A High Electric Power Supply to Electric Cars Using the Electric Field Resonance

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ABSTRACT In consideration of the electric field in the near region, we are conducting a study with the purpose of achievement of a wireless power transmission system using the electric field resonance. In this report, a comparison of the electric field coupling type and the magnetic field coupling type has been conducted and it was demonstrated by the equivalent circuit analysis that the series resonance structure in the electric field coupling type makes it possible to transmit the electric power with high efficiency even at a remote distance. Furthermore, we have mounted the system in a mobility car and have demonstrated that it is possible to transmit the power in the kW order.

1. INTRODUCTION

Currently, the researches on the wireless power transmission using the magnetic field coupling are active. This technology has been put to practical use in the electric home appliances such as in an electric toothbrush, in an electric shaver, etc. that are used around the water and a smart phone, etc. The magnetic field coupling type wireless power supply uses the frequencies around 100 kHz and the devices with improved power factor by adding a capacitance component to the inductance component of the power transmission and reception part have been produced and the commercialization is proceeding. Furthermore, in 2006, the technology named “Magnetic Field Resonance” was presented by the Massachusetts Institute of Technology in the United States of America[1), 2)], and the research on the wireless power transmission has been active. In the EV field, the standardization of the wireless power supply using the 85 kHz band is under way. In the electric circuit, the magnetic field and the electric field are closely related and what is made possible in the magnetic field is also made possible in the electric field. In the wireless electric power transmission using the electric field coupling, the researches of the high electric power supply from the electrode buried in the asphalt to the steel belt in the tire[3)] and the power supply to the multimedia transmission line[4)] are under way, but due to the constraint of the breakdown voltage in the air, etc., the number of the research example is fewer compared to the one of the magnetic coupling. In this report, while contrasting with the magnetic field coupling type, we analyze the fact that the electric power transmission is possible by using the electric field coupling even if the transmission and reception distance is long.

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2. THE WIRELESS POWER TRANSMISSION USING THE ELECTRIC FIELD COUPLING

As a coupler structure using the wireless electric power transmission by means of the electric field coupling, two types of systems, a Meander line shape with the tip of the power transmission coil opened[5)] and a flat plate electrode plate shape[6)] are being studied: In the Meander line shape, there is an advantage that a complete planar structure can be easily obtained. However, since the transmission line length is long, the loss is increased due to the influence of the skin effect at high frequencies similar to the magnetic field coupling type. On the other hand, in the system using the flat electrode, even if a skin effect occurs, the loss due to the high frequency is small because its surface area is large. In addition, it is possible to constitute an electrode surface material from an inexpensive metal material such as aluminum, etc. other than copper.

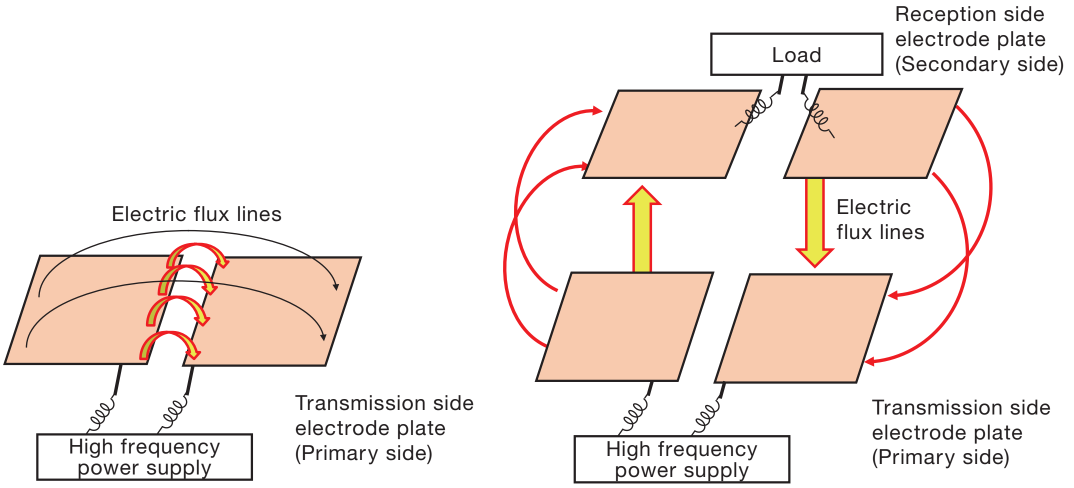
As a weak point of the electric field coupling type, there is a limitation of the power supply due to the breakdown voltage value. In addition, since the electric field is a divergent field, the leakage electric field around the coupler tends to be generated as a noise. On the other hand, in the magnetic field coupling type, this limitation exists in the withstand voltage of the resonance capacitor for improving the power factor and between the coil windings, but this restriction does not occur between the primary side transmission line and the secondary side transmission line.

3. THE STRUCTURE AND THE OPERATION OF THE ELECTRIC FIELD COUPLING TYPE WIRELESS POWER TRANSMISSION COUPLER

At first, we will explain the operation of the electric field coupling type wireless power transmission with a flat plate electrode structure. The circuit has a series resonance structure in which the resonance coil and the flat plate electrodes for transmitting and receiving the electric power are connected in series. When the high frequency power is applied to this circuit, the electric flux lines are generated. A high electric field is generated at the end where the electrode plates are close to each other and a lower electric field is generated at the separated portion (Figure 1 (a)). At this time, if the coupler having the same resonance frequency is brought close to it, this electric flux line faces the direction of the power transmission and reception (Fig. 1 (b)). This enables the power transmission between the transmission and reception electrodes. In addition, at this time, a curved electric flux line is generated by the fringe effect at the end of the coupler. This bent state of the electric flux lines generates a high electric field intensity region in the vicinity of the coupler. This characteristic gives a high degree of freedom to the positional characteristics between the transmission and reception electrodes, but also creates the coupling with the low electric potential objects. This measure will be described in Section 7.

4. THE COMPARISON OF THE EQUIVALENT CIRCUIT MODEL BETWEEN THE ELECTRIC FIELD COUPLING AND THE MAGNETIC FIELD COUPLING

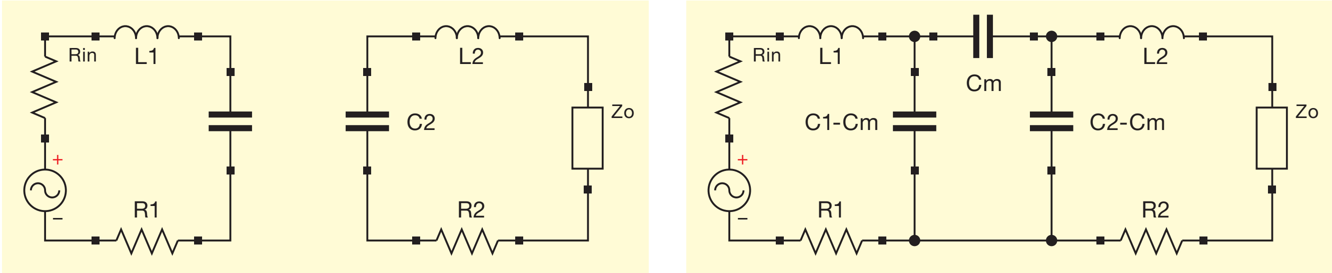
An equivalent circuit model of the electric field coupling type and of the magnetic field coupling type contactless power supply system are shown in Figure 2 and Figure 3. In the electric field coupling type, a π type equivalent circuit model is used from the configuration system and in the magnetic field coupling type, the T type equivalent circuit model is used. In the model shown, a matched load Z_0 is connected. R is the parasitic resistance such as in the capacitance, the internal resistance of the coil, the wiring, etc. Therefore, the capacitance and the inductance on the model can be treated as an ideal element without the loss.



(a) The electric flux lines at the time when the coupler is alone

(b) The state where the transmission coupler and the reception coupler face each other.

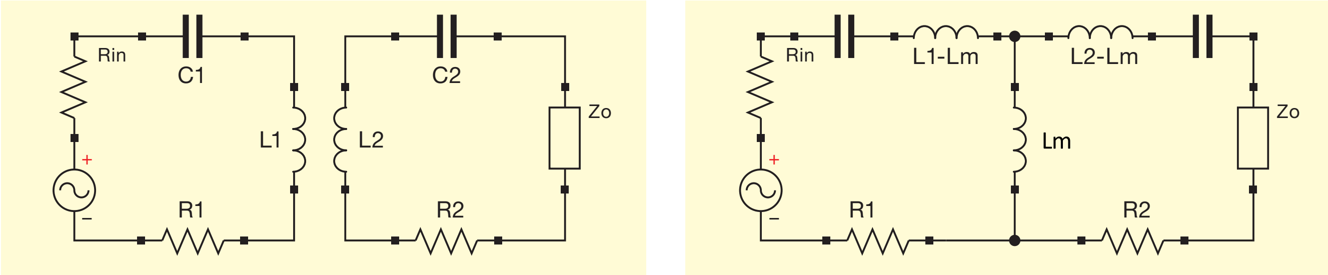
Figure 1 The image of the power transmission using the electric field resonance.



(a) Schematic model

(b) Model for the circuit analysis

Figure 2 The model for the electric field coupling type equivalent circuit.



(a) Schematic model (b) Model for the circuit analysis

Figure 3 **The model for the magnetic field coupling type equivalent circuit.**

5. THE ANALYSIS ON THE ELECTRIC FIELD COUPLING TYPE AND THE MAGNETIC FIELD COUPLING TYPE NON-CONTACT POWER SUPPLY

5.1 The Analytical Equation for the Electric Field Coupling Type

The analysis is started by transforming Figure 2 of the electric field coupling type equivalent circuit model into that of Figure 4. We analyze under the assumption that the loaded end is a short circuit.

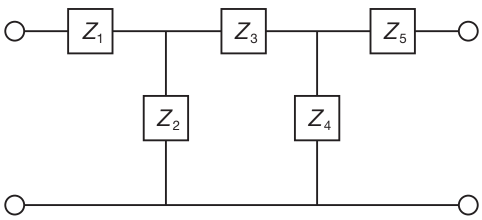


Figure 4 **The model for the electric field type analysis.**

The impedance seen from the power supply is expressed by the equation (1) and if transformed, it becomes the equation (2).

$$Z = Z_1 + \frac{1}{Z_2^{-1} + \dfrac{1}{Z_3 + \left(Z_4^{-1} + Z_5^{-1}\right)}} \tag{1}$$

$$Z = Z_1 + \frac{Z_2\left(Z_3Z_4 + Z_4Z_5 + Z_5Z_3\right)}{Z_3Z_4 + Z_4Z_5 + Z_5Z_3 + Z_2Z_4 + Z_2Z_5} \tag{2}$$

Since the equivalent circuit model is a symmetric system, the equation (2) becomes the equation (3) if $Z_1 = Z_5$ and $Z_2 = Z_4$.

$$Z = Z_1 + \frac{Z_2\left(Z_1Z_2 + Z_2Z_3 + Z_3Z_1\right)}{2Z_1Z_2 + Z_2Z_3 + Z_3Z_1 + Z_2^{\,2}} \tag{3}$$

5.2 The Analysis Equation for the Magnetic Field Coupling Type

Also, as for the magnetic field coupling type, Figure 3 of the equivalent circuit model is transformed as shown in Figure 5 and the impedance seen from the power supply becomes the equation (4) and can be transformed into the equation (5).

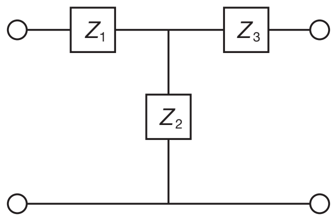


Figure 5 **The model for the magnetic field coupling type equivalent circuit analysis.**

$$Z = Z_1 + \frac{1}{Z_2^{\,-1} + Z_3^{\,-1}} \tag{4}$$

$$Z = Z_1 + \frac{Z_2Z_3}{Z_2 + Z_3} \tag{5}$$

Similar to the electric field coupling type, the equivalent circuit model is a symmetrical system and since $Z_1 = Z_3$, it becomes the equation (6).

$$Z = Z_1\left(1 + \frac{Z_2}{Z_1 + Z_2}\right) \tag{6}$$

5.3 The Analysis in the Ideal State

We analyze in an ideal state where the circuit configuration element, the internal resistance and the load of the power supply are 0 Ω.

5.3.1 The theoretical equation for the electric field coupling type

Using the equation (3), input

$Z_1 = j\omega L$, $Z_2 = 1 / j\omega(C - C_m)$, $Z_3 = 1 / j\omega C_m$

The equation (7) is obtained.

$$Z = \mathrm{j}\,\frac{\omega^4 L^2\left(C^2 - C_m^{\ 2}\right) - \omega^2 2LC + 1}{\omega^2 L\left(C^2 - C_m^{\ 2}\right) - \omega C} \tag{7}$$

Since the resonance mode appears at each frequency where the imaginary part becomes zero, only the numerator of the equation (7) is taken out,

$$\omega^4 L^2\left(C^2 - C_m^{\ 2}\right) - \omega^2 2LC + 1 = 0 \tag{8}$$

and solve this equation (8). Therefore, the solution is

$$\omega_{1,2} = 1 \Big/ \sqrt{LC\left(1 \pm k_e\right)} \tag{9}$$

Here, $k_e = C / C_m$ (coupling coefficient).

5.3.2 The theoretical equation for the magnetic coupling type

Using the equation (6), input $Z_1 = \mathrm{j}\omega\,(L - L_m) + 1 / \mathrm{j}\omega C$, $Z_2 = \mathrm{j}\omega L_m$. The equation (10) is obtained.

$$Z = \frac{\left\{1 - \omega^2\left(L + L_m\right)C\right\}\left\{1 - \omega^2\left(L - L_m\right)C\right\}}{j\omega C\left(1 - \omega^2 LC\right)} \tag{10}$$

Since the resonance mode appears at each frequency where the imaginary part becomes zero, only the numerator of the equation (10) is taken out,

$$\left\{1 - \omega^2\left(L + L_m\right)C\right\}\left\{1 - \omega^2\left(L - L_m\right)C\right\} = 0 \tag{11}$$

and solve this equation (11). Therefore, the solution is

$$\omega_{1,2} = 1 \Big/ \sqrt{LC\left(1 \pm k_m\right)} \tag{12}$$

Here, $k_m = L / L_m$ (coupling coefficient)

5.4 The Analysis Including the Loss Term

In the actual experiment system, it is necessary to consider the impedance, the internal resistance and the load of the power supply. Here, we perform the analysis including such a loss term.

5.4.1 The analysis equation for the electric field coupling type

Using the equation (3), input $Z_1 = R + \mathrm{j}\omega L$, $Z_2 = 1 / \mathrm{j}\omega(C - C_m)$, $Z_3 = 1 / \mathrm{j}\omega C_m$ and proceed with the analysis. The real part is shown in the equation (13) and the imaginary part is shown in the equation (14).

Here, R is assumed to include all loss terms included in the actual equipment.

$$\mathrm{Re}\left[Z\right] = R + \frac{\dfrac{K_3}{\omega^2\left(C - C_m\right)^2} R}{\left(RK_1\right)^2 + \left(\omega L K_1 - \dfrac{K_2}{\omega\left(C - C_m\right)}\right)^2} \tag{13}$$

$$\mathrm{Im}\left[Z\right] = \omega L + \frac{\dfrac{R^2 K_1 K_2}{\omega\left(C - C_m\right)}}{\left(RK_1\right)^2 + \left(\omega L K_1 - \dfrac{K_2}{\omega\left(C - C_m\right)}\right)^2} + \frac{\left\{\dfrac{LK_2}{C - C_m} - \dfrac{1}{\omega^2\left(C - C_m\right)^2}\right\}\left\{\omega L K_1 - \dfrac{K_2}{\omega\left(C - C_m\right)}\right\}}{\left(RK_1\right)^2 + \left(\omega L K_1 - \dfrac{K_2}{\omega\left(C - C_m\right)}\right)^2} \tag{14}$$

Here, $K_1 = (C + C_m) / (C - C_m)$, $K_2 = C / (C - C_m)$, $K_3 = C_m / (C - C_m)$

Since the resonance mode appears at each frequency where the imaginary part becomes zero, it becomes the equation (15) if only the numerator of the equation (14) is taken out.

$$\omega^6 + \alpha\omega^4 + \beta\omega^2 + \gamma = 0 \tag{15}$$

Here, α, β and γ are as follows.

$$\alpha = \frac{\left(C - C_m\right) R^2 K_1 - 3LK_2}{L^2\left(C - C_m\right) L K_1}$$

$$\beta = \frac{2LK_2^{\ 2} + LK_1 - \left(C - C_m\right) R^2 K_1 K_2}{L^3\left(C - C_m\right)^2 K_1^{\ 2}}$$

$$\gamma = -\frac{K_2}{L^3\left(C - C_m\right)^3 K_1^{\ 2}}$$

By factorizing the equation (15), the equation (16) is obtained.

$$\left\{1 - \omega^2 LC\left(1 + k_e\right)\left(1 - k_e\right)\right\}\left[\omega^4 - \frac{1}{\left(1 + k_e\right)\left(1 - k_e\right)}\left\{\frac{2}{LC} - \frac{R^2}{L^2}\left(1 + k_e\right)\left(1 - k_e\right)\right\}\omega^2 + \frac{1}{L^2 C^2\left(1 + k_e\right)\left(1 - k_e\right)}\right] = 0 \tag{16}$$

From the equation (16), the solution is as follows.

$$\omega_0 = 1 \Big/ \sqrt{LC\left(1 + k_e\right)\left(1 - k_e\right)}$$

$$\omega_{1,2} = \sqrt{\frac{1}{\left(1 + k_e\right)\left(1 - k_e\right)}\left\{\frac{1}{LC} - \frac{R^2}{2L^2}\left(1 + k_e\right)\left(1 - k_e\right)\right\}\left(1 \pm \sqrt{1 - \kappa_e}\right)}$$

Here, K_e becomes as follows.

$$\kappa_e = \frac{\left(1 + k_e\right)\left(1 - k_e\right)}{1 + \dfrac{CR^2}{L}\left(\dfrac{CR^2}{4L} - 1\right)\left(1 + k_e\right)\left(1 - k_e\right)}$$

5.4.2 The analysis equation for the magnetic field coupling type

Using the equation (6), input $Z_1 = R + j\omega L + 1 / j\omega C$, $Z_2 = j\omega L_m$ and proceed with the analysis. The real part is shown in the equation (17) and the imaginary part is shown in the equation (18).

Here, R includes all loss terms included in the actual machine

$$\mathrm{Re}\left[Z\right]=R+\frac{\omega^2 L_m CR}{\left(1-\omega^2 LC\right)^2+\left(\omega CR\right)^2} \tag{17}$$

$$\mathrm{Im}\left[Z\right]=-\frac{1-\omega^2\left(L-L_m\right)C}{\omega C}\times\left(1-\frac{\omega^2 L_m C\left(1-\omega^2 LC\right)}{\left(1-\omega^2 LC\right)^2+\left(\omega CR\right)^2}\right)+\frac{\omega^3 L_m C^2 R}{\left(1-\omega^2 LC\right)^2+\left(\omega CR\right)^2} \tag{18}$$

In the resonance mode, since it appears at each frequency where the imaginary part becomes zero, it becomes the equation (19) if only the numerator of the equation (18) is taken out and factorized. .

$$\left(1-\omega^2 LC\right)\left\{\omega^4-\frac{1}{(1+k_m)(1-k_m)}\left(\frac{2}{LC}-\frac{R^2}{L^2}\right)\omega^2+\frac{1}{L^2C^2(1+k_m)(1-k_m)}\right\}=0 \tag{19}$$

From the equation (16), the solution is as follows.

$$\omega_0=1/\sqrt{LC}$$

$$\omega_{1,2}=\sqrt{\frac{1}{(1+k_m)(1-k_m)}\left\{\frac{1}{LC}-\frac{R^2}{2L^2}\right\}\left(1\pm\sqrt{1-\kappa_m}\right)}$$

Here, K_m becomes as follows.

$$\kappa_m=\frac{(1+k_m)(1-k_m)}{1+\frac{CR^2}{L}\left(\frac{CR^2}{4L}-1\right)}$$

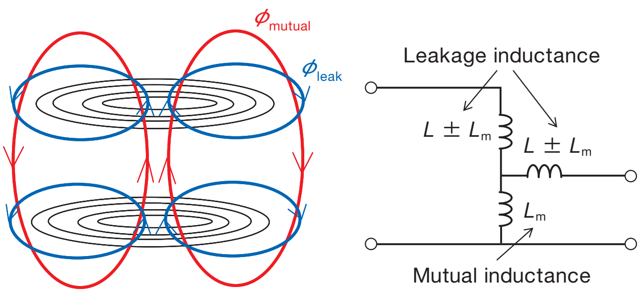
5.5 The Consideration of the Analysis Equation

The analysis of the electric field coupling type and the magnetic field coupling type including the ideal state and the loss term is carried out in the equivalent circuit model used for analyzing the wireless power transmission system so that in the ideal state, the frequency split that depends on the coupling coefficient as the center of the resonance frequency $\omega_0 = 1 / \sqrt{LC}$ could be derived by the mathematical equation for both types. In addition, If the loss term is included, there is a difference between the electric field coupling type and the magnetic field coupling type and as far as the resonance frequency ω_0, it does not change from the ideal state in the magnetic field coupling type, but it is understood that the coupling coefficient contributes to the electric field coupling type. It is considered that this is due to the fact that the mutual capacitors contribute serially from the equivalent circuit model. For this reason, in the electric field coupling type, the Q value can be increased by the series resonance structure and the distance between the power transmission and reception electrodes can be increased with high efficiency, but a matching circuit on the power transmission side and the power reception side is needed because of the influences of the output impedance of the power supply and load impedance.

6. THE CIRCUIT CONFIGURATION METHOD IN THE ELECTRIC FIELD RESONANCE AND THE MAGNETIC FIELD RESONANCEC

6.1 The Interpretation of the Coupling With the Magnetic Field

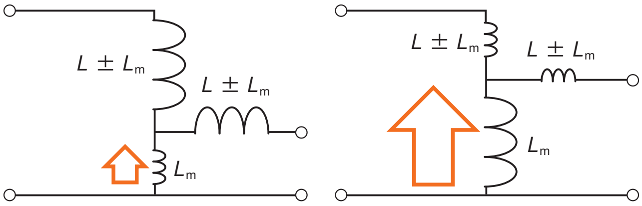
Taking a transformer as an example, there are two coils and a magnetic flux is generated by the currents flowing in them. Focusing on one coil, the magnetic flux generated by the coil itself is divided into a magnetic flux penetrating only the coil itself and a magnetic flux penetrating the other coil at the same time (Figure 6 (a)). The former corresponds to the leakage inductance and the latter is called the mutual inductance. At this time, since the total amount of the magnetic flux generated by the coil does not change, the sum of the aforementioned inductances is equal to the self-inductance of the coil itself.



(a) Magnetic flux flow (b) equivalent circuit

Figure 6 The coupling with the magnetic field.

If ignoring the loss in the equivalent circuit of the transformer, the magnetic field resonance is represented by a T type equivalent circuit. (Figure 6 (b)). The voltage transmission rate from the primary side to the secondary side varies depending on the magnitude of the coupling. If the coupling is small, the voltage drop at the leakage inductance is large and the voltage applied to the mutual inductance becomes small, so that the secondary side voltage cannot be picked up (Figure 7 (a)). If the coupling is large, the voltage drop due to the leakage inductance is small and the most of the power supply voltage is applied to the mutual inductance so that the voltage can be picked up on the secondary side (Figure 7 (b)). As described above, the ratio of the voltage applied to the leakage inductance and the mutual inductance is determined by the magnitude of the coupling and the voltage generated on the secondary side varies. In other words, it is important to find how to reduce the leakage inductance and raise the ratio of the voltage applied to the mutual inductance for the wireless power transmission.

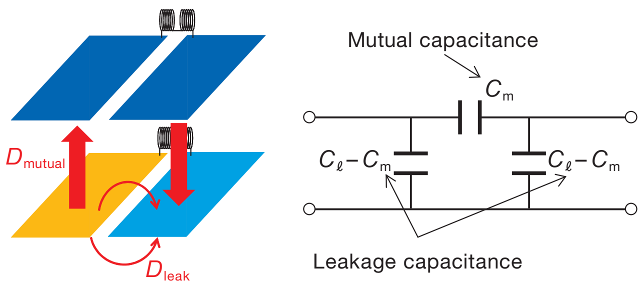


(a) If the coupling is small (b) If the coupling is large

Figure 7 The image diagram for the equivalent circuit based on the magnitude of the coupling (the magnetic field resonance).

6.2 The Interpretation of the Coupling With the Electric Field

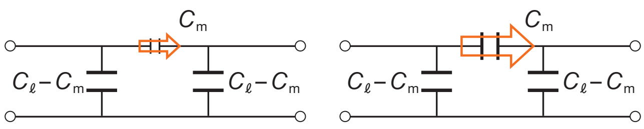
We introduce the electric flux in consideration of the electric field coupling. The electric flux is proportional to the amount of the charge accumulated on the electrode plate. In the case of the electric field, an attention is required since it is the divergent field rather than the rotating field like the magnetic field. If there are two pairs of the electrodes that are positively charged and negatively charged, the electric flux terminates between the two electrodes and a potential difference based on either one can be defined and a proportional constant capacitance can be defined between the charge amounts accumulated between the electrodes and the potential difference. If there are two pairs of electrodes as well as the case of the magnetic field coupling, it can be divided into the electric flux that terminates between a pair of electrodes and the electric flux that terminates via another set of electrodes (Figure 8 (a)). If assigning the term with the electric field, the former is the leakage capacitance and the latter is the mutual capacitance. The electric flux generated from the accumulated charge is constant.



(a) The direction of the electric field. (b) The equivalent circuit.

Figure 8 The coupling with the electric field and the equivalent circuit.

The equivalent circuit of the electric field resonance can be represented by a π type equivalent circuit (Figure 8 (b)). If the degree of the coupling is small, the leakage capacitance is large and the mutual capacitance is small. So the voltage drop increases and the voltage on the secondary side cannot be picked up (Figure 9 (a)). If the coupling is large, the leakage capacitance is small and the mutual capacitance is large. So a voltage can be taken on the secondary side (Figure 9 (b)).



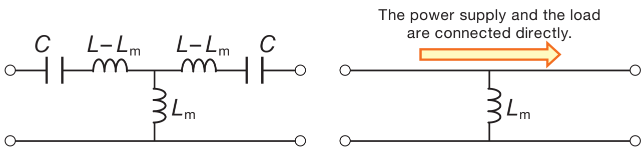
(a) If the coupling is small. (b) If the coupling is large.

Figure 9 The image diagram for the equivalent circuit based on the magnitude of the coupling (the electric field resonance).

6.3 The Interpretation in the Resonance Circuit Configuration

6.3.1 The series resonance type of the magnetic resonance system

The series resonance circuit in the magnetic field resonance coupling has a circuit configuration in which the resonance capacitance is connected in series in order to cancel the voltage drop caused by the leakage inductance (Figure. 10 (a)). It is also called S-S system. Although the leakage inductance is present in this configuration, the leakage inductance is canceled in terms of circuit. Therefore, if the resonance condition is satisfied, the power supply voltage is equally connected to the load as it is and the voltage can be transmitted to the secondary side with high efficiency (Figure 10 (b)).

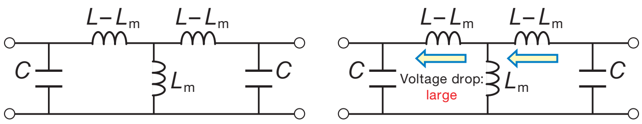


(a) The equivalent circuit for configuration circuit. (b) The equivalent circuit at resonance.

Figure 10 The equivalent circuit for the series resonance type of the magnetic field resonance system.

6.3.2 The parallel resonance type of the magnetic resonance system

The parallel resonance circuit in the magnetic field resonance connects the resonance capacitance to the transmission and reception coil in parallel (Figure 11 (a)). It is noted that in the case of this resonance type, since the resonance capacitance does not work so as to cancel the leakage inductance, the voltage which can be transmitted to the secondary side is basically lowered due to the voltage drop of the leakage inductance part similar to the electromagnetic induction (Figure 11 (b)). However, since the Q value multiplied current flows, the power input to the transformer can be increased by the Q value. Therefore, there is a possibility that the voltage drop due to the leakage inductance can be compensated by increasing the number of the windings for the secondary side.

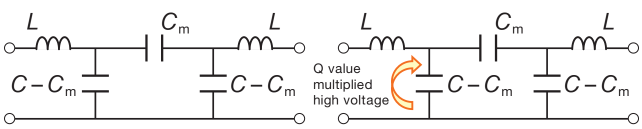


(a) The equivalent circuit of the configuration circuit. (b) The equivalent circuit at the resonance.

Figure 11 The equivalent circuit for the parallel resonance type of the magnetic field resonance system.

6.3.3 The series resonance coupling type of the electric field resonance system.

In the electric field resonance type of the series resonance system, the resonance inductance is connected to the electrode in series (Figure 12 (a)). This resonance inductance generates the Q value multiplied voltage of the power supply voltage at both ends of the leakage capacitance by resonating with the leakage capacitance. For this reason, even if the voltage drops because the mutual capacitance is large, the electric power can be transmitted to the secondary side (Figure 12 (b)). Therefore, it is considered that electric power can be transmitted even if the power transmission distance is large. We are researching and developing this series resonance type of the electric field resonance system.



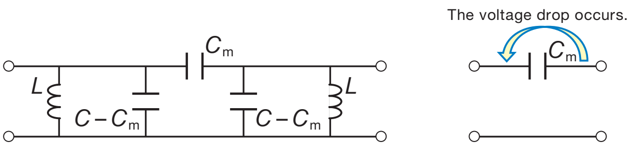
(a) The equivalent circuit of the configuration circuit. (b) The equivalent circuit at the resonance.

Figure 12 The equivalent circuit for the parallel resonance type of the electric field resonance system.

6.3.4 The parallel resonance type of the electric field resonance system

In the parallel resonance type of the electric field resonance system, the resonance inductance is connected to the electrode in parallel (Figure 13 (a)). This resonance inductance can cancel the leakage capacitance component by the resonance. Since the impedance at the parallel resonance can be considered as open, the equivalent circuit at the resonance is only the mutual capacitance (Figure 13 (b)). Even at the resonance, the voltage drop corresponding to the mutual capacitance becomes a loss, so that the transmission distance cannot be increased and the transmission distance becomes short.

In the resonance coupling system of the magnetic field and the electric field, the parallel resonance type is the same as the electromagnetic induction in the case of the magnetic field resonance but since the Q value multiplied current is flowing, the voltage which can be transmitted to the secondary side can be increased by increasing the number of windings. In the case of the electric field resonance type, it is possible to increase the transmission voltage on the secondary side by increasing the mutual capacitance and decreasing the voltage drop by interposing a dielectric material.



(a) The equivalent circuit of the configuration circuit. (b) The equivalent circuit at the resonance.

Figure 13 The equivalent circuit for the parallel resonance type of the electric field resonance system.

From the viewpoint of the circuit theory, the electric field resonance system corresponding to the series magnetic field resonance system is parallel type. Unlike the serial magnetic field resonance system, the mutual capacitance remains between the power supply and the load in the parallel type electric field resonance system. Therefore, in the view of the conventional electric field resonance system, it has been considered that it can be used only in a short distance. However, by applying the series type, the electric power can be practically transmitted over a long distance, even with the electric field resonance system because the electric field resonance coupler can be driven with the Q value multiplied power supply voltage. This can similarly be said for the parallel type magnetic field resonance, but in the case of the magnetic field resonance, since the current is multiplied by the Q value, it is considered that the advantage is stronger when the power is transmitted mainly by the current, not by increasing the number of windings of the coil or by increasing the voltage.

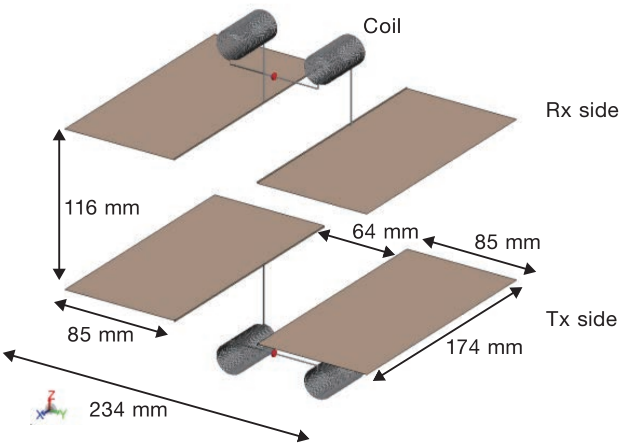
7. THE MEASURES TO REDUCE THE PERIPHERAL ELECTRIC FIELD OF THE ELECTRIC FIELD RESONANCE COUPLER

Electric flux lines in a bent state are generated due to the fringe effect generated at the end of the electric field resonance coupler and a high electric field intensity region is generated in the vicinity of the coupler. As a countermeasure against this, we studied a structure that suppresses the unnecessary coupling by installing a coupler in a metal case where the power transmission surface is open. Figure 14 and 15 show the characteristics of the electric field near the coupler analyzed by the electromagnetic field simulation (moment method) when the power is applied the level of 1 kW and the couplers with the same configuration are opposed for the power transmission and reception. Figure 14 is a diagram showing the X axis in the power transmission direction, the Y axis in the direction parallel to the electric field vector and the Z axis in the power transmission and reception direction if the circumference of the coupler is free space. Figure 15 shows the characteristics if a metal case is provided for this coupler. An attenuation in the Y axis and the Z axis can be confirmed by installing the metal case. In this case, since the distance between the power transmission surface and the shield plate is required to be about the same as the power supply distance, thinning this equipment is a future subject.

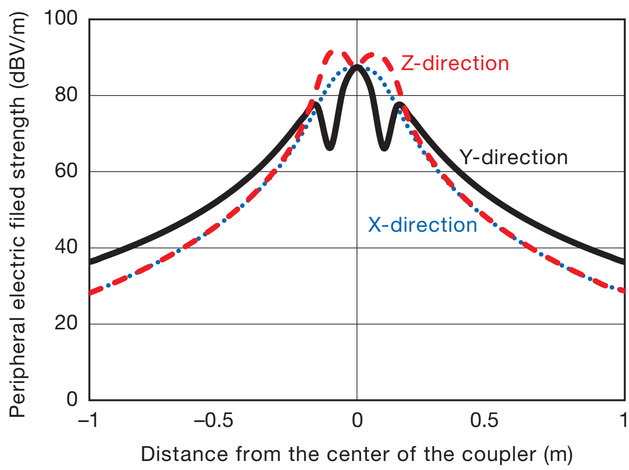
8. THE DEPLOYMENT IN THE MOBILITY CAR

We have developed a system that provides the wireless power transmission by mounting the electric power resonance type coupler with the series resonance structure in a mobility car. Figure 16 shows a demonstration equipment of an electric field resonance coupler with a shield box mounted in a mobility car.

In the coupler configuration, two electrodes are provided on the insulating plate and the resonance coil is connected to them. The electrode size is 458 mm × 220 mm and 2 electrode plates are set 18 mm apart. The material of the electrode plate is an Aluminum plate of A1100 and is placed in a shield case of 480 mm × 480 mm × 86 mm. The impedance of the transmission and reception coupler is 50 Ω and the power supply distance showing the maximum efficiency is 70 mm. The coupler is capable of the wireless power transmission of up to 1 kW in a natural air cooling condition.

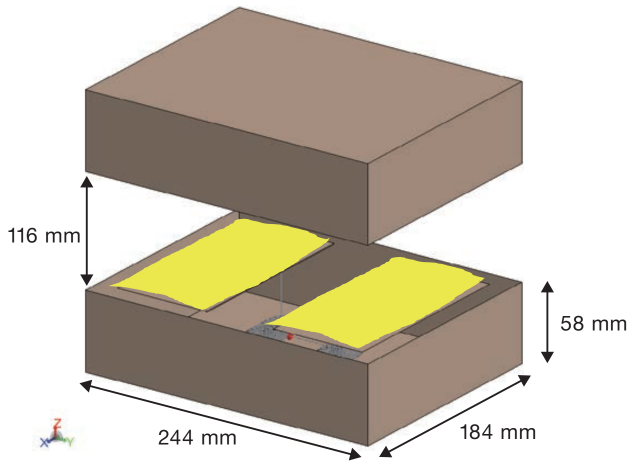


(a) The model with the coupler alone

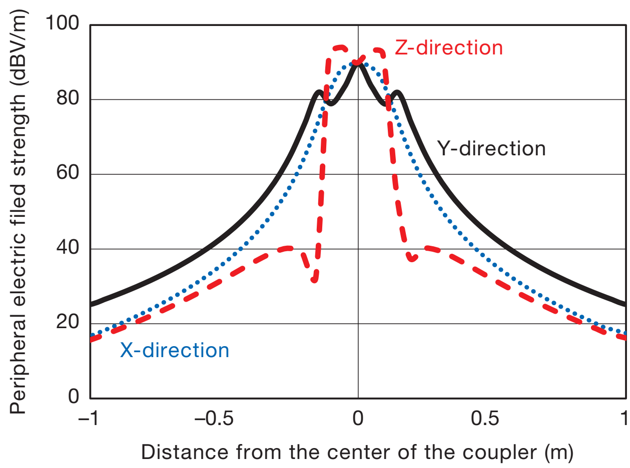


(b) The peripheral electric field strength

Figure 14 The peripheral electric field strength of the electric field resonance coupler.



(a) Schematic model



(b) The peripheral electric field strength

Figure 15 The peripheral electric field strength of the electric field resonance coupler with a shield box.

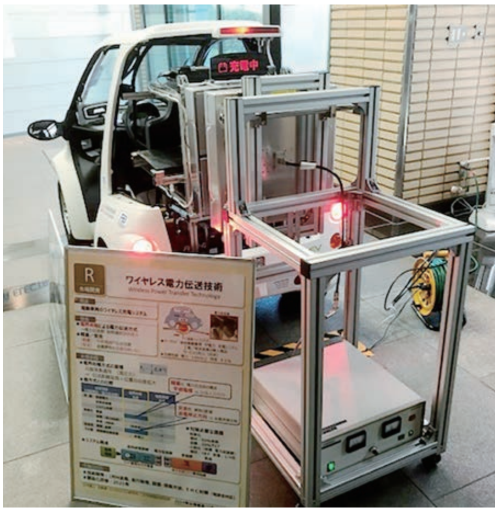


Figure 16 **The electric field resonance coupler with a shield box mounted in a mobility car.**

9. CONCLUSION

We compared and considered the electric field coupling type and the magnetic field coupling type for the wireless power transmission and demonstrated that even the electric field coupling type can transmit the power at a remote distance by using the series resonance structure. This technology was mounted in a mobility car and verified that even the electric field resonance type can transmit the power in kW order.

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