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Integration of MAV Wireless Power Transmission Systems

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An auto-tracking wireless power transmitter system for a Micro Aerial Vehicle has been developed. In this paper, a beam transmitter system and a tracking system were combined. A MAV model sending a 2.45GHz pilot signal was tracked by retro-directive function while it was circling over the transmitter at the altitude of 100cm and a 3.5W beam of 5.8GHz microwave was sent back to the MAV by an active phased array. In addition, flexible and light-weight rectennas were developed. They are easily mountable on our flying-wing shape MAV model.

I. Introduction

Micro Aerial Vehicle (MAV) flight using microwave power supply has been investigated at the University of Tokyo. Figure 1 shows a flying-wing shape MAV model equipped with a light-weight flexible rectenna. Microwave wireless power transmission system has been intensively studied as the technology for the Solar Power Satellite (SPS) system. [1,2] The concept of our system is as follows. An MAV, working over the area struck by disaster for example, comes back to the power station when its battery becomes low. Then the battery is charged by receiving the microwave beam transmitted from the power station while it is circling over it. As a result, the MAV's battery is charged semi-automatically without landings and take-offs. Figure 2 shows the schematic of the system developed in our laboratory. [3, 4]

Figure 1 Micro Aerial vehicle model above a microwave power transmitter. Patch rectenna array is mounted.

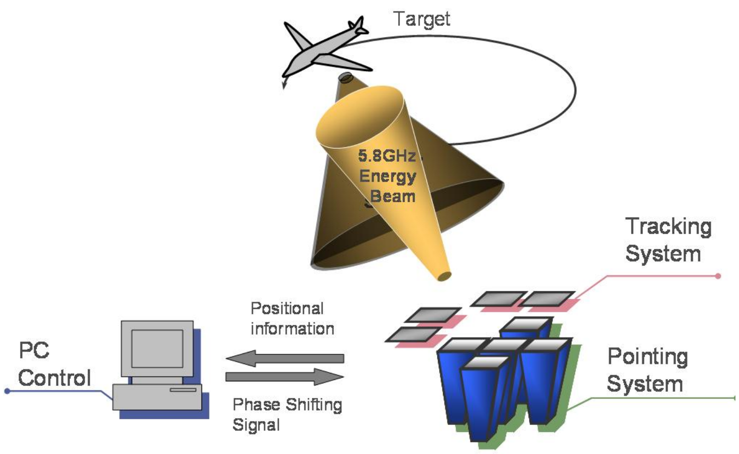

Figure 2 Microwave wireless power supply system to a MAV.

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The Microwave power supply system consists of three subsystems; power transmitter, rectenna, and tracking subsystem. In the transmitter subsystem, a microwave beam of 5.8GHz is formed and steered using a phased array antenna.

In the rectenna system, the microwave power received by an antenna is converted to DC power by an in-house rectifier and used to drive an electric motor on a MAV model. In the tracking system, the position of the MAV is detected using a software-retro-directive mechanism.

The microwave beam from the transmitter system is pointed to the MAV using the information of its position analyzed in the tracking system and the MAV flies by the electric motor on it using the power received by the rectenna system.

II. Microwave Power Transmittersubsystem

Beam forming and steering of a 5.8GHz microwave beam was achieved by an active phased array antenna. Figure 3 shows the photograph of the horn antenna array (top) and microwave amplifier system (bottom). Figure 4 shows the block diagram of the system. The array antenna consists of five horn antennas. Each horn antenna transmits 0.7W power amplified by Field Effect Transistors and its phase was controlled by 6-bit digital phase shifters connected to a PC. Measured main-lobe fractional energy and main-lobe beam divergence angle are well agreed with the calculated ones. The beam divergence was about 9deg, which corresponds to the beam quality factor M^2=1.6. The beam steering angle was from -9deg to +9deg. Its specifications are listed in Table 1.

With a circularizer on the horn antennas, circular polarized wave can be emitted. This is essential for stable power transmission regardless the yaw angle of the circling MAV.

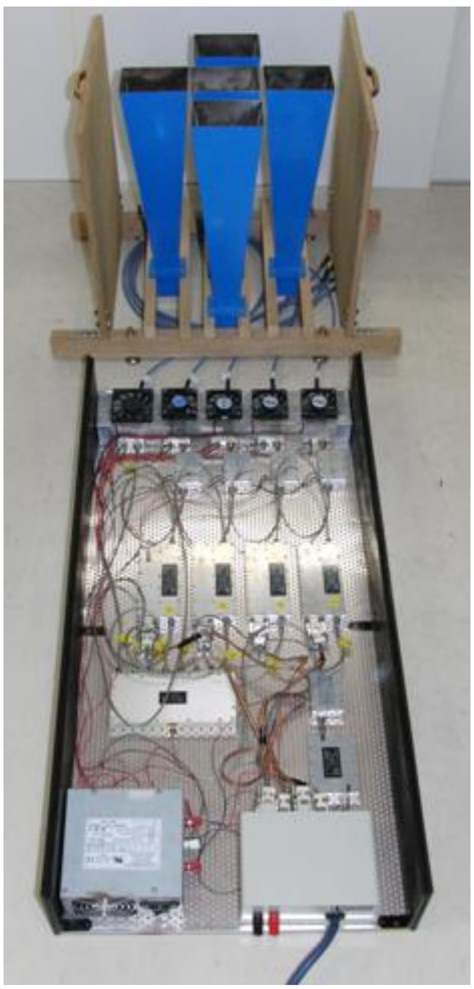

Figure 3 Power transmitter subsystem. horn antenna array (top) and microwave amplifier system (bottom).

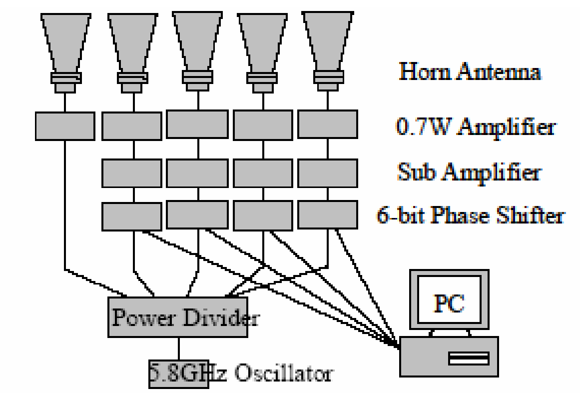

Figure 4 Block diagram of the power transmitter subsystem.

Table 1 Specifications of the five-element active 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

III. Tracking subsystem

A 2-dimensional tracking system using software retro-directive function was developed. 2.45GHz microwave was used as a pilot signal and its incident angle can be detected using the phase difference in the signals received by multiple antennas. Figure 5 shows the block diagram of the tracking system. The phase difference of $\pi/2$ is added to one of the antenna lines as indicated in the figure.

Three patch antennas are installed beside the transmitter horn antennas as shown in Fig. 6. With this incorporation, simultaneous auto-tracking and beam steering become possible. The antennas pitch is 1.39λ (=17cm) so that each pair of tracking antennas is able to detect incident angles α_x, and α_y from −10.4 degree to 10.4 degree.

The MAV model sending a10mW pilot signal was slid in the *x* and *y* directions at the altitude of 100cm. The result was plotted in Figure 7.

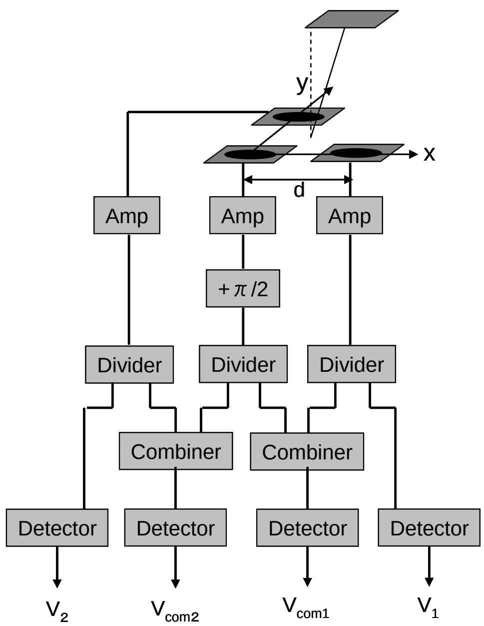

Figure 5 The block diagram of 2-dimensional tracking system.

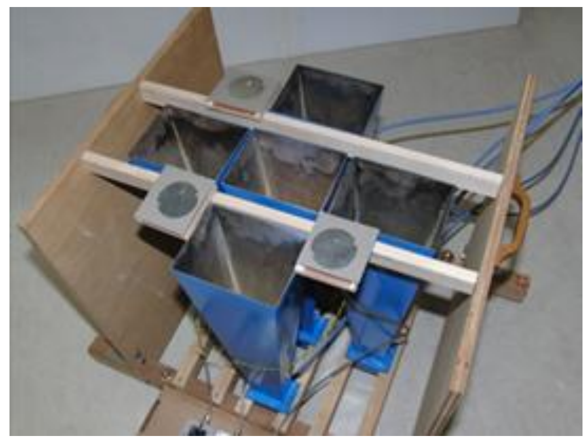

Figure 6 Integration of the transmitter antennas and tracking antennas.

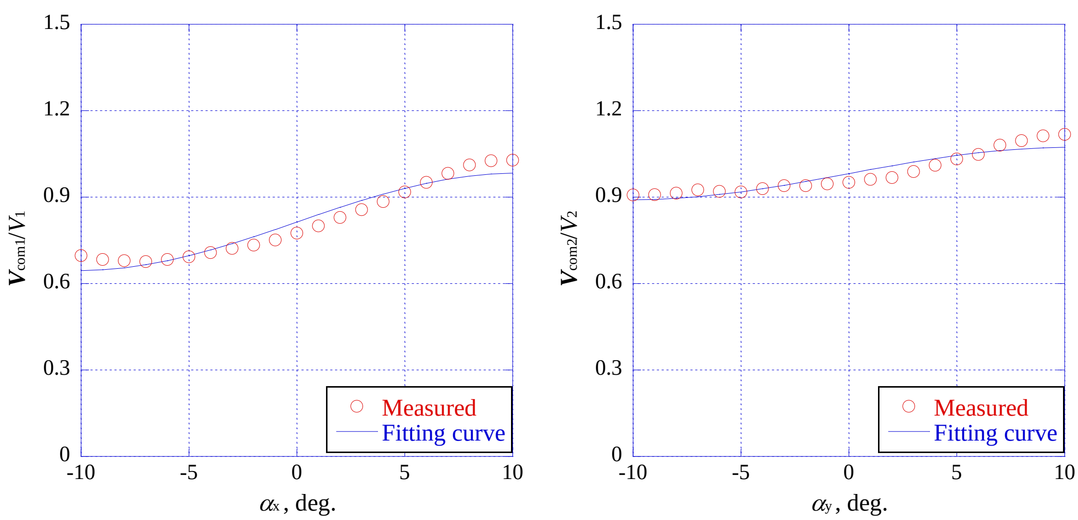

Figure 7 Relations between the output signal and the incident angle in the *x* direction (left) and the *y* direction (right) .

Next, the MAV model was rotated using a motor and a supporting bar at the altitude of 100cm. (The MAV model cannot fly by itself yet.) The rotation radius was 10cm and corresponding incident angle was 5.7 degree. The rotation period was 1.57 second per round. That is, the rotation speed was 48.8 rpm. Figure 8 shows the estimated incident angles using the correlation shown in Figure 7.

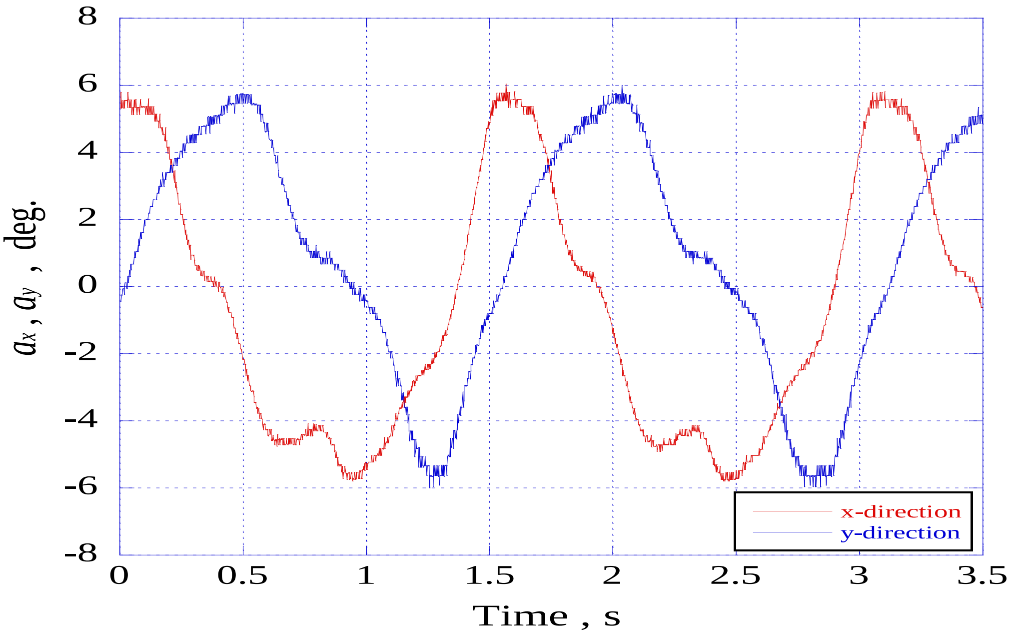

Figure 8 Incident angles α_x and α_y while the MAV model is circling at the radius of 10cm and the altitude of 100 cm.

To detect MAV position, we just need to know the circling angle θ. Figure 9 shows the temporal change in circling angle θ estimated from the data shown in Fig. 8. This result indicates that the rotation speed and the MAV's direction were accurately detected using the retro-directive function.

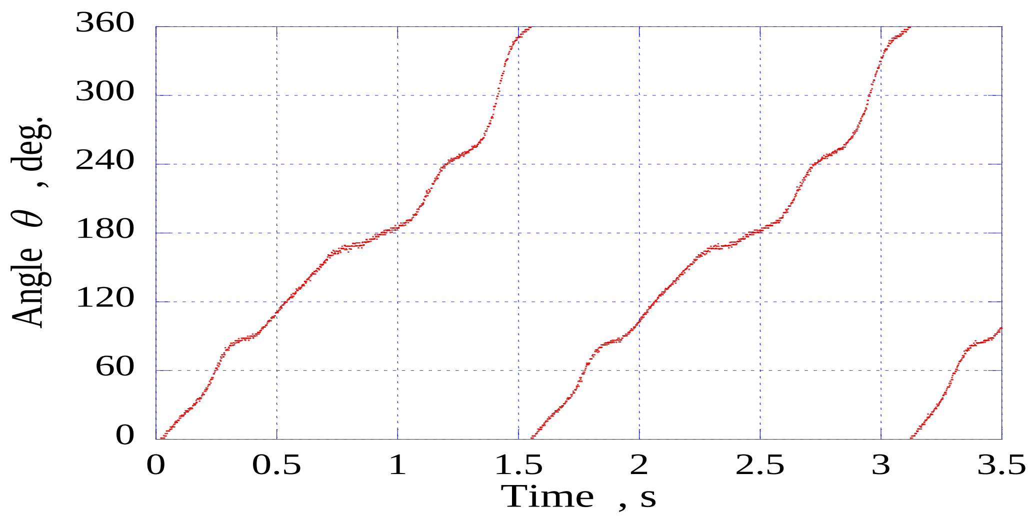

Figure 9 Detected circling angle of the MAV at 100 cm altitude.

IV. Receiving Subsystem

In our previous study, a circular polarized wave patch rectenna on a silicon substrate was developed. Because the size of the rectifier circuit was larger than the effective area of the patch antenna, the rectifier circuit was attached perpendicular to the patch circuit, resulting in a very thick, rigid and heavy rectenna. Therefore, it was unsuitable for mounting on the MAV.

In this study, two thin, flexible and light-weight rectenna were developed. One is a membrane dipole rectenna composed of a dipole antenna and a rectifier circuit, both of which were fabricated on the front and back of a thin polyimide film. The antenna and rectifier circuit were made by cupper films. A pair of dipole antennas was arrayed for higher input power to the rectifier circuit. (H-shape) Figure 10 shows the rectenna which is composed of 16 elements.

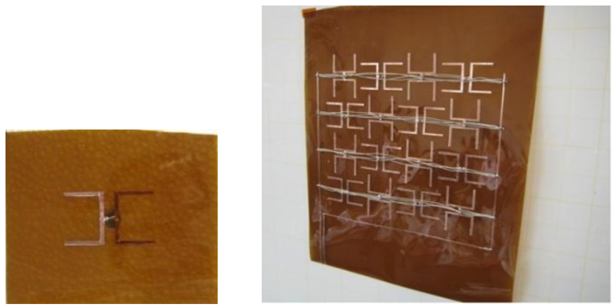

Figure 10 H-shaped dipole on a polyimide film (left) and 16-element rectenna array (right).

Theoretical power reception per unit area of a dipole antenna is about half of that of a patch rectenna. Then we used a felt pad as a dielectric substrate and manufactured a flexible patch rectenna. Figure 11 shows the flexible patch rectenna. The conductive material is a cupper film.

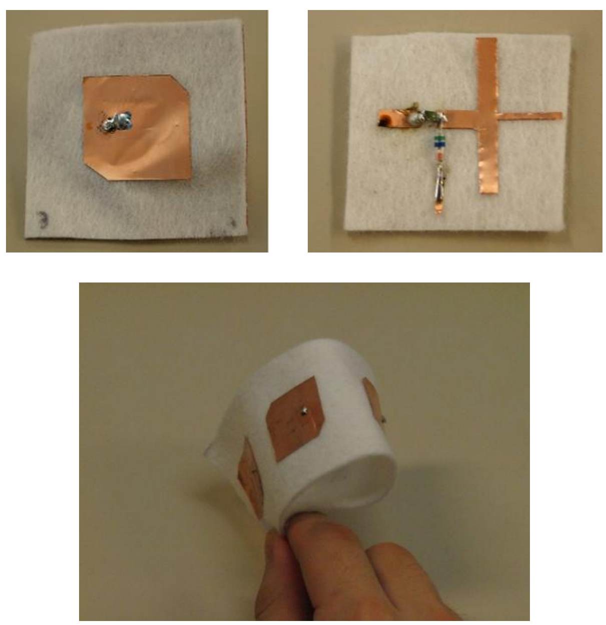

Figure 11 Flexible patch antenna on the front of felt (upper left), the rectifier circuit on the back of felt (upper right), and Flexible patch rectenna array(bottom).

Table 2 shows the measured power reception efficiency along with weight, thickness and weight per unit area. The efficiency of the patch on felt was inferior to the conventional patch on silicon. The power reception efficiency was defined as a ratio of a receiving power to a power which comes to effective antenna area. This would be because its geometrical parameters (feeding point and cutoff size) have not been optimized yet. However, the patch on felt is as light and thin as the dipole on membrane dipole; it is very attractive for mounting on the MAV.

Table 2 Comparison of in-house rectennas.

	Antenna type		
	patch of felt	dipole on membrane	patch on silicon
power reception efficiency, %	56	25	69
Weight, g	1.6	0.65	10.68
Thickness, mm	1 - 1.2	0.05 - 1	32
weight per unit area, g/cm^2	0.079	0.026	1.15

V. Summary

A 2-dimensional tracking system using software retro-directive function was developed and the tacking antennas were set beside the transmitter antennas. Its tracking performance was demonstrated using the MAV model rotating with the radius of 10 cm at the altitude of 100cm. As a result, the rotation speed and the MAV's direction were accurately detected using the retro-directive function.

Thin, flexible and light-weight rectennas were developed; dipole on polyimide membrane and patch on felt. Their thickness and the weight per unit area were less than 1 mm and 0.08 g/cm^2, respectively. Both are suitable for a MAV rectenna system.

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