Latest Trends in Rulemaking for Capacitive Coupling Wireless Power Transmission Systems Using 6.7MHz Frequency Band

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ABSTRACT: As the Broadband Wireless Forum (BWF), a standardization organization for radio systems, we have participated in the Wireless Power Transmission (WPT) Working Group of the Radio Environment Committee of the Information and Communications Council of the Ministry of Internal Affairs and Communications of Japan since 2020. We have been deliberating on the institutionalization of Capacitive (or electric field) Coupling Wireless Power Transmission Systems (CC-WPT) Using 6.7MHz Frequency Band for AGVs and AMRs under the Radio Act. In May 2024, the results of the research to determine the technical conditions were put out for public comment, and submitted to the Minister of Internal Affairs and Communications in June 2024. In response to this report, the Ministry of Internal Affairs and Communications prepared a draft amendment to the regulations related to the Radio Act, which was then submitted to the public for comment in October 2024. The amendment was revised and enacted as a Ministry of Internal Affairs and Communications Ordinance in December 2024. This article explains the technical discussions in the institutionalization of the Radio Act.

KEY WORDS: Wireless Power Transmission Systems, Capacitive Coupling, Radio Act, Automatic Guides Vehicle, Autonomous Mobile Robot

1. INTRODUCTION

WPT is classified as high-frequency equipment under Article 100 of the Radio Act of Japan, which states that "Any person who wishes to install the following equipment must obtain permission from the Minister of Internal Affairs and Communications." In the Radio Act Enforcement Regulations, which stipulate the details of high-frequency equipment under this Act, equipment with a high-frequency output power exceeding 50W and a frequency of 10kHz or more requires individual permission from the Minister of Internal Affairs and Communications. Therefore, mass production like wireless LAN equipment was impossible. However, there are exceptions to the rule that do not require individual permission from the Minister of Internal Affairs and Communications for some high-frequency equipment, such as microwave ovens and induction cookers.

Regarding WPT, a license-free Radio Act system was established in 2016 for WPT for EVs using capacitive coupling in the 85 kHz band, WPT for mobile devices using capacitive coupling in the 400 kHz band, and WPT for mobile devices using inductive (or magnetic field) coupling in the 6.7 MHz band. This license-free system (rules) is essential for the mass production of WPT and is indispensable for promoting its widespread use.

As such, we have been working to establish rules under the Radio Act that will make license-free CC-WPT systems using the 6.7 MHz band. This CC-WPT system is mainly used for robots (AGV, AMR, etc.) in manufacturing plants and logistics centers, and has a moving WPT (DWPT) function. Therefore, it enables maintenance-free robots to operate 24 hours a day without the need to charge batteries when not in operation, which is considered important for responding to the declining birthrate and aging population and for realizing the SDGs.

2. Importance of the Ministerial Ordinance Revision

Japan's Radio Act consists of two types of equipment: radio equipment (radio stations) and high-frequency equipment. Currently, there are approximately 300 million pieces of radio

equipment requiring a license in Japan, the majority of which are mobile phones. If radio stations that do not require a license (such as wireless LAN or Bluetooth) are included, the number is several times higher.

On the other hand, high-frequency equipment is equipment that does not actively emit radio waves but uses high-frequency currents, and its installation requires permission from the Minister of Internal Affairs and Communications in each case. Compared to radio equipment, there are not many of these, and a typical example that is widespread is the microwave oven.

In Japan, the first domestically produced microwave oven was developed in 1959. A popular model was then developed in 1963. The price at the time was equivalent to the annual salary of a new college graduate at a company, but microwave ovens began operation after receiving individual installation permission from the Minister of Internal Affairs and Communications in order to be used in the kitchens of the dining cars on the Tokaido Shinkansen, which had opened just before the 1964 Tokyo Olympics.

In 1972, as microwave ovens became cheaper and began to spread to ordinary households, the Ministry of Internal Affairs and Communications implemented the Radio Act's regulations, which called for "type designation," which did not require individual approval from the Minister of Internal Affairs and Communications, and in 1985, as their use accelerated, the Ministry of Internal Affairs and Communications moved to a system called "type confirmation," which allowed businesses to manufacture and sell microwave ovens with their own confirmation. The current price of a microwave oven is less than 1% of the annual salary of a new college graduate.

Thus, in order to popularize high-frequency equipment such as WPT among general users, "revision of Radio Act regulations to eliminate the need for individual approval from the Minister of Internal Affairs and Communications," such as "type designation," is essential and is of utmost importance for the expansion of the WPT manufacturing and sales business.

Against this background, we revised the ministerial ordinance for type designation of capacitive coupling WPT (85 kHz band, 7.7 kW) for EVs in 2016, and approximately eight years later, we have now realized the revision of the ministerial ordinance for type designation of capacitive coupling WPT.

3. Characteristics of CC-WPT Systems

The image of CC-WPT is shown in Figure 1. The inductively coupled WPT (IC-WPT) system, which has been developed in many cases worldwide, is used for wireless charging of EVs and mobile phones. On the other hand, the capacitively coupled WPT (CC-WPT) system has been developed in few cases, and Japan is the world's leading WPT system.

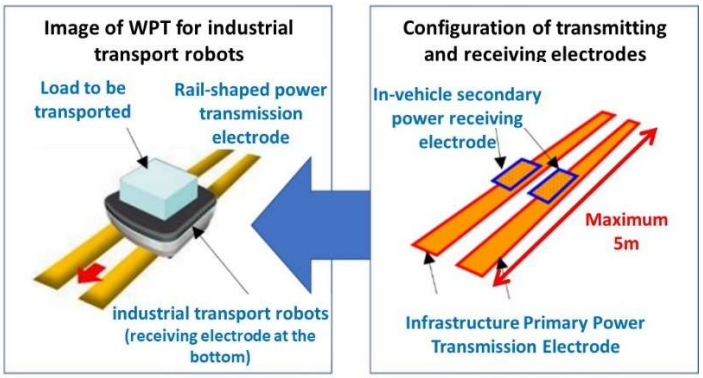

Fig. 1 Image of CC-WPT

Figure 2 shows a Example of CC-WPT operation in a factory. Five-meter-long power transmission electrodes are placed in the aisle at 20-30-meter intervals, and the robot moves at its working speed.

By wirelessly feeding power while moving over the electrodes, it is no longer necessary to stop and charge the robot or to replace the battery, and it can be operated 24 hours a day, completely automatically.

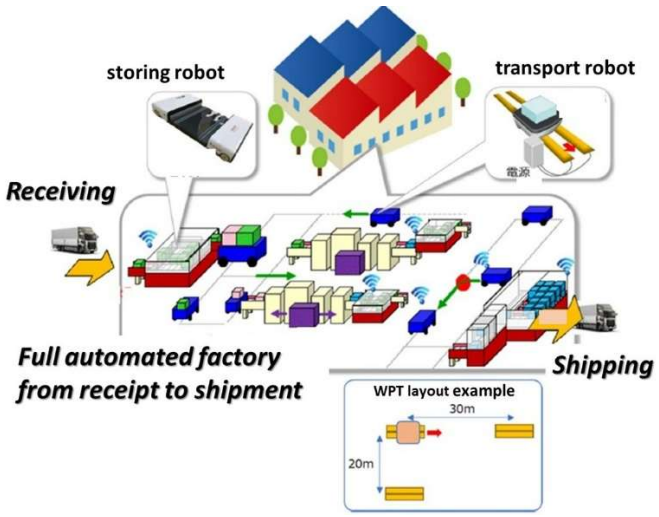

Fig. 2 Example of CC-WPT operation in a factory

A comparison of these two WPT systems is shown in Table 1. Compared to IC-WPT, CC-WPT has problems such as higher frequency, higher circuit cost, and vulnerability to water intrusion. However, we believe that CC-WPT is an extremely useful method for DWPT for mobile robots (AGV, AMR, etc.)

that do not change much in height, due to the low installation cost of the power transmitter and receiver, low eddy current heating of magnetic metals that are common in factory environments, and a large degree of freedom in horizontal positioning, and therefore we proposed to institutionalize it in Radio Act.

Table 1 Comparison CC-WPT and IC-WPT

	CC-WPT	IC-WPT
Components cost	High : high frequency band	Low : high frequency band
Construction cost	Low : Lay the electrode plate	High : fill the coil
Environmental resistance	Weak against water (high dielectric constant) entering between gaps	Eddy currents cause surrounding metal to overheat
Misalignment	Resistant to horizontal displacement	Resistant to vertical displacement

4. Use Cases of 6.7 MHz band CC-WPT

Figure 2 shows a use case of CC-WPT systems. C-WPT will be used in factory automation, logistics, construction, commercial facilities, etc. According to our calculations, factories will require 3 million robots, logistics 9 million robots, construction 300,000 robots, and commercial 500,000 robots, resulting in a total of 12.8 million robots required.

In the factory field, it can be used not only for transport robots, but also for storing robots that automatically sort parts and the like, and assembly robots.

In the logistics field, the application of WPT to not only transport robots, but also drones that charge while parked will be important.

In the construction field, construction support robots, cleaning robots, etc. can be used. At construction sites, once the construction period is over, the robots are moved to another construction site for use, so interoperability (interconnectivity between transmitters and receivers) is important for the sharing business.

The use case illustrated in the figure is also useful in the commercial field. However, after technical discussions in this WG, the result was that only "WPT in a controlled environment" was covered, and discussions on "WPT in a general environment" will continue in the next working group.

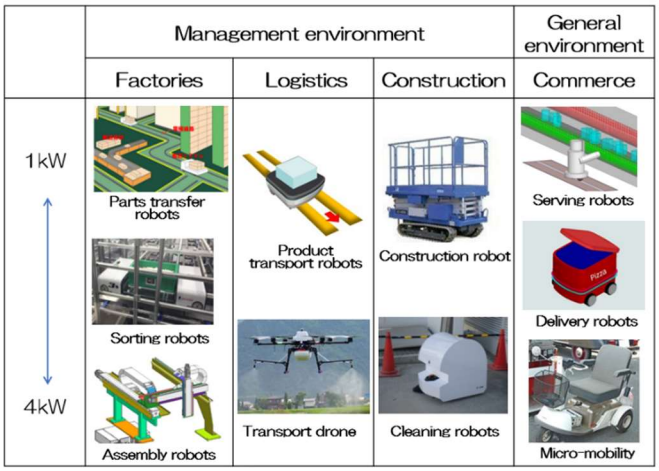

Fig. 2 Use Cases of 6.7 MHz band CC-WPT

5. Activities of the WPT Working Group

The Ministry of Internal Affairs and Communications' WPT Working Group has discussed topics such as the outline of capacitive coupling type WPT systems, market forecasts, frequency sharing considerations, radio wave protection guidelines, and aggregation (the effect of interference power addition when multiple WPTs are operated simultaneously), and has compiled technical conditions for "Capacitive Coupling type wireless power transmission systems using frequencies in the 6.7 MHz band."

Among these activities, we will introduce frequency coexistence studies. In general, to regulate a new radio wave utilization system, it is necessary to conduct a Frequency Coexistence Study with other existing wireless systems that use the same or adjacent frequency bands. In order to make the proposed CC-WPT in the .7MHz band a regulation of the Radio Act, we discussed frequency coexistence between the public "fixed mobile radio" that uses the same frequency and the "amateur radio" that uses the 7MHz band.

WPT is a system that transmits high-power non-modulated continuous waves, so compared to general wireless communication equipment (such as mobile phones or wireless LANs), there is less spurious emission due to the modulation process to sidebands, but there is a tendency for harmonics that are integer multiples of the carrier wave to be large due to the nonlinearity of the transmission circuit. Since the frequencies of the harmonics do not match all amateur radio frequency bands, the spectral purity of the carrier wave became an issue.

Figure 3 shows the WPT spectrum purity that we demonstrated in discussions with amateur radio operators. The horizontal axis of the measurement graph is 50Hz/div., and the WPT carrier

spectrum is less than 50Hz wide, proving that spurious emissions into the sideband are below the measurement limit.

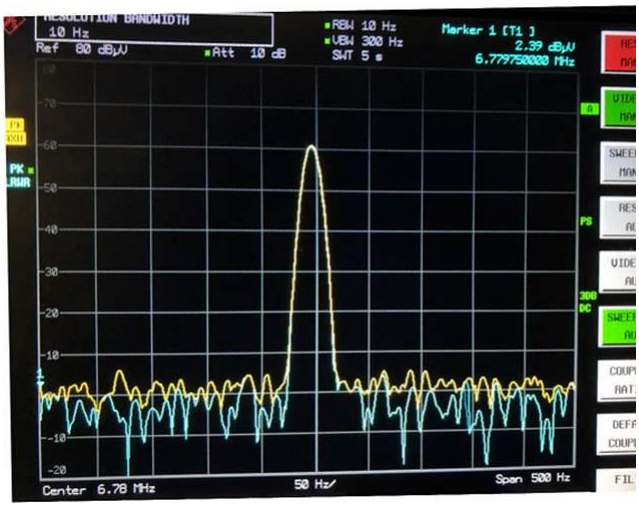

Fig. 3 Spectrum purity of 6.7MHz band CC-WPT

Through such technical discourse, Coexistence became possible, and we were able to realize the establishment of new regulations.

6. Radio Radiation Protection Guidelines

Since CC-WPT transmits high power, it is required to comply with the "Human Body Protection Guidelines" that determine exposure to surrounding human bodies. As a result of demonstration experiments and working group discussions, we were able to satisfy human body protection regulations around CC-WPT.

7. Technical Specifications of 6.7 MHz band CC-WPT

Table 2 Technical Specifications of 6.7 MHz band CC-WPT

Device to be charged	factory automation, logistics, construction business,
Usage environment	Factories, logistics bases, construction sites
Transmission power	4kW or less
Transmission distance	30mm or less
Frequency band	6.765 MHz – 6.795 MHz
Length of Tx-electrode	Less than 5m

Table 2 shows the main technical specifications of CC-WPT. It can transmit 4kW of power in the 6.7MHz band. CC-WPT is also the first DWPT that can supply power while driving under the Radio Act regulations.

8. CONCLUSIONS

We have proposed WPT for robots (AGV, AMR, etc.) using the 6.7MHz band in the Wireless Power Transmission Working Group of the Information and Communications Council of the Ministry of Internal Affairs and Communications, and we have proposed WPT for robots (AGV, AMR, etc.) using the 6.7MHz band, and we have proposed WPT for robots (AGV, AMR, etc.) using the adjacent frequency band, Discussions were held with experts, human protection experts, and others, making it possible to establish new regulations under the Radio Act.

This CC-WPT is a dynamic WPT that can be charged while on the move, and that is the first to be regulated under the Radio Act.

In this discussion, the target of use was controlled environments such as factories, but in the future, we would like to further promote its use with the aim of using it in general environments such as commercial facilities and residential areas.

ACKNOWLEDGMENT

WE WOULD LIKE TO THANK THE MINISTRY OF INTERNAL AFFAIRS AND COMMUNICATIONS, THE WIRELESS POWER TRANSMISSION WORKING GROUP, AND THE BROADBAND WIRELESS FORUM FOR THEIR SUPPORT IN ADVANCING THIS RESEARCH.

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