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High Efficiency 10kW Class Wireless Power Transmission Using Electric Field Coupling

- High Efficiency 10kW Class Wireless Power Transfer by CPT -

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ABSTRACT: Wireless power transmission technology is attracting attention from the viewpoint of improving user convenience during charging. Among wireless power transmission methods, the electric field coupling type has been considered unsuitable for large power transmission compared to the magnetic field coupling type. This time, as a result of repeated studies on the electrode and coil structure of the electric field coupling coupler, we achieved power transmission up to 10.1 kW on the power transmission side and 9.2 kW on the power reception side, and evaluated various characteristics.

KEY WORDS: electric vehicle, wireless power transfer, CPT

1. INTRODUCTION

Wireless power transmission, which can transmit and receive power energy without using electric wires, is expected to increase user convenience and create new industries. Qi standard products using magnetic coupling are installed in smartphones and provide wireless power of several watts. In addition, the US SAE J2954 task force has issued a standard for up to 11 kW for the North American automobile market. As described above, the development of wireless power transmission using magnetic field coupling has reached the commercialization stage and is approaching the popularization stage. On the other hand, electric field coupling is thought that it is unsuitable for high power transfer and long distance. Therefore, research for electric field coupling has not made much progress. In this report, it was demonstrated that electric field coupling can achieve power transmission of 10 kW class over a transmission distance of 53 mm, and that the efficiency between couplers can be as high as 90.9% or more. We also discuss the advantages of using electric field coupling and future issues.

2. CHARACTERISTICS OF ELECTRIC FIELD COUPLING

2.1. Issues of electric field coupling compared to magnetic field coupling

It has been thought that electric field coupling wireless power transmission is unsuitable for high power transmission and long distance, due to dielectric breakdown voltage and viewpoint that inter electrode capacitance decrease as the distance between power transmission and reception increase.

In order to solve these problems, utilization of high frequencies is considered. As the frequency band of radio waves established by the international organization ITU, it is used the HF band (High Frequency band). On the other hand, in many power electronics, the LF band (Low Frequency Band) is often used. Since the LF band is also used for magnetic field coupling, these technologies can be diverted to peripheral circuits. Compared to magnetic field coupling, research on electric field coupling has not made much progress due to the many problems caused by the high frequency. Recently, as the commercialization of compound power semiconductors has progressed, in the field of power electronics, studies on circuits utilizing the HF band are progressing. It is believed that the development of high-efficiency power circuits in the HF band along with the development of compound power semiconductors will lead to the development of electric field coupling wireless power transmission technology.

2.2. Features of electric field coupling couplers

As mentioned above, although there is a need for progress in peripheral circuit technology, research is being conducted in Japan and the United States on couplers using electric field coupling technology. We have also successfully demonstrated a 5kW class power transmission coupler using electric field coupling. Although higher power is often required for fast charging, etc. Accordingly, it is necessary to demonstrate whether higher power can be transmitted even in electric field coupling, so this research was conducted.

Table 1 shows a comparison between magnetic field coupling and electric field coupling. In electric field coupling, if the distance between power transmission and power reception is widened, the capacitance between the electrodes will decrease, and the coupling coefficient will decrease. In order to transmit power with high efficiency, it is necessary to increase the Q value. It is effective to increase the frequency to improve the Q value of the inductance to resonate with the coupling capacitance that is connected. Typically, the frequency band that can be used for wireless power transmission is often selected from the ISM band, 6.78 MHz, 13.56 MHz, 27.12 MHz, etc. In this case, 13.56 MHz was selected so that even harmonics can be kept within the ISM band. Therefore, the electrode plate used in the coupler can be composed of a very thin metal plate. In addition, since an air-core coil can be applied to the inductance for resonance, there is no need for a magnetic material such as ferrite. Furthermore, the electric field is a diverging field. Therefore, there is no need to control the direction of the magnetic flux, such as the ferrite plate or thick aluminum plate used for magnetic field coupling. In addition, unlike magnetic shielding, the electric field can be easily shielded with a metal plate. A feature of electric field coupling is that there is no need for such components and a lighter weight coupler can be constructed compared to magnetic field coupling.

Table 1 Method Comparison Table

System	Magnetic Field Coupling	Electric Field Coupling
Frequency	kHz Band	MHz Band
Field	Rotating Field	Divergence
Efficienc improvement Circuit	Power factor Improvement circuit	Matching circuit
Shielding	Ferrite,Ferromagnet	Metal plate
Coupler	Coil (Litz wire)	Metal plate
Balanced circuit measures	Unnecessary	Necessary
Meta body heat generation	Yes	Hardly
Measures against Electric shock	Unnecessary	Necessary
Biometric detection	Necessary	Necessary

3. COUPLER STRUCTURE AND PROPERTIES

3.1. Coupler Structure

The coupler structure consists of four electrodes, three coils, and one high-frequency connector in an aluminum box surrounded on five sides. Additionally, As will be described later, an air-cooling fan is installed to cool the coil. The external dimensions are 480 mm × 480 mm × 80 mm, and the weight of the coupler is 4.7 kg.

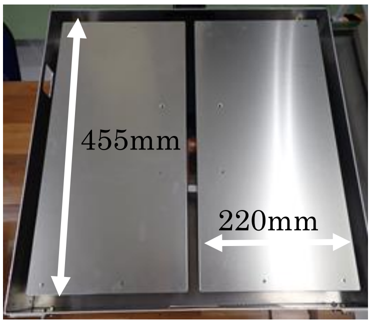

Fig.1 Coupler Appearance Diagram

A structural diagram is shown in Fig.2. The electrodes that act on the electric field coupling have four electrodes, the top two of which are the feeding electrodes connected to the resonance coil, and the two non-feeding electrodes below them to increase the inter-electrode capacitance. The five-sided aluminum box serves as a coupler case to support the electrodes and reduces the leakage electric field. From the viewpoint of the skin effect of the 13.56 MHz band, the electrode’s depth is as thin as 26.6μm, an aluminum plate with a thickness of about 1 mm is used.

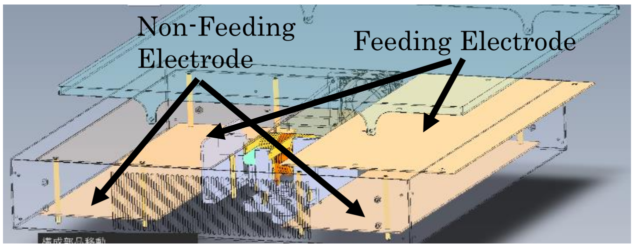

Fig.2 Structural Cross Section

3.2. Resonant Coils and baluns

There is a phenomenon that must be considered in order to achieve high power and high efficiency in the MHz band. One of them is the viewpoint of balance and unbalance of the circuit. A high-frequency power supply circuit, a high-frequency connector, and a coaxial connector are unbalanced circuits, but an electric field coupling coupler is a balanced circuit. Therefore, a balun circuit is required to connect these circuits in a high-frequency circuit. In this case, using a coil as shown in Fig.3, we constructed a circuit with a balun structure and realized balanced/unbalanced conversion.

Fig.3 Coil overview

3.3. Coupler characteristics

Coupler characteristics are measured by a network analyzer. The result is shown in Fig.4. At about 13.56 MHz, S21 is -0.33 dB, S11 is -21.0 dB, and S22 is -20.7 dB. Since S21 exhibits transmission characteristics, it is 92.6% when expressed as an antilogarithm.

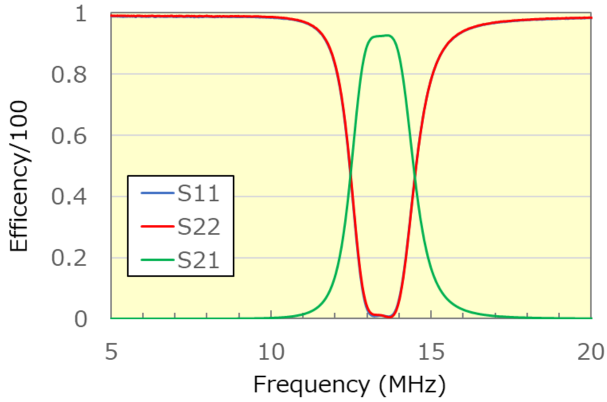

Fig.4 S parameter of coupler

3.4. Misalignment Characteristics

When the power transmitting coupler and the power receiving coupler are displaced from the optimum receiving distance, the impedance of the coupler changes and the power transmission efficiency changes. Fig.5 shows one of the examples of misalignment characteristics of electric field coupling coupler. It is characterized by wide directivity against misalignment in the direction orthogonal to the electric line of force and narrow directivity in the direction parallel to.

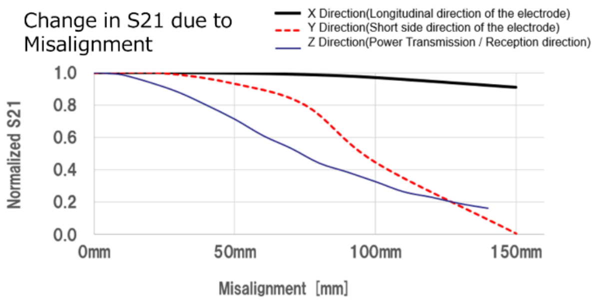

Fig.5 Normalized Efficiency Change

4. 10KW CLASS CPT POWER TRANSMISSION EXPERIMENT

4.1. Evaluation System

We fabricated a system in which a 13.56MHz high-frequency power supply and a power sensor are connected to a power transmission coupler with a coaxial cable, and a power receiving coupler is connected to a 50Ω water-cooled dummy load through a power sensor. In Fig.6 we show the block diagram of this evaluation system. Furthermore, in Fig.7 we show the coupler part of the developed measurement system, and in Fig.8 an overview the measurement system. It is a system that can shift arbitrarily the position of receiving coupler, and automatically collect data on the characteristics of positional deviation.

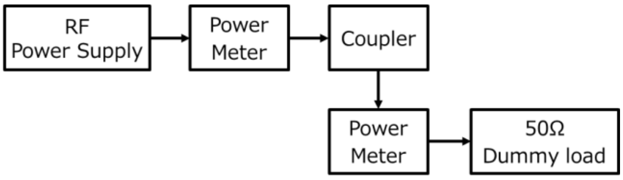

Fig.6 Inside of Measurement System

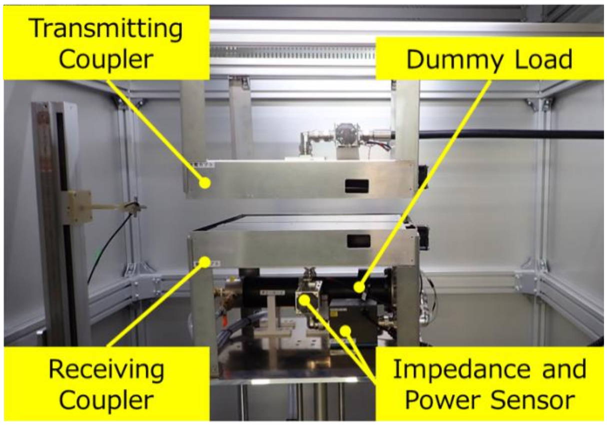

Fig.7 Inside of Measurement System

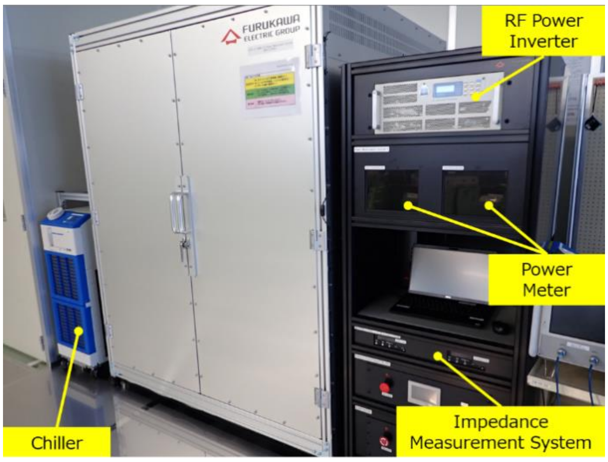

Fig.8 Appearance Measurement System

4.2. High power transmission experiment

Using the measurement system shown in Fig.7 and Fig.8, we measured the high-power characteristics of the manufactured electric-field coupling coupler. The power measurement results are shown in Fig.9 and Fig.10. In Fig.9 and Fig.10, we demonstrated power transmission with received power of 9.2kW and efficiency of 90.9%.

Fig.9 Received power and transmitted power

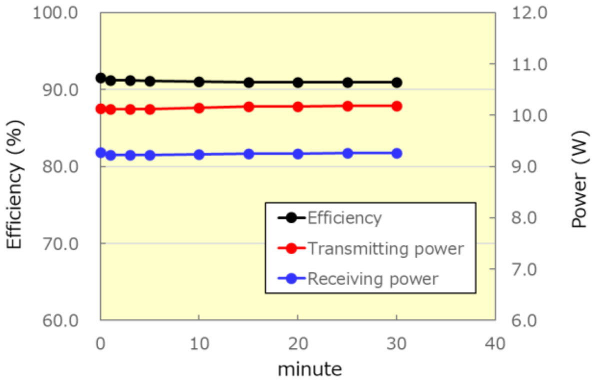

Fig.10 Efficiency electric field couplers

5. LEAKAGE ELECTRIC FIELD EVALUATION

5.1. Evaluation System

In order to measure the electric field near the coupler, the electric field was measured by an optical field strength meter. (Frankonia model EFS-10) measurement system is shown in Fig.11.

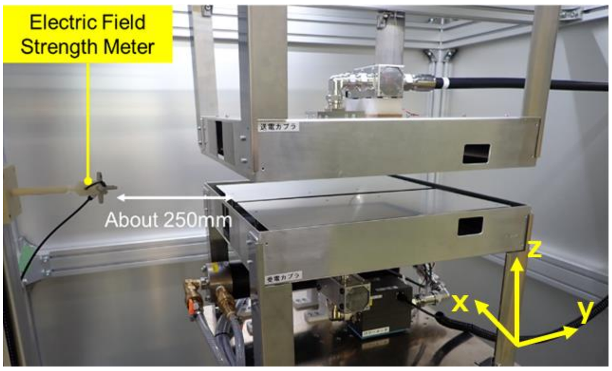

Fig.11 Measurement system

5.2. Measurement results

We measured the peripheral electric field near the coupler when up to 10 kW class power transfer using the measurement system shown in Fig.11. The measurement results are shown in Fig. 12. The electric field strength was about 163.8 V/m at the center of the coupler (Z-Direction movement distance is 0 mm).

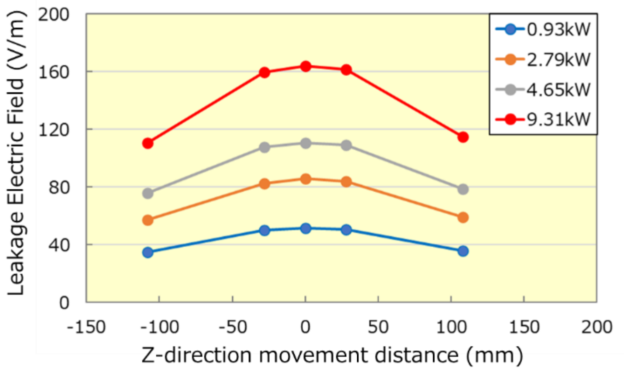

Fig.12 Electric field strength measurement result near the coupler

6. CONCLUSION

Electric field coupling was thought to be an impossibility of large power transmission or distance between power transmission and power reception. But we demonstrated 10kW class wireless power transmission by using the MHz band and balun circuit and so on. The coupler structure does not require special parts such as ferrite or high-voltage capacitors, and can be made lightweight and inexpensive. In the future, we will promote the development of high-frequency power sources suitable for reducing electric field leakage and wireless power transmission in the MHz band. It is planned.

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