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A 2.45 GHz Rectifying Circuit with Enhanced Range of Input Power and Load

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Introduction

Rectennas have been developed since wireless power transformation began to attract researchers' attention. Nowadays kinds of rectifiers are available [1,2]; rectenna arrays have been studied to improve their performances [3]. Recently, harmonic rejecting rectennas to improve the radio frequency to direct current conversion efficiency (RF-to-DC Eff.) have been investigated [4,5].

Diodes, GaAsFETs or HEMETs are the most critical components in microwave rectifiers. In [6], the model of a Schottky diode has been presented, and proper matching circuits are achieved. Single diode rectifier circuit suffers the relatively low RF-to-DC Eff. and a narrow dynamic range of loads [4,7]. To overcome those disadvantages, this paper presents a novel single diode rectifier circuit with an inductor series-connected to a Schottky diode.

Rectifier Design

A large signal Schottky diode model and its impedance are analyzed in [6] and [7]. A widely used Schottky diode in rectennas is the HSMS 282 of Avago Inc. Its basic parameters are: the series resistance R_s = 6 Ω, the zero-bias junction capacitance C_{J0} = 0.7 pF, the forward bias turn on voltage V_{bi} = 0.65 V, and the reverse break-down voltage V_B = 15V. The same Schottky diode is used in our design.

The scheme of the proposed rectifier is shown in Fig. 1. An inductor L is series connected with the Schottky diode D, which is the only difference compared to the conventional rectifier. The rectifier is realized on a substrate with relative dielectric constant ε_r=2.65 and thickness of 1mm. The layout and photo are shown in Fig. 1 and Fig. 2, respectively. A low pass filter is applied before the diode to block the harmonic frequencies produced in rectifying. A series capacitor C_1 is applied to isolate DC from/to the RF power source. The Schottky diode is followed by a segment of microstrip line with a capacitor C_2 and a load R. The return loss and insertion loss of the low pass filter are simulated. $|S_{11}|$ and $|S_{21}|$ are -44.8 dB and -0.08 dB at 2.45 GHz, -0.6 dB and -15.2 dB at 4.9 GHz, respectively. Microstrip lines before and after the Schottky diode are applied to adjust the impedance match. The optimum lengths of those 50 Ω microstrip lines are 25.0 mm and 16.8 mm, respectively.

Comparison between Proposed and Conventional Single Diode Rectifiers

In circuit simulations, some caparisons between the proposed and conventional single diode rectifiers are shown in Fig. 3, Fig. 4 and Fig. 5.

When the load R = 500 Ω and the input RF power P_{RF} = 17 dBm, Fig. 3 shows the voltages V_D at the diode in time domain. V_D of the proposed circuit is smoother than that of the conventional one, because the series inductor L slows down the voltage variation. This indicates the harmonic frequencies are suppressed and the RF-to-DC Eff. is improved.

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Fig. 4 gives the spectrums of the diode currents with the varied loads and the fixed input RF power P_{RF} = 17 dBm. It shows that the harmonics are suppressed in the proposed rectifier. The amplitudes of the diode current I at the second harmonic frequencies have been greatly suppressed, since the series inductor is inclined to maintain a constant current and counteract a varying current. The higher harmonics are suppressed well because the inductor has much greater resistances at those frequencies. The DC components are dependent on the load R as well. There is a threshold R_{TH} = 350 Ω for the load R. When R > R_{TH}, the DC components in the proposed circuit is greater than the conventional circuit. When R < R_{TH}, the conventional circuit presents higher DC component values. The series inductor widens the dynamic range of the load R.

Fig. 5 shows the simulated RF-to-DC Eff. of both rectifiers with input RF power at 17 dBm and 20 dBm, respectively. The RF-to-DC Eff. of the proposed rectifier is lower than that of the conversional one, when R < R_{TH}. However, a much wider range of the load R is achieved in the proposed rectifier, when R > R_{TH}. This indicates that the range of the load R widens and the RF-to-DC Eff. increases in the proposed rectifier.

The inductance L in the proposed rectifier is depended on the operational frequency and the diode parameters. Its optimum value could be achieved from circuit simulations. In addition, the threshold of the load (R_{TH} = 350 Ω) can be also confirmed in Fig. 5.

Experimental results

An Agilent E8267C microwave vector signal generator, a dual-channel microwave power meter, a bi-directional coupler, and a DC voltage meter are used in experiments. The RF-to-DC Eff. is

$$\eta = \frac{(V_{DC})^2}{R} \times \frac{1}{P_{RF}} \times 100\% \qquad (1)$$

where V_{DC} is the output DC voltage, R is the load, and P_{RF} is the input RF power. When P_{RF} is 17 dBm and 20 dBm at 2.45 GHz, respectively, the RF-to-DC Eff. are measured with loads from 50 Ω to 2000 Ω and shown in Fig. 5. These efficiencies are the average of two measurements, which agree well to the circuit simulations. If the reflected RF power is taken into consideration, the conversion efficiency will increase about 3% to 5%.

The reflected RF power is depended on the load R, since the Schottky diode is a non-linear device. The voltage reflection coefficient could drop to -20 dB with a suitable load R at a fixed RF input power in our measurements. It indicates that there is an optimum load for the rectifier to reach a minimum reflection. And vice versa, there may be an optimum input RF power at a fixed load R to achieve best Voltage reflection coefficient.

Conclusion

In this paper, a novel rectifier using a single diode with a series inductor is proposed. The introduced series inductor has effects on the voltage and the current of the diode. It aids to suppress the harmonic frequencies and improve the RF-to-DC Eff. consequently. Both circuit simulation and experimental results show the dynamic range of the load widens and the RF-to-DC Eff. increases, compared with a conventional single diode rectifier. The rectifier using a diode with a series inductor could enhance the impedance matching and improve the rectifying performance, while the design procedure remains unchanged and there is no extra complexity in the rectifier.

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Figures

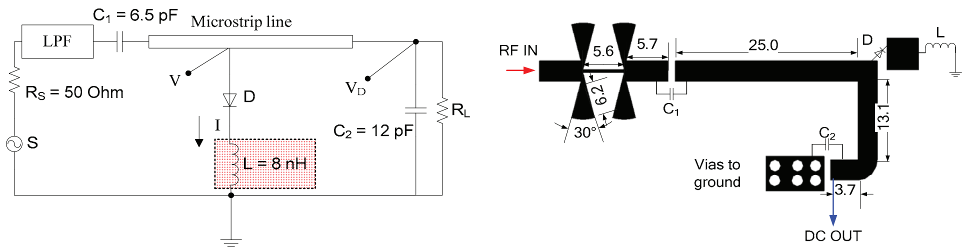


Fig. 1 Proposed single diode rectifying circuit and layout

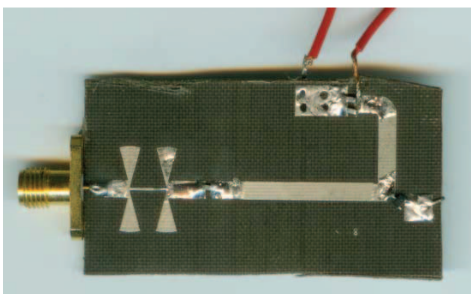


Fig. 2 Photo of the proposed rectifier

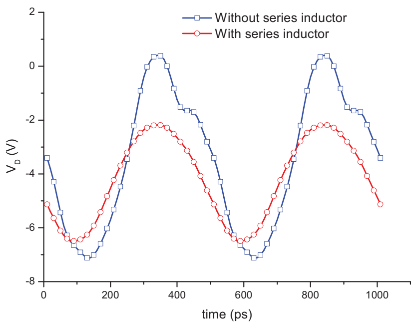
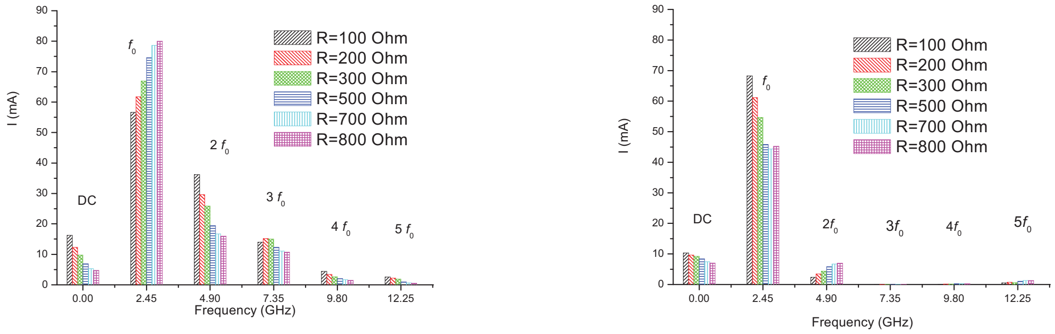
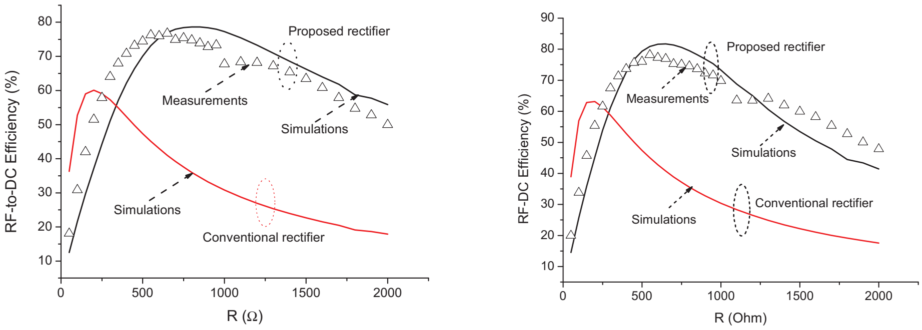


Fig. 3 V_D with a load of 500 Ω



(a) Conventional rectifier (b) Proposed rectifier

Fig. 4 Spectrums of the diode current



(a) $P_{RF} = 17$dBm (b) $P_{RF} = 20$dBm

Fig. 5 Simulated and measured RF-to-DC conversion efficiency