A Miniature Packaged Rectenna for Wireless Power Transmission and Data Telemetry

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Abstract

Embedded wireless sensors are becoming crucial for many safety critical applications. Sensor batteries must be charged as needed to support high data rate communications. A miniature packaged circularly polarized rectenna is proposed. With the help of an integrated band-reject filter the proposed rectenna suppresses the second harmonic emission at 11 GHz by more than 50 dB and has a conversion efficiency of 74%.

1. Introduction

Lately there is a growing concern on the safety and security aspects of our civil infrastructures [1]. Monitoring of the health of infrastructures requires sensors that can transmit and receive data wirelessly. While RFID type passive sensors support short distance interrogation active battery operated active sensors are needed if high data rate and continuous communication are desired. In that case the batteries of embedded sensors must be supplied with power wirelessly [2-6]. Circularly polarized rectennas help achieve the same dc voltage irrespective of the rotation of the rectenna. In this paper a miniature packaged rectenna is proposed which with the help of an integrated band-reject filter suppresses the second harmonic emission at 11 GHz by more than 50 dB and has a conversion efficiency of 74%. This work is based on our earlier work [4-6]. The new rectenna contains a microstrip patch antenna on one side of the substrate backed by a band-reject filter on the other side. The rectenna dimensions are only 40 mm by 40 mm by 4.7 mm.

2. Rectenna Design

Fig. 1 shows the schematics of the proposed miniature packaged rectenna with the integrated band-reject filter. The filter is used to reduce the out of band harmonics generated by the rectifying schottkey diode. The circularly polarized microstrip patch antenna is etched on a 3.175 mm thick Duroid 5880 ($\varepsilon_r = 2.2$) substrate. The band-reject filter is printed on a 1.524 mm thick RO4003 substrate ($\varepsilon_r = 3.38$) on the back side of the antenna. The two slots positioned along the left diagonal of the patch create right-hand circular polarization (RHCP). The dimensions of the microstrip patch antenna are 14.8 mm by 14.8 mm. Other antenna parameters, such as slot length, width, and feed position are available in [5]. An HSMS-2862 microwave Si Schottky detector diode pair was used to design the rectenna.

3. Results

For miniaturization we chose to design a 3-element filter based on the design equations given in [7]. Considering a 1.524 mm thick RO4003 ($\varepsilon_r = 3.38$) substrate the corresponding characteristic impedances were calculated as: $Z_1 = Z_3 = 124\ \Omega$, $Z_2 = 60\ \Omega$, $Z_{1,2} = Z_{2,3} = 83\ \Omega$. The widths of the stubs and the unit lines were calculated as: $W_1 = W_3 = 0.45$ mm, $W_2 = 2.4$ mm, $W_{1,2} = W_{2,3} = 1.25$ mm. The equivalent lengths of the stubs and the unit lines are quarter wavelength long at 11 GHz and are given here: $L_1 = L_3 = 4.3$ mm, $L_2 = 4.0$ mm, $L_{1,2} = L_{2,3} = 3.5$ mm.

Schematics of this microstrip line filter are shown in Fig. 2(a). HFSS computed S-parameter data are illustrated in Fig. 3(a). The filter has small insertion loss (less than 1 dB) at 5.5 GHz and has out of band rejection of about 25 dB at 11 GHz. This rejection can be further improved by our new improved filter illustrated in Fig. 2(b). Simulated and measured performance characteristics of the new filter are shown in Fig. 3(b). The insertion loss at 5.5 GHz is good and the out of band rejection at 11 GHz is excellent (50 dB). The proposed filter, when integrated with the RHCP antenna, also blocks the resonance of the antenna from 9 to 16 GHz.

The rectenna performance was measured at 5.5 GHz in the far-field by conducting a radiated test where transmit antenna gain $G_t = 9.4$ dBi (gain of microstrip patch array), transmit power $P_r = 7$ W, load resistance $R_L = 300\ \Omega$ and receive antenna gain $G_r = 7.6$ dBi (gain of circularly polarized rectenna). The output dc voltage and conversion efficiency of this rectenna are shown in Fig. 4. The maximum output voltage V_{out} is 2.15 V at a distance of 40 cm and highest conversion efficiency is 74%. At power densities higher than 0.75mW/cm^2 the conversion efficiency is nearly constant.

Conclusion

A miniature packaged rectenna is introduced which with the help of an integrated band-reject filter prevents the out of band harmonics generated from the diode from being re-radiated by the antenna. The rectenna operates at 5.5 GHz and has a conversion efficiency of 74%. The rectenna can be used for microwave power reception at 5.5 GHz and for data communication within the 5.15-5.35 GHz band.

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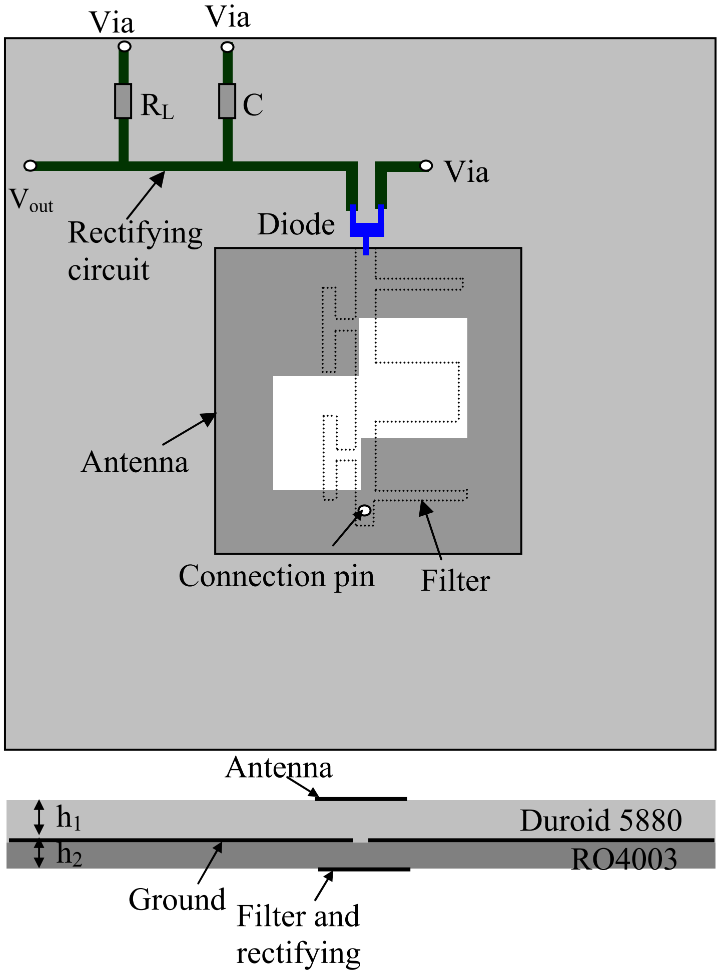

Fig. 1. Miniature rectenna with filter.

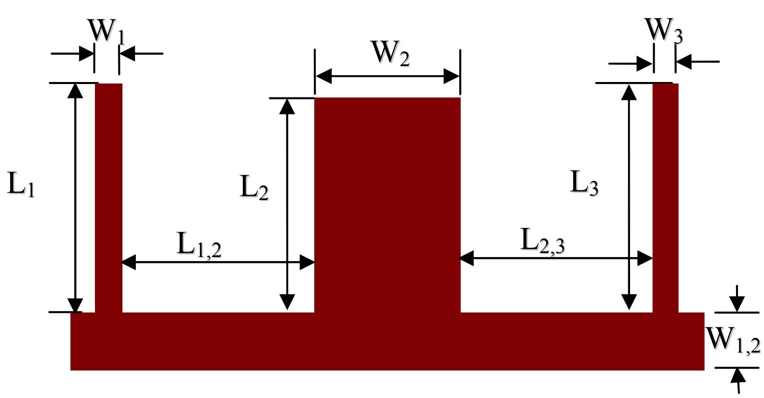

Fig. 2a. S-parameters of (a) filter 1 and (b) filter 2.

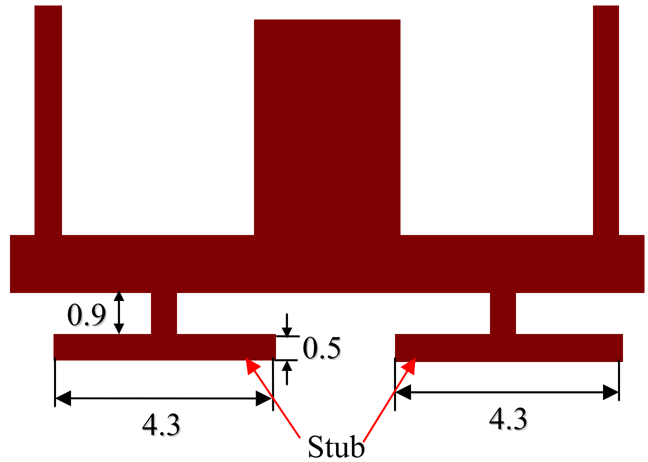

Fig. 2b. S-parameters of (a) filter 1 and (b) filter 2.

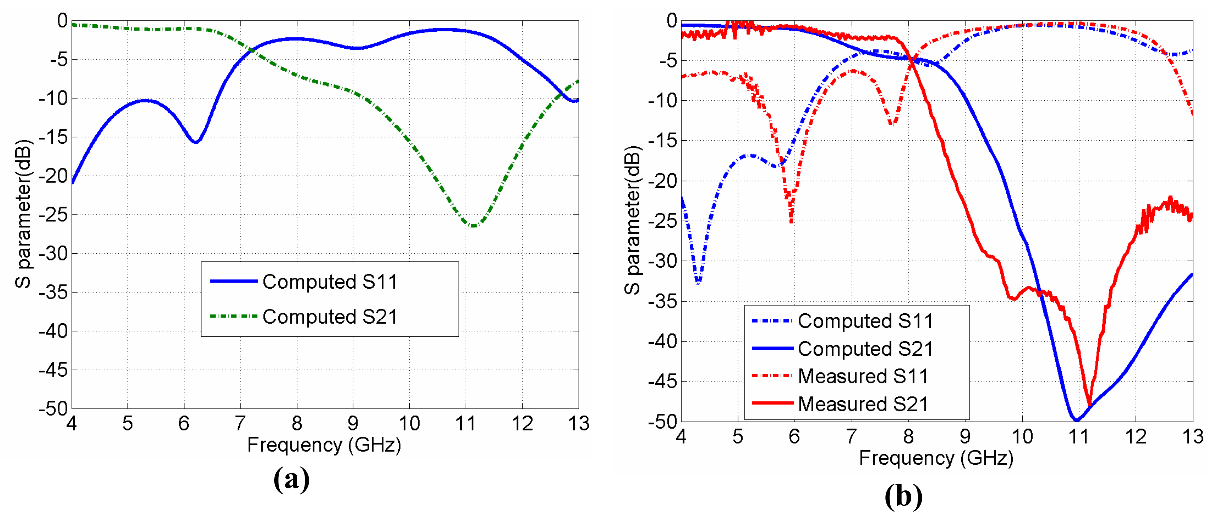

Fig. 3. S-parameters of (a) filter 1 and (b) filter 2.

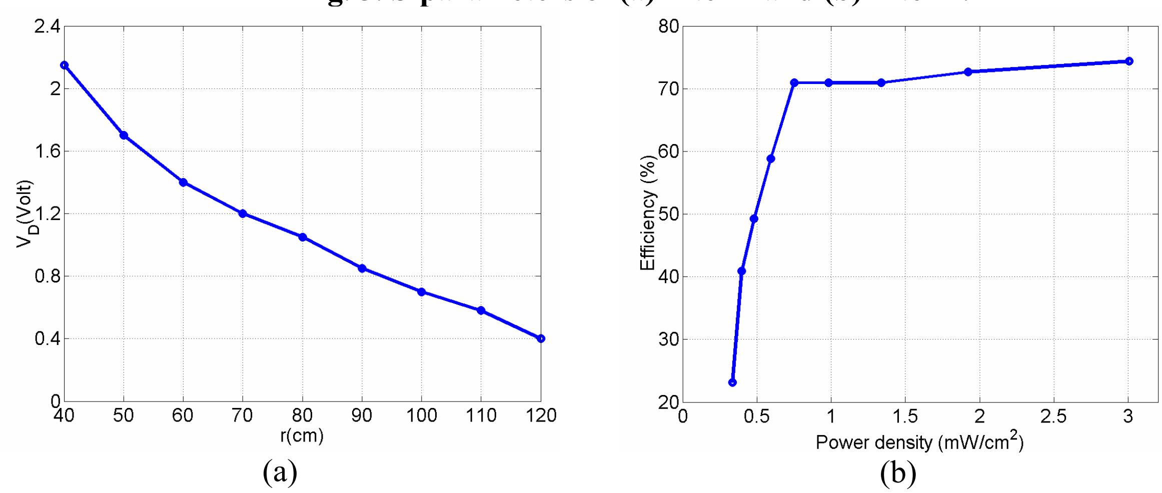

Fig. 4. Measured output voltage, V_D versus distance and (b) conversion efficiency versus power density at 5.5 GHz.