Wireless Energy Supply for a MAV Propulsion System

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Abstract

Wireless energy supply for an MAV propulsion system using microwave was developed. This system consists of three sub system; the transmitter system, the rectenna system, and the tracking system. In the transmitter system five horn antennas were used as the antenna elements for the phased array system and both the beam divergence and steering angle was about 9deg. Eight rectennas were arrayed in parallel to obtain enough power to drive the electric motor on the MAV (the voltage was 250mV and the current was 6.8mA) in rectenna system. In tracking system two units of antenna system with leaf pattern which received the linearly-polarized wave despite the MAV yaw angle were set in each axis (x, y) for tracking an MAV in a 2-Dimentional space. And three output voltages V_{com}, V_1 and V_2 were loaded in the PC to detect if the distance between transmitter and receiver was not constant. Finally when the microwave beam was steered by the phased array system the output voltage from rectenna was measured at 62cm while the MAV circled around above the transmitter system.

Introduction

Wireless energy supply for a Micro Aerial Vehicle (MAV) propulsion system using microwave has been planned in the Department of Aeronautics and Astronautics, the University of Tokyo, as a part of 21st century Japanese Center of Excellent projects.

Energy transmission by microwave has been studied as the technology for the Solar Power Satellite (SPS) intensively. In the SPS microwave is transmitted from the satellite to the ground. [1,2]

Figure 1 shows the system developed in our laboratory. It consists of three sub systems; the transmitter system, the rectenna system, and the tracking system. [3,4]

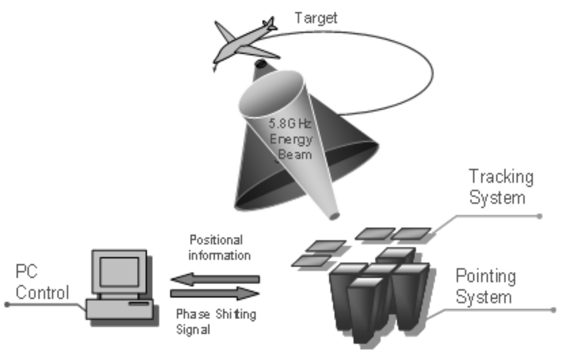

Fig. 1. System of microwave power supply to MAV.

In the transmitter system a microwave beam is formed and pointed to an MAV by phased array system. The rectenna system receives the power of microwave and converts AC into DC for operating of the electric motor on the MAV. In the tracking system the pilot signal sent from the MAV is received and the position of it is analyzed by the Software retro directive system. The analysis result is sent to the transmitter system for beam steering.

By using this system an MAV, for example a plane working for the area struck by disaster, will not need to land in every refill time and just need to circle around above the energy station. As a result of this the charging time becomes shorter.

Transmitter System

Figure 2 shows the block diagram of phased array system. The phases of 5.8GHz microwaves from each antenna element were controlled by the phase shifters connected a PC and a microwave beam was formed and steered. Table 1 is its specification and figure 3 shows geometry of the antenna.

Five horn antennas were used for the antenna elements and 0.7W power was transmitted from each antennas. The beam divergence was about 9deg and the beam steering angle was from -9deg to +9deg.

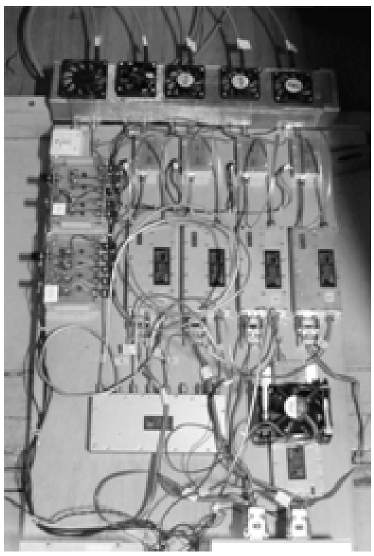

Fig. 2. The picture of the antenna array system.

Table 1. Specifications of the five-element phased array antenna.

Parameters	values
microwave frequency	5.8GHz
wavelength, λ	51.7mm
total transmission power, *P*	3.5W
array pitch, *d*	110mm (d/λ=2)
diameter of the array, *D*	330 mm

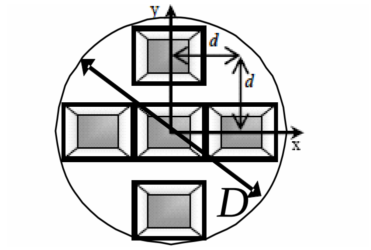

Fig. 3. Geometry of the five arrayed antenna elements.

Rectenna System

The rectenna system consists of the receiver antenna with leaf pattern on the front side and the rectifier circuit on the back side. Because the antenna receives linearly polarized microwave as circular polarized one it receives constant power at various MAV's yaw angle.

The dependence of rectification efficiency η on the external load *R* was measured in figure 4. The maximum efficiency of η=23% was obtained at *R*=150Ω.

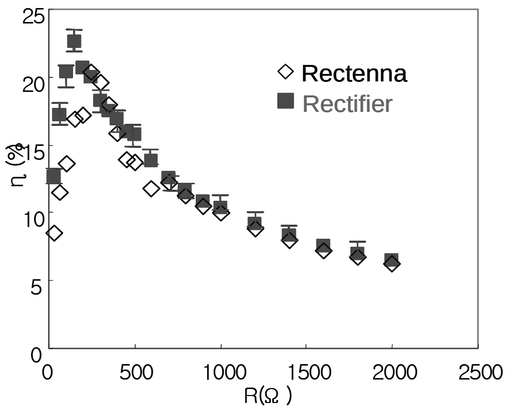

Fig. 4. Relation between the rectifying efficiency and the external load.

To operate the electric motor on an MAV whose minimum driving power is 200mV and 6mA eight rectennas were arrayed in parallel. Figure 5 shows the eight-element rectenna array and figure 6 shows the rectifying characteristic of single and eight-rectenna arrays at 62cm from transmission antenna. The measured output voltage of eight-element array was slightly lower than the calculated because of mismatch between the antenna and the rectifier and reflection and radiation on MSL. In spite of this the output voltage was 250mVand the current was 6.8mA and this was the maximum value in power. Also it is enough to operate the electric motor.

Fig. 5. The picture of eight-rectenna array. Rectifier circuit attached perpendicular to the patch on its back side to minimize antenna pitch.

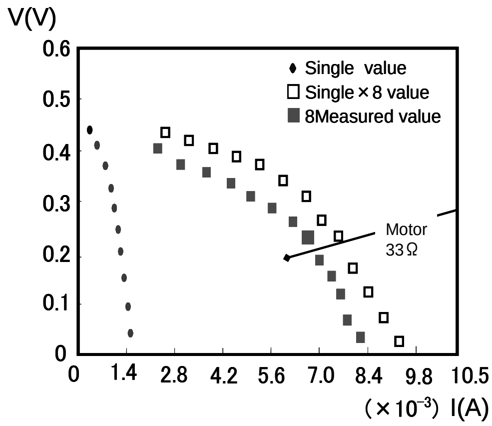

Fig. 6. *I-V* characteristics of single and eight-rectenna arrays. Solid line shows the motor load characteristics.

Tracking System

The block diagram of tracking system is shown in figure 7.

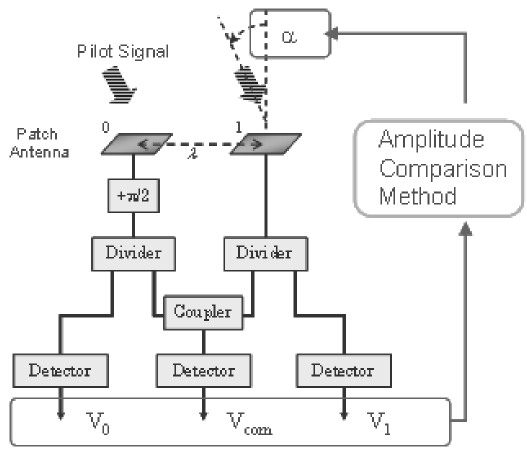

Fig. 7. The block diagram of tracking system.

This system receives the pilot signal of 2.45 microwave sent from the MAV and analyzes its current position by the phase difference between two

patch antennas aligned in the certain direction with the pitch of λ. An analog phase shifter was inserted in one line to make π/2 of phase difference to each other. Divided and coupled microwave signals are rectified using a commercially available detectors. Finally three DC outputs V_0, V_{com}, V_1 are read in the software retro directive system in the PC. The incident angle of a pilot signal α is computed by a LabVIEW program.
The following equation expresses the relationship among these parameters:

$$V_{com} = \eta_1 \left(V_0 + 2\eta_2 V_0^{0.5} V_1^{0.5} \sin\phi_1 + V_1 \right) \qquad (1)$$

Here, $\varphi_1$is expressed by the incident angle to the antennas α.

$$\varphi = 2\pi \sin\alpha \qquad (2)$$

The relationship between incident angle α and output signal V_{com} was plotted in figure 8. To fit the measured line the line calculated by Eq. (1) with η_1=0.48, η_2=0.60 (if α>0) and η_1=0.55, η_2=0.65 (if α>0). The detectable range of α is -13deg to +13deg.

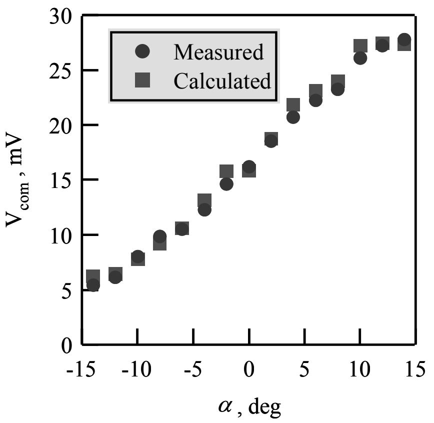

Fig. 8. Relation between incident angle α and output signal V_{com}.

For tracking an MAV in a 2-Dimentional space, two units of antenna system shown in Fig. 7 were set as indicated in figure 9.

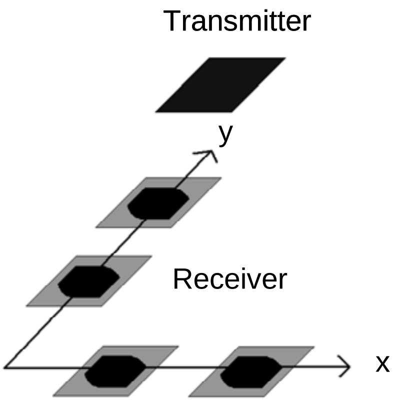

Fig. 9. Antenna arrangement for 2-dimensional tracking.

The incident angles in two rectangular coordinates α_x and α_y are analyzed using a LabVIEW program in a PC. Leaf pattern antennas same as rectenna system is employed to detect the linearly-polarized wave despite the MAV yaw angle.

In our previous research, only V_{com} was used to analyze the incident angle because the distance between transmitter and receiver was constant and V_1 and V_2 are constant too. When the distance is not constant, variation of V_1 and V_2 as well as V_{com} will be analyzed for angle detection.

Beam Steering

An electric motor with a propeller of 6cm in diameter was mounted on a MAV model. Figure 10 shows the installation of equipment for beam steering. The MAV circles over the transmitter antenna at the hight of 62cm by another electric motor not using the transmitter system and the microwave beam from the transmitter was steered for the point (0, -12deg).

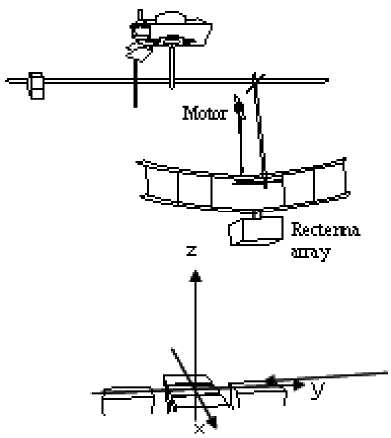

Fig. 10. Installation of equipment for power transmission demonstration.

The output voltage from rectenna was measured in one cycle of the MAV in figure 11.

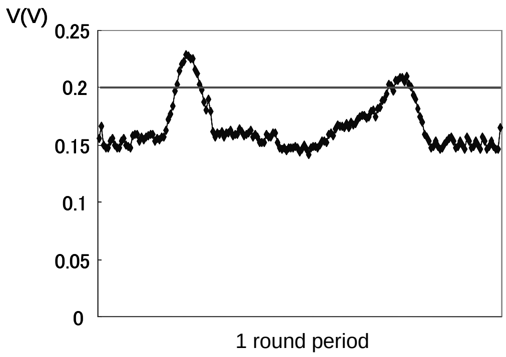

Fig. 11. The rectenna array output voltage during one cycle.

The line at 0.2V means the minimum requirement for operation of the motor on the MAV. The main lobe (the left side peak in fig.11) and the side lobe (the right side peak in fig.11) was measured at the expected point. At the point of main lobe the output voltage satisfied the condision of motor operation though it also satisfied at the point of side lobe.

Conclusion

In the transmitter system the beam divergence and the steering angle were measured. Both of them was about 9deg. The electric motor on the MAV was operated by eight rectennas array whose output voltage was 250mV and current was 6.8mA in rectenna system. It was also the maximum value in power. In the tracking system two units of antennas with leaf pattern were set in each axis to detect the position of the MAV in 2-Demetional space and at any yaw angle. And three outputs were loaded in the PC for tracking at any altitudes. Moreover while the MAV circled around above the transmitter system the output voltage from rectenna was measured with beam steering.

Acknowledgments

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