A Novel Wideband Rectifier With Two-level Impedance Matching Network For Ambient Wireless Energy Harvesting

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Abstract. A wideband rectifier for ambient wireless energy harvesting is presented in this paper. By utilizing a new type of two-level impedance matching network, the rectifier can achieve high-efficiency rectification within a broad range of operation bandwidth (1.8-2.45GHz). A resonant inductor and L-type matching network are used to achieve impedance matching at a specific single frequency point. A band-pass matching network is then used to achieve impedance matching over the desired operation frequency band. Simulation results show that when the input power is -15dBm, the rectifier can achieve more than 30% rectification efficiency (1.75-2.45GHz). When the input power is -4dBm, it can achieve more than 55% peak rectification efficiency (1.8-2.5GHz). Its wideband and features suitable for low power environments make it widely used in environmental wireless energy harvesting.

1. Introduction

With the development of Internet of things, wireless sensors have been more and more widely used. The power supply of wireless sensors has become an urgent problem to be solved. Therefore, ambient wireless energy harvesting technology has attracted much attention due to its protection from the weather and pollution [1]. Rectifier, as a key part of the ambient wireless energy harvesting technology, directly determines the performance of the harvesting system.

Currently high-efficiency rectifiers have been achieved [2-3], but broadband or multi-frequency rectifiers can collect energy in more frequency bands than rectifiers that can only operate in a single frequency point. There have been some studies on broadband rectifiers. By connecting multiple rectifier branches in parallel, each rectifier branch achieves impedance matching in a relatively narrow frequency band to obtain a broadband multi-frequency rectifier [4-7]. However, these solutions require the design of multiple rectifier branches, which leads to a complex design and an increase in production costs. In [8], when the input power is above 4dBm, the rectifier can work from 4GHz to 6.3GHz. Through the source traction simulation [9], the proposed rectifier achieves 50% rectification efficiency from 0.8GHz to 1.4GHz when the input power is 14dBm. However, these designs must work at higher power points and do not apply to the ambient wireless energy harvesting. Therefore, it is of great practical value to propose a wideband rectifier that has a simple structure, is easy to manufacture, and can operate in a low power environment.

In this paper, in order to solve the above problems, we propose a novel wideband rectifier with two-level impedance matching network to work in a low-power environment. In the first step, a resonant inductor is used to provide resonance at a specific frequency point, and an L-type matching network is used to tune the input impedance of the circuit without changing the resonance frequency
point to facilitate the broadband of the next step. In the second step, a bandpass matching network is used to achieve impedance matching over the desired broadband.

After optimizing the parameters by using the simulation software ADS, a broadband rectifier covering the wireless communication systems of GSM-1800/4G, UMTS-2100/3G, and WiFi was designed. The rectifier can work normally at low input power, and its structure is simple and easy to manufacture. It can be widely used in the field of ambient wireless energy harvesting.

2. The design of rectifier

2.1 Rectifier configuration

This part mainly discusses the configuration of the rectifier. As shown in Figure 1, the rectifier uses a voltage doubler rectifier circuit as the rectifier unit, the load resistance is 4kΩ. To design a high-efficiency rectifier, it is necessary to select a diode which has a low conduction voltage and sensitivity. Schottky diodes SMS7630 are selected diodes D1 and D2. The Capacitance C1 and C2 is designed by 82pF. Zin and Zm are the input impedances of the circuit. Z0 is the source impedance of the signal source and is generally set to 50 ohms. The impedance matching network is divided into two parts: part 1 and part 2. They are the key to achieving broadband impedance matching networks and wideband rectification. The following will mainly introduce their structure.

![Rectifier configuration diagram](image)

**Figure 1. Structure of the rectifier.**

**Figure 2. Rectifier equivalent circuit diagram**

2.2 Design of Part 1

The equivalent circuit of the rectifier is shown in Figure 2. When the input power is -15dBm, the input impedance of the doubled voltage rectifier circuit (C1, C2, D1, D2, RL) versus frequency is shown in Figure 3a. After the resonant inductor L1 is added, the input impedance Zin versus frequency is shown in Figure 3b.
Figure 3. (a) Input impedance of double voltage rectifier circuit versus frequency (b) Input impedance versus frequency after adding the resonant inductor L1.

From the figure, it can be seen that a resonance point is obtained near 2.3GHz, but the change of the input impedance in the desired frequency band is still drastic, which will affect the subsequent broadband impedance matching, so the L-type matching network is added. The input impedance and S11 parameters after the L-type matching network is added are shown in Figure 4:

Figure 4. (a) Input impedance Zm (b) Return loss(S11) versus frequency.

It is observed that the input impedance variation range is compressed, and the resonance point is still around 2.3GHz and remains unchanged, which provides a good premise for the following part2 matching.

2.3 Design of Part 2
Part 2 has a band-pass property that can adjust the real part of Zm and further offset the imaginary part, where inductor L5 is used to cancel the imaginary part and part 2 can adjust the real part of Zm to 50 ohms. The simulated input impedance and S11 of the rectifier after adding the bandpass matching network part2 is shown in Figure 5:

Figure 5. (a) Input impedance (b) Return loss(S11) versus frequency.

It can be seen that when the input power is -15dBm, the S11 of the rectifier forms a pass band (1.75-2.45 GHz). The theoretical design of the wideband rectifier is completed.
3. Realization and Result

Because of the high frequency environment, the parasitic effects of discrete devices will become serious, which will affect the performance of the rectifier, so we use the microstrip line to build the actual circuit, converting the inductance and capacitance of the lumped parameters in part1 and part2 to Distributed parameter devices. After optimization of ADS software, the value of resonant inductor L1 is chosen as 16nF. The value of geometric parameters of the rectifier are listed in table 1. The layout and geometric parameters are shown in Figure 6:

![Figure 6. Layout and geometric parameters.](image)

Table 1. Dimension of the proposed rectifier.

| Geometric Dimensions(mm) | W1 | W2 | W3 | W4 | L1 | L2 |
|--------------------------|----|----|----|----|----|----|
|                          | 7.8| 4.2| 37.3| 7.8| 25.8| 8.9|
| L3 | L4 | R | θ | L5 |
| 28 | 71.4 | 47.7 | 41.3 | 3.6 |

Among them, TL1 and TL2 are the equivalent inductors L2 and L3 respectively, TL3 and TL4 are the equivalent inductors L4 and L5, and the fan-shape stub is the equivalent capacitor C3. The rectifier is designed on a Rogers Duriod5880 Substrate with the relative dielectric constant εr of 2.2, thickness h of 0.8mm. Its S11 parameters versus different input power are shown in the Figure 7:

![Figure 7. Return loss(S11) versus frequency in different input power.](image)

It can be obtained that when the input power vary from -15dBm to 0dBm, a passband from 1.75GHz to 2.45GHz is formed, and its rectification efficiency versus different input power is shown in Figure 8.
Figure 8. Rectification efficiency versus frequency in different input power.

From Figure 8, it can be obtained that the rectifier can realize high-efficiency rectification from -15dBm to 0dBm. When the input power is -15dBm, the rectifier can achieve more than 30% rectification efficiency in 1.75-2.45GHz. When the input power is -4dBm, it can achieve more than 55% peak rectification efficiency in 1.8-2.5GHz.

4. Conclusion

In this paper, a broadband high-efficiency rectifier based on a two-level impedance match network has been presented. The two-level impedance match network is designed to extend the operation bandwidth. A resonant inductor and L-type matching network are used to achieve impedance matching at a specific single frequency point. A band-pass matching network is then used to achieve impedance matching over the desired operation frequency band. The simulation results have shown that when the input power is -15dBm, the rectifier can achieve more than 30% rectification efficiency when the operation frequency increases from 2.2GHz to 3.3GHz. When the input power is -4dBm, it can achieve more than 55% peak rectification efficiency (from 1.8GHz to 2.5GHz). Furthermore, the rectifier possesses the characteristics of a simple structure and being suitable for low power environment, which can be applied in the ambient Wireless Energy Harvesting systems.

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