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Wireless Power Transmission Efficiency of Dipole Array Antenna using a Left-Handed Waveguide Slot Antenna as a Feeder

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Abstract: This paper proposes to transform microwaves for snow melting, which slightly leaking from the slotted waveguide, into electric power using a wireless power transmission technique for effective use. A combination of left-handed and right-handed waveguides is a method to melt snow evenly over a large area using microwaves. The left-handed waveguide, however, has large loss because of stubs. In order to evaluate the effect of the left-handed waveguide's loss, this paper analyzed the wireless power transmission efficiency when the left-handed waveguide with a slot was set as the power transmission part, and a dipole array was placed above the left-handed waveguide as a power reception unit. The wireless power transfer efficiency was calculated using kQ product from S-parameters that were obtained by using the method of moments. The results clarified that the sum of the maximum efficiencies of the arrayed dipoles could be made larger than the maximum efficiency of one dipole.

Keywords: Left-hand, Waveguide, Wireless power transmission, Microwave heating, Snow melting.

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1. INTRODUCTION

Snow melting methods using microwaves have been proposed to quickly remove snow with low cost without requiring space for storing snow [1], [2]. In these methods, leaking microwaves from the slot waveguides heat the mortar blocks that are set on the waveguides, and the heat melts the snow that has piled up or around the mortar blocks. A method to uniformly melt snow over a wide area by combining a right- and a left-handed waveguide has been studied [3]. In general, slotted waveguides have the highest electric field strength near the feeding point [4]. Reference 3 uses a left-handed waveguide to match the direction of electromagnetic wave travel, when the feeding points are set alternately, to achieve uniform electric field strength. A circuit-type waveguide has also been proposed as a method for evenly melting snow in an area with a single power source [5]. Even in this case, the traveling direction control for microwaves can be expected by applying a left-handed waveguide. In addition, a method has been proposed in which this microwave snow melting device is embedded in the road to melt the snow, and at the same time, an electric vehicle is driven by wireless power supply using the same microwave. Experiments have been reported in which a small model of an electric vehicle (EV) is driven on a right-hand waveguide using wireless power transmission [6]. In the case of left-handed waveguide, however, has large loss because of the long stub, and not enough consideration about wireless power transmission efficiency using the slotted left-handed waveguide as feeder, has been given. Therefore, in this study, the wireless power transmission efficiency [7] was obtained by using the electromagnetic field analysis using the moment method and the kQ product [8]. In this paper, in order to increase the power of the power receiving unit, the power receiving antenna is an array antenna composed of dipole antennas. Each element constituting the array is operated as a power receiving unit to synthesize the power to be obtained. If the extracted electric power can be increased, a snow removal robot [9] can be operated using microwaves for snow melting, and more efficient snow melting can be realized.

2. ANALYSIS MODEL

Fig. 1 shows an analysis model in which the left-handed waveguide is the power transmission unit and the two-element dipole array is the power reception unit. Each elements of dipole array are attached rectifier to act as rectena array. The waveguide in Fig. 1 has the stubs in a direction orthogonal to the traveling direction of the waveguide so that the positions of the inductance L and the capacitance C generated in the right-handed waveguide can be exchanged. Here, the electromagnetic field analysis software WIPL-D, which employed the method of moments, was used for the analysis. In order to make the calculation area compact, it has a symmetrical structure with respect to the X axis. S-parameters were calculated by using the asymmetry mode. Here, # 1 is the power supply pin of the left-handed waveguide, and Port1 is set on it. # 2 is a half-wavelength dipole antenna placed on the X-axis, and Port2 is set on it. # 3 is a half-wavelength dipole antenna installed at a distance of Sp = 20 mm from the X-axis in the Z-axis direction. Ports 3 is set on the #3. For comparison, analysis was also performed in the case that # 3 was removed from the analysis model of Fig. 1, and that the power receiving unit was a single-element dipole.

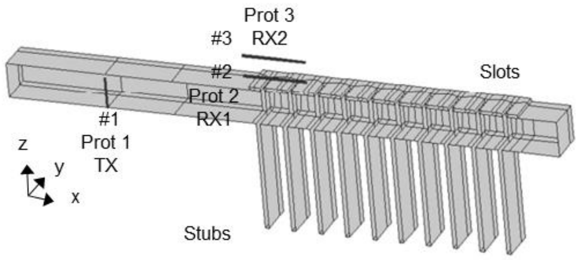
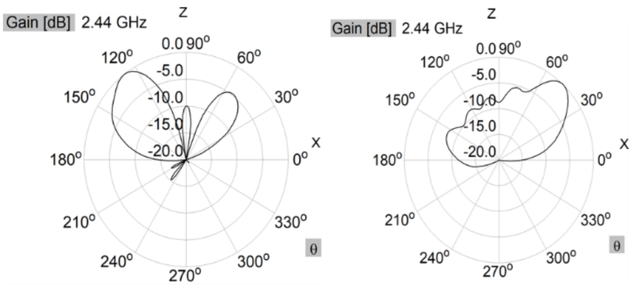


Figure 1. An analysis model in which the left-handed waveguide is the power transmission unit and the two-element dipole rectenna array is the power reception unit..

3. ANALYSIS RESULTS

First, we show the analysis results for the left-handed waveguide only, which does not include wire elements # 2 and #3. In addition, the analysis results of the right-hand waveguide are prepared for comparison. Fig 2 shows the radiation pattern at 2.44 GHz. From Fig. 2, it can be confirmed that the beam is directed in the negative direction of the X-axis in the case of the left-handed system and in the positive direction of the X-axis in the case of the right-handed system.



(a) Left-handed waveguide (b) Right-handed waveguide

Figure 2. The radiation pattern at 2.44 GHz.

Next, Fig. 3 (a) and (b) show the electromagnetic field distributions on the XY plane with the case of the left-handed system and the case of the right-handed system, respectively, for comparison. In the case of the left-handed system, the radio wave spreads and propagates in the negative direction of the X-axis, and in the case of the right-handed system, the radio wave spreads and propagates in the opposite direction of the X-axis.

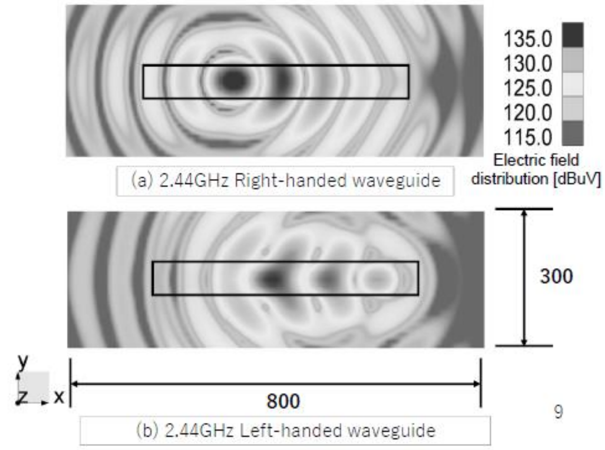


Figure 3 The Electromagnetic field distributions on the XY plane.

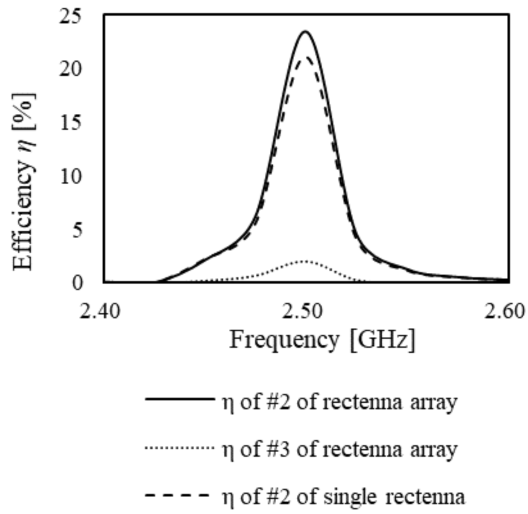


Figure 4 The wireless power transmission efficiencies η vs. frequency.

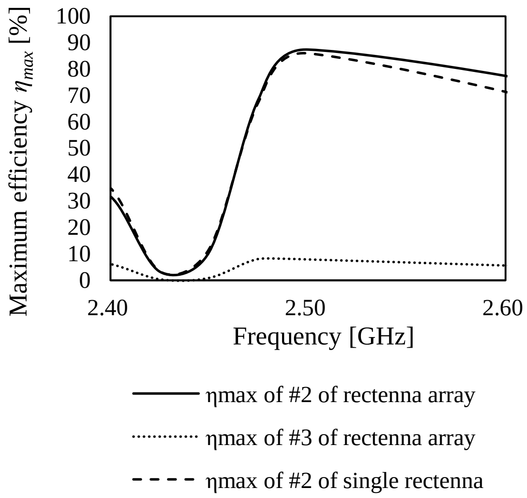


Figure 5 The maximum wireless power transmission efficiencies η_max vs. frequency.

Fig. 4 shows the wireless power transmission efficiency obtained from the kQ product using S-parameter that were calculated by the method of moments electromagnetic field analysis [8], and Fig. 5 shows the maximum wireless power transmission efficiency. Note that kQ product is defined as coupling coefficient multiplied by quality factor, and exclusively rules the maximum efficiency as

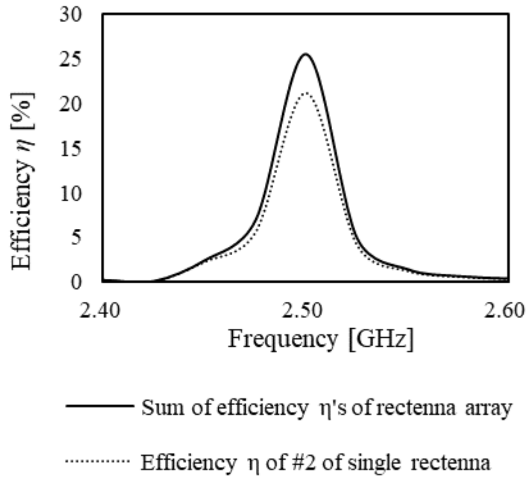
$$\eta_{max} = \frac{\rho-1}{\rho+1}, \ ...(1)$$

$$\rho = \sqrt{1+kkQQ}. \ ...(2)$$

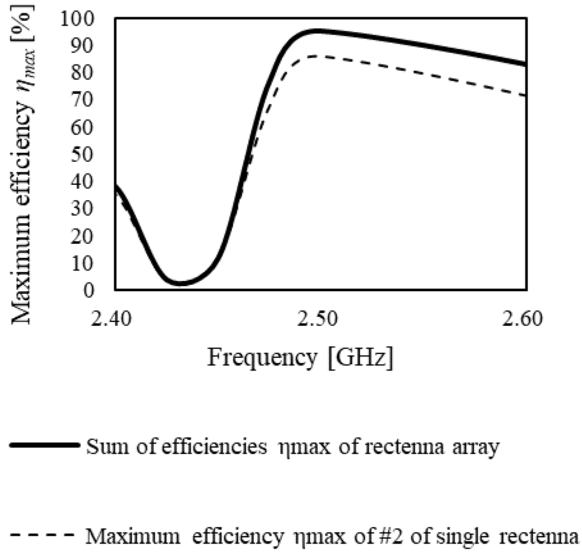
Here, k and Q are equal to coupling coefficient and quality factor, respectively. See [4] for mathematical proof. The efficiency of element #2 of the rectenna array is slightly higher than that of the single rectenna, and #3 also has an efficiency of about 2%. In other words, the #3 element is receiving power itself while increasing the efficiency of #2. The maximum wireless power transmission efficiency shown in Fig. 5 is almost 90% for the both elements. In this case also the element #3 is receiving power itself while increasing the efficiency of #2. Here, the maximum wireless power transmission efficiency is obtained when a matching circuit that satisfies this condition is added to each element. If the power obtained by each element can be added, it can be considered that the total power obtained by using rectenna array is larger than that obtained by using only one element. Fig. 6 shows the comparison of wireless power transmission efficiencies obtained by sum of the two-element rectenna array and the single rectenna.
It can be seen that the resultant efficiency is larger than that for the case of single element rectenna.

3. CONCLUSION

This paper proposed to transform microwaves for snow melting, which slightly leaking from the slotted waveguide, into electric power using a wireless power transmission technique for effective use. The waveguide applied the left-handed waveguide, however, has large loss because of the stub. In order to evaluate the effect of the left-handed waveguide's loss, this paper analyzed the wireless power transmission efficiency when the left-handed waveguide with a slot was set to as the power transmission part, and a rectenna array was placed on the left-handed waveguide as a power reception unit. The wireless power transfer efficiency was calculated using kQ product from S-parameters that were obtained by using moment method analysis. The results clarified that rectenna array successfully work to increase the wireless power transmission efficiencies. Each element of rectenna array also received the power itself. The sum of the maximum efficiencies of the arrayed rectennas could be made larger than the maximum efficiency of single rectenna.



(a) Efficiency η



(b) Maximum efficiency η_{max}.

Figure 6 The comparison of wireless power transmission efficiencies obtained by sum of the two-element rectenna array and the single rectenna.

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