# Performances of Magnetic Field Shielding Materials for Roadbed Recharging Vehicle by 20 kHz Magnetic Field Coupling

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## Abstract

Roadbed recharging is wireless energy transmission to the batteries in the vehicles by 20 kHz magnetic field induction. It is possible to reduce the capacity of the batteries in the vehicle by this scheme whose weight and cost is not ignored for the usual electric vehicles.

Although it needs very strong magnetic field from the embedded power lines along the road for recharging, it is necessary to shield the emanating magnetic field in the booth of the transportation system. The proper material for shielding the 20 kHz magnetic field in the vehicle booth is investigated by numerical analyses and by experimental measurements.

Good conductors such as copper and aluminum showed better shielding effectiveness at 20 kHz than magnetic materials such as silicon steel or ferrite.

## 1. Introduction

Road-embedded recharging system is an experimenting electric transportation system with embedding electric wires in the roadbeds that magnetically transfer energy to battery-powered vehicles above [1][2]. The charging electricity to the batteries is furnished by picking up 20 kHz magnetic field generated by the pairs of wires buried shallow in the ground.

To supply enough electric power to the traction batteries, it is necessary to generate very strong magnetic field up to near 200 μT (2 Gauss) on the charging alley along the road lane. The leakage field emanated from this strong magnetic field source can expose the passengers in the vehicle with the comparable magnitude of the safety guide lines. The strongest magnetic flux density was measured up to 7.5 μT at one spot in the road-embedded recharging bus, which is above 6.25 μT, the former ICNIRP guideline at 20 kHz for general public [3].

It is very good if the magnetic field in the vehicle can be reduced by small effort and reasonable cost which coincides with the ALARA principle.

The shielding effectiveness (SE) of some materials to 20 kHz magnetic field was calculated and measured to select the pertinent shielding material for the wireless recharging electric vehicle.

## 2. Test of Shielding Effectiveness of Magnetic Field

Usually magnetic materials such as iron alloys and ferrites are used for shielding low frequency magnetic field and it is usually considered that nonmagnetic materials such as copper or aluminum are poor in shielding the low frequency magnetic field. On the other hand good conductors are used to shield the high frequency electromagnetic field. 20 kHz field is seldom used in practical world, and it is not obvious that 20 kHz field can be categorized in low or high frequency at this situation. Thin sheets of silicon steel, ferrite, copper and aluminum were considered to be examined for shielding 20 kHz magnetic field [4].

The shielding effectiveness (SE) of such materials of 600 mm square sheet with various thicknesses in Fig. 1 were calculated by commercial simulation tool for low frequency field. Also SE was measured by experiment with 20 kHz magnetic field generated by 30 turns square shaped coil (330 x 330 $mm^2$) in Fig. 2. The current flow was 0.1 Amp (half-peak) through 1 mm radius copper wire 25 cm below the thin shielding plane.

The calculations were performed in 4.6 m (wide) x 4.06 m (high) x 4.6 m (deep) rectangular parallelepiped volume shown in Fig. 1. The purpose of much bigger calculation volume than the hardware volume in Fig. 2 is to let the fringing magnetic flux go as freely as possible not to be blocked by the boundary walls.

The values of permeability and conductivity of the silicon steel and ferrite at 20 kHz are not found in any other documents so they were measured in the previous study and the data of air and the good conductors were given by the simulation tool itself. The values of permeabilities and conductivities of the materials used for the field computations are given in Table 1.

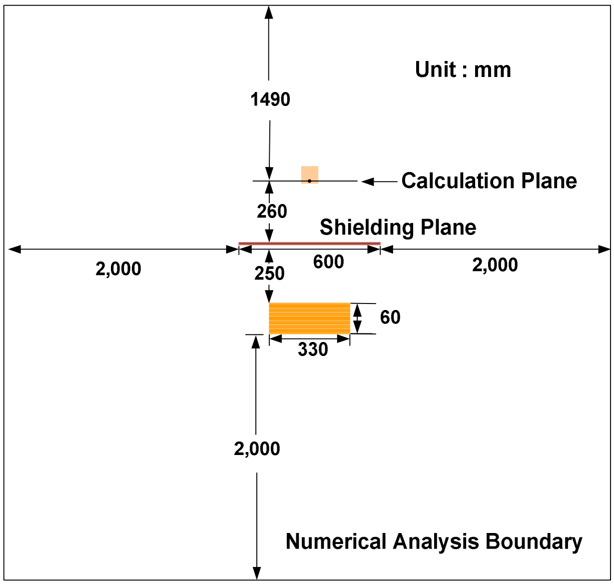


Figure 1. Geometrical structure for numerical analysis of the magnetic field.

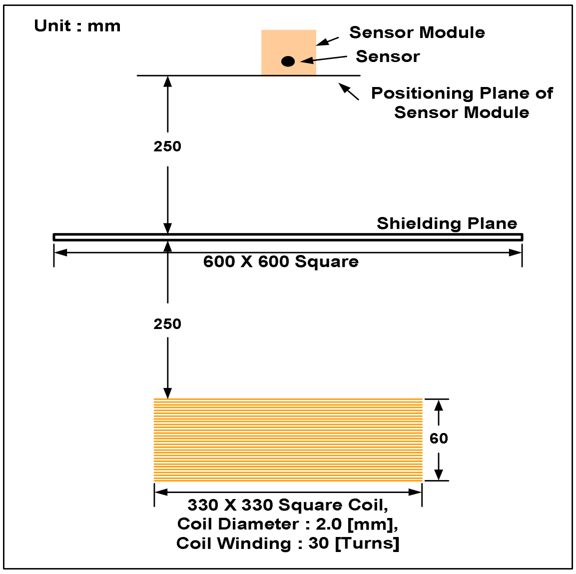


Figure 2. Geometrical structure for magnetic field measurement.

Table 1. The inserted values of permeabilities and conductivities of the materials at 20 kHz used for magnetic field computation.

| Materials | Relative Permeability | Conductivity [S/m] |
|---|---|---|
| air | 1.0000004 | 0 |
| silicon steel strip | 446 | 0 |
| ferrite | 2000 | 0.01 |
| copper | 0.999991 | $5.8 \times 10^7$ |
| aluminum | 1.000021 | $3.8 \times 10^7$ |

To verify the calculation results of the shielding the experimental test set shown in Fig. 3 was built with magnetic flux generating coil and shunt resistors for lowering Q of the coil, a 20 kHz signal generator and its amplifier, and a magnetic field sensor.

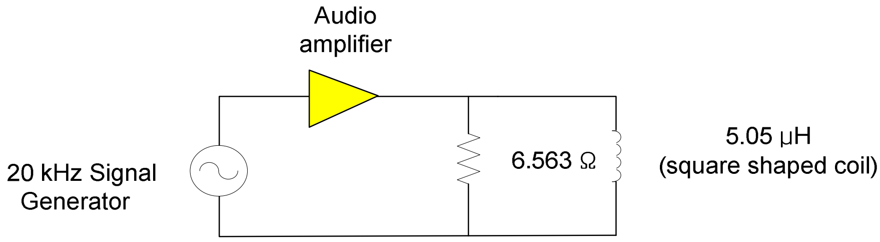

Figure 3. Circuit diagram for magnetic field generation.

## 3. Analysis of Numerical Simulation and Measurement Results

The magnetic fields were calculated on the plane at 26 cm above the shielding sheet in Fig. 1. Also the magnetic fields were measured on the plane 25 cm above the shielding sheet in Fig. 2.

The shielding effectiveness of the covering sheet is defined as;

$$SE = -20 \log_{10} \left| B_{shielded} / B_{no\ shield} \right| \quad [dB] \qquad (1)$$

The magnetic fields B in Eq. (1) were the values calculated or measured on the center point of the calculation or measurement planes. All of the calculated and measured values are tabulated in Table 2.

Table 2. Magnetic field and their shielding effectiveness of the five kinds of materials including air.

| Shielding material | Material thickness [mm] | B at center position on the calculation plane in Fig. 1 (half-peak) [nT] | SE by numerical analysis [dB] | B at the center position on the measurement plane in Fig. 2 (half-peak) [nT] | SE by measurement [dB] |
|---|---|---|---|---|---|
| Air | | 349.0 | 0 | 355.5 | 0 |
| Silicon steel (μr = 446) | 0.1 | 326.2 | 0.58 | 323.3 | 0.82 |
| Ferrite (μr = 2,000) | 1.0 | 224.9 | 3.81 | - | - |
| Copper | 0.1 | 81.0 | 12.68 | 87.3 | 12.18 |
| | 0.2 | 80.5 | 12.73 | 87.1 | 12.21 |
| | 0.5 | 80.0 | 12.79 | 85.9 | 12.33 |
| | 0.8 | 80.0 | 12.79 | - | - |
| | 1 | 80.0 | 12.79 | - | - |
| Aluminum | 0.1 | 81.5 | 12.63 | - | - |
| | 0.2 | 80.7 | 12.71 | - | - |
| | 0.5 | 80.1 | 12.78 | 91.6 | 11.77 |
| | 0.8 | 80.1 | 12.78 | 90.6 | 11.87 |
| | 1.0 | 80.0 | 12.79 | 91.7 | 11.76 |

The resolution of magnetic field sensor is 10 nT which can cause invalid measurement data if magnetic field to be measured is too week. Also there was our deficiency in the measurements that the size of the magnetic field sensor of 8 cm cubic in the highly divergent field is too large to give good space resolutions in the measurement.

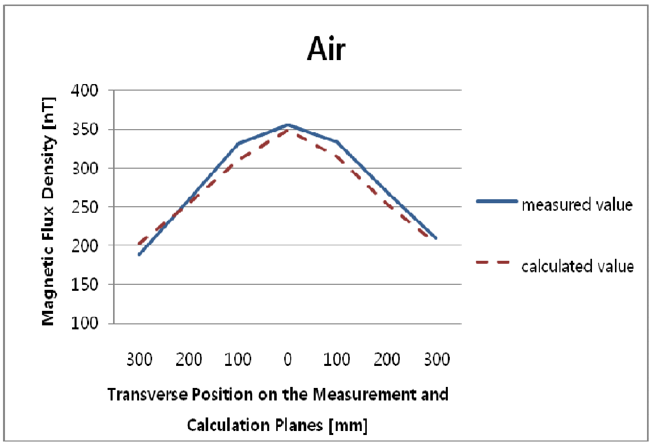


Figure 4. Calculated and measured magnetic fields on the numerical analysis and measurement planes in Fig. 1 and 2 without any shielding materials.

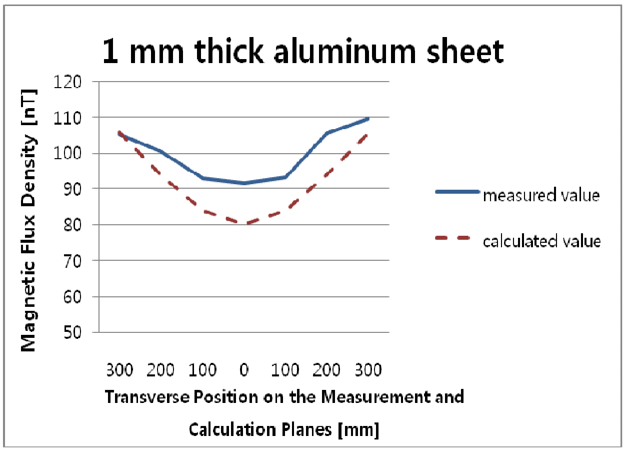


Figure 5. Calculated and measured magnetic fields on the numerical analysis and measurement planes in Fig. 1 and 2 with an 1 mm thick aluminum sheet.

The magnetic field distribution on the calculation and measurement planes were achieved in Fig. 4 without any shielding material and in Fig. 5 with 1 mm thick aluminum sheet. Fig. 4 showed typical field variation around the wired loop magnetic sources.

The shielding phenomenon is very clearly demonstrated in Fig. 5 by the thin aluminum sheet. The field increases as the sensor goes out to the edge of the calculation or measurement planes because of the limited area of the shielding sheet.

## Conclusion

Although silicon steel or ferrite sheets did not show satisfiable shielding characteristics, both thin 60 cm square of copper and aluminum sheets showed good shielding capabilities of more than 10 dB for 20 kHz magnetic field. It can be confirmed in both calculations and measurements that good conductor sheets are good shielding materials to 20 kHz magnetic field which is not generally well known. Shielding effectiveness (SE) of copper and aluminum plates are very close and there was no dependency on the thickness of the good conductors between 0.1 and 1 mm.

2 mm thick aluminum plate was applied in road-embedded recharging bus, which was proved to give more than 20 dB SE in reality because of wider shielding plane than the area of the sheet in this study.

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