Prototype of 5.8 GHz Wireless Power Transmission System for Electric Vehicle System

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***Abstract*—Wireless power transmission technology via microwave was advanced from 1960's. Wireless power transmission is the transmission of electrical energy from a power source to an electrical load without artificial interconnecting conductors. This technique is useful in cases where interconnecting wires are inconvenient, hazardous, or impossible. In this paper, we describe the developed prototype of 5.8 GHz wireless power transmission system with a 4×4 rectenna array for electric vehicles. The rectenna element is a microstrip patch antenna with PTFT board of 10 dielectric constant and 1.6 mm thick that has a gain of 6dBi. The conversion efficiencies are 49% and 75% at the transmission distances of 200mm and 400mm.**

***Index Terms*—Wireless power transmission (WPT), rectenna, patch antenna, electric vehicle (EV).**

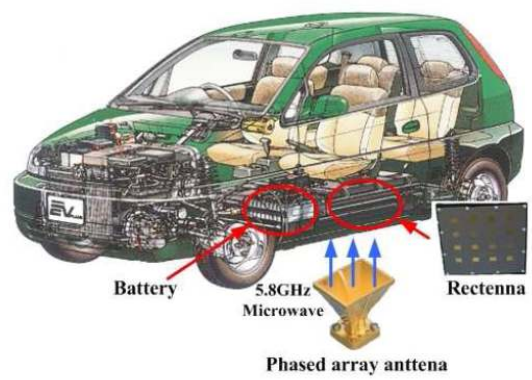

Fig. 1. The concept of wireless power transmission for electric vehicles.

I. Introduction

During the last few decades, increased concern over the environmental impact of the petroleum-based transportation infrastructure, along with the specter of peak oil, has led to renewed interest in an electric transportation infrastructure. Battery-powered electric vehicles (EVs) seem like an ideal solution to deal with the energy crisis and global warming since they have zero oil consumption and zero emission [1][2]. Moreover, we are quite rapidly reaching the end of the cheap oil era. Therefore, the need for alternative growing and the price competition of alternatives against oil is becoming more and more realistic.

Electric vehicles differ from fossil fuel-powered vehicles in that the electricity they consume can be generated from a wide range of sources, including fossil fuels, nuclear power, and renewable sources such as tidal power, solar power, and wind power or any combination of those. However it is generated, this energy is then transmitted to the vehicle through use of overhead lines, wireless energy transfer such as inductive charging, or a direct connection through an electrical cable [3],[4]. The electricity may then be stored onboard the vehicle using a battery, flywheel, or super-capacitors. Vehicles making use of engines working on the principle of combustion can usually only derive their energy from a single or a few sources, usually non-renewable fossil fuels. A key advantage of electric or hybrid electric vehicles is regenerative braking and suspension, their ability to recover energy normally lost during braking as electricity to be restored to the on-board battery [5]. However, EVs are highly depended on the external energy support.

Wireless power transmission technology via microwave was advanced from 1960's [6]. Recently, Intel Corporation fulfilled a high power of wireless coupling to power up electrical appliance, 60 Watt bulbs, with the efficiency more than 75% at the distance of 2meter in 2008. These show the feasibility of the wireless power transmission technology. Wireless power transmission is the transmission of electrical energy from a power source to an electrical load without artificial interconnecting conductors [7]-[10]. Wireless transmission is useful in cases where interconnecting wires are inconvenient, hazardous, or impossible. The rectenna, rectifying antenna, is one of the primary components in the application of wireless power transmission system. The rectenna, for receiving and converting the microwave power to direct current (DC) power, has received much attention lately in the development of the wireless power transmission. The application of this technology can be used in radio-frequency identification (RFID) and electric vehicles as shown in Fig. 1. Recently, many rectennas have been reported, including a rectenna using rhombic hula loop antenna [11], a dual-frequency rectenna [12], and a

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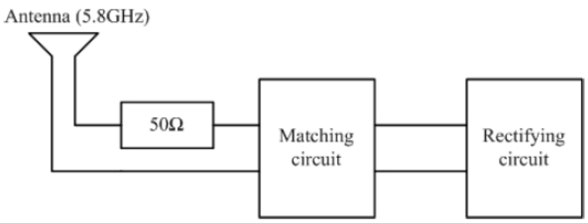

Fig. 2. The diagram of rectenna circuit.

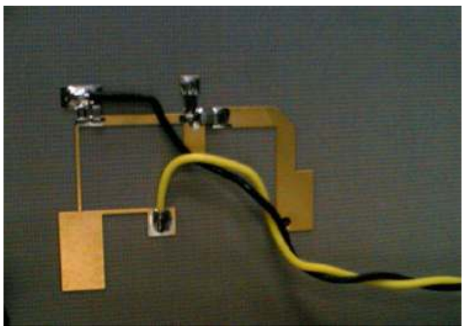

Fig.3. The manufactured rectifying circuit.

dual-diode rectenna [13]. In this paper, we focus on the rectenna with a patch antenna and describe the developed prototype of 5.8 GHz wireless power transmission system with a 4 × 4 rectenna array for electric vehicles. The developed rectenna element is a microstrip patch antenna that has a gain of 6dBi. Rectenna is designed with the PTFT board of 10 dielectric constant and 1.6 mm thick. This paper is organized as follows. The rectenna design is described in Section II. In Section III, we show the system experimental results. Finally, the conclusion is given in Section IV.

II. RECTENNA DESIGN

The rectenna is useful as the receiving terminal of a power transmission system where dc power needs to be delivered to a load, through free space, for which physical transmission lines are not feasible. It is also suitable in applications where dc power needs to be distributed to more numbers of load elements that are spatially distributed. Such power distribution is achieved by the dispersive nature of microwave energy in space, eliminating the need for physical interconnects to individual load elements. The rectenna was invented by Brown and has been used for various applications such as the microwave power

TABLE I
SYSTEM SPECIFICATION.

Device	Specification
Oscillator	10dBm
Power amplification	30dBm
Power divider	-6.4dB
Horn antenna	15dBi
Patch antenna	6dBi

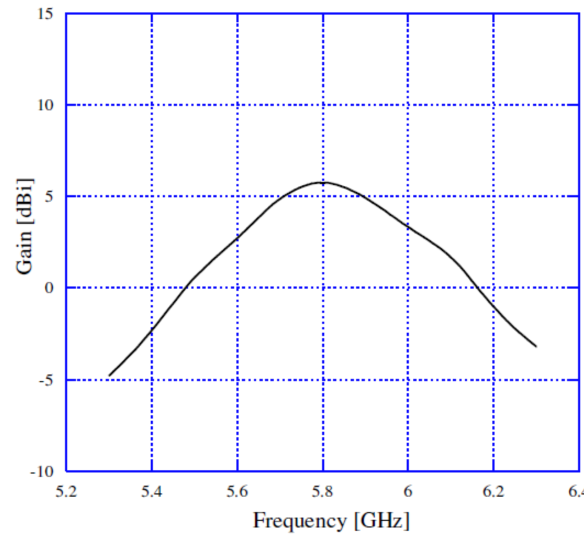

Fig.4. The measured gain of the manufactured rectenna.

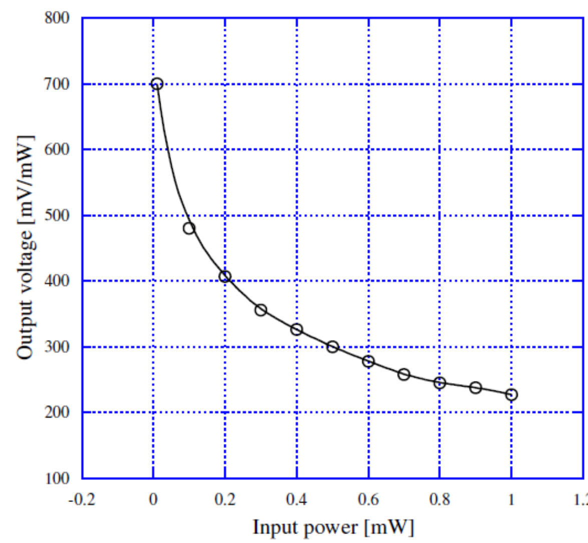

Fig.5. The output voltage performance versus input power.

helicopter and the receiving array for Solar Power Satellite [6], [14]. The experiment on the microwave powered aircraft which was conducted in Canada under the project SHARP (Stationary High Altitude Relay Platform), in which the structure of rectenna was evolved from a bulky bar-type to a planar thin-film type. It was found that the weight to power output ratio reduces effectively, and the power conversion efficiency of 85% is observed at 2.45 GHz [15], [16].

The rectenna consists of antenna, matching circuit, and rectifying circuit. The diagram of rectenna circuit is shown in Fig. 2. In the design of rectenna for electric vehicles, we should consider the frequency, the atmospheric attenuation, and rectenna size. In this paper, we adopted 5.8GHz rectenna since the frequency of 5.8GHz is ISM band. Therefore, the license is not necessary to experimentalize the wireless power transmission for electric vehicles. As shown in Fig. 1, the

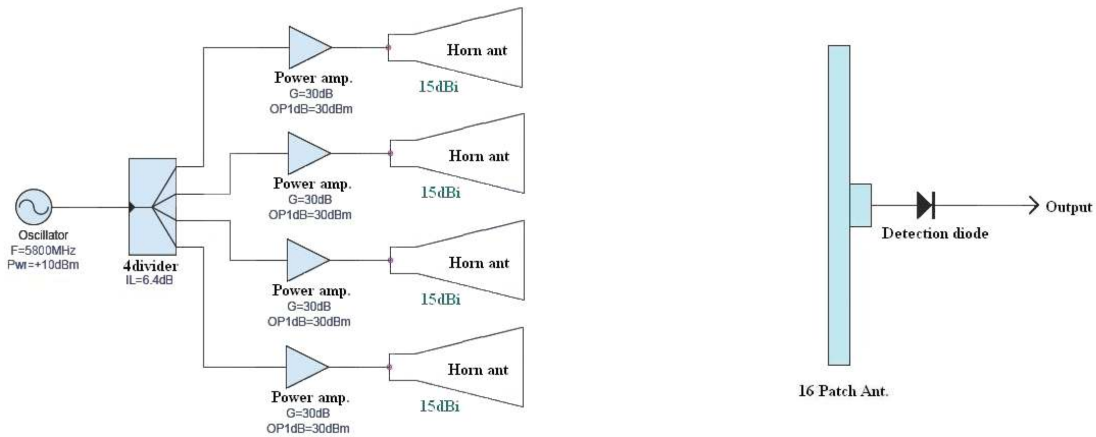

Fig.6. The experimental configuration of the wireless power transmission for electric vehicles.

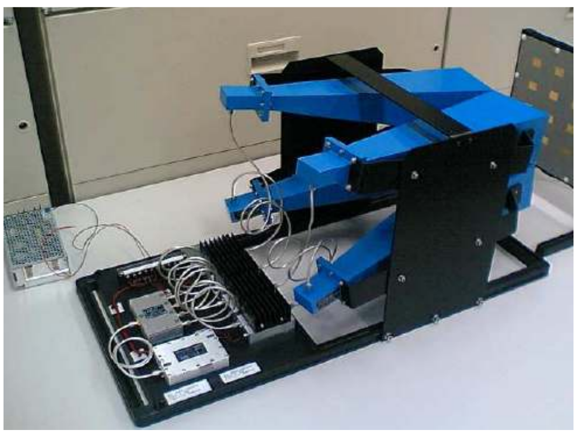

Fig.7. The transmitter for wireless power transmission.

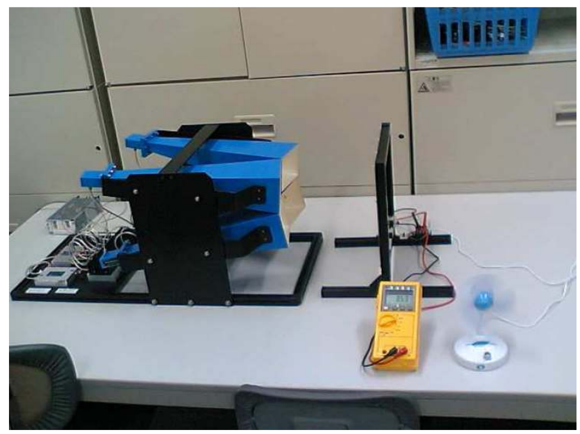

Fig.9. Test devices for wireless power transmission for electric vehicles

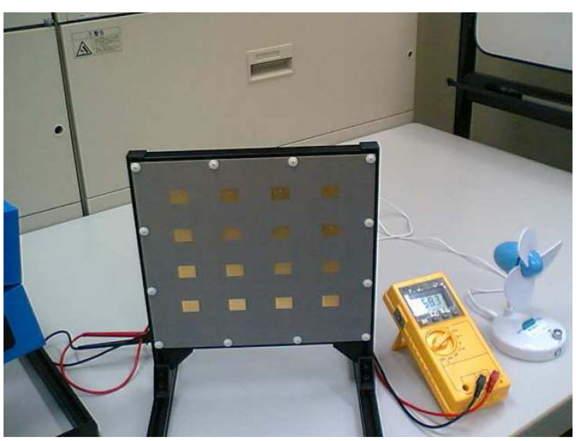

Fig.8. The 4×4 array rectenna..

distance between transmitter and receiver is about 40cm. From this reason, the atmospheric attenuation is not serious problem to compare with the satellite solar power system. In the design of rectenna, microstrip dipole and patch antennas are widely used. Microstrip antenna has the characteristics of light, easy and small-size manufacturing. However, it has demerits due to relatively narrow bandwidth, restricted incident power and low gains. However, in this paper, microstrip patch antenna is adopted due to its big size and no polarization characteristics.

Fig. 3 shows the prototype of rectifying circuit. The rectenna circuit consists of a matching circuit and rectifying circuit. The rectifying circuit is a key element to improve the RF-DC conversion efficiency. A Schottky diode HSMS-8202 is chosen for the rectifying circuit. The measured gain of the manufactured rectenna is shown in Fig. 4. The rectenna shows the maximum gain as 6.2dBi at the frequency of 5.8 GHz with PTFT (Teflon) board of 10 dielectric constant and 1.6 mm thick. Usually higher DC output voltage results in a smaller junction capacitance, which also gives better conversion efficiency. A broadband capacitor C08BLBB1X5UX is chosen as the DC pass filter.

Fig. 5 shows the output voltage performance versus input power. The output voltage performance of the rectenna is performed in free space, since the wireless power transmission

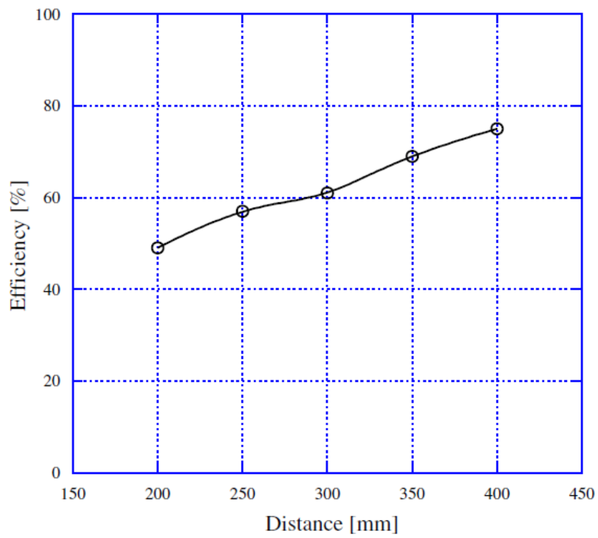

Fig.10. The rectenna conversion efficiency versus transmission.

for electric vehicle is carried out in free space. From the measured results, output voltage is increased when increase the input power. For the input power of 1 mW, the output voltage is obtained about 230 mV.

III. EXPERIMENTAL RESULTS

The system specifications are summarized in Table 1. Fig. 6 shows the experimental configuration of the wireless power transmission for electric vehicles is provided by a field effect transistor (FET) oscillator and divided into four elements using a power divider. Four FET amplifiers with the output power of 1 watt each are used to have totally 4 watts output power. Each microwave is guided to an antenna through a coaxial cable. In this experiment, a horn antenna, whose exit plane size is 112mm ×85mm, is used and four horn antennas are arranged as shown in Fig. 7. Each horn antenna gain is 16dBi. The distances between the horn antenna and the center of rectenna array for measurement are 200mm, 250mm, 300mm, 350mm, and 400mm. Rectenna is designed with the PTFT board of 10 dielectric constant and 1.6 mm thick. The 4×4 rectenna array consists of 16 patch antennas and each patch antenna size is 19mm×15mm as shown in Fig. 8. The patch antennas are in front and rectifying circuits are in back of antenna.

We adopted 5.8 GHz rectenna since the frequency of 5.8 GHz is ISM band. In this case, no license is necessary to experimentalize the wireless power transmission for electric vehicles. However, a possible transmission power is also limited. Thus, in this experiment, 4 watts is used as a transmitted power. The 4×4 rectenna array is used and the load resistance is chosen as 50 Ω. The RF-to-DC efficiency is defined as

$$\eta = \frac{P_{dc}}{P_r} \times 100\% \qquad (1)$$

where P_{dc} is the DC output power and P_r is the power received by the array rectenna that is calculated by using the Friss transmission equation [17]. By changing the distance between the transmitting antenna and rectenna array, the efficiencies for different power densities can be determined. The power density P_d is given by

$$P_d = \frac{P_t G_t}{4\pi D^2} \qquad (2)$$

where P_t is the transmitting power, G_t is the horn antenna gain, and D is the distance between the horn antenna and the center of the rectenna array. Figure 10 shows the rectenna conversion efficiency versus transmission distance. From the measurement results, the conversion efficiencies are 49% and 75% for 4×4 rectenna array at the transmission distance of 200mm and 400mm, respectively. For a small transmission distance, the rectenna does not work as well as those at long distance like 400mm. One possible reason is that the incident power density is not uniform for a large array. Therefore, not all of the rectenna elements have the same output voltage due to their different positions. From this reason, transmitter beamforming is necessary to increase the conversion efficiency. When we can increase the transmission power, the transmission distance can be increased. In this case, the incident power density would be uniform. Therefore, the conversion efficiency of the rectenna array would be improved. The experimental results are summarized in Table 2.

TABLE II
EXPERIMENTAL RESULTS.

Distance (mm)	Conversion efficiency (%)
200	49
250	57
300	61
350	69
400	75

IV. CONCLUSION

In this paper, a 4×4 rectenna array has been developed for electric vehicles. The rectenna element is a microstrip patch antenna that has a gain of 6dBi. Rectenna is designed with the PTFT board of 10 dielectric constant and 1.6 mm thick. The conversion efficiencies are 49% and 75% at the transmission distance of 200mm and 400mm, respectively. Without transmission beamforming, the incident power density is not uniform for a large array. Therefore, not all of the rectenna elements have the same output voltage due to their different positions. From this reason, transmitter beamforming is necessary to increase the conversion efficiency.

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