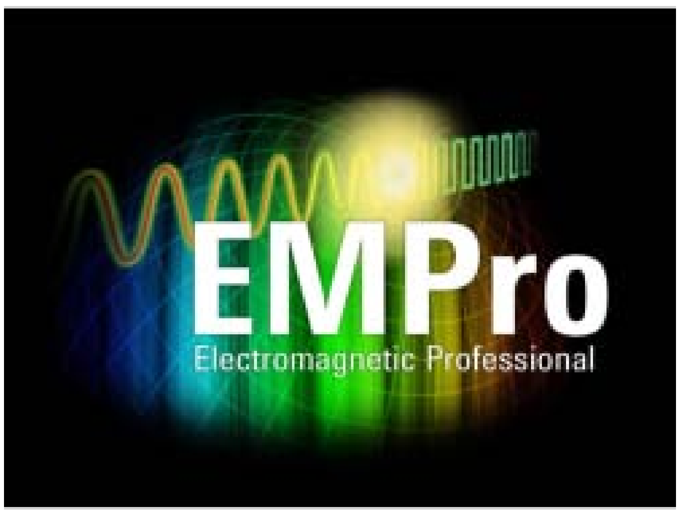
Agilent EEsof 3D EM Application series

Wireless Power Transfer of Magnetic Resonances



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Application Overview

Typical Situation

The contactless feed system of the electric power is studied and put to practical use. Many of these systems are based on the principle of electromagnetic induction. Therefore, there is a challenge to meet both transmission efficiency and transmission distance requirements. Recently, the method "Magnetic resonance" was proposed at MIT[1] and was verified with a prototype. This highly effective method can achieve high power and long-distance transmission. To realize a practical design, knowledge of electric circuit logic and electromagnetic theory are required.

Potential Users and Targeted Markets

- Designer of Wireless power transfer (Contactless power transfer) related components or systems.
- All systems which need a power supply (Consumer electronics, Automobile, PC, Medical equipment, etc.)

3D EM Product contributions to the application

- EMPro GUI : Creating 3D components
- EMPro Simulation technologies : FEM and FDTD

Value Delivered

It is possible to define the model easily by entering shape information and material definitions in the 3D EM simulator. In addition, it is possible to simulate the optimum point with a parameter sweep function. Moreover, the evaluation in a realistic environment is possible by utilizing a circuit simulator (complete system evaluation can be executed).

Wireless Power Transfer System of Magnetic Resonance

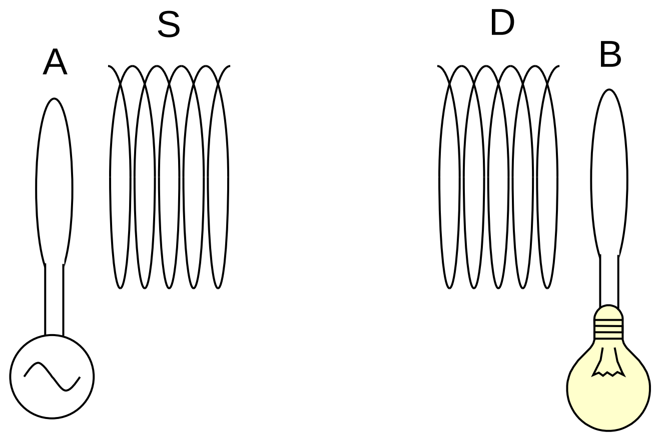


Fig. 1 Schematic of wireless power transfer system[1]

Fig. 2 Verification experiment model by MIT[2]
The transmitting efficiency was 40%
(Helical coil distance was 2.1 m).

Figure 1 shows the wireless power transfer system proposed by the MIT team. A is a single copper loop of radius 25 cm that is part of the driving circuit. S and D are respectively the source and device coils with the same resonance frequency mutually. B is a single loop of wire attached to the load. The angle between coil D and the loop A is adjusted to ensure that their direct coupling is zero. Coils S and D are aligned coaxially.

Loop Coil (A, B)
- radius : r = 250 [mm]
- metal line diameter : a= 3.0 [mm]

Helical Coil (S, D)
- coil length : a = 200 [mm]
- radius : r = 300 [mm]
- metal line diameter : a= 3.0 [mm]
- number of terns : n = 5.25

Material of line : Cupper

Magnetic resonance type wireless power transfer modeling by EMPro

To analyze the magnetic resonance method, a 3D model can be created in EMPro, a 3D EM simulator. Figure 3 shows a model generated in EMPro. The size such as the loop coils referred to the MIT model of Figure 2, and the distance between antennas was analyzed by 1.5m. For the simplification of a model, a coil is made into eight square shapes instead of a true circle, and also models the section of a lead in four square shapes.

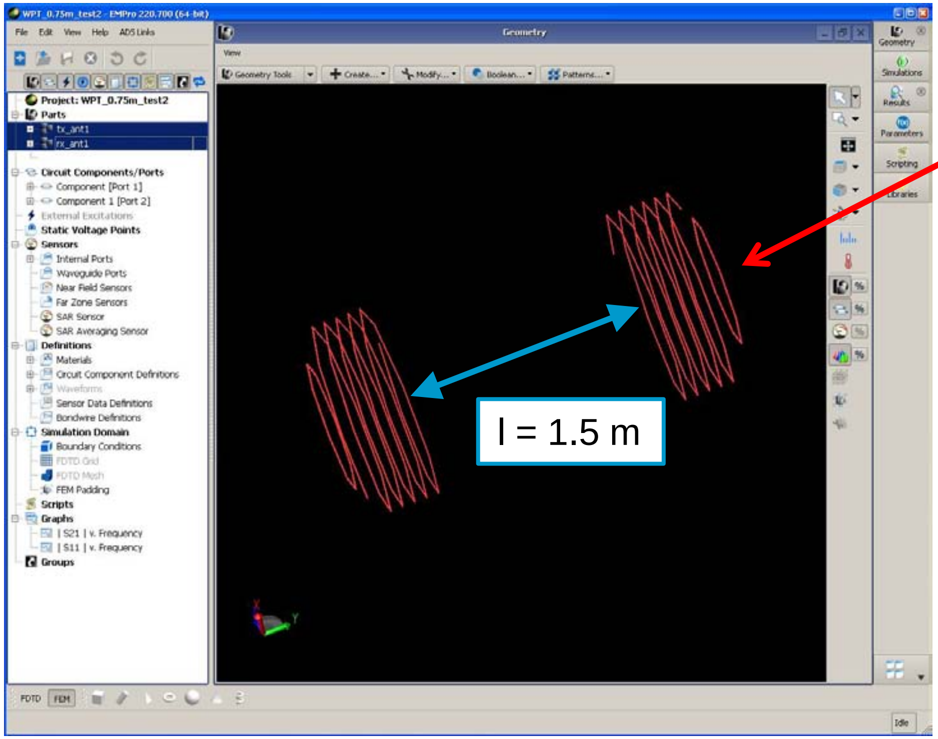
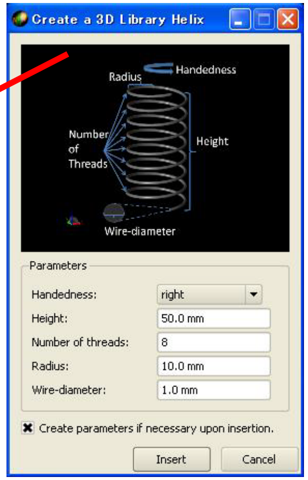


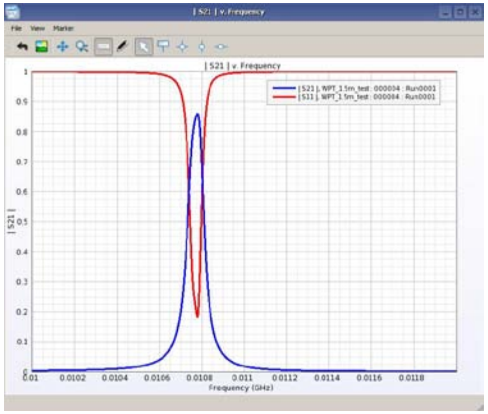
Fig. 3　EMPro GUI



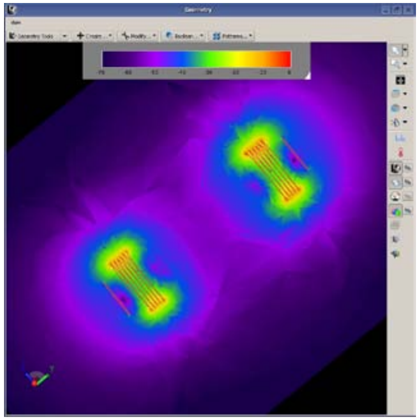
EMPro Parts Library can enter the helical shape

EMPro FEM Analysis

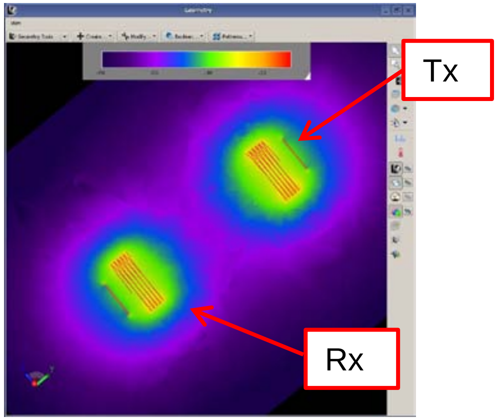
Figure 4 shows the simulation results by EMPro FEM. EMPro can analyze the spatial distribution of the E-field and H-field as well as S-parameters.



a) Results of S-parameter (S_{21}, S_{11})



b) E-field plot



c) H-field plot

Fig. 4 Simulation results of EMPro

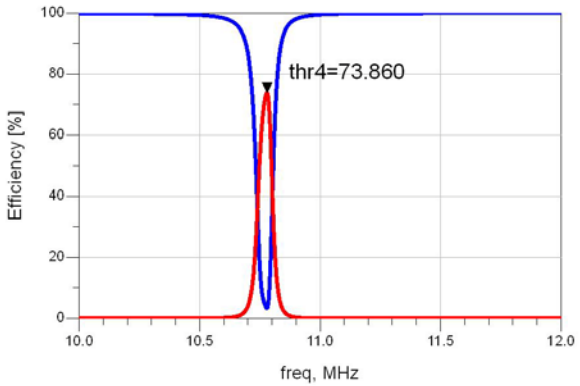


Fig. 5 Transmission Efficiency (l = 1.5 m)

When transmission efficiency is calculated from Figure 4, **about 74%** transmission efficiency is calculated(Figure 5). This is almost corresponding to the theory of MIT of Figure 6.

Power Transmission Efficiency : η_{21}

$\eta_{21} = 100 \times |S_{21}|^2$ [%]

Comparison between analysis and theory

The distance between transmitter and receiver coils in Figure 3 was parameterized, and a swept simulation was performed in EMPro. Figure 7 shows the simulation results. The result of analysis matched well with the theory and the experimental results from MIT of Figure 6.

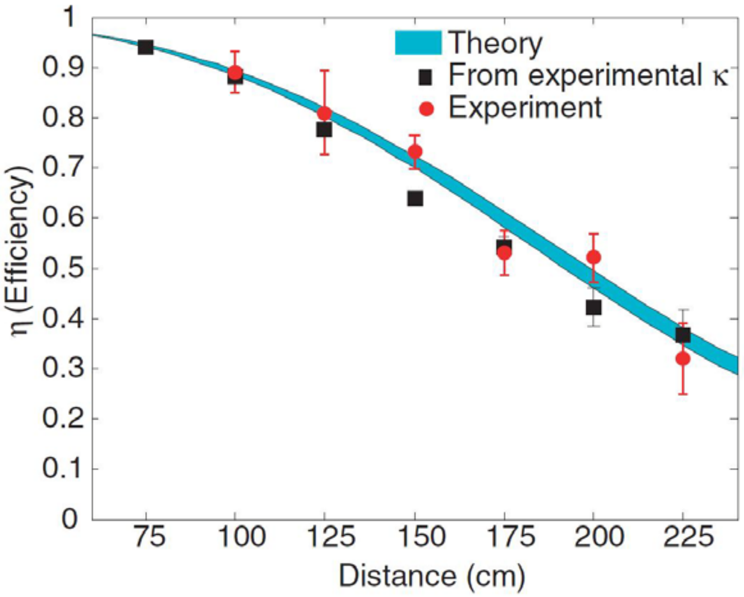


Fig. 6 Transmission efficiency vs. distance[1]

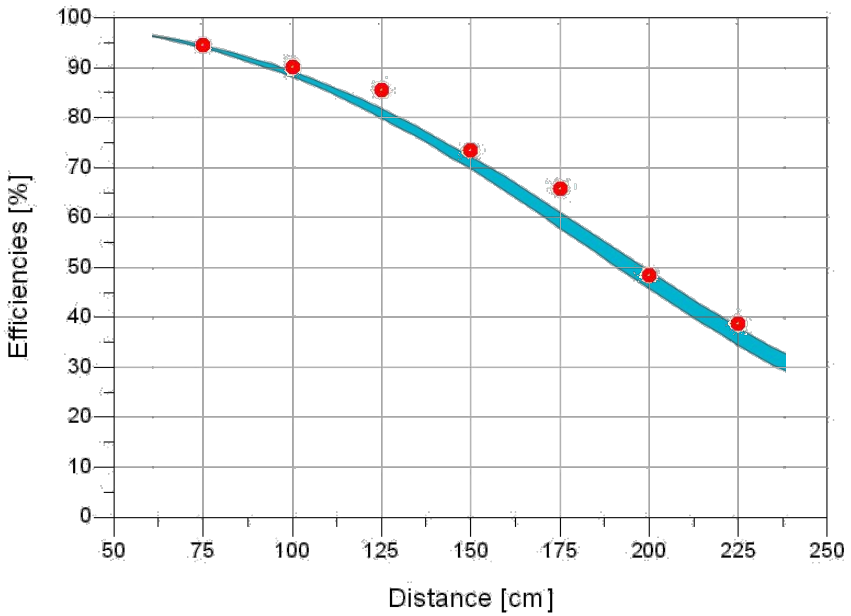


Fig. 7 EMPro simulation results

Influence of Environment around model :
Effect of Metal Plate

With the magnetic resonance method, there is less environmental influence compared with electromagnetic induction method. Influence by a large metal plate inserted between the helical coils was analyzed with EMPro. The distance between coils was 1 m, and a metal plate was located at the center.

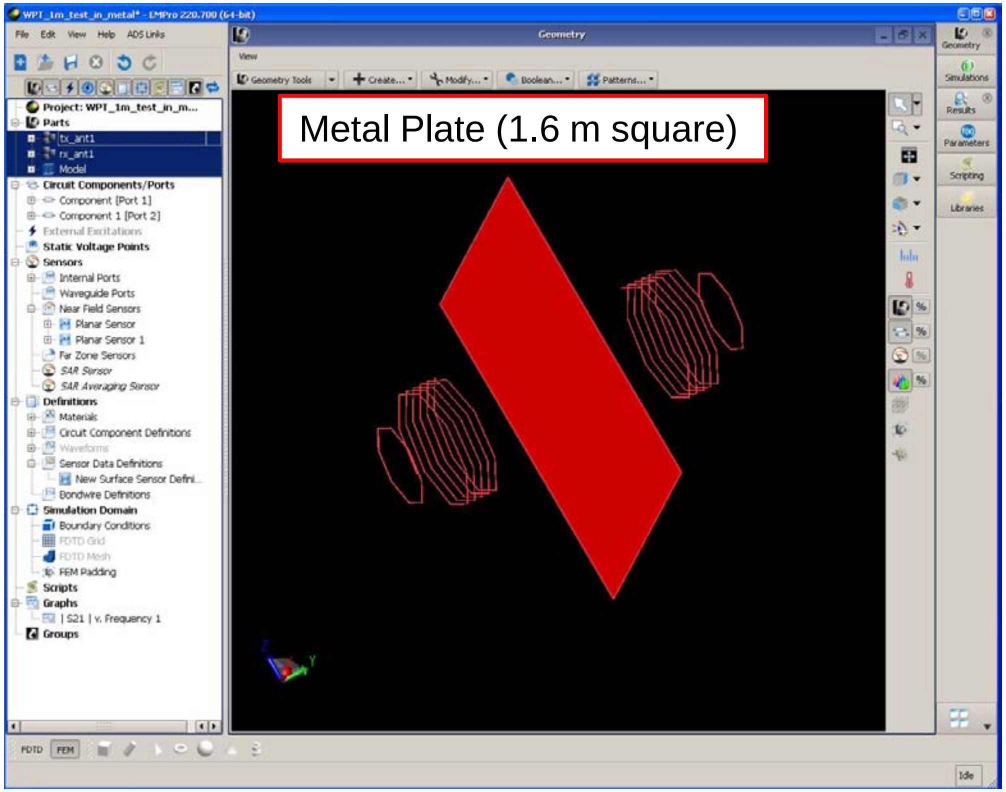


Fig. 8 Analysis of influence of metal plate
(Distance between helical coils : l = 1 m)

Influence of Environment around model :
Effect of Metal Plate

Table 1 shows the simulation results. The transmitting efficiency becomes 57% with an inserted metal plate compared with 90% transmitting efficiency without the metal plate. Although transmission efficiency fell, it still exceeded 50%, which is difficult for other transfer system to realize.

Figure 9 shows the results of E-field and H-field. It confirms a resonant state even in the presence of a metal plate.

Table 1 Transmission Efficiency

Simulation model	Efficiency [%]
Without metal plate	90.1
With metal plate	56.7

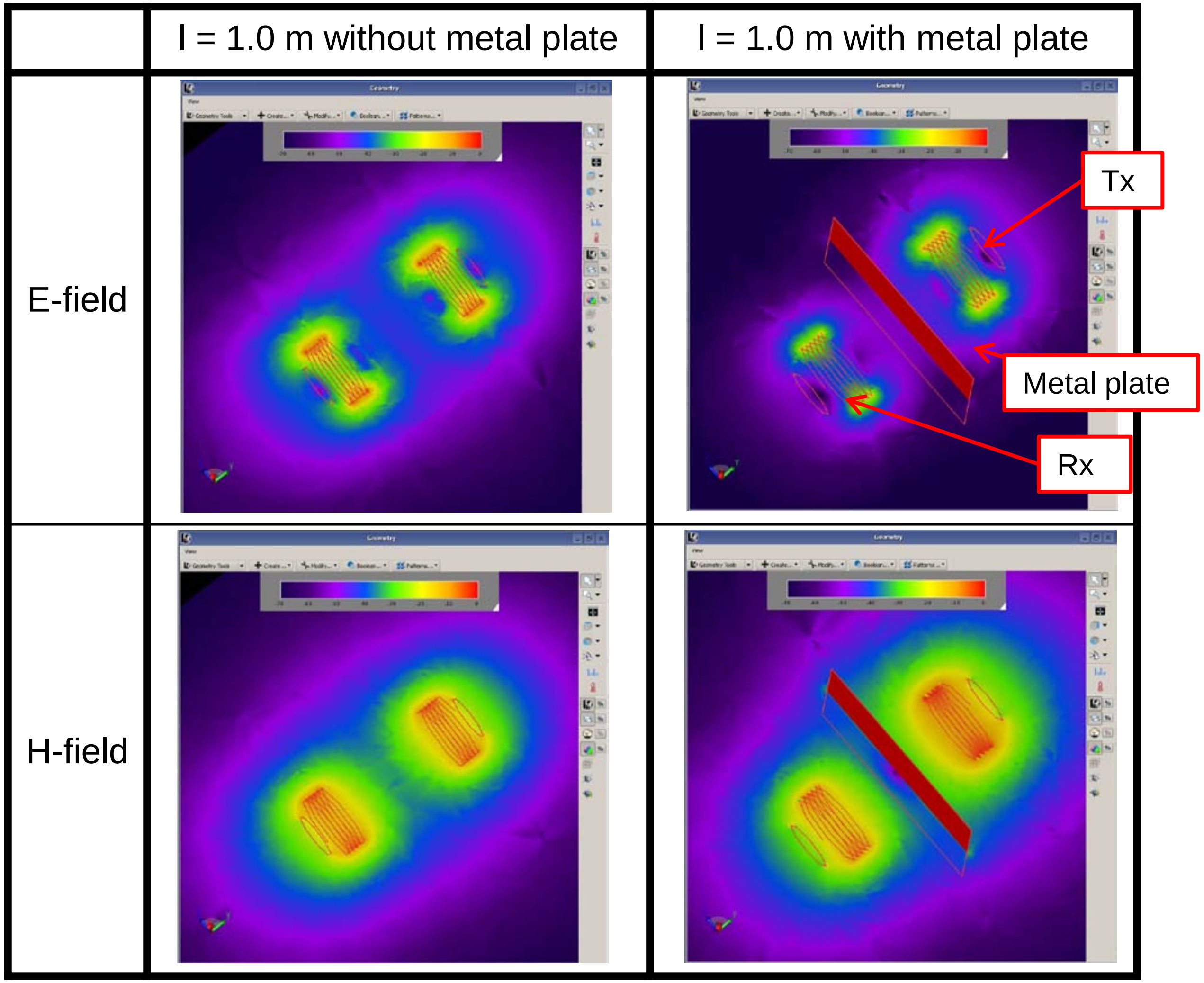
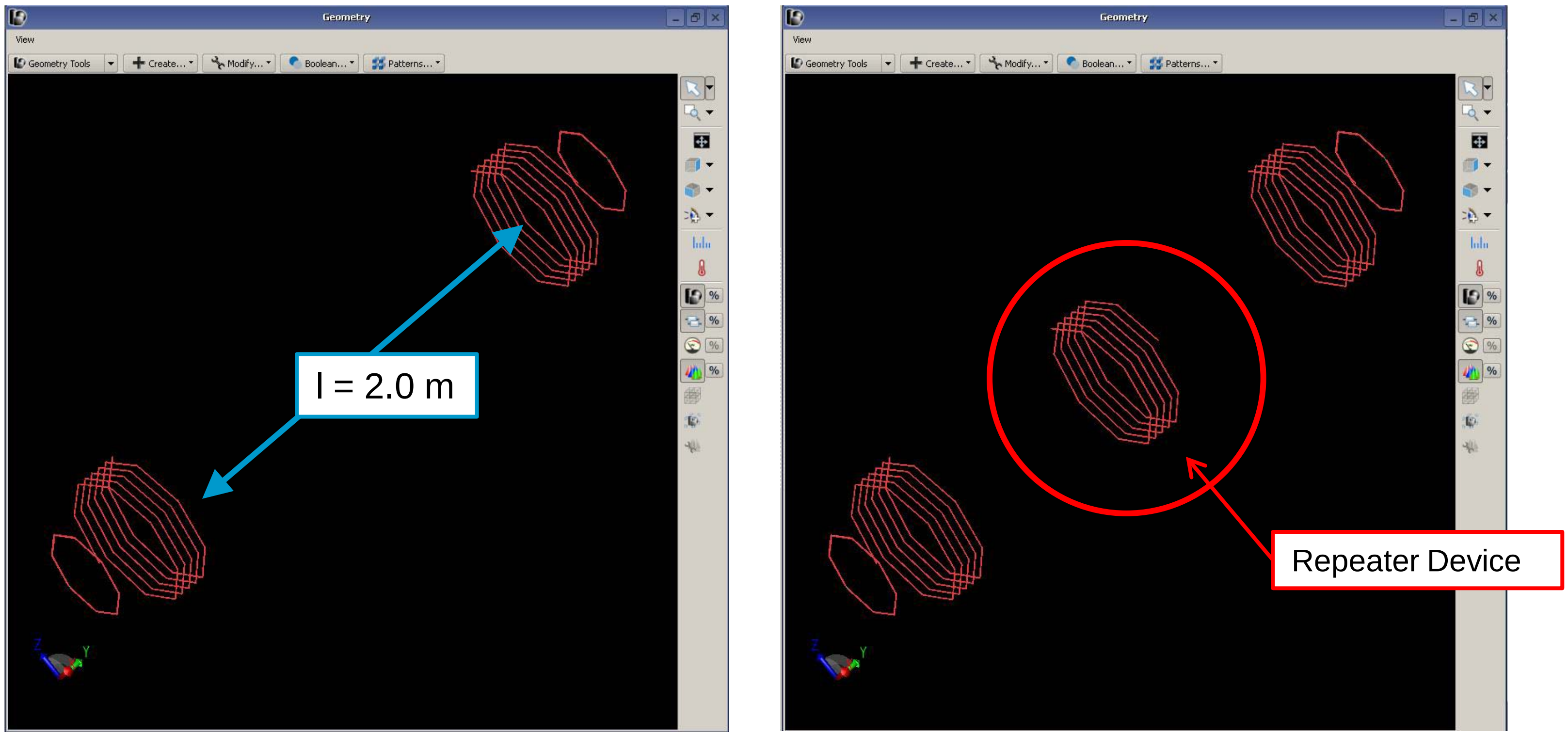


Fig. 9 Results of electric and magnetic field

Examination of transmission efficiency improvement

The method of inserting the “Repeater Device” is proposed to improve the transmitting efficiency. To confirm this, an additional coil, identical to the helical coil of S and D of Figure 1, was inserted between S and D as a repeater device, and analyzed with EMPro.



a) Without repeater device

b) With repeater device

Fig. 10 Analysis of repeater device
(Distance between helical coils : l = 2 m)

Examination of transmission efficiency improvement

Table 2 shows the simulation results. The transmitting efficiency in a free space was 48.4% between antennas at the distance 2 m.
The efficiency improved to about 80% by inserting the repeater device.

Figure 11 shows the E-field and H-field results. This confirms a resonant state in each helical coil when the repeater device is inserted.

Table 2 Transmission Efficiency

Simulation model	Efficiency [%]
Without Repeater Device	48.4
With Repeater Device	80.1

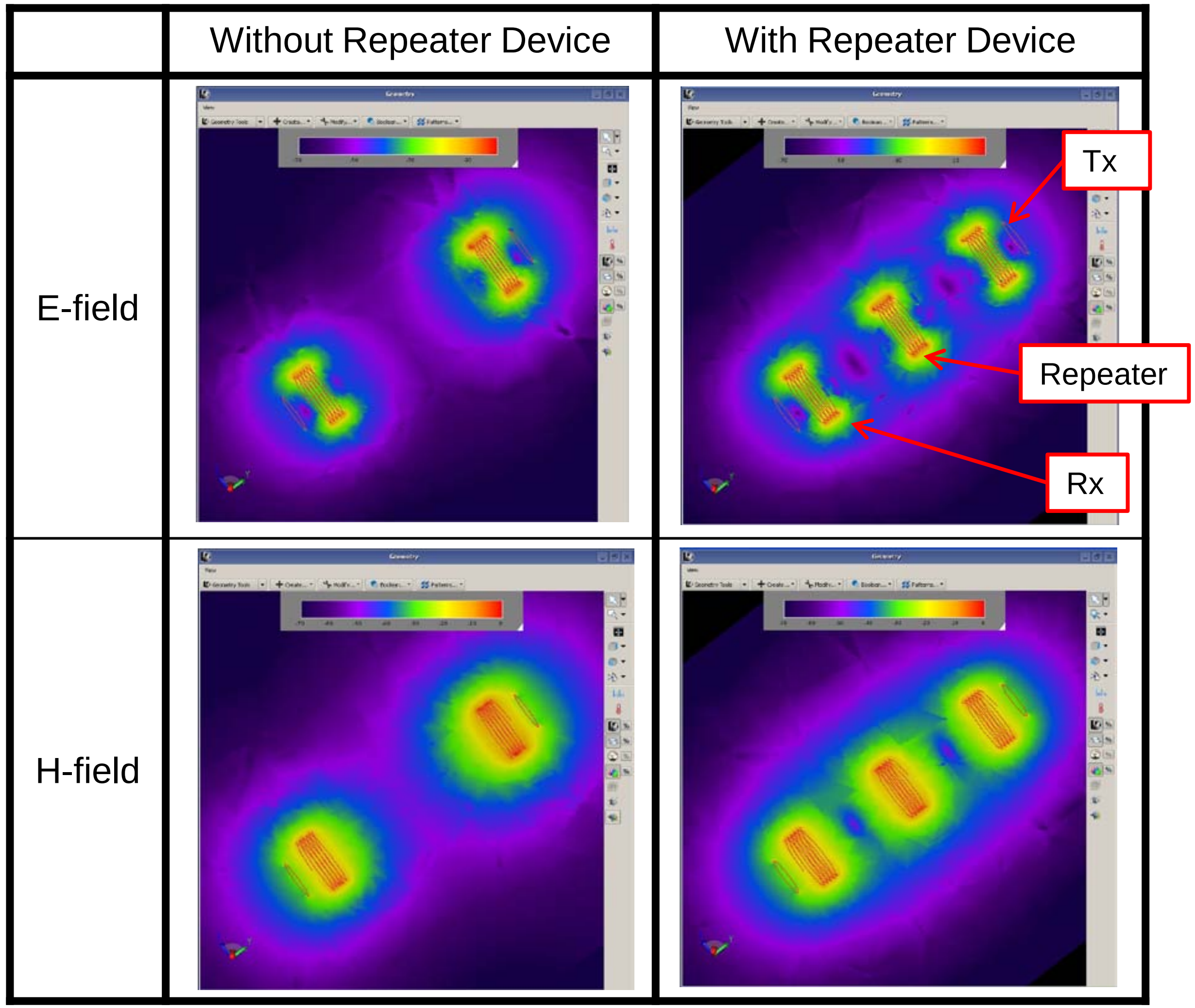
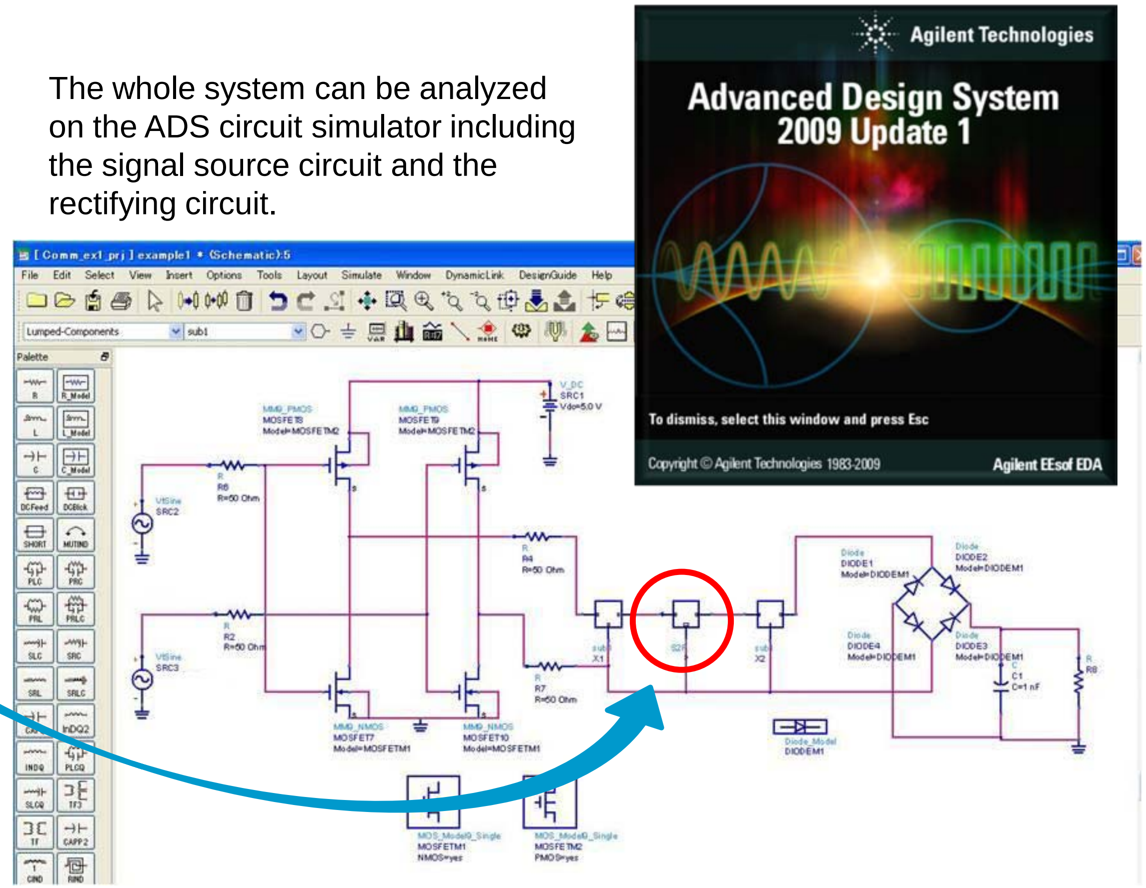


Fig. 11 Results of electric and magnetic field

Next Step …
Verification of transmitting efficiency in the whole system

After verifying electromagnetic models of wireless power transfer, the analysis of a complete system, including the transmission model and a circuit, would be desired. This can be accomplished with the combination of EMPro and the ADS circuit simulator.

The whole system can be analyzed on the ADS circuit simulator including the signal source circuit and the rectifying circuit.



EMPro analysis results can be imported as the ADS DesignKit.

Summary

- With a 3D EM simulator, the wireless power transfer method of magnetic resonance can be easily analyzed and modeled.
- The results of EMPro FEM analysis match well with the MIT theoretical results.
- In addition to the basic wireless power transfer model, EMPro can analyze behavior with additional elements, such as a metal plate, or a repeater.
- EMPro & ADS make it possible to verify performance of a complete system, including the designed wireless power transfer system. This is an ideal solution for optimizing each component for maximizing whole system performance.

References

[1] A. Kurs, A. Karalis, R. Moffatt, J.D. Joannopoulos, P. Fisher, and M. Soljačić : "Wireless Power Transfer via Strongly Coupled Magnetic Resonances," Science, 317, pp. 83-86 (2007)

[2] Supporting Online Material for [1]

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