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A Novel 24-GHz Miniaturized Flexible Rectifier for Wireless Energy Harvesting

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***Abstract*— In this research article, the design and fabrication of a miniaturized flexible rectifier at 24 GHz for wireless power transfer to wearables is presented. The proposed circuit consists of a shunt topology rectifier including a single stub impedance matching network. Conventional PCB fabrication technique is used for the prototyping of the proposed flexible rectifier. It has a total footprint of 5.29 cm^2. The proposed rectifier exhibits a good trade-off between compactness and RF-to-DC conversion efficiency. The implementation on a very thin substrate (130 µm) makes it durable for wearables applications. Experimental results of the proposed rectifier show an output DC voltage of 2.0 V across an optimal load resistance of 250 Ω and measured RF-DC conversion efficiency of 23% for an input power of 17 dBm at 24 GHz.**

Keywords*— *Millimetre-waves, Rectifiers, Rectennas, Wireless Power Transfer

I. INTRODUCTION

Far-field wireless power transmission (WPT) technology have gained significant attention due to its potential applications for wearables and Internet-of-Things (IoT) [1]-[2]. A compact and efficient rectifier circuit is the major requirement for an effective wireless power transfer system [2]. Nowadays most of the research efforts [3]-[12] are focused on the miniaturization and enhancement the performance of the antennas for improving the RF-DC conversion efficiency, specifically for flexible substrate materials [13]-[18].

Fig. 1 shows a simple block diagram of a rectifier circuit. The constituent components are the input impedance matching network (IMN), rectifying diode, output DC filter and the DC load resistor. There are only a handful research articles available in published literature on flexible rectifiers at 24 GHz. A flexible ink-jet printed rectifier circuit was published in [19] for wearable IoT applications. A flexible liquid crystal polymer substrate was used for fabrication. It shows an output voltage of 2.5 V with an input power of 18 dBm at 24 GHz. In [20]-[21], they were presented a paper substrate based rectenna design at 24 GHz for RFID applications using ink-jet printing technology. The size of this rectenna design was 0.75 cm × 1.3 cm for 24.15 GHz. It shows an RF-DC conversion efficiency of 32.5% with an input power of 15 dBm. A flexible RF energy harvester was presented in [22] using hybrid printed technology for energy harvesting applications. It generates an output voltage of 2.9 V with an RF-DC conversion efficiency of 20 % at 7 dBm of input power.

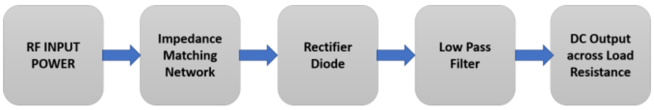


Fig 1. Block Diagram of a Rectifier Circuit

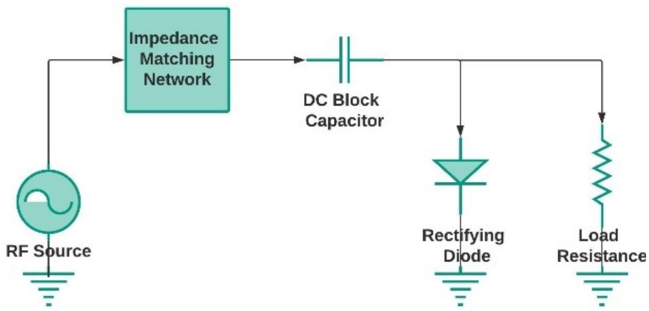


Fig 2. Rectifier circuit in Shunt topology.

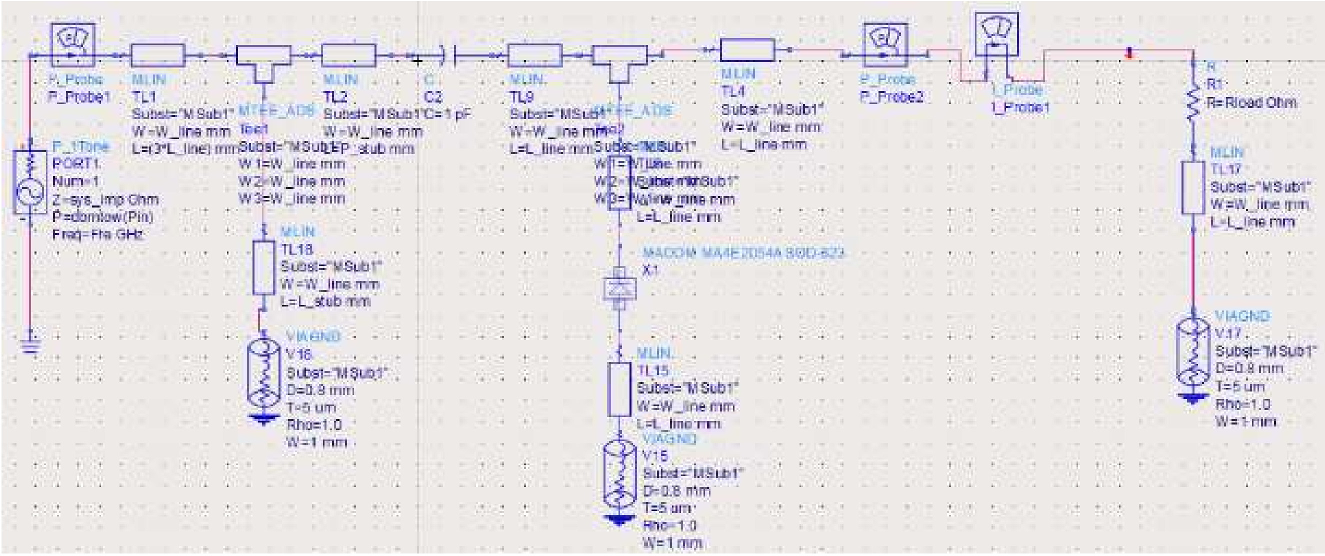


Fig 3. ADS Schematic of the proposed rectifier circuit

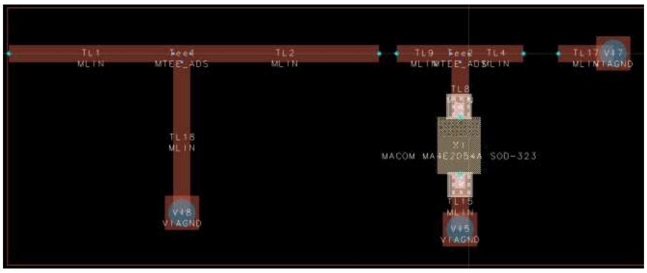


Fig 4. ADS layout of the proposed rectifier circuit

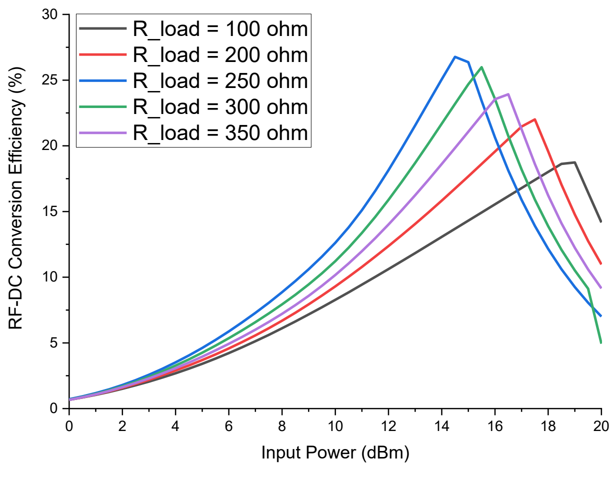


Fig 5. Simulated RF-DC conversion eefficiency of proposed rectifier as a function of input power across different DC load resistance.

This research work presents the design, optimization, and fabrication of a miniaturized flexible rectifier for WPT applications to wearable IoT devices. The rectifier was fabricated on a Rogers 3003 substrate with thickness of 0.13 mm, $\varepsilon_r = 3$ and $\tan\delta = 0.001$. To verify the performance of the proposed rectifier, the multimetre was used to measure the output power of the proposed rectifier, for different input RF power ranging from 0 dBm to 20 dBm. The measurement result shows an efficiency of the proposed rectifier of 23% at 24 GHz, while the proposed rectifier had an input power of 17 dBm at 24 GHz.

II. Design and Simulations

In this research article a compact flexible as well as efficient rectifier based on simple shunt configuration has been designed and optimized to get maximum performance and compactness. RF-DC conversion efficiency is the main metric for performance evaluation of rectifiers circuits and is defined as:

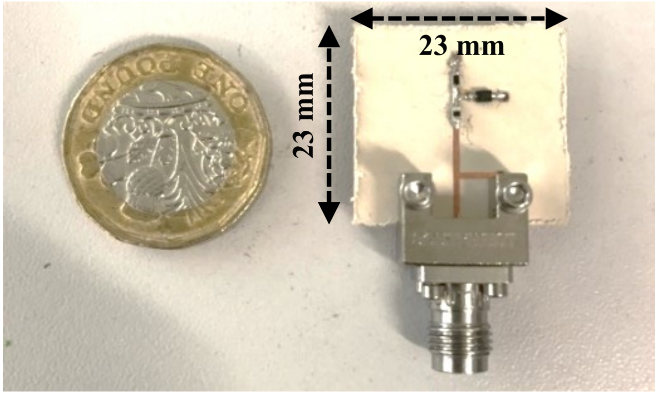
$$\eta = \frac{P_{out}}{P_{in}} \tag{1}$$

Where η represents the RF-DC conversion efficiency, P_{out} is the output power in DC, and P_{in} is the input RF power. Fig 2 shows the schematic of the proposed rectifier circuit in shunt configuration. Simulation and optimization of the proposed rectifier were carried out in Advanced Design System (ADS). To get the maximum RF-DC conversion efficiency, special attention was paid to optimize these two design parameters 1) impedance matching network, and 2) load resistance. An extensive set of simulations using ADS were carried to choose the most optimum compactness and efficiency of the proposed rectifier. MACOM MA4E2054A Schottky diode is used in simulations as well as fabrication of proposed rectifier. Flexibility of proposed rectifier was achieved with the help a very thin substrate material having thickness of just 0.13 mm.

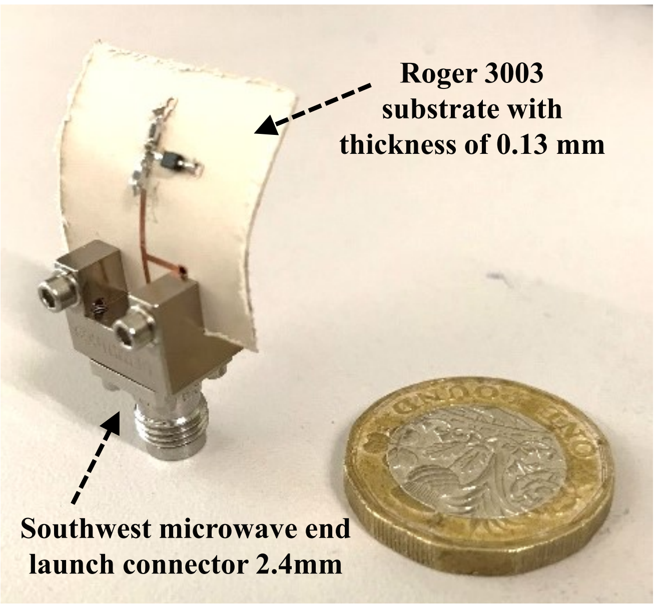
The ADS circuit schematic and layout of the proposed flexible rectifier in shunt topology are shown in Fig 3 and Fig 4 respectively. Fig 5 depicts the simulated RF-DC conversion efficiency of proposed rectifiers across different load resistances as a function of input power. It gives a maximum simulated RF-DC conversion efficiency of 26% with an input power and DC load resistance of 14 dBm and 250 Ω respectively, at 24 GHz frequency.

III. Measurement and Discussion

After successfully achieving the most optimum simulated results of proposed rectifier, the next step is the fabrication of



(a)



(b)

Fig. 6 Fabricated Prototypes a). top view and b) perspective view

a prototype for results validation. Rogers 3003 substrate material with thickness 0.13 mm was used to fabricate the proposed flexible rectifier. Fig 6 shows the fabricated rectifier prototype. 2.4 mm field replaceable connectors were used to connect the rectifier circuit to a signal generator, outputting an RF signal at 24 GHz. The output voltages of the rectifiers were measured across a 250 Ω DC load resistance, using a multimetre, for different input RF power ranging from 0 dBm to 20 dBm. Fig 7 shows the measured output voltage across the load resistance of the proposed flexible rectifier. Fig 8 shows the comparison between the measured and simulated RF-DC conversion efficiency as a function of the RF input power. There is some inconsistency between the simulated and measured RF-DC conversion efficiency as the input power increases. This can be explained by detuning of the input matching network, losses due to the coax-to-microstrip transition, as well as general manufacturing tolerances.

IV. Conclusion

In this proposed work, the design and implementation of a miniaturized as well as efficient flexible rectifier circuit

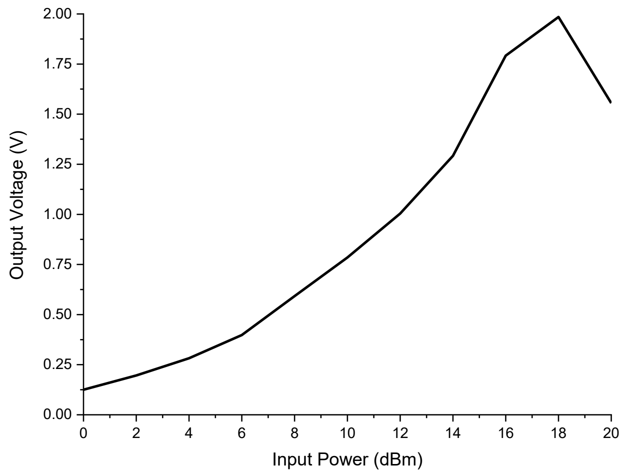


Fig 7 Measured voltages across the load resistance of proposed flexible rectifier

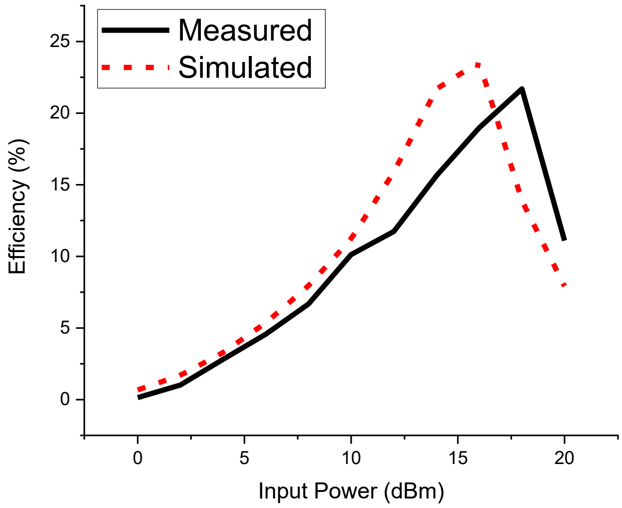


Fig 8 Measured RF-DC conversion efficiency of proposed flexible rectifier as a function of input power

based on simple shunt configuration has been presented for wireless power transfer applications in wearable Internet-of-Things. The performance of the proposed flexible rectifier circuit has been verified experimentally. It gives an output voltage and measured RF-DC conversion efficiency of more than 2.0 V and 23% respectively for an input power of 17 dBm at 24 GHz. The proposed compact and flexible rectifier could find numerous applications in the field of WPT to wearable IoT devices.

Acknowledgment

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