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TECHNICAL REPORT

Radio frequency beam wireless power transfer (WPT) for mobile devices

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RADIO FREQUENCY BEAM WIRELESS POWER TRANSFER (WPT) FOR MOBILE DEVICES

FOREWORD

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IEC TR 63239, which is a Technical Report, has been prepared by technical area 15: Wireless power transfer, of IEC technical committee TC 100: Audio, video and multimedia systems and equipment.

The text of this Technical Report is based on the following documents:

Draft TR	Report on voting
100/3212/DTR	100/3317/RVDTR

Full information on the voting for the approval of this Technical Report can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

RADIO FREQUENCY BEAM WIRELESS POWER TRANSFER (WPT) FOR MOBILE DEVICES

1 Scope

This Technical Report presents the surveyed technologies, product development trends, international standards, and regulation trends of RF beam WPT. This report can be used for the research and analysis of projects that apply small-output remote WPT to mobile devices, such as smartphones, Internet of Things (IoT) devices, and ultra-small sensors.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1
IoT
Internet of Things
service-based facilities to provide advanced services by connecting the various things of the physical world and the virtual world based on information communication technology

Note 1 to entry: Infrastructure computing devices for realizing ubiquitous space are embedded in environments and things to make them intelligent and to expand the machine-to-machine (M2M) concept, which is capable of intelligent communication between humans and things or between things to the internet.

Note 2 to entry: The concept has evolved into a concept that interacts with all the information of reality and the virtual world as well as things. The major technologies of IoT include sensing technology, wired and wireless communication and network infrastructure technology, IoT interface technology, and service technology through IoT.

3.2
Wi-Fi
Wireless-Fidelity
certification mark provided to products compatible with the regulations determined by the wireless LAN (WLAN) specifications (IEEE 802.11b) using 2,4 GHz

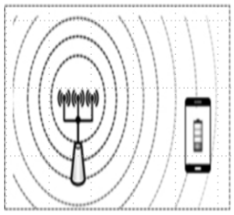
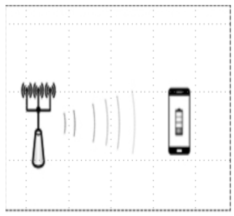
Note 1 to entry: Among the products manufactured in accordance with these specifications, the ones that passed the test of the Wireless Ethernet Compatibility Alliance (WECA), a group founded by wireless-network-related companies, can have this mark.

4 Introduction to RF beam WPT

4.1 Overview of the RF beam WPT type

RF beam WPT performs remote WPT using omnidirectional or directional antenna beam patterns. This type is divided into the omnidirectional type, in which electromagnetic waves are radiated in all directions to achieve constant radiation intensity in any direction, and the directional type, in which radio waves are transmitted in a certain direction. Table 1 shows the Overview of the RF beam WPT type.

Table 1 – Overview of the RF beam WPT type

	Electromagnetic waves	
	Omnidirectional	**Directional**
Representative figure		
Operating principle	Electromagnetic wave radiation	
Electric field intensity	Pt (Pt: transmitting power)	Pt X Gt (Gt: Antenna Gain by beamforming)
Efficiency	Small in proportion to Gt compared to directional RF beam WPT	Large in proportion to Gt compared to omnidirectional RF beam WPT
Transfer distance	Long distance (up to ~m)	Long distance (transfer up to the ~m unit is possible if Line of Sight (LOS) is secured)
Mobility	Possible	Possible
Safety	There are issues on human safety. Human body protection should be considered.	There are issues on human safety. Human body protection should be considered.
Used frequency	RF (Hundred MHz, Several GHz)	RF (Hundred MHz, Several GHz)
Standardization trend	No standard	No standard

4.2 Requirements for RF beam WPT

4.2.1 General

RF beam WPT radiates electromagnetic waves and is significantly different from the two following two non-beam types in the operating principle for transferring power. The magnetic induction and magnetic resonance types use non-radiation WPT and transfer power between TX(Transmitter) and RX(Receiver) in close proximity using the magnetic lines of force and resonance generated by alternating current (AC). On the other hand, RF beam WPT can transfer power by radiating electromagnetic waves through an antenna as in wireless communication. TX transmits the power of an electromagnetic wave oscillator using a directional antenna while RX receives microwaves using an antenna and converts it to a direct current (DC) power source through a rectifier to obtain power.

While RF beam WPT has a benefit in the charging distance because it enables remote charging for multiple devices at the same time, it may affect the human body and exhibits very low power efficiency. The recent technology achieved the power efficiency of very low power at the distance of several meters, but studies to verify and avoid its effects on human health are considered essential for the commercialization of RF beam WPT in the future. It is important to note that the beam WPT needs to arrange conditions for sharing the frequency with existing radio stations because it has the property of radiating the beam into space and transmitting power. In this Subclause 4.2, the system design of the RF beam type, candidate frequencies, and the operating principles of the omnidirectional and directional RF beam types are discussed.

4.2.2 Power transfer system design of RF beam WPT

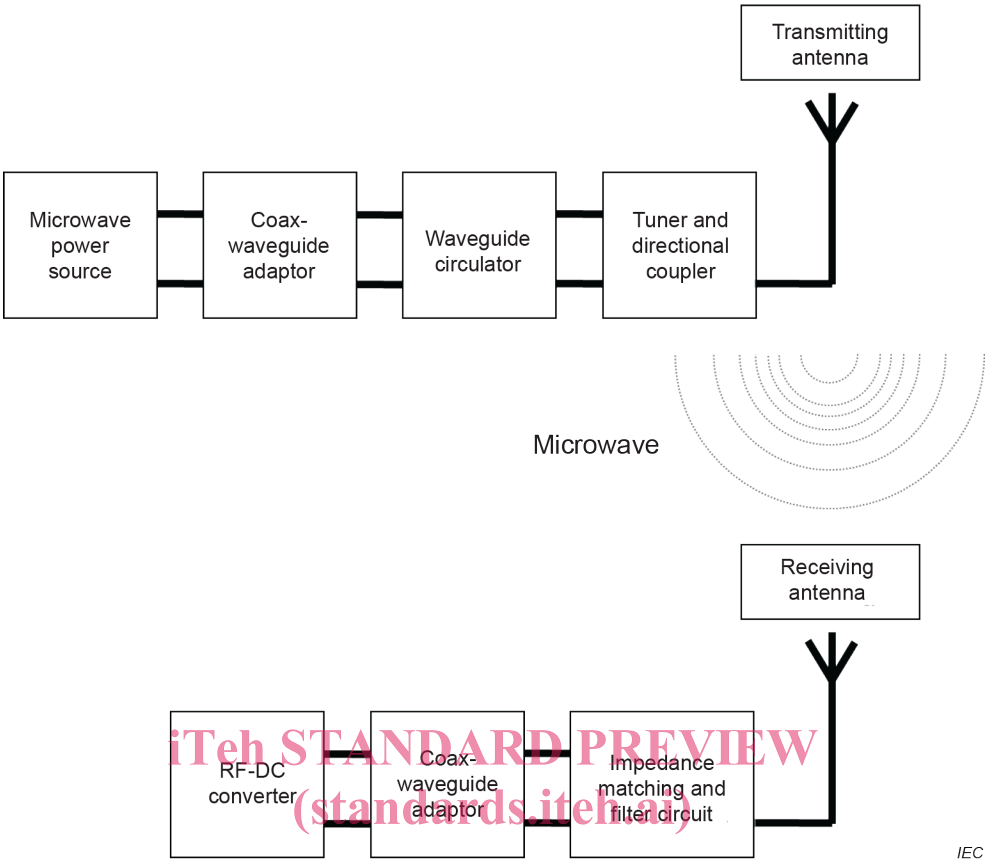


Figure 1 – TX and RX structures of RF beam WPT

Figure 1 shows the TX and RX circuit diagrams of RF beam WPT. In a WPT system, TX consists of a microwave power source, a waveguide circulator, a waveguide adaptor, and a tuner and directional coupler. The microwave power source generates an amplified signal for signal control. The waveguide circulator and adaptor are required to generate specific required frequencies such as GHz through signal response and adjustment. The tuner and directional coupler filters unrequired frequencies as well as noise and matches the transmitter impedance for the transmitting antenna.

RX consists of an impedance matching and filter circuit, a coax-waveguide adaptor, and an RF-DC converter. The impedance matching and filter circuit matches the receiver impedance for the receiving antenna, and the coax-waveguide adaptor extracts specific required frequencies through signal response and adjustment. Finally, the RF-DC converter converts the received electromagnetic waves into DC power.

Since the purpose of RF beam WPT systems is to radiate power wirelessly, it is necessary to design systems focusing on the transfer distance, spatial loss, power consumption of RX, and RF-DC rectification efficiency. In RF beam WPT systems, the magnitude of the spatial loss of power according to the distance is given by the Friis equation and its value is determined by the three major elements, which are the used frequency, transferred power, and transfer distance. Equation (1) shows the Friis equation.

$$P_{RX} = P_{TX}G_{TX}G_{RX}\left(\frac{\lambda}{4\pi r}\right)^2 \qquad (1)$$

where P_{RX} is the power input to the receiving module, P_{TX} the power produced by the transmitting antenna of the transmission module, G_{TX} and G_{RX} the gains of the transmitting and receiving antennas, λ the wavelength of the used frequency, and r the distance between the transmitting and receiving modules.

4.2.3 Available candidate frequencies of RF beam WPT

Electromagnetic radiation technology uses GHz frequencies with short wavelengths for long-distance wireless power transfer. Long-distance power transfer using high-output electromagnetic waves in the industrial, scientific, and medical (ISM) bands such as 900 MHz, 2,4 GHz, and 5,8 GHz (900 MHz for the United States), may cause problems in terms of efficiency and human health effects. Table 2 shows the characteristics of some candidate frequencies for RF beam WPT. Whether RF beam WPT is ISM equipment or not is currently being examined in ITU-R, and no conclusion has been obtained yet. Generally, in order to share a frequency, coordination with radio stations that already use the frequency is required.

Table 2 – Characteristics of candidate frequencies for RF beam WPT

Candidate frequency		Characteristics
900 MHz	Pros	More robust, less prone to interference Lower attenuation, travels further through more obstacles
	Cons	Components are larger at lower frequencies
2,4 GHz	Pros	Wi-Fi facility can be used if possible Components are smaller, cheaper
	Cons	Congested band due to abundance of Wi-Fi, Bluetooth, microwaves, cordless phones Attenuates much more quickly, will not pass through metal
5,8 GHz	Pros	Less congested, few RF devices in this band
	Cons	Low transmit power limitations High attenuation in cables, requires very high gain antennas

4.2.4 Operating principle of omnidirectional RF beam WPT

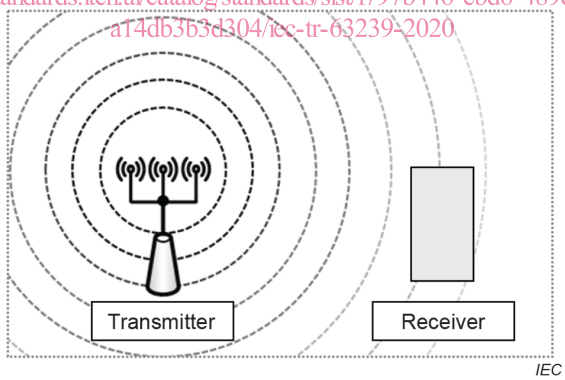


Figure 2 – Beam pattern diagram of omnidirectional RF beam WPT

Figure 2 shows a brief diagram of a beam pattern diagram of omnidirectional RF beam WPT. Omnidirectional RF beam WPT mainly transfers power to a remote distance by radiating electromagnetic signals from a transmitting antenna to all directions through the air using the electromagnetic waves of several GHz or higher. This type is capable of long-distance transmission and reception because it uses high frequencies such as GHz and THz frequencies. Its operating principle can be briefly introduced as follows. First, TX transmits electromagnetic waves using a frequency with high energy. RX then receives the waves using a rectenna (in which an antenna and a rectifier are combined) and converts them into DC power. If approximately 5 W power is radiated from TX, RX receives only 2 mW to 4 mW of power (less than 1 % efficiency). The power received by RX causes no human safety problem because it is too small, but serious human safety problems may occur near TX with high output. Currently, there is no efficient method capable of using this type, but technologies for high-output WPT have been devised to be used in outer space in the future. Figure 3 shows an example of high-output omnidirectional RF beam WPT in outer space.

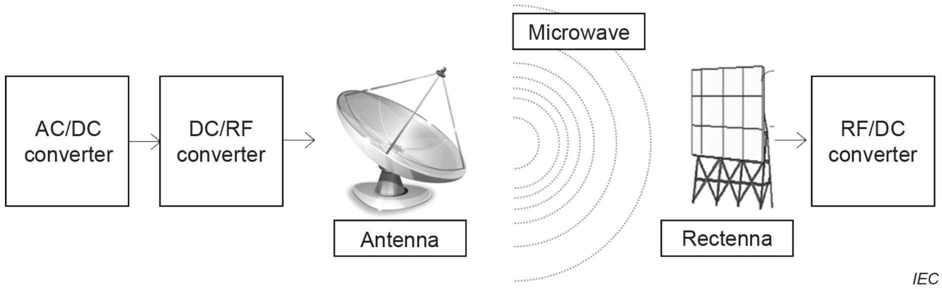


Figure 3 – Example of high-output omnidirectional RF beam WPT in space

4.2.5 Operating principle of directional RF beam WPT

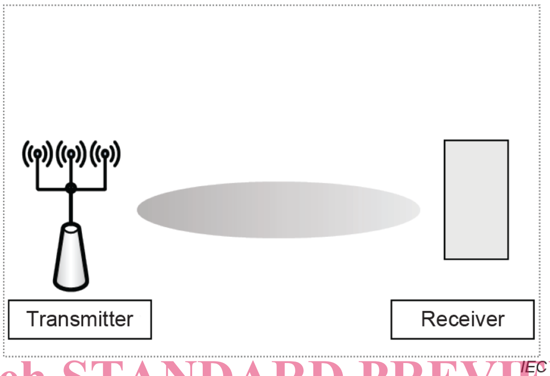


Figure 4 – Beam pattern diagram of directional RF beam WPT

Directional RF beam WPT has the same effect as the spotlight shed on an actor on stage. In an antenna array, the signals of each antenna are filtered or added depending on the frequencies of adjacent signals. TX transfers power to limited targets by forming directional beam patterns using constructive interference or destructive interference at certain angles. Figure 4 shows a beam pattern diagram of directional RF beam WPT. Directional RF beam WPT may occur at TX or RX to achieve spatial selectivity. It is different from omnidirectional transmission and reception in that signals can be directional.

The signal radiation principle of directional RF beam type can be briefly summarized as matching phases between the radiating signals of adjacent antennas. Each antenna offsets signals in unwanted directions for radiating signals in a desired direction. Each antenna is designed to control the direction of signals to obtain the antenna gain of the signals in a desired direction. Figure 5 shows electromagnetic wave transmission/reception at each pattern antenna of directional RF beam WPT. For example, each antenna pattern is designed to be a constant pattern so that it could be half the used electromagnetic wave frequency. In this way, when electromagnetic waves are transmitted, the delay between the transmitted signals becomes a fixed value, making it possible to control the signals generated by all antennas. By adjusting the phase of each antenna in this way, the transmission direction and magnitude of the entire beamforming signals of an array antenna system can be controlled. Figure 6 shows the direction RF beam WPT description on delay generation at each pattern antenna and Figure 7 shows an example of beam pattern formation by the delay and direction adjustment of the transmission signals of each antenna.