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A prototype of rectenna integrated with a 900 MHz band antenna and a rectifier

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Abstract

A rectenna for wireless power transmission via radiowaves in the 900 MHz band was developed with a focus on impedance, aiming to improve efficiency. There are two types of impedance matching conditions: conjugate matching and image impedance matching. In order to satisfy both conditions simultaneously, it is necessary to match with a pure resistance. Therefore, rectifier circuits and antennas were made with the same pure resistance value and combined as an integrated rectenna. A double voltage rectifier circuit and a monopole antenna were installed in the integrated rectenna. The rectenna could be matched with almost pure resistance and evaluated about 1.03 of the VSWR. The efficiency of the rectenna was measured to be about 37.4 [%] at a transmission power of 15 [dBm] and a distance of 50 [cm].

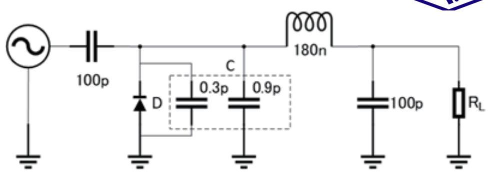
1 Introduction

Researches on an integrated rectenna combining rectifier circuits and antennas has been conducted in the field of wireless power transmission via radiowaves [1]. In order to efficiently transmit the high frequency power received by the antennas to the rectifier circuits without reflection, conjugate matching and image impedance matching must be satisfied at the same time [2]. This report presents a prototype of an integrated rectenna combined with a rectifier circuit and an antenna both with pure resistance in 900 MHz band.

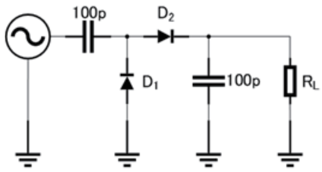
2 A prototype of rectifier with pure resistance

We prototype a class E rectifier and a voltage doubler (VD) rectifier. Sunhayato's glass epoxy (FR-4) double-sided substrate NZ-G34KR (dielectric constant: 4.7, dielectric loss tangent: 0.015, substrate thickness: 1.6 [mm], conductor thickness: 35 [μm]) is used for the prototype. Impedance measurements are performed on Anritsu vector network analyzer MS46121A in 900 MHz band (from 815 to 1015 [MHz]).

Circuit diagrams of the class E and the VD rectifiers are depicted in Fig. 1. The diodes in the figures are adopted the SKYWORKS Schottky barrier diode SMS7630 series from the standpoint of low forward voltage and short on-off recovery time [3]. We give the prototypes of the rectifiers in Fig. 2 and impedance frequency characteristics in Fig. 3. Figure 3 supports that the class E and VD rectifiers having the elements constants shown in Fig. 1 are, respectively, about 17 [Ω] and 73 [Ω], which are almost pure resistance.

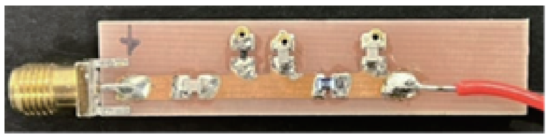


(a) A class E rectifier



(b) A VD rectifier

Figure 1. Circuit diagrams of rectifiers.



(a) The class E rectifier

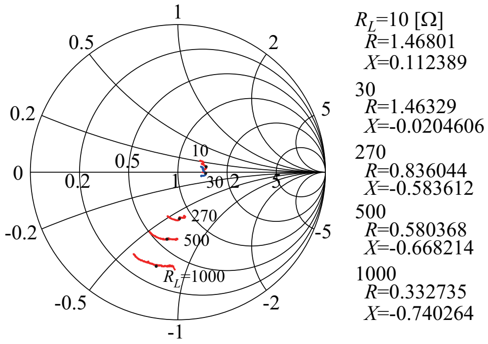
(b) The VD rectifier

Figure 2. Prototypes of the rectifiers in Fig. 1.

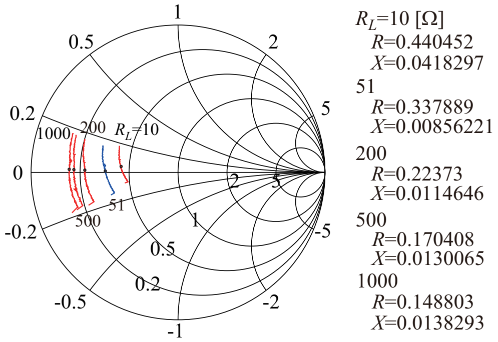
We measure a rectification efficiency that is defined by Eq. (1).

$$\eta = \frac{P_o}{P_i} \times 100 \quad [\%] \tag{1}$$

Here, P_i and P_o are, respectively, high frequency input power and DC output one for the rectifiers. We check the output DC voltage V_o to the load resistance (51 [Ω] and 30 [Ω] resistances in Fig. 1) and evaluate the P_o by using the



(a) The class E rectifier



(b) The VD rectifier

Figure 3. Measurement results of impedance frequency characteristics for the rectifiers in Fig. 1.

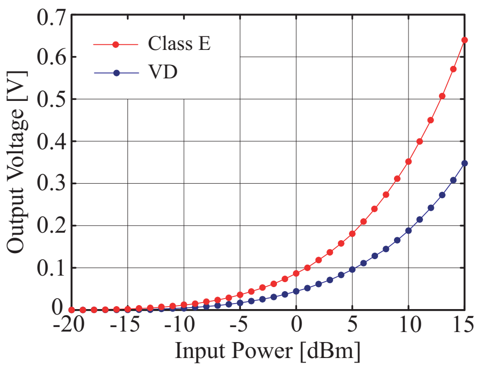


Figure 4. Output voltages for the rectifiers in Fig .1.

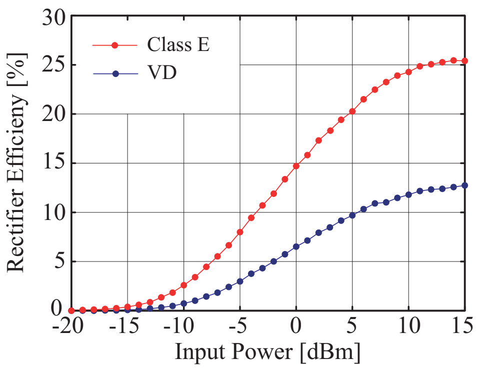


Figure 5. Rectification efficiencys for the rectifires in Fig. 1.

following equation:

$$P_o = \frac{V_o^2}{R_L} \quad [\mathrm{W}] \tag{2}$$

Sanwa digital multimeter CD771 is used for the check the output DC voltage.

Figures 4 and 5 exhibit the output voltage and the rectification efficiency, respectively. The maximum rectification efficiency is 25.5[%] at +14[dBm] of the input power for the class E rectifier and 12.7[%] at +15[dBm] of one for the VD rectifier. Deteriorations of the rectification efficiency for the class E and the VD rectifiers may be caused that the reduction of the switching loss in the diodes does not effect and that unmatching loss to the measurement equipment occurs. For the VD rectifier, moreover, a reason is considered that the load resistance in Fig. 1 (b) is far from the theoretical optimum value cite4.

3 A prototype of antenna with pure resistance

A planar monopole antenna is installed to the integrated rectenna on a circuit substrate. It notes here that unbalanced antennas are had to choose because the rectifires in the previous section are unbalanced circuits.

Figures 6 and 7 shows a structure of a monopole antenna and a prototype of it, respectively. We design the lengths of monopole_d and feedline_d in such a way that the input impedance of the antenna becomes pure resistance. Impedance frequency characteristics shown in Fig. 8 reveals that it is possible to achieve an almost pure resistance of about 71 [Ω] for 62.5 [mm] of monopole_d and 90 [mm] of feedline_d. The 71 [Ω] is close the resistance of the VD rectifier described in the previous section. If the planar monopole antenna connects to the VD rectifier, the VSWR is calculated to about 1.03.

Figure 8 illustrates characteristics of directivities and polarizations of the prototype planar monopole antenna on the 3 orthogonal principal planes. We confirm from Fig. 8 that the directivities of the co-polarization component of the presented antenna are similar to that of a standard monopole one. Distortions of the shapes of directivities can be seen on the $x-y$ and $y-z$ planes. This may be caused by scatterings from a connector and a coaxial cable in the measurements. The same distortions are also confirmed for the $\theta = 90$ [deg] directions on $x-z$ plane. Since these directions are those of the thickness of a substrate, a reason is considered as a very weak grand plane effect due to the use of a planar structure.

The absolute gain is measured by the comparison of receiving power between a reference antenna and the presented one. We note here that the unmatched loss due to the connection between the presented antenna and measurement

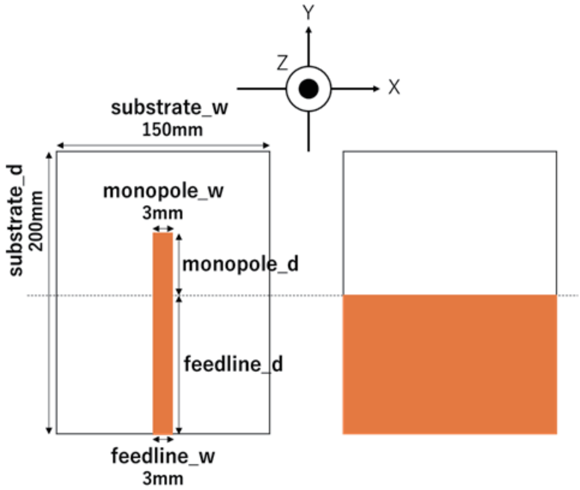


Figure 6. A structure of a planar monopole antenna. The left and right sides in this figure are corresponds to the front and back sides of a substrate, respectively.

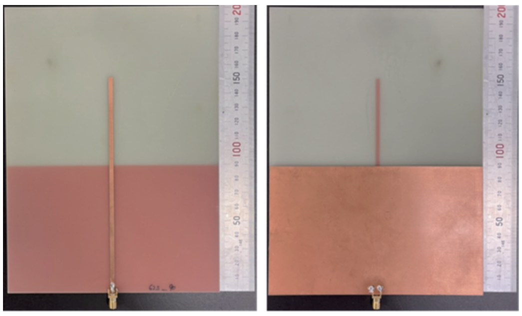


Figure 7. A prototypes of the planar monopole antenna in Fig. 6.

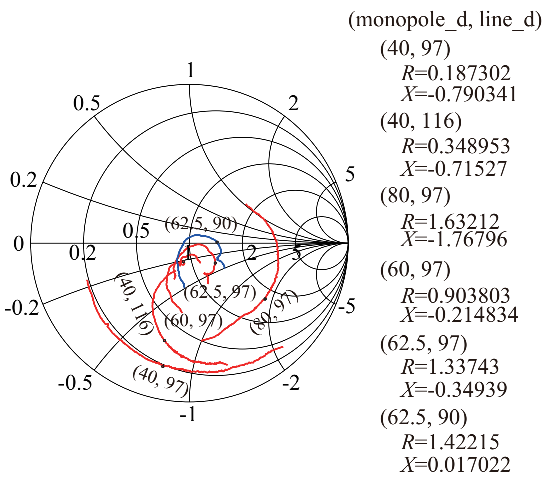


Figure 8. Measurement results of impedance frequency characteristics for the planar monopole antenna in Fig. 6.

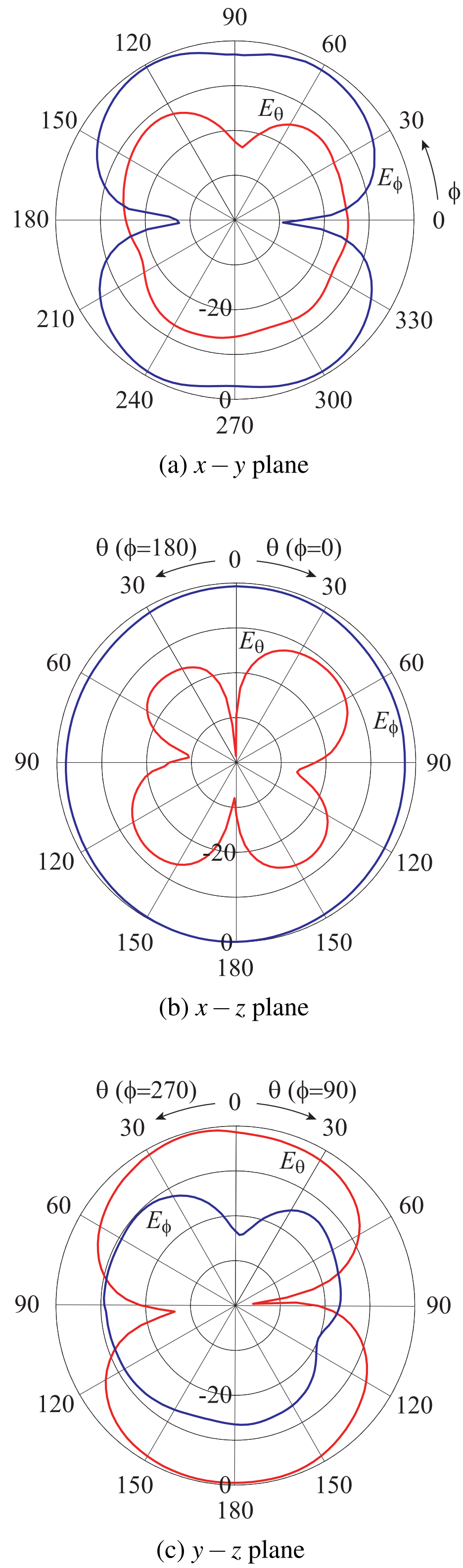


Figure 9. Measurement results of directivities for the planar monople antenna in Fig. 6.

equipment is corrected. The reference antenna is chosen a log-periodic antenna USLP9142 D-69250 from Schwarzbeck. The absolute gain of the presented antenna is measured at 0.61 [dBi] that is much less than a standard quarter-wavelength monopole one. The reasons for the above result is thought to be that the lengh of radiating element is not quarter-wavelength and that the size of the ground plane is not sufficient.

4 Rectenna

We fabricate an integrated rectenna by connecting the VD rectifier to the feeding point of the monopole antenna at right angles to it. Figure 10 shows the prototype rectenna. Performance evaluations are carried out by using 915 [MHz] electromagnetic wave that is radiated from the log-periodic antenna USLP9142 D-69250. The input power of the antenna is set at 15 [dBm].

Figure 11 (a) and (b) clarify that the performance deteriorate for the distance between the transmitting antenna and the rectenna from over 100 [cm]. The efficiency, for example, is evaluated about 37.4 [%] and 2 [%] for the distance of 50 [cm] and 100 [cm], respectively. The far field component of the radiating wave from the transmitting antenna is dominant for over 100 [cm] of the distance in the case of 915 [MHz]. The receiving power of the far field component is proportional to inverse square of the distance. It can be confirmed the fact in Fig. 11(c). We can find from Fig. 11(c) that the input power to the rectifier is about -20 [dBm] for 60 [cm] of the distance. Although Fig.5 indicates the efficiency of the rectifier is almost 0 [%], it improves to about 25 [%] shown in Fig. 11(b). The authors assume the improvement may be caused by the matching at pure resistance.

5 Conclusion

We proposed an integrated rectenna that a voltage doubler rectifier circuit and a planar monople antenna are matched at pure resistance. The efficiency is improved by satisfying the impedance matching condition. However, it deterorate proportional to the distance between the transmitting antenna and the rectenna. Future issues include improving the rectification efficiency of the rectifier circuit and the gain of the antenna. In addition, it is thought that a diode with a small forward voltage is necessary to realize long-distance transmission.

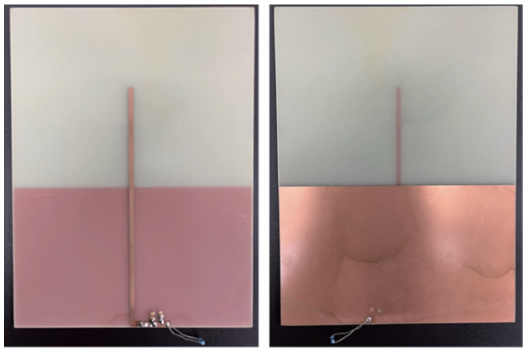
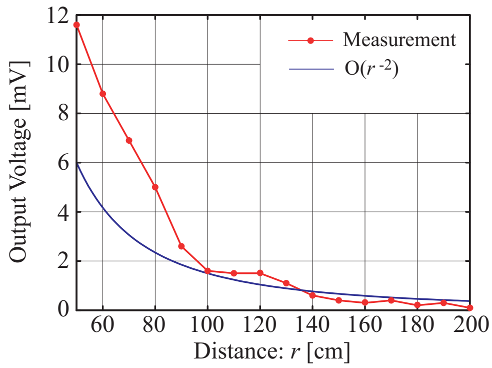
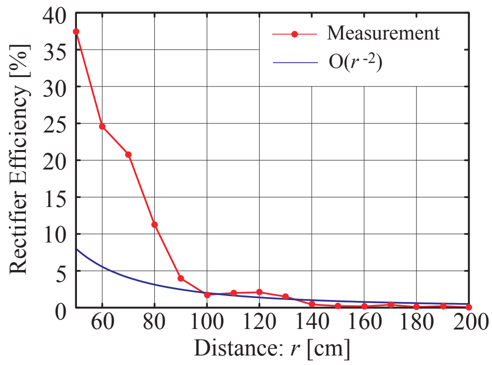


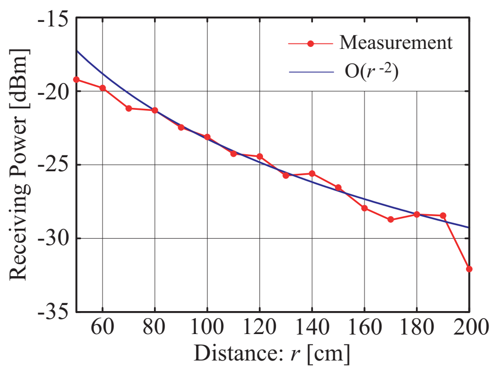
Figure 10. A prototype of an integrated rectenna



(a) Output Voltage



(b) Rectifier Efficiency



(c) Recieving Power of the monopole antenna

Figure 11. Performance evaluation of the integrated rectenna

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