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Rectifiers Configurations for Rectenna Design

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Abstract

A rectenna is a device that combines a rectifier with an antenna. The significance of rectennas lies in their potential for harvesting wireless energy. They can capture and convert ambient RF/microwave signals from sources like Wi-Fi routers, cell phone towers, and other communication systems into electricity. In this paper, different rectifier configurations have been implemented and analyzed for rectenna applications. The rectifier circuits include half-wave and full-wave. The performance metric of the rectenna for all configurations has been created and discussed. The matching and filtering elements are also taken into account while analyzing the performance metric. For some designs, the distributed element structure is developed which may further.

Keywords: *Half Wave Rectifier, alternating current, direct current, Full Wave Rectifier*

1. Introduction

A rectenna is a device that combines a rectifier (a device that converts alternating current to direct current) with an antenna (a device that receives or transmits electromagnetic waves) [1]. It's used to convert electromagnetic energy, usually in the form of radiofrequency or microwave radiation, into usable direct current (DC) electricity. The significance of rectennas lies in their potential for harvesting wireless energy. They can capture and convert ambient RF/microwave signals from sources like Wi-Fi routers, cell phone towers, and other communication systems into electricity. This technology could enable various applications, including powering remote sensors, and Internet of Things (IoT) devices, and even providing a new way to charge electronic devices wirelessly. This wireless energy harvesting capability has the potential to reduce the reliance on traditional wired power sources and extend the operational life of battery-powered devices.

Various rectennas have been reported in the literature. In [2], a half-wave rectifier-based rectenna is presented. Authors have developed a hybrid sensitive rectenna system operating at 2.45 GHz. Initially, we optimized and validated a zero-bias microwave-sensitive rectifier using commercial Schottky diodes. Subsequently, we optimized a 2×2 patch antenna array and integrated it with the rectifier to create the rectenna system, achieving an experimental RF-to-DC conversion efficiency of 56%. To reduce the rectenna's size, we utilized the OMMIC ED02AH 0.20-µm GaAs pseudomorphic high electron-mobility transistor process to create a monolithic rectifier operating at 2.45 GHz with an RF-to-DC conversion efficiency of 65%. In [3], a novel rectenna for RF power harvesting, utilizing a beamwidth-enhanced antenna array. Schematic diagram of filter integrated half-wave rectifier with two diode configurations shown in Figure 1.

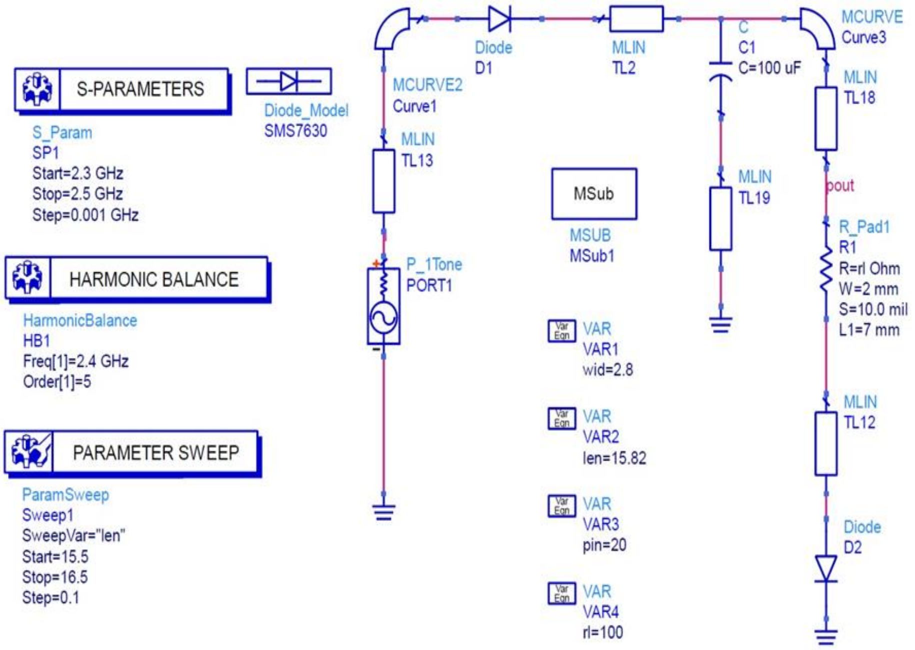
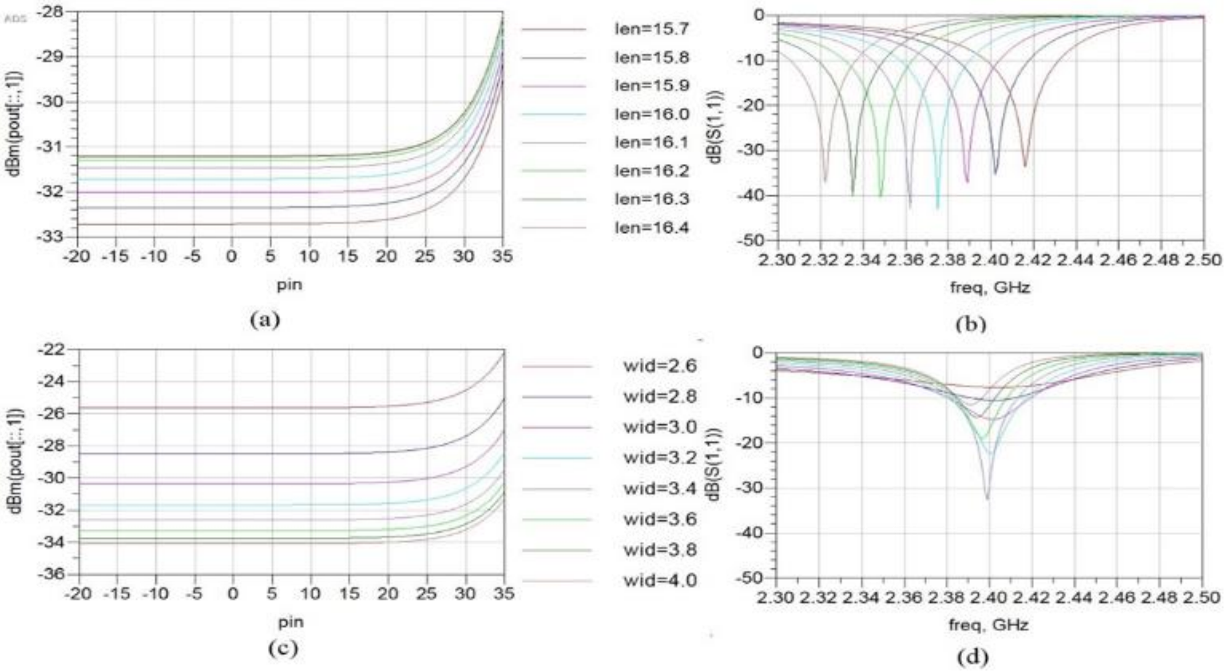


Figure 1 Schematic Diagram of Filter Integrated Half-Wave Rectifier with Two Diode Configuration

We demonstrate this approach using a 1×4 patch antenna array as an example. By optimizing the excitation distribution to maximize power transmission efficiency between the 1×4 antenna array and two auxiliary antennas, we achieve an enhanced beamwidth, which [5] is approximately twice as wide as the uniform amplitude and phase-fed array. A high-efficiency rectifier is employed to convert RF power to DC power and integrated with the 1×4 antenna array [6] to create the beamwidth-enhanced rectenna. Measurement results indicate an efficiency exceeding 50% within an incident wave angle range of -38◦ to 35◦ at the H-plane, with a power density of 1276 μW/cm2. Similarly, in [4]-[11] different efforts are taken to improve the performance of the rectenna. [7] Presented is a novel six-band dual circular polarization (CP) rectenna designed for ambient RF energy harvesting. Addressing the challenges posed by nonlinearity and complex input impedance in multiband or broadband rectennas, we introduce an improved impedance matching technique to enhance rectifier performance under varying conditions. The design includes a broadband dual CP receiving antenna with a wide bandwidth (550 to 2.5 GHz) and a compact form factor. This antenna employs an annular ring structure and a novel feeding technique to reduce size while improving performance. The rectenna covers six frequency bands, including digital TV and most cellular and WLAN bands in the U.K., with an optimal load range for constant conversion efficiency from 10 to 75 kΩ. Measurement results demonstrate a maximum harvested DC power of 26W in typical outdoor environments and 8 μW indoors, making it suitable for various low-power wireless applications. This [8] paper presents a comprehensive exploration of rectifier circuitry, encompassing the creation, analysis, and performance assessment of two distinct rectifier circuits. The experimental investigation unfolds within the realm of advanced design systems software, where intricate design elements come into play. Central to the study is the optimization of transmission lines, a crucial aspect aimed at achieving the coveted 50 Ω impedance matching. This optimization process is pivotal in determining the overall effectiveness [9] of the circuits.

Additionally, the investigation scrutinizes how these optimized transmission lines influence scattering parameters and the ultimate output power of the circuits. The foundation of this analysis is a meticulously constructed diode model, with parameter values sourced from the relevant technical datasheet. This ensures that the diode characteristics are faithfully represented in the circuit simulations. Furthermore, both of these rectifier circuits are meticulously tailored to operate within the 2.4 GHz frequency range, a strategically chosen frequency band for their intended applications. Throughout the paper, a rigorous and in-depth [10] discussion unfolds, illuminating the operational intricacies and inherent limitations of the examined rectifier circuits. This discussion not only enhances our understanding of their functioning but also provides valuable insights into their potential real-world applications and constraints. The results of filter-integrated HWR with two diode configurations are shown in Figure 2.



(a) (b)

(c) (d)

Figure 2 **Results of Filter Integrated HWR with Two Diode Configuration**

2. Half Wave Rectifier

A half-wave rectifier holds a significant role in rectenna applications by efficiently converting alternating current (AC) electromagnetic energy into usable direct current (DC) power. In this configuration, the rectifier circuit allows only the positive half-cycles of the AC input signal to pass through, effectively blocking the negative half-cycles. This results in a pulsating DC output that can be further smoothed using capacitors. The simplicity of the half-wave rectifier makes it suitable for rectenna designs, as it can efficiently capture and rectify RF/microwave signals, which are often used for wireless energy harvesting. The rectified DC output can then be stored or used to power various low-power electronic devices, contributing to advancements in wireless power transmission, remote sensing, and energy-efficient IoT applications. In this section, we have analyzed different configurations of half-wave rectifiers, and their performance is discussed. Figure 1 shows the layout of the half-wave rectifier. It consists of an input power source, SMS7630, FR4-based substrate, 100 μF capacitor, and a resistive load. The input power source is set for 2.4 GHz operating frequency. The first and second diodes will allow only one half-wave cycle leading to a unipolar polarity to the resistor. To further purify the output, a 100 100 µF capacitor is loaded. A capacitor filter is essential for enhancing a half-wave rectifier's performance. In a half-wave rectifier, which converts only half of the incoming AC waveform into DC, the output exhibits a pulsating or rippled DC voltage. The primary role of the capacitor filter is to reduce or eliminate this ripple, resulting in a more stable and smoother DC output [12]. The research in this study involves the careful adjustment of the dimensions of transmission lines, and the resulting impact is visually represented in Figure 2. In Figure 2, we observe the influence of transmission line length on the output power. To provide a comprehensive perspective, we've generated graphs illustrating the relationship between input power and output power for various transmission line lengths. It becomes readily apparent that optimizing the length of the transmission line is crucial for achieving higher output power levels. Moving on to Figure 2b, we delve into the effect of transmission line length on a parameter known as the scattering parameter. Schematic diagram of filter integrated full-wave rectifier with two diode configuration shown in Figure 3.

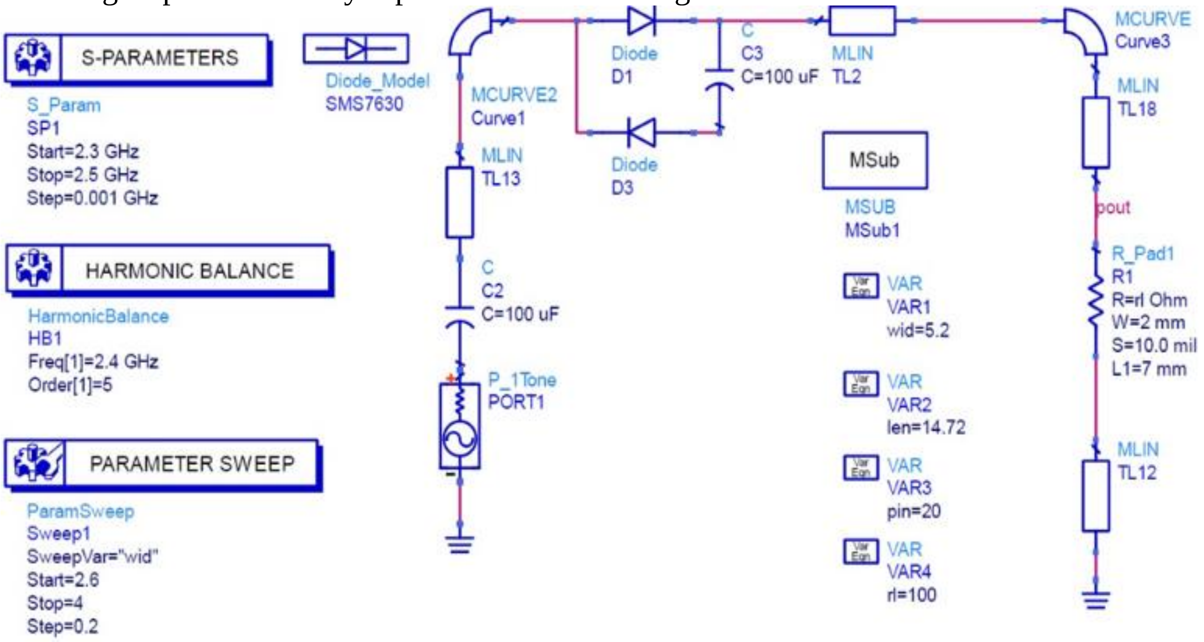


Figure 3 Schematic Diagram of Filter Integrated Full-Wave Rectifier with Two Diode Configuration

This analysis demonstrates that adjusting the length of the transmission line has a direct bearing on the operating frequency of the circuit. In essence, by fine-tuning the transmission line length, we can manipulate the circuit's operational frequency, offering valuable insights for tuning and optimization. Our investigation also extends to the dimensions of the transmission line width, as showcased in Figures 2b and c. Here, we make observations similar to those about transmission line length. However, the width primarily exerts its influence on impedance matching, playing a critical role in ensuring that the system is appropriately matched to the desired impedance. Additionally, it has a minor impact on the circuit's resonant frequency, although its significance lies predominantly in achieving optimal impedance characteristics. These findings contribute to a comprehensive understanding of how transmission line dimensions affect circuit performance, opening doors to further fine-tuning and optimization strategies.

3. Full Wave Rectifier

The full-wave rectifier plays a pivotal role in rectenna applications by enhancing the efficiency of converting alternating current (AC) electromagnetic energy into usable direct current (DC) power. Unlike the half-wave rectifier, the full-wave rectifier allows both the positive and negative half-cycles of the AC input signal to be utilized, resulting in a smoother and more consistent DC output. This is achieved by utilizing a bridge rectifier configuration, which employs a combination of diodes to effectively rectify the entire AC waveform. The results of filter-integrated FWR with two diode configurations are shown in Figure 4.

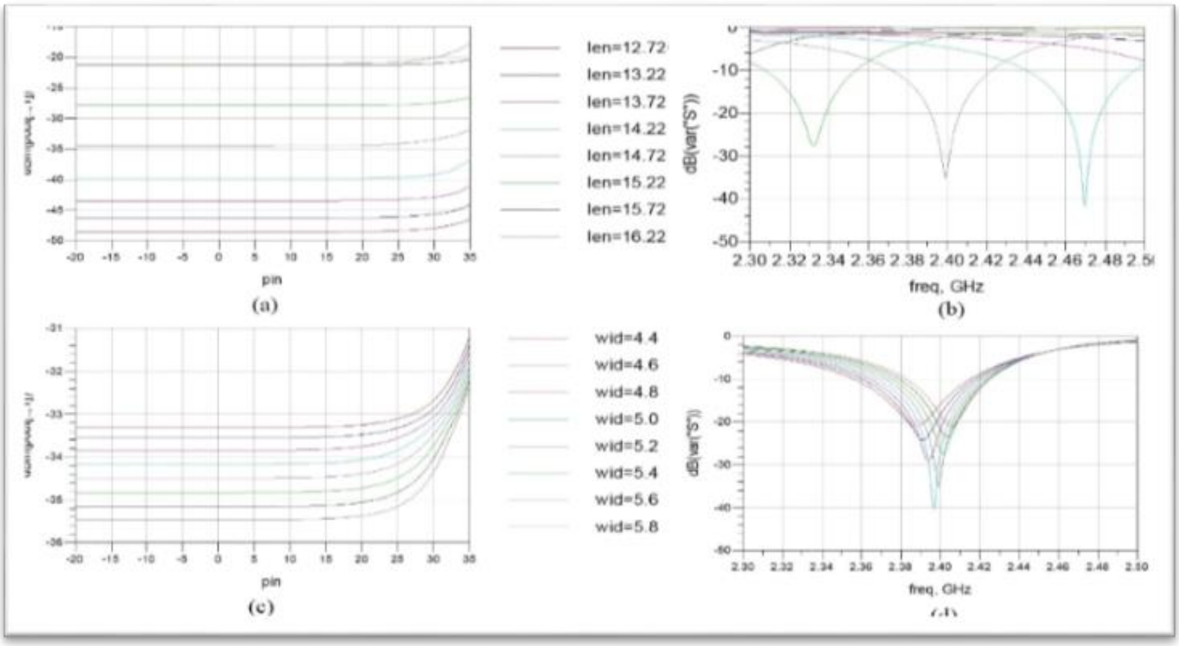


Figure 4 Results of Filter Integrated FWR with Two Diode Configuration

This improved rectification process makes the full-wave rectifier especially advantageous for rectenna designs, as it can efficiently capture and convert RF/microwave signals into a more stable DC output. The rectified power can then be harnessed for various applications, including wireless energy harvesting for IoT devices, remote sensors, and other low-power electronic systems, thus paving the way for innovative advancements in wireless power transmission and sustainable energy solutions. In this section, we have analyzed different configurations of the full-wave rectifier and its performance is discussed. In Figure 3, you can see the layout of the full wave rectifier setup. It includes an input power source, two SMS7630 diodes, an FR4-based substrate, a 100 µF capacitor, and a resistive load. The input power source operates at a 2.4 GHz frequency. The two diodes in this setup permit only one-half of the wave cycle to pass through, resulting in a unipolar polarity at the resistor. Our research in this study involves carefully adjusting the dimensions of transmission lines, and you can see the effects in Figure 4. Figure 4a illustrates how the length of the transmission line impacts the output power. We've created graphs that show the relationship between input power and output power for different transmission line lengths. Optimizing the transmission line length is crucial for achieving higher output power levels. Moving to Figure 4b, we explore how the transmission line length affects a parameter called the scattering parameter. This analysis reveals that adjusting the length of the transmission line directly affects the circuit's operating frequency. Essentially, by fine-tuning the transmission line length, we can control the circuit's frequency, providing valuable insights for tuning and optimization. Our investigation also extends to the width of the transmission line, as seen in Figures 4b and c. Here, we make similar observations to those regarding the length of the transmission line. However, the width primarily influences impedance matching, ensuring that the system matches the desired impedance properly. It also has a minor impact on the circuit's resonant frequency, but its main role is in achieving optimal impedance characteristics [13]. These findings give us a comprehensive understanding of how transmission line dimensions affect circuit performance and offer opportunities for further fine-tuning and optimization strategies.

Discussion

Half-wave and full-wave rectifiers are two common configurations used in wireless energy harvesting using rectennas. The key difference between them lies in how they convert alternating current (AC) signals, such as those received from Wi-Fi routers, cell phone towers, or other wireless sources, into direct current (DC) electricity. A half-wave rectifier allows only one-half of the AC signal to pass through, effectively capturing energy from either the positive or negative half-cycles of the waveform. While this approach is simple and cost-effective, it results in a relatively lower DC output compared to a full-wave rectifier. On the other hand, a full-wave rectifier is more efficient as it captures energy from both the positive and negative half-cycles of the AC signal. This leads to a smoother and more consistent DC output with reduced ripple, making it better suited for applications where a stable power supply is crucial. While a half-wave rectifier is simpler and more cost-effective, a full-wave rectifier offers superior energy harvesting capabilities, producing a more reliable and stable DC output, which is advantageous for wireless energy harvesting applications where consistent power generation is essential. The choice between the two depends on the specific requirements and constraints of the given application.

Conclusion

The key thing about rectennas is that they have the potential to collect and turn wireless energy into usable electricity. They can snatch energy from things like Wi-Fi routers, cell phone towers, and other communication systems, and change it into power [14]. In our research, we've tried out different setups of rectifiers for rectenna purposes. These setups include half-wave and full-wave rectifier circuits. We've also looked at how well the rectenna performs in each configuration and talked about the factors like matching and filtering elements that play a role in its performance. In some cases, we've even developed a distributed element structure for the design, which could potentially be created and tested in the future.

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