# Mid-Distance Wireless Power Transmission for Electric Truck via Microwaves

Naoki Shinohara[#1], Yuta Kubo[#2], Hiroshi Tonomura[*3]

[#] *Research Institute for Sustainable Humanosphere, Kyoto University*
*Gokasho, Uji, Kyoto, 611-0011, Japan*
[1] shino@rish.kyoto-u.ac.jp
[2] y-kubo@rish.kyoto-u.ac.jp
[*] *Volvo Advanced Technology & Research*
*External Research Collaborations, Japan*
*Nihon Joshi Kaikan Building 6F, Shiba-Koen 2-6-8, Minato-ku, Tokyo, 105-0011, Japan*
[3] hiroshi.tonomura@volvo.com

***Abstract*— Various wireless power transmissions (WPT) are applied to charge an electric vehicle (EV). An inductive coupling WPT and resonance coupling WPT are often used. We proposed a WPT via microwave (microwave power transmission ; MPT) for the wireless charging of the EV because we consider that merits of the MPT, which are mid or far distance WPT and no coupling between a transmitter and a receiver, are suitable for the WPT for the EV. However, there are some problems which we should solve before its commercialization. One of the problems is antenna and beam forming. In this paper, we describe a suitable beam forming design of the MPT system for an electric truck with genetic algorism.**

## I. Introduction

Research of a wireless power transmission (WPT) has a long history from 1960s[1]. In 20th century, the WPT was conducted by a microwave power transmission (MPT) and its application of a Solar Power Satellite/Station (SPS). But there was no commercial product of the MPT except RF-ID which was born in 1990s. In 21st century, simpler and more effective WPT was proposed by Massachusetts Institute of Technology (MIT) which was called resonance coupling WPT[2]. The resonance coupling WPT is explained with help of an inductive coupling theory which has a long research history. After the MIT's revolution, number of researchers and developers of the WPT increases ten times larger and various WPT commercial products are provided for users.

One of the hopeful WPT applications and products is a wireless charging for an electric vehicle. An inductive coupling WPT and resonance coupling WPT are often used for the WPT for the EV[3]-[5]. All WPT system is a WPT from a load to a body of the EV whose distance is within some dozen centimeters. The distance between the road to the body is suitable for the inductive coupling WPT and resonance coupling WPT. But we have some restrictions for the body of the EV and roads. It is problems which people step the WPT road when there is no EV.

So we propose a MPT wireless charging for the EV, especially for an electric truck. Our proposed MPT wireless charging system is shown in the figure 1. We use roof of the electric track for a receiving antenna. We transmit a microwave power above the roof. The MPT system can adapt various height trucks which may not park on optimum position for the wireless charging. In order to increase efficiency and to reduce unexpected radiation outside of the receiving antenna, we need uniform beam form. We have try to form uniform microwave beam with a horn antenna with a dielectric lens[6]. But it was not enough. So next we apply a phased array antenna technology on a transmitting antenna to control and adjust a form of microwave power beam. In order to form an uniform beam, we apply a genetic algorism as the beam forming algorism.

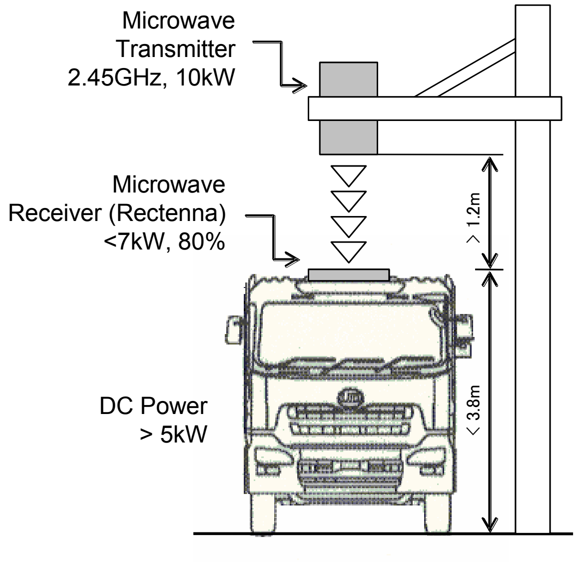


Fig. 1 Proposed MPT wireless charging system for an electric vehicle

## II. Beam Forming with Genetic Algorism

Ideal and target beam form is shown in the figure 2. We assume that 10kW and 2.45GHz microwave will be transmitted from 6m above of the receiving antenna on the roof. We need (1) uniform and higher efficiency beam form in receiving antenna (2) below 1 $mW/cm^2$ microwave density, which is safety level for human in 2.45GHz, outside of guard area. In order to satisfy both condition, we use the following target function in the genetic algorism.

$$ML = \sum(\mathrm{A} - S(x))^2 \ldots (-0.6 < x < 0.6) \qquad (1)$$

$$SL = \sum(\mathrm{B} - S(x))^2 \ldots (x < -1, \ \ 1 < x) \qquad (2)$$

$$SUM = ML + SL \qquad (3)$$

where ML indicates main lobe, SL indicates side lobe, and S(x) indicates pointing vector. We set A=4000 as 10kW radiation and B=1 as safety level. We will reach optimum beam form with minimization of SUM. Table I indicates parameters of transmitting and receiving antenna for the genetic algorism.

The optimized beam form is shown in figure 3. Beam efficiency in 1.2m x 1.2m area is 59.2% which is calculated with uniform beam area. The beam efficiency will increase to 79.1% in 1.4m x 1.4m where the beam density is within -2dBc. Of cause, power density outside of the guard area is below $1\mathrm{mW/cm}^2$.

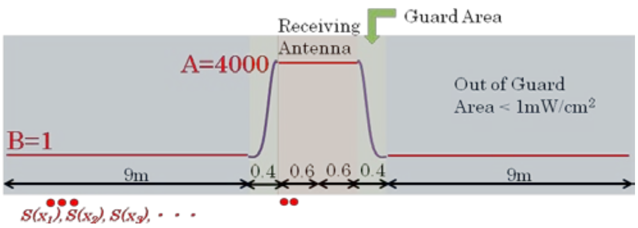


Fig. 2 Target Beam Form for Wireless Charging of EV Truck (1D)

TABLE I
PARAMETERS OF TRANSMITTING AND RECEIVING ANTENNA ARRAY

| | | |
|---|---|---|
| Transmitting Array | Frequency | 2.45GHz, CW |
| | Element Number | 42 x 42 |
| | Transmitted Power | 10kW |
| | Array | Rectangular |
| | Element Spacing | 0.9λ |
| | Polarisation | Linear |
| | Power from One Element (to optimize) | 0.2 – 100W |
| | Phase (to optimize) | -180 - +180 degree |
| Receiving Array | Receiving Antenna | 1.2 m x 1.2 m |
| | Power Distribution (Target) | Uniform and Higher Efficiency |
| | Guard Area | 1.8 m x 1.8 m |
| | Power Density outside of Guard Area (Target) | < 1 mW/cm2 |

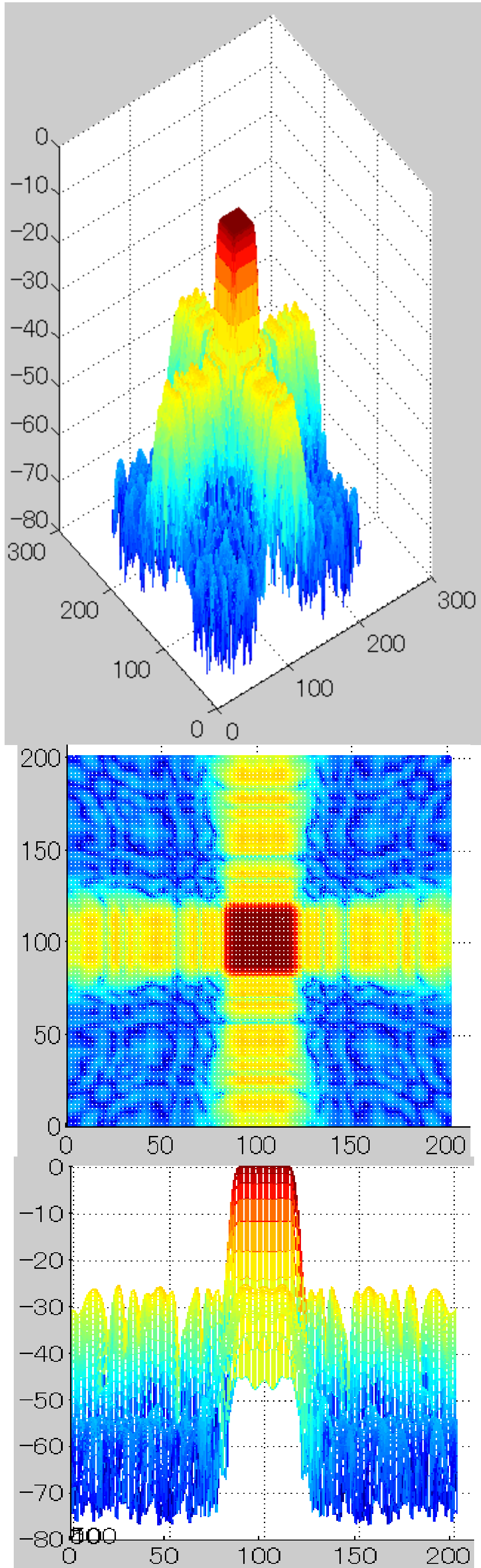


Fig. 3 Optimized Beam Form for Wireless Charging of EV Truck (2D)

## III. Conclusion

We proposed a MPT wireless charging system for an electric truck, which composed of a transmitting phased array on the top of the truck and a receiving array on the roof of the truck. In order to increase beam efficiency and to keep safety power level outside of the MPT system, we optimize beam form with genetic algorism. As a result, we can realize uniform beam form on the receiving array and keep safety level outside of the MPT system. In next step, we must develop high efficiency phased array and carry out the MPT experiment. We have already developed high efficiency receiving array called rectenna with Nihon Dengyo Kosaku, co., which can rectify 10kW with over 80% RF-DC conversion efficiency. We will use this rectenna in future experiment.

## References

[1] N. Shinohara, “Power without Wire”, IEEE Microwave Magazine, Vol.12, No.7, 2011, pp.S64-S73

[2] A., Karalis, J.D. Joannopoulos, and Marin Soljačić, “Efficient wireless non-radiative mid-range energy transfer”, *Annals of Physics*, vol. 323, no. 1,2008, pp.34-48

[3] G.A. Covic, L. G. Kissin, D. Kacprzak., N. Clausen and H. Hao “A Bipolar Primary Pad Topology for EV Stationary Charging and Highway Power by Inductive Coupling” Proc. of IEEE Energy Conversion Congress and Exposition ECCE 2011, 2011, pp. 1832-1838

[4] Y. Hori, “Novel EV Society based on Motor/Capacitor/Wireless - Application of Electric Motor, Supercapacitors, and Wireless Power Transfer to Enhance Operation of Future Vehicles –“, Proc. of 2012 IEEE MTT-S International Microwave Workshop Series on Innovative Wireless Power Transmission Technologies, Systems, and Applications (IMWS-IWPT), 2012, pp.3-8

[5] Y.-B. Chun, S. Park, J. Kim, H. Kim, K. Hwang, J. Kim and S. Ahn, “System and Electromagnetic Compatibility of Resonance Coupling Wireless power Transfer in On-line Electric Vehicle”, Proc. of 2012 International Symposium on Antenna and Propagation (ISAP), 2012, pp.158-161

[6] Y. Kubo, N. Shinohara, and T. Mitani, “Development of a kW Class Microwave Wireless Power Supply System to a Vehicle Roof”, Proc. of 2012 IEEE MTT-S International Microwave Workshop Series on Innovative Wireless Power Transmission: Technologies, Systems, and Applications (IMWS-IWPT), 2012, pp.205-208