to "1 Introduction" in Appendix 1.

4.2 Fundamental Requirements

Refer to "2 High Level Requirements" in Appendix 1.

4.3 Power Transmitting Unit and Power Receiving Unit Classifications

Refer to "3 Device Types" in Appendix 1.

4.4 Power Transfer Specifications

Refer to "4 Power Transfer Specifications" in Appendix 1.

4.5 Power Control Specifications

Refer to "5 Power Control Specifications" in Appendix 1.

4.6 Specifications for Control and Control Communications

Refer to "6 Signaling Specifications" in Appendix 1.

4.7 Power Transmitter Reference Resonator

Refer to "7 PTU Resonators" in Appendix 1.

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Chapter 5 Measurement Methods

In this chapter, the measurement methods are stipulated for confirming that the system meets the requirements in “Chapter 3Technical requirements of the system."

5.1 Test Conditions

5.1.1 Humidity and temperature of the measurement location

(1) Measurements shall be performed in the temperature range of 5 - 35°C.

(2) Measurements shall be performed in the humidity range of 45 - 85%.

5.1.2 Load

The requirements for the load used in the measurements are described in 5.2. Use the following loads: Power Receiving Unit, resistance load or electronic load device.

5.2 Measurement Conditions

5.2.1 Power transmission frequency ranges

The power transmission frequency shall be measured 15 minutes after the PTU starts transferring power.

5.2.2 Output power

The power supplied to the power amplifier of the Power Transmitting Part is defined as the output power, and it shall be measured with reference to the system diagram shown in Figure 5-1 and in accordance with the following conditions:

- Switch the power delivery unit output from the Power Amplifier of the PTU to an electronic load device for measurement.
- Measure the power at an electronic load device that simulates the load condition at the maximum power transmission of the PTU.

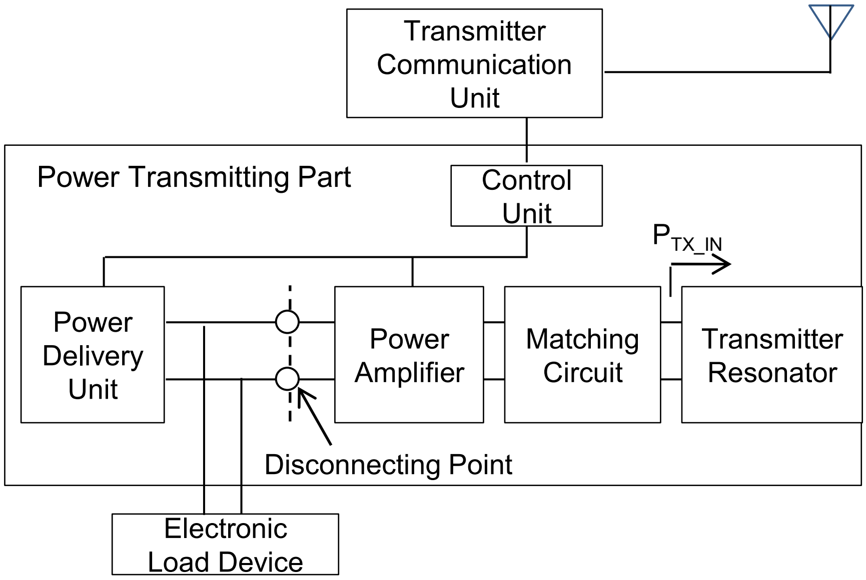

Figure 5-1 Output power measurement system diagram

5.2.3 Radiated emission limits

Radiated emission limits shall be measured based on following clauses of [2]: "2.3 Measurement equipment", "2.4 Configuration and arrangement of devices under test", "2.5 Operational requirements of devices under test" and "2.6 Measurement method". The measurements shall be performed when the PTU is transferring power at the maximum level.

5.2.4 RF exposure limits for the human body

The RF exposure limit for the human body shall be measured based on "3.3 The evaluation method for verifying the guideline pattern and values to be applied in the wireless power transmission system" in [2] under the condition that the PTU is transferring power at the maximum level

5.2.5 Verification of the control communication functions

Refer to [1] for the requirements for verifying the control communication functions.

Chapter 6 Terms and Definitions

6.1 Terms and Defintions

The terms used in this Standard are defined as follows:

[A4WP (Alliance for Wireless Power)]

An independently operated, non-profit organization founded in 2012 that is dedicated to building a global wireless charging ecosystem. A4WP activities include the development of wireless power transfer technology and specifications based on the principles of magnetic resonance.

[DC-DC Converter]

A converter for converting the DC voltage level at the DC power input to another level while maintaining high efficiency

[Other Equipment]

Equipment categorized as “high-frequency-based equipment” with no communication function that is used for directly providing high frequency energy to the load, or is otherwise used for heating, ionization, etc.

[Output Power]

Electrical power transmitted via a power line conducting high frequency current at 10 kHz or greater. In the 6.78 MHz Magnetic Coupling WPT System, it is the electric power provided to the power amplifier in the PTU.

[High-Frequency-Based Equipment]

A category of equipment that utilizes high frequency current of 10 kHz or greater that is stipulated in Article 100, Paragraph 1 of the Japan Radio Act.

[Magnetic Coupling WPT System]

A Wireless Power Transmission System, which transfers electric power from a PTU to a PRU where the PTU and the PRU are tuned at the same frequency and resonate in a magnetic field.

[Receiver Resonator]

A magnetic field generator in the PRU such as a coil or an electrical conducting wire that satisfies the resonance condition used for the efficient transfer of electrical power.

[Power Receiving Unit]

A unit that receives electrical power wirelessly transferred from a power transmitting unit.

[Control Unit]

A unit governing the state and the performance of a PTU or PRU for transferring the necessary power wirelessly.

[Rectifier]

An electronic circuit that converts electric power from AC to DC.

[Transmitter Resonator]

It is a magnetic field generator in the PTU such as a coil or an electrical conducting wire that satisfies the resonance conditions used for the efficient transfer of electrical power.

[Power Transmitting Unit]

A unit that transfers electrical power wirelessly to a power receiving unit.

[Power Supply]

A device that supplies electric power to an electrical load

[Radio-Radiation Protection Guidelines]

It stipulates the recommended guidelines to be used when a person uses radio waves and the human body is exposed to an electromagnetic field (in a frequency range of 10 kHz through 300 GHz) in order to ensure that the electromagnetic field is safe and has no unnecessary biological effect on the human body. These guidelines consist of numeric values related to electromagnetic strength, the method of evaluating the electromagnetic field and the method of protecting and reducing electromagnetic field exposure.

In this Standard, these guidelines refer to (1) Safety Guidelines for Use of Radio Waves (Report by the Telecommunications Technology Council of the Ministry of Posts and Telecommunications [June 1990]: Inquiry No. 38 "The Protection Policy for the Human Body from Effects of Radio Waves use") and (2) Safety Guidelines for Use of Radio Waves (Report by the Telecommunications Technology Council of the Ministry of Posts and Telecommunications [April 1997]: Inquiry No. 89 "Protection from the Radio Waves on the Human Body")

[Power Amplifier]

An electrical amplifier that amplifies the input power to the level used for power transfer.

[Matching Circuit]

An electrical circuit that generates maximum output power transfer by impedance matching of the input and output circuits.

6.2 Abbreviations

The abbreviated terms used in this standard are defined as follows.

[A]

A4WP	Alliance for Wireless Power

[P]

PRU	Power Receiving Unit
PTU	Power Transmitting Unit

[W]

WPT	Wireless Power Transmission

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Appendix 1

A4WP Wireless Power Transfer System, Baseline System Specifications (BSS) V1.2.1, May 07, 2014

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A4WP Wireless Power Transfer System Baseline System Specification (BSS) V1.2.1

Final Approved Specification

May 07, 2014

ALLIANCE FOR WIRELESS POWER

(A4WP)

LEGAL NOTICES AND TERMS OF USE

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Revision History

Revision	Date	Description
1.0	October 25, 2012	First draft
1.1	June 13, 2013	Incorporation of changes accepted from December 2012 through June 2013.
1.2	November 21, 2012	Incorporation of accepted changes resulting from Plug-fest 1 and 2.
1.2.1	May 07, 2014	Incorporation of TWC1 accepted phase 1 input, resonat-or resolutions and plugfest #4 resolutions.

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Foreword

This document was prepared by the Technical Working Committees (TWC 1+2) of the Alliance for Wireless Power (A4WP).

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1 Introduction

This document provides technical requirements for flexibly coupled wireless power transfer (WPT) systems. This specification pertains only to behaviors and interfaces which are necessary for ensuring interoperability.

1.1 Compliance Notation

As used in this document "shall" and "must" denote mandatory provisions of the standard. "Should" denotes a provision that is recommended but not mandatory. "May" denotes a feature whose presence does not preclude compliance, and implementation of which is optional. "Optional" denotes items that may or may not be present in a compliant device. RFU (Reserved for Future Use) bits and fields defined in this specification are designated for exclusive use by A4WP and shall not be used for vendor proprietary purposes.

1.2 References

References are either normative or informative. A normative reference is used to include another document as a mandatory part of an A4WP specification. Documents that provide additional non-essential information are included in the informative references section.

1.2.1 Normative References

The following standards contain provisions which, through reference in this text, constitute provisions of this standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based upon this document are encouraged to investigate the possibility of applying the most recent editions of the standards indicated published by them.

Bluetooth Core Specification v4.0 with CSA4.

1.2.2 Informative References

A4WP-T-0001 A4WP New PTU Resonator and Resonator Interface Acceptance Test

1.3 Acronyms and Definitions

Table 1.3-1 Acronyms

Acronym	Definition
GAP	Generic Access Profile
GATT	Generic Attribute Profile
MCU	Microcontroller
NFC	Near Field Communication
LE	Low Energy
OCP	Over Current Protection
OTP	Over Temperature Protection

Acronym	Definition
OVP	Over Voltage Protection
PA	Power Amplifier
PRU	Power Receiving Unit
PTU	Power Transmitting Unit
RFU	Reserved for Future Use
UUID	Universally Unique Identifier
WPT	Wireless Power Transfer

Table 1.3-2 Definition of Terminologies

Terminology	Definition
Advertisement	A Connectable Undirected Advertising Event where the device transmits three WPT Service Specific ADV_IND packets, one on each of the advertising channels, and accepts both scan requests and connect requests. Receipt of an advertisement is defined to be receipt of one of the three advertisement packets.
Category	A type of PRU.
Charge Area	When the PRU (i.e., the entire device) is larger than the charge area, the test area (charge area in tests) is defined as the region of maximum overlap between the PTU charge area (ided by vendor)[1] and the PRU Resonator. Otherwise, when the PRU is smaller than the charge area, the Test Area (charge area in tests) is defined as the region of maximum overlap between the PTU charge area (ided by vendor)[1] and the PRU (entire device). The boundaries of the PTU charge area and the PRU resonator area should be identified by the PTU and PRU vendors, respectively. Vendor charge area indication shall be equal or smaller than test charge area. Additionally, "within the charge area" is equated to mean "within the test area".
Class	A type of PTU.
Concurrent Multiple Charging	Magnetic resonant coupling may occur among one transmitting resonator and many receiving resonators while tight coupling is restricted to only one transmitting coil and one receiving coil. This enables the magnetic resonance coupling technology to transmit power concurrently to multiple receiving units while the tightly coupled technology only allows one-to-one power transmission.
Delta R1	The change in the measured resistance of a PTU resonator when a PRU, with an open-circuit PRU resonator, is placed in the center of the charge area of the PTU resonator, as compared to the resistance of the PTU resonator when no objects are in the charge area.
Device registry	A list of active PRU's maintained by the PTU. These PRU's are connected to the PTU via the BLE link and can be charged.
Dominant PRU	The PRU that is consuming the highest percentage of its rated output power (V_{RECT} * I_{RECT} / P_{RECT_MAX}).

1 This does not preclude the PRU resonator being larger than the PTU resonator.

Terminology	Definition
Flexibly Coupled Wireless Power Transfer	A flexibly coupled wireless power transfer system provides power through magnetic induction between a transmitter coil and a receiver coil where the coupling factor (k) between the coils can be large or very small (e.g., less than 0.025). Also, in a flexibly coupled system the transmitter (i.e., the primary) coil can be of the same size, or much larger than the receiver (i.e., secondary) coil. The allowable difference in coil size enables concurrent charging of multiple devices as well as more flexible placement of receiver coils within the charging area.
High voltage	PRU region in which V_{RECT} levels result in high power dissipation but do not damage the PRU.
Low voltage	PRU region in which V_{RECT} levels are below the operational range
Normal operation	The range of all specified WPT states other than PRU System Error State for over-voltage.
Over Voltage	PRU region in which V_{RECT} voltages greater than V_{RECT_MAX} can permanently damage PRU components if the PRU does not correct the condition (refer to section 5.3.6, PRU System Error State for Over-voltage).
Power Receiving Unit (PRU)	A Unit receiving electrical power wirelessly from a power transmitting unit.
Power Transmitting Unit (PTU)	A Unit transferring electrical power wirelessly to each power receiving unit.
R_{RX_IN}	The parasitic resistance of the PRU resonator.
Rectifier efficiency	The rectifier efficiency is equal to P_{RECT} / P_{RX_OUT}.
Rectifier impedance transform	The rectifier impedance transform is equal to I_{RX_IN} / I_{RECT}.
Resonance	The condition of a body or system when it is subjected to a periodic disturbance of the same frequency as the natural frequency of the body or system. At this frequency, the system displays an enhanced oscillation or vibration.
Resonator	A magnetic field generator such as a coil or an electrical conducting wire satisfying resonance condition to be used for efficiently transferring electrical power from a PTU to a PRU.
Rogue Object	An object such as a piece of metal or an uncertified (i.e., a non-A4WP) device that can interrupt the general charging mechanism. Note: Test to Resonator Interface Test (RIT) device, RIT 3-1, with a 50 ohm load. Refer to A4WP New PTU Resonator and Resonator Interface Acceptance Test [A4WP-T-0001].
Wireless Power Transfer	The processes and methods that take place in any system where electrical power is transmitted from a power source to an electrical load without interconnecting wires.

Table 1.3-3 Definition of Variable Parameters

Variable	Definition
η_{RECT}	Rectifier efficiency (P_{RECT_OUT} / P_{RECT_IN}).
I_{RECT}	The DC current out of the PRU's rectifier.
I_{RECT_REPORT}	The I_{RECT} value which a PRU reports to a PTU.
I_{RX_IN}	The RMS current out of the resonator/into the rectifier, while in the PRU On State.
I_{TX}	The RMS current into the Z_{TX_IN} impedance.

Variable	Definition
I_{TX_COIL}	The RMS current into the PTU resonator coil.
$I_{TX\_LONG\_BEACON}$	The RMS current provided to the PTU resonator, during the long beacon period in the PTU Power Save State. This current is used to provide minimum power for waking up a PRU signaling module and MCU, and to initiate communication.
$I_{TX\_SHORT\_BEACON}$	The RMS current into the PTU resonator, while in the Power Save State, to detect the PTU impedance change caused by the placement of an object in the charging area.
I_{TX_START}	The RMS current into the PTU resonator, to provide minimum power for waking up a PRU signaling module and MCU, and to initiate communication and registration.
P_{IN}	The DC power into the PTU.
P_{TX_IN}	Input power to the resonator.
P_{RECT}	Average power out of the PRU's rectifier (V_{RECT}*I_{RECT}).
P_{RECT_IN}	The average power into the PRU rectifier.
$P_{RX\_REPORTED}$	V_{RECT_REPORT} * I_{RECT_REPORT}.
P_{RX_OUT}	Power out of the PRU resonator.
R_{RECT}	Effective load resistance at the output of the PRU's rectifier.
R_{RECT_MP}	Maximum power point resistance.
V_{PAa}	DC input voltage to the PTU's power amplifier.
V_{RECT}	DC voltage at the output of a PRU's rectifier.
V_{RECT_REPORT}	V_{RECT} value which a PRU reports to a PTU.
Z_{RX_IN}	The input impedance of the PRU resonator and matching network.

Table 1.3-4 Definition of PTU/PRU Design Dependent Parameters

Variable	Definition
ADV_PWR_MIN	The minimum BLE advertisement power as seen at the PTU BLE antenna.
$I_{TX\_ABS\_MAX}$	Absolute maximum PTU current[2].
$I_{TX\_LONG\_BEACON\_MIN}$	Minimum allowed current during PTU Long beacon[2].
$I_{TX\_SHORT\_BEACON\_MIN}$	Minimum allowed current during PTU Short beacon[2].
I_{TX_MAX}	Operational maximum PTU current[2].
I_{TX_MIN}	Operational minimum PTU current[2].
$I_{TX\_NOMINAL}$	Nominal PTU resonator current which drives all PRUs to operate in the optimum voltage region[2].
P_{RECT_MAX}	PRU's maximum rated P_{RECT} power.
P_{RECT_MIN}	PRU's minimum rated P_{RECT} power.

2 Typically applies to either I_{TX} or I_{TX_COIL}.

Variable	Definition
$P_{RX\_OUT\_MAX}$	The maximum output power of the PRU resonator.
R_{RX_MIN}	The minimum value of resistance that will be presented to the PRU resonator terminals during normal operation.
R_{RECT_MP}	R_{RECT} resistance which achieves maximum P_{RECT} power.
R_{TX_IN}	The real part of Z_{TX_IN}.
V_{RECT_BOOT}	Boot V_{RECT} voltage. Below this level, the PRU can not enter the Boot State.
V_{RECT_HIGH}	Maximum operational V_{RECT} voltage.
V_{RECT_MAX}	PRU's maximum allowable V_{RECT} voltage.
V_{RECT_MIN}	Minimum operational V_{RECT} voltage. Below this voltage, PRUs may not deliver full power.
V_{RECT_SET}	PRU's preferred V_{RECT} voltage.
V_{RECT_UVLO}	Under Voltage Lock Out V_{RECT} voltage. Below this level, the PRU may not enable MCU and communication module.
X_{TX_IN}	The imaginary part of Z_{TX_IN}.
Z_{PA_SOURCE}	Source impedance of resonator power supply.
$Z_{PA\_SOURCE\_MIN}$	The minimum allowable source impedance of the amplifier or supply which provides current to the PTU resonator.
$Z_{RX\_IN\_PORT}$	Reference Port Impedance of PRU Resonator to measure S21.
$Z_{TX\_IN\_IMG\_MAX}$	Maximum allowable reflected Tx reactance ($Im\{Z_{TX\_IN}\}$).
$Z_{TX\_IN\_IMG\_MIN}$	Minimum allowable reflected Tx reactance ($Im\{Z_{TX\_IN}\}$).
$Z_{TX\_IN\_LOAD\_CHANGE}$	The minimum load change in Z_{TX_IN} created by a PRU when placed in the charge area of a PTU when a current greater than or equal to $I_{TX\_SHORT\_BEACON\_MIN}$ is applied. This value is specific to a PTU Resonator design.
$Z_{TX\_IN\_LOAD\_DETECT}$	The minimum change in Z_{TX_IN} that the PTU resonator circuitry shall be able to detect.
$Z_{TX\_IN\_PORT}$	Reference Port Impedance of PTU Resonator to measure S21.
$Z_{TX\_IN\_REAL\_MAX}$	Maximum allowable reflected Tx resistance ($Re\{Z_{TX\_IN}\}$).
Z_{TX_IN}	Input Impedance of PTU Resonator and matching network.

1.4 System Description

The Alliance for Wireless Power (A4WP) WPT system transfers power from a single Power Transmitter Unit (PTU) to one or more Power Receiver Units (PRU's.) The power transmission frequency is 6.78 MHz, and up to eight devices can be powered from a single PTU depending on transmitter and receiver geometry and power levels. The Bluetooth Low Energy (BLE) link in the A4WP system is intended for control of power levels, identification of valid loads and protection of non-compliant devices.

Figure 1.4-1 illustrates the basic WPT system configuration between a PTU and a PRU. The PTU can be expanded to serve multiple independent PRUs. The PTU comprises three main functional units which are a resonator and matching unit, a power conversion unit, and a signaling and control unit. The PRU also comprises three main functional units like the PTU.

The control and communication protocol for the WPT network is designed as the bidirectional and half duplex architecture and is used to signal PRU characteristics to the PTU as well as to provide feedback to enable efficiency optimization, over-voltage protection, under-voltage avoidance, and rogue object detection.

The WPT network is a star topology with the PTU as the master and PRUs as slaves. The PTU and the PRU perform the bidirectional communication to each other to identify the device compliance and to exchange the power negotiation information.

In this specification, section 2 provides high level requirements and section 3 identifies device classifications. Section 4 provides power transfer requirements (including a fixed 6.78 MHz operating frequency, resonator requirements and load parameters) while section 5 provides PTU and PRU power control requirements. Section 6 provides signaling requirements, section 7 identifies approved PTU resonator designs and Annex A includes reference PRUs for PTU acceptance testing. Annex B is an informative annex for PTU lost power.

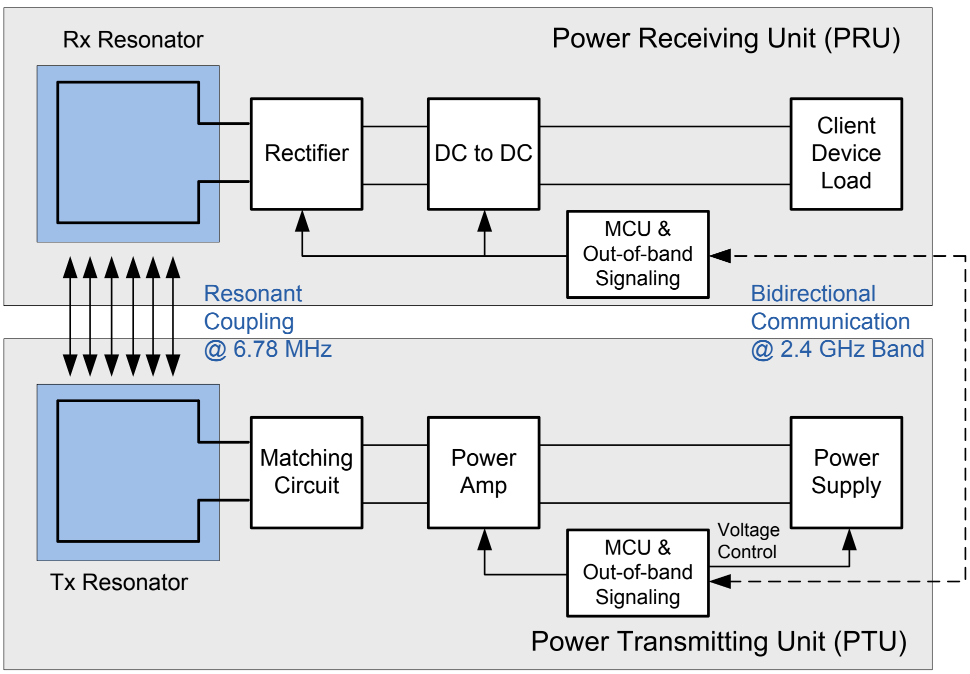

Figure 1.4-1 Wireless Power Transfer System

2 High Level Requirements

2.1 Conformance

PRU and PTU units shall comply with all normative sections of this specification.

2.2 Resonator Designs

The Certification Authority (CA) administers the approval process of new PTU resonator designs and is responsible for the review of test results and the determination regarding acceptance. Approved PTU resonator designs are added to section 7, PTU Resonators. Refer to the A4WP Certification Program Management Document for further information.

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3 Device Types

3.1 PTU Classification

There are five classes which are defined by the following:

1. The capability of the PTU to inject power into the PTU resonator ($P_{TX\_IN\_MAX'}$). The PTU shall be capable of attaining the value of $P_{TX\_IN\_MAX'}$, where P_{TX_IN} is the real power, Avg V(t)*I(t). Refer to section 4 for power transfer requirements.
2. The number and category of PRUs that are supported.

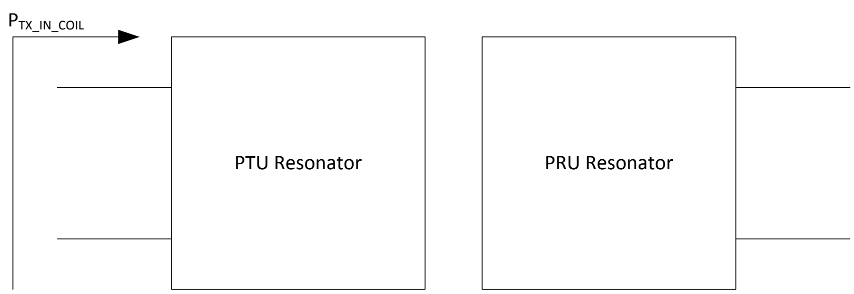

Figure 3.1-1 PTU-PRU Resonator P_{TX_IN}

Table 3.1-1 PTU Classification

	$P_{TX\_IN\_MAX'}$	Minimum PRU Support Requirements
Class 1	TBD	1 x Category 1
Class 2	10 W	1 x Category 1, 2, or 3
Class 3	16 W	2 x Category 1,2, or 3, or 1 x Category 4
Class 4	22 W	3 x Category 1, 2, or 3, or 1 x Category 4
Class 5	TBD	TBD

3.2 PRU Category

Illustrated in Figure 3.2-1, the PRU resonator output power denoted by P_{RX_OUT} is the real power Avg V(t)*I(t). Table 3.2-1 lists the PRU resonator output power ($P_{RX\_OUT\_MAX'}$) for PRU categories. Refer to section 4 for power transfer requirements.

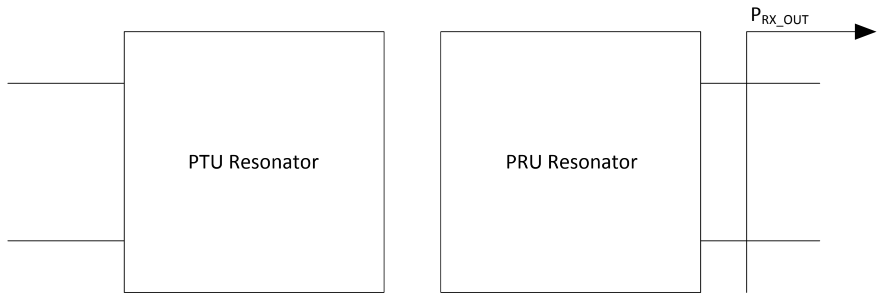

Figure 3.2-1 PTU-PRU Resonator P_{RX_OUT}

The PRU shall not draw more power than specified for its category. Refer to Table 3.2-1.

Table 3.2-1 PRU Category

PRU	$P_{RX\_OUT\_MAX}$'	Example Applications
Category 1	TBD	BT headset
Category 2	3.5W	Feature Phone
Category 3	6.5W	Smart Phone
Category 4	TBD	Tablet
Category 5	TBD	Laptop

NOTE: For P_{RX_OUT}, the PRU power is the output power of the PRU resonator.

NOTE: 6.5 W is intended to allow 5W at the charge port if the implementation has an efficiency greater than 80%.

4 Power Transfer Specifications

4.1 System Equivalent Circuit and Reference Parameters

The equivalent circuit of the PTU resonator shall be series-tuned, or series-shunt-tuned. The equivalent circuit of the PRU resonator shall be series-tuned, shunt tuned, or series-shunt tuned. Figure 4.1-1 shows the interface point where the reference parameters are measured.

NOTE: The methodology for designing a matching network for a PTU or PRU coil-amplifier interface is described in an A4WP matching network White Paper.

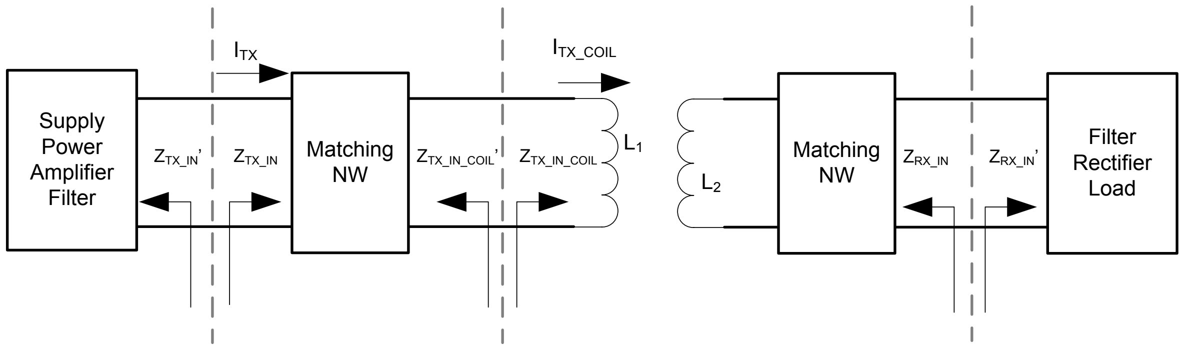

Figure 4.1-1 Equivalent Circuit and System Parameters

4.2 General System Requirements

4.2.1 Operating Frequency

The resonator system shall operate at 6.78 MHz ± 15 kHz.

4.2.2 Z_{TX_IN} Relationship to R_{RECT}

The real part of Z_{TX_IN} shall be inversely related to the load resistance of the rectifier. An increase in R_{RECT} shall cause a decrease in Z_{TX_IN}. A decrease in R_{RECT} shall cause an increase in Z_{TX_IN}.

4.2.3 Power Stability

Under all operational conditions (transient/steady state) involving two or more PRUs, the change in rectified-output power of a first PRU, should be no more than 10% in the following two conditions:

1. A second PRU is physically added or removed from the charge area in a location that does not overlap with the first PRU.
2. A second PRU which is already in the charge area makes step response from 0% load to 100% load in less than 1ms.

4.2.4 PTU Co-location Protection

A PTU shall protect itself when collocated with a PTU resonator of section 7, PTU Resonators, which is conducting $I_{TX\_ABS\_MAX}$.

4.2.5 PRU Self Protection (Informative)

PRU's can experience high field strengths as a result of $I_{TX\_ABS\_MAX}$ and are expected to protect themselves accordingly.

4.3 Resonator Requirements

4.3.1 Resonator Coupling Efficiency (RCE)

S_{21} shall be measured at 6.78 MHz with the reference port impedances of one PTU and one PRU as specified in sections 4.3.1.1 and 4.3.1.2. The S_{21} shall be equal to or higher than the minimum values given in Table 4.3.1-1. The S_{21} efficiency measurements shall be based on perfectly-matched port impedance conditions. The methodology for achieving perfectly matched port impedance conditions is described in an A4WP impedance matching White Paper.

The assessment of coupling efficiency can also be conducted using Z parameters.

NOTE: The equivalence of S parameters and Z parameters for the assessment of coupling efficiency shall be described in an A4WP S and Z parameter equivalence White Paper.

NOTE: Assessment shall be performed within the physical charging area specified in section 7, PTU Resonators.

NOTE: Assessment for a new PRU must be performed on all approved PTUs at the time of certification.

Table 4.3.1-1 Minimum S21 (dB) between PRU and PTU

	Category 1	Category 2	Category 3	Category 4	Category 5
Class 1	TBD	TBD	TBD	TBD	TBD
Class 2	TBD	-1.3	-1.3	TBD	TBD
Class 3	TBD	-1.3	-1.3	TBD	TBD
Class 4	TBD	TBD	TBD	TBD	TBD
Class 5	TBD	TBD	TBD	TBD	TBD

NOTE: When multiple PRUs are used, the coupling efficiency will increase.

4.3.1.1 Reference Port Impedance of PTU Resonator

The reference port impedance of PTU resonator to measure S_{21} shall be Z_{TX_IN}, and is PTU resonator design dependent.

4.3.1.2 Reference Port Impedance of PRU Resonator

The reference port impedance of PRU resonator to measure S_{21} shall be equal to Z_{RX_IN}.

4.3.2 PTU Resonator Requirements

4.3.2.1 Approved PTU Resonator Designs

Only approved PTU resonator designs shall be used. PTU resonators shall be built according to the requirements in section 7, PTU Resonators.

4.3.2.2 Resonator Current

4.3.2.2.1 Threshold Values

1. The PTU resonator coil current shall not exceed I_{TX_MAX} during either the long beacon-on period or the short beacon-on period.
2. The PTU shall conduct a current greater than $I_{TX\_SHORT\_BEACON\_MIN}$ through the PTU resonator coil during the short beacon-on period.
3. The PTU shall be capable of conducting a current $I_{TX\_NOMINAL}$ through the PTU resonator coil during the PTU Power Transfer State. The tolerance of $I_{TX\_NOMINAL}$ shall be no greater than 5% excluding measurement error. $I_{TX\_NOMINAL}$ shall be derated at high values of R_{TX_IN} based on the value of $P_{TX\_IN\_MAX'}$ which is defined according to the PTU Class[3]. The equation for the derated current is:

   $$I_{TX\_NOMINAL\_DERATED} = \text{MIN}\ (I_{TX\_NOMINAL}, \text{SQRT}\ (P_{TX\_IN\_MAX'}/R_{IN\_TX})$$

4. The PTU shall be capable of conducting a current I_{TX_MAX} through the PTU resonator coil. I_{TX_MAX} shall be derated at high values of R_{TX_IN} based on the value of $P_{TX\_IN\_MAX'}$ which is defined according to the PTU Class. The equation for the derated current is:

   $$I_{TX\_MAX\_DERATED} = \text{MIN}\ (I_{TX\_MAX}, \text{SQRT}\ (P_{TX\_IN\_MAX'}/R_{IN\_TX})$$

5. The PTU resonator coil shall not conduct more than $I_{TX\_ABS\_MAX}$ in any transient or steady state condition.

4.3.2.2.2 Transitions

The PTU resonator coil shall not exceed its maximum slew rate. Refer to Table 7.1.1-1.

4.3.2.3 Resonator Power Supply Characteristics

The PTU resonator shall be driven by a supply that has a source impedance that is greater than $Z_{PA\_SOURCE\_MIN}$.

NOTE: $Z_{PA\_SOURCE\_MIN}$ is specified because it affects the source impedance of PRUs.

NOTE: $Z_{PA\_SOURCE\_MIN}$ is specified to approximate a current source behavior at the PTU resonator interface.

4.3.2.4 Resonator Power Supply Impedance Range

The PTU shall be capable of conducting current levels through the PTU resonator coil that satisfy the Resonator Current Threshold Values across its specified range of Z_{TX_IN}.

$$R_{TX\_IN\_MIN} \leq \text{Re}\{Z_{TX\_IN}\} \leq R_{TX\_IN\_MAX}$$

$$X_{TX\_IN\_MIN} \leq \text{Im}\{Z_{TX\_IN}\} \leq X_{TX\_IN\_MAX}$$

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[3] Note that in implementation, the provision of $I_{TX\_NOMINAL}$ to all loads is not intended to cause a rise in the charging area temperature.

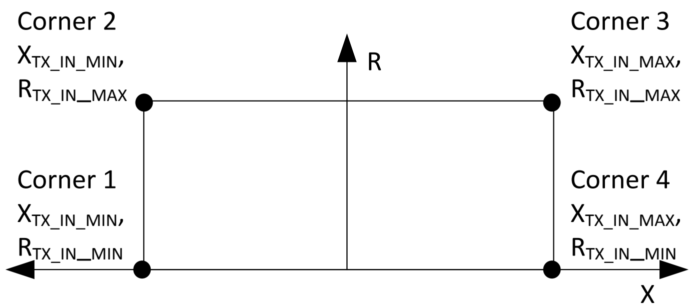

Figure 4.3.2.4-1 PTU Resonator-load Considerations

4.3.2.5 Resonator Geometry

The PTU resonator geometry shall be built to the requirements of section 7, PTU Resonators.

NOTE: The above PTU resonator requirements are resonator design specific and numbers for the above parameters are specified in section 7, Approved PTU Resonators.

4.3.2.6 Resonator Impedance Sensitivity

The PTU resonator control circuitry shall be capable of detecting a load change of $Z_{TX\_IN\_LOAD\_DETECT}$ in the value of Z_{TX_IN}.

$Z_{TX\_IN\_LOAD\_DETECT}$ shall be at least 30% less than both the Real (R) and Imaginary (X) components of the $Z_{TX\_IN\_LOAD\_CHANGE}$ specified for the PTU resonator used in the PTU (refer to RAT, [A4WP-T-0001]).

4.3.3 PRU Resonator Requirements

4.3.3.1 PRU Operating Points

V_{RECT} can be derived as a function of the Z matrix, I_{TX_COIL}, rectifier characteristics and load. The relationship between all of the parameters is dependent on PRU implementation. It is the responsibility of the Original Equipment Manufacturer (OEM) to produce a design that allows for conformance.

4.3.3.1.1 PRU Low Voltage Sub-state Threshold

A PRU's V_{RECT} shall exceed its V_{RECT_BOOT} when I_{TX_COIL} is greater than $I_{TX\_LONG\_BEACON\_MIN}$ on presently approved PTU resonators (refer to section 7).

NOTE: This requirement is for start-up conditions and a PRU load is not required (refer to section 5.3.4.1).

4.3.3.1.2 PRU Optimum Voltage Sub-state Threshold

For a single-PRU configuration (i.e., for a PTU that only charges one PRU):

1. The PRUs V_{RECT} shall exceed its V_{RECT_MIN} if I_{TX_COIL} is greater than or equal to I_{TX_MAX},
2. The PRUs V_{RECT} shall not exceed its V_{RECT_HIGH} if I_{TX_COIL} is less than or equal to $I_{TX\_NOMINAL}$.

Otherwise, a PRU shall be in the *PRU Optimum Voltage Sub-state* when I_{TX_COIL} is equal to $I_{TX\_NOMINAL}$ on presently approved PTU resonators (refer to section 7).

4.3.3.1.3 PRU Set-point Limit

A PRU shall not require I_{TX_COIL} to exceed I_{TX_MAX} to reach V_{RECT_SET} on presently approved PTU resonators (refer to section 7).

4.3.3.1.4 PRU Over-voltage Threshold

A PRU in normal operation shall not enter the PRU System Error State if I_{TX_COIL} is less than or equal to I_{TX_MAX} on presently approved PTU resonators (refer to section 7).

4.3.3.1.5 PRU Over-voltage Protection

A PRU shall not be damaged if I_{TX_COIL} is less than or equal to $I_{TX\_ABS\_MAX}$ on presently approved PTU resonators (refer to section 7).

4.3.3.2 PRU-induced Reactance Change

A PRU shall present X_{TX_IN} which is within the X_{TX_IN} range defined in section 7, PTU Resonators.

4.3.3.3 PRU-induced Resistance Change

A PRU shall present R_{TX_IN} which is within the R_{TX_IN} range defined in section 7, PTU Resonators.

4.3.3.4 Short Beacon PRU-induced Impedance

On or before March 1, 2015, a PRU of Category 2 or greater should create a change in reactance and/or resistance of at least $Z_{TX\_IN\_LOAD\_CHANGE}$ when placed in charge area of all currently approved PTU resonators.

After March 1, 2015, a PRU of Category 2 or greater shall create a change in reactance and/or resistance of at least $Z_{TX\_IN\_LOAD\_CHANGE}$ when placed in charge area of all currently approved PTU resonators.

If a Category 1 PRU does not create an impedance change of at least $Z_{TX\_IN\_LOAD\_CHANGE}$ then it shall advertise that it does not create an impedance shift in the PRU Advertising Payload (refer to section 6.5.1).

4.4 Load Parameters

NOTE: PRUs with non-integrated loads (e.g., backpack phone chargers that plug into a mobile phone) have to comply with the requirements in this section for any devices with which they might be connected. This may require the PRU to include mechanisms to ensure that they are compliant when connected to their intended load devices.

4.4.1 Minimum Load Resistance

The minimum value of R_{RECT} shall be greater than the maximum power point resistance (R_{RECT_MP}). The maximum power point resistance, R_{RECT_MP}, is defined as the load resistance measured after the rectifier at which maximum power delivery is achieved.

NOTE: R_{RECT_MP} is a function of Z_{PA_SOURCE}, PTU resonator design, and PRU resonator design.

4.4.2 Maximum Allowable Dynamic Load

The load, measured at the output of the rectifier, shall not change by more than 650 mW/µs or X/µs, which ever is greater. X shall be calculated as 2% times the maximum output power of the PRU resonator in mW.

4.4.3 Maximum Load Capacitance

The effective load capacitance connected after the rectifier shall be no greater than the maximum effective capacitance shown in Table 4.4.3-1.

Table 4.4.3-1 Maximum Load Capacitance

Category	Maximum Effective Capacitance
Category 1	TBD
Category 2	100 µF
Category 3	100 µF
Category 4	TBD
Category 5	TBD

5 Power Control Specifications

5.1 Control Objectives

The control specifications are designed to:

1. Protect PRU's V_{RECT} from over-voltage (i.e., $V_{RECT} > V_{RECT\_MAX}$).
2. Reduce PRU's V_{RECT} such that $V_{RECT} \leq V_{RECT\_HIGH}$ within 5s after a PRU reports it $V_{RECT} > V_{RECT\_HIGH}$.
3. Ensure that all PRUs are provided a V_{RECT} voltage greater than V_{RECT_MIN} and less than V_{RECT_HIGH}, if objectives #1 and #2 are satisfied.
4. Control I_{TX_COIL}, if objectives #1, #2 and #3 are satisfied, to:
   a. Optimize the V_{RECT} of the PRU with the highest percentage utilization of P_{RECT} power, or
   b. Maximize the total system efficiency.

5.2 PTU Specifications

5.2.1 PTU State

The PTU shall have the following states: PTU Configuration, PTU Power Save, PTU Low Power, PTU Power Transfer, PTU Local Fault, and PTU Latching Fault.

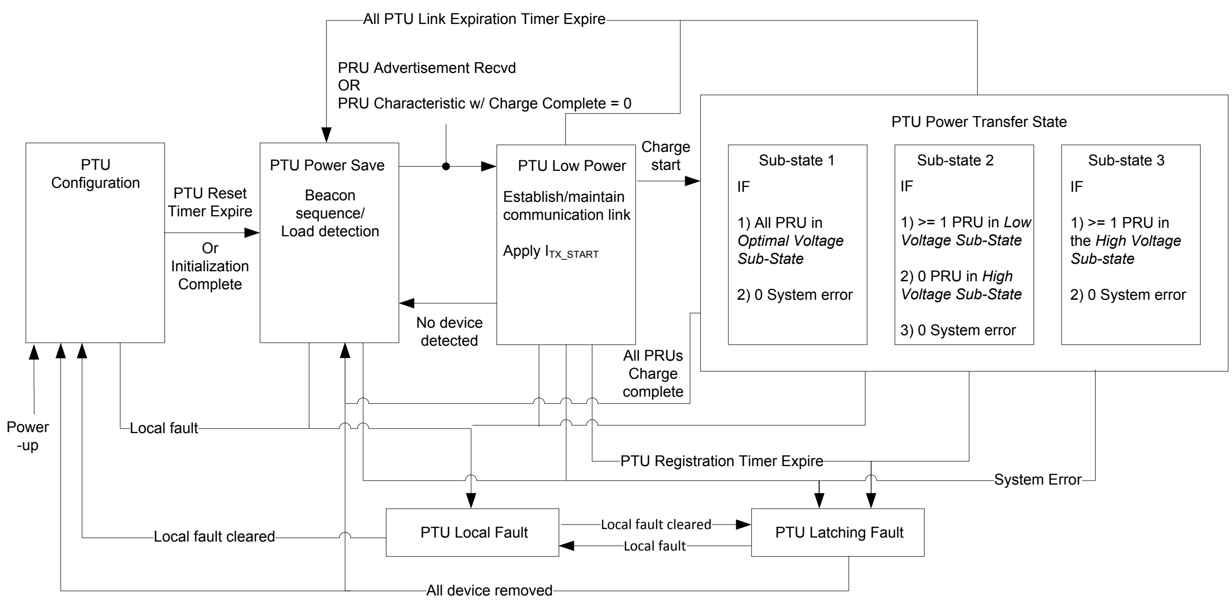

Figure 5.2.1-1 PTU State Model

5.2.2 General State Requirements

This section defines requirements that are not specific to one PTU state.

5.2.2.1 New Device Registration

The PTU shall allow for registration of new devices (including response to PRU advertisements and exchange of static characteristics) in the Low Power and Power Transfer states.

5.2.2.2 PTU Link Supervision Timer

The PTU shall maintain a separate link supervision timer for each PRU connection. The link supervision timer shall be started at zero seconds when a connection is established. The link supervision timer shall reset immediately after an expected BLE message is received. The link supervision timer shall expire in one second.

If a PTU link supervision timer expires with less than 2W of P_{TX_IN} variation before the timer expires, the PTU shall attempt the link loss reconnection procedure. Reference section 6.4.5.2.3. If the reconnection procedure is not successful within 1.1 seconds of the PTU link expiration, the PTU may consider that a PRU malfunction has occurred and enter the PTU Latching Fault State.

If the PTU link supervision timer expires with greater than or equal to 2W of P_{TX_IN} variation before the timer expires, then the PRU shall be removed from the system registry. If afterwards, the system registry is empty, the PTU shall enter the PTU Power Save State.

5.2.2.3 Messaging Latency

Latency introduced by packet error rate is not considered as part of the specification.

5.2.2.4 PTU Response Time for PRU Detection

The PTU shall be capable of detecting a PRU placed in the charging area and enter PTU Power Transfer State or inform the PRU of power denial within the time as specified Table 5.2.2.4-1.

NOTE: The PTU informs the PRU of power denial through writing in the permission field of the PRU Control characteristic as described in Table 6.5.3.2-3.

Table 5.2.2.4-1 Time Requirement to Enter Power Transfer State

Condition	Maximum Time for Initiating Charge of PRU
Category 1 PRU	3.5 s
Until March 01, 2015: PRU creates less than $Z_{TX\_IN\_LOAD\_CHANGE}$	7 s
PRU creates $Z_{TX\_IN\_LOAD\_CHANGE}$ or greater	1 s

Refer to section 4.3.3.4, for Short Beacon PRU-induced Impedance, $Z_{TX\_IN\_LOAD\_CHANGE}$.

NOTE: For category 2-5 PRUs, the maximum time for initiating charge of a PRU is based on short beacon operation (refer to section 5.2.3.3) as well as the PTU-PRU ability to establish a BLE connection and complete WPT registration (refer to section 5.2.4.2).

5.2.2.5 PTU Registration Timer

The PTU shall start a Registration Timer when a valid advertisement is received in the PTU Low Power or PTU Power Transfer states. The timer shall be stopped when the PTU writes the control characteristic to the PRU. The registration timer shall expire in 500 ms. If the registration timer expires, the PTU follows the state transitions described in section 5.2.9.10. If the PTU receives a valid PRU Advertisement while in the PTU Low Power State or the PTU Power Transfer State, the PTU shall remain in the current state.

5.2.3 PTU Power Save State

5.2.3.1 State Entry Procedure

5.2.3.1.1 Beacon Sequence Start

The PTU shall start the beacon sequence within 50 ms of entering the PTU Power Save State.

5.2.3.1.2 Device Registry

The device registry shall be cleared.

5.2.3.2 Beacon Sequence

During the PTU Power Save State, the PTU shall:

1. Periodically apply current to the PTU resonator to detect changes of impedance of the PTU resonator.
2. Periodically apply current to the PTU resonator to wake up the PRU's MCU and signaling module to allow communication between PTU and PRU.

The beacon sequence is comprised of long beacons and short beacons as shown in Figure 5.2.3.2-1.

NOTE: Short beacon is required for the purpose of detecting changes in PTU impedance caused by the placement of an object in charging area. The use of short beacon reduces standby power.

NOTE: Long beacon is required for the purpose of guaranteeing that PRUs have sufficient power to boot and respond.

Refer to 6.6.2, Acceptance of Advertisement, for additional requirements.

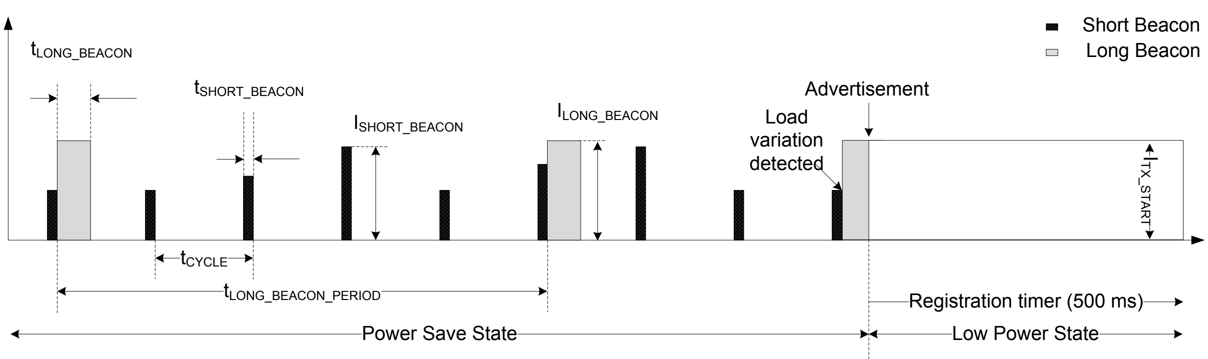

Figure 5.2.3.2-1 Beacon Sequences

5.2.3.3 Short Beacon

5.2.3.3.1 Short Beacon Timing

The PTU shall periodically apply a short beacon to the PTU resonator to detect changes in impedance. The period, t_{CYCLE}, shall be 250 ms ±5 ms. The short beacon-on-period (t_{SHORT_BEACON}) shall be less than 30 ms.

NOTE: While minimum duration for the short beacon is not defined, the PTU shall emit a short beacon of a measurable duration.

5.2.3.3.2 Short Beacon Current

The PTU shall conduct a current greater than $I_{TX\_SHORT\_BEACON\_MIN}$ through the PTU resonator coil. $I_{TX\_SHORT\_BEACON\_MIN}$ is defined to be sufficient to enable detection of Category 2 and larger PRUs.

NOTE: The PTU shall emit a short beacon with a measurable current greater than $I_{TX\_SHORT\_BEACON\_MIN}$.

5.2.3.3.3 Load Variation Detection

With the short beacon, the PTU shall be capable of sensing the reactance and resistance change of $Z_{TX\_IN\_LOAD\_DETECT}$. $Z_{TX\_IN\_LOAD\_DETECT}$ is called out in section 7, Approved PTU Resonators. Refer also to 4.3.3.4, for Short Beacon PRU-induced Impedance.

The PTU shall initiate long beacon immediately when it detects a load variation during short beacon.

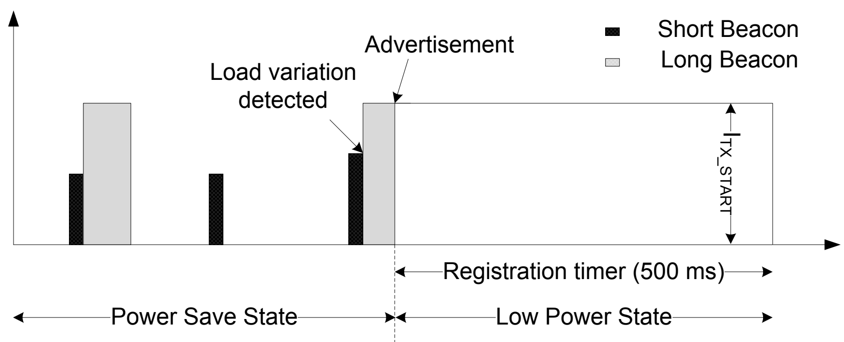

Figure 5.2.3.3.3-1 Load Variation Detection

5.2.3.4 Long Beacon

5.2.3.4.1 Long Beacon Timing

The PTU shall periodically apply current, $I_{TX\_LONG\_BEACON}$ to the PTU resonator. The PTU shall apply current $I_{TX\_LONG\_BEACON}$, as defined in section 5.2.3.4.2, within 10 ms of the short beacon ending. The beacon-on-period (t_{LONG_BEACON}) shall be 105 ms$\pm$5 ms, unless exiting Power Save State, in which case it may be shorter. The beacon period ($t_{LONG_BEACON_PERIOD}$) shall be longer than 850 ms and shall not exceed 3000 ms. The Long Beacon shall be concatenated with a Short Beacon.

NOTE: The purpose of the Long Beacon is to induce sufficient voltage in a PRU to elicit a response.

NOTE: The beacon-on-period is defined as the period of time during which the I_{TX_COIL} is greater than $I_{TX\_LONG\_BEACON\_MIN}$. Rise and fall times are not included.

5.2.3.4.2 Long Beacon Current

$I_{TX\_LONG\_BEACON}$ shall be greater than $I_{TX\_LONG\_BEACON\_MIN}$.

5.2.3.4.3 Discovery

The PTU shall scan for WPT Service related BLE advertisements during the long beacon-on period. Refer to Figure 5.2.3.4.3-1 and also to section 6.4.5, Connection Establishment.

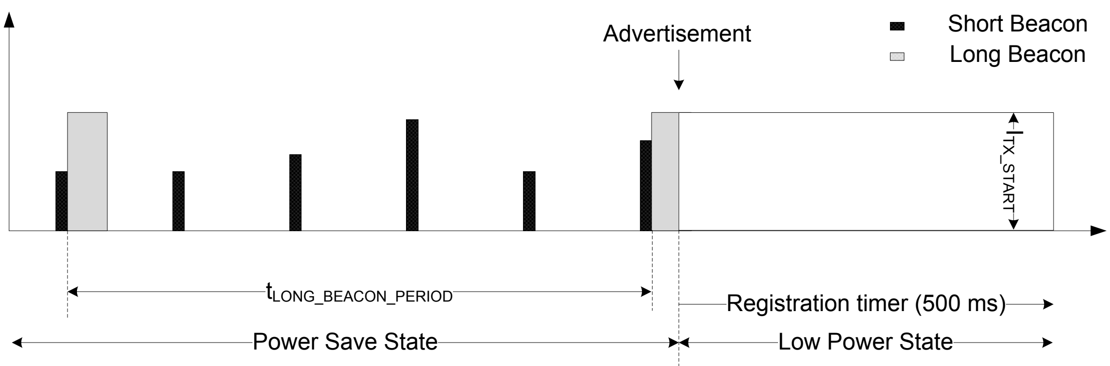

Figure 5.2.3.4.3-1 Discovery

5.2.4 PTU Low Power State

5.2.4.1 State Entry Procedure

5.2.4.1.1 I_{TX_COIL} Adjustment

The PTU shall apply a current ranging from 0.8 * I_{TX_START} to I_{TX_START} within 100 ms of entering the PTU Low Power State. I_{TX_COIL} shall change monotonically between its previous state and a level between 0.8 * I_{TX_START} and I_{TX_START}. The PTU shall then maintain the current between 0.8* I_{TX_START} to I_{TX_START} until exiting the PTU Low Power State.

NOTE: I_{TX_START} is sufficient to wake up the communication circuit of the PRU.

5.2.4.2 WPT Device Registration

In the PTU Low Power State the PTU shall establish a BLE connection with the PRU and complete registration according to the requirements in sections 6.4.5, Connection Establishment and 6.3.6 Timing and Sequencing Requirements.

5.2.5 PTU Power Transfer State

5.2.5.1 State Entry Procedure

5.2.5.1.1 I_{TX_COIL} Adjustment

The PTU shall apply a current ranging from 0.8 * $I_{TX\_NOMINAL}$ to $I_{TX\_NOMINAL}$ within 500 ms of entering the PTU Power Transfer State.

5.2.5.2 General Requirements

5.2.5.2.1 PTU Power Transfer State I_{TX_COIL}

The PTU shall continuously apply I_{TX_COIL}. The PTU shall adjust its I_{TX_COIL} as per the algorithms specified in section 5.2.5.5.1.

5.2.5.2.2 I_{TX_COIL} Adjustment Timing

The PTU shall adjust I_{TX_COIL} once and only once every 250 ms if an adjustment is required. If only Category 4 and above PRUs are present, adjustments may be made at up to a rate of once per TBD ms.

5.2.5.2.3 PTU I_{TX_COIL} Transition Response

When increasing or decreasing I_{TX_COIL}, the transition shall not be under-damped.

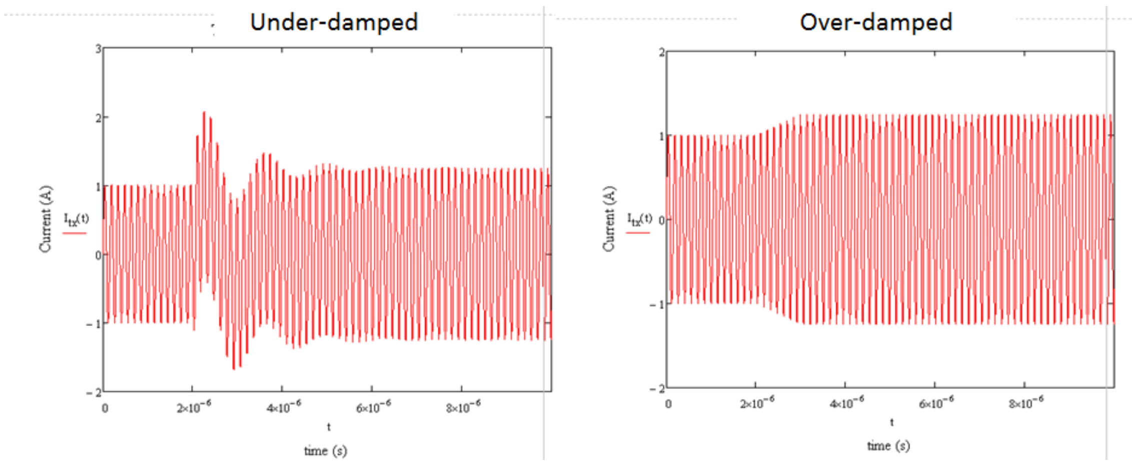

Figure 5.2.5.2.3-1 PTU I_{TX_COIL} Transition Responses

5.2.5.2.4 PTU Power Transfer State I_{TX_COIL} Settling Time

I_{TX_COIL} shall reach steady state (90% of the delta between the start and end current values) within 250 ms of any transition.

5.2.5.2.5 I_{TX_COIL} Minimum

The PTU shall conduct a current greater than or equal to I_{TX_MIN} through the PTU resonator coil during the PTU Power Transfer State, unless any PRU is reporting a V_{RECT} over V_{RECT_HIGH}.

5.2.5.3 Sub-state Definitions and Transitions

The PTU Power Transfer State shall have three sub-states with the conditions for entering the sub-state shown in Table 5.2.5.3-1.

Table 5.2.5.3-1 Sub-state of Power Transfer

Sub-state	Condition for Entering Sub-state
1	All PRUs are in Optimum Voltage Sub-state 0 System error
2	One or more PRUs are in Low Voltage Sub-state. 0 device are in High Voltage Sub-state 0 System error
3	One or more PRUs are in High Voltage Sub-state. 0 System error

5.2.5.4 PRU Reported Values

The sub-state of a PRU is determined by examining the V_{RECT} reported by the PRU in relation to the $V_{RECT\_MIN\_STATIC}$ and $V_{RECT\_HIGH\_STATIC}$ parameters reported in the PRU Static Parameter Characteristic (refer to section 6.5.4.12). If the PRU reports $V_{RECT\_MIN\_DYN}$ and $V_{RECT\_HIGH\_DYN}$ parameters in the PRU Dynamic Parameter Characteristic (refer to section 6.5.6), the PTU shall use the most recently reported values in place of the values reported in the PRU Static Parameter Characteristic.

If the PRU reports a $V_{RECT\_SET\_DYN}$ value in the PRU Dynamic Parameter message, the PTU shall use the most recently reported value in place of the V_{RECT_SET} value in the PRU Static Parameter Characteristic.

5.2.5.5 PTU Power Transfer Sub-state 1

5.2.5.5.1 PTU Power Transfer Sub-state 1 Algorithm Selection

The PTU shall use either the $V_{RECT\_MIN\_ERROR}$ or η_{MAX} algorithm. The PTU may switch between algorithms. However, the PTU shall not make an adjustment to I_{TX_COIL} that will cause any PRU operation to move outside of the optimum voltage region.

NOTE: It is recommended that the PTU select the preferred algorithm of the dominant PRU.

NOTE: For V_{RECT}*I_{RECT} / P_{RECT_MAX}, P_{RECT_MAX} is reported in the PRU Static Parameter Characteristic value.

5.2.5.5.1.1 PTU Power Transfer Sub-state 1 $V_{RECT\_MIN\_ERROR}$ Algorithm

If the PTU is paired with one PRU, the PTU shall minimize the value of $E_{VRECT} = |V_{RECT} - V_{RECT\_SET}|$.

If the PTU is paired with more than one PRU, the PTU shall adjust I_{TX_COIL} to minimize the E_{VRECT} for the PRU with the highest percentage utilization of its rated output.

The percentage of the rated output shall be calculated as P_{RECT}/P_{RECT_MAX}. P_{RECT_MAX} is the maximum output power of a PRU design.

NOTE: $P_{RECT} = I_{RECT} * V_{RECT}$.

5.2.5.5.1.2 PTU Power Transfer Sub-state 1 η_{MAX} Algorithm

The PTU shall adjust I_{TX_COIL} to maximize the total system efficiency. η_{MAX} is calculated as $\Sigma(P_{RX\_REPORTED})/P_{IN}$.

5.2.5.5.2 PTU Power Transfer Sub-state 1 I_{TX_COIL} Adjustment Step Size

I_{TX_COIL} adjustments shall have a step size no greater than 5% of I_{TX_MAX} and no smaller than 1% of I_{TX_MAX} with the following exceptions:

1. If any PRU's V_{RECT} is greater than V_{RECT_HIGH} * 0.95, the positive I_{TX_COIL} step size may be reduced.
2. If any PRU's V_{RECT} is less than V_{RECT_MIN} * 1.05, the negative I_{TX_COIL} step size may be reduced.
3. If the dominant PRU's V_{RECT} is between $V_{RECT\_SET}/1.05$ and $V_{RECT\_SET}/0.95$, the positive and negative I_{TX_COIL} step size may be reduced.
4. If I_{TX_COIL} is above I_{TX_MAX}, the positive I_{TX_COIL} step size may be reduced to avoid exceeding $I_{TX\_ABS\_MAX}$.

The PTU shall be able to drive V_{RECT} of a PRU within 5% of V_{RECT_SET}.

If only Category 4 and above PRUs are present, adjustments may be made at up to a step size of TBD%.

5.2.5.6 PTU Power Transfer Sub-state 2

5.2.5.6.1 PTU Power Transfer Sub-state 2 Algorithm

The PTU shall increase I_{TX_COIL} until all PRUs have $V_{RECT(N)} \geq V_{RECT\_MIN(N)}$, however the PTU should not make an adjustment to I_{TX_COIL} that causes any PRU to move into the High-voltage Sub-state or the PRU System Error State for an over-voltage.

5.2.5.6.2 PTU Power Transfer Sub-state 2 I_{TX_COIL} Adjustment Step Size

I_{TX_COIL} adjustments shall have a step size no greater than 5% of I_{TX_MAX} and no smaller than 1% of I_{TX_MAX}.

5.2.5.7 PTU Power Transfer Sub-state 3

5.2.5.7.1 PTU Power Transfer Sub-state 3 Algorithm

The PTU shall decrease I_{TX_COIL} until all PRUs report $V_{RECT(N)} \leq V_{RECT\_HIGH(N)}$.

5.2.5.7.2 PTU Power Transfer Sub-state 3 I_{TX_COIL} Adjustment Step Size

I_{TX_COIL} adjustments shall have a step size no greater than 5% of I_{TX_MAX} and no smaller than 1% of I_{TX_MAX}.

5.2.6 PTU Configuration State

5.2.6.1 State Entry Procedure

5.2.6.1.1 I_{TX_COIL} Adjustment

If the I_{TX_COIL} > 50 mA_{rms} at the state entry, the PTU shall decrease I_{TX_COIL} to below 50 mA_{rms} within 500 ms of entering the PTU Configuration State.

5.2.6.1.2 PTU Configuration State Timer

Unless the PTU goes to the PTU Local Fault State, the PTU shall exit the PTU Configuration State within 4s of entering the state and then enter the PTU Power Save State.

5.2.6.1.3 Device Registry

The device registry shall be cleared.

5.2.6.2 PTU Configuration State Functions

The PTU may perform self and system checks during the PTU Configuration State.

5.2.6.3 PTU Configuration State I_{TX_COIL}

I_{TX_COIL} shall remain below 50 mA_{rms}.

5.2.7 PTU Local Fault State

The PTU may exit any state and enter the PTU Local Fault state if the PTU experiences any local fault condition, that requires power to be shut down. This may include, but is not limited to PTU local over-temperature, local over-current, local over-voltage or any local PTU failure.

5.2.7.1 State Entry Procedure

5.2.7.1.1 I_{TX_COIL} Adjustment

If the I_{TX_COIL} > 50 mA_{rms} at the state entry, the PTU shall decrease I_{TX_COIL} to below 50 mA_{rms} within 500 ms of entering the Fault State.

5.2.7.1.2 Device Registry

The device registry shall be cleared.

5.2.7.2 PTU Local Fault State I_{TX_COIL}

I_{TX_COIL} shall remain below 50 mA_{rms}.

5.2.8 PTU Latching Fault State

A PTU enters the PTU Latching Fault State in response to at least one of the triggers listed in Table 5.2.9.11-1.

5.2.8.1 State Entry Procedure

5.2.8.1.1 I_{TX_COIL} Adjustment

If the I_{TX_COIL} > 50 mA_{rms} at the state entry, the PTU shall decrease I_{TX_COIL} to below 50 mA_{rms} within 500 ms of entering the PTU Latching Fault State.

5.2.8.1.2 Device Registry

The device registry shall be cleared.

5.2.8.2 Load Variation Detection

After 1 s ±0.1 s from entering the PTU Latching Fault State, the PTU shall perform the Short Beacon Sequence with constant I_{TX_COIL} described in section 5.2.3.3. The PTU shall transition to Power Save or PTU Configuration State if the short beacons detect a load variation indicating the removal of device or devices from the charge area (except for PTU Local Fault conditions).

NOTE: The purpose of using the sequence is to determine whether or not a rogue object is on the pad.

5.2.9 PTU State Transitions

The PTU shall not make any state transitions unless they are defined in this section as required or optional.

The PTU shall make all transitions designated as required.

5.2.9.1 PTU Power-up

PTU is powered up.

Origin State	Destination State	Required or Optional	Additional Required Conditions	Exceptions
Null	PTU Configuration	Required	None	None

5.2.9.2 PTU Initialization

The PTU completes its self test.

Origin State	Destination State	Required or Optional	Additional Required Conditions	Exceptions
PTU Configuration	PTU Power Save	Required	None	At least one PTU Local Fault

5.2.9.3 Device Detected and Charge Start from PTU Power Save

The PTU shall begin device registration when one of the following occurs:

- The PTU receives a valid Advertisement (refer to 6.6.2) from a non-connected PRU.
- The PTU reads a Dynamic Parameter or receives an Alert from a connected PRU that indicates charge required (Charge Complete = 0).

Origin State	Destination State	Required or Optional	Additional Required Conditions	Exceptions
PTU Power Save	PTU Low Power	Required	0 system errors or PTU receives: - Advertisement or - Characteristic with Charge Complete = 0	None

5.2.9.4 PTU Link Supervision Timer Expired

The PTU link supervision timer expires for one or more PRUs.

Origin State	Destination State	Required or Optional	Additional Required Conditions	Exceptions
PTU Power Transfer PTU Low Power	PTU Power Save	Required	0 System errors All connections lost.	At least one PTU Local Fault
PTU Power Transfer PTU Low Power	PTU Latching Fault	Required	0 System errors Any connection lost without power variation and unsuccessful reconnection.	None

5.2.9.5 PTU-PRU Registration Complete

The PTU has completed the registration process and sent a PRU Control Characteristic to the PRU.

Origin State	Destination State	Required or Optional	Additional Required Conditions	Exceptions
PTU Low Power	PTU Power Transfer	Required	0 System errors	None
PTU Power Transfer				

5.2.9.6 Charge Complete

This state transition indicates that a PTU has received a charge complete notification from *all* PRU units.

Origin State	Destination State	Required or Optional	Additional Required Conditions	Exceptions
PTU Power Transfer	PTU Power Save	Required	0 system errors All PRU units indicate charge complete	At least one PTU Local Fault

5.2.9.7 PTU Local Fault

The PTU experiences a local fault condition.

Origin State	Destination State	Required or Optional	Additional Required Conditions	Exceptions
PTU Power Save	PTU Local Fault	Optional	None	The local fault does not cause a state transition itself
PTU Low Power				
PTU Power Transfer				
PTU Configuration				
PTU Latching Fault				

5.2.9.8 PTU Configuration State Timer Expired

The PTU Configuration State Timer has expired.

Origin State	Destination State	Required or Optional	Additional Required Conditions	Exceptions
PTU Configuration	PTU Power Save	Required	None	At least one PTU Local Fault

5.2.9.9 PTU Local Fault Cleared

The PTU determines that the PTU Local fault has been cleared.

NOTE: The PTU Local fault is cleared when the conditions that caused the local fault are resolved.

Origin State	Destination State	Required or Optional	Additional Required Conditions	Exceptions
PTU Local Fault	PTU Configuration	Optional	None	State preceding the PTU Local Fault was a PTU Latching Fault.
PTU Local Fault	PTU Latching Fault	Optional	State preceding the PTU Local Fault was a PTU Latching Fault	None

5.2.9.10 PTU Registration Timer Expired

The PTU Registration Timer has expired.

Origin State	Destination State	Required or Optional	Additional Required Conditions	Exceptions
PTU Low Power	PTU Latching Fault	Required	Three successive registration failures with the same PRU	At least one PTU Local Fault
PTU Power Transfer				
PTU Low Power	PTU Power Save	Required	None	Entering PTU Latching Fault

5.2.9.11 PTU Latching Fault

The PTU Latching Faults are defined in Table 5.2.9.11-1.

Table 5.2.9.11-1 PTU Latching Faults

PTU Latching Faults	Latching Fault Description
1	Rogue object detected
2	System error - PRU over-voltage, over-current, over temperature
3-16	Reserved

NOTE: PTU Latching Fault #1, for Rogue object detected, is untestable until Rogue Object is clearly defined in the BSS and the threshold of detecting it. Lost power or checking power variation is not necessarily the right way to detect because it does not indicate whether or not the system would be damaged.

Origin State	Destination State	Required or Optional	Additional Required Conditions	Exceptions
PTU Power Save	PTU Latching Fault	Required	None	None
PTU Low Power				
PTU Power Transfer				

5.2.9.12 User Clears PTU Latching Fault

All latching faults are cleared by the user removing objects.

Origin State	Destination State	Required or Optional	Additional Required Conditions	Exceptions
PTU Latching Fault	PTU Power Save or PTU Configuration	Required	Load change detected	At least one PTU Local Fault

5.2.9.13 PTU Permission Denied

The PTU denies permission due to limited PTU class support.

Origin State	Destination State	Required or Optional	Additional Required Conditions	Exceptions

Origin State	Destination State	Required or Optional	Additional Required Conditions	Exceptions
PTU Low Power	PTU Power Save or PTU Low Power or PTU Local Fault	Optional	None	None

5.3 PRU Specifications

5.3.1 PRU General Requirements

5.3.1.1 Local Protections

5.3.1.1.1 Over-temperature

If the PRU implements local over-temperature protection, this protection shall occur at a temperature below the OTP alert limit. If the PRU is designed in a way such that it does not reach the over-temperature condition, then reporting is optional. Otherwise the PRU shall report the over-temperature condition.

5.3.1.1.2 Over-current

If the PRU implements local over-current protection, this protection shall occur at a current below the OCP alert limit. If the PRU is designed in a way such that it does not reach the over-current condition, then reporting is optional. Otherwise the PRU shall report the over-current condition.

5.3.1.1.3 Over-voltage

If the PRU implements local over-voltage protection, this protection shall occur at a voltage below the OVP alert limit (V_{RECT_MAX}). The PRU may regulate its voltage by periodically closing and opening the OVP switch so that V_{RECT} stays within a region that allows communications with the PTU, and ensures that power dissipation and voltage levels are within acceptable levels. If the PRU is designed in a way such that it does not reach the over-voltage condition, then reporting is optional. Otherwise the PRU shall report the over-voltage condition.

5.3.1.2 PRU Signaling

The PRU shall be able to communicate in all V_{RECT} operating regions (refer to Figure 5.3.2-2) except the Under Voltage region.

5.3.1.3 PRU Link Establishment

The PRU shall not attempt to join a PTU network unless it is receiving power from a PTU.

5.3.1.4 PRU Link Supervision Timer

The PRU shall maintain a separate link supervision timer for connection with the PTU. The link supervision timer shall start when a connection is established. The link supervision timer shall reset immediately after an expected BLE message is received. The link supervision timer shall expire in one second.

If a PRU link supervision timer expires, the PRU shall attempt the link loss reconnection procedure. The PRU shall maintain use of the same device address used prior to link expiration during the reconnection procedure. Refer to section 6.4.5.1.3. If the link loss reconnection procedure fails, then the PRU shall disable its charge output.

5.3.1.5 PRU Link Termination

When a PRU has an established link to a PTU and V_{RECT} drops below V_{RECT_BOOT} , the PRU shall initiate the GAP Terminate Connection procedure within 500 ms as described in section 6.4.5.1.4, Idle Connection.

5.3.1.6 PRU V_{RECT} Set Value

V_{RECT_SET} shall always be greater than or equal to $V_{RECT\_MIN\_STATIC}$, and less than or equal to $V_{RECT\_HIGH\_STATIC}$ as reported in the PRU Static Parameter Characteristic (refer to section 6.5.4.12). Likewise, if the PRU reports updated values in the PRU Dynamic Parameter message (refer to section 6.5.6), $V_{RECT\_SET\_DYN}$ must be greater than or equal to the most recently reported $V_{RECT\_MIN\_DYN}$, and less than or equal to $V_{RECT\_HIGH\_DYN}$. If no $V_{RECT\_SET\_DYN}$ is reported, $V_{RECT\_MIN\_DYN}$ must never be greater than V_{RECT_SET}, and $V_{RECT\_HIGH\_DYN}$ must never be less than V_{RECT_SET}.

5.3.1.7 PRU Reported Parameters

The PRU shall report V_{RECT}, I_{RECT} and PRU alert, and may report V_{OUT}, I_{OUT}, $V_{RECT\_HIGH\_DYN}$, $V_{RECT\_MIN\_DYN}$, $V_{RECT\_SET\_DYN}$ and Temperature in the ON and BOOT states.

5.3.1.7.1 PRU Reporting Data Age

At a given reporting instance, the value of each parameter shall be measured at least once since the last report. I_{RECT} and V_{RECT} values given in any report should be made within 1 ms of each other.

NOTE: The 1 ms timing requirement between I_{RECT} and V_{RECT} measurements is highly desired and not intended to preclude implementations.

5.3.1.7.2 Accuracy of Reported Voltage

The value of V_{RECT_REPORT} shall be reported with an accuracy better than ± 3%, unless the PRU is in the PRU System Error State.

NOTE: The voltage accuracy requirement is necessary for system control. The system is specified such that multi-device PTUs can keep all combinations of PRUs in the optimum voltage region. If there is error in the reported value of V_{RECT} the system may be unable to keep all PRUs in the optimum voltage region.

5.3.1.7.3 Accuracy of Reported Current

The value of I_{RECT_REPORT} shall be reported with accuracy better than 8% of P_{RECT_MAX} divided by V_{RECT_MIN}. P_{RECT_MAX} and V_{RECT_MIN} are those reported within the PRU Static Parameters. Refer also to Table 5.3.1.7.3-1.

$$ABS\ (I_{RECT} - I_{RECT\_REPORT}) \leq (8\%)\ (P_{RECT\_MAX} / V_{RECT\_MIN})$$

Table 5.3.1.7.3-1 Example of Accuracy of Reported Current

Allowable I_{RECT} Report Delta (in milliamps) for 8% Error							
	Pwr	Current	Cat 1	Cat 2	Cat 3	Cat 4	Cat 5
Max W				3.5	5		

V_{RECT_MIN}				8	8		
	0	0.000		35.00	50.00		
	0.5	63		35.00	50.00		
	1	125		35.00	50.00		
	1.5	188		35.00	50.00		
	2	250		35.00	50.00		
	2.5	313		35.00	50.00		
	3	375		35.00	50.00		
	3.5	438		35.00	50.00		
	4	500			50.00		
	4.5	563			50.00		
	5	625			50.00		
	5.5	688			50.00		
	6	750			50.00		
	6.5	813			50.00		
	7	875					
	7.5	938					
	8	1000					
	8.5	1063					
	9	1125					

5.3.2 PRU State Model

The PRU can be in one of five states identified in Figure 5.3.2-1 and five operating regions at any given time. The operating region shall be determined by the value of V_{RECT} (as identified in Figure 5.3.2-2).

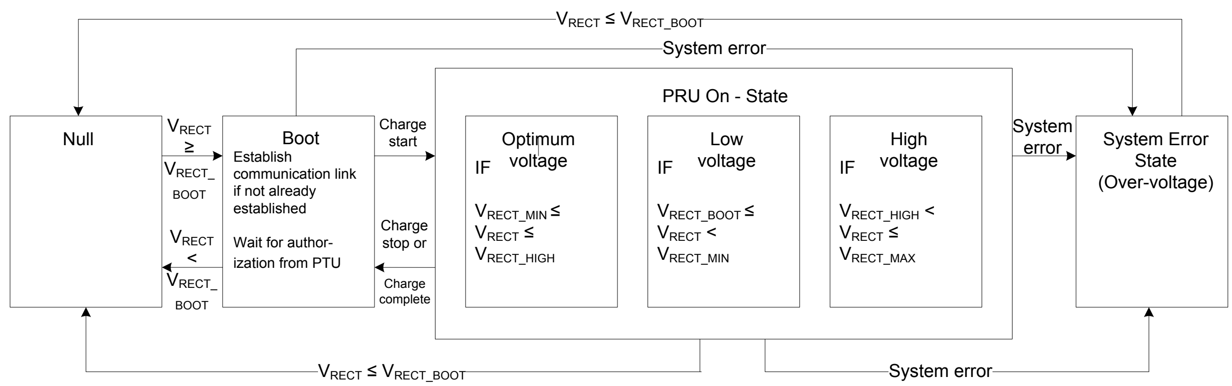

Figure 5.3.2-1 PRU State Model

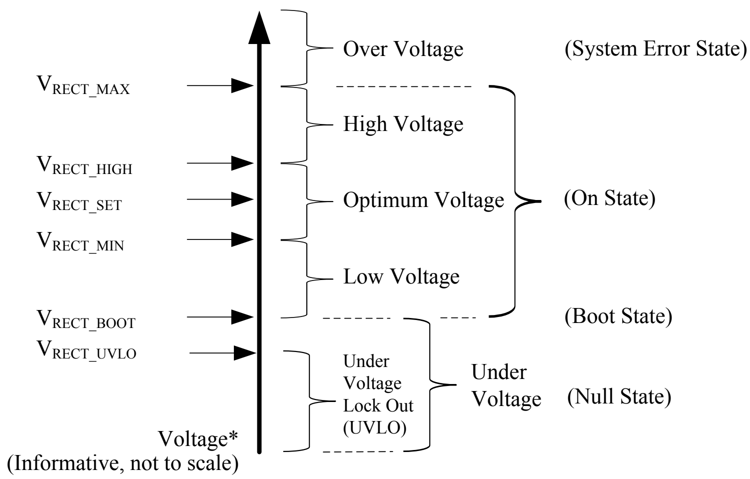

Figure 5.3.2-2 V_{RECT} Operating Regions

5.3.3 Null State

At start-up, a PRU shall be considered to be in the Null State when $V_{RECT} < V_{RECT\_BOOT}$. After exiting the Null State, a PRU shall be considered to re-enter the Null State when V_{RECT} falls below V_{RECT_UVLO}.

5.3.4 PRU Boot

5.3.4.1 State Procedure

The PRU shall disable its output at start-up.

If the PRU is not in a connection with the PTU:

- If Charge Complete = 0, the PRU shall send an advertisement within 100 ms of I_{TX_COIL} exceeding $I_{TX\_LONG\_BEACON\_MIN}$.
- Otherwise if I_{TX_COIL} continuously exceeds $I_{TX\_LONG\_BEACON\_MIN}$ for a period of 600 ms, the PRU shall send an advertisement within 800 ms of I_{TX_COIL} exceeding $I_{TX\_LONG\_BEACON\_MIN}$.

5.3.5 PRU On State

5.3.5.1 PRU On State General Requirements

5.3.5.1.1 Output Enable/Disable

The PRU shall draw less than 1.1 W from the rectifier unless allowed by the PTU. The PRU shall reduce its output to less than 1.1 W if instructed by the PTU (reference section 6.5.3, PRU Control).

5.3.5.2 Optimum Voltage Sub-state

A PRU is in the optimum Voltage Sub-state when $V_{RECT\_MIN} < V_{RECT} < V_{RECT\_HIGH}$.

5.3.5.3 Low Voltage Sub-state

A PRU is in the Low Voltage Sub-state when $V_{RECT\_BOOT} \leq V_{RECT} < V_{RECT\_MIN}$.

5.3.5.4 High Voltage Sub-state

A PRU is in the High Voltage Sub-state when $V_{RECT\_HIGH} < V_{RECT} \leq V_{RECT\_MAX}$.

NOTE: In the high voltage Sub-state the PRU may not be capable of continuous operation.

5.3.5.4.1 High Voltage Operation Time

A PRU shall not disconnect its output if $V_{RECT\_HIGH} < V_{RECT} \leq V_{RECT\_MAX}$ for a period of less than five seconds. This time shall be measured starting from the moment that the PRU communicates information indicating that it is within the High Voltage Sub-state. A PRU may disconnect the output after five seconds.

5.3.5.4.2 High Voltage Sustain Time

The PRU shall not be damaged in the High Voltage Sub-state.

5.3.5.5 PRU Local Fault

PRU Local Fault is any error condition that is not required to be reported to the PTU (i.e., any non-system error). For system errors, refer to section 5.3.6. PRU Local Faults then by their nature do not require the PTU to transition to the PTU Latching Fault State and therefore do not need to be specifically identified in this specification. While experiencing a PRU Local Fault, the PRU shall continue communicating with the PTU, and shall not indicate a System Error if there is not a system error (refer to 5.3.6). However, the PRU may adjust or disconnect its output.

5.3.6 PRU System Error State

A PRU shall be considered to be in the PRU System Error State when:

1. Over-voltage alert is active ($V_{RECT} > V_{RECT\_MAX}$), or
2. Over-current alert is active, or
3. Over-temperature alert is active.

5.3.6.1 Charge Output

The PRU shall shut down output charging power in the PRU System Error State until the error condition is removed, except for PRU System Error State caused by PRU over-voltage.

5.3.6.2 PRU Alert

The PRU shall send one or more alerts to the PTU when it is in the PRU System Error State within 250 ms of entering the PRU System Error State. Refer to sections 6.5.7 and 6.5.6.

5.3.6.3 Over-voltage Sustain Time

The PRU shall not be damaged after any period of time when placed in the maximum coupling position and the PTU resonator is conducting $I_{TX\_ABS\_MAX}$.

5.3.6.4 PRU Alert Messaging

The PRU shall be capable of sending notifications to the PTU as long as it is in the PRU System Error State and the PRU is receiving power from the PTU.

5.3.7 PRU State Transitions

The PRU shall not make any state transitions unless they are defined in this section as required or optional.

The PTU shall make all transitions designated as required.

5.3.7.1 Power Applied

Power is applied. The PRU is in the charge area and $V_{RECT} \geq V_{RECT\_BOOT}$.

Origin State	Destination State	Required or Optional	Additional Required Conditions	Exceptions
PRU Null	PRU Boot	Required	None	None

5.3.7.2 On State

The PRU enters the PRU On State when the PRU Control is written during device registration by the PTU.

Origin State	Destination State	Required or Optional	Additional Required Conditions	Exceptions
PRU Boot	PRU On	Required	None	None

5.3.7.3 Charge Complete

PRU is disconnected or power is removed from the PRU after the PTU receives the Charge Complete = 1 indicator from the PRU.

Origin State	Destination State	Required or Optional	Additional Required Conditions	Exceptions
PRU On	PRU Boot	Required	None	None

5.3.7.4 Power Removed

Power is removed from the PRU. This may be related to PTU shutdown ($V_{RECT} < V_{RECT\_BOOT}$) or the PRU has been removed from the charge area.

Origin State	Destination State	Required or Optional	Additional Required Conditions	Exceptions
PRU Boot	Null State	Required	None	None
PRU On				
PRU System Error				

5.3.7.5 PRU System Error

The PRU shall transition to the PRU system error state only if the PRU is unable to handle the condition locally without shutting down PTU power (i.e., moving to PTU latching fault). Refer to section 5.3.1.1. The PRU System Errors are defined in the Table 5.3.7.5-1.

Table 5.3.7.5-1 PRU System Errors

System Error	System Error Description
1	PRU over-voltage
2	PRU over temperature
3	PRU over-current
4	A PRU determines it is receiving power from a first PTU, but is connected to the network of a second PTU.
5-16	Reserved

<table>
<tr><th>Origin State</th><th>Destination State</th><th>Required or Optional</th><th>Additional Required Conditions</th><th>Exceptions</th></tr>
<tr><td>PRU Boot</td><td rowspan="2">PRU System Error</td><td rowspan="2">Required</td><td rowspan="2">None</td><td rowspan="2">None</td></tr>
<tr><td>PRU On</td></tr>
</table>

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6 Signaling Specifications

6.1 Architecture and State Diagrams

6.1.1 Architecture

The WPT network is a star topology. The PTU exchanges information with the PRUs, and make operating point decisions, and resource allocations, if applicable. Each PRU transmits its information and receives network management information from the PTU operating as a network coordinator.

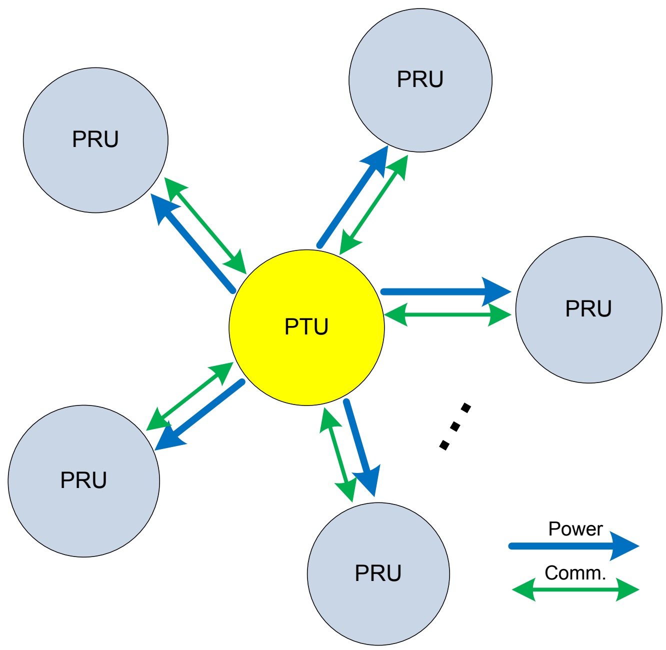


Figure 6.1.1-1 Basic Architecture of WPT System

The PTU shall create and maintain the WPT network.

In Power Transfer State, the PTU configures timing and sequence of PRUs.

The PTU shall manage and update the device control table (which has a role of managing and checking status of PRUs in its own network) and maintain its network with its time sync clock. It manages the timing and sequence of PRU communication.

6.1.2 Overall Charge Process

The wireless power transfer process begins with the PTU in the PTU Power Save State applying short and long beacons to the PTU resonator as required for load variation detection and eliciting a PRU response (refer to section 5.2). Upon device detection, the PTU transitions to PTU Low Power State, establishes a communication link with the PRU, and exchanges information necessary for wireless power transfer. Refer also to Figure 6.1.2-1.

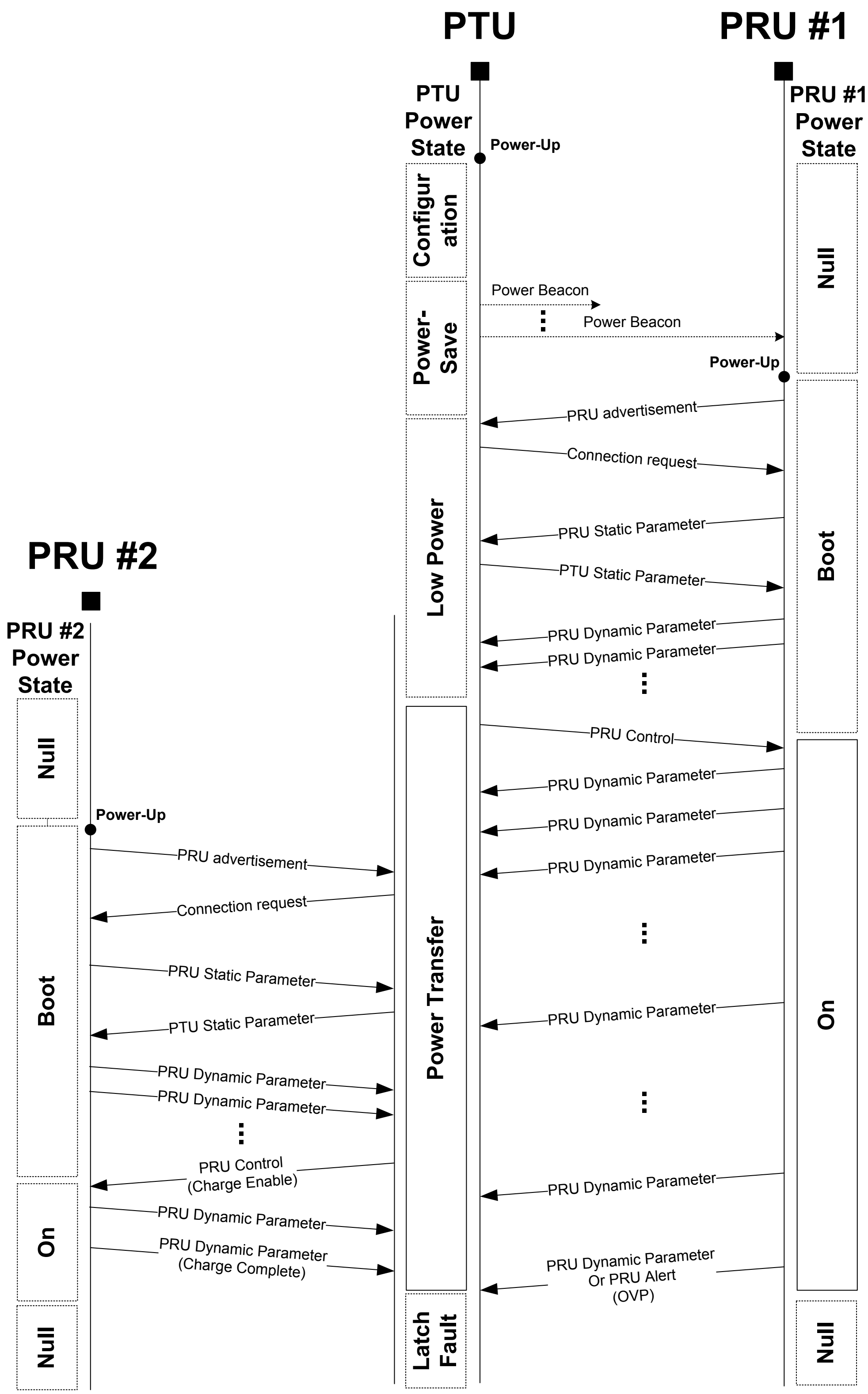


Figure 6.1.2-1 Basic State Procedure (Informative)

No PTU power transmission except beacon power takes place until the PTU receives a PRU advertisement. The PRU repeatedly sends advertisements until it receives a PTU Connection Request (reference 6.3.6).

Upon receiving the PRU advertisement, the PTU enters PTU Low Power State if it is in Power Save State. The PRU stops sending advertisements after it has received a Connection Request from the PTU. The PRU and the PTU form a connection.

The PTU first reads the value of the PRU Static Parameter that describes the status of the PRU. The PTU then writes a value to the PTU Static Parameter that describes the capabilities of the PTU.

Once the devices have exchanged static information, the PTU reads the PRU Dynamic Parameter that provides measured parameters from the PRU. The PTU then writes a value to the PRU Control including the information such as enable/disable charge and permission. The PTU may write to the PRU Control as needed and the PTU periodically reads the PRU Dynamic Parameter that contains values such as voltage, current, PRU status, and/or temperature.

Charging is initiated when the PTU writes a value to the PRU Control of the PRU that enables charging and it is delivered when the PTU has enough power to charge the PRU. In this state (PRU On), the PRU Dynamic Parameter is read by the PTU at least every 250 ms.

Based on the power information in the PRU Dynamic Parameter, the PTU updates the device control table in the registry corresponding to each PRU status.

If the PRU detects a system error or completes charging, the PRU sends one or more PRU Alert notifications to the PTU. The PRU Dynamic Parameter is updated to include data describing the reason for the alert before sending to the PTU (e.g., over current, over voltage, over temperature and self protection notifications).

6.2 Charge Procedure and Requirements

6.2.1 Removing PRU from WPT Network

A PRU shall be removed from the network when the conditions described in sections 5.2.2.2 and 5.2.9.4 are met.

6.3 Bluetooth Low Energy Requirements

This section provides baseline requirements for the Bluetooth Low Energy Profile to control a WPT system which operates with resonant coupling between two or more devices.

6.3.1 Bluetooth Low Energy Objectives

The BLE radio system is intended to provide communication between one PTU and the PRU's being charged by that PTU.

6.3.2 PTU Hardware Requirement

A PTU Wireless Power Transfer service and profile shall be implemented using a Listed Bluetooth Qualified Design (QDL) with an LE Core Configuration or Basic Rate and Low Energy Combined Core Configuration as defined in Specification of the Bluetooth System Version 4.0, Volume 0, Part B, Section 3.1. Refer to section 1.2.1, Normative References.

6.3.3 PRU Hardware Requirement

A PRU shall incorporate a compliant and qualified Bluetooth End Product with an LE Core Configuration or Basic Rate and Low Energy Combined Core Configuration as defined in Specification of the Bluetooth System Version 4.0, Volume 0, Part B, Section 3.1. Refer to section 1.2.1, Normative References.

6.3.4 Basic Network Structure

The BLE network structure shall consist of one central device in the PTU and up to eight PRU peripherals.

6.3.5 RF Requirements

6.3.5.1 PTU BLE Transmit Power

The PTU BLE radio shall transmit between -6 and +8.5 dBm measured at the antenna connector.

6.3.5.2 PTU BLE Sensitivity

The PTU BLE radio shall have sensitivity of better than -77 dBm at the antenna connector.

6.3.5.3 PTU BLE Saturation

The PTU BLE radio shall support a maximum usable input level of -1 dBm at the antenna connector.

6.3.5.4 PRU BLE Transmit Power

The PRU BLE radio shall transmit between -6 and +8.5 dBm measured at the antenna connector.

6.3.5.5 PRU BLE Sensitivity

The PRU BLE radio shall have sensitivity of better than -77 dBm at the antenna connector.

6.3.5.6 PRU BLE Saturation

The PRU BLE radio shall not saturate below -1 dBm at the antenna connector.

6.3.5.7 Interference (Informative)

The system should accept up to 36 dB of desense from other nearby 2.4 GHz radios.

The system should accept up to 35 dB of path loss due to variable placements on the pad.

6.3.5.8 Link budget (Informative)

Table 6.3.5.8-1 RF Budget (Informative)

Stage	Worst Case Loss
PTU	0dBm
Filter	-3 dB
Antenna	-5 dB
Path loss	-35 dB
Desense	-36 dB

Stage	Worst Case Loss
Antenna	-5 dB
Filter	-3 dB
Resulting signal at PRU	-87dBm

6.3.6 Timing and Sequencing Requirements

If a BLE connection does not already exist:

1. The PRU shall present an advertisement to the PTU within the time allowed by the Power Transfer and Control requirements (refer to section 5.3.4.1). The PRU shall use an advertising interval that is no greater than 20 ms.
2. The PTU shall issue a connection request within 50 ms of the received advertisement only if the conditions in section 6.6.2, Acceptance of Advertisement, are met. If the PTU does not receive response from the PRU after sending a connection request, the PTU shall restart the registration timer and retry the WPT device registration process once before declaring registration timeout.

The exact sequence of the PTU's access of the PRU's WPT Service during the registration period shall be:

1. Read PRU Static Parameter Characteristic (mandatory if a BLE connection does not already exist, optional otherwise),
2. Write PTU Static Parameter Characteristic (mandatory if a BLE connection does not already exist, optional otherwise),
3. Read PRU Dynamic Parameter Characteristic, one or more times (mandatory if a BLE connection does not already exist, optional otherwise), and
4. Write PRU Control Characteristic (always mandatory)

During the registration period:

- The PRU shall respond, with a Read Response, to a Read Request within 50 ms.
- The PTU shall only use the GATT Write Without Response procedure for writing characteristics on the PRU.

The BLE connection interval during the registration period ($t_{CI\_REGISTRATION}$) shall be less than or equal to 50 ms. Once the PRU Control Characteristic has been written, the BLE connection interval (t_{CI}) shall be less than or equal to 250 ms.

The PRU Dynamic Parameter Characteristic shall be read by the PTU at least every 250 ms.

The PTU shall not write a PRU Control Characteristic to a PRU, to enable charge port output, until it has read at least one PRU Dynamic Parameter Characteristic from that PRU.

If the PRU is allowed to be charged, a PRU Control characteristic containing the Enable PRU Output command (refer to 6.5.3.2) shall be written by the PTU within 500 ms of the received advertisement.

The registration timing and sequencing described in this section is illustrated in Figure 6.3.6-1.

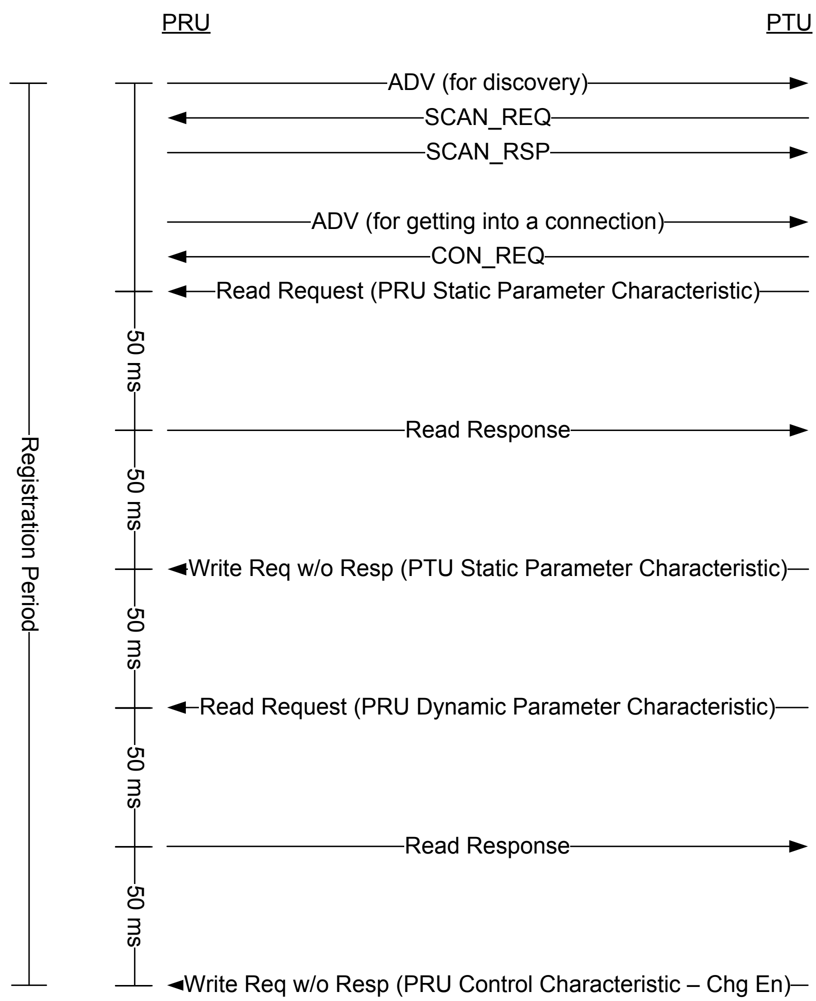


Figure 6.3.6-1 Registration Period Timeline Example (Informative)

Table 6.3.6-1 Timing Constraints

Time Constraint	Value	Description	Reference Section
t_{SHORT_BEACON}	< 30 ms	The short beacon-on-period	5.2.3.3.1
t_{LONG_BEACON}	105 ms ± 5 ms	The long beacon-on-period	5.2.3.4.1
t_{CYCLE}	250 ms ± 5 ms	The short beacon period	5.2.3.3.1
$t_{LONG\_BEACON\_PERIOD}$	> 850 ms, ≤ 3000 ms	The long beacon period	5.2.3.4.1
$t_{ADVERTISEMENT}$	< 100 ms	The PRU sends an advertisement within 100 ms of V_{RECT} exceeding V_{RECT_BOOT} on state entry	5.3.4.1
$t_{CONNECTION\_REQUEST}$	< 50 ms	The PTU issues a connection request within 50 ms of discovery of the PRU	6.3.6

Time Constraint	Value	Description	Reference Section
$t_{REGISTRATION}$	< 500 ms	The PTU writes a PRU Control characteristic containing the PRU enable command within 500 ms of the received advertisement.	6.3.6
$t_{DYNAMIC}$	≤ 250 ms	The period in which PRU Dynamic Parameter Characteristic is read by the PTU	6.1.2 6.3.6
$t_{CI\_REGISTRATION}$	< 50 ms	The BLE connection interval during $t_{REGISTRATION}$	6.3.6
t_{CI}	< 250 ms	The BLE connection interval	6.3.6

6.3.7 Profile Structure

The BLE client and server shall support the following characteristics.

Table 6.3.7-1 BLE Profile Characteristics

Characteristic	Data Direction	Properties	Description
PRU Control	PTU → PRU	Write and Read	PRU ON/OFF control. PTU initiates write when command needs to be sent
PTU Static Parameter	PTU → PRU	Write and Read	Contains static characteristics of the PTU. PTU initiates write when new device connects.
PRU Alert	PTU ← PRU	Notifications (Indications conditional upon support for the Mode Transition Procedure in section 6.7)	Notifies the PTU of overvoltage, over-current, over-temperature and self protection conditions of the PRU.
PRU Static Parameter	PTU ← PRU	Read	Contains static characteristics of the PRU. PTU initiates read when device connects (can be more)
PRU Dynamic Parameter	PTU ← PRU	Read	Contains dynamic characteristics of the PRU. PTU initiates read from each device.

6.4 BLE Profile Definition

6.4.1 Introduction

The following section contains specific information needed to implement the BLE profile. It is intended to allow programmers to implement the BLE profile within the GATT framework.

6.4.1.1 GATT Sub-Procedure Requirements

Additional GATT Sub-Procedures requirements beyond those required by all GATT clients are indicated below.

Table 6.4.1.1-1 GATT Sub-Procedure

GATT Sub-Procedure	Requirement
Discover All Characteristic Descriptors	M
Read Characteristics Value	M
Write With Response	M
Write Without Response	M
Notifications	M

6.4.2 Configuration

6.4.2.1 Roles

The PRU shall be a GATT Server for the Wireless Power Transfer (WPT) Service.

The PTU shall be a GATT Client for the WPT Service.

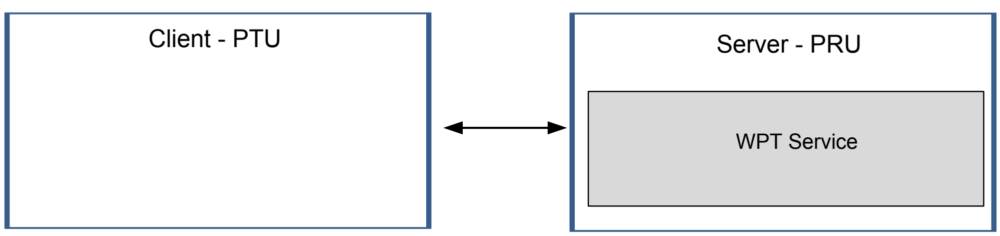


Figure 6.4.2.1-1 PTU/PRU Services/Characteristics Communication

NOTE: Standard and WPT services and associated characteristics are defined in Table 6.5.2.2-1.

6.4.2.2 Concurrency Limitations and Restrictions

There are no concurrency limitations or restrictions for the PRU and the PTU roles imposed by this profile.

6.4.2.3 Topology Limitations and Restrictions

The PRU shall implement the GAP Peripheral role.

The PTU shall implement the GAP Central.

6.4.2.4 Transport Dependencies

This profile shall operate over a Bluetooth Low Energy transport only.

6.4.2.5 Error Codes

This service does not define any Attribute Protocol Application Error Codes.

6.4.2.6 Byte Transmission Order

All multi-byte data fields used with this service shall be sent with the least significant octet first (i.e., Little Endian). Multi-character string values shall be sent as individual byte fields. Structures such as GATT Characteristics included in this specification are transmitted in the order shown where they occur from top to bottom and left to right.

6.4.3 PRU Requirements

The PRU shall instantiate one and only one WPT Service.

The WPT Service shall be instantiated as a Primary Service.

The Bluetooth Device Information Service does not pertain to this profile. Information that is specific to the WPT capability of the PRU device, including the PRU Static Parameter Characteristic defined in section 6.5.5.1 and independent of any implementation of the Bluetooth Device Information Service.

6.4.3.1 Writeable GAP Device Name Characteristic

The PRU may support the write property for the Device Name characteristic to allow the PTU to write a Device Name to the PRU.

6.4.4 PTU Requirements

The PTU shall discover and use the PRU's WPT Service. The Bluetooth Device Information Service does not pertain to this profile. Information that is specific to the WPT capability of the PTU device, including hardware and firmware versions, are contained in the PTU Static Parameter Characteristic defined in section 6.5.4.2 and are independent of any implementation of the Bluetooth Device Information Service.

6.4.4.1 Discovery of Services and Characteristics

The PTU discovers the PRU's WPT service and characteristics using the WPT Service Data within the PRU advertisement payload which contains the GATT Primary Service Handle. The advertisement payload is defined in section 6.5.1. The GATT Primary Service Handle, together with the handle offsets defined in section 6.5.2.2 is used to discover all characteristics and descriptors in the service.

The PTU may perform service discovery using the GATT *Discover All Primary Services* sub-procedure or the GATT *Discover Primary Services by Service UUID* sub-procedure and characteristic discovery using the GATT *Discover Characteristics by UUID* sub-procedure or the *Discover All Characteristics of a Service* sub-procedure. These procedures may be used at any time except during registration. The procedures may be used in response to Service Changed indication or to discover services other than the WPT service supported by the PRU.

6.4.5 Connection Establishment

This section describes the PRU discovery, connection establishment and connection termination procedures used by a PRU and PTU.

6.4.5.1 PRU Connection Establishment

6.4.5.1.1 Connection Procedure for Unbonded Devices

This procedure is used for connection establishment when the PTU connects to a PRU which it is not bonded. This procedure is automatic and not initiated by user interaction.

The PRU shall enter the *GAP Limited Discoverable Mode* using Undirected Advertising (ADV_IND) packets for discovery and connection. PRU Discovery is used to identify a PRU device to the PTU and for receiving WPT Service specific Advertising data.

PRU Advertising Data shall contain an advertising payload as defined in section 6.5.1, PRU Advertising Payload.

The PRU shall use Security Mode 1 level 1 when connecting to an unbonded device. If a connection is not established within a time limit defined by the PRU, the PRU may exit the GAP connectable mode and wait for the next Beacon signal.

6.4.5.1.2 PRU Connection Procedure for Bonded Devices

This procedure is applicable after the PRU has bonded with the PTU using the connection procedure defined in section 6.3.6.

The PRU should use the recommended advertising interval value shown in 6.3.6.

Once connected, the PRU may request to change to the preferred connection parameters that best suits its use case.

If the PTU indicates during pairing that only security level 2 can be achieved, the PRU shall not request any security level higher than level 2 in responding to PTU's service request.

If a connection is not established within a time limit defined by the PRU, the PRU may exit the GAP connectable mode and wait for the next Beacon signal.

6.4.5.1.3 Link Loss Reconnection Procedure

When a connection is terminated, a PRU, if powered by the PTU, shall attempt to reconnect to the PTU by entering a GAP connectable mode using the recommended advertising interval value shown in 6.3.6. Note that if the PRU does not reconnect, it can appear to the PTU as a rogue object.

6.4.5.1.4 Idle Connection

The PRU shall perform the *GAP Terminate Connection* procedure if power is removed from the PRU. The PRU shall not initiate a terminate connection to a BLE host at any time if is powered from a PTU.

6.4.5.2 PTU Connection Establishment

6.4.5.2.1 Connection Procedure for Unbonded Devices

This procedure is used for connection establishment when the PTU connects to a PRU to which it is not bonded. This may be initiated either through user interaction or autonomously when a PTU requires data from a PRU.

The PTU shall scan using the *GAP Limited Discovery* procedure and perform active scanning.

A PTU shall use the *GAP General Connection Establishment* procedure. The PTU may use this procedure when it requires data from one or more PRU(s). This procedure allows a PTU to connect to a PRU discovered during a scan without using the white list.

If a connection is not established within a time limit defined by the Power Control requirements (refer to section 5), the PTU may transition state and cease scanning for new devices.

6.4.5.2.2 PTU Connection Procedure for Bonded Devices

This procedure is applicable after the PTU has bonded with the PRU using the autonomous connection procedure in section 6.4.5.2.1.

A PTU may use one of the following GAP connection procedures based on its connectivity requirements:

1. General Connection Establishment Procedure. The PTU may use this procedure when it requires dynamic parameters or notifications from one or more PRUs. This procedure allows a PTU to connect to a PRU discovered during a scan without using the White List.
2. Selective Connection Establishment Procedure. The PTU may use this procedure when it requires dynamic parameters or notifications from one or more PRUs. This procedure allows a PTU to connect to a PRU discovered during a scan while using the White List.
3. Direct Connection Establishment Procedure. The PTU may use this procedure when it requires data from a single (or specific) PRU. The PTU may also use this procedure for link loss reconnection described in section 6.4.5.2.3.
4. Auto Connection Establishment Procedure. The PTU may use this procedure when it requires dynamic parameters or notifications from one or more PRUs. This procedure will automatically initiate connection to a PRU in the White List.

When initiating a connection while in PTU Low Power State, the PTU should use the continuous scan window/scan interval pair to attempt fast connection. When initiating a connection while in PTU Power Transfer State, the PTU should use an implementation specific scan window/scan interval to attempt a fast connection.

Notwithstanding the above, the PTU should use a scan window and scan interval suitable to its power and connection time requirements. Increasing the scan window increases the power consumption, but decreases the connection time.

The PTU should write the address of the target PRU in its White List and set its controller advertising filter policy to 'process scan and connection requests only from devices in the White List'.

The PTU shall support LE security mode 1, level 1 and level 2 as specified in the BT 4.0 spec.

6.4.5.2.3 Link Loss Reconnection Procedure

When a connection is terminated due to link loss, a PTU shall attempt to reconnect to the PRU by making a connection request after detecting a PRU advertisement shown in 6.4.5.1.1.

6.4.5.2.4 Idle Connection

If a connection is idle, the PTU may perform the *GAP Terminate Connection* procedure. An Idle Connection shall be determined if the PRU does not respond to Read Requests from the PTU and the PRU does not send alerts for greater than one second.

6.4.5.2.5 Fast Connection Interval

The PTU shall implement a connection interval that supports rapid service discovery, rapid encryption setup and the ability to receive a PRU Dynamic Parameter Characteristic from all PRUs within 250 ms.

6.4.6 Security Considerations

This section describes the security procedures used by a PRU and PTU.

6.4.6.1 PRU Security Considerations

All supported characteristics specified by the WPT Service shall be set to Security Mode 1 and should be set to Security Level 1 (No Security) or 2 (Unauthenticated pairing with encryption).

The PRU shall use the *SM Slave Security Request* procedure to inform the PTU of its security requirements.

6.4.6.2 PTU Security Considerations

The PTU may bond with the PRU.

The PTU shall accept any request by the PRU for LE Security Mode 1 and Security Level 1 or 2.

6.4.7 Charge Completion

PTU support of the Charge Complete, Disconnected Mode is mandatory. Likewise, PRU support of the Charge Complete, Disconnected Mode is mandatory. A PTU may optionally support Charge Complete, Connected Mode. A PRU may also indicate support for the Charge Complete, Connected Mode in the PRU Static.

PRUs shall indicate Charge Complete = 1 if they do not require charging from the PTU. When all PRUs on a PTU indicate Charge Complete = 1, the PTU shall transition to the Power Save state according to section 5.2.9.6.

Prior to transitioning to Power Save state,

- The PTU shall instruct the PRU to disable its charge output by setting the Enable PRU Output bit in the Enables field to 0 in the PRU Control.
- The PTU shall perform the GAP Terminate Connection procedure with all PRUs that do not support Charge Complete, Connected Mode.
- The PTU may maintain a BLE connection with PRUs supporting Charge Complete, Connected Mode. Once in the PTU Power Save state, the PTU may increase the time between connection intervals to further conserve power.

After indicating Charge Complete = 1, the PRU shall transition to Boot State as described in section 5.3.7.3, Charge Complete.

6.5 WPT Service Characteristics

The PRU shall support the writing of the PRU Control and PTU Static Parameter characteristics by the PTU and the configuration of the PTU Alert characteristic by the PTU for notifications and optionally indications (conditional upon support for Mode Transition).

The PTU shall support reading the PRU Static Parameter and PRU Dynamic Parameter characteristics and shall also support the configuration of the PRU Alert characteristic for notifications and optionally indications (conditional upon support for Mode Transition).

As described elsewhere in this specification, the PRU and PTU are required to determine the contents of the characteristics based on the contents of the Optional Fields Validity fields in most characteristics.

All characteristic Reserved for Further Use (RFU) bits and fields shall be set to zero by the sending entity and ignored by the receiving entity. If the PTU or PRU receives a characteristic that includes additional octets that are not recognized by the implementation, the receiving entity shall ignore those bits and continue to process the characteristic normally.

6.5.1 PRU Advertising Payload

For the purpose of communicating with a PTU, the PRU shall use the advertising packet payload format defined in Table 6.5.1-1.

Table 6.5.1-1 PRU Advertising Payload

Flags AD Type	Service Data AD Type			
Flags	WPT Service 16-bit UUID	GATT Primary Service Handle	PRU RSSI Parameters	ADV Flags

The Flags field shall use the Bluetooth Generic Access Profile, Flags Advertising Data type format and indicate:

- LE Limited Discoverable Mode

The Service Data AD Type is used to indicate specific WPT Service information and shall use the Bluetooth Generic Access Profile, Service Data AD type format. The first 16-bits (after the AD type length field) shall hold the 16-bit Bluetooth SIG assigned Service UUID value as shown in Table 6.5.2.1-1.

The GATT Primary Service Handle field is included in the Bluetooth Generic Access Profile, Service Data Advertising Data type after the 16-bit Service UUID field and shall contain the PRU's attribute handle for the WPT Primary Service as defined in Table 6.5.2.2-1. All local characteristic handle values for this service shall be ordered sequentially starting from the (GATT Primary Service Handle + 1) in the order of the listed Characteristics as represented in Table 6.5.2.2-1.

The PRU RSSI Parameters field is included in the Bluetooth Generic Access Profile, Service Data Advertising Data type after the GATT Primary Service Handle field and shall contain a PRU output power (PRU_Pwr) in bits 7 to 3 and PRU antenna gain (PRU_Gain) in bits 2 to 0, if known by the PRU application. If unknown by the PRU, the PRU application shall ensure that all bits in the unknown value fields are set to '1'.

7:3	2:0
PRU_Pwr	PRU_Gain

PRU output power shall be encoded as follows:

- PRU_Pwr = (-20 dBm + PRU output power in dBm), or
- PRU_Pwr = 11111b if output power unknown by PRU

3 bit PRU antenna gain shall be encoded as follows:

- PRU_Gain = (-5 dB + PRU antenna gain in dBi), or
- PRU_Gain = 111b if antenna gain unknown by PRU

The ADV Flags field is included in the Bluetooth Generic Access Profile, Service Data Advertising Data type after the PRU RSSI Parameters field and shall contain A4WP specific information and shall use the following bit format:

7	6	5	4	3	2	1	0
Impedance Shift Bit 2	Impedance Shift Bit 1	Impedance Shift Bit 0	Reboot Bit	OVP Status (optional)	Time Set Support	RFU	RFU

- Bits 5-7 - Impedance Shift Bits
- Bit 4 - Reboot Bit ('0' = recent reset, '1' = connection drop with no reset)
- Bit 3 - OVP Status (optional) - set to '0' if not used ('0' = no OVP, '1' = OVP)

- Bit 2 - Time Set Support ('0' = no support, '1' = support)

The Impedance Shift bit field shall be as defined in Table 6.5.1-2 (refer to section 4.3.3.4 for Short Beacon PRU-induced Impedance).

Table 6.5.1-2 Impedance Shift Bit

Impedance Shift Bits	Definition
000	Can never create an impedance shift
001	Cat 1 PRU
010	Cat 2 PRU
011	Cat 3 PRU
100	Cat 4 PRU
101	Cat 5 PRU
110	Reserved
111	Reserved

6.5.1.1 Sample Data

The following shows sample data for PRU Advertising payload contents reflecting the following settings.

Flags AD Type:

- Limited Discoverable Mode is set.
- All other bits set to zero.

Service Data AD Type:

- 16-bit UUID is set to 0xFFFE
- GATT Primary Service Handle is set to 0x0101
- PRU RSSI Parameters is set to 0xFF
- ADV Flags are set to:
    - CAT3 PRU
    - Reboot bit is set to zero
    - OVP indicator is set to zero

Sample Data: 0000: 0201010716FEFF0101FF60

6.5.2 WPT Service

The WPT Service exposes related control and status data for proper coordination between a PRU and a PTU.

6.5.2.1 WPT Service UUID

Table 6.5.2.1-1 shows the mandatory UUID definitions for the WPT Service.

Table 6.5.2.1-1 WPT Service UUID

UUID	Value	Definition
WPT_CHARACTERISTIC_BASE_UUID	0x6455e670-a146-11e2-9e96-0800200c9a67	128-bit A4WP WPT Characteristic Base UUID.
WPT_SERVICE_UUID	0xFFFE	16-bit Bluetooth SIG assigned WPT

UUID	Value	Definition
		Service UUID.

1 ### 6.5.2.2 WPT Service Definition

2 The mandatory service definition for the WPT Service is shown in Table 6.5.2.2-1.

3 **Table 6.5.2.2-1 WPT Service**

Type (16 bit)	Default Value	Attribute Permissions	Notes	Mandatory Handle Value
0x2800 GATT_PRIMARY_SERVICE_UUID	WPT_SERVICE_UUID (16-bit)	GATT_PERMIT_READ	Start of WPT Service	(GATT Primary Service Handle)
0x2803 GATT_CHARACTERISTIC_UUID	Properties = read/write UUID = WPT_CHARACTERISTIC_BASE_UUID	GATT_PERMIT_READ	PRU Control Characteristic declaration	GATT Primary Service Handle) + 1
WPT_CHARGING_PRU_CONTROL_UUID	00000 (5 Octets)	GATT_PERMIT_READ | GATT_PERMIT_WRITE	PRU Control Characteristic value	GATT Primary Service Handle) + 2
0x2803 GATT_CHARACTERISTIC_UUID	Properties = read/write UUID = WPT_ CHARACTERISTIC_BASE _UUID+1	GATT_PERMIT_READ	PTU Static Parameter Characteristic declaration	GATT Primary Service Handle) + 3
WPT_CHARGING_PTU_STATIC_UUID	00000000000000000 (17 Octets)	GATT_PERMIT_READ | GATT_PERMIT_WRITE	PTU Static Parameter Characteristic value	GATT Primary Service Handle) + 4
0x2803 GATT_CHARACTERISTIC_UUID	Properties = read/notify UUID = WPT_ CHARACTERISTIC_BASE _UUID+2	GATT_PERMIT_READ	PRU Alert Parameter Characteristic declaration	GATT Primary Service Handle) + 5
WPT_CHARGING_PRU_ALERT_UUID	0 (1 Octet)	GATT_PERMIT_READ | GATT PERMIT_NOTIFY	PRU Alert Parameter Characteristic value	GATT Primary Service Handle) + 6
0x2902 CLIENT_CHARACTERISTIC_CONFIGUARATION_UUID	0 (1 Octet)	GATT_PERMIT_READ | GATT_PERMIT_WRITE	Client Characteristic Configuration UUID for PRU Alert	GATT Primary Service Handle) + 7
0x2803 GATT_CHARACTERISTIC_UUID	Properties = read UUID = WPT_ CHARACTERISTIC_BASE _UUID+3	GATT_PERMIT_READ	PRU Static Parameter Characteristic declaration	GATT Primary Service Handle) + 8
WPT_CHARGING_PRU_STATIC_UUID	00000000000000000000 (20 Octets)	GATT_PERMIT_READ	PRU Static Parameter Characteristic value	GATT Primary Service Handle) + 9
0x2803 GATT_CHARACTERISTIC_UUID	Properties = read UUID = WPT_ CHARACTERISTIC_BASE _UUID+4	GATT_PERMIT_READ	PRU Dynamic Parameter Characteristic declaration	GATT Primary Service Handle) + 10
WPT_CHARGING_PRU_DYNAMIC_UUID	00000000000000000000 (20 Octets)	GATT_PERMIT_READ	PRU Dynamic Parameter Characteristic value	GATT Primary Service Handle) + 11

4 The definition for the mandatory GAP Service is shown in Table 6.5.2.2-2.

Table 6.5.2.2-2 GAP Service

Type (16 bit)	Default Value	Attribute Permissions	Notes
0x2800 GATT_PRIMARY_SERVICE_UUID	0x1800 (GAP_SERVICE_UUID)	GATT_PERMIT_READ	Start of GAP Service
0x2803 GATT_CHARACTERISTIC_UUID	02 (properties: read only) 00 2A (UUID: 0x2A00)	GATT_PERMIT_READ	Device Name characteristic declaration
0x2A00 GAP_DEVICE_NAME_UUID	"WPT PRU"	GATT_PERMIT_READ	Device Name characteristic value
0x2803 GATT_CHARACTERISTIC_UUID	02 (properties: read only) 01 2A (UUID: 0x2A01)	GATT_PERMIT_READ	Appearance characteristic declaration
0x2A01 GAP_APPEARANCE_UUID	0x0000 (unknown)	GATT_PERMIT_READ	Appearance characteristic value
0x2803 GATT_CHARACTERISTIC_UUID	02 (properties: read only) 04 2A (UUID: 0x2A04)	GATT_PERMIT_READ	Peripheral Preferred Connection Parameters characteristic declaration
0x2A04 GAP_PERI_CONN_PARAM_UUID	50 00 (100ms preferred min connection interval) A0 00 (200ms preferred max connection interval) 00 00 (0 preferred slave latency) E8 03 (10000ms preferred supervision timeout)	GATT_PERMIT_READ	Peripheral Preferred Connection Parameters characteristic value

The definition for the GATT Service, shown in Table 6.5.2.2-3, is mandatory if service definitions on the PRU can be added, changed, or removed, optional otherwise.

Table 6.5.2.2-3 GATT Service

Type (16 bit)	Default Value	Attribute Permissions	Notes
0x2800 GATT_PRIMARY_SERVICE_UUID	0x1801 (GATT_SERVICE_UUID)	GATT_PERMIT_READ	Start of GATT Service
0x2803 GATT_CHARACTERISTIC_UUID	20 (properties: indicate only) 05 2A (UUID: 0x2A05)	GATT_PERMIT_READ	Service Changed characteristic declaration
0x2A05 GATT_SERVICE_CHANGED_UUID	(null value)	(none)	Service Changed characteristic value

6.5.3 PRU Control

When written, this characteristic initiates PTU commands (e.g., start charge) at the PRU. The PTU must write a PRU Control Characteristic whenever it requires a status change in the PRU. The designated PRU shall change configuration according to the PRU Control Characteristic.

6.5.3.1 PRU Control Characteristic Behavior

The PRU Control characteristic is written using the GATT Write procedure. The PTU writes this characteristic to send commands to the PRU.

6.5.3.2 PRU Control Characteristic Value

The PRU Control characteristic value fields are described in Table 6.5.3.2-1. The length of the characteristic value is 5 octets.

Table 6.5.3.2-1 PRU Control Characteristic

Field	Octet	Description	Use	Units
Enables	1	PTU turn on, PTU on indication etc.	Mandatory	N/A
Permission	1	PRU is permitted in PTU.	Mandatory	N/A
Time Set	1	PTU sets up time.	Mandatory	ms
RFU	2	Undefined	N/A	N/A

Table 6.5.3.2-2 Detail: Bit Field for Enables

7	6	5	4	3	2	1	0
Enable PRU output	Enable PRU charge indicator	Adjust power command		RFU	RFU	RFU	RFU
1 = Enable 0 = Disable	1 = Enable 0 = Disable	00 = Maximum power 01 = 66% * P_{RECT_MAX} 10 = 33% * P_{RECT_MAX} 11 = 2.5W		RFU	RFU	RFU	RFU

Enable PRU output allows the PRU to go to full power. Before this it must draw less than 1.1 W. It should draw as little power as possible.

Enable PRU charge indicator, when set to '1' allows the PRU to indicate that charging may occur. Otherwise this bit is set to '0'.

If supported by the PRU, the Adjust power command requires PRUs to adjust power draw. PTUs are not required to send this command if the PRU supports Adjust power.

Table 6.5.3.2-3 Detail: Bit Field for Permission

Value (Bit)	Description
0000 0000	Permitted without reason
0000 0001	Permitted with waiting time due to limited available power
1000 0000	Denied with PTU Latching Fault 4 described in section 5.2.9.11.
1000 0001	Denied due to limited available power
1000 0010	Denied due to limited PTU Number of Devices
1000 0011	Denied due to limited PTU Class support
All other values	RFU

If a PTU writes “Permitted with waiting time due to limited available power”, once the PTU has power available, it shall update the value of the Permission field to “Permitted without reason” to allow the PRU to begin charging.

Table 6.5.3.2-4 Detail: Bit Field for Time Set

Value (Bit)	PTU Setting Time
0000 0000	RFU
0000 0001	10ms
0000 0010	20ms
0000 0011	30ms
0000 0100	40ms
0000 0101	50ms
0000 0110	60ms
0000 0111	70ms
0000 1000	80ms
All other values	RFU

NOTE: This field is used for cross connection check (refer to section 6.6.5).

6.5.4 PTU Static Parameter

The PTU Static Parameter characteristic contains data with constant values on the PTU.

6.5.4.1 PTU Static Parameter Characteristic Behavior

The PTU Static Parameter characteristic is written using the GATT Write procedure.

This Characteristic is intended to provide static PTU parameters to a PRU.

6.5.4.2 PTU Static Parameter Characteristic Value

The PTU Static Parameter characteristic value fields are described in the Table 6.5.4.2-1. The length of the characteristic value is 17 octets.

PTU static parameter characteristic shall have the following fields.

Table 6.5.4.2-1 PTU Reporting Static Values to PRU

Field	Octets	Description	Use	Units
Optional fields validity	1	Defines which fields are valid	Mandatory	
PTU Power	1	Power of PTU	Mandatory	
PTU Max Source Impedance	1	Maximum source impedance of the PTU	Optional	
PTU Max Load Resistance	1	Maximum load resistance of the PTU	Optional	
RFU	2	Undefined	N/A	
PTU class	1	PTU class	Mandatory	Class 1-5
Hardware rev	1	Revision of the PTU HW	Mandatory	
Firmware rev	1	Revision of the PTU SW	Mandatory	

Field	Octets	Description	Use	Units
Protocol Revision	1	A4WP Supported Revision	Mandatory	
PTU Number of Devices Supported	1	Max Number of Devices	Mandatory	
RFU	6	Undefined	N/A	

6.5.4.3 Optional Fields Validity

The Optional Fields Validity field shall identify which optional fields have valid values. All optional fields not identified as valid shall be set to zero.

Table 6.5.4.3-1 Detail: Bit Field for Optional Fields Validity

7	6	5	4	3	2	1	0
Max Impedance	Max Resistance	RFU	RFU	RFU	RFU	RFU	RFU

6.5.4.4 PTU Power

The PTU Power field shall be set equal to the value shown in Table 3.1-1 according to the PTU class. The eight bits of the PTU Power field are populated per the State Definition Bit field (shown in decimal). Power values called out in Table 6.5.4.4-1 are in Watts.

Table 6.5.4.4-1 PTU Power

7	6	5	4	3	2	1	0
PTU Power							

State Definition Table (Values in Decimal, Power in Watts)									
Value	Pwr	Value	Pwr	Value	Pwr	Value	Pwr	Value	Pwr
0	0	32	4.4	64	13.6	96	28	128	50
1	0.1	33	4.6	65	14	97	28.5	129	51
2	0.2	34	4.8	66	14.4	98	29	130	52
3	0.3	35	5	67	14.8	99	29.5	131	53
4	0.4	36	5.2	68	15.2	100	30	132	54
5	0.5	37	5.4	69	15.6	101	30.6	133	55
6	0.6	38	5.6	70	16	102	31.2	134	56
7	0.7	39	5.8	71	16.4	103	31.8	135	57
8	0.8	40	6	72	16.8	104	32.4	136	58
9	0.9	41	6.3	73	17.2	105	33	137	59
10	1	42	6.6	74	17.6	106	33.6	138	60
11	1.1	43	6.9	75	18	107	34.2	139	61
12	1.2	44	7.2	76	18.4	108	34.8	140-255	RFU
13	1.3	45	7.5	77	18.8	109	35.4		

State Definition Table (Values in Decimal, Power in Watts)									
Value	Pwr	Value	Pwr	Value	Pwr	Value	Pwr	Value	Pwr
14	1.4	46	7.8	78	19.2	110	36		
15	1.5	47	8.1	79	19.6	111	36.6		
16	1.6	48	8.4	80	20	112	37.2		
17	1.7	49	8.7	81	20.5	113	37.8		
18	1.8	50	9	82	21	114	38.4		
19	1.9	51	9.3	83	21.5	115	39		
20	2	52	9.6	84	22	116	39.6		
21	2.2	53	9.9	85	22.5	117	40.2		
22	2.4	54	10.2	86	23	118	40.8		
23	2.6	55	10.5	87	23.5	119	41.4		
24	2.8	56	10.8	88	24	120	42		
25	3	57	11.1	89	24.5	121	43		
26	3.2	58	11.4	90	25	122	44		
27	3.4	59	11.7	91	25.5	123	45		
28	3.6	60	12	92	26	124	46		
29	3.8	61	12.4	93	26.5	125	47		
30	4	62	12.8	94	27	126	48		
31	4.2	63	13.2	95	27.5	127	49		

6.5.4.5 PTU Max Source Impedance

The PTU Max Source Impedance, if included, shall designate the maximum output impedance of the PA / filter in the PTU.

Table 6.5.4.5-1 Max Source Impedance

7	6	5	4	3	2	1	0
PTU Max Source Impedance					RFU	RFU	RFU

State Definition	
Value (Decimal)	PTU Maximum Source Impedance (ohms)
0	50
1	60
2	70
3	80
4	90
5	100

State Definition	
Value (Decimal)	PTU Maximum Source Impedance (ohms)
6	110
7	120
8	130
9	140
10	150
11	175
12	200
13	225
14	250
15	275
16	300
17	350
18	375
19 - 31	RFU

6.5.4.6 PTU Max Load Resistance

This field, if included, defines the maximum PTU load resistance as seen at the input to the PTU resonator.

Table 6.5.4.6-1 Max Load Resistance

7	6	5	4	3	2	1	0
PTU Max Load Resistance					RFU	RFU	RFU

State Definition	
Value (Decimal)	PTU Max Load Resistance (ohms)
0	5
1	10
2	15
3	20
4	25
5	30
6	35
7	40
8	45
9	50
10	55
11 - 31	RFU

6.5.4.7 PTU Number of Devices

This field defines the number of devices that the PTU can support.

Table 6.5.4.7-1 PTU Number of Devices

7	6	5	4	3	2	1	0
RFU	**RFU**	**RFU**	**RFU**	PTU Number of Devices			

State Definition	
Value (Decimal)	Number of devices
0	1
1	2
2	3
3	4
4	5
5	6
6	7
7	8
8 - 255	RFU

6.5.4.8 PTU Class

The PTU class field shall identify the class to which the PTU is assigned (refer also to section 3.1).

State Definition
00000000 = Class 1
00000001 = Class 2
00000010 = Class 3
00000011 = Class 4
00000100 = Class 5
00000101 - 11111111 = reserved

6.5.4.9 Hardware Revision

The PTU Hardware Revision is vendor proprietary.

6.5.4.10 Firmware Revision

The PTU Firmware revision is vendor proprietary.

6.5.4.11 Protocol Revision

The PTU Protocol Revision field shall be assigned a number that maps to the highest A4WP specification revision supported per Table 6.5.4.11-1.

Table 6.5.4.11-1 A4WP Protocol Revision Field

Protocol Revision	Revision Description
0	A4WP Revision 1.2
1 - 255	Reserved

6.5.4.12 PRU Static Parameter Characteristic Behavior

6.5.5 PRU Static Parameter Characteristic

The PRU Static Parameter Characteristic contains data with constant values from a PRU.

This characteristic is intended to enable a PTU to read the static information from the PRU.

6.5.5.1 PRU Static Parameter Characteristic Value

The Charging Parameters characteristic value fields are described in Table 6.5.5.1-1. The length of the characteristic value is 20 octets.

Table 6.5.5.1-1 PRU Reporting Static Values to the PTU

Field	Octets	Description	Use	Units
Optional fields validity	1	Defines which optional fields are populated	Mandatory	
Protocol Revision	1	A4WP Supported Revision	Mandatory	
RFU	1	Undefined	N/A	
PRU Category	1	Category of PRU	Mandatory	
PRU Information	1	Capabilities of PRU (bit field)	Mandatory	
Hardware rev	1	Revision of the PRU HW	Mandatory	
Firmware rev	1	Revision of the PRU SW	Mandatory	
P_{RECT_MAX}	1	P_{RECT_MAX} of the PRU	Mandatory	mW*100
$V_{RECT\_MIN\_STATIC}$	2	V_{RECT_MIN} (static, first estimate)	Mandatory	mV
$V_{RECT\_HIGH\_STATIC}$	2	V_{RECT_HIGH} (static, first estimate)	Mandatory	mV
V_{RECT_SET}	2	V_{RECT_SET}	Mandatory	mV
Delta R1 value	2	Delta R1 caused by PRU	Optional	.01 ohms
RFU	4	Undefined	N/A	

6.5.5.2 Optional Fields Validity

The Optional Fields Validity field shall identify which optional fields have valid values. All optional fields not identified as valid shall be set to zero.

Table 6.5.5.2-1 Detail: Bit Field for Optional Fields Validity

7	6	5	4	3	2	1	0
Delta R1	RFU	RFU	RFU	RFU	RFU	RFU	RFU

6.5.5.3 Protocol Revision

The PRU Protocol Revision field shall be assigned a number that maps to the highest A4WP specification revision supported per Table 6.5.4.11-1.

6.5.5.4 PRU Category

The PRU Category shall be assigned a Category number.

Bit Field	Version Description
0	Undefined
1	Category 1
2	Category 2
3	Category 3
4	Category 4
5	Category 5
6-255	Undefined

6.5.5.5 PRU Information

The PRU Information including BLE radio count and NFC capabilities, shall be defined by this field.

Table 6.5.5.5-1 Detail: Bit Field for PRU Information

7	6	5	4	3	2	1	0
NFC receiver	Separate BTLE radio in PRU	Power Control Algorithm Preference	Adjust power capability	Charge Complete Connected Mode	RFU	RFU	RFU
0 = Not supported 1 = Supported	0 = Not supported 1 = Supported	0 = $V_{RECT\_MIN\_ERROR}$ 1 = Max System Efficiency	0 = Not supported 1 = Supported	0 = Not supported 1 = Supported			

6.5.5.6 PRU Hardware Revision

The PRU Hardware Revision is vendor proprietary.

Bit Field	Hardware Revision Description
	Defined by OEM

6.5.5.7 PRU Firmware Revision

The PRU Firmware Revision is vendor proprietary.

Bit Field	Firmware Revision Description
	Defined by OEM

6.5.5.8 P_{RECT_MAX}

The PRU shall report its maximum rated P_{RECT} power as P_{RECT_MAX}. The value is in increments of 100 mW.

Bit Field	Power in mW
0-255	0-25500 mW

6.5.5.9 $V_{RECT\_MIN\_STATIC}$ (Static, First Estimate)

The PRU shall report its minimum V_{RECT} voltage as $V_{RECT\_MIN\_STATIC}$. The value is in mV.

Bit Field	Voltage Minimum
0-65535	0-65535 mV

6.5.5.10 $V_{RECT\_HIGH\_STATIC}$ (Static, First Estimate)

The PRU shall report its maximum V_{RECT} voltage as $V_{RECT\_HIGH\_STATIC}$. The value is in mV.

Bit Field	Voltage Maximum
0-65535	0-65535 mV

6.5.5.11 V_{RECT_SET}

The PRU shall report its desired V_{RECT} voltage as V_{RECT_SET}. The value is in mV.

Bit Field	V_{RECT_SET}
0-65535	0-65535 mV

6.5.5.12 Delta R1 Caused by PRU

The PRU may report its Delta R1, if included, in increments of 0.01 ohms.

Bit Field	Delta R1
0-65535	0 - 655.35 ohms

6.5.6 PRU Dynamic Parameter

The PRU Dynamic Parameter characteristic contains measurement data with values that change during the charging process on the PRU.

6.5.6.1 PRU Dynamic Parameter Characteristic Behavior

The PRU Characteristic Behavior characteristic returns its value when read using the GATT Read Characteristic Value procedure. The PTU shall read this characteristic at least every 250 ms.

When a PTU requires a connection to a PRU to read PRU Dynamic Parameter Characteristic values it shall follow the connection procedures described in section 6.4.5.2.

Based on the PRU Dynamic Parameter Characteristic, the PTU shall update the device control table in the registry corresponding to each PRU status.

6.5.6.2 PRU Dynamic Parameter Characteristic Value

The PRU Dynamic Parameter characteristic value fields are described in the Table 6.5.6.2-1. The length of the characteristic value is 20 octets.

When read, this characteristic returns dynamic variables from the PRU (e.g., V_{RECT}) to the PTU.

Table 6.5.6.2-1 PRU Dynamic Parameter Characteristic

Field	Octets	Description	Use	Units
Optional fields validity	1	Defines which optional fields are populated	Mandatory	
V_{RECT}	2	DC voltage at the output of the rectifier.	Mandatory	mV
I_{RECT}	2	DC current at the output of the rectifier.	Mandatory	mA
V_{OUT}	2	Voltage at charge/battery port	Optional	mV
I_{OUT}	2	Current at charge/battery port	Optional	mA
Temperature	1	Temperature of PRU	Optional	Deg C from -40C
$V_{RECT\_MIN\_DYN}$	2	The current dynamic minimum rectifier voltage desired	Optional	mV
$V_{RECT\_SET\_DYN}$	2	Desired V_{RECT} (dynamic value)	Optional	mV
$V_{RECT\_HIGH\_DYN}$	2	The current dynamic maximum rectifier voltage desired	Optional	mV
PRU alert	1	Warnings	Mandatory	Bit field
RFU	3	Undefined		

6.5.6.3 Optional Fields Validity

The Optional Fields Validity field shall identify which optional fields have valid values. All optional fields not identified as valid shall be set to zero.

Table 6.5.6.3-1 Detail: Bit Field for Optional Fields Validity

7	6	5	4	3	2	1	0
V_{OUT}	I_{OUT}	Temperature	$V_{RECT\_MIN\_DYN}$	$V_{RECT\_SET\_DYN}$	$V_{RECT\_HIGH\_DYN}$	RFU	RFU
1 = Yes 0 = No	1 = Yes 0 = No	1 = Yes 0 = No	1 = Yes 0 = No	1 = Yes 0 = No	1 = Yes 0 = No	RFU	RFU

6.5.6.4 V_{RECT} - Voltage at Diode Output

The PRU shall report the voltage at its rectifier output as V_{RECT}. The value is in mV.

Bit Field	V_{RECT}
0-65535	0-65535 mV

6.5.6.5 I_{RECT} - Current at Diode Output

The PRU shall report the current at its rectifier output as I_{RECT}. The value is in mA.

Bit Field	I_{RECT_SET}
0-65535	0-65535 mA

6.5.6.6 V_{OUT} - Voltage at Charge Battery Port

The PRU may report its charge output voltage as V_{OUT}. The value is in mV.

Bit Field	Charge Battery Port Voltage
0-65535	0-65535 mV

6.5.6.7 I_{OUT} - Current at Charge Battery Port

The PRU may report its charge output current as I_{OUT}. The value is in mA.

Bit Field	Charge Battery Port Current
0-65535	0-65535 mA

6.5.6.8 PRU Temperature

The PRU may report its temperature in this field. The value is in degrees Celsius, with 0 corresponding to -40C, and 255 corresponding to +215C.

Bit Field	Temperature C
0-255	Deg C from -40C to +215C

6.5.6.9 $V_{RECT\_MIN\_DYN}$ (Dynamic Value)

The PRU may report its dynamic minimum rectifier voltage as $V_{RECT\_MIN\_DYN}$. The value is in mV.

Bit Field	V_{RECT} Dynamic Value
0-65535	0-65535 mV

6.5.6.10 $V_{RECT\_SET\_DYN}$ (Dynamic Value)

The PRU may report the desired voltage at its rectifier output as $V_{RECT\_SET\_DYN}$. The value is in mV.

Bit Field	V_{RECT} Dynamic Value
0-65535	0-65535 mV

6.5.6.11 $V_{RECT\_HIGH\_DYN}$ (Dynamic Value)

The PRU may report its dynamic maximum rectifier voltage as $V_{RECT\_HIGH\_DYN}$. The value is in mV.

Bit Field	V_{RECT} Dynamic Value
0-65535	0-65535 mV

6.5.6.12 PRU Alert

PRU Alert is included in both the PRU Dynamic Parameter Characteristic and the PRU Alert Characteristic so as to provide for the fastest potential delivery and response.

Table 6.5.6.12-1 Detail: Bit Field for PRU Alert

7	6	5	4	3	2	1	0
Over-voltage	Over-current	Over-temp	PRU Self Protection	Charge Complete	Wired Charger Detect	PRU Charge Port	RFU

Refer to 6.5.7, PRU Alert Characteristic, for details on the following fields.

- Over-voltage
- Over-current
- Over-temp
- PRU Self Protection
- Charge Complete
- Wired Charger Detect

The PRU Charge Port bit is set to '1' to indicate that the PRU charge port output is activated. Otherwise this bit is set to '0'.

6.5.7 PRU Alert Characteristic

The PRU Alert characteristic enables a PTU to receive notifications or indications of the PRU Alert characteristic from a PRU supporting this feature to show alerts (e.g., OVP, OCP, OTP and PRU Self Protection).

6.5.7.1 PRU Alert Characteristic Behavior

The PRU Alert characteristic enables a PTU to receive notifications of the OVP, OCP, OTP and PRU Self Protection, Charge Complete and Wired Charger Detect flags from a PRU supporting this feature.

The PRU Alert characteristic also enables a PRU to send indications to the PTU regarding Mode Transition as described in section 6.7 via the Mode Transition Bits.

The PTU shall be able to receive multiple notifications and indications of the PRU Alert characteristic from the PRU.

6.5.7.2 PRU Alert Characteristic Value

The PRU Alert characteristic value fields are described in the Table 6.5.7.2-1. The length of the characteristic value is 1 or 7 octets depending on the presence of the optional Device Address.

Table 6.5.7.2-1 PRU Alert fields

Field	Octets	Description	Use	Units
PRU Alert	1	Defines the Over Voltage, Over Current, Over Temperature and Self Protection Alerts	Mandatory	
Device Address (Optional)	6	Bluetooth device address (48 bits) used in mode transition reconnect	Conditional upon support for the Mode Transition feature.	

Table 6.5.7.2-2 Detail: Bit Field for PRU Alert Notification

7	6	5	4	3	2	1	0
PRU Over-Voltage	PRU Over-Current	PRU Over-Temperature	PRU Self Protection	Charge Complete	Wired Charger Detect	Mode Transition Bit 1	Mode Transition Bit 0

6.5.7.3 PRU Over-voltage

This bit, when set to '1', indicates that V_{RECT} at the PRU has exceeded the OVP limit. Refer to 5.2.9.11 for PTU Latching Fault requirements. Otherwise, this bit is set to '0'.

6.5.7.4 PRU Over-current

This bit, when set, indicates that I_{RECT} at the PRU has exceeded the PRU's current limit. Refer to 5.2.9.11 for PTU Latching Fault requirements.

6.5.7.5 PRU Over-temperature

This bit, when set, indicates that measured temperature at the PRU has exceeded the PRU's temperature limit. Refer to 5.2.9.11 for PTU Latching Fault requirements.

6.5.7.6 PRU Self Protection

This bit, when set, indicates that the PRU is protecting itself by reducing power to its load. The PTU does not need to change states as a result. The PTU may provide feedback to the user via its user interface that one of the PRU's may not be charging at full rate.

6.5.7.7 Charge Complete

This bit, when set, indicates that the PRU does not require charging.

6.5.7.8 Wired Charger Detect

This bit, when set, indicates that the PRU is powered by external wired power.

6.5.7.9 Mode Transition Bits

The Mode Transition bits shall be set to a non-zero value to indicate to the PTU the duration of the pending Mode Transition procedure as described in section 6.7. The bits shall indicate the Mode Transition duration values as defined in Table 6.5.7.9-1.

Table 6.5.7.9-1 Mode Transition

Value (Bit)	Mode Transition Bit Description
00	No Mode Transition
01	2 s Mode Transition time limit
10	3 s Mode Transition time limit
11	6 s Mode Transition time limit

6.5.7.10 Device Address

The Device Address field shall be included as part of the PRU Alert Notification field if and only if the Mode Transition bits are set to a non-zero value. Refer to section 6.7 for the Mode Transition procedure.

6.6 Cross Connection Algorithm

The cross connection algorithm is a set of functions designed to prevent connection between a PTU and a PRU that is not in the PTU's charging area.

6.6.1 Definitions

A distant PRU is defined as one that is not within a given PTU's charging area. A local PRU is defined as one that is within a given PTU's charging area. A distant list is a persistent list of PRU addresses that are assumed to not be within a given PTU's charging area.

6.6.2 Acceptance of Advertisement

During a long beacon, the BLE client (PTU) shall issue a connection request between 0 and 50 ms of a received WPT Service related advertisement provided that:

1. the RSSI of the advertisement is greater than ADV_PWR_MIN as measured at the receive antenna, AND
2. the PTU observes an impedance shift close to the time of the advertisement as described in section 6.6.3.

NOTE: The ADV_PWR_MIN recommended value is -60 dBm, but may vary based on implementation.

If neither of these conditions are satisfied, the PTU shall ignore advertisements from that device. If one of these conditions is satisfied, then once the 11th advertisement is received, or more than 1700 ms elapses, then the PTU shall issue a connection request.

For information on use of the Distant List, refer to section 6.6.4.

The PTU shall ignore any advertisements if they occur when the PTU's resonator is unpowered.

The PTU conditions for acceptance of advertisement shall not apply for PRUs in mode transition (refer to section 6.7).

6.6.3 Impedance Shift Sensing

Each PTU design contains a table of Short Beacon PRU-induced Impedance, $Z_{TX\_IN\_LOAD\_DETECT}$ that can be detected by the PTU. Refer to Table 7.1.1-1.

Upon receipt of an advertisement from a PRU during a long beacon, the PTU shall look up the $Z_{TX\_IN\_LOAD\_DETECT}$ from its internal table. From the time an impedance shift is detected, the PTU shall look for an advertisement during the next 110 ms. (Note that if this period extends beyond the boundaries of the long beacon, a comparison to the values measured during the previous beacon may need to be made.)

The PTU shall then compare the impedance change to the $Z_{TX\_IN\_LOAD\_DETECT}$. (If the PTU is capable of measuring only one of reactance or resistance changes, then only one comparison is made.) If either the resistance or the reactance exceeds the values from the table, then the PTU is to consider the PRU to have an associated impedance shift. If the PRU reports Impedance Shift bits set to 000 in the PRU advertising payload (refer to sections 4.3.3.4 and 6.5.1), the PTU is to consider the PRU to have an associated impedance shift no matter what the measured value.

6.6.4 Reboot Bit Handling

A PTU may have an algorithm that looks for advertisements during periods when the power amplifier is off. Since advertisements are not allowed when the PRU is unpowered, any advertisement that occurs during this time may be considered an advertisement from a distant PRU. The PTU may retain the address of such advertisements and place them on a "distant" list, to be ignored in the future. This prevents future cross-connections to that PRU.

If a PTU implements such a system, it must ignore the “distant” list whenever the reboot bit in the PRU advertisement is set to '0'. In addition it must clear that device from the “distant” list whenever the reboot bit in the PRU advertisement is set to '0'. The reboot bit indicates that the PRU has recently had power removed and re-applied, as it would if the phone were moved from one pad to another; this makes any “distant” list invalid. Otherwise, the PTU may ignore this bit.

6.6.5 Time Set Handling

After the PRU Control characteristic is written that includes a Time Set value and Enable PRU output set to '1', the PRU shall create a valid load variation of at least $Z_{TX\_IN\_LOAD\_DETECT}$ which is defined for each PTU resonator in section 7, maintain that load condition for the defined time in the Time Set field (Table 6.5.3.2-4), and upon completion, the PRU shall return to its original load condition and maintain it for 20 ms. The PRU shall enable the output after checking cross connection by the Time Set value.

If present, the PTU shall detect the PRU load variation and compare the measured load variation period to the defined Time Set value with a tolerance of ± 5 ms. If the PRU does not create the expected load variation for the defined Time Set value and the PRU supports Time Set (refer to 6.5.1 for Time Set Support bit), the PTU shall consider the PRU to be cross-connected, and the PTU shall enter the PTU Latching Fault State (refer to 5.2.9.11).

6.7 Mode Transition

A PRU’s BLE controller may need to re-initialize during an active charging session when the PRU is in Power On State as described in section 5.3.5 and the PTU is in the Power Transfer State as described in section 5.2.5. An example of when this procedure may be necessary is when a PRU initially charging from a completely dead battery condition retains enough battery charge where it is then possible to energize other subsystems comprised in the platform containing the PRU.

If the BLE controller re-initialization procedure requires the BLE link between a PRU and a PTU to terminate and then reinitialize, then the Mode Transition procedure described in this section shall be followed.

6.7.1 Mode Transition Procedure

The PRU shall notify the PTU of its intent to terminate the BLE link prior to executing its re-initialization procedure (of the BLE link). This Mode Transition notification is a GATT indication to the PTU that the PRU’s physical BLE link is about to drop and that the PTU and PRU will take the following actions. It is mandatory for the PTU to support the mode transition procedures defined for both zero and non-zero Device Address fields in the Mode Transition indication.

While in the PRU On State, if the PRU needs to reinitialize the BLE link with the PTU, the PRU shall notify the PTU by issuing a Mode Transition alert. A Mode Transition shall be performed by the PRU sending an Alert characteristic indication as described in section 6.5.7. The PRU shall include the following information within the Mode Transition alert:

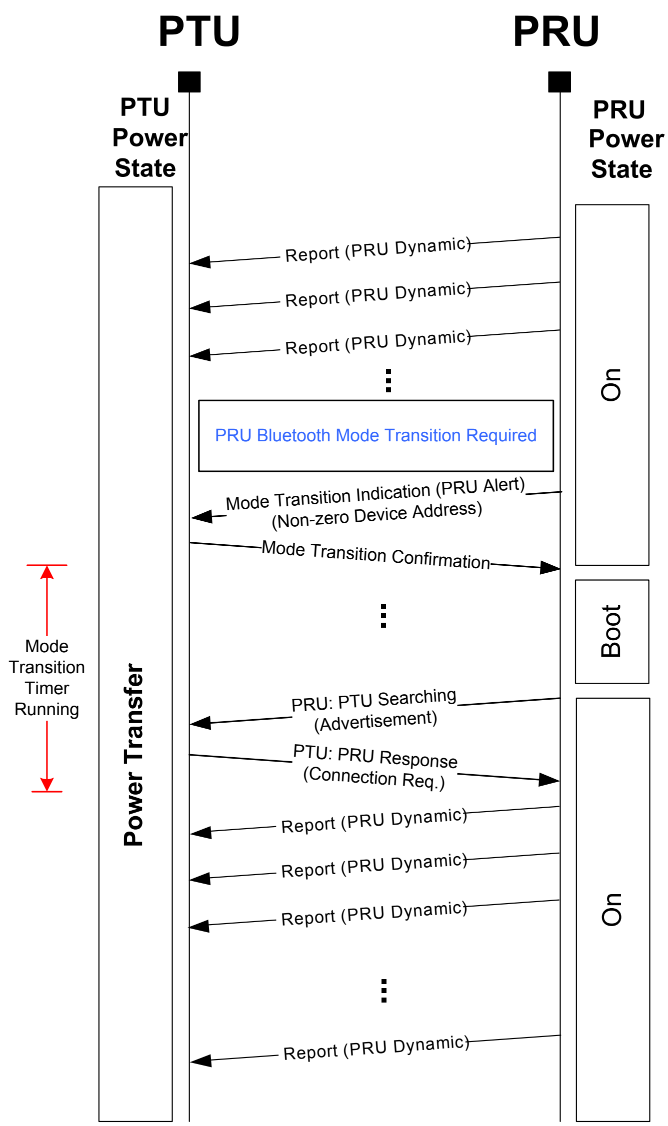
1. The Mode Transition Bits shall be set to the (non-zero) time required for mode transition to complete. The bit settings shall indicate the duration of the Mode Transition using the format described in section 6.5.7.9, Mode Transition Bits.
2. If known, the Device Address field shall be set to the BLE device address to be used when the PRU’s advertises and reconnects to the PTU after BLE device re-initialization. If this device address is unknown at the time this indication is sent, then the PRU shall set the Device Address field to all zeros. Refer to section 6.5.7.10, Device Address.

If the Mode Transition Bits indicate a period of less than or equal to 3 seconds, then the PTU shall maintain I_{TX_COIL} relative to the PRU for the duration of the Mode Transition period. The PTU shall exclude the PRU from being classified as a rogue object only during the Mode Transition procedure.

If the Mode Transition Bits are set to a value greater than 3 seconds, then prior to the beginning of the Mode Transition procedure, the PRU shall change its input impedance setting to support no more than a 1.1 watt power draw and shall restrict any impedance change to this level during the entire Mode Transition procedure. The PTU shall adjust I_{TX_COIL} to this setting and shall maintain I_{TX_COIL} relative to the PRU for the duration of the Mode Transition procedure. If the Mode Transition device address is set to a non-zero value, then the Mode Transition expiration timer shall be stopped once the BLE connection is re-established. Otherwise the Mode Transition expiration timer shall be stopped once the registration procedure concludes at the issuing of the Control Characteristic containing the Enable PRU Charge command as described in section 6.5.2.2.

6.7.2 BLE Reconnection Procedure

If the Device Address field within the Mode Transition alert is set to a non-zero value, then the PRU shall use this device address as its own in advertisements issued after re-initializing. BLE device discovery shall not be executed by the PTU and the PTU shall attempt to reconnect to the PRU on receipt of the first advertisement from the PRU as well as any subsequent advertisements due to failed connection attempts. Once reconnected, the PTU shall be able to immediately support the previous charging session parameters used prior to re-initialization and execution of the registration procedure shall not be executed and the PRU is not subjected to the Acceptance of Advertisement checking, specified in section 6.6.2. Figure 6.7.2-1 contains an illustrative message sequence chart depicting this procedure. GATT responses are omitted in the chart for simplicity.

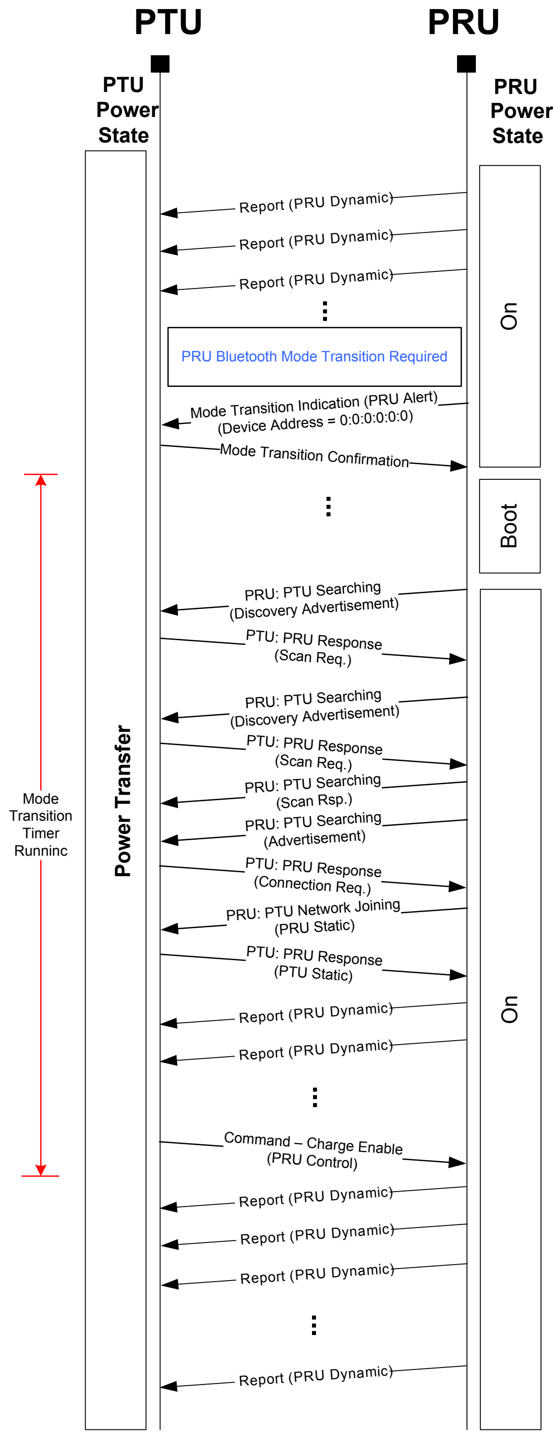


NOTE: Read Requests are omitted for simplicity. Read Responses are shown as "Report (PRU Dynamic)".

Figure 6.7.2-1 PRU Mode Transition - Device Address Field set to a Non-zero Value

If the Device Address field within the Mode Transition alert is set to all zeros, then the PTU will not have any information regarding the address used by the PRU during BLE link reconnection. In this case the PTU shall rediscover the PRU's BLE device address when the PRU once again begins advertising. Subsequently, the PTU shall reconnect with the PRU and execute the entire registration procedure which concludes at the issuing of the Control Characteristic containing Enable PRU Charge command as described in section 6.5.3.2. Figure 6.7.2-2 contains an illustrative message sequence chart depicting this procedure.

1



2 **Figure 6.7.2-2 PRU Mode Transition - Device Address Field set to all Zeros**

3

4

7 PTU Resonators

The purpose of this section is to define the parameters required for the specification of approved PTU resonators as well as to identify currently approved PTU resonators. Refer to A4WP New PTU Resonator and Resonator Interface Acceptance Test [A4WP-T-0001], for PTU resonator test methodology.

NOTE: All resonator impedance ranges and interfaces are specified in a manner which excludes the influence of any adaptive matching circuit.

7.1 Class n Design Template

The following sections are required to be completed for every class of PTU resonator design. Refer to section 3.1 for PTU classifications.

7.1.1 Table of Specifications

If a parameter in Table 7.1.1-1 is not applicable to the PTU resonator design (e.g., the PTU does not support a category of PRUs), that parameter is to be identified as Not Applicable (N/A). Refer to section 3.2 for PRU categories.

Table 7.1.1-1 PTU Resonator Table of Specifications

Resonator Type (e.g., Spiral Type # Resonator)		
Resonator current	$I_{\_TX}$ (Current mA_{rms})[4]	$I_{\_TX\_COIL}$
I_{TX_MIN}	TBD	TBD
$I_{TX\_SHORT\_BEACON\_MIN}$[5]	TBD	TBD
$I_{TX\_LONG\_BEACON\_MIN}$	TBD	TBD
I_{TX_START}	TBD	TBD
$I_{TX\_NOMINAL}$	TBD	TBD
I_{TX_MAX}	TBD	TBD
$I_{TX\_ABS\_MAX}$	TBD	TBD
Max rising edge slew rate	TBD mA/ms	
Resonator current derating	Power (W)	
Current derating power level	TBD	
$Z_{TX\_IN'}$	Minimum (Ohms)	
$Z_{PA\_SOURCE\_MIN}$	TBD	
Z_{TX_IN}	X_{TX_IN} (jOhms)	R_{TX_IN} (Ohms)

4 Approved PTU resonator specifications may define I_{TX} in addition to I_{TX_COIL}.

5 This parameter is provided for PRU design guidance.

Corner 1	TBD	TBD
Corner 2	TBD	TBD
Corner 3	TBD	TBD
Corner 4	TBD	TBD
Allowance for X_{TX_IN} per PRU category	Minimum (jOhms)	Maximum (jOhms)
$X_{TX\_IN\_CAT1}$	TBD	TBD
$X_{TX\_IN\_CAT2}$	TBD	TBD
$X_{TX\_IN\_CAT3}$	TBD	TBD
$X_{TX\_IN\_CAT4}$	TBD	TBD
$X_{TX\_IN\_CAT5}$	TBD	TBD
Allowance for R_{TX_IN} per PRU category	Minimum (Ohms)	Maximum (Ohms)
$R_{TX\_IN\_CAT1}$	TBD	TBD
$R_{TX\_IN\_CAT2}$	TBD	TBD
$R_{TX\_IN\_CAT3}$	TBD	TBD
$R_{TX\_IN\_CAT4}$	TBD	TBD
$R_{TX\_IN\_CAT5}$	TBD	TBD
Short Beacon PRU-induced Impedance	X_{TX_IN} (jOhms)	R_{TX_IN} (Ohms)
$Z_{TX\_IN\_LOAD\_DETECT}$	TBD	TBD
$Z_{TX\_IN\_LOAD\_CHANGE}$[6]	TBD	TBD
Matching	TBD	
Resonator geometry	Distance (mm)	
Length	TBD	
Width	TBD	
Configuration	TBD	
Wire gauge	TBD	
Resonator clearances	Distance (mm)	
Clearance to charge surface	TBD	
Clearance to enclosure edges	TBD	
Clearance to bottom enclosure	TBD	

1

6 This is the minimum change in Z_{TX_IN} caused by the PRU, refer to RAT, A4WP-T-0001.

7.1.2 PTU Resonator Structure

The PTU resonator design shall include all criteria necessary to build the PTU coil to the specification. The PTU resonator structure shall be defined including, however not necessarily limited to, the following:

- resonator geometry (a dimensioned drawing of the front, side, and top views shall be included),
- required resonator clearances (e.g., to charge surface, bottom of enclosure, enclosure edges),
- tuning,
- shielding, and
- matching network (if included as a component of the design).

7.2 Approved PTU Resonators

The following documents in Table 7.2-1 comprise the set of approved PTU resonators at the time of this publication. Parties to agreements based on this specification are also required to investigate the possibility of additional approved PTU resonators at:

https://www.rezence.com.

Table 7.2-1 Approved PTU Resonators by Class

Resonator Class	Resonator Id (by Class)	Document
2	0000 0001	A4WP TWC-S-0002 v1.0, *A4WP PTU Resonator Class 2 Design - Spiral Type S-1 (PTU 2-0001)*.
3	0000 0001	A4WP TWC-S-0003 v1.0, *A4WP PTU Resonator Class 3 Design - Spiral Type 210-140 Series (PTU 3-0001)*.
…	…	…

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Annex A Reference PRU for PTU Acceptance Testing (Informative)

Refer to section 3.2 for PRU categories.

A.1 Category 1

A.1.1 TBD

A.2 Category 2

Refer to the RIT 3-2 design in A4WP TWC-T-0001, A4WP New PTU Resonator and Resonator Interface Acceptance Test [A4WP-T-0001].

A.3 Category 3

A.3.1 PRU Design 3-1

PRU Table of Specifications

Parameter	Value	Units
$V_{RX\_OC\_BOOT}$	5.8	Volts
$V_{RX\_OC\_MIN}$	8.9	Volts
$V_{RX\_OC\_HIGH}$	13.7	Volts
$V_{RX\_OC\_MAX}$	18	Volts
R_{RX_MIN}	12.5	Ohms
Minimum clearance from charger area surface	0.5	mm

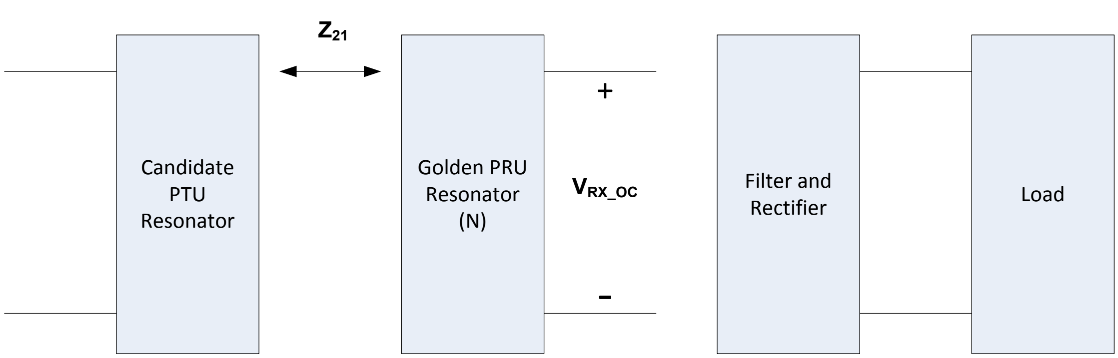
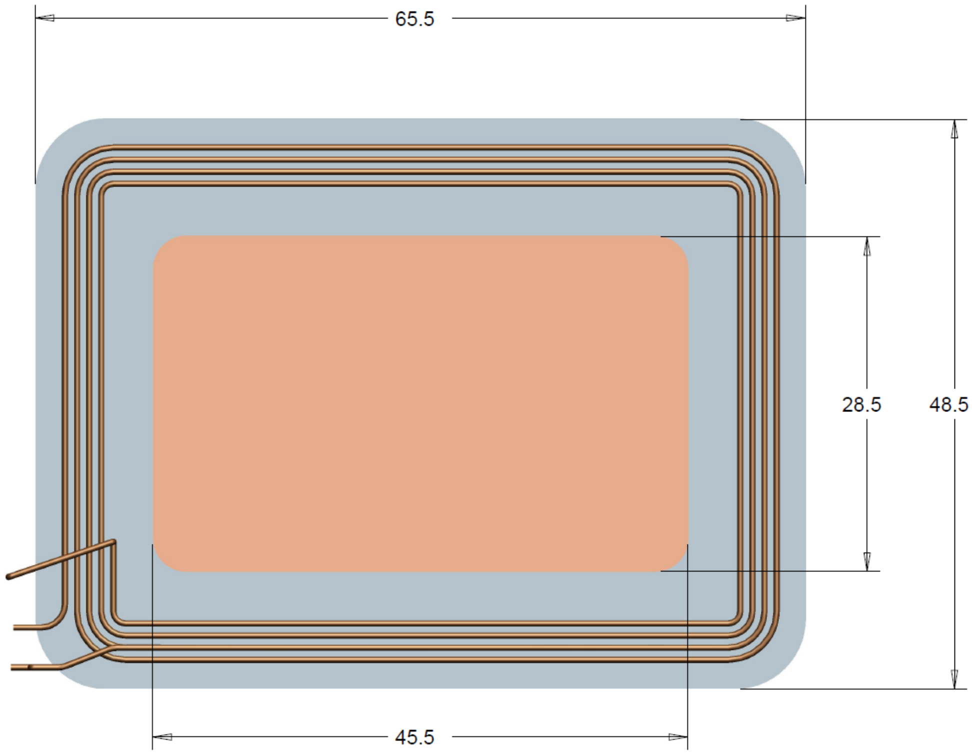


Figure A.3.1-1 PRU Design 3 Block Diagram

1 ## A.3.2 Geometry



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3 **Figure A.3.2-1 Front View**

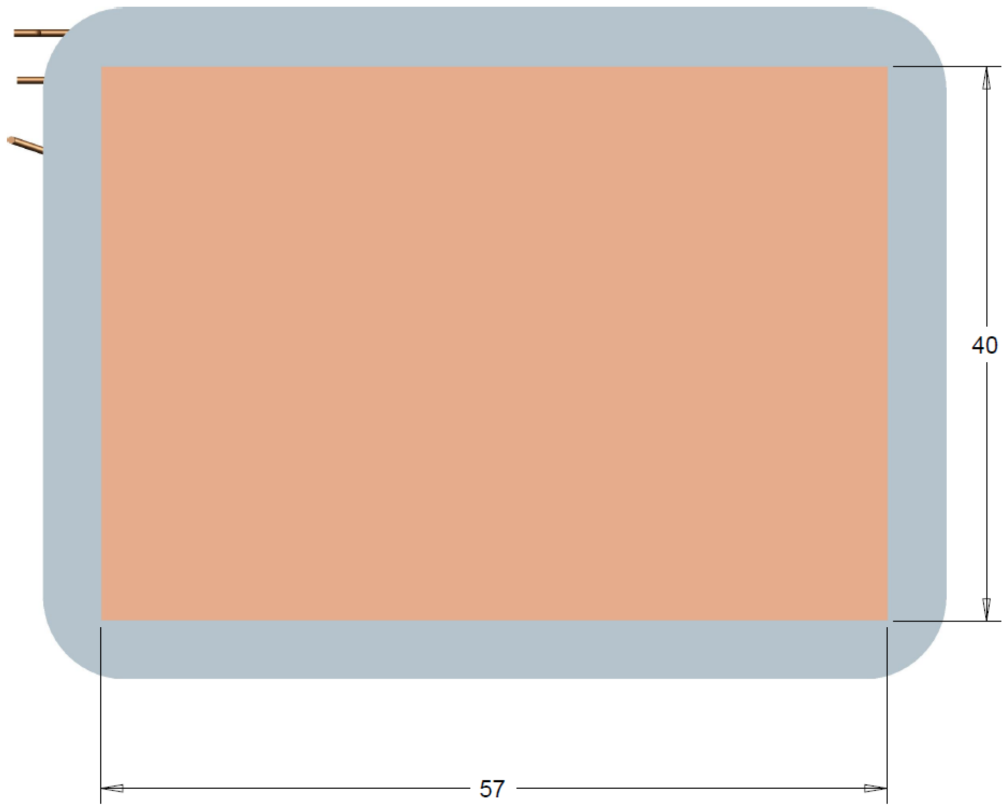

Figure A.3.2-2 Back View

Figure A.3.2-3 Side View

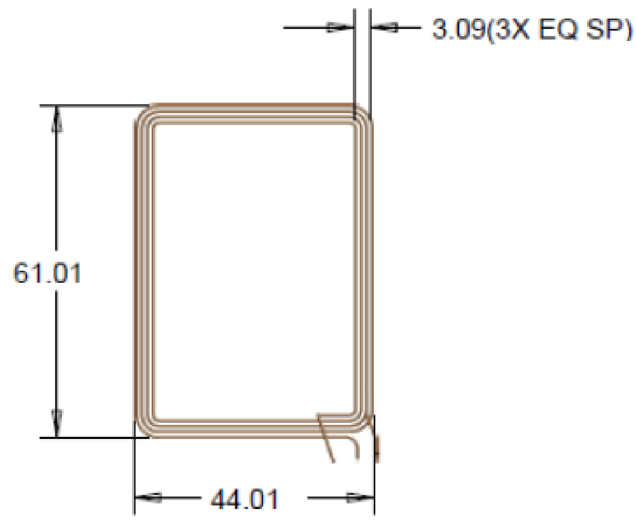

Figure A.3.2-4 Front View, Coil Only

NOTE: In the above figure, "3X EQ SP" means, "Three equal spaces".

Figure A.3.2-5 Side View, Coil Only

A.4 Category 4

A.4.1 TBD

A.5 Category 5

A.5.1 TBD

Annex B Lost Power (Informative)

This section provides considerations for the development of lost power procedures and lost power calculations.

B.1 Introduction

Lost power is defined as the power that can not be accounted for by the system. System power losses include:

- Efficiency losses in the PTU power section
- Losses in the PTU resonator
- Radiated losses
- Losses in the PRU resonator
- Efficiency losses in the PRU power section
- Losses caused by induction heating of the body of the PRU
- Losses caused by induction heating of other objects in the vicinity

Generally the PTU will have the ability to measure power in and the PRU will have the ability to measure and report power out. There will always be a difference between these two caused by the losses listed above. Some of the losses (such as PTU and PRU resonator losses, and PRU induction heating losses) can be estimated and accounted for fairly accurately. Some of the losses (such as induction heating of other objects) are unknowns.

Since induction heating of other objects is undesirable, PTU designers will often wish to estimate the amount of lost power assignable to induction heating of other objects. Simulation and empirical testing demonstrates that this can be done with an accuracy of a few watts. If an unaccountable amount of lost power is detected, PTU designers may elect to shut down the PTU to prevent potential heating of other objects.

This annex lists some of the issues surrounding lost power detection.

B.2 Cross Connection Issues

When a device is cross-connected it will be reporting its power to the “wrong” PTU and will generally cause a significant amount of lost power error. This can be used to help remedy cross connection issues, since a shutdown will tend to reset all BLE links on that PTU and allow the cross-connected device to “try again.”

B.3 Handoff Issues

In some cases a device may need to “hand off”, i.e., to transfer control from one BLE link to another, or from one BLE radio to another. During this time there will often be a transient in unreported power, and PTU designers must ensure that this does not cause an undesired lost power detection shutdown.

B.4 Power noise issues

The “spectrum” of power draw of a phone in current limit (i.e., drawing maximum power during charge) is relatively quiet since most phone inputs are current-regulated. However, once fully charged or close to fully charged, the power drawn becomes very noisy and thus hard to measure accurately. System designers can overcome this by implementing filters with a time constant much longer than the 250 ms sampling interval for PRU power, but this is somewhat difficult to implement. Thus measurement of lost power during periods other than full power may be difficult or impossible.

B.5 PTU Lost Power Calculation

B.5.1 Lost Power Detection Threshold

The PTU shall be capable of detecting when $P_{LOST} \geq$ TBD for at least six seconds.

B.5.2 Lost Power Detection Speed

If lost power exceeds, and then stays above TBD, the PTU shall shut down within six seconds measured from the moment that TBD was first exceeded.

B.5.3 PTU Lost Power Calculation

The PTU may implement the calculation $P_{LOST} = P_{TX\_OUT} - P_{ACK}$

- P_{TX_OUT}: Power output of the PTU resonator
- $P_{TX\_OUT} = P_{TX} - P_{TX\_RESONATOR\_DISSIPATION}$
- $P_{TX\_RESONATOR\_DISSIPATION}$: Power dissipated in the PTU resonator
- P_{ACK}: Power consumption acknowledged by PRUs
- $P_{ACK} = (P_{AC1} + P_{RXCOIL1} + P_{INDUCTION1}) + \ldots + (P_{AC\_N} + P_{RXCOIL\_N} + P_{INDUCTION\_N})$
    - P_{AC1}: Power into the rectifier of PRU 1
    - P_{RX1}: Power dissipated in the coil of PRU 1
    - $P_{INDUCTION1}$: Power consumed by the induction heating of PRU 1

B.5.4 PTU Power Transmission Detection Accuracy

The PTU should be able to detect the amount of power transmitted to within TBD.

B.6 PRU Lost Power Reports

NOTE: The PRU reports are used to calculate a total value of power consumption and dissipation that is acknowledged by the PRU (P_{ACK}). The parameters V_{RECT}, I_{RECT}, R_{RX_IN}, η_{RECT}, and Delta R_1 can be used to compute the total of power delivered to the load, power consumed by any PRU circuitry, power consumed by the resonator, and power consumed by any induction heating effects.

B.6.1 Accuracy of Reported Power

The total error of the power acknowledged by an each PRU, (P_{ACK}) shall be less than 0.75 W.

Part 3

Microwave Electromagnetic Field Surface Coupling Wireless Power Transmission Systems for Mobile Devices

Contents

Chapter 1 General Descriptions

1.1 Outline

This ARIB STANDARD (hereinafter referred to as “Standard”) specifies the wireless interface between a wireless power transmitting unit and a wireless power receiving unit of “Microwave Electromagnetic Field Surface Coupling Wireless Power Transmission (WPT) Systems” (hereinafter referred to as “System”). Two types of interfaces are specified. One is for the wireless power transmission and the other is for the radio communication which controls the power transmission in the WPT System.

This system is operated at a transmission power not exceeding the limitation allowed for use without permission in the "Other Equipment" category stipulated in “Article 45, Item (3) of the Regulations for Enforcement of the Radio Act” and the “Equipment Utilizing High Frequency Current” stipulated in “Article 100, Paragraph (1), Item (ii) of the Radio Act”.

1.2 Scope of the Standard

The configuration of the Microwave Electromagnetic Field Surface Coupling WPT System is shown in Figure 1-1.

The Microwave Electromagnetic Field Surface Coupling WPT System consists of a power transmitting unit (PTU), which transmits electrical power supplied from an external device, and a power receiving unit (PRU), which receives electric power transmitted by the PTU and supplies it to an external device. An Electromagnetic Field Surface Coupling is formed between power transmission device (PTD) of the PTU and power receiving device (PRD) of the PRU, and the electric power is wirelessly transferred. Signaling communication is used to control the power transmission, and such communication is performed between the radio communication parts of the PTU and radio communication parts of the PRU. The wireless communication parts of the PTU and PRU consist of a communication device and antenna, respectively. In general, the “external device” at the power transmitting unit is assumed to be the power supply equipment, and the “external device” at the power receiving unit is assumed to be the power receiving equipment.

The radio communication uses a different frequency from that of wireless power transmission

The scope of this Standard is illustrated in the configuration of the Microwave Electromagnetic Field Surface Coupling WPT System shown in Figure 1-1, and it specifies the wireless interface between the PTU and PRU and the wireless interface between the radio communication parts of PTU and PRU. As shown in Figure 1-1, the “specified point” is the position defining the wireless section interface, and there are two specified points: one is for power transmission and the other is for control signaling.

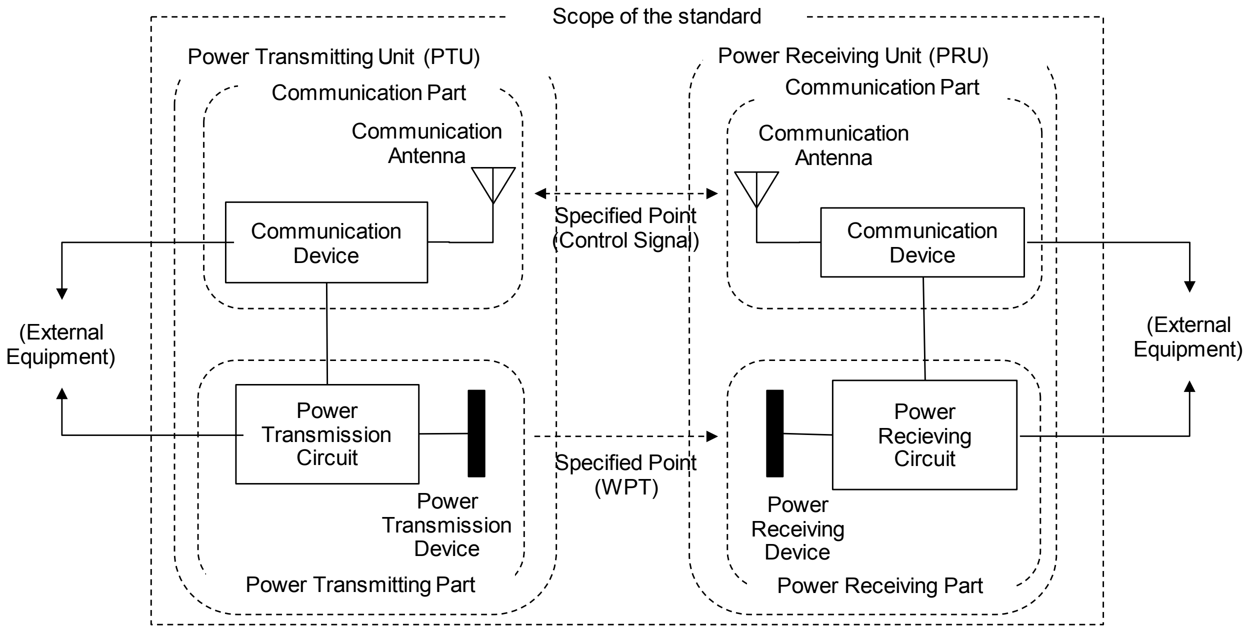

Figure 1-1 Configuration of the Microwave Electromagnetic Field Surface Coupling WPT System

1.3 Normative References

The terms used in this Standard follow the definitions specified in the Radio Act and other related regulations unless otherwise noted. In addition, "RERA" in the Chapter 3 means the "Regulations for Enforcement of the Radio Act".

Furthermore, this Standard refers to the following documents as needed and uses the corresponding reference numbers:

[1] Safety Guidelines for Use of Radio Waves, Inquiry Number 89 -Protection from the Radio Waves on the Human Body, Telecommunications Technology Council of Ministry of Posts and Telecommunications (MPT), April 1997.

[2] Inquiry Number 2030 - The Policy for the Regional Absorption, Telecommunications Technology Council of Ministry of Internal Affairs and Communications (MIC), May 2011.

[3] ARIB STD-T66 "Second Generation Low Power Data Communication System/ Wireless LAN System"

[4] ARIB STD-T56 "Specific Absorption Rate (SAR) Estimation for Cellular Phone Version",

Chapter 2 System Overview

2.1 System Characteristics

This System is designed and intended for indoor use, such office or household use, and outdoor use is not permitted. It is equipped with a wireless power transmission function for mobile device users based on electromagnetic field surface coupling utilizing the 2.4GHz band. This system adopts a star-network topology; namely, one power transmitting part (PTP) and communication part of PTU can serve multiple sets of power receiving parts (PRP) and communication parts of the PRU. Thus, this System can transmit power to multiple PRPs simultaneously.

2.2 System Architecture

Figure 2-1 shows the basic configuration of the System. This System is composed of a PTP, a communication part of the PTU, a PRP and a communication part of the PRU. The latter two are connected to the Receiving Target Device (mobile device). The whole system can be set up indoors on a table, desk or shelf. Configurations of the PTP and communication part of the PTU and the PRP and communication part of the PRU are described in Sections 2.2.1, 2.2.2 and 2.2.3. Again, one set of PTP and the communication part of the PTU can serve multiple sets of PRPs and communication parts of the PRUs. One set of PRP and communication part of the PRU is connected to the target mobile device.

2.2.1 Power transmitting part

The PTP is composed of a power transmission circuit and PTD. The power transmission circuit consists of a high frequency generating circuit and a power transmission control circuit. The input electric power from the power supply is converted into high-frequency power and fed to the PTD. The PTD transmits the high-frequency power to the PRD, which is placed on the PTD. The power transmission control circuit controls the output of the electric power from the high frequency generation circuit and switches the power transmission on and off.

2.2.2 Power receiving part

The PRP is composed of a power receiving circuit and PRD. The power receiving circuit is composed of a high frequency rectifier circuit and a power receiving control circuit. The PRD(s) receive the high-frequency power through the microwave electromagnetic field surface coupling over the surface proximity of the PTD. The high frequency rectifier circuit converts the received high-frequency power into direct current electric power and supplies it to the power receiving target device, such as a mobile device. It is sometimes used to charge the storage battery installed in the power receiving target device. The power receiving control circuit detects the output electric power (voltage or current) of the high-frequency rectifier circuit. Moreover, the power receiving control circuit has functions for stopping the circuit operation, etc. in the PRP based on the state of the PRP.

2.2.3 Communication parts of the PTU and PRU

The communication parts of the PTU and PRU are utilized for the communications related to power transmission / reception control between the PTP and PRP. The communication part of the PTU transmits the information on the state of the PTP, such as the start or stop of power transmission, to the communication part of the PRU. At the same time, the communication part of PTU also receives information on the state of the PRP sent from the communication part of PRU and conveys it to the power transmission control circuit. Moreover, the communication part of PRU transmits the PRP information related to the output voltage (power receiving voltage), output current (power receiving current), etc. to the communication part of PTU and receives information on the state of the PTP sent from the communication part of the PTU.

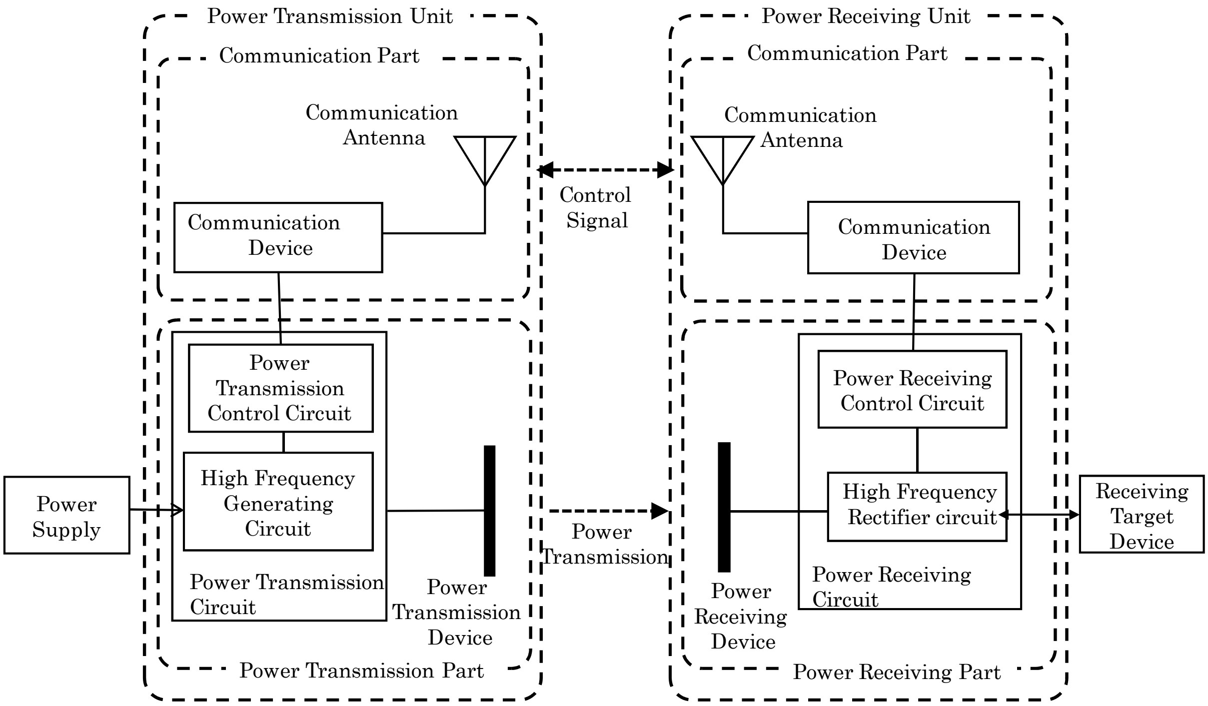

Figure 2-1 Basic configuration of the Microwave Electromagnetic Field Surface Coupling Wireless Power Transmission System

2.3 Requirements for the System

The use of this System is limited to indoor use, such as households, offices, etc., and realizes the following functions.

- Power supply to mobile devices, etc.
- Charging the batteries installed in mobile devices, etc.

Moreover, the basic requirements for this System are as follows.

- From the viewpoint of effective spectrum use, the power transmission system uses a narrowband continuous wave without modulation.
- The 2.4 GHz frequency band is used for operation.
- For safety and reliability, the system has a function for detecting the existence of a PRP.

2.3.1 Power transmitting part

The PTP shall satisfy the following requirements.

- PTP falls into the category of "Other Equipment" in "RERA Article 45 (iii)". Accordingly, it shall be operated at a transmission power below the high-frequency output limit that does not require permission.
- Unnecessary power leaks in the electromagnetic fields in this system shall not cause harmful interference with other systems.
- In order to protect the human body from RF exposure in relation to the WPT System, all possible measures shall be taken to comply with the requirements stipulated in the "Radio-radiation Protection Guidelines" and related regulations.
- The PTD shall be designed appropriately based on the return loss (reflectance loss) in order to secure transmission efficiency.
- The PTD power transmission device is assumed to have an equivalent composition to the standard PTD shown in Appendix 3.

2.3.2 Power receiving part

The PRP shall satisfy the following requirements.

- The Q factor, which is defined under the condition that both the PRD and the PTD are configured, shall meet the specified value range in order to secure transmission efficiency.
- The PRD is assumed to have an equivalent composition to the standard receiving device shown in Appendix 3.

2.3.3 Control scheme

The control operations provide the functions for detecting of the PRP, the power transmission control provides the functions for detecting the status of power transmission etc. and the communication control provides the functions for exchanging data signals etc. between the PTP and PRP. This system adopts a control scheme that uses the power transmission control functions together with the communication control function. The details of the control scheme are described in Chapter 4.

Chapter 3 Technical Requirements of the System

3.1 General Requirements

3.1.1 Power transmission method

A continuous wave without modulation shall be used for power transmission.

3.1.2 Power transmission frequency ranges

The frequency range used for power transmission shall be greater than 2497MHz and less than 2499MHz. The median frequency used for power transmission shall be 2498MHz

3.1.3 Power transmission frequency tolerance

The tolerance of the median frequency used for power transmission shall be less than 50ppm.

3.1.4 Radiated emission limits

The peak of radiated emission limits shall be in the range shown below at the distance of 30m with reference to “Article 46, Paragraph 1, Item 1 of Japan Radio Act Enforcement Regulations”.

(1) Less than or equal to 0.03mV/m under the condition that the frequency is at least 90MHz and does not exceed 108MHz; at least 170MHz and does not exceed 222MHz; or at least 2500MHz and does not exceed 2535MHz

(2) Less than or equal to 283mV/m under the condition that the frequency is greater than 2497MHz and less than 2499MHz

(3) Less than or equal to 0.1mV/m under the condition that the frequency does not exceed 10GHz besides the frequencies stated in (1) and (2)

3.1.5 Radiated leakage power limits

The total radiated leakage power of the power transmission, which is the summation of radiated power leaks in all directions, shall not exceed 0.15W (Refer to Section 5.2.5 and Description 2).

The total radiated leakage power of the inquiry power transmission defined in Section 3.2.4 shall not exceed 0.02W.

3.1.6 Strength of the RF exposure on the human body

The strength of the RF exposure on the human body shall be limited so that the Local SAR (Specific Absorption Rate) (average value over 6 minutes) per 10g of human tissue in a general environment is under the guideline values.

Refer to [1] and [2] for the guideline values for Local SAR in a general environment.

3.2 Power Transmission Part

3.2.1 High-frequency output

The high-frequency output, which is evaluated as the output power of the high frequency generating circuit, shall not exceed 30 W.

The high-frequency output in the case of the inquiry power transmission defined in Section 3.2.4 shall not exceed 0.5W when evaluated as the output power of the circuit that generates the radiation.

3.2.2 High-frequency output tolerance

The high-frequency output tolerance is not defined, but the maximum high-frequency output shall not exceed 30W.

3.2.3 Return loss of PTD

Return loss of the transmitter shall not exceed 7 dB under the condition that the receiver is not placed on top of the transmitter.

3.2.4 Inquiry power transmission

When the transmitter is not transmitting power, it executes the inquiry power transmission to check for the existence of the receiver on top of the transmitter. The high frequency output for the inquiry power transmission shall not exceed the power level defined in Section 3.2.1, even in the case that the communication part of the PRU works when the battery of the power receiving device is totally discharged into an unavailable status.

3.2.5 Q factor of the input element

The Q factor shall be at least 200 when the input element, a component of the transmitter, is placed on top of the reference model of receiving device for Q factor calculation described in Appendix 2.

3.3 Power Receiving Part

3.3.1 Q factor of the PRD

The Q factor shall be at least 200 when the receiver is placed on top of the reference model of power transmission device for Q factor calculation described in Appendix 2.

3.4 Radio Communication Parts of the PTU and PRU

3.4.1 Communication system

The communication system used for communication control shall refer to [3]. The details of the communication control method, including the communication protocol, depend on the technology specification of the adopted communication system. In this standard, the user data necessary for WPT is defined in Section 4.

3.4.2 Communication frequency range

The communication frequency used for communication control shall be at least 2400MHz and not exceed 2483.5MHz.

3.5 Others

3.5.1 Case

The case of the PTP, except the PTD, shall not be easy to open, and the cases of the communication parts of the PTU and PRU shall refer to [3].

3.5.2 Environmental conditions

The usage environmental conditions shall be limited to indoor use.

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Chapter 4 System Control Requirements

4.1 Outline

In this System, the main control functions for reliably and safely performing power transmission are listed in table 4-1.

Table 4-1 Control Functions

Control Functions	Main functions
Control functions for power transmission	・Detecting the PRP (checking whether it is appropriately placed on the PTD) ・Detecting the status of power transmission (including detecting anomalies, PRP removal, power related information, etc.) ・Controlling the power transmission status (such as the start and stop of power transmission, etc.)
Communication control function	・Exchanging user data between the communication part of the PTU and the communication part of the PRU

Control functions for power transmission include PRP detection, detection of the power transmission status, control of the power transmission status, etc. The communication control function is the function that certainly transmits the user data necessary for power transmission control between the communication part of the PTU and the communication part of the PRU. The control functions of this System detect the existence of a PRP and the status of power transmission using both the control functions for power transmission and data communication. Also, the control functions of this System transmit user data between the communication part of the PTU and the communication part of the PRU to control the status of power transmission, such as the start and stop of power transmission. Figure 4-1 shows the System configuration that achieves the control described above.

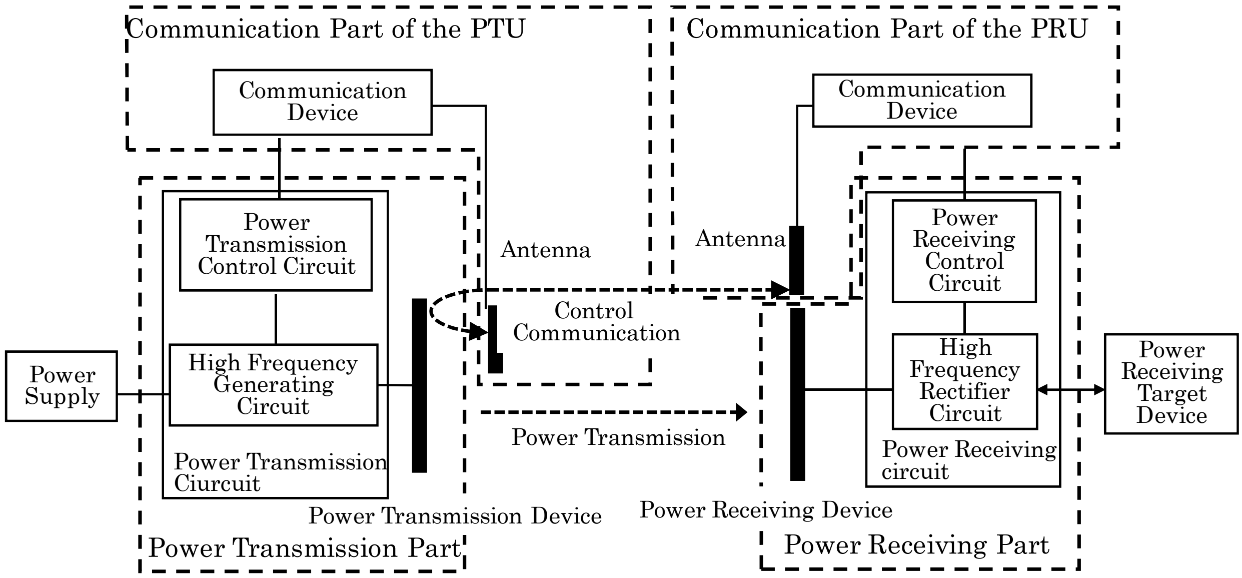

Figure 4-1 Detailed configuration of the microwave electromagnetic field surface Coupling WPT System

The communication device and antenna of the PTU and the communication device and antenna of the PRU shown in Figure 2-1 need to be radio equipment that meets the standard specified in Article 2, Item 1, No. 19 regarding the technical standard conformance certificate for specific radio equipment.

Communication control is performed via the PTD between the antenna mounted on the communication device of the PTU and the antenna mounted on the communication device of the PRU, respectively. An example of the antennas on the PTU and PRU is shown in Expository 1.

The communication control function utilizes a different frequency from the radio waves used for power transmission.

The details of the communication control system, such as the communication protocol, are described in the technical specifications for the communication system, and the framework of the communication procedure is set forth in this chapter.

4.2 Power Transmission Control System

The system that realizes the control function shown in Table 4-1 consists of four blocks, including the communication device of the PTU, power transmission control circuit, communication device of the PRU and power receiving control circuit.

The main function of each block is shown in Table 4-2.

Table 4-2 Main Function of Each Block

Block	Main function
Communication device of the PTU	・Control the communication of user data User data：identification number, PTP information, PRP information ・Transfer user data using the power transmission control circuit
Power transmission control circuit	・Status switching for power transmission, generation of PTP information, detection of PRP PTP information: power transmission start, power transmission stop Status of power transmission: inquiry power transmission, power transmission start, power transmission stop ・Transfer user data using the communication device of the PTU
Communication device of the PRU	・Control the communication of user data User data: identification number, PTP information, PRP information ・Transfer of user data using the power receiving control circuit
Power receiving control circuit	・Detect the information from the PRP PRP information: power receiving voltage, power receiving current, generation of PRP information by detecting the charging status ・Transfer user data using the communication device of the PRU

The communication device of the PTU and communication device of the PRU perform the control communication via the PTD and transfer the user data regarding the information related to the PTP and PRP. The individual identification number (ID) of the PRP is used as the MAC (Media Access Control) address of the communication device of the PRU.

The power transmission control circuit switches the status of power transmission such as the start and stop, and controls the output of the high frequency generation circuit, by the means that the control information is exchanged between the communication device of the PTU and the communication device of the PRU.

The power receiving control circuit detects the information related to the PRP, such as the power receiving voltage (output voltage from the high frequency rectifier circuit), power receiving current (output current from the high frequency rectifier circuit) and charging status, and the information is exchanged between the communication device of the PTU and the communication device of the PRU.

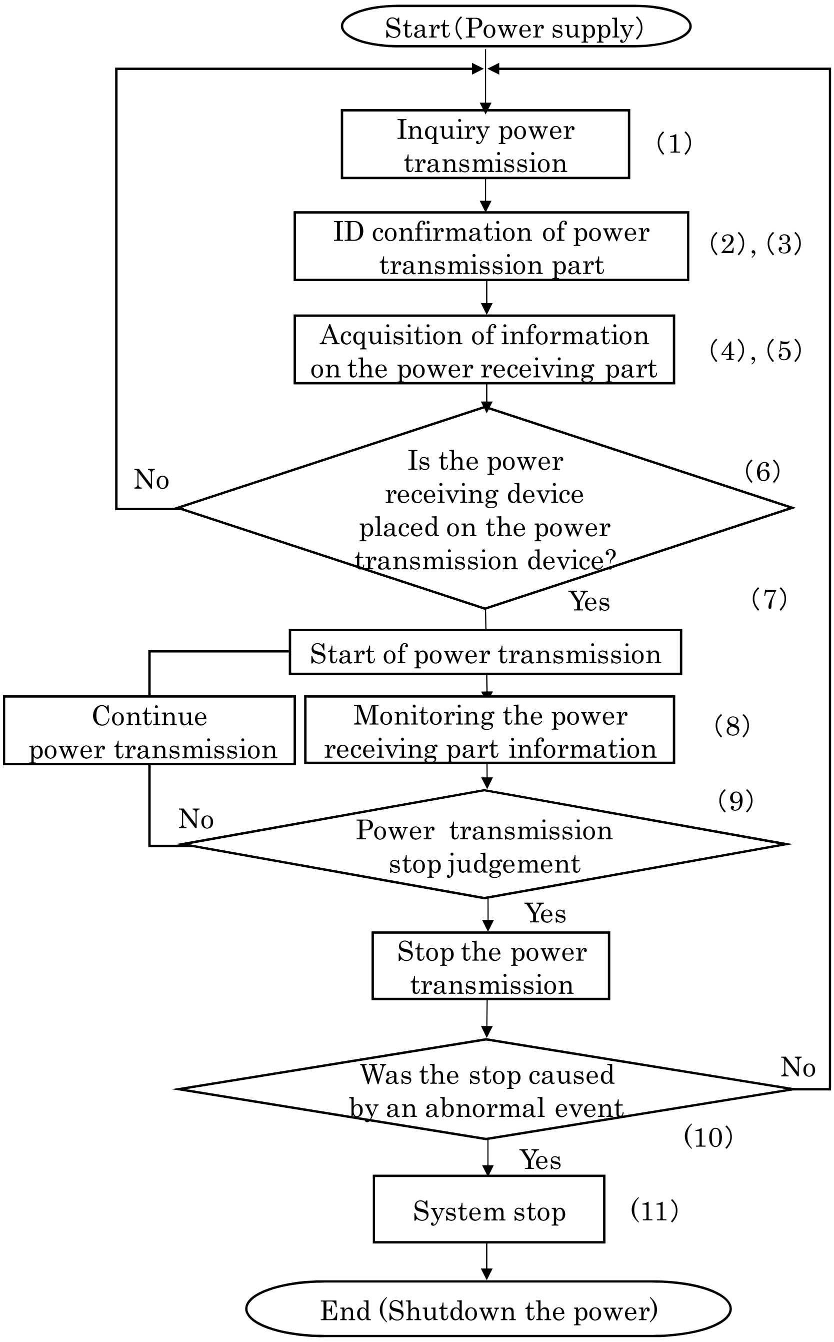

Figure 4-2 Control flow of PTP

The control flow of PTP is shown in Figure 4-2.

The operational status of the communication part and the PTP of the PTU, as well as the communication part and the PRP of the PRU, on the control flow shown in Figure 4-2 are described as follows. These functions are related to the procedure for starting power transmission when the PRP is detected on the PTD, procedure for stopping power transmission when the PRP is removed from the PTD and the exchange of information or procedures through the control communication between the communication part of the PTU and the communication part of the PRU via the PTD.

(1) After turning the power on, the PTP performs an inquiry power transmission using the same frequency radio waves as used for power-transmission and at an electric power level described in Section 3.2.1 for safety, and then, the PTP detects the PRP.

(2) The PTP requests the ID of the PRP via the communication part of the PRU using the communication part of PTU. This request is sent periodically for handling multiple PRPs. The interval of the ID request is 1 second or less.

(3) The communication part of the PTU receives the ID sent from the communication part of the PRU.

(4) The PTP requests the information related to the PRP (such as the power receiving voltage, power receiving current, maximum voltage and maximum current) through the communication part of the PTU. This request is sent periodically for handling multiple PRPs.

(5) The communication part of the PTU obtains the information of the PRP sent by the communication part of the PRU.

(6) The PTP judges that a PRP has been placed on the PTD when the receiving power (the power obtained from the high frequency rectifier circuit: power receiving voltage x power receiving current) exceeds 50mW, which is the high-frequency output for the inquiry power transmission, by referring to the information related to the PRP sent by the communication part of the PTU.

(7) The PTP starts the power transmission when a PRP is detected on the PTD. In the cases of (6) and (7), in the event it is detected that a PRP has been placed on the PTD, the power transmission is started when the total receiving power of all PRPs exceeds the 50mW high frequency output of the inquiry power transmission.

(8) The PTP monitors the information from the PRP regarding the power receiving status sent by the communication part of the PRU. The information is obtained by the communication part of the PTU after the power transmission starts. The monitoring interval is 1 second or less.

(9) Based on the monitoring results, the PTP determines whether the power transmission will be continued or terminated. The cases that the decision to stop the power transmission in normal status should be made are specified in Appendix 1. In cases when the decision to stop the power transmission is made, the power transmission should be suspended promptly.

(10) In the case of stopping the transmission for a reason other than malfunction, the

system returns to (1). The following cases are judged to be a malfunction.

・Either the voltage or current of the PTP exceeds the rated maximum value.

・A malfunction stop notification sent by the PRP is received.

・The control communication is disrupted

(11) When it is judged to be malfunction, the power supply by the PTP is terminated. The system operation is terminated when the power is shutoff.

Regarding the operation of each block, the procedure for connection establishment according to the control flow of the PTP is shown in Figure 4-3, and the control procedures from power transmission start to the power transmission stop are shown in Figure 4-4.

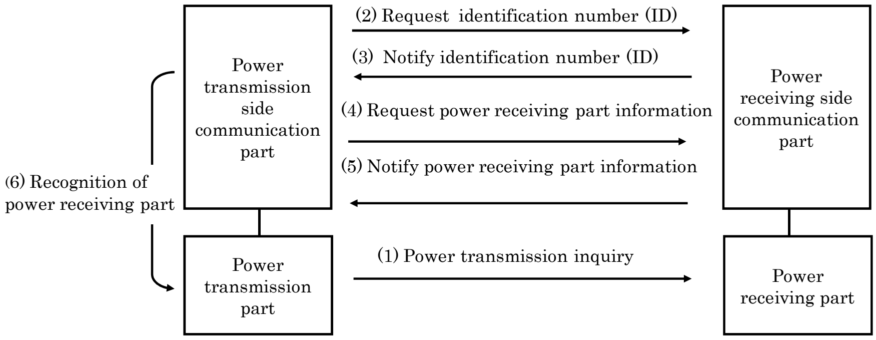

Figure 4-3 Procedure for establishing a connection

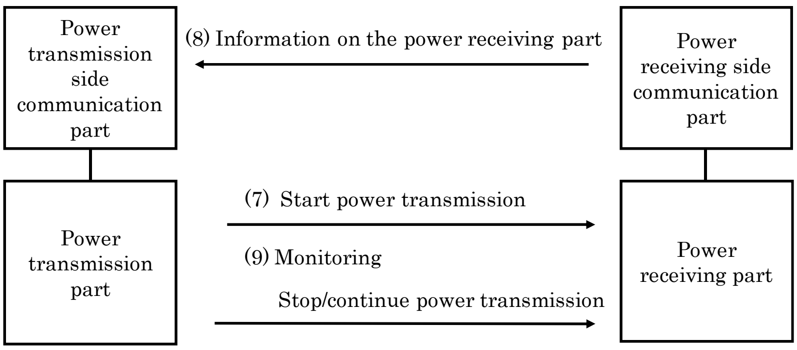

Figure 4-4 Control procedure

4.3 Communication Control System

The communication system for control communication is specified in reference [3]. The details of the communication control method, such as the communication protocol, are described in the standard for the adopted communication system. This Standard prescribes the user data required for power transmission. The structure of the user data used by the communication control system is shown in Figure 4-5.

Command	Data
8bit	0～56bit

Figure 4-5 User data Structure

The user data consists of the command part, which stores the program commands with 8 bits, and the data part with 0～56 bits.

Table 4-3 Details of the user data

Command segment (8 bits)			Data segment (0~56 bits)	
0x: 01	PTP→PRP	Request for the PRP ID	–	No use
0x: A1	PTP→PRP	Notification of PRP ID	0x: XXXXXXXXXXXX	PRP ID (48bits)
0x: 02	PTP→PRP	Request for the PRP information	–	No use
0x: A2	PTP←PRP	Notification of PRP information (Power receiving voltage / current)	Power receiving voltage 0x: XXXX XXXX Power receiving current	Power receiving voltage (16bita)[mV] Power receiving current (16bits)[mA]
0x: A3	PTP←PRP	Notification of PRP information (Maximum of related voltage / current)	Maximum related voltage 0x: XXXX XXXX Maximum related current	Maximum related voltage (16bits) [mV] Maximum related current (16bits) [mA]
0x: 04	PTP→PRP	Notification of power transmission starting	–	no use
0x: 05	PTP→PRP	Request for the PRP information (Power receiving voltage / current, charging status information)	–	no use
0x: A5	PTP←PRP	Notification of PRP information (Power receiving voltage / current, charging status information)	Power receiving voltage 0x: XXXX XXXX XX Power receiving current Charging status Information	Power receiving voltage(16bits) [mv] Power receiving current (16bits) [mA] Charging status information (8bits)
0x: 06	PTP→PRP	Notification of power transmission stop	–	No use
0x: 07	PTP→PRP	Notification of abnormal stop	–	No use
0x: A7	PTP←PRP	Notification of abnormal stop	–	No use

0x : hexadecimal number

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Chapter 5 Measurement Methods

In this chapter, the measurement methods are stipulated to confirm that the System meets the requirements in "Chapter 3: Technical requirements of the system". The testing conditions of the measurement refers to ”Item 8, Japan Radio Act Enforcement Regulations”. However, if alternative measurement methods are announced, those alternative methods or other methods considered to be better than the alternative methods should be applied.

5.1 Testing Conditions

5.1.1 Temperature and humidity of the measurement location

(1) Measurements should be performed in the temperature range of 5 - 35° C.

(2) Measurements should be performed in the humidity range of 45 - 85%.

5.1.2 Power supply

The power supply available in the market is utilized when the measurement requires a power supply.

5.1.3 Load

The details of the load under various measurement conditions are described in Section 5.2. The PRP should be used as the load.

5.2 Measurement Conditions

5.2.1 High-frequency output power

The measurement system for the high-frequency output of the high-frequency generating circuit in the power transmission circuit is shown in Figure 5-1. The measurement conditions of the high frequency output are as follows.

- The output terminal of the high frequency generating circuit is connected to a power meter through the attenuator.
- The high-frequency output shall be measured by the high-frequency power meter in the power transmission state while transmitting the maximum power.
- The measured electric power is confirmed to conform to the high-frequency output described in Section 3.2.1. Furthermore, when multiple high-frequency generating circuits are used in parallel, the sum of all electric power is deemed to be the high-frequency

output.

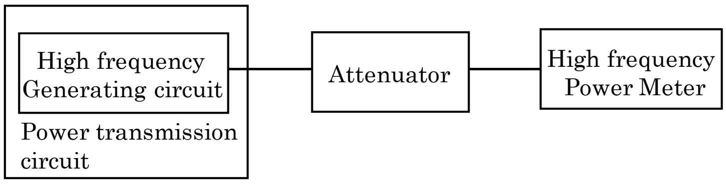

Figure 5-1 Measurement system for high-frequency output

5.2.2 Power transmission frequency ranges

Figure 5-2 shows the measurement system for the frequency used in the high frequency generating circuit of the power transmission circuit. The frequency of the power transmission circuit of the power supply is measured 15 minutes after the power supply is turned on.

- The frequency is measured using a frequency counter or spectrum analyzer.
- The output terminal of the high-frequency generating circuit is connected to the frequency counter through the attenuator.
- The frequency of the transmission circuit is measured by the frequency counter.
- The measured frequency is confirmed to be in the power transmission frequency range described in Section 3.1.2.

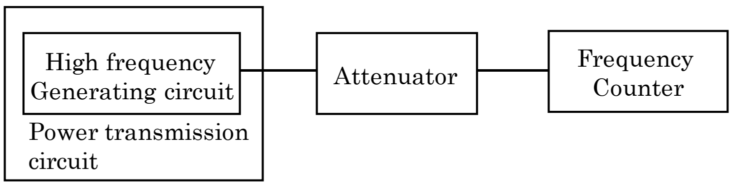

Figure 5-2 Measurement system for power transmission frequency

5.2.3 Median frequency tolerance

The frequency of the power transmission circuit of the power supply is measured 15 minutes after the power supply is turned on. The measurement conditions are assumed to be the same as those in Section 5.2.2, and the measured frequency is confirmed to be the median frequency prescribed in Section 3.2.1. It is also confirmed that the measured frequency is in the range of allowable variation prescribed in Section 3.1.3.

5.2.4 Radiated emission

Radiated emission is measured with reference to “Item 1, Japan Radio Act Enforcement

Regulations", and it must be confirmed that the radiated emission is below the limit value provided in Section 3.1.4.

When measuring either the PRP or PTP, the two parts must be working together and transmitting power at the maximum capacity.

Furthermore, the PTP and PRP must be placed in the position where the level of radiated emission becomes the maximum.

When the PTP or PRP is not available, the PTP or the PRP can be replaced with the reference model specified in Appendix 3, respectively.

5.2.5 Radiated leakage power

The radiation emission level at the median frequency of the power transmission is measured with reference to "Item 8, Japan Radio Act Enforcement Regulations". The radiated leakage power is calculated based on the measurements, and it has to be confirmed that the power is below the limit prescribed in Section 3.1.5. For the method of calculating radiated leakage power, refer to Description 2 for an example. When measuring either the PRP or PTP, the two parts must be working together and transmitting power at the maximum capacity. When the PTP or the PRP is not available, the PTP or the PRP can be replaced with the reference model specified in Appendix 3, respectively

5.2.6 Local SAR

The PTD in this system is not assumed to be used physically close to the side of human head. Therefore, regarding the measurement method for SAR among the methods described in Chapter 3, Article 4, the measurement location should conform to the method for "General machinery" described in Section 3.1.4 of Article 4 but exclude the side of the human head.

The distribution of the electric field in the Phantom Model is measured using a highly accurate isotropic electrical field probe. Based on the measurement, the Local SAR average in 10g of tissue is calculated with reference to Section 2.2 and 3.2.5 in Article 4. Furthermore, the measurement result shall be below the human body exposure indicator limit defined in Section 3.2.6 of Article 4.

Figure 5-3 shows the SAR measurement system for the PTP. The SAR of the PTP must be measured under the condition that the PTP containing the PTD is evaluated, combined with the PRP containing the reference model of PRD described in Appendix 3, and that it is transmitting power at the maximum capacity. SAR of the PTP in the inquiry power transmission state without the presence of a PRP must also be measured.

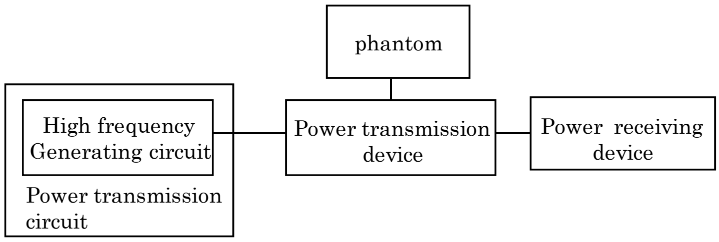

Figure 5-3 Measurement system for SAR

5.2.7 Return loss of the power transmission device

Figure 5-4 shows the system for measuring the return loss of the input part of the PTD. The network analyzer is connected to the input element of the PTD, and the reflection property (S_{11}) is measured. The measurement result shall be below the return loss value defined in Section 3.2.3.

The relationship between S_{11} and return loss (RL) can be expressed as RL=-10log(abs(S_{11})^2) (unit: dB).

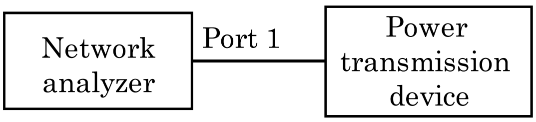

Figure 5-4 Measurement system for the return loss of the PTD input section

5.2.8 Q factor

Figure 5-5 shows the system for measuring the transmission coefficient when the PRD is placed on top of the PTD. The transmission coefficient S_{21} between the PTD and PRD must be measured using a network analyzer with the PRD placed on top of the PTD. The Q factor should be calculated using the measured S_{21}, and it must be confirmed that the value is more than the Q factor defined in Section 3.3.1. Refer to Appendix 2 for the method used to calculate the Q factor.

The PTD must be measured when it is combined with the reference model of PRD. The reference model of PRD shall meet all of the conditions specified in Appendix 3, and the method for calculating the Q factor shall follow that described in Appendix 2.

The PRD must be measured when it is combined with the reference model of PTD for the Q factor calculation that meets all of the conditions specified in Appendix 2. The reference model of PTD for the Q factor calculation has the same composition as the reference model of PTD for radiated emission measurement (refer to Appendix 3), but it is designed to have a taper shape for obtaining the Q factor with high accuracy.

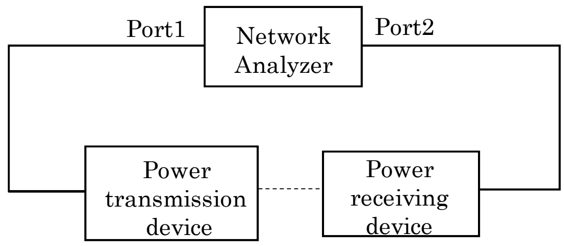

Figure 5-5 Measurement system for the transmission coefficient

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Chapter 6 Terms and Definitions

6.1 Terms and Definitions

The terms used in this standard are defined as follows:

[MAC Address]

Unique 48bit identifier assigned to hardware such as the communicator of the PTU or the communicator of the PRU.

[Q Factor]

Q factor describes the sharpness of the resonance of the resonance circuit. When the Q factor is high, the resonator bandwidth becomes narrow.

[Specific Absorption Rate: SAR]

The electric power absorbed per unit mass when electromagnetic radiation is irradiated through living tissue.

The value can be computed using the following equation.

SAR [W/kg] = $d(dW/dm)/dt = d(dW/\rho dV)/dt = \sigma E2 / \rho$

ρ : Density [kg/m^3]; dv : Micro volume element; dm : Micro mass element; dW : Energy absorbed in dm,

σ : Conductivity of the material (i.e. living tissue) [S/m],

E : Actual electric field intensity in the material [V/m]

[General Environment]

It implies to cases (or environments) with an indefinite factor, which means the status detection and adequacy management cannot be determined, when the human body is exposed to an electromagnetic field. It is the appropriated case where residents are exposed to an electromagnetic field in the general living environment and other similar scenarios. Therefore, regarding the needle value to be applied, the general environment is more severe than the administration environment.

[Other Equipment]

Equipment categorized as "high-frequency-based equipment" with no communication function that is used for directly providing high-frequency energy to a load or otherwise used for heating, ionization, etc.

[Local SAR]

SAR is a numeric value per micro volume element, which is the space distribution function depending on the irradiance condition and location in the body tissue. The local SAR is the average supervisor analysis router in 1 g or 10 g of human tissue.

[Proximity Region]

It is used as the terminology for the distance from the PTD, and in this standard, it means the region closer than the near-field.

[Output Power]

Electrical power transmitted via a power line conducting high frequency current at 10 kHz or higher. In this System, it is the electric power provided to the output terminal of the high frequency generating circuit in the PTP.

[High-Frequency Rectifier Circuit]

An electric circuit that converts high-frequency microwaves into DC power.

[High-Frequency Generating Circuit]

An electric circuit that converts the input power from the power supply for the WPT into the desired high-frequency electric power.

[High-Frequency-Based Equipment]

A category of equipment that utilizes high frequency current of 10 kHz or higher that is stipulated in Article 100, Paragraph 1 of the Japan Radio Act.

[Individual Identification Number]

A unique number assigned to every individual

[Power Receiving]

Receiving electric power at the PRP.

[Power Receiving Circuit]

A system component which consists of a high-frequency rectifier circuit and power receiving control circuit.

[Power Receiving Device (PRD)]

A component of the power receiving part that is used to receive the induction field of the microwaves from the PTD.

[Power Receiving Antenna]

Antenna connected to the communicator of the PRU that is used for the control communication to restrain the leak of the radio waves from the PTD.

[Communicator of the PRU]

Communicator connected to the power receiving circuit that is used for control communication to ensure safe power transmission.

[Communication Part of the PRU]

A system component connected to the power receiving part that is used for the control communication to ensure the security of the WPT. The communication part of the PRU consists of a PRU communicator and antenna.

[Power Receiving Control Circuit]

A circuit which detects the information from the PTP and delivers it using the PRU communicator.

[Receiving Power Voltage]

Voltage output from the high-frequency rectifier circuit.

[Receiving Power Current]

Current output from the high-frequency rectifier circuit.

[Receiving Power]

Electric power (receiving power voltage × receiving power current) output from the high-frequency rectifier circuit.

[Power Receiving Part (PRP)]

A system component consisting of the PRD and power receiving circuit.

[Power Receiving Part Information]

Information on the power receiving voltage, power receiving current, and charging status of the PTP.

[Power Transmission]

Transmission of power from the PTP.

[Power Transmission Circuit]

A system component consisting of the high-frequency generating circuit and power transmission control circuit

[Power Transmission Antenna]

An antenna connected to the communicator of the PTU that is used for the control communication of the PRU to restrain the leak of the radio waves from the PTD.

[Communicator of the PTU]

A communicator connected to the power transmission circuit that is used for the control communication of the PRU to ensure the security of the WPT.

[Communication Part of the PTU]

A system component connected to the PTP that is used for the control communication of the PRU to ensure the security of the WPT. It consists of a PTU communicator and an antenna.

[Power Transmission Device (PTD)]

A component of the PTP comprised of a sheet device that produces an instruction electromagnetic field for the WPT and an input element.

[Power Transmission Control Circuit]

A circuit which delivers the information using the PTU communicator and switches the power transmission status, such as starting and stopping the power transmission, by managing the output of the high-frequency generating circuit.

[Power Transmitting Part (PTP)]

A system component consisting of the PTD and power transmission circuit.

[Information from the PTP]

Information on the status of power transmission, such as starting and stopping.

[Median Frequency Tolerance]

Maximum permissible deviation from the assigned median frequency.

[Direct Power]

Electric power of the direct current.

[Safety Guidelines for Use of Radio Waves]

The guideline that is recommended for determining safe situations in which an electromagnetic field does not have an undue impact on the human body when exposed to electromagnetic fields (the frequency range is limited by 300GHz from 10kHz.).

The guidelines are comprised of "numerical values for electromagnetic field strength", "methods for evaluating the electromagnetic field" and "a protection method for reducing electromagnetic field irradiation".

The "Safety Guidelines for Use of Radio Waves" in this standard is the Telecommunications Technology Council Reports (April, 1997) of the Ministry of Posts and Telecommunications: Inquiry No. 89 "Protection from the Radio Waves on the Human Body"

[Inquiry Power Transmission]

For the purpose of detecting the PRP, microwaves are delivered at the allowable safe power using the same frequency as the WPT, which uses continuous microwaves without modulation, and without communicating any information.

[Input Element]

A component of the PTD that provides high frequency power to the sheet-like device, which has the equivalent composition as the PRD.

[Via (hole)]

The plating hole for the interlayer connection between the multilayer printed boards

[Phantom Model]

The pseudo human body model used to estimate SAR experimentally. When the whole model is made of the same material, it is called a uniform phantom model. In contrast, when the electrical characteristics faithfully imitate each corresponding tissue, it is called as a non-uniform phantom. In this system, a uniform phantom model consisting of an outer shell (case) filled with liquid, is used.

[Microwave]

Microwave refers to electromagnetic waves with a very short wavelength. Here, we call the frequency band of at least 2.4GHz frequency a microwave.

[Microwave WPT (Wireless Power Transmission) System]

A WPT system which transmits electric power using microwave radio waves between the PTD and PRD.

[Microwave Band Surface Coupling WPT System]

A microwave WPT System that wirelessly transmits power using an induction field when the PRD is placed on the surface proximity region.

[User Data]

Information, including the individual identification number, power transmission part and PRP, that is exchanged by the control communication between the PTU and PRU.

[Induction Field]

Electromagnetic field in the proximity region near the radiation source when the regions around the electromagnetic radiation source are divided into the three regions of proximity, near-field and far field.

[Return Loss: RL]

It expresses the quantity of electricity reflected in a high-frequency circuit. The relationship between the reflection coefficient S11 of the S parameter and return loss (RL) is shown by the following equation.

$RL = -10\log|S_{11}|^2$ (unit: dB)

[Power Transmission Frequency Ranges]

Frequency ranges of the electromagnetic field transmitting the electric power in the wireless WPT.

6.2 Abbreviations

The abbreviated terms used in this standard are defined as follows.

[H]

HFGC	High-frequency generating circuit
HFRC	High-frequency rectifier circuit

[I]

ID	Identification Data

[L]

LAN	Local Area Network

[M]

MAC	Media Access Control

[P]

PRP	Power receiving part
PTP	Power transmitting part
PRC	Power receiving circuit
PRCC	Power receiving control circuit
PRD	Power receiving device
PRU	Power receiving unit
PTC	Power transmission circuit
PTCC	Power transmission control circuit
PTD	Power transmission device
PTU	Power transmitting unit

[Q]

QED	Q-factor evaluation device

[R]

RL	Return loss

[S]

SAR	Specific Absorption Rate

[W]

WPT	Wireless Power Transmission

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Appendix 1 Details of the Control Method

This appendix defines the cases where power transmission is suspended through the normal operation of the control method in this system.

As defined in Section 4.2 of Chapter 4, the PTP monitors the information on the PRP (power receiving voltage, power receiving current, charging state, etc.) after the beginning of the WPT, and it determines whether to continue or suspend the WPT based on the monitoring. The concrete cases in which normal operation is suspended are shown in table A1-1.

Table A1-1 Cases in which normal WPT operations are suspended

Target device is connected to the PRU	Cases of suspend as normal operation
Battery powered device (B) only	・Charging is completed for all B units ・No PRU is on the power transmission device (PTD)
Battery powered device (B) And Non-battery powered device (BX)	・No PRU connected to a B or BX is on the power transmission device ・Charging is completed for all B units, and no PRU connected a BX is on the PTD
Non-battery device (BX) only	・No PRU connected to a BX is on the PTD

If all the target devices connected to the PRUs on the PTD use batteries, the WPT continues power transmission until all devices are fully charged and suspends power transmission when all devices are fully charged or when all of the PRUs are removed from the PTD.

If the target device(s) includes both battery powered and non-battery powered devices, the WPT continues power transmission as long as the PRUs connected to the non-battery devices are on the PTD regardless of the charging status of the battery powered devices.

If all of the PRUs are removed or if all of the battery powered devices are fully charged and all of the PRUs connected to the non-battery powered devices are removed from the PTD, the WPT is suspended.

If all of the target devices connected to the PRUs are not powered by batteries, WPT is continued even if a single PRU is detected on the PTD. If all of the PRUs are removed, WPT suspend power transmission.

The criteria used to recognize that a PRU has been removed from the PTD is when the power received by the PRU is one-tenth or lower of the normal receiving power or the communication between the PTU and PRU is disrupted.

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Appendix 2　Evaluation of the Quality Factor

This appendix defines the method for calculating the quality factor (Q factor) of the System.

1. Abstract

The PRD is a resonator coupled with a PTD under it. Thus, the Q factor must be evaluated with the PRD placed on a Q-factor evaluation device (QED) described in Section 3.

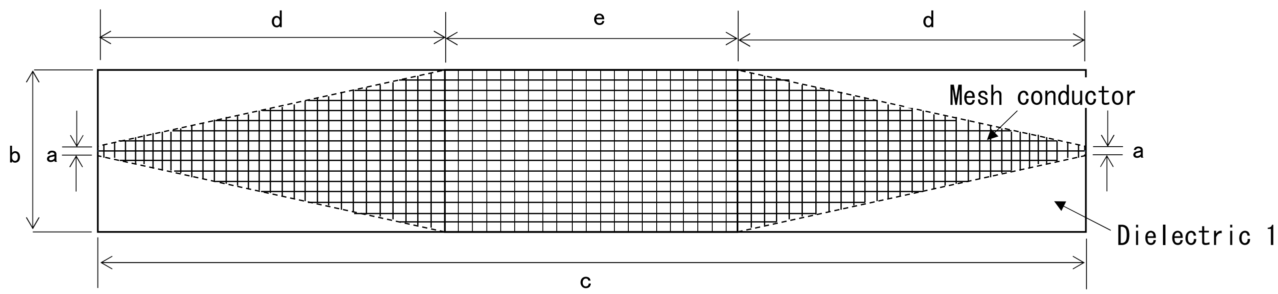
The Q factor of the input interface (IIF) must be evaluated with the IIF placed on a QED in Section 3. The QED in Section 3 is used to evaluate the Q-factor of a PRD and IIF as defined in Section 4.

The structure of the PRD and IIF must be equivalent to the reference model of PRD described in Appendix 3.

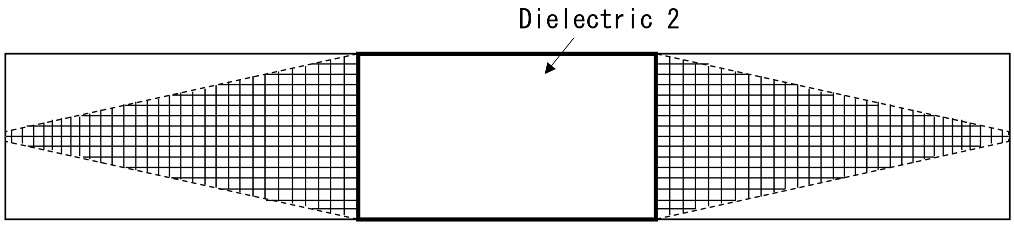
2. Configuration of the Q-factor evaluation device (QED)

The configuration of the QED is shown in Figure A2-1. Figure (a), (b) and (c) are the top view omitting Dielectric 2, top view with Dielectric 2, and cross-section, respectively. Dielectric 1 has two conductive layers, one on the top surface and one on the bottom surface. The bottom conductive layer is planar and the one on top has a mesh pattern. Dielectric 2 is placed in the middle of the QED.

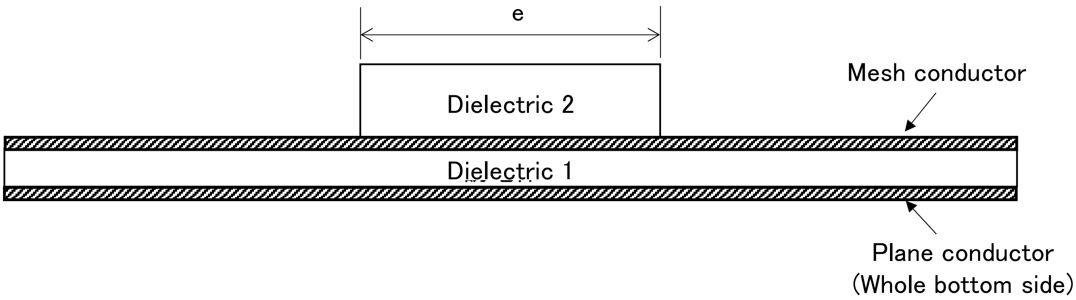
The shape of the mesh-pattern conductive layer is tapered around both sides. The tapered shape is given for avoiding discontinuity between the middle part and both edges connected to the coaxial connectors. The parameters of the QED are shown in Table A2-1. The measured insertion loss must be less than 1.7dB between the two coaxial connectors attached to both ends of the QED.



(a) Top view omitting Dielectric 2



(b) Top view



(c) Cross-section

Figure A2-1 Configuration of the QED

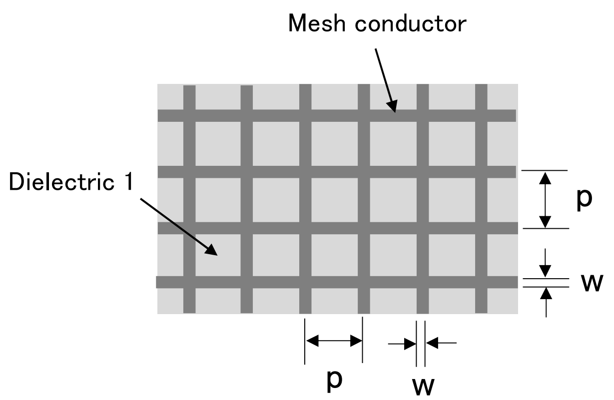
Table A2-1 Configuration parameters of the QED

Parameter	Symbol	Value
Edge width of the mesh conductor	a	4mm
Sheet width	b	73mm
Sheet length	c	444mm
Taper length	d	156mm
Dielectric length	e	132mm

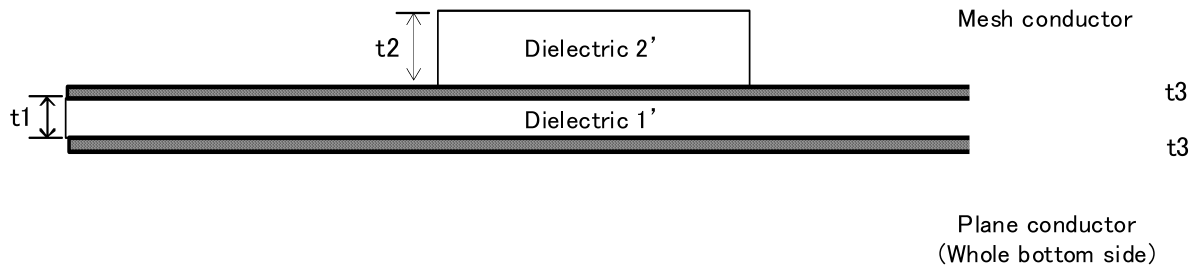
3. Components of the QED

The components of the QED are shown in Figure A2-2. Figure (a) and (b) are the top view and cross-section, respectively. Dielectric 1' has conductive layers on the top and bottom surfaces. The bottom layer is planar and the top layer has a mesh pattern. Dielectric 2' is placed on top of the mesh-pattern conductor. The material and structural parameters of each part are shown in Tables A2-2 and A2-3, respectively.

The external forms of the QED and the mesh-pattern conductor must be identical to the ones shown in Section 2. The materials of Dielectric 1 and 2 must be the same as 1' and 2', respectively.



(a) Top view



(b) Cross-section

Figure A2-2 Device components of the QED

Table A2-1 Material parameters of the QED

Index	Material parameter
Dielectric 1'	$\varepsilon_r = 2.3$、$\tan\delta = 0.5\times 10^{-3}$
Dielectric 2'	$\varepsilon_r = 1.1$、$\tan\delta = 0.1\times 10^{-2}$ (hollow structure)

εr : relative permittivity、$\tan\delta$: dielectric tangent

Table A2-2 Structural parameters of the QED

Parameter	Symbol	Value
Thickness of Dielectric 1'	t1	1mm
Thickness of Dielectric 2'	t2	4mm
Thickness of the mesh and plane conductors	t3	17μm
Period of the mesh pattern	p	4mm
Width of the mesh line	w	1mm

4. Measurement of the S Parameter and Evaluation of the Q Factor

The measurement system for the transmission coefficient $|S_{21}|$ is shown in Figure A2-3.

The Q factor of a PRD is measured with the PRD placed on the center of a QED (on

Dielectric 2'). Port 1 of a network analyzer is connected to the coaxial connector at the edge of the QED, and Port 2 is connected to the output port (p1, p2) of the PRD.

The Q factor of an IIF is measured with the IIF placed on the center of a QED (on Dielectric 2'), similar to the Q factor measurement of a PRD. The difference is that Ports 1 and 2 are reversed in this case. In the PRU, (p1, p2) is an output port, while it becomes the input port when the measured device is an IIF.

The network analyzer is connected between the coaxial connector at the QED edge and the output port (p1, p2) of the PRU or input port (p1, p2) of an IIF.

The other end of the QED is terminated with 50Ω in order to lessen the effect on the Q factor evaluation by reflection at the end.

Figure A2-4 shows an example of $|S_{21}|$. The Q factor is evaluated using Equation (1) as the ratio of f0 maximizing $|S_{21}|$ to the bandwidth Δf between the -3dB frequencies from the maximum value of $|S_{21}|$.

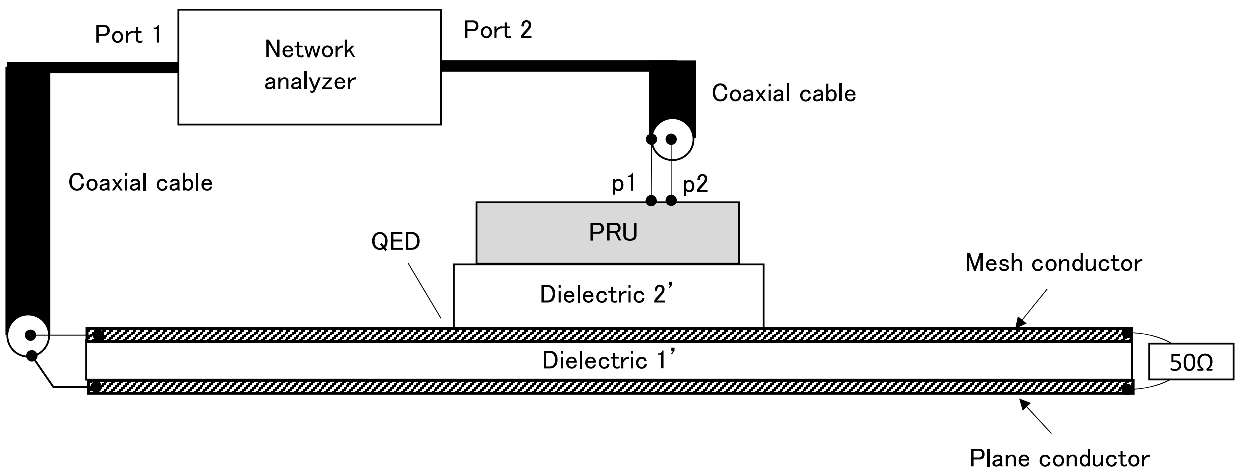


Figure A2-3 Measurement system for the transmission coefficient $|S_{21}|$

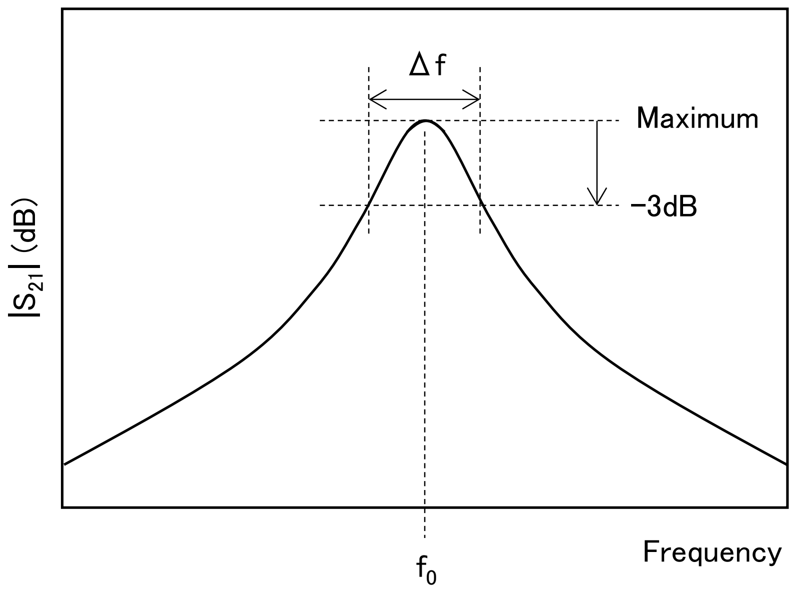


Figure A2-4 Example of the transmission coefficient $|S_{21}|$

$$Q = \frac{f_0}{\Delta f} \qquad \cdots\cdots \ (1)$$

Appendix 3 Reference Devices for the PTD and PRD

This appendix defines the specifications for the reference model of the PTD and PRD in the System.

1. Abstract

The reference devices for the PTD and PRD in the Standard are defined herein.

2. Specifications for the Reference PTD

The cross-section of the reference PTD is shown in Figure A3-1. In Figure A3-2, the input interface is omitted. Dielectric 1 has two conductive layers, one on the top surface and one on the bottom surface. The bottom layer is planar, and the top layer has a mesh pattern. The two layers are electrically shorted at the edges of the device. Dielectric 2 is placed on top of the conductive layer. Dielectric 2 is a material with a low dielectric constant and low loss that is realized by a hollow structure or foamed material. The material and structural parameters are shown in Tables A3-1 and A3-2, respectively.

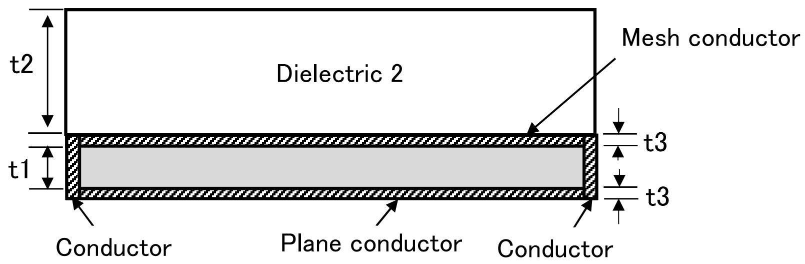


Figure A3-1 Cross-section of the reference PTD

The perspective view of the reference PTD is shown in Figure A3-2. The parameters of the mesh-pattern conductor (line width, pattern period, etc.) are shown in Table A3-2. The IIF is omitted in Figure A3-2, and the state with the IIF on the RPTD is shown in Figure A3-3. The dimensions of the reference PTD are 390 × 560mm. The input interface has equivalent components as the standard PRD described later.

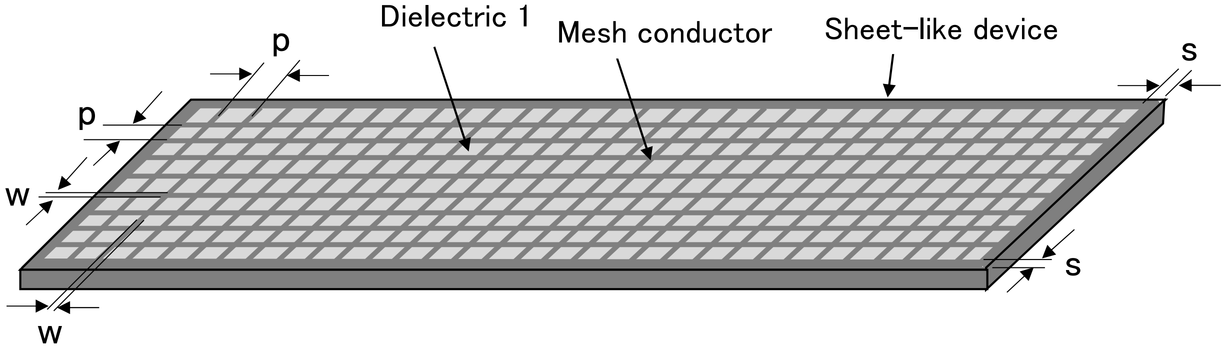


Figure A3-2　Perspective view of the reference PTD omitting the input interface and Dielectric 2

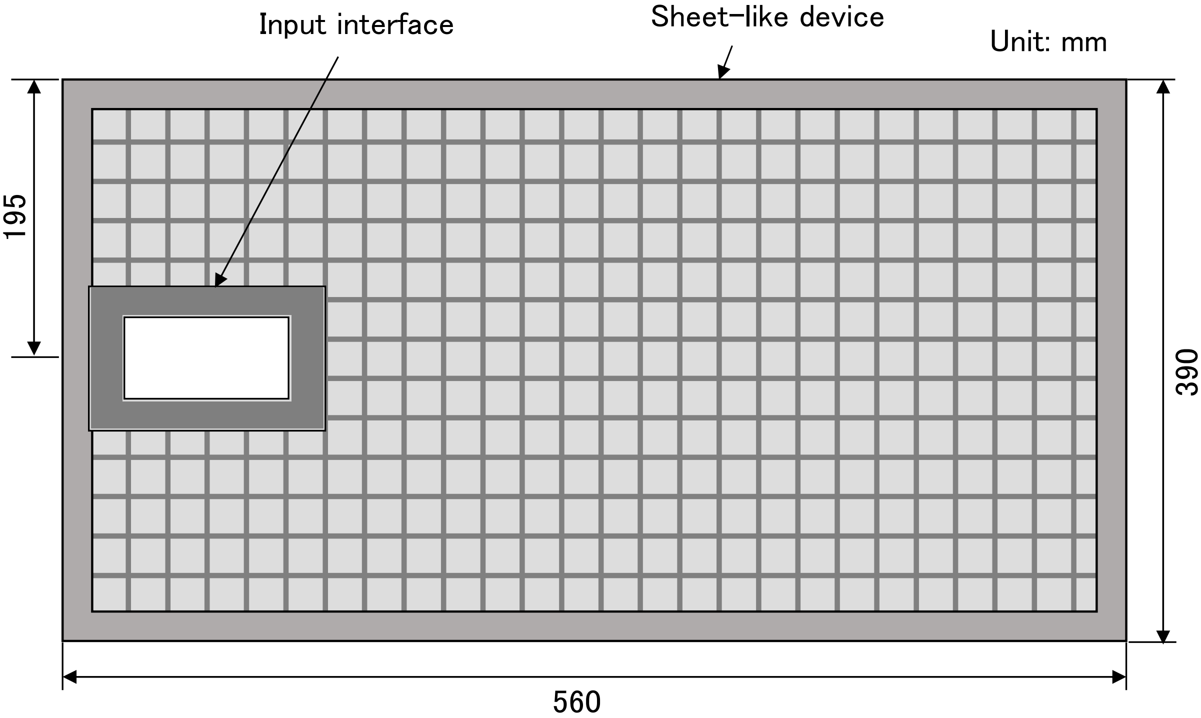


Figure A3-3 Top view of the reference PTD omitting Dielectric 2

Table A3-1　Material parameters of the reference PTD

Index	Material parameter
Dielectric 1	$\varepsilon_r = 2.3$、$\tan\delta = 0.5 \times 10^{-3}$
Dielectric 2	$\varepsilon_r = 1.1$、$\tan\delta = 0.1 \times 10^{-2}$ (hollow structure)

εr : relative permittivity 、$\tan\delta$: dielectric tangent

Table A3-2 Structural parameters of the reference PTD

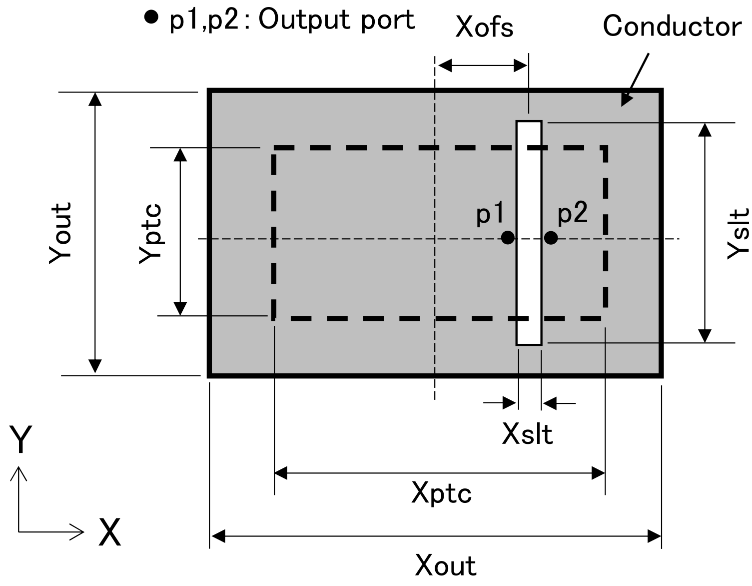
Parameter	Symbol	Value
Thickness of Dielectric 1	t1	1mm
Thickness of Dielectric 2	t2	4mm
Thickness of the mesh/plane conductors	t3	17μm
Period of the mesh pattern	p	4mm
Width of the mesh line	w	1mm
Width of the shield conductor	S	8mm

3. Specifications for the Reference PRD

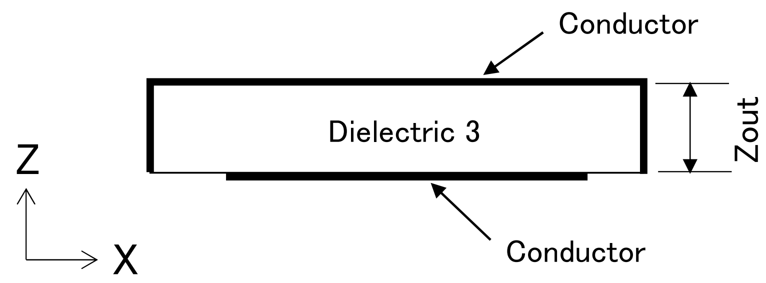
The specifications of the reference PRD are shown in Figure A3-4. Figure (a) is the top view, and (b) and (c) are cross-section views. The reference PRD is basically a three-layer structure. Dielectric 3 has a conductive layer on the top and bottom sides. The bottom layer conductor has a patch-like shape, and the top layer conductor is planar with a slit. The lateral faces of the reference PRD are covered with conductors. The material and structural parameters are shown in Tables A3-3 and A3-4, respectively. The x-direction length of the bottom patch-like conductor is a half wavelength.

The reference PRD is a resonator coupled with a PTD when the patch-like conductor side of the reference PRD contacts the PTD surface. The power is extracted through the output port (p1, p2) attached to both sides of the slit in the top layer plane conductor.

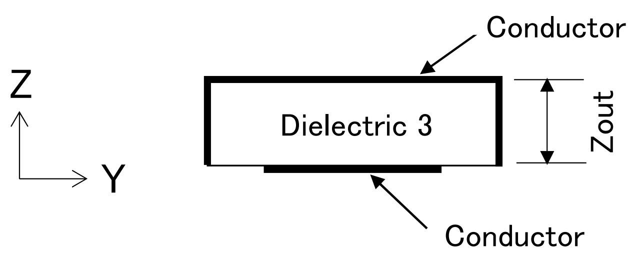
An additional structured board (ASB) is connected around the reference PRD as shown in Figure A3-5 in order to suppress electromagnetic leakage. The gap between the ASB and the reference PRD must be sealed with metal like solder to suppress electromagnetic leakage from the gap. The structure of the ASB is shown in Figure A3-6. The middle part of the ASB is cut out to allow placement of the reference PRD. The conductor of the L1 layer has no fine patterns, and the L2 layer has a 4mm-square periodic fine structure. The specifications of the fine structure are shown in Figure A3-7. The material parameters of the ASB and the structural parameters of the fine structure are shown in Tables A3-5 and A3-6, respectively.



(a) Top view



(b) Cross section 1



(c) Cross section 2

Figure A3-4 Structure of the reference PRD

Table A3-3 Material parameters of the reference PRD

Index	Material parameter
Dielectric material 3	$\varepsilon_r = 1.1$、$\tan\delta = 0.1\times10^{-2}$ (Hollow structure)

ε r : relative permittivity、$\tan\delta$: dielectric tangent

Table A3-4 Structural parameters of the reference PRD

Parameter	Symbol	Value
Device length	Xout	64mm
Device width	Yout	36mm
Device thickness	Zout	4mm
Patch length (half wavelength)	Xptc	52mm
Patch width	Yptc	24mm
Slit width	Xslt	1mm
Slit length	Yslt	30mm
Offset	Xofs	15mm

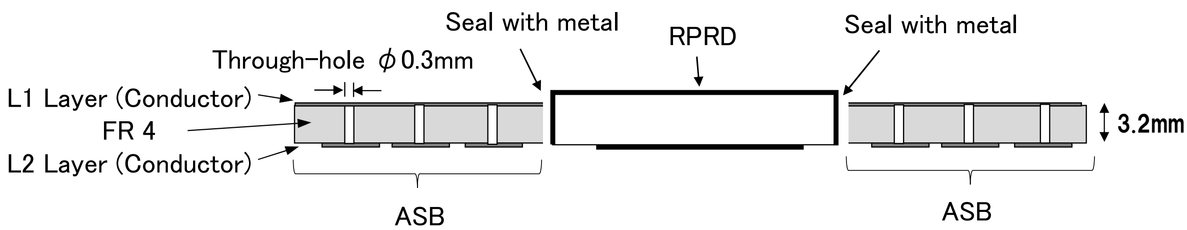
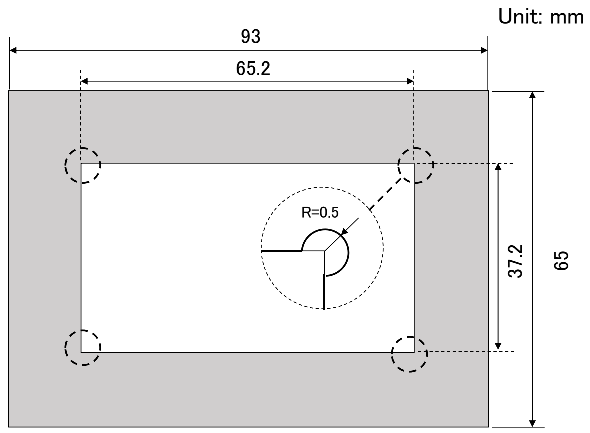
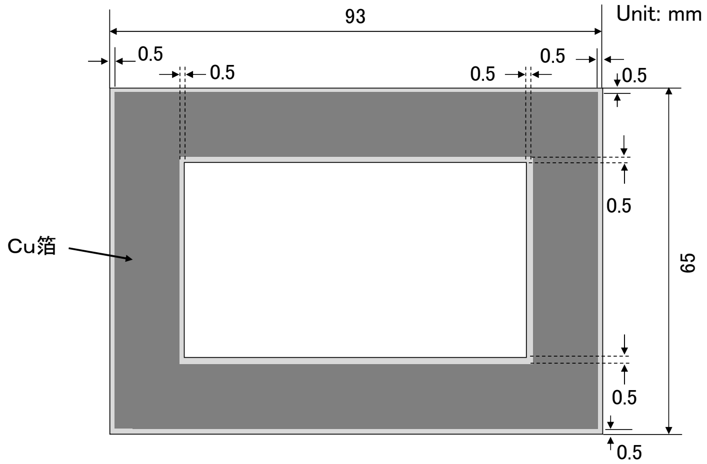


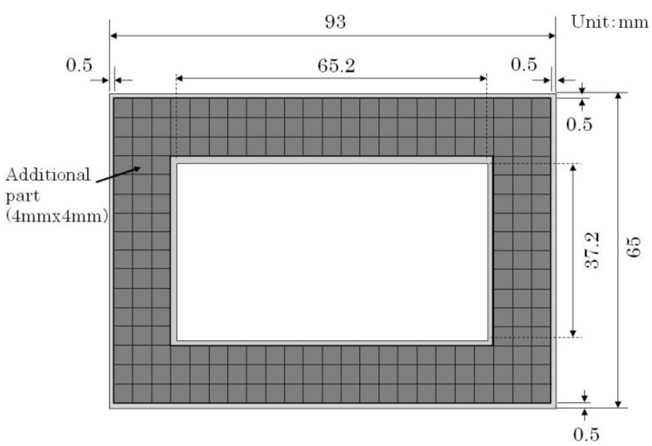
Figure A3-5 Connection to the additional structured board (Cross-section)



(a) External form



(b) Pattern of the L1 layer



(c) Pattern of the L2 layer

Figure A3-6 Specifications of the ASB connected to the reference PTD

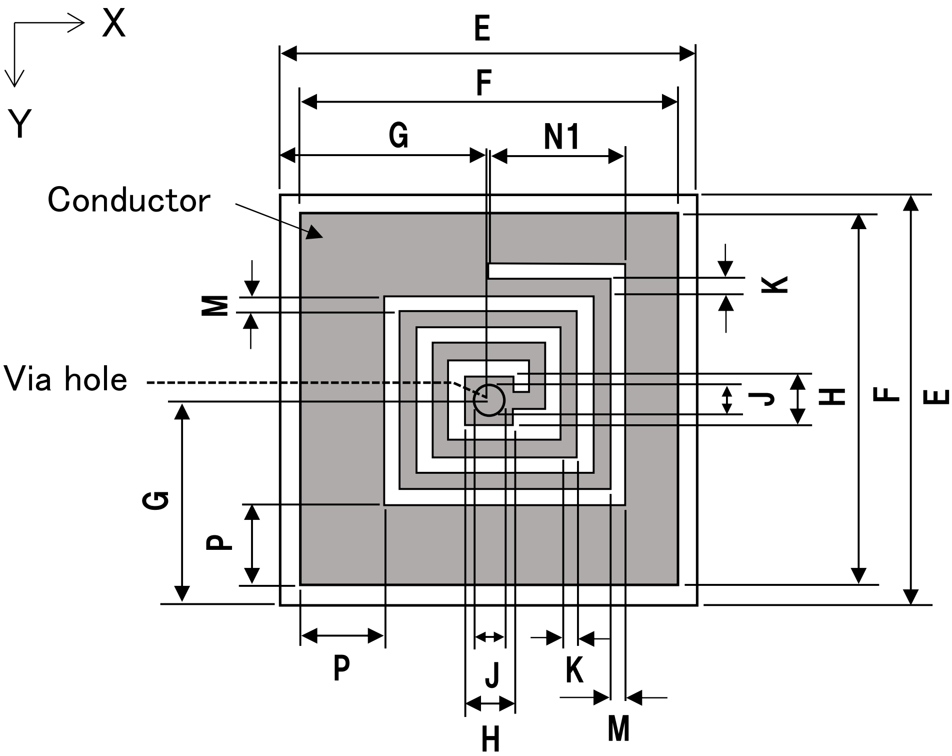


Figure A3-7　Specifications of the fine structure of the ASB (4mm square)

Table A3-5　Material parameters of the ABS

Index	Material parameter
FR4	ε_r = 4.1、tan δ = 0.02

ε r : relative permittivity、tan δ : dielectric tangent

Table A3-6 Structural parameters of the ASB

Parameter	Symbol	Value
Unit length	E	4.0mm
Conductor external length	F	3.6mm
Distance to the via-hole center	G	2.0mm
Pad external length	H	0.5mm
Via hole diameter	J	0.3mm
Spiral line width	K	0.15mm
Spiral line space	M	0.15mm
Spiral terminal length	N1	1.75mm
Distance to the spiral area from unit edge	P	0.8mm

Appendix 4 Instruction Manual to Users

This appendix specifies the instruction statements to users for the operation of this WPT System.

1. Abstract

This appendix aims to specify the instruction statements for avoiding interference or disturbance to other wireless equipment using similar frequencies and for effectively utilizing spectrum resources when this System is used.

2. Susceptible Systems

Other systems that may be affected by this System include: specified low power radio stations using the 2.4GHz-band, low power data communication radio stations and portable satellite communication terminals.

3. Scope of Applications

This appendix is applied to manufacturers and distributors of Microwave Surface Coupling WPT Systems.

4. Instructions to Users

4.1 Instruction Manual of Equipment

Instruction statements that have the same contents as the text in the following box shall be included in the user's instruction manual or directly indicated on the equipment of Microwave Surface Coupling WPT System.

4.2 Catalogs, Pamphlets, Websites and Other Media

It is recommended to include the same instruction statements in catalogs, pamphlets, websites and other media related to the Microwave Surface Coupling WPT System.

This system might collocate with other radio equipment utilizing neighboring frequency ranges, including: high frequency equipment such as microwave ovens, specified low power radio stations using the 2.4GHz-band, low power data communication radio stations and portable satellite communication terminals. Users shall carefully avoid detrimental interference with such communication systems by taking the following actions or measures;

1. Consider the location of this system to reduce detrimental interference to the communication systems with neighboring frequency ranges;
   ① Place this system in the back of the room where there is expected to be less interference with other neighboring systems.
   ② Avoid placing this system close to an open area of the room such as a window.
2. If there is a user of a 2.5GHz satellite communication terminal in your neighborhood, ask the user if the terminal suffers interference from this system. If it does, take the following actions to resolve the interference with the 2.5GHz satellite communication terminal.
   ① Rotate the operating position of this system
   ② Change the operating position of this system
3. Immediately stop using this system if the neighbor reports interference with a communication device that uses frequencies close to this system. Take the actions stated in item 2 to resolve the interference with the communication device.
4. In the case that radio communication device are used on or around this system, consider taking the following measures for reducing interference;
   ① For a radio communication device on your power transmission device.
   Shift the position of the communication device or rotate the communication device by +/-90 degrees. Avoid placing the communication device directly on this system. Insert something between the communication device and this system.
   ② For radio communication devices around this system.
   Place the communication device away from this system or rotate the communication device by +/-90 degrees.
   ③ Other ideas
   If the communication device is capable of changing frequencies, try using a different frequency from this system.

Description 1 Specification Examples of the PTP Antenna and PRP Antenna

1. Outline

The specifications of the PTP antenna and PRP antenna are provided here as examples in order to aid in the realization of the Microwave Electromagnetic Field Surface Coupling WPT System specified in this Standard.

2. Specifications of the PTP Antenna and PRP Antenna

Figure D1-1 shows an example of the structure of the PTP antenna used in the communication part of the PTU and the structure of the PRP antenna used in the communication part of the PRU. Fig. D1-1(a) shows a cross section view, and Fig. D1-1(b) is the bottom view. Both the PTP antenna and PRP antenna are basically patch antennas, which can be realized by two layers of conductive printed circuits. The upper conductive layer has a planar shape, and a conductor patch is positioned at the center of the lower conductive layer. The length marked by “A” in the figure equals half of the wave length. The position of Via, which specified by the length “B”, is the point where the impedance match meets the connectors connected to the input-output port (p3-4).

To suppress the leakage of control communication signals, it is desirable to place the additional parts illustrated in Figure D1-2 around the conductor patch in about three rows. The conductor at the center of the additional part is connected to the plane conductor using Via. The material parameters and structural parameters are listed in Tables D1-1 and D1-2, respectively.

The PTP antenna and PRP antenna are used with the patch conductor side attached to the PTD. The relative positions of the PTD, PTP antenna, PRD and PRP antenna are shown in Figure D1-3.

In addition, the standard PRD defined in Section 3 of Appendix 3 can also be used with a PRP antenna.

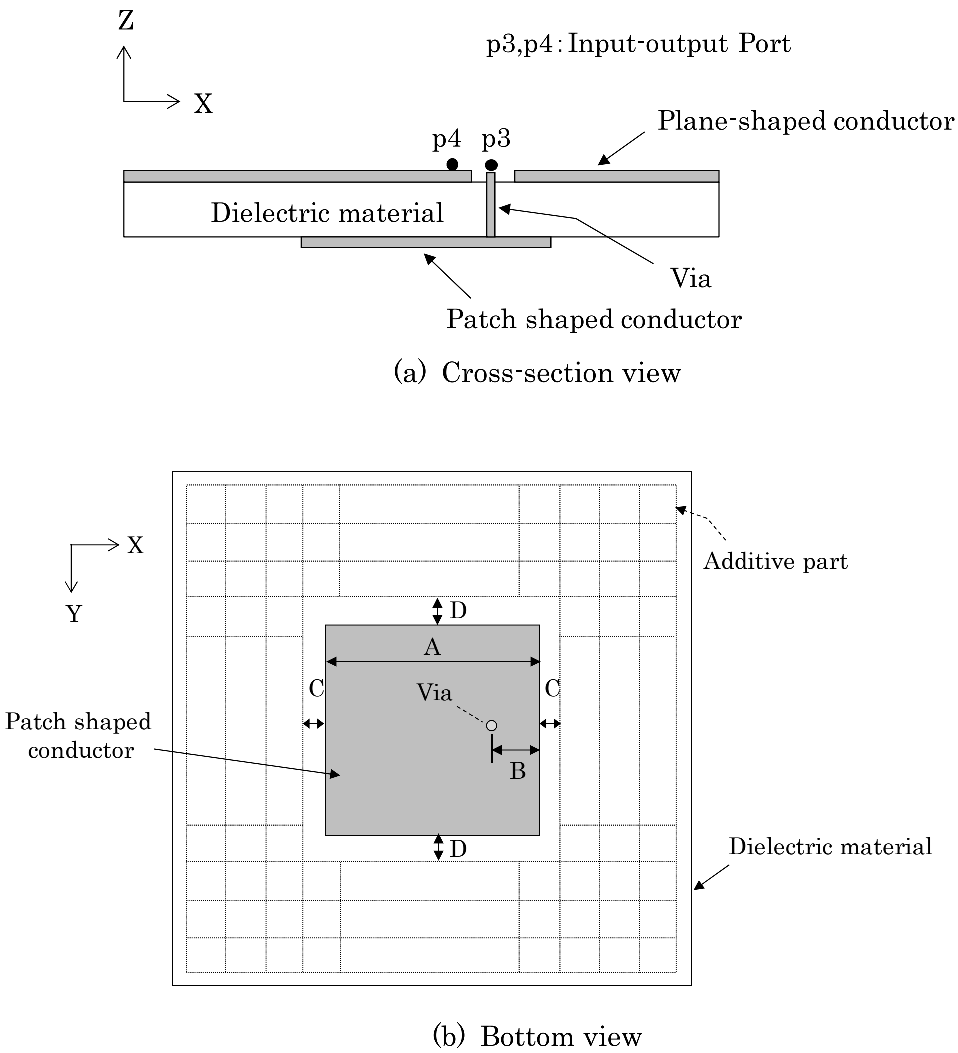


Figure D1-1 Structure of the PTP antenna and PRP antenna

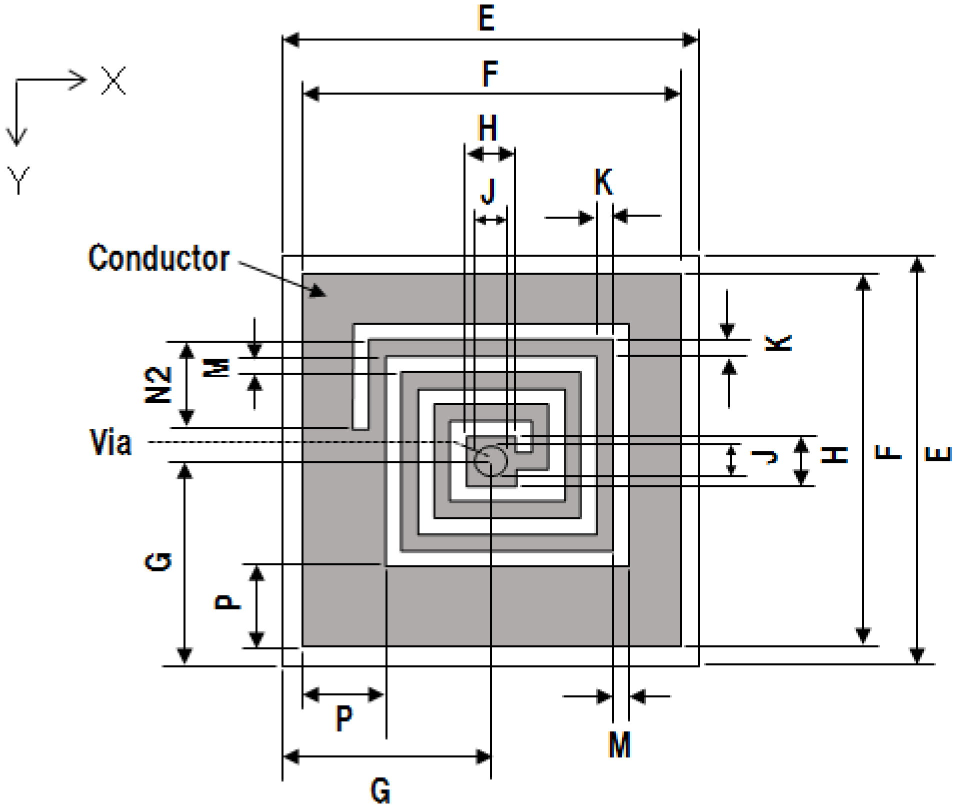


Figure D1-2 Structure of the additional part for the PTP antenna and PRP antenna

Table D1-1 Material parameters of the additional part for the PTP antenna and PRP antenna.

Material	Material constants
FR4	ε_r =4.1、tanδ = 0.02

ε_r: relative permittivity, tanδ: dielectric tangent

Table D1-2 Structural parameters of the additional part for the PTP antenna and PRP antenna.

Parameter	symbol	value
Distance to the patch conductor in Fig. D1-1	C	>3.0mm
Distance to the patch conductor in Fig. D1-1	D	>3.0mm
External dimensions of the additional part	E	4.0mm
External dimensions of the conductor	F	3.6mm
Distance from the external edge of the additional part to the center of the Via	G	2.0mm
External dimensions of the pad	H	0.5mm
Via diameter	J	0.3mm
Width of the spiral line	K	0.15mm
Distance between spiral lines	M	0.15mm
Length of the spiral line terminal	N2	0.81mm
Distance from the external edge of the conductor to the spiral line region	P	0.8mm

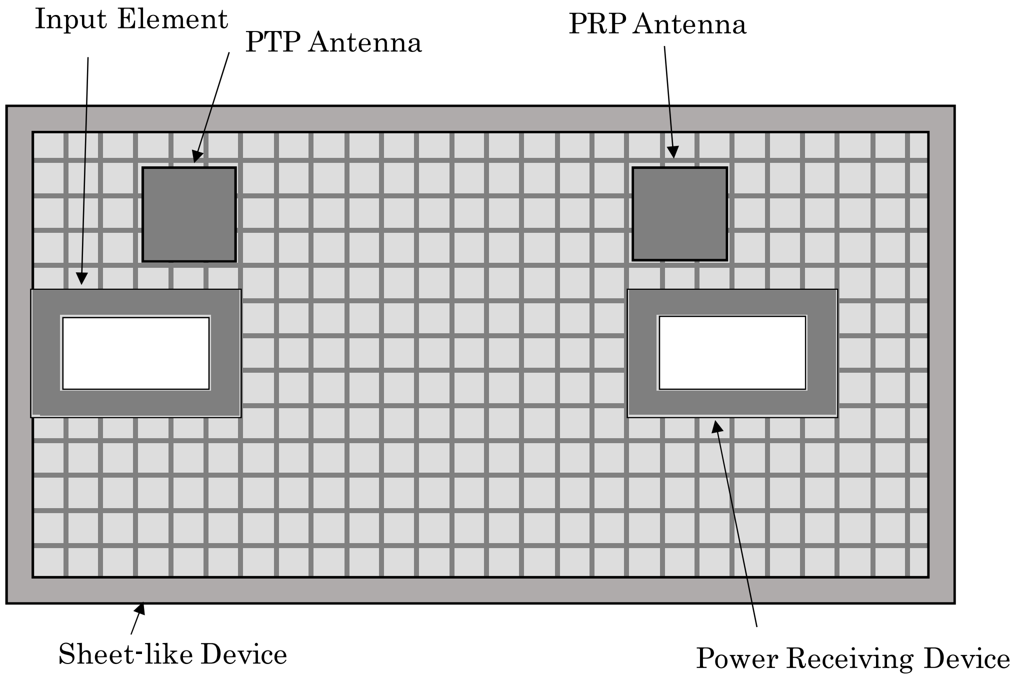


Figure D1-3 Example showing the relative positions of the PTD, PTP antenna, PRD and PRP antenna (dielectric material is not illustrated)

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Description 2 Method of Calculating Leakage Electric Power

1. Methods for Calculating Leakage Electric Power

The leakage power from this System is evaluated using the total radiated power (TRP) P_{TRP}. As defined in equation (1), P_{TRP} is calculated by integrating the radiation power density, $U(\theta, \Phi)$, over the entire surface of a ball with radius r.

$$P_{TRP} = \int_0^{2\pi}\int_0^{\pi} U(\theta,\phi)\sin\theta d\theta \qquad (1)$$

where $U(\theta, \Phi) = U_\theta(\theta, \Phi) + U_\Phi(\theta, \Phi)$, $U_\theta(\theta, \Phi)$, and $U_\Phi(\theta, \Phi)$ is the radiation power density in the θ and Φ directions, respectively.

To obtain P_{TRP} in an actual measurement, in the spherical coordinate system (r, θ, Φ) shown in Fig. D2-1, first measure discretely the electric field intensity $E(\theta, \Phi)$ in the θ and Φ directions, and then calculate P_{TRP} from the sum of the radiated power density. Assuming the number of partitions in the θ direction and Φ direction are denoted by N_θ and N_Φ, respectively, P_{TRP} is calculated using equation (2).

$$P_{TRP} = \sum_{j=1}^{N\phi}\sum_{i=2}^{N\theta} U(\theta_i,\phi_j)\sin\theta_i\Delta\theta\Delta\phi \qquad (2)$$

where $\theta i = (i\text{-}1)\Delta\theta$, $\Phi j = (\text{j-}1)\,\Delta\Phi$, $\Delta\theta = \pi/N_\theta$, $\Delta\Phi) = 2\pi/N_\Phi$, $U(\theta, \Phi) = \{E(\theta, \Phi)\}^2/120\pi$.

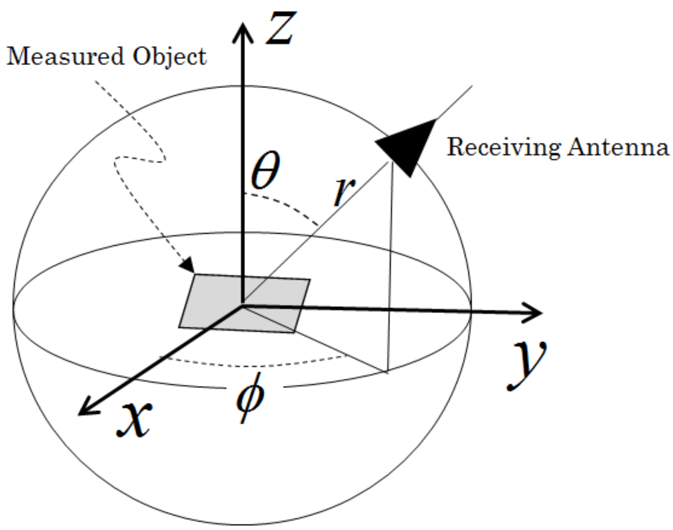

Figure D2-1 Measured object and spherical coordinate system (r, θ, Φ)

Amendment History

Version 1.1

Page	Para.no	Content of Amendment	Present	Reason
3-i~ii 3-1~3-58		Part 3 is added.		Add

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Wireless Power Transmission Systems

ARIB STANDARD

ARIB STD-T113　Version 1.1

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