The Development of MHz Band Wireless Power Transfer Aiming for the Dynamic Wireless Power Transfer

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ABSTRACT The wireless power transfer technology is now attracting attention as the technology which contributes to improvement of a cruising range of electric vehicles aiming at the carbon-neutral society. We have been developing the capacitive power transfer method, which was one of two categories of methods, classified in general, of the wireless power transfer technology required to realize the dynamic wireless power transfer. This time, we will report on the coupler which is a necessary component for the wireless power transfer technology that we have realized a high-power transfer of 10 kW class by developing measures to mitigate the heat generation and other problems.

1. INTRODUCTION

It has been required to reduce the greenhouse gas emissions to prevent the global warming. In the automotive industry as well, the reduction of emission is promoted by spreading zero-emission vehicles, mainly electric vehicles (hereinafter shortened to EVs). Aiming at promoting the spread of EVs, we have many subjects to improve such as the reduction of the required battery capacity, the shortening of charging time and the reduction of time and effort for charging.

The dynamic wireless power transfer is expected to solve these problems. The dynamic wireless power transfer is the technology that transfers electric power to an EV wirelessly when either driving or parking and either charge a power storage such as a battery and a capacitor or drive a motor directly as well. Applying this technology, electric power can be supplied without connecting any cables and furthermore the additional reduction of required battery capacity and the further improvement of a cruising range can be realized[1].

Research and development of the dynamic wireless power transfer has been driven based on applying kHz or MHz frequency band. In comparison with the kHz band, the MHz band can contribute to especially the downsizing and weight-reduction of the system. On the other hand, it is more difficult for the MHz band to realize the high-power transfer exceeding the kW range, because it is difficult to improve the efficiency of the power transfer because of losses in conductors generated by factors such as the skin effect and the proximity effect as examples of main losses.

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In this paper, we will report that we have reviewed and improved the structure of the coupler in our development looking ahead the dynamic wireless power transfer based on the capacitive power transfer method in the MHz band to improve the power efficiency and realized the high-power transfer, and that we have carried out a high-power transfer as high as 10 kW class.

2. THE TECHNOLOGY OF THE DYNAMIC WIRELESS POWER TRANSFER

2.1 The Dynamic Wireless Power Transfer System

An example of the system expected for the dynamic wireless power transfer is shown in Figure 1 below;

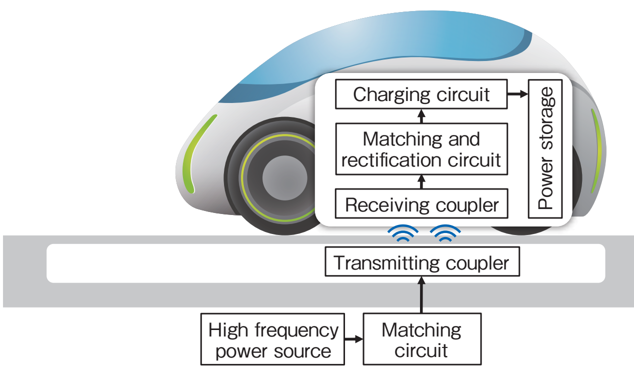

Figure 1 Dynamic wireless power transfer system.

The impedance matching is carried out through a matching circuit located before a transmitting coupler to supply the power to a power storage at a high efficiency, which is input from a high frequency power source. Then, the wireless power transfer is carried out through a coupler. Here, a coupler means a part for transmitting and receiving power in the wireless power transfer system.

The high-frequency power is converted into DC power through a matching and rectification circuit located after a power receiving coupler, and the power is charged to a power storage through a charging circuit.

2.2 Required Power for the Dynamic Wireless Power Transfer System

A larger power is required in the wireless power transfer system when charging the power to a moving vehicle which is consuming energy as well in comparison to a current system in which the power is charged to a parked vehicle from a charging station. Here, the power required for the wireless power transfer is shown in Figure 2.

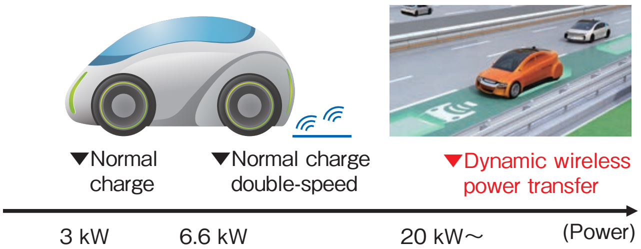

Figure 2 Power required for the dynamic wireless power transfer.

As shown in Figure 2, we have to transfer the power wirelessly more than approximately 22 kW in the dynamic wireless power transfer system[2]. Accordingly, the coupler is required essentially to transfer a high power, as well.

3. THE TECHNOLOGY OF THE WIRELESS POWER TRANSFER

3.1 The Inductive Power Transfer Method and the Capacitive Power Transfer Method

We have two categories of wireless power transfer system, classified in general, the inductive power transfer method and the capacitive power transfer method. In the inductive power transfer method, the power is transferred based on the principle of electromagnetic induction of a coil. Recently, this method is ahead of the capacitive power transfer method in the standardization, as Qi Standard has been examined, which was already applied to mobile phones and further, SAE in U.S.A. examined to standardize the output class, 3.7 kW, 7.7 kW and 11 kW[3]. Furthermore, it has the advantage of transferring high power over a long distance utilizing a resonance phenomenon. On the other hand, it has a demerit to heat up metal bodies located in the surroundings caused by mainly its magnetic field.

In the capacitive power transfer method, the power is transferred from a transmitting electrode to an opposing receiving electrode through the electric field generated between the electrodes when inputting high-frequency power to the transmitting electrode based on the same theory as the capacitor. It has the advantage that no metal bodies located in the surroundings can be easily heated up because it works based on mainly the electric field. Furthermore, it has also the merit of the capacitive power transfer method to be manufactured flexibly in its shape according to the structure of the electrode and tolerate a position misalignment of the coupler. On the other hand, generally speaking, it is said that it is not suited for the high-power transfer from the viewpoint of electrical insulation, because a high voltage is loaded on the electrode at the application of high power.

Here, features of each method is shown in Table 1 and the overview of each method applied to the dynamic wireless power transfer is shown in Figure 3.

As shown in Figure 3, in case of applying the inductive power transfer method to the dynamic wireless power transfer system, the power is transferred to a receiving

Table 1 Comparison of the inductive power transfer method and the capacitive power transfer method.

	Inductive power transfer method	Capacitive power transfer method
kW class power transfer	Many actual results in the kHz band	Limitations due the dielectric breakdown
Transmission distance	～ several m	～ several tens cm
Safety against a foreign metal body	Induction heating caused by magnetism	Induction heating hardly occurs
Quantity of high-frequency power source units for the dynamic wireless power transfer system	Many units are required	Possibility for small quantity of units

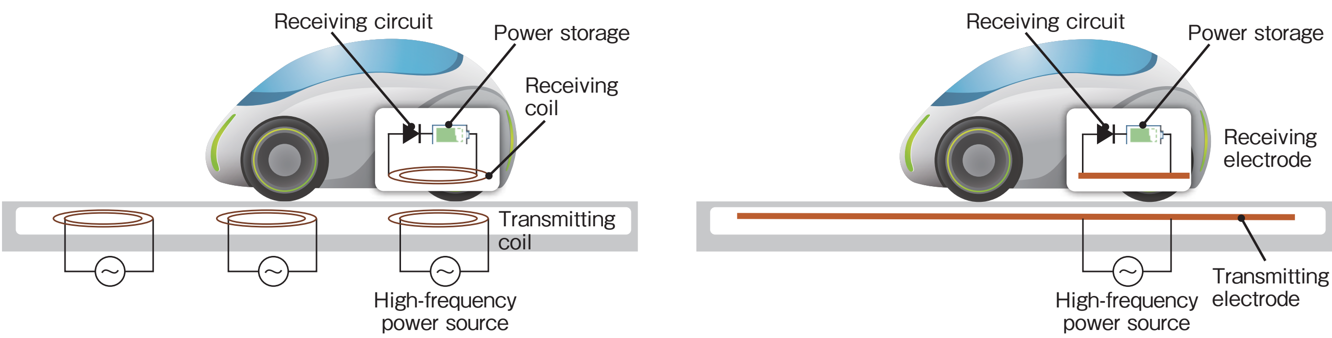

Figure 3 Overview of the dynamic wireless power transfer system. (Left: Inductive power transfer method, Right: Capacitive power transfer method)

coil equipped on an EV from many transmitting coils buried under a road. Because a high-frequency power source is necessary for each coil, it is feared that the cost may increase further.

On the other hand, in the capacitive power transfer method, it may be possible to transfer the power through a transmitting electrode which is several meters long and buried under a road and a receiving electrode equipped on an EV. In comparison with the inductive power transfer method, the quantity of the high-frequency power source units can be smaller.

3.2 Frequencies

85 kHz band (79 kHz to 90 kHz) which was selected as a standard by SAE, 6.78 MHz and 13.56 MHz band which was an application of ISM band are examined as potential frequency bands applied to the dynamic wireless power transfer system. The features of the kHz band and the MHz band are shown in Table 2.

A down-sized small coupler is one of the important elements in the dynamic wireless power transfer system from the viewpoint of the cruising range. The downsizing can be realized with applying the MHz band. Considering this point, we have decided to develop the capacitive power transfer method on the 13.56 MHz band in this research from the viewpoint of downsizing & weight-reduction, reduction of inductive heating of metal bodies and less installation number of high-frequency power source units. It is necessary to demonstrate first of all that the wireless power transfer of 10 kW class becomes realistic in order to apply the capacitive power transfer theory to the dynamic wireless power transfer system. Accordingly, we have started working on the development of a higher power coupler at first among the elements composing the system.

4. THE DEVELOPMENT OF THE CAPACITIVE POWER TRANSFER TYPE COUPLER FOR HIGH POWER TRANSFER

4.1 The Structure of a Coupler

The structure of a coupler under the development is shown in Figure 4. It is composed of electrode plates and coils for resonance, and each electrode is covered with a shield case and an insulating cover. The coupler is constructed to resonate at 13.56 MHz in accordance with the characteristics of the electrode and the coil.

4.2 Measures Against Heat Generation of a Coil

We already worked on the development of a higher power coupler and achieved the power transfer of 4.7 kW in 2020[5]. At that time, we found that the measures against the heat generation of coils was necessary when aiming at the further higher power transfer, and we have reviewed and improved the structure of the coil.

Until today, we applied coils wound with round magnet wires but now we recently applied the edgewise coil wound with rectangular magnet wires shown in Figure 5.

This edgewise coil is excellent in the efficiency of heat radiation because of its flat shape. On the other hand, its inductance is not easy to change continuously because of its difficulty in processing. Therefore, it is difficult to control its characteristics to adjust its resonance frequency to 13.56 MHz with high accuracy. But we worked on the electrode structure of the coupler and designed it to resonate at 13.56 MHz in this development.

Table 2 Features of each method for the kHz band and the MHz band[3), 4)].

	The kHz band	The MHz band
Inductive power transfer method	- Many actual results in the power transfer of over kW - Standardization is ahead - Ferrite cores are required, large coils	- No ferrite cores are required, light weight by down-sized coils
Capacitive power transfer method	- Domestic regulation of radio wave was issued at the 400 kHz band as a department ordinance - Short transmission distance, large coupler	- Transmission distance is efficiently improved by improved Q value - Downsizing of a coupler

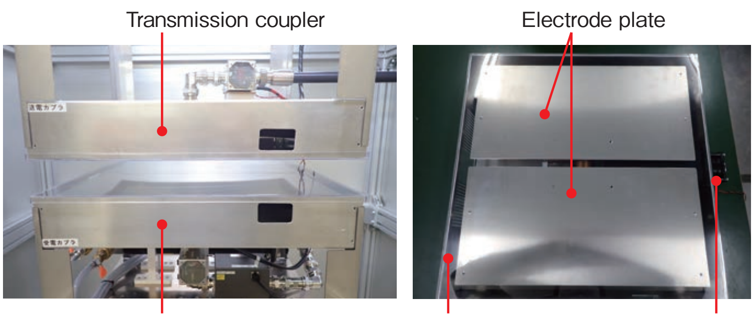

Figure 4 The structure of developed couplers. (Left: The transmitting & receiving coupler, Right: Shape of the transmitting coupler)

Figure 5 Edgewise coils.

4.3 Characteristics of the Coupler

We measured the transmission characteristic of the developed coupler by a network analyzer. The transmission characteristic of the developed coupler was optimized at 13.56 MHz when setting the distance between the transmitting coupler and the receiving coupler at 53 mm. The transmission characteristic and the reflection characteristic at the measurement are shown in Figure 6.

In Figure 6, S21 indicates the transmission characteristic and S11 and S22 indicate the reflection characteristic of the transmitting side and the receiving side respectively. The result of S21 has shown that the transmission efficiency at micro-signals of the coupler was 92.7%.

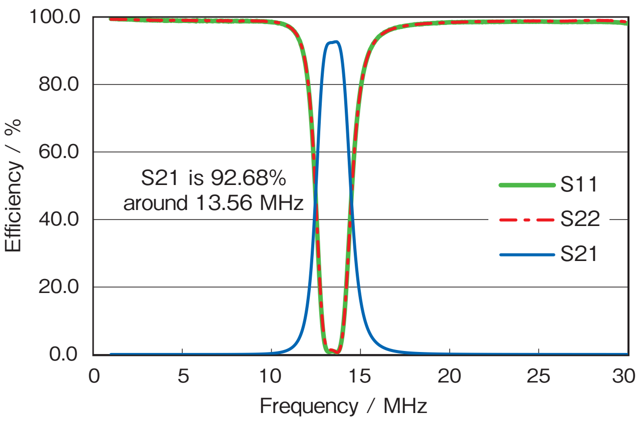

Figure 6 **Evaluation results of transmission characteristic and reflection characteristic.**

5. THE POWER TRANSFER TEST OF 10 kW CLASS

We have carried out the power transfer test of the coupler shown in Figure 4.

Here, the testing system is shown in Figure 7.

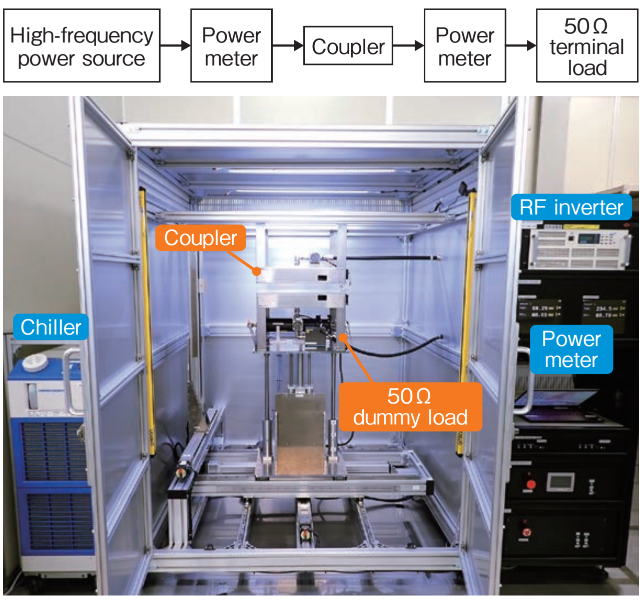

Figure 7 **10 kW class power transfer system.**

The result of the power transfer test up to 10 kW, which is the maximum transmitting power at 13.56 MHz measured in the 50Ω measuring system is shown in Figure 8.

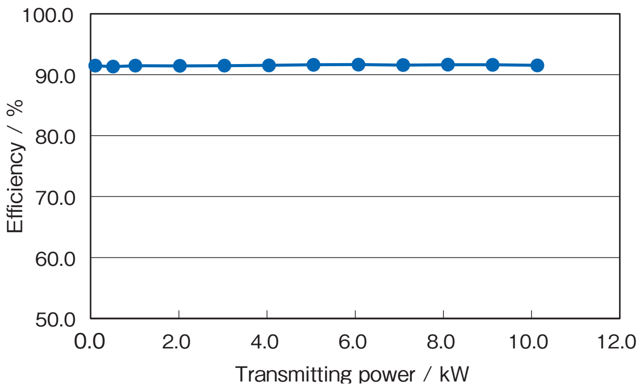

Figure 8 **The result of the power transfer test up to 10 kW transmitting power.**

According to the result shown in Figure 8, it is observed that the power transfer of the maximum power transfer 10.1 kW was achieved at 91.5% in efficiency.

6. CONTINUES POWER TRANSFER TEST

Next, applying the same testing system and the coupler as mentioned above, we carried out the 45-minute continuous power transfer test of the power transfer 10 kW class. The result is shown in Figure 9.

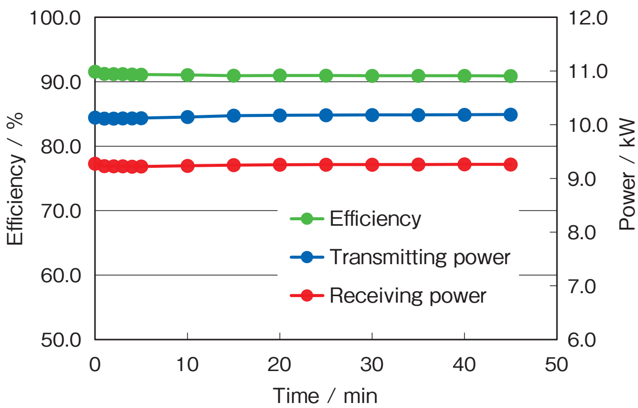

Figure 9 **The result of 45-minute continuous power transfer of 10 kW class.**

According to the result shown in Figure 9, it is observed that the power transfer was achieved at a power transfer as high as 10.1 kW. The transmission efficiency after 45 minutes duration was 90.8%.

7. CONCLUSION

We have been working on developing a higher power coupler for the 13.56 MH band capacitive power transfer system and validated the power transfer of 10 kW class. We have reviewed and improved the structure of the coupler and achieved the 45-minute continuous power transfer at as high as 90.8% in efficiency even under the condition with the insulation cover.

Presently, the power transfer through the coupler is carried out in an experimental system surrounded on all sides with metal plates. As our prospect for the near future, we will develop the mitigations against the leakage electromagnetic field and the radiation noise and not only examine the application on a vehicle body but also aim to demonstrate the power transfer of kW class to a moving body in order to apply our system to the dynamic wireless power transfer system.

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