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INVITED PAPER *Special Section on Microwave and Milli-meter wave Technologies*

Japanese institutionalization and global standardization of Wireless Power Transmission, and Recently R&D trend in Japan

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SUMMARY In Japan, research on spatial transmission Wireless Power Transfer / Transmission (WPT) for long-distance power transmission has been conducted ahead of the rest of the world; however, until 2022, there has been no category under the Radio Law, and it has been treated as an experimental station. The authors are working on Japanese institutionalization (revision of ministerial ordinances) and global standardization of this spatial transmission WPT for social implementation. This paper describes the Japanese and international institutionalization and standardization trends. In addition, as the latest trend in R&D trends, as the next step of institutionalization, the author introduces two national projects that are being worked on by industry, academia, and government for Step 2, which can be used for a wider range of applications by relaxing the scope of use and restrictions from Step 1, which has various restrictions.
The first is about the Cross-ministerial Strategic Innovation Promotion Program (SIP) Phase 2. In SIP Phase 2, we conducted R&D on "WPT system for sensor networks and mobile devices". This R&D is research on detecting and avoiding people so that radio exposure does not exceed protection guidelines and detecting incumbent radios and avoiding harmful interference so that more power can be transmitted under coexistence conditions.
The other is "Research and Development for Expansion of Radio Resources" to be conducted by the Ministry of Internal Affairs and Communications (MIC), which is scheduled for four years from FY2022. This is also a more concrete research and development project for Step 2 institutionalization, along with the results of the SIP mentioned above.
key words: *wireless power transfer / transmission, microwave, beamforming, Internet of Things.*

1. Introduction

WPT systems can be broadly classified into four types: electromagnetic induction, magnetic resonance coupling, electric field coupling, and spatial transmission. The electromagnetic induction, magnetic resonance coupling, and electric field coupling methods are classified as proximity coupling WPT systems because the power transmission distance is less than several 10 cm and are treated as high-frequency use facilities under the Japanese Radio Law.
On the other hand, Japan has led the world in research on spatial transmission WPT [1]-[5], which transmits power using radio waves above sub-GHz over long transmission distances, but until 2022, spatial transmission WPT has not been categorized under the Japanese Radio Law and has been treated only as an experimental test station. Internationally, the ITU-R, which manages international radio frequency resources, has not clarified the category in its Radio Regulations (RR) as well.
However, WPT is expected to be a next-generation infrastructure technology that will support the Internet of Things (IoT) society, and in recent years, it has been used to feed power to sensor devices used in factories, In recent years, it has been particularly important to establish an environment for the world's pioneering commercialization of power supply for sensor devices used in factories, as well as to develop a system that will enable Japan to gain a strong competitive edge. Development is underway both in Japan and overseas for practical application in applications such as powering, and it is important for Japan to promote practical application while keeping its international advantage. This paper introduces the current status of institutionalization and standardization related to these WPT systems, focusing on spatial transmission WPT systems.

2. Institutionalization status in Japan

Broadband Wireless Forum (BWF) and Wireless Power Transfer Consortium for Practical Applications (WiPoT), representing the industry, have been working to create an environment for the world's pioneering commercialization of powering for sensor devices used in factories, and to establish a system for achieving a strong competitive edge in Japan. The two organizations, BWF and WiPoT, have been working on behalf of the industry by submitting requests [6] to "Advisory Group on Strategies for Effective Use of Radio Waves".
As a result, the report [7] of the Advisory Group highlighted the WPT as one of the seven next-generation wireless systems that should be realized in the 2030s.
In response to this proposal, the Information and Communications Technology Subcommittee of the Information and Communications Council of the MIC consulted on it in December 2018 as Advisory No. 2043 "Technical Conditions for Spatial Transmission Wireless Power Transmission Systems," and in January 2019, the following year, the Land Radio Communications Committee of the Information and Communications Technology Subcommittee established the Spatial Transmission Wireless Power Transmission System

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Working Group was established by the Land Mobile Communications Committee of the Information and Communication Technology Subcommittee in January 2019, and the working group began its investigations [8]. Based on the report of the working group, the Information and Communications Council issued a partial report [9] on "Technical Conditions for Wireless Power Transmission Systems for Spatial Transmission in Premises" among the "Technical Conditions for Spatial Transmission Wireless Power Transmission Systems" in July 2020.
Based on the report, the Radio Regulatory Council made a report [10] on the draft ministerial ordinance to be revised, and in May 2022, the ordinance was adopted [11] as Step 1 of the spatial transmission type WPT system as a system development for the introduction of a spatial transmission type wireless power transmission system. From now on, BWF plans to expand the application area from the viewpoint of use in general and outdoor environments, from sensors to digital devices, etc., as Step 2, and is also considering Step 3, which aims to transmit larger amounts of power over greater distances. Fig. 1 shows a scenario for the practical application of spatial WPT.

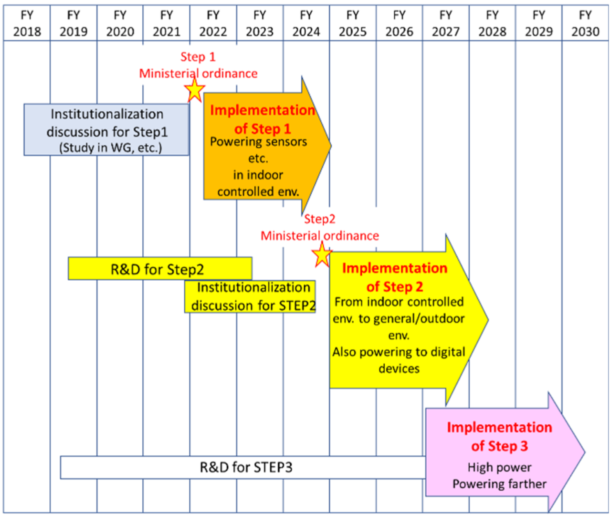


Fig. 1 Practical scenarios for spatial transmission WPT.

2.1 Institutionalization of spatial transmission WPT system Step 1

The technical conditions of spatial transmission WPT systems for institutionalization and ministerial ordinances in Step 1 were reported in 2020 by the Land Radio Committee of the Information and Communications Council of the MIC in the "Technical Conditions for Space-Transmission Wireless Power Transmission Systems on Premises". Technical Conditions for Wireless Power Transmission Systems in Premises" by the Land Radio Committee of the Information and Communications Council of the MIC. In this report, it is appropriate to use the 920 MHz, 2.4 GHz, and 5.7 GHz bands as "premises radio stations" for wireless power transmission applications. Table 1 shows the characteristics and usage of each of these three bands.

Table 1 Characteristics and usage of the three frequencies [9].

FRQ.	Features (same conditions)				Usage rules
	Dist.	TX/RX Cir-cuit	Ant. Size	Propa-gation char.	
920 MHz band	Long dist.	Low cost	Up sizing		Transmits over a wide area, including non-line-of-sight areas such as shadows, by omni or wide beams, with multiple powering.
2.4 GHz band					Linking with existing systems using beacon signals, etc. using wireless LAN devices, and 1-to-1 transmission of electric power using low-cost power receiving equipment.
5.7 GHz band		High cost	Down sizing	Straight-ness	Beam control of the transmitter device with fine control by a dedicated power receiver and switching the direction of the power receiver to perform the equivalent of a long duration, high power, one-to-one transmission.

In establishing this system, MIC established the "Study Group on the Operation and Coordination of Spatial Transmission Wireless Power Transmission Systems" to discuss the concept and mechanism of operational coordination for coexistence with incumbent wireless systems, etc. The results of the study were published as "Basic Idea on the Operation and Coordination of Spatial Transmission Wireless Power Transmission Systems" in 2021 by the MIC [12].
This document presents the basic concept, process, and support system for operational coordination to establish a system that enables smooth operational coordination between the spatial transmission WPT system and incumbent wireless systems, etc.

2.2 Overview of spatial transmission WPT system

With the institutionalization of the spatial WPT system, the "premises radio station for WPT" was specified in the enforcement regulations of the Radio Law, and power transmission using the microwave band, which had previously been permitted only for experimental stations, gained citizenship in the radio world. Table 2 shows an overview of the spatial WPT system. The spatial transmission WPT system ordained in Step 1 consists of three bands: the 920 MHz band, the 2.4 GHz band, and the 5.7 GHz band.

Table 2 Spatial transmission WPT system [9].

	920MHz band	2.4GHz band	5.7GHz band
Frequency	917.8MHz-919.4MHz	2410MHz-2486MHz	5738MHz-5766MHz
Channel	918.0MHz, and 919.2MHz (2 channels)	2412MHz, 2437MHz, 2462MHz, 2484MHz (4 channels)	5740MHz, 5742MHz, 5744MHz, 5746MHz, 5748MHz, 5750MHz, 5752MHz, 5758MHz, 5764MHz (9 channels)
MAX Output power	1 W	15 W	32 W
MAX Antenna gain	6 dBi	24 dBi	25 dBi
MAX e.i.r.p	36 dBm	65.8 dBm	70 dBm
e.i.r.p. limit	NON	47dBm/MHz (80~90deg)	47dBm/MHz (80~90deg)
Bandwidth	200 kHz	N/A (CW)	N/A (CW)
Beacon signals	Other wireless systems	Other wireless systems	Beam-WPT dedicated wireless system
Antenna	NON	Beam forming	Beam forming
Usage environment	Indoor WPT controlled environment and/or WPT general environment	Indoor WPT controlled environment	Indoor WPT controlled environment

(1) 920MHz band

Fig. 2 shows the application scenario of the 920 MHz band. 920 MHz band has low propagation loss and can propagate in the shadows of structures, so it is expected to transmit power to sensors installed over a wide area despite its low power consumption. This makes it suitable as a power source for sensor networks in factories and nursing care facilities.

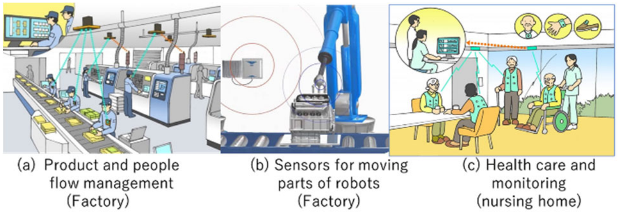


Fig. 2 Application scenario of the 920 MHz band [9].

The electrical specifications are equivalent to those of RFID, making it possible to link with and apply RFID systems already in the market, and it is expected to be used to supply power to vital sensors and position sensors that are easily shielded by the human body, and to sensors used in devices such as robots that have difficulty directing their aerials in a fixed direction due to their mobility.
Therefore, the frequency used is set as 917.8 MHz to 919.4 MHz, and the channels used are two of the four channels used by the RFID 1W station.

(2) 2.4GHz band

Fig. 3 shows an application scenario for use of the 2.4 GHz band, in which incumbent wireless systems (specified low-power data communications such as Bluetooth) are used on the power receiver side for beacon signals and power supply information, enabling location estimation and control communications with inexpensive equipment. The system uses array antennas for beamforming to provide one-to-one transmission of power. The system uses four channels in the 2410MHz to 2486MHz bandwidth, with a maximum EIRP of 65.8dBm and no-modulated wave (CW) transmission, assuming a transmission power of 15W and 64-element array antenna.

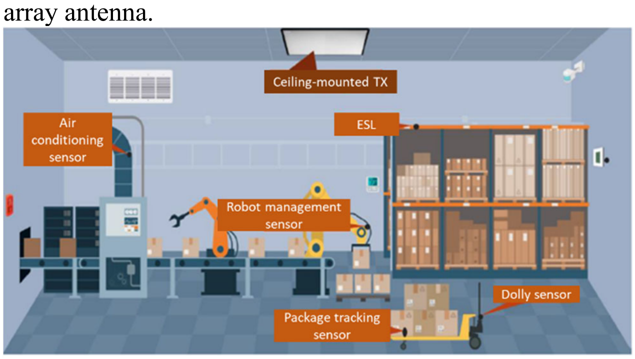


Fig. 3 Application scenario of the 2.4 GHz band [9].

(3) 5.7GHz band

Fig. 4 shows an application scenario in the 5.7-GHz band. 5.7-GHz has a higher frequency and shorter wavelength, making it possible to develop smaller and lighter devices than in the 2.4-GHz band, as the antenna size can be made even smaller. The receiver uses a beacon signal from a dedicated device and beamforming control using array antennas to transmit power for long periods of time and at high power. The bandwidth used is 9 channels between 5738MHz and 5766MHz, with a maximum EIRP of 70dBm and no-modulated wave (CW) transmission, assuming a transmission power of 32W and the use of a 64-element array antenna.

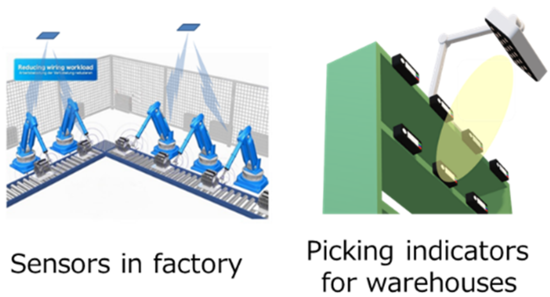


Fig. 4 Application scenario of the 5.7 GHz band [9].

2.3 Installation environment for spatial transmission WPT

When installing the spatial transmission WPT system, "WPT indoor installation environment" is newly defined as the environment in which the spatial transmission WPT system is used to ensure coexistence with other radio systems and the effects of radio wave protection on the human body. In addition, outdoor use is excluded from the installation environment because it was defined as indoor use only in the Step 1 institutionalization.

The "WPT indoor environment" is defined as the installation environment where the spatial transmission WPT system is used. This is defined as a "WPT controlled environment" as an environment in which the effects on other radio systems and human exposure can be controlled at the location where the spatial transmission WPT system is used. On the other hand, the use environment that does not require control based on this definition is classified as a "WPT general environment.

2.4 Operational Coordination Mechanism

Operational coordination will efficiently and effectively ensure interference prevention from the perspectives of avoiding and reducing the impact on the spatial transmission WPT system and existing wireless systems, taking installation environment into account, and effectively using frequencies. This is what is required when installing a spatial transmission WPT system. The Wireless Power Transmission Operation Coordination Council (JWPT) was established as an organization with a mechanism to smoothly coordinate this operation, and is responsible for coordinating operations. The idea behind establishing JWPT is shown in Fig.5.

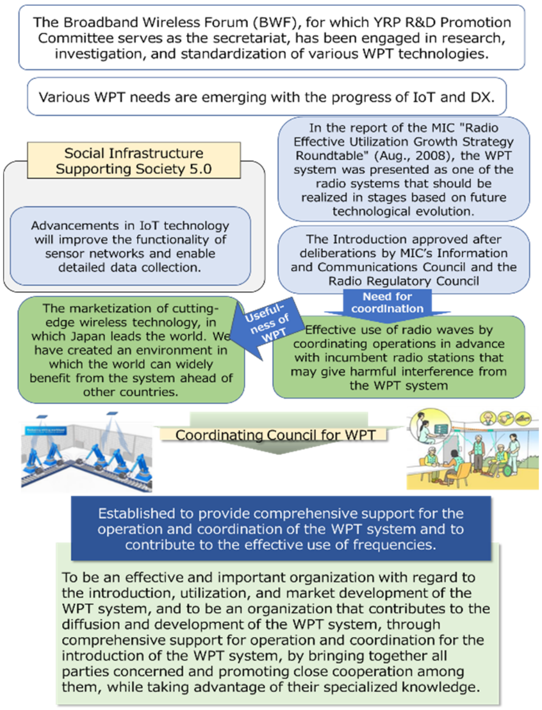


Fig. 5 Concept of establishment of JWPT [13].

JWPT provides operational coordination support to prevent interference from the WPT system to other radio stations. Fig. 6 shows "Procedures for opening a WPT station by JWPT". In addition to confirming whether the WPT system that has been developed is compatible with the institutionalized conditions, we also check whether operational adjustments are necessary by making inquiries to existing wireless system users and disclosing information. In addition, if there is a request for operational adjustment from the existing wireless system, or if it is determined that the WPT station is installed within a distance from the existing wireless system, we support operational adjustments at the time of establishment by conducting an impact study and presenting the impact assessment of installing a WPT station to the interfering parties. On the other hand, in response to inquiries regarding interference from existing wireless systems after the station has opened, by supporting the operational coordination of WPT wireless stations, we can efficiently and effectively ensure interference prevention and ensure that radio waves are properly distributed. While maintaining a safe usage environment, we are conducting activities that will lead to expanding opportunities to use the WPT system, which is a new area of radio wave usage.

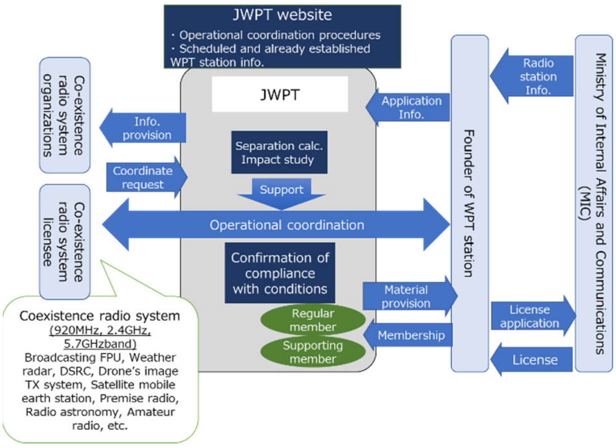


Fig. 6 Procedures for opening a WPT station by JWPT [13].

3. International Institutionalization and Standardization Trends

In Japan, as mentioned earlier, the WPT system is clearly institutionalized as a power transmission system under the Radio Laws and Regulations. However, the treatment of these devices differs depending on the country, such as being considered ISM (Industrial, Scientific, and Medical) devices or SRD (Short Range Device) devices. However, it is desirable to unify the frequencies used as much as possible on an international basis. For this reason, the authors are participating in Study grope 1 / Working Party 1A (SG1/WP1A) meetings of the ITU-R

(International Telecommunication Union, Radiocommunication Sector) as a delegation of Japan, playing a central role in international coordination discussions.
As shown in Fig. 7, the ITU-R starts deliberations by approving a Question (research issue), and then produces a Report, which is a compilation of collected information, a Recommendation, which is not legally binding but is recommended, and, if necessary, a Regulation, which is legally enforceable internationally. The discussion on the formulation of international legally enforceable Regulations is then conducted as necessary.

Fig.7 Working procedures in ITU-R.

In the ITU-R, all WPTs were initially discussed on the same ground, but since 2013, the discussion has been divided into NON-BEAM WPT for proximity coupling type and BEAM WPT for spatial transmission type. The latest status of the discussion is presented here.
In 2016, the report ITU-R SM.2392-0 was approved and published, which summarizes the results of research on BEAM WPT technology and applications, and in 2016, a report was initiated by Japan to study the sharing of frequencies used by BEAM WPT with other radio systems with a view to making it a recommendation. In 2016, a report on the study of sharing the frequencies used by BEAM WPT with other radio systems with an eye to making it a recommendation was initiated at the initiative of Japan. In 2019, work was also initiated on the US proposal to make the frequencies used by the BEAM WPT into a Recommendation. The report was published as Recommendation ITU-R SM.2151-0.
However, recommendations are guidelines and are not enforceable. Therefore, it is important to discuss the next step, which is to put the WPT on the agenda for incorporation into the Radio Regulation (RR).
Discussions for incorporation into the RR usually take place at the WRC, which meets every four years. The agenda for discussion at this meeting was decided at the WRC four years ago and is then considered by SG 1 within the ITU-R over the next four years.
The WPT was discussed at WRC-23 in 2023 as an agenda item for inclusion in the Radio Regulation (RR), and although it was not named as an agenda item for the next meeting, a provisional resolution was adopted to place it on the agenda for WRC-31 at the following meeting. This is expected to lead to more active discussions at the SG 1 meeting in 2024 and beyond.

3.1 Report

(1) Report ITU-R SM.2392-1: This report is a summary specifically on applications by BEAM WPT, and the revised version of -1 was approved in 2021 [14].

(2) Report ITU-R SM.2505-0: In the report, seven BEAM WPT systems using the 920 MHz, 2.4 GHz, 5.7 GHz, and 61 GHz bands are discussed, as shown in Table 3 Systems 4, 5, and 6 are the systems considered in Step 1 in Japan [15].

Table 3 Beam WPT system in Rep. ITU-R SM.2505-0 [15].

System	System 1	System 2	System 3	System 4	System 5	System 6	System 7
Frequency	915-921 MHz	915-921 MHz	915-921 MHz	917-920 MHz	2 410-2 486 MHz	5 738-5 766 MHz	61-61.5 GHz
Output power	4 W	15 W	Up to 50 W	1 W	15 W	32 W	50 W
Antenna gain	7 dBi	8.24 dBi	10 dBi	6 dBi	24 dBi	25 dBi	45 dBi (1)
e.i.r.p.	43 dBm	50 dBm	54.8 dBm	36 dBm	65.8 dBm	70 dBm	92 dBm (1)
Bandwidth	500 kHz	500 kHz	500 kHz	200 kHz	N/A (2)	N/A (2)	10 MHz
Beacon signals	Other wireless systems	Other wireless systems	Other wireless systems	Other wireless systems	Other wireless systems	Beam-WPT dedicated wireless system	Other wireless systems
Antenna	Wide-angle directional antenna	Wide-angle directional antenna	Wide-angle directional antenna	Wide-angle directional antenna	Beam forming	Beam forming	Near field beam focusing
Applications	Wireless charging of mobile/portable devices Wireless powered and charging of sensor networks						

NOTE – The technical specifications contained in this Table describe some of the characteristics used in the respective studies and are not meant to be interpreted as regulatory limits, as there may be other beam WPT systems with higher power than those listed. In most cases, out-of-band emission limits for beam WPT devices are set by each Administration.

(1) The figures given for antenna gain and e.i.r.p. here are for cases where the device receiving power is in the far field of the transmitter.

(2) The regulation on this system designates its occupied bandwidth as zero because its modulation is CW.

3.2 Recommendation

(1) Recommendation ITU-R SM. 2151-0: This recommendation is a guideline for the frequency bands recommended for the BEAM WPT system, and is not a mandate for governments to use these bands. However, this recommendation is a significant step forward, as it will be reflected in future international cooperative discussions, including international standardization of the BEAM WPT. As shown in Table 4, the frequencies to be used in the Recommendation are the 920 MHz, 2.4 GHz, 5.7 GHz, and 61 GHz bands [16].

Table 4 Beam WPT frequency Guidelines in Rec. ITU-R SM.2151-0 [16].

Frequency range	Suitable beam WPT technologies and applications
915-921 MHz	Wireless charging of mobile/portable devices Wireless powered and charging of sensor networks
2 410-2 483.5/2 486 MHz	
5 725-5 875 MHz	
61-61.5 GHz	

NOTE 1 – The frequency ranges listed in this Table indicate those with possible use for beam WPT, noting that some frequency ranges may not be designated for ISM applications, and may not be available for beam WPT applications in some countries, as a result of the different national allocations and regulatory conditions.
NOTE 2 – In some administrations in Regions 1 and 3, the compatibility study of beam WPT is still ongoing and the available frequency ranges for beam WPT are still under consideration.

4. Latest R&D Trends in Japan

Based on the scenario for the practical application of spatial transmission WPT shown in Fig. 1, BWF is also working toward institutionalization as Step 2. The reasons why the industry is requesting institutionalization as Step 2 at this time, in contrast to Step 1, which is for limited use, are as follows;
(1) The need to expand the scope of use in response to future demands from society for spatial transmission WPT systems.
(2) As a new area of radio use in the 5G/IoT era, which is expected to improve convenience and go into full swing in the future, it can be one of the basic environments that support innovation creation and DX, and will greatly contribute to the industrial development of our country.
The practical application of Step 2 will lead to the creation of industries with new usage patterns, such as sensors in factories and warehouses and for industrial applications, logistics, nursing care, and IoT devices, and BWF estimates that the market size will exceed 800 billion yen per year by 2030 at least.
The key points of the institutionalization of Step 2 (the difference from Step 1) are as follows;
・From indoor use to outdoor use
・From WPT controlled environment, to be available in the general environment
・Expand the target of power receiving from small power devices such as sensors and indicators to digital devices including mobile terminals (more power receiving)
・Enable safe power transmission even in environments where people are present
・To enable 24 GHz band in addition to the frequency bands used in Step 1 (920 MHz, 2.4 GHz, and 5.7 GHz bands) to accommodate expanded use.
Based on the results of various research and development activities, we are currently studying the sharing of the system with other wireless systems and its suitability for exposure to radio waves in preparation for the institutionalization of Step 2. The results of these studies will be proposed for discussion at the Land Radio Committee of the Information and Communications Council of the MIC at an early stage, with the aim of institutionalizing the system in FY2024.
As R&D for this purpose, at least the following two national projects are being conducted in Japan.

(1) SIP Phase 2

The SIP is characterized by the Council for Science, Technology, and Innovation (CSTI) acting as a control tower, selecting issues that are essential to society and important for Japan's economic and industrial competitiveness, allocating its own budget, and promoting initiatives that transcend the boundaries of ministries and fields and focus on basic research through to exit (practical application and commercialization) [17]. As a major research theme of SIP Phase 2 "Energy System for IoE Society", "WPT System for Sensor Networks and Mobile Devices" was the subject of a five-year research project through FY2022 to develop technologies for Step 2 in industry, government, and academia[18]-[32]. In the research and development, two transmission methods and several elemental technologies development were conducted as shown in Fig.8 [31]. The results of this research will be reflected in the institutionalization Step 2.

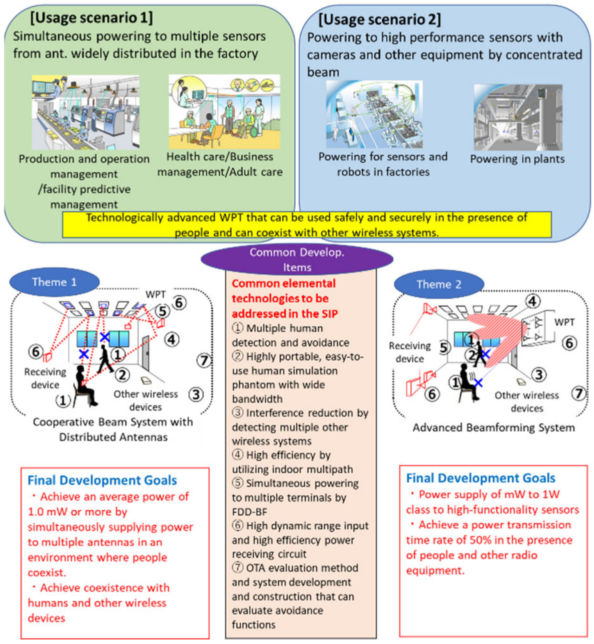
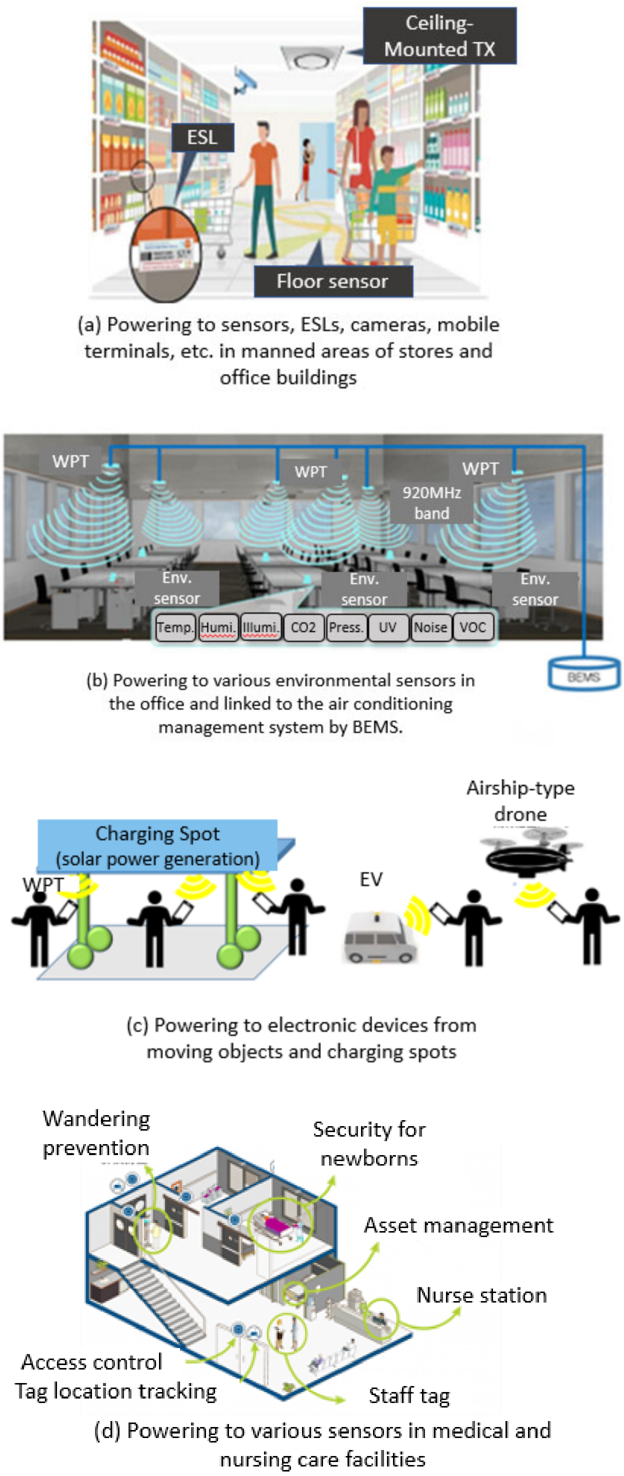


Fig. 8 Overview of SIP-funded technical research [31].

(2) R&D for Expansion of Radio Resources

The "Research and Development of Interference Suppression and Upgrading Technology for Spatial Wireless Power Transmission" is being conducted by the Ministry of Internal Affairs and Communications under its "Research and Development for Expansion of Radio Resources" program, with a four-year plan starting in FY2022.
Fig. 9 shows an overview of "R&D of Interference Suppression and Upgrading Technology for Spatial Wireless Power Transmission". In this R&D, research will be conducted to develop technology for devices including power receiving devices in the 24 GHz band, which will be the quasi-millimeter wave band targeted in Step 2, to develop protocols to improve the power feeding efficiency of all spatial transmission WPT, and to evaluate the coexistence of spatial transmission WPT systems and other wireless systems, and the research results will be used for the institutionalization and

standardization of Step 2 [33].



(a) Powering to sensors, ESLs, cameras, mobile terminals, etc. in manned areas of stores and office buildings

(b) Powering to various environmental sensors in the office and linked to the air conditioning management system by BEMS.

(c) Powering to electronic devices from moving objects and charging spots

(d) Powering to various sensors in medical and nursing care facilities

Fig. 9 Overview of "R&D of Interference Suppression and Upgrading Technology for Spatial Wireless Power Transmission" [33].

5. Conclusion

The above discussion has focused on Japanese and international institutionalization and standardization of spatial transmission WPT, as well as R&D trends in Japan. However, to achieve full-fledged diffusion, it is necessary to deregulate various restrictions as the second step, and research and development for this purpose is currently underway. We also believe that it is necessary to incorporate wireless power transmission into RRs on a global basis.
WPT allows wireless energy to be sent everywhere without having to worry about wires or batteries, and the network system that is not only convenient but also free from batteries and power lines in combination with IoT technology will lead to a new future as it can be used for all kinds of DX, leading to decarbonization. On the other hand, for the future development, it is important to discuss the common use of other wireless systems in general, and the understanding and cooperation of everyone involved is indispensable. To this end, the WPT parties are making further efforts[34].

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