Circuit Analysis of Series and Shunt Rectifier Topologies for RF Energy Harvesting Applications At 5.80 GHz

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Abstract: This study examines the topologies of RF-DC converter circuits designed for wireless energy harvesting at 5.80 GHz. At the conversion power level, two rectification circuits are researched, developed, and compared. The power efficiency of the shunt and series topologies at 5.80 GHz is 74 % and 70 %, respectively. These topologies have been studied and their effectiveness evaluated. The Advanced Design System-ADS Software is used to obtain the simulation results of the rectifier circuit.

1 INTRODUCTION

Wireless energy transfer has gotten a lot of interest in recent years. The possibility of recycling ambient electromagnetic energy is being seriously researched (Kawahara et al. 2009), especially in densely populated metropolitan space. The lead for low-power current wireless communication systems is battery life maximization and miniaturization.

As a result, low power, low voltage circuits, energy compact size, cheap cost, and high integration power have attracted a lot of attention (Suh and Chang, 2002; Hagerty et al., 2004). Reduced power dissipation shrinks the battery's physical size, allowing it to last longer.

A gadget powered by a single cell can be powered by using a short supply voltage. In a wireless energy transmission system, a rectenna is an important component: His function is to convert the RF power received into DC power, which the structure's other components can subsequently utilise. The rectenna design technique consists of three basic components: an antenna, a matching network, and a rectifier circuit. In most situations, the rectifier circuit consists of a series or parallel connection of one or more Schottky diodes in a dual voltage arrangement or a modified bridge converter. There's also an LPF, a pass filter, and a resistive load. This study looks at the topologies of series and shunt rectifier circuits for wireless energy transfer. To improve the rectifier's RF-to-DC conversion efficiency, harmonic balancing (HB) modeling is used.

2 TECHNOLOGY AND CIRCUIT CONFIGURATION

A rectifier is a non-linear circuit made up of one or more diodes that convert RF input power to continuous output power. Figure 1 depicts a traditional block design. A rectifier is made up of Schottky diodes, an output bypass capacitor, and a load resistor in most cases. Between the diodes and the antenna lies the HF input filter. The nonlinear diode's performance produces harmonics, which are suppressed by the low-pass filters.

In addition, it serves as a matching circuit for the rectifier and the antenna. (Ren and Chang, 2006; Douyère et al., 2008).

Microwave rectifiers are utilized in a wide range of applications.

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The single serial (Douyère et al., 2008; Akkermans et al., 2005) and shunt topologies, on the other hand, are the most widely used (Douyère et al., 2008; Strassner and Chang, 2002).

We can also employ a voltage doubler to boost the DC output (Ren and Chang, 2006; Heikkinen and Kivikoski, 2004; Heikkinen and Kivikoski, 2003). Schottky diodes and power levels are the most important factors in determining the efficiency of a rectifier. On the other hand, the distance between the output DC filter and the diode is important. It is used to improve the diode's efficiency by removing the capacitive reactance. The rectifying circuit must also be changed to improve the rectenna's efficiency.

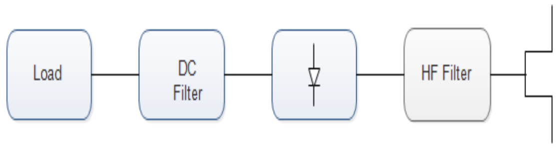
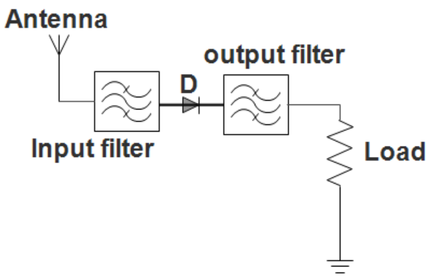


Figure 1: General block diagram of rectenna

The accuracy of rectenna estimation is determined by the amount of its output voltage and the effectiveness of its RF-DC conversion (Suh and Chang, 2002; Paing et al., 2007). The efficiency of RF-DC conversion is calculated as follows:

$$\eta = \text{PDC out} / \text{PRF int} \qquad (1)$$

The RF input power is P_{RF}, while the DC output power is P_{DC}. Depending on the topology of the diodes used, the rectification circuits can be configured in a variety of ways. The bridge configuration, which is extensively used for low-frequency rectification, is insufficient for low-power applications (Merabet et al. 2009). The shunt and series single diode topologies allow you to reduce the diode's loss, which is proportional to the diode junction resistance. The capacity to boost DC voltage levels for the same incident power level is primarily what the voltages of the doubler type arrangement can do.



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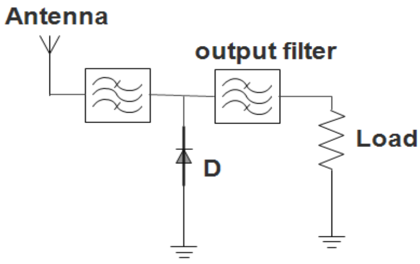


b)

Figure 2: Rectenna circuit topologies: a) series; b) shunt

2.1 Rectenna Design

2.2.1 Series Mounted

Figure 3 shows the circuit of a Schottky diode in a series topology. To eliminate all the harmonics created, a pair of HF and DC filters were used on one and the other sides of the diode. The HF filter is frequently represented by a capacitor, which allows the DC element to be recovered. The low-pass filter is made up of a parallel capacitor and a series inductor. The last one can pass the 5.80 GHz signal while blocking all other harmonics.

Rectification circuits are well-known for their non-linear characteristics. It's pointless to study subparts separately because they work so well together.

The diode and the output filter establish the load.

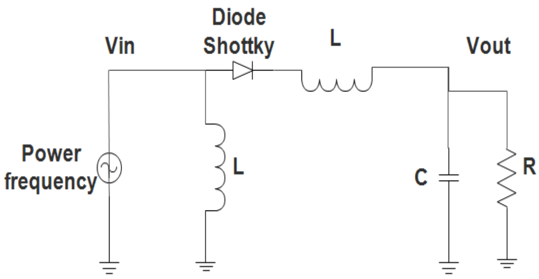
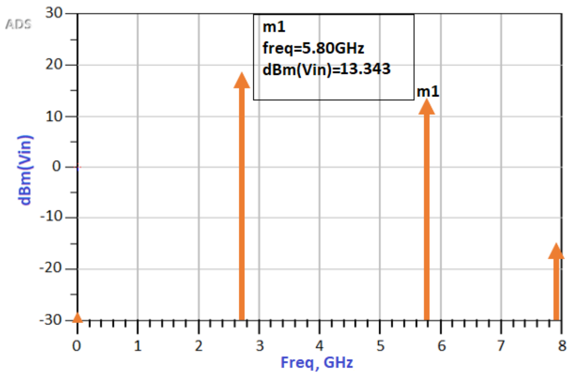


Figure 3: Single series mounted diode

Figure 4 shows the power levels before and after the rectifier circuits. The power is transferred to DC at the output, as can be observed.



a)

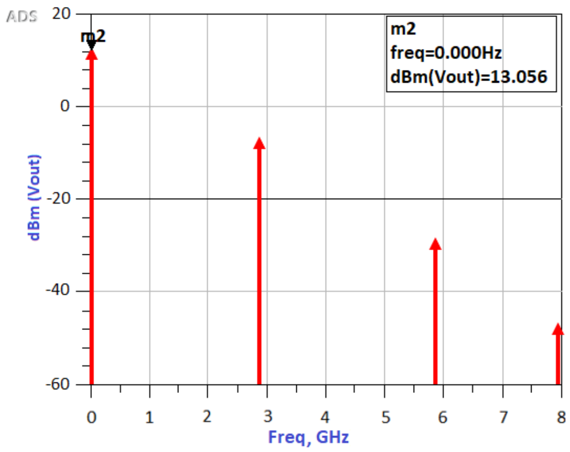


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Figure 4: a) Input Spectrum power; b) Output Spectrum power.

Figure 5 illustrates a simulation of power efficiency vs load impedance. For 448Ω, the maximum efficiency is reached.

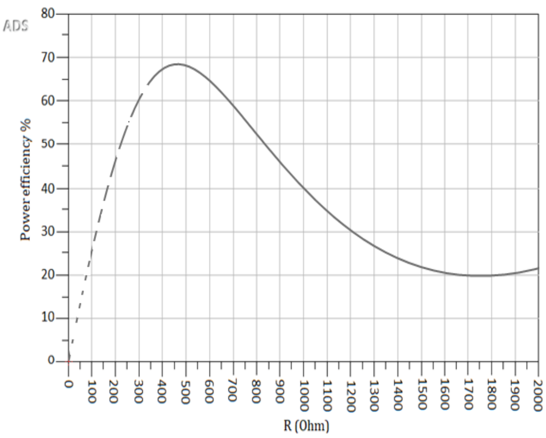


Figure 5: Power efficiency versus load impedance.

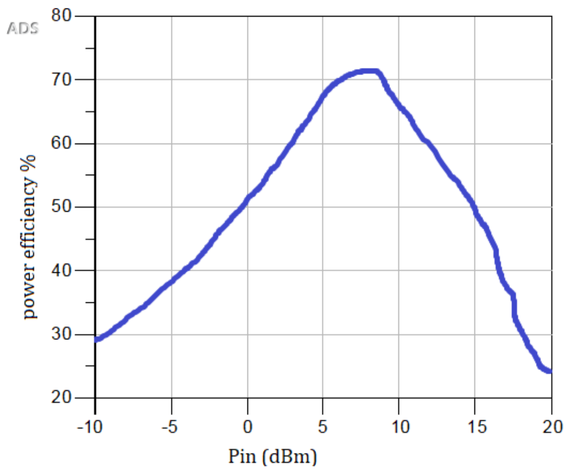


Figure 6: Power efficiency versus input power.

Figure 6 represents the variation in efficiency as a function of incident RF power.

We can observe that the rectification circuit can achieve maximum efficiency of 72% at 5.80 GHz with an incidence power of 8 dBm.

2.2.2 Shunt Mounted Diode

Figure 7 depicts a second rectifier configuration. The diode is shunt placed and is identical to those used in series topologies.

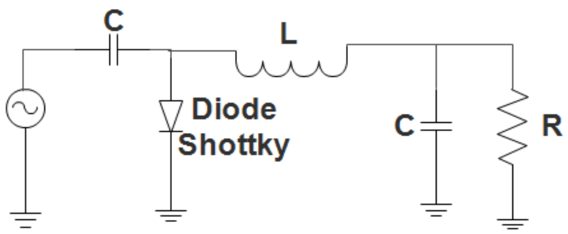
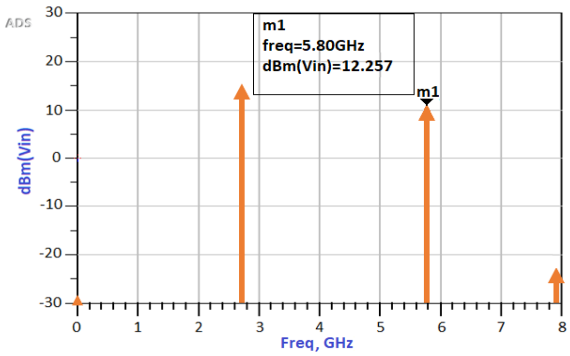


Figure 7: Single shunt mounted diode

Figure 8 depicts the power levels before and after the rectifier circuit. The power is transferred to DC at the output, as can be observed.



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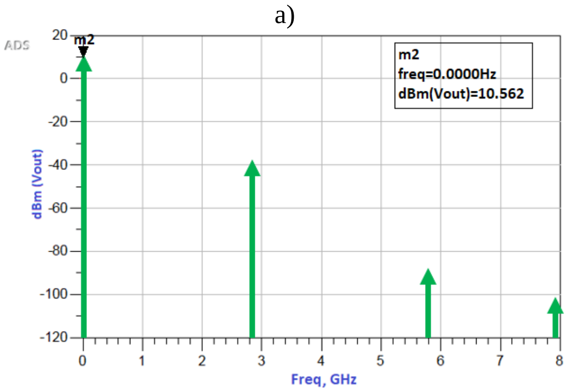

b)

Figure 8. a) Input Spectrum power; b) Output Spectrum power

Figure 9 demonstrates the power efficiency against load impedance simulation. For 1.8KΩ, the highest efficiency is obtained.

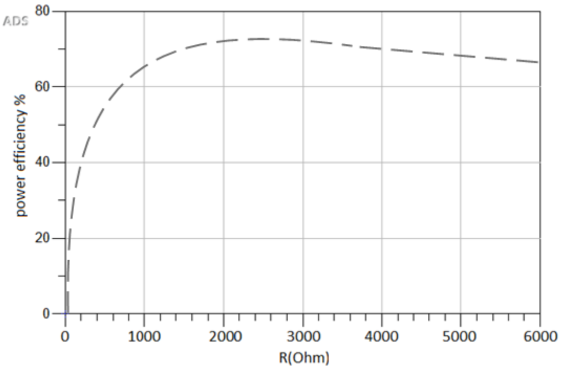

Figure 9. Power efficiency versus load impedance

Figure 10 indicates that the structure achieves a maximum conversion efficiency of 74% when the input power is 10 dBm and the frequency is 5.80 GHz.

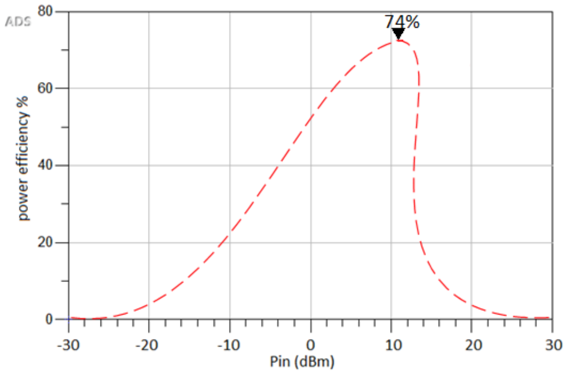

Figure 10. Power efficiency versus input power

Table 1 and Table 2 summarize the results achieved with the two topologies (serie and shunt) studied in this work and a prior similar investigation at 5.80 GHz using the same topology.

Table 1: Comparison with anterior rectifier using diode serie.

Ref	Topology	Input power (dBm)	Efficiency (%)	Freq (GHz)
This work	Diode in series	8	71	5.80
(Liu et al., 2016)	Diode in series	20	80	2.45
(Sun, 2015)	Diode in series	10.1	74.9	2.45

Table 2: Comparison with anterior rectifier using diode shunt.

Ref	Topology	Input power (dBm)	Efficiency (%)	Freq (GHz)
This work	Diode in shunt	10	74	5.80
(Sun et al., 2012)	Diode in shunt	10	60	2.45

3 CONCLUSIONS

In this research, we introduced two rectifier topologies for an RF energy harvesting system. The serial rectifier's RF-DC conversion efficiency is roughly 71%. When employing the HSMS2860 diode, the shunted rectifier has an RF-DC conversion efficiency of 74% at a frequency of 5.80 GHz.

The incident power is set at 10 dBm for these tests. In terms of RF-DC conversion efficiency, the shunt topology has shown promising results.

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