PROCEEDINGS OF ISAP '92, SAPPORO, JAPAN

FUNDAMENTAL EXPERIMENT OF A RECTENNA ARRAY FOR MICROWAVE POWER RECEPTION

Takeo Ito, Yoshiyuki Fujino and Masaharu Fujita
Communications Research Laboratory
Koganei, Tokyo 184, Japan

INTRODUCTION

Microwave power transmission is an important future technology for energy supply to an isolated and/or moving object to which it is difficult to construct a power line. The technology is a strong candidate as a means of energy supply to an unmanned vehicle flying at 20 km altitude for microwave relay, environmental monitoring and other applications. An instrument called a rectenna (rectifying antenna) is used to extract a DC power from a propagating microwave. Several studies have already been performed on rectenna(1),(2),(3); however, they are designed basically for SPS (solar power satellite) applications.

In this paper, we propose a new type of rectenna consists of a flat mount rectifying circuit for a flying unmanned vehicle. Some preliminary results from a fundamental experiment are given to show the feasibility of rectenna development.

DESIGN

A rectenna element is a device with which a propagating microwave is received and converted into DC power. It consists of an antenna element, a diode for rectifying a microwave and filters. A half-wavelength dipole antenna is sometimes used as an antenna element for a rectenna. Since the rectifying diode is a nonlinear element, higher harmonics are generated when a microwave is applied to the diode. Filters are thus used to reduce the amount of higher harmonics power which backs to the antenna element. The higher harmonics energy must be only a fraction of the received microwave energy; however, total amount of microwave energy impinging onto the rectenna is very large, so that it would be impossible to neglect the influence of the higher harmonics energy even it is only a fraction. It is therefore worth to reduce the efficiency of the antenna element to radiate higher harmonics. Since a half wavelength dipole also resonates at higher harmonic frequencies, better selection of an antenna element is necessary from a radio environment point of view. Here, we have adopted a circular microstrip antenna for a rectenna as was used in (1), since its resonance frequencies correspond to roots of a cylindrical function and do not coincide with higher harmonic frequencies. A microstrip structure is suitable from a view point to protect a rectifying circuit including a diode with a ground plane from a strong microwave radiation. For ease of fabrication and adjustment, it is desirable to accommodate a rectifying circuit on one plane with microwave feeders. To realize a one plane rectifying circuit in which no through holes are necessary to mount diodes, we have adopted the balanced circuit as shown in Figure 1. A circular patch is fed at two points where the signal phases are different by 180^0 to each other. An electromagnetic coupling technique is intended to use in the present rectenna design to separate the antenna and the rectifying circuitry. Filters to reject the 3rd and 5th harmonics are inserted

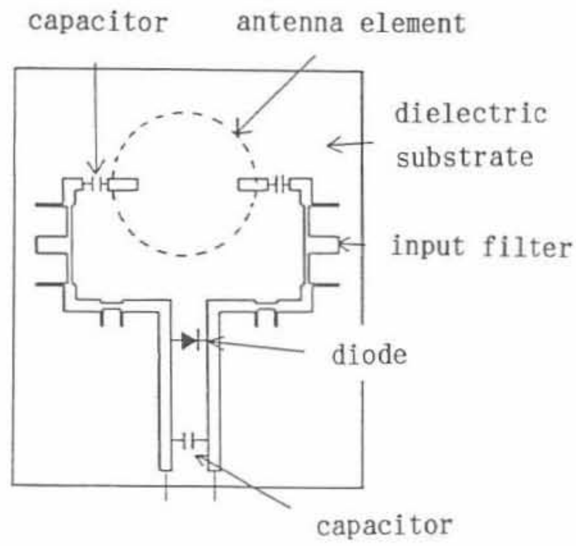

Figure 1. A proposed rectifying circuit for a rectenna.

between the antenna feed points and the diode. After rectification, DC energy is introduced into a DC bus line. A capacitor attached in the DC bus line reflects the odd-order harmonics and shorts the circuit for even-order harmonics. Thus there would be no microwave component in the DC bus line after the capacitor.

CHARACTERISTICS OF A RECTIFYING CIRCUIT

Prior to the experiment using a propagating microwave, fundamental characteristics of the proposed rectifying circuit are measured by connecting the circuit and a microwave signal generator with a cable(4),(5). The measurements are made on a conversion efficiency from a microwave to DC and a generation characteristics of higher harmonics.

To obtain a high microwave-DC conversion efficiency, it is necessary to use a diode with low loss resistance and a high peak inverse voltage. At present, there are no diodes applicable to microwaves which satisfy the above requirements. Thus we use 8 Schottky diodes (HP5082-2350) to improve the characteristics by combining them in series and parallel manner. Figure 2 shows the microwave input-DC output characteristics, and the conversion efficiency as a function of the input power. DC output power of 1 W is obtained with 67% conversion efficiency; however the maximum efficiency of 70% is attained when the output power is around 0.84 W. Larger power would be obtained if input microwave power increases, although the efficiency would become lower. It is confirmed experimentally that the higher output power of 3.36 W is obtained at 65.3 % efficiency when 4 rectifying circuits are operated in parallel.

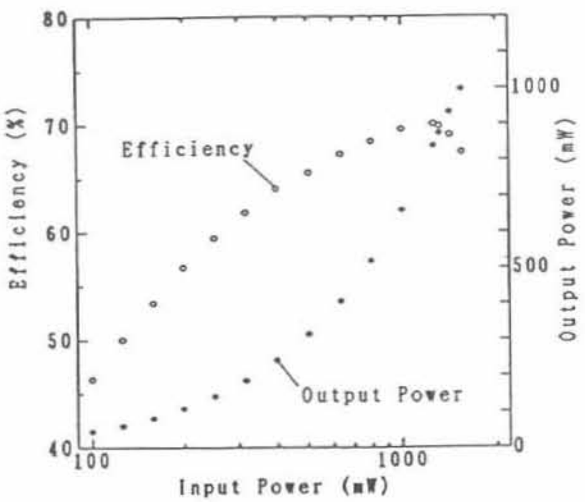

Figure 2. Microwave input-DC output characteristics of the rectifying circuit and the conversion efficiency.

MICROWAVE POWER TRANSMISSION EXPERIMENT

A microwave power transmission experiment is carried out in CRL radio unechoic chamber. A rectenna array composed of 9 elements is placing 60 cm apart from a 2.45 GHz band transmitter of an active phased array design as shown in Figure 3. The transmission power is about 60 W. For ease of fabrication and adjustment, the antenna elements are fed by probes in the present prototype rectenna. In the experiment, 4 rectenna elements locating the center of each side from 3x3 arrangement are actually fed for energy reception. Remaining elements are terminated except the central one with which we monitor the impinging microwave power. Prior to the experiment, a distribution of the microwave power flux density (PFD) is measured with an open waveguide over a plane on which the rectenna is placed. Since the distance between the transmitting and the receiving antennas are close enough, the microwave PFD varies by about 2 dB over the rectenna surface. This variation must be taken into account when evaluating the conversion efficiency of the rectenna.

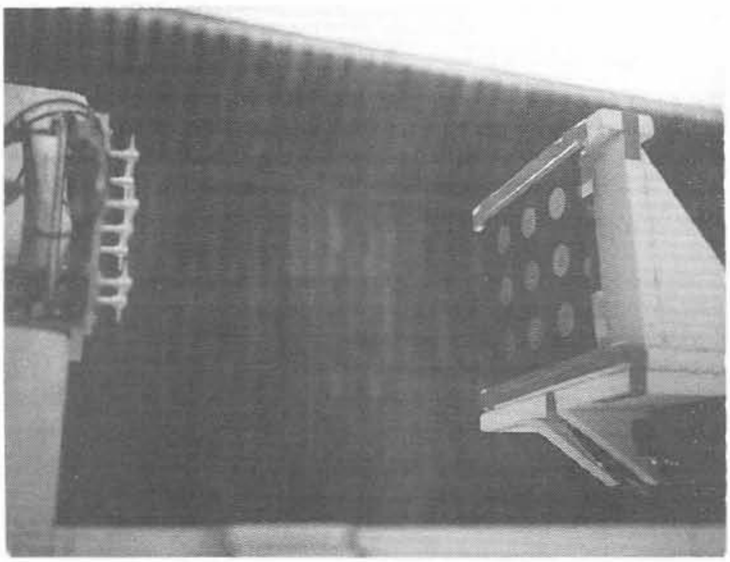

Figure 3. Outer view of the microwave power transmission experiment. Transmitter (left) and rectenna (right).

The microwave powers impinging on each rectenna element are estimated from a received power detected with the central element and a microwave PFD distribution measured previously. By integrating the microwave power over the valid (4) rectenna elements, we can estimate the total microwave input power to the rectenna. The outputs of 4 rectenna elements are connected in parallel to a load resistance of 50 ohms, and its terminal voltage is measured to calculate the output DC power. The load resistance of 50 ohms is the optimum value to give the highest microwave-DC conversion efficiency. The DC output power of 4.0 W is obtained at 61 % of the microwave-DC conversion efficiency as a preliminary result. This value must be improved by fine adjustment of the circuit. The present experiment would be the first step for practical development.

CONCLUDING REMARKS

A rectenna with a planar rectifying circuit is proposed as a candidate of a means of energy supply to an unmanned flying vehicle. The rectifying circuit using 8 schottky diodes provides more than 1 W DC output at 67 % of microwave-DC conversion efficiency. A microwave power transmission experiment using a rectenna array is conducted in an unechoic chamber and demonstrates that 4 W DC output power is obtained from a propagating microwave with a 4-element rectenna array at 61 % of the microwave-DC conversion efficiency. The result is from a preliminary experiment and a higher conversion efficiency is expected after adjustment of the rectifying circuits. This result is promising for future development of a microwave power transmission technology. A microwave diode with higher peak inverse voltage and lower internal resistance is one of the key elements for the rectenna development.

ACKNOWLEDGMENT

The authors would like to express their sincere gratitude to Dr. N. Kaya of Kobe University who made it possible to use the transmitter in the experiment. They express their thanks to Dr. T. Teshirogi for his guidance throughout this study. Thanks are also due to Dr. K. Gyoda for his assistance to conduct the experiment.

REFERENCES

(1)K. Ito, Fundamental investigation on an earth terminal element "rectenna" for solar power satellite reception (in Japanese), Report for the Scientific Research Fund of the Ministry of Education, March 1984.

(2)Y. Shimanuki and S. Adachi, Theoretical and experimental study on rectenna array for microwave power transmission (in Japanese), Trans. IEICE, J67-B, pp.1301-1308, Nov. 1984.

(3)M. Otsuka et al., Relation between spacing and receiving efficiency of finite rectenna array (in Japanese), Trans. IEICE, J73-B-II, pp.133-139, March 1990.

(4)T. Ito et al., A rectenna for a stratosphere radio relay system (1) (in Japanese), B-113, 1990 Spring Nat'l Conv., IEICE, March 1990.

(5)T. Ito et al., A rectenna for a stratosphere radio relay system (2) (in Japanese), B-69, Proc. 1991 IEICE Fall Conf., Sept. 1991.