Low Frequency Electromagnetic Field Reduction Techniques for the On-Line Electric Vehicle (OLEV)

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Abstract— **In this paper, we introduce the On-line Electric Vehicle (OLEV) system and its non-contact power transfer mechanism and propose some techniques for the reduction of electromagnetic fields (EMFs) from the power line and the vehicle itself. By applying a metallic plate shield, horizontal/vertical shield, and connecting wire for loop cancellation, the low frequency EMFs have been significantly reduced. Simulation and measurement results for application to vehicles currently in service are also given.**

I. Introduction

One of the biggest issues around the world in recent years is environmental problems. Every country tries to adopt green technologies which offer the potential to improve the air quality in currently polluted environment and which will save money by reducing fossil fuel consumption. As the use of electric cars is expected to significantly reduce the aforementioned problems of air pollution and fossil fuel consumption costs, numerous studies on electric vehicles have been performed over a long period of time and numerous hybrid vehicles are currently sold by several vehicle manufacturers worldwide.

However, there is no shortage of hot topics on electric vehicles: limitations of battery size and power, issue of battery weight, battery life, battery recharge time, and the availability of charging points. Moreover, there is also a resource issue for electric vehicles. As more vehicles become reliant upon batteries as power sources, availability of the compounds and metals used to make batteries may become increasingly scarce. Dwindling stocks of substances such as lithium could trigger increasingly high prices and lead to electric vehicles pricing themselves out of the automotive marketplace.

The On-line Electric Vehicle (OLEV) developed by KAIST is an electric transport system in which the vehicles absorb their power from power lines underneath the surface of the road. Even though the basic concept was invented in 1970's [1], the circuit system and power transfer system are totally different. Rather than relying on battery technology, OLEV picks up a charge using a non-contact magnetic charging method in which a power source is placed underneath the road surface and power is wirelessly picked up by the vehicle itself.

The power supply system of OLEV generates a large amount of magnetic flux to transfer 100kW of power, which are necessary for the vehicle. The power rail is designed to generate the magnetic flux with a frequency of 20 kHz to the direction of the pickup module on the vehicle. However, there could be some leakage of magnetic flux, and the amount of leakage can exceed the limit of magnetic flux regulations. A great deal of research has been performed on the shielding of the low frequency and high power electromagnetic fields (EMFs) [2],[3],[4]. However, research on electromagnetic fields from an electric vehicle which is powered by the magnetic flux of the rail has not performed yet.

In this paper, we introduce the On-line Electric Vehicle (OLEV) system and its non-contact power transfer mechanism and propose some techniques for the reduction of electromagnetic fields (EMFs) from the power line and vehicle. By applying a metallic plate shield, horizontal/vertical shield, and connecting wire for loop cancellation, the low frequency EMF has significantly reduced. Simulation and measurement results for application to vehicles currently in service are also given.

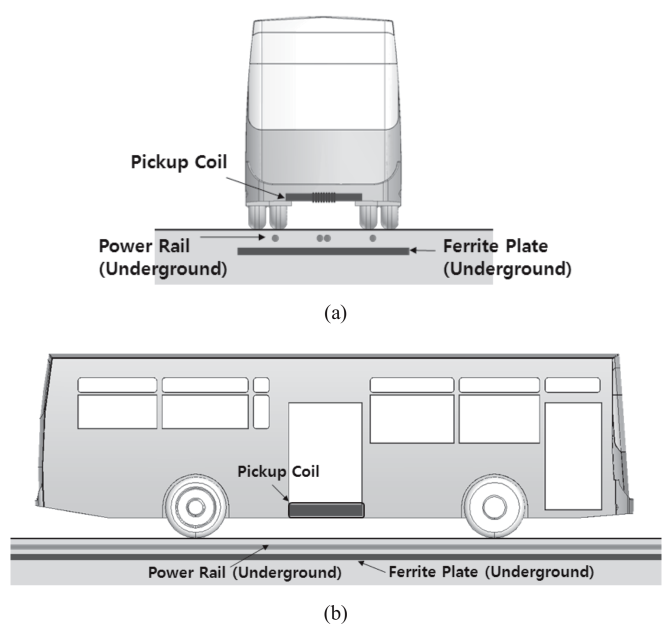


Fig. 1. The On-line Electric Vehicle (OLEV) and power transfer system using power lines placed underneath the road surface for non-contact charging: (a) Side view and (b) front view.

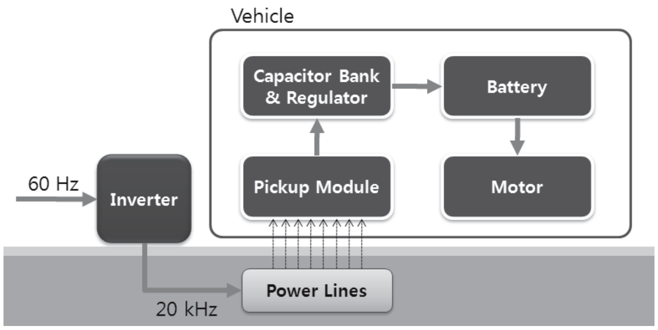


Fig. 2. The overall power transfer system for OLEV. 100 kW of power is transferred from the power lines to the pickup module without contact.

II. Power Transfer System

The power transfer system consists of an inverter, power lines, pickup module, capacitors, battery, and motor, as shown in Fig. 2. 60 Hz of power is converted to 20 kHz at the inverter stage and a current of around 200A flows through the power lines. The magnetic flux generated from the power lines is gathered at the pickup module to generate DC power for the motor of the vehicle. The non-contact power transfer occurs between power lines and the pickup module generating huge magnetic flux. The design of power lines and the pickup module are the key technologies for effective power transfer and solution of the EMF problem. Generally, two types of power line / pickup module pairs are designed for non-contact power transfer according to the direction of the magnetic flux at the pickup module: vertical magnetic flux type and horizontal magnetic flux type.

A. Vertical Magnetic Flux Type

Fig. 3 shows the vertical magnetic flux type of power lines and pickup module. There are two power lines with opposite current directions underneath the road surface forming a current loop. Due to the current in the power lines, magnetic flux is induced around each power line. Between the power lines, the magnetic fluxes from the two power lines are added. The pickup module catches the vertical magnetic flux through copper coils around the ferrite core. This type has the advantage of efficient power transfer because the direction of the magnetic flux from the power lines is the same as the direction of the flux to the pickup module.

B. Horizontal Magnetic Flux Type

Fig. 4 shows the horizontal flux type of power lines and pickup module. In this type, there are four power lines forming two current loops. As two center conductors are placed close together, there are three magnetic flux loops. The copper coils around the horizontal ferrite core catches the horizontal magnetic flux to generate power for vehicles. This type has a disadvantage in that the power transfer is less efficient; however, because there are more power lines that have opposite current directions, the magnetic flux density levels cancel each other when seen from 1.7m from the road center, which is the observation point of EMF level measurement.

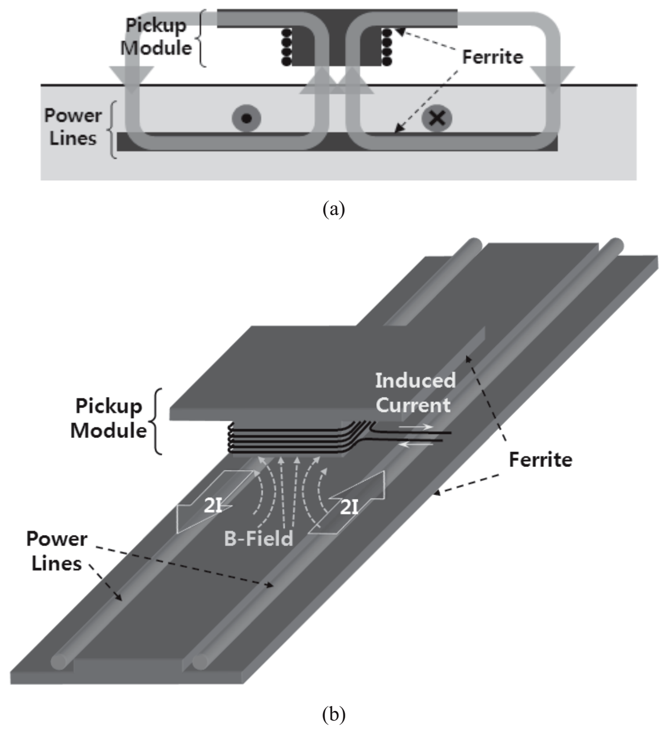


Fig. 3. Vertical magnetic flux type power lines and pickup module: (a) Cross-sectional view (b) Perspective view.

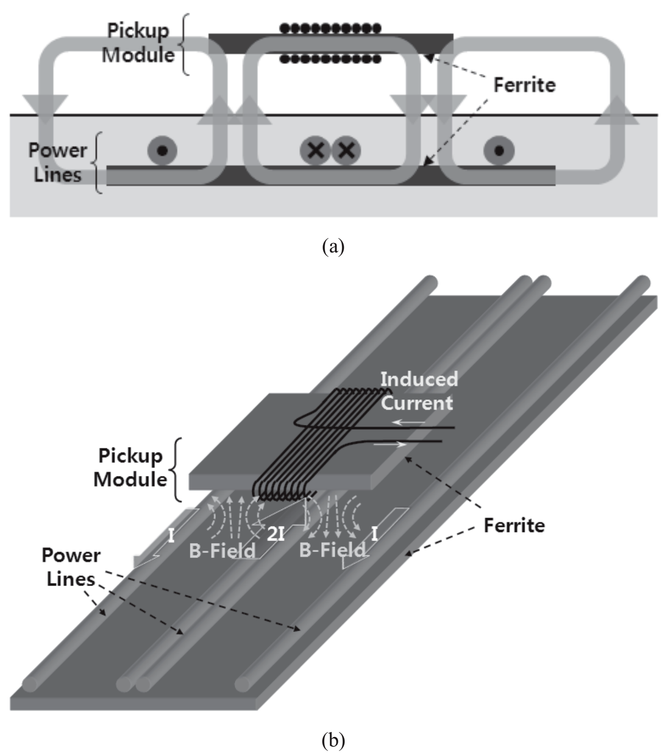
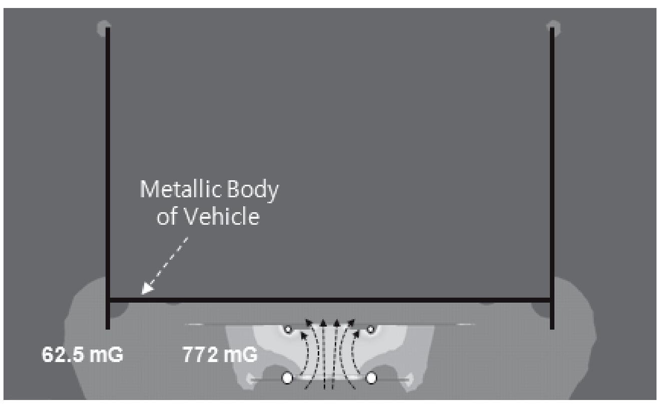


Fig. 4. Horizontal magnetic flux type power lines and pickup module: (a) Cross-sectional view (b) Perspective view.

III. Simulation for Magnetic Field Reduction

Fig. 5 shows the magnetic flux density distribution of OLEV. In the case of the vertical magnetic flux type, there is one magnetic flux path between the power lines and pickup module where the power is transferred. The return flux comes back to the power lines via the sides of the main flux path. The horizontal magnetic flux type has two magnetic flux paths. The side power lines of this type have return flux paths on the side of the main flux path. The return flux path creates the fringing magnetic flux, and this flux is measured as the EMF level of OLEV. In this work, the target EMF level of OLEV is 62.5 mG according to the Korea Communications Commission [5].

There are a number of well-known techniques to reduce radiated emissions from many studies [6]. However, one of the most popular methods for reducing radiated emission is shielding, and this method can be also applied to low frequency magnetic fields [7],[8],[9]. As OLEV uses a current source to generate a magnetic field and large currents are flowing in power lines and pickup coils, the EMF from OLEV consists more of magnetic flux than an electric field. In this case, high conductivity metal and highly permeability material can be used as a shield. For simplicity and cost effectiveness, we used aluminium for the shield.



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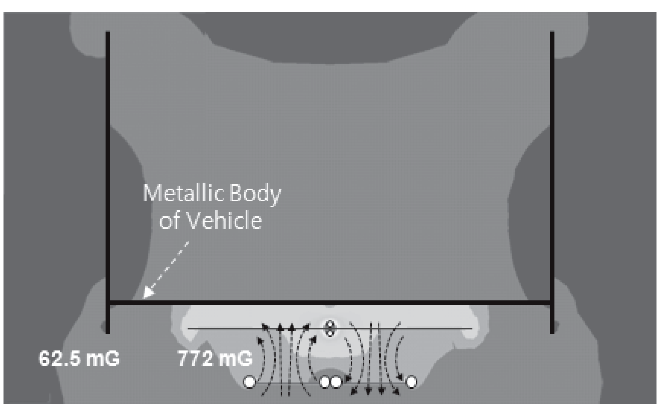

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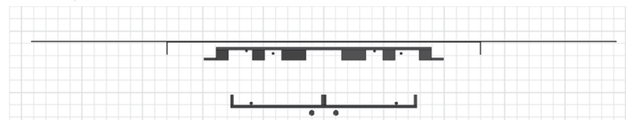
Fig. 5. Simulated magnetic flux density distribution for OLEV (a) Vertical magnetic flux type (b) Horizontal magnetic flux type.

A. Vertical Metal Plate Shield on Vehicle

As the vehicle should move on the road, there should be some space between the vehicle and the surface of the road. For this application, the space is 13 cm to allow the vehicle to move. If the vertical plate shield on the vehicle in Fig. 6 could be placed between vehicle bottom and the road surface, the EMF could be significantly reduced. Because of the space, however, the shield has limited length toward the road surface. Fig. 6 shows the effect of the vertical plate shield on the vehicle. When the vertical plate shield on the vehicle reaches the road shield, the EMF level could be reduced from 128 mG to 97 mG. Because of the required space between the vehicle and road surface, the vertical plate shield length also has a limit of length, and the EMF level is reduced from 128 mG to 121 mG.



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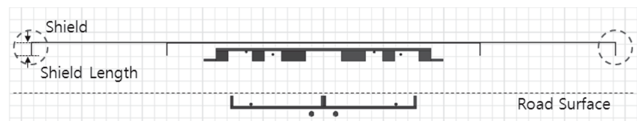

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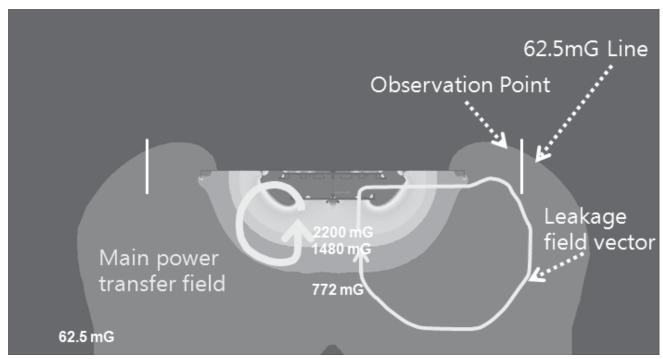

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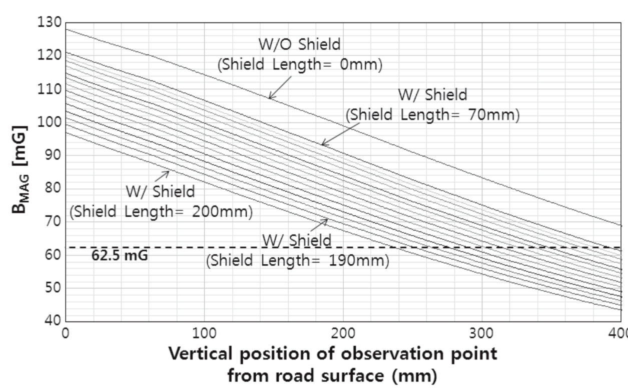
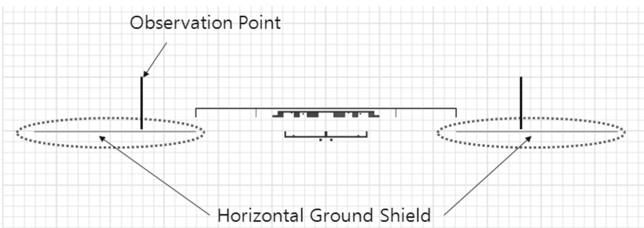


(d)

Fig. 6. Effect of metal plate shield on the vehicle: (a) Without a shield (b) With a shield (c) Magnetic flux density distribution (d) Effect of the metal vertical plate shield on the vehicle.

B. Horizontal Ground Shield

The regulation of the EMF level is designed to protect the human body, so the shield can be placed on the sidewalk to reduce the EMF levels of the observation point. Fig. 7(a) shows the horizontal ground shield on the sidewalk. Fig. 7(b) shows the magnetic flux distribution when the horizontal ground shield is applied. The horizontal ground shield blocks the leakage of magnetic flux flowing to the observation point. Fig. 7(c) shows the EMF level under 2.05 mG, which is much less than the target. In this result, we should notice that the simulation assumes that the power lines and pickup module generate Bx and By components, and that there is no Bz component. In real conditions, if Bx and By components are shielded, Bz component is dominant.



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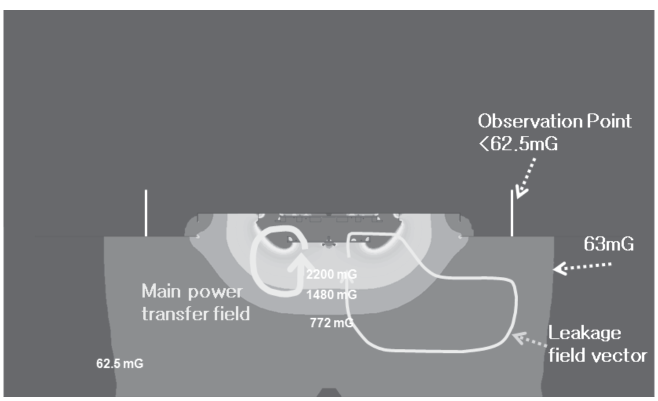

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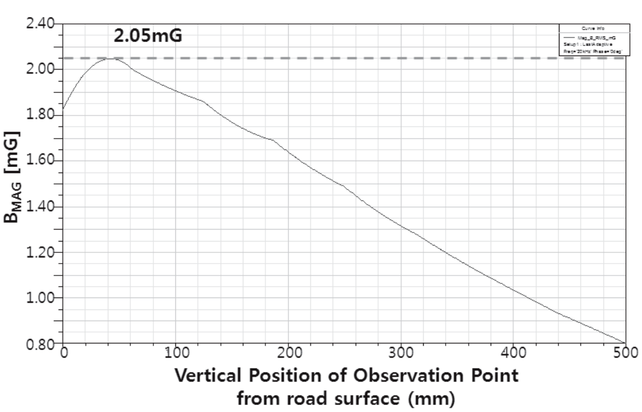

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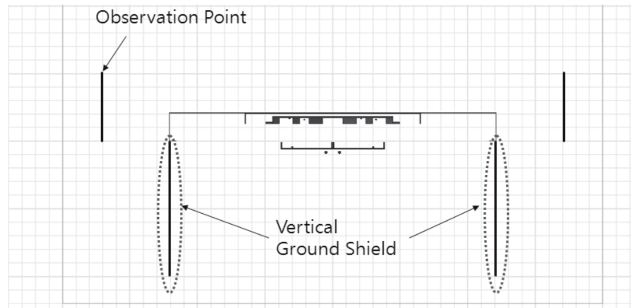
Fig. 7. Horizontal ground shield at the sidewalk: (a) Horizontal ground shield (b) Magnetic flux density distribution (c) EMF level.

C. Vertical Ground Shield and Contact with the Vehicle

Similar to the horizontal ground shield, the vertical ground shield can be also an effective way to reduce the EMF level. To increase the effectiveness, we connect the vertical ground shield to the metallic vehicle body. The vehicle body, vertical ground shield, and the connection create a good shielding box, confining the fringing field inside the box. The EMF level at the observation point is greatly reduced. Fig. 8 shows the vertical ground shield and the effect on the reduction of the EMF level. The magnetic flux is reduced to 25% of that of the horizontal ground shield. Even though the effect of connection is significant, it is not easy to connect the vehicle and ground shield, and this is discussed in the next section.



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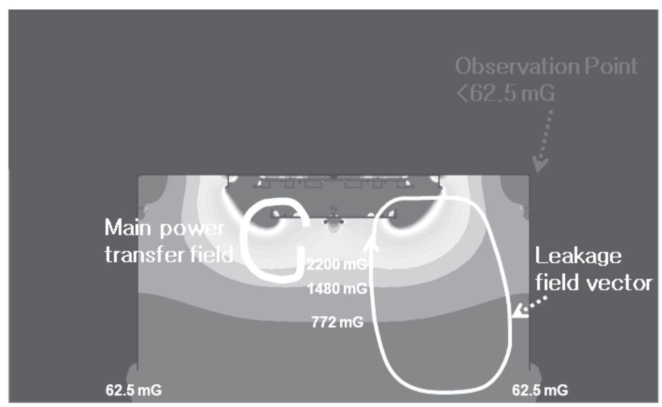

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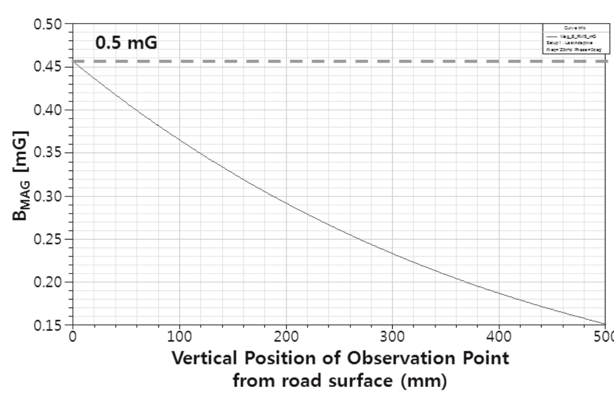
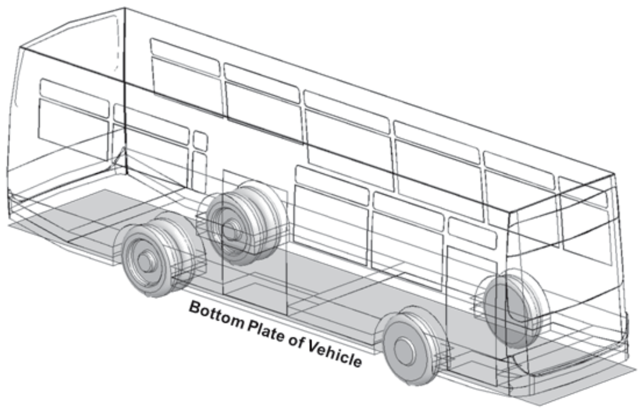


(c)

Fig. 8. Vertical ground shield between the road and sidewalk, and the connection between the shield and the vehicle body: (a) Vertical ground shield (b) Magnetic flux density distribution (c) EMF level.

IV. Measurement

The methods shown in the previous section were implemented, and the EMF level of each case was measured. Fig. 9 shows the bottom of test vehicle, which is the same as the actual vehicle bottom. The EMF level is measured at the center in terms of length, 50 cm from the vehicle.



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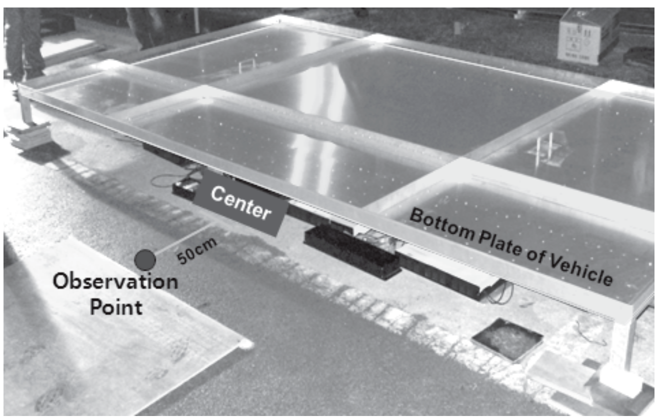

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Fig. 9. Test vehicle and measurement setup for reference. (a) The bottom plate of the vehicle body (b) Only the bottom plate is used for test measurement.

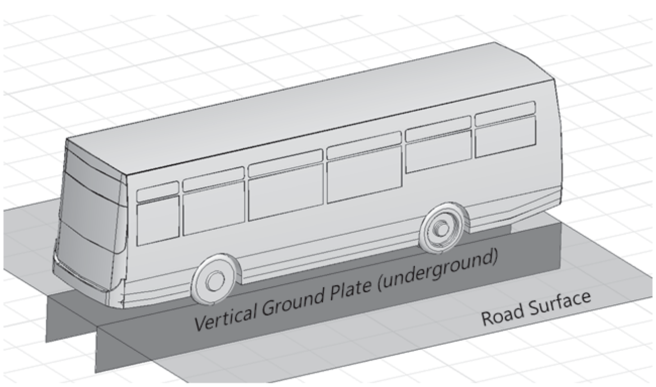
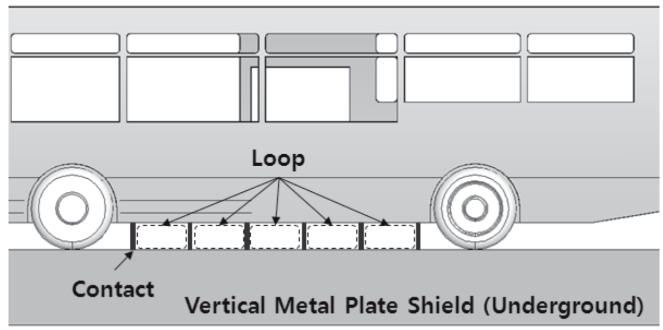


Fig. 10. The concept of vertical ground shield under the vehicle

Fig. 10 shows the vertical ground shield, and the marked metal plate is part of the vertical ground shield. Fig. 11 (a) shows the concept of the vertical ground shield and contacts to metallic bottom plate of vehicle. When the contacts are applied the EMF level is significantly reduced. Fig. 11 (b) shows the horizontal ground shield using metal meshes and connecting wire between metallic vehicle body and horizontal ground shield. As the number connection increases, the loop size is decreased and the EMF level is reduced. Fig. 11 (c) shows the brushes implemented to the real vehicle application. The vehicle with the brush has been now operating in Seoul Grand Park since 9 March 2010.



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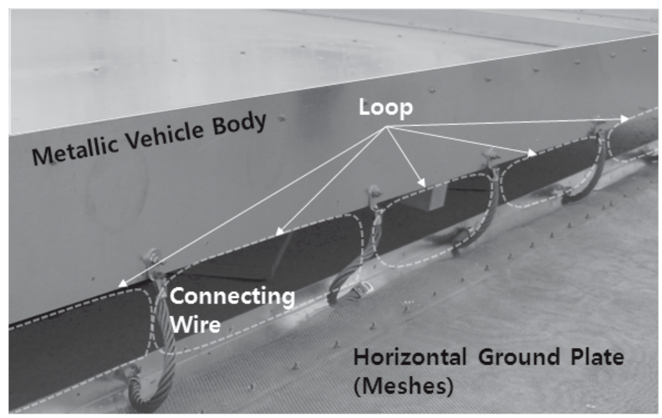

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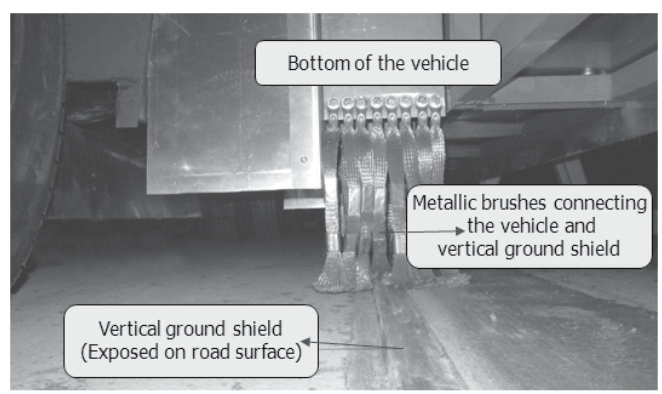

(c)

Fig. 11. Implemented horizontal ground shield (a) connecting wire for test vehicle (b) connecting brushes for the real application

We compared two cases: with and without a connection between the vehicle body and horizontal ground shield. Table 1 shows a comparison of the EMF levels for different cases. From the reference condition, when we applied a vertical shield to the vehicle, as shown in Fig 6(b), even when the shield reached the road surface, the EMF level was reduced by only 6 mG, which is only 4% of the original value. When applying the vertical ground shield and horizontal ground shield, the EMF level became even larger. As the magnetic flux Bz component was not calculated in either case, the magnitude was not correctly calculated. Due to the metal plate for vertical and horizontal ground plates, the current induced by magnetic flux is generated. Because of the current component Ix and Iy, which were not calculated in the simulation, much higher EMF levels were measured than the reference levels. When we connected the horizontal ground shield to the metallic vehicle body, the EMF level was reduced to a lower value than the reference level.

Even though there should be space between the vehicle and road surface, the soft contact between the vehicle and road surface can be allowable for some applications. Fig. 12 shows a comparison of the EMF levels for different numbers of connections between the metallic vehicle body and horizontal ground shield. When the number of connections is increased, the size of the loop, which consists of the metallic vehicle body, horizontal ground plate, and connecting wire, is decreased. Hence, the EMF level is also decreased. When eight connecting wires are applied, the EMF level is reduced to 35 mG, which is 25% of the reference value.

TABLE I
COMPARISON OF EMF LEVELS FOR DIFFERENT CONDITIONS

Condition		EMF Level
Reference		138 mG
Vertical Shield on Vehicle	No space between vehicle and road surface	132 mG
Vertical Ground Shield		178 mG
Horizontal Ground Shield	NOT connected to vehicle body	180 mG
	Connected to vehicle body (4 Connections)	120 mG

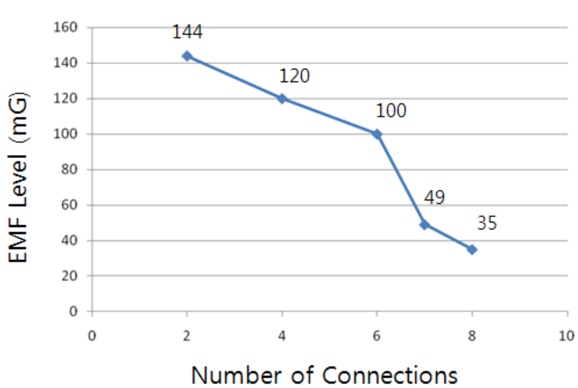

Fig. 12. Effect of the number of connections between the metallic vehicle body and the horizontal ground shield on the EMF level.

V. CONCLUSION

In this paper, we introduced the On-line Electric Vehicle (OLEV) system and its non-contact power transfer mechanism and proposed some techniques for the reduction of electromagnetic fields (EMFs) from the power line and vehicle itself. By applying a metallic plate shield, horizontal/vertical shield, and connecting wire for loop cancellation, the low frequency EMF was significantly reduced. Simulation and measurement results for application to vehicles currently in service are also given.

From the result of the simulation and measurement, we have shown the EMF level of the OLEV can be reduced to less than 62.5 mG by these techniques we suggested.

ACKNOWLEDGMENT

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