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Efficient and Simple Structured Five-Band Rectifier for Wireless Power Transfer

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Abstract— **An efficient and simple structured five-band rectifier with high frequency ratio is designed in this paper, which adopts only two HSMS-2822 Schottky diode, a simple T-type matching network, class F harmonic control network and DC-pass lowpass filter. The proposed rectifier operates at frequencies of 0.67, 1.31, 2.57, 5.28 and 5.77 GHz. With 29 dBm input power, RF-DC power conversion efficiencies (PCEs) up to 76.3%, 77.1%, 69.9%, 69.1%, 67.3% at 0.67, 1.31, 2.57, 5.28 and 5.77 GHz respectively according to the simulation results. Compared to the traditional multi-band rectifiers, topology of the design shows the advantages of high efficiency, simple structure, and high frequency ratio. This allows rectifier circuits to be widely utilized by wireless power transfer (WPT).**

Keywords— **rectifier, five-band, high efficiency, simple structure, high frequency ratio, wireless power transfer (WPT).**

I. INTRODUCTION

Wireless power transfer (WPT) technology is in high demand because it can provide power to electronic equipments for extended time without the use of wires[1]. The microwave rectifier plays a crucial role in the Wireless Power Transfer (WPT) system by transforming RF power into direct current (DC). And the power conversion efficiency (PCE) of the rectifier circuit will determine the performance of the entire energy transmission system. Thus an efficient rectifier is essential to obtain a high-performance WPT system.

In the past few years, scholars have worked on single-band high-efficiency rectifier circuits, some with efficiency of 80% or more [2], [3], [4].

Nonetheless, the origins of electromagnetic energy are variable and may encompass a variety of frequency ranges. Numerous endeavors have been undertaken to enhance the extraction of energy from these sources, leading to significant progress in multi-band rectifier design [5], [6], [7], [8], [9].

A multibranch structure was proposed in [5], [6], such structure designs individual rectifiers, each uses a matching network, and then combines the DC outputs of the rectifiers. Such approach is very effective to make a design of multi-band rectifier, but at the same time, the loss of multiple diodes should also be considered. The construction method of [7], [8], [9] consists of a single rectifier circuit coupled with multiple frequency matching circuitry which makes its design complex and challenging.

In the current work, an efficient and simple structured five-band rectifier is proposed and the circuit structure proposed is described in Fig. 1. The rectifier adopts the voltage double topology, the selected diode is HSMS-2822 Schottky diode, such only two diodes used in the design reduces the circuit's cost and loss. The simulation results show that it works well in the five frequency bands: 0.67GHz, 1.31GHz, 2.57GHz, 5.28GHz, 5.77GHz, with 29 dBm input power, the PCEs peak reach 76.3%, 77.1%, 69.9%, 69.1%, 67.3%, respectively.

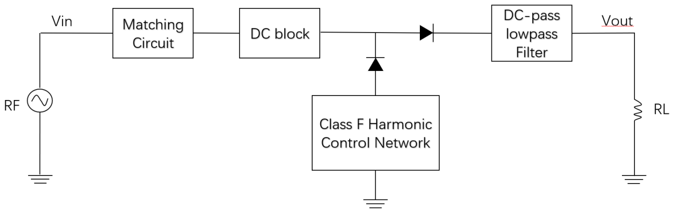

Fig. 1. Block diagram of the proposed five-band rectifier system.

II. DESIGN AND ANALYSIS

The whole five-band rectifier system is depicted in Fig. 2. The proposed rectifier circuit consists of T-type matching network, a 90 pF capacitor, two rectifier diodes, class F harmonic control network and DC-pass lowpass filter.

A. Design of the DC-pass Lowpass Filter

For the output DC-pass lowpass filter of RF rectifier circuits, the RF energy generally contains fundamental and high harmonics components, and there is no power at other frequencies, so only the fundamental and harmonics need to be filtered out. This design uses two microstrip radial stubs connected in parallel to the output to design the DC-pass lowpass filter. At the same time, the DC-pass lowpass filter also acts as an impedance matching in the whole rectifier circuit, especially at low frequency. Fig. 3 shows the simulation results $|S(1,1)|$ of the whole circuit with and without the DC-pass lowpass filter. Comparing the simulation results of the circuit with DC-pass lowpass filter, when the circuit does not have DC-pass lowpass filter, the matching is not good at low frequencies.

B. Design of the Harmonic control Network

This circuit utilizes a Class F harmonic control network. The class F microwave rectifier circuit is designed based on the idea of the class F amplifier, and the harmonic control structure is added to regulate the time-domain waveforms of

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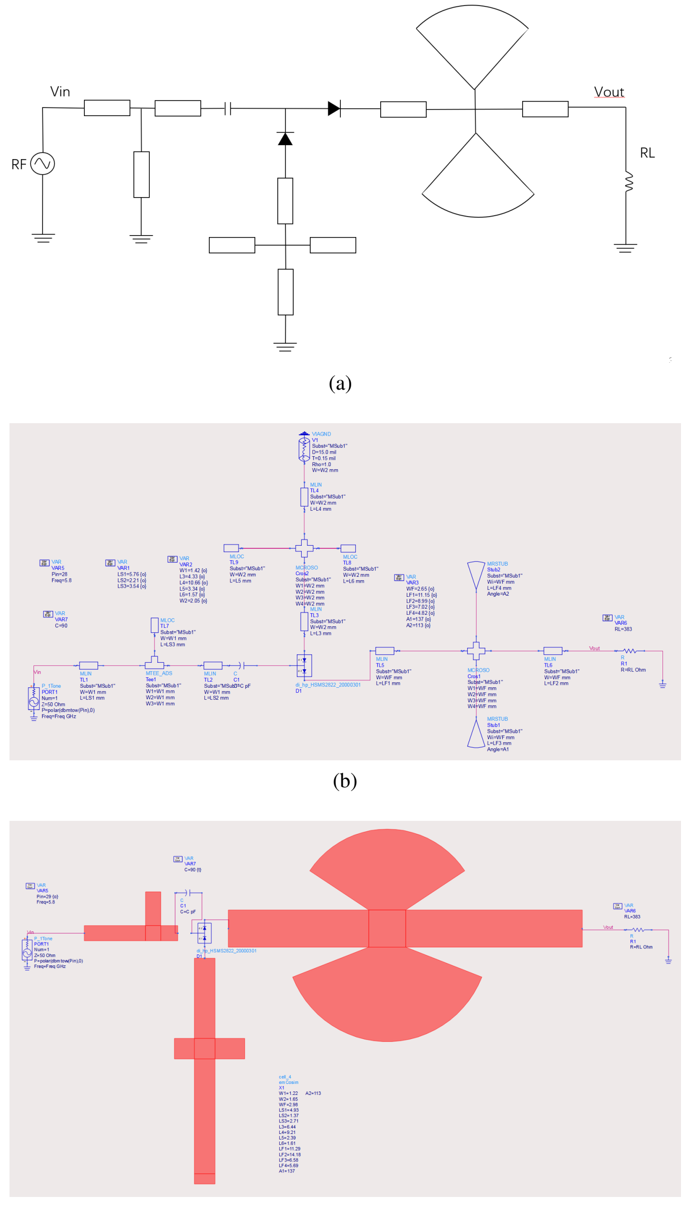

(a)

(b)

(c)

Fig. 2. The whole rectifier system: (a) Circuit diagram. (b) ADS schematic. (c) ADS layout

the voltage and current flowing through the diode, so that the voltage is a square wave, the current is a half-sine wave, and the voltage and current are presented in a quadrature state. Class F harmonic control network is applied to the circuit structure of this paper to realize the voltage and current waveform regulation of a single diode and to further increase the efficiency of energy conversion. As with DC-pass lowpass filters, Class F harmonic control has the effect of impedance matching in the whole circuit, especially at high frequencies. Fig. 4 shows the simulation results $|S(1,1)|$ of the whole circuit with and without the class F harmonic control network. Compared with the simulation results of the circuit with class F harmonic control network, when the circuit does not have class F harmonic control network, the matching is not good at high frequencies.

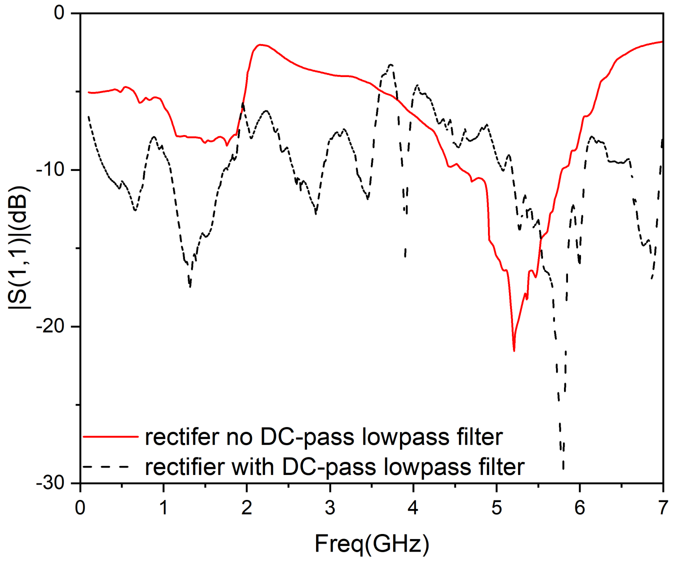

Fig. 3. Simulated $|S(1,1)|$ of the circuit with and without DC-pass lowpass filter.

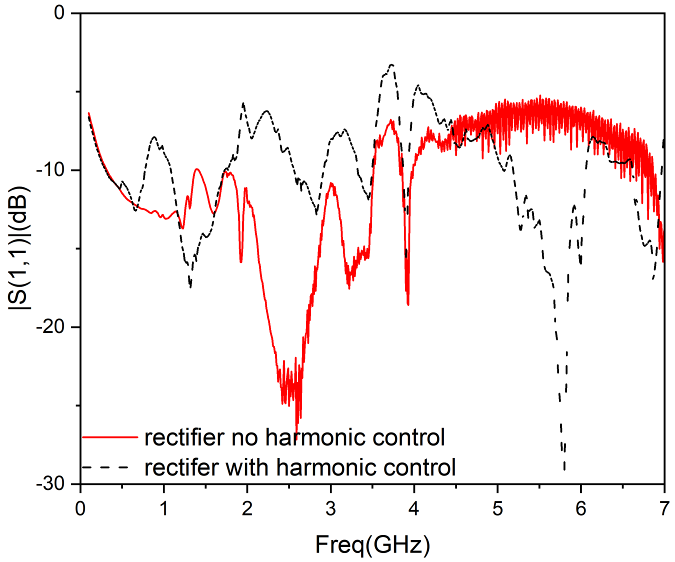

Fig. 4. Simulated $|S(1,1)|$ of the circuit with and without harmonic control network.

C. Design of the Matching Circuit

For the network composed of rectifier diode and its subsequent circuit structure, its impedance generally does not match the characteristic impedance of the input signal when viewed from the input side, so it is necessary to design an impedance matching network to realize that all the input microwave energy is transmitted to the rectifier diode for rectification. This circuit adopts a simple T-type marching network to satisfy the source and load matching.

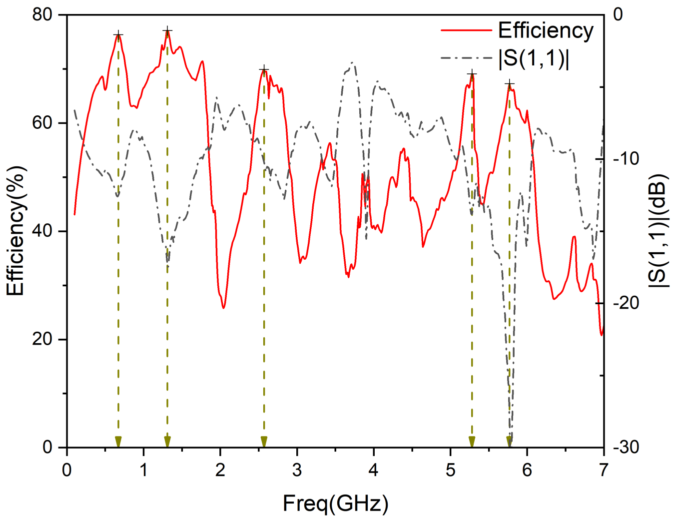

Fig. 5. Simulated PCE and $|S(1,1)|$ versus frequency at 29 dBm input power.

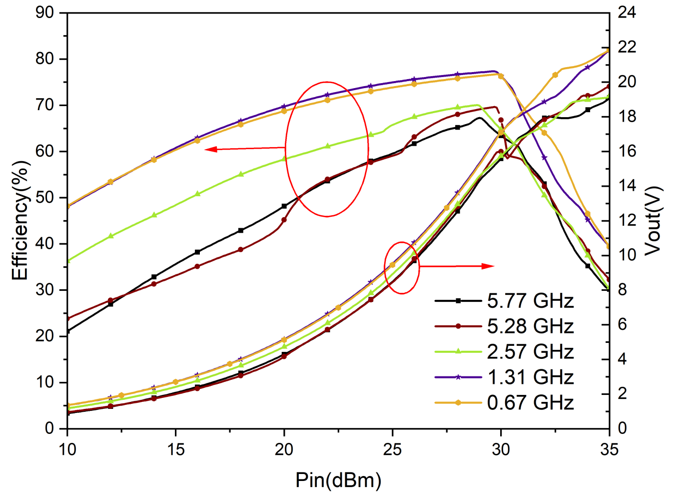

Fig. 6. Simulated PCE and V_{out} versus input power at five operating frequencies.

III. Simulation Results

The whole five-band rectifier system is depicted above. The substrate utilized for this rectifier is Rogers 4003C ($\epsilon_r = 3.55, \tan\delta = 0.002$) with a thickness of 0.813mm. The HSMS-2822 Schottky is selected here for the voltage double topology. The whole circuit simulation and optimization are done in Keysight ADS.

Furthermore, the rectifier's performance of RF-DC conversion efficiency is derived by HB simulation, which equation is:

$$PCE = \frac{{V_{out}}^2}{R_L} / P_{in} \times 100\% \tag{1}$$

where V_{out} is the output direct current(DC) voltage on the load resistance $R_L(383\ \Omega)$, P_{in} is the input power which can be supplied by the signal generator.

The simulated PCEs and $|S(1,1)|$ over the frequencies from 0.1 to 7 GHz at 29 dBm input power are plotted in Fig. 5. It can be noticed in Fig. 5 that with 29 dBm input power, the PCEs peak at 0.67GHz, 1.31GHz, 2.57GHz, 5.28GHz, 5.77GHz are 76.3%, 77.1%, 69.9%, 69.1%, 67.3%. And the $|S(1,1)|$ simulated at five operating frequencies are all below -10dB. It indicates that while achieving high efficiencies, the circuit also achieves good impedance matching.

Fig. 6 illustrates the variation of the simulated PCEs and V_{out} with the input power P_{in} at 0.67GHz, 1.31GHz, 2.57GHz, 5.28GHz, 5.77GHz. When P_{in} is between 21 and 32 dBm, the simulated PCEs are more than 50% in the five working frequency bands.

IV. Conlusion

Within this work, an efficient and simple structured five-band rectifier for wireless power transfer (WPT) is presented. Simulations validate the performance of the proposed circuit. When the input power level is 29 dBm, the achieved power conversion efficiencies (PCEs) up to 76.3%, 77.1%, 69.9%, 69.1%, 67.3% at 0.67, 1.31, 2.57, 5.28 and 5.77 GHz, respectively. In comparison with other already been reported multi-band rectifiers, the submitted rectifier has the merits of simple structure and high efficiency. The rectifier has excellent performance and is applicable to WPT system.

Acknowledgment

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