Low-Profile Circularly Polarized Rectifying Antenna for Wireless Power Transmission at 5.8 GHz

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***Abstract*—Portable devices operating without batteries are sometimes desired in wireless applications such as RFID (Radio Frequency Identification) and telemetry. A novel circularly polarized shorted annular ring-slot rectenna (rectifying antenna) on a 0.5 mm thick flexible microwave laminate is proposed for the powering of these devices. Output dc voltage of 1.3 V and axial ratio of 1.5 dB were measured when 32 dBm microwave power was transmitted at 5.8 GHz over a distance of 2 m. Comparing the results with a rectenna designed on a thick rigid laminate, similar performance was observed.**

***Index Terms*—Circular polarization, rectifier, slot antenna.**

I. Introduction

A RECTENNA is a RF power receiver that converts the received power into dc power that can then be consumed, e.g., by an active RFID tag [1] integrated into the rectenna structure. The advantage of a circularly polarized (CP) rectenna over a linearly polarized one is that nearly constant dc output can be achieved even if the rectenna's rotation angle, relative to the transmitter, changes.

Several antennas for CP radiation have been designed over the last few years using a circular ring, e.g., with stripline hybrid coupler feed at 2.45 GHz [2], with microstrip feed at 1.5 GHz [3], and with coplanar waveguide and coaxial line feed at 2.45 GHz [4]. To the best of our knowledge, few rectenna for CP radiation have been proposed so far [5], [6]. Furthermore, these rectennas are intended for the operation at relatively high power densities.

An annular ring-slot rectenna designed for low power densities and operating at 5.2 GHz was introduced in [7]. In this letter, an enhanced design operating at 5.8 GHz is proposed and the performance of the two designs is compared.

II. Test Structure

Rectenna was designed on a thin high-frequency laminate RO3003 ($\mathrm{h} = 0.5\ \mathrm{mm}$, $\varepsilon_\mathrm{r} = 3.0$, $\tan\delta = 0.0013$, copper thickness 35 $\mu\mathrm{m}$). The layout of the rectenna is shown in Fig. 1. Antenna and rectifier (interface indicated with a dashed line in Fig. 1) were initially designed, manufactured and measured separately in order to validate their performance prior to the realization of the complete rectenna.

A shorted annular ring-slot structure, first introduced in [8], was utilized as an antenna element. Antenna feed was composed of a transmission line TL1 and two quarter-wave transformers TL2 and TL3. Antenna was designed for 50 Ω input impedance for measurement purposes. The mean slot radius $(\mathrm{R1} + \mathrm{R2})/2$ was preliminarily designed so that the slot wavelength λ_s [9] at the desired center frequency 5.8 GHz was equal to the mean slot circumference

$$\lambda_s = \pi(R1 + R2)\left(1 - \frac{\alpha}{360^\circ}\right). \tag{1}$$

Such a structure was simulated using MOM (Method of Moments) so that the input impedance was calculated at the outer edge of the slot (at the end of TL1). It was found out that (1) predicted the vicinity of the antennas first resonant frequency at reasonable accuracy, but the frequency for the optimum CP radiation was about 1.4 times higher. That was mainly because (1) does not include the effect of the ring-slot feed. Mean slot radius, slot width $(\mathrm{R2} - \mathrm{R1})$ and short angle (α) were therefore varied in simulations to find the minimum axial ratio at 5.8 GHz. All simulations were performed with ADS (Advanced Design System) Momentum using strip metallization layers. Final dimensions of the antenna are listed in Table I.

Rectifier was composed of a microwave Schottky detector diode pair D, a bypass capacitor C, a load resistor R and a choke inductor L. The diode pair (HSMS-2862) was connected in a shunt-series manner (so-called voltage doubler circuit) in order to lower the input impedance and maximize the output dc voltage. The input impedance of the rectifier circuit was transformed into 50 Ω with transmission lines TL4 and TL5 and two symmetrical sections of an open Stub. Rectifier was designed with ADS EM/Circuit co-simulation feature using strip metallization layers. Component values and dimensions of the matching elements are given in Table I.

III. Results

Separate antenna and rectifier as well as the complete rectenna were manufactured by wet etching. Measured and simulated input return loss of the antenna and the rectifier (input power -5 dBm) are shown in Fig. 2. Theoretical and experimental results agreed fairly well and a quite good impedance match was achieved in the vicinity of 5.8 GHz. The difference between simulated and measured results was mainly due to manufacturing tolerances and an error due to the connector used in measurements.

Antenna performance for CP radiation was tested in an anechoic chamber. A linear gain of 4 dB and an axial ratio of 2 dB were measured. A CP gain corresponding to these results was therefore 6.1 dB [10]. Performance was quite similar with a 5.2 GHz antenna designed on a nearly three times thicker rigid laminate [7]. It should be also noted that the proposed antenna

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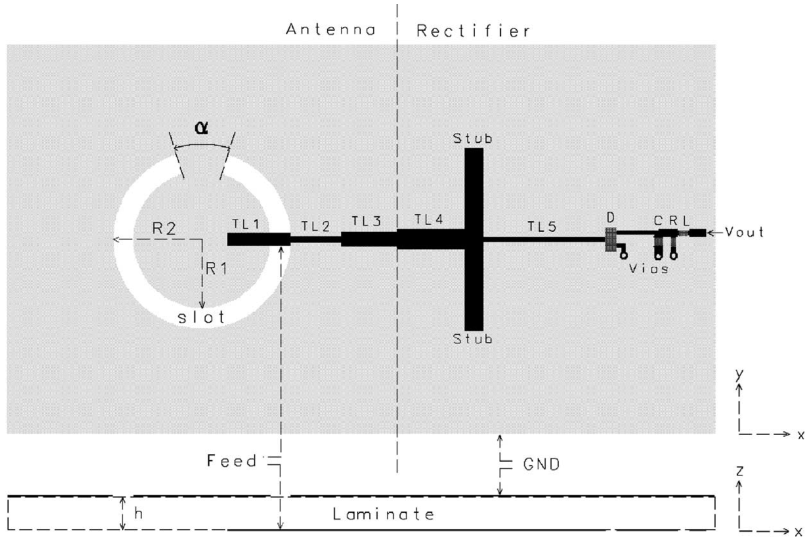

Fig. 1. Rectenna layout (top view and cross section).

TABLE I
DIMENSIONS AND COMPONENT VALUES FOR THE RECTENNA SHOWN IN FIG. 1

Antenna	
Ground plane [mm]	57.4 x 57.4
R1 [mm]	10.1
R2 [mm]	13.1
α [deg]	33.6
TL1 [mm]	1.9 x 9.3
TL2 [mm]	1.0 x 7.5
TL3 [mm]	2.2 x 8.1

Rectifier	
Ground plane [mm]	47.0 x 57.4
TL4 [mm]	3.0 x 10.0
Stub [mm]	2.75 x 12.0
TL5 [mm]	0.8 x 18.0
C [pF]	68
R[kΩ]	8.2
L [nH]	6.8

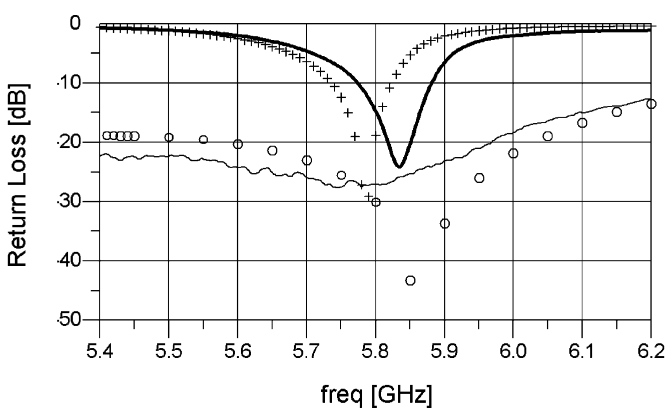

Fig. 2. Measured and simulated return loss of the antenna and the rectifier. — Antenna, measured; ○ antenna, simulated; — rectifier, measured; + rectifier, simulated.

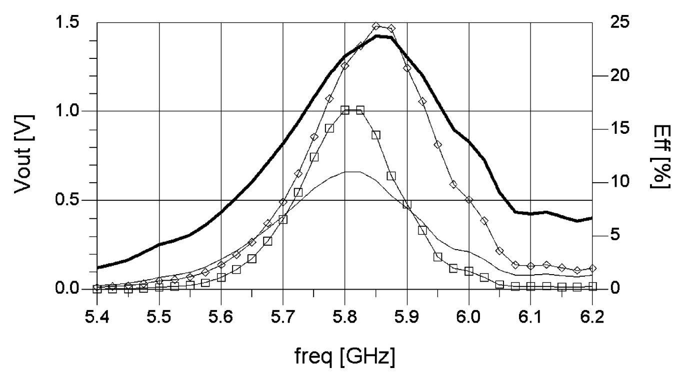

Fig. 3. Measured rectifier output dc voltage (Vout) and efficiency (Eff) at two different input power (Pin) levels. — $\mathrm{Vout@Pin} = -5$ dBm; — $\mathrm{Vout@Pin} = 0$ dBm; ⊟ $\mathrm{Eff@Pin} = -5$ dBm; ◇ $\mathrm{Eff@Pin} = 0$ dBm.

is bidirectional, that is the radiation patterns are nearly identical on both sides the antenna plane (xy-plane in Fig. 1).

The performance of the rectifier was measured at power levels of −5 dBm and 0 dBm. The input of the rectifier was connected to a microwave signal generator and the output resistance and dc voltage (Vout) was measured. From these results the conversion efficiency was calculated. Results are represented in Fig. 3. Compared to the results reported in [7], a higher output voltage was achieved mainly due to a higher load resistance. However, lower conversion efficiency was detected as a result of reduced current through the diode pair.

The complete rectenna was measured in an anechoic chamber. A standard gain horn antenna (gain 20 dB) was used as a transmitter. The rectenna was rotated 360° in 45° steps in the xy-plane and the output voltage was measured at each position. Measurements were performed at 1 m and 2 m distance between the antennas. The transmitted power was 26 dBm at 1 m and 32 dBm at 2 m. Results for output voltage and axial ratio are shown in Fig. 4. At 5.8 GHz, output voltage of 1.1 V and 1.3 V and axial ratio of 2.1 dB and 1.5 dB was measured at 1 m and 2 m distances, respectively. The maximum output was measured at 5.85 GHz, as expected based on Fig. 2.

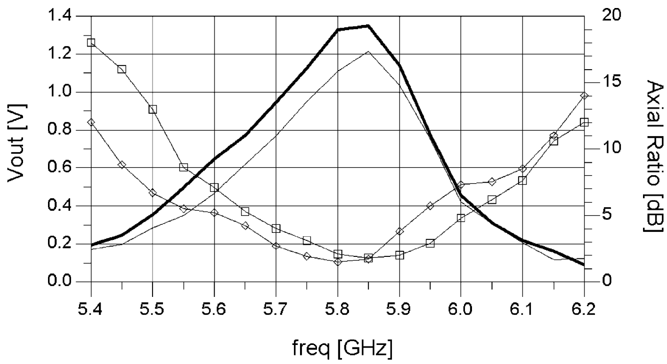

Fig. 4. Measured rectenna output dc voltage (Vout) and axial ratio at two different transmission distances and transmitted power levels (Pt). $\text{Distance} = 1\ \text{m}, \text{Pt} = 26\ \text{dBm}$; — output dc voltage; —□— axial ratio; $\text{Distance} = 2\ \text{m}, \text{Pt} = 32\ \text{dBm}$; **—** output dc voltage; —◇— axial ratio.

The axial ratios at 1 m and 2 m distances are not identical because the measured rectenna was in the near-field region of the transmitter antenna, where the radiation properties vary with distance. The far-field distance of the transmitter antenna at 5.8 GHz was 2.4 m.

IV. CONCLUSIONS

A circularly polarized rectenna for microwave wireless power transmission at 5.8 GHz was manufactured on a thin low-loss microwave laminate. Based on the test results, the chosen low-profile and flexible laminate is well suited for this design. The proposed rectifying antenna should be useful as a "virtual battery" in applications where the receiver is rotating relative to the transmitter. The use of thin and flexible laminate instead of thick and rigid enables mounting into slightly curved surfaces and reduces the weight of the rectenna. The measured rectenna, having an axial ratio of 1.5 dB, produced an output voltage of 1.3 V over a 2 m distance when 32 dBm microwave power was transmitted. Compared to a previous design, the performance was better in terms of higher output voltage whereas some deterioration in axial ratio and conversion efficiency was noticed.

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