2.44GHz RF Energy Harvesting System Design

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Abstract

In this paper, a radio frequency energy harvesting system for the 2.44GHz frequency band is designed. ADS software is used to design and optimize the four-unit microstrip antenna. The quarter wavelength impedance converter is used to match the system connection impedance. Then, the Wilkinson power distributor is adopted for energy output and the collected energy is rectified and boosted by the quadruple voltage rectifier circuit.

Keywords

Energy Harvesting System; Impedance Converter; Microstrip Antenna; Wilkinson Power Distributor; Quadruple Voltage Rectifier Circuit.

1. Introduction

RF power conversion is the process of converting the RF energy existing in the external space into electrical energy. In the 21st century, countries have gradually entered into the era of the Internet of Everything, and technologies such as sensor communication have also developed rapidly. The number of data transmission points is increasing at a high speed. However, the traditional battery will bring environmental pollution, high cost of battery replacement, and poor reliability [1]. With the rapid development of wireless communication technology, collecting and storing the radio frequency energy that has always existed in space and converting it into electrical energy to replace the traditional battery power supply method has attracted more and more attention [2-4]. This article selects 2.44GHz as the center frequency of the designed antenna for energy harvesting.

2. Microstrip antenna design

2.1 Rectangular microstrip antenna design

For rectangular microstrip antenna design, the patch design formula is shown as follows [5].

Effective radiation patch width:

$$W = \frac{c}{2f}\left(\frac{\varepsilon_\gamma+1}{2}\right)^{\frac{-1}{2}} \tag{1}$$

Non-radiation edge patch length:

$$L = \frac{c}{2f\sqrt{\varepsilon_e}} - 2\Delta L \tag{2}$$

The effective dielectric constant ε_e is:

$$\varepsilon_e = \frac{\varepsilon_\gamma+1}{2} + \frac{\varepsilon_\gamma-1}{2}\left(1+12\frac{h}{W}\right)^{-\frac{1}{2}} \tag{3}$$

The equivalent radiation gap ΔL is:

$$\Delta L = 0.412h\frac{(\varepsilon_e+0.3)(\frac{W}{h}+0.264)}{(\varepsilon_e-0.258)(\frac{W}{h}+0.8)} \tag{4}$$

According to the above formula, this article designs a microstrip antenna based on Rogers RO4350 as the matrix material for electromagnetic waves for collecting the 2.44GHz microwave energy. The relative permittivity of the material $\varepsilon_\gamma = 3.66$, the thickness h=1.524mm, the copper thickness h1=35um. According to formulas (1)-(4), the width W of the radiating patch antenna is about 40mm, the effective dielectric constant ε_e is about 3.43, the equivalent radiation gap ΔL is about 0.72mm, and the length L of the non-radiating side patch is about 31.75 mm. According to these parameters, we establish an ADS imitation chart and draw its Smith chart, shown in Figure 1.

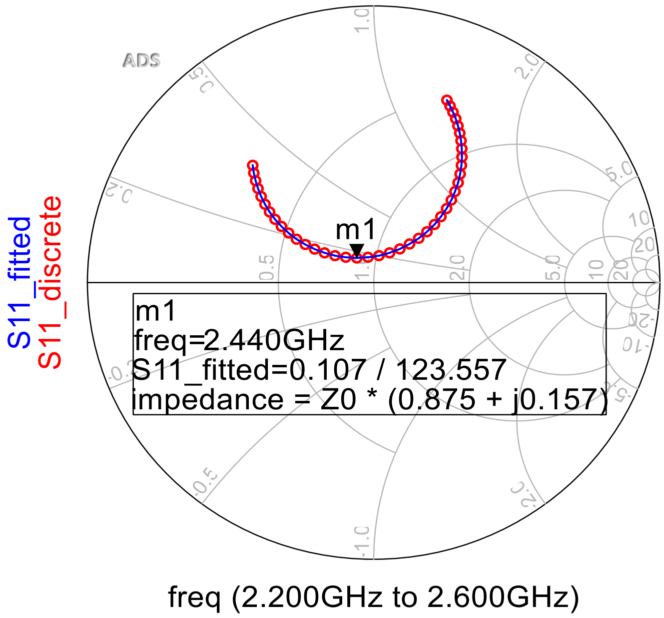

Figure 1. Smith chart of rectangular microstrip antenna

According to Figure 1, at 2.44GHz the input impedance of point m1 is $Z_0 = (43.75 + j7.85)\Omega$, not a pure resistance of 50 ohms. For this reason, it is necessary to optimize the design of the feeder of the microstrip antenna.

2.2 Optimal design of microstrip antenna

The transmission power will be maximized when the impedance of the microstrip antenna is matched. For this reason, a 50Ω wire is connected in series at the antenna signal output pot, making the parameter S11 rotate on the equal reflection coefficient circle and reach the equal conductance circle with g=1, and then connect a 50Ω transmission line in parallel to transfer the S11 parameter to 0. Then use ADS to optimize the microstrip antenna. The optimized S11 parameter distribution and Smith's original graph distribution are shown in Figure 2 and Figure 3, respectively.

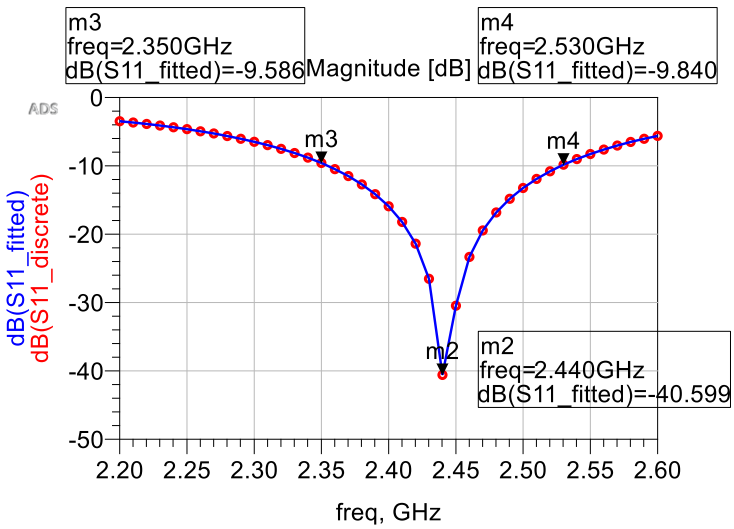

Figure 2. S11 parameter distribution

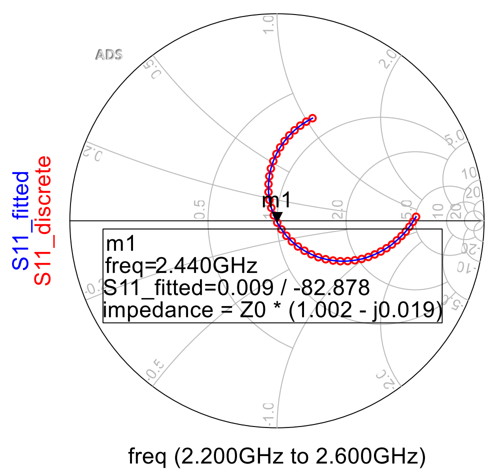

Figure 3. Optimized simulation of Smith chart distribution

At a frequency of 2.44GHz, the reflection coefficient S11 of the antenna is -40.60dB, Taking -10dB as the antenna bandwidth, it can be known from point m3 and m4 that the microstrip antenna designed in this article can pick up energy from 2.35GHz-2.53GHz. From the optimized Smith distribution in Figure 3, it can be seen that the impedance at the point m1 at a frequency of 2.44GHz is $Z_0 = (50.1 - j0.95)\Omega$, which can basically meet the design requirements.

3. Antenna array matching optimization

In order to obtain more energy, this paper adopts a four-unit patch microstrip array antenna design. The shape and size of the four units are the same. Therefore, a power divider is required for power matching. In this paper, three Wilkinson power dividers are used for energy distribution [6]. Figure 4 is a schematic diagram of the joint simulation of the microstrip array antenna and the Wilkinson power divider and Figure 5 shows the S11 parameter curve. It can be seen from Figure 5 that the center frequency of the four-unit patch microstrip array antenna is still 2.44GHz, and the bandwidth is about 100MHz, which meets the design requirements.

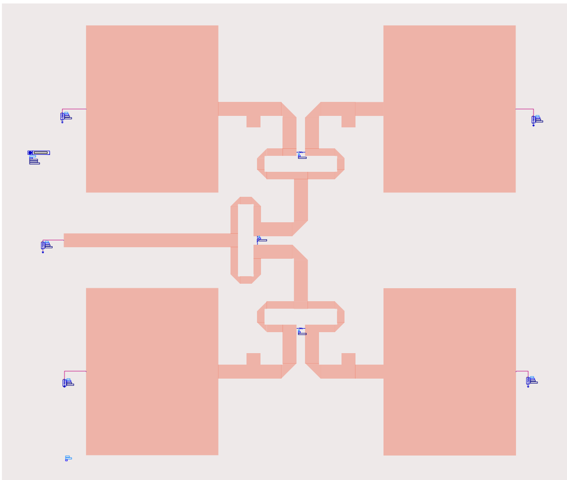

Figure 4. Antenna system schematic diagram of ADS simulation

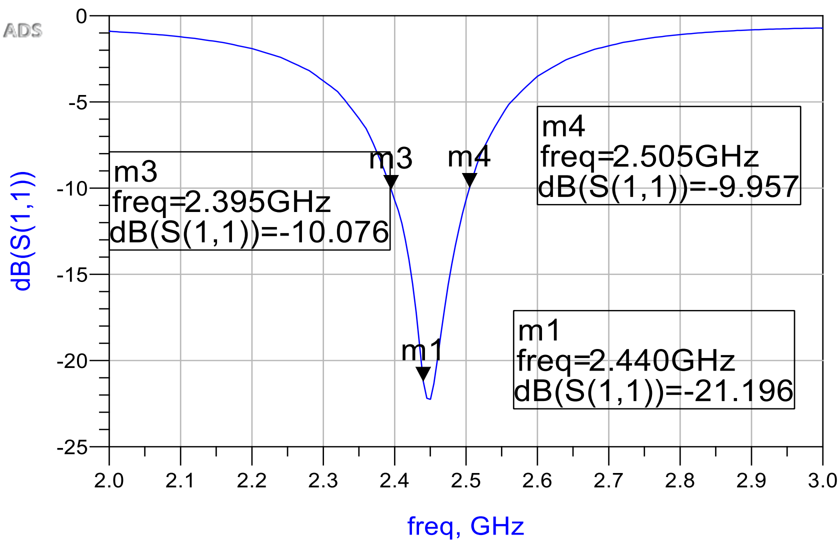

Figure 5. S11 parameter curve

Make a microstrip antenna according to Figure 4, and use the miniVNA Tiny 3G vector network analyzer to test its performance. Figure 6 is the physical image of microstrip antenna. Figure 7 is the input reflection coefficient S11 and the standing wave ratio SWR. Figure 8 is the Smith chart.

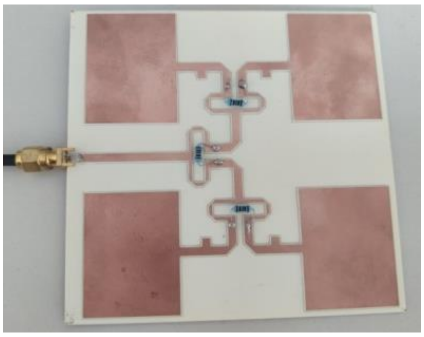

Figure 6. Physical image of microstrip antenna

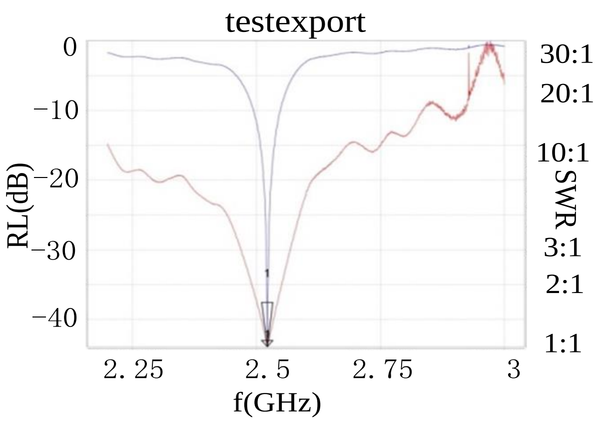

Figure 7. The input reflection coefficient S11 and the standing wave ratio SWR

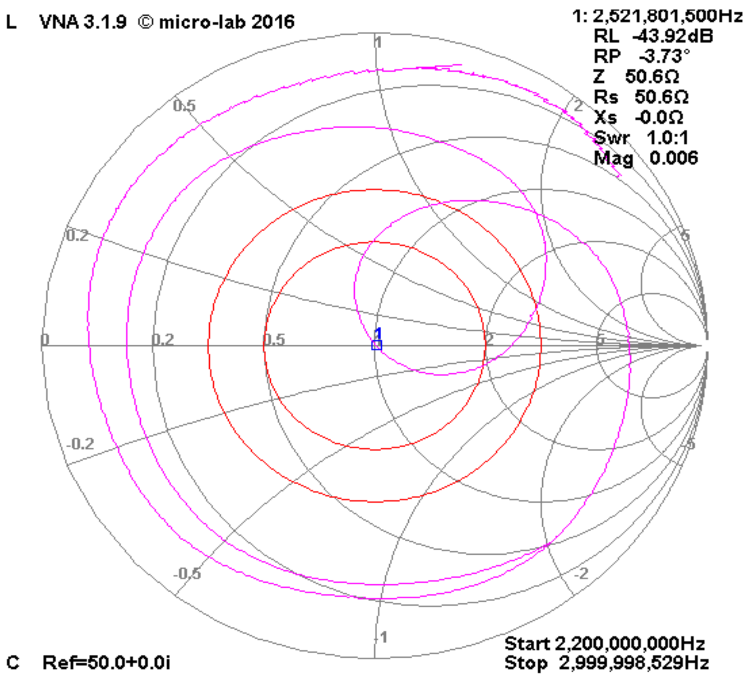

Figure 8. The Smith chart.

It can be seen from Figure 7 that the center frequency of the antenna is about 2.52 GHz, and the S11 parameter at the center frequency is -43.92 dB. At the center frequency the value of SWR is about 1, and the reflection of the radio wave transmitted to the antenna is extremely small. And it can be seen from Fig. 8 that the impedance of the antenna system is about 50Ω. On the whole, the antenna meets the expected requirements.

4. Voltage rectifier circuit design

The energy voltage collected by the radio frequency antenna is relatively low and cannot provide a stable voltage for low-power components. For this reason, a quadruple voltage rectifier circuit [7] is used in this article, shown in Figure 9. The HSMS286C Schottky diode, which has low power consumption and can be capable of 0.9 GHz ~ 5.8 GHz rectification, is selected as the rectifier diode.

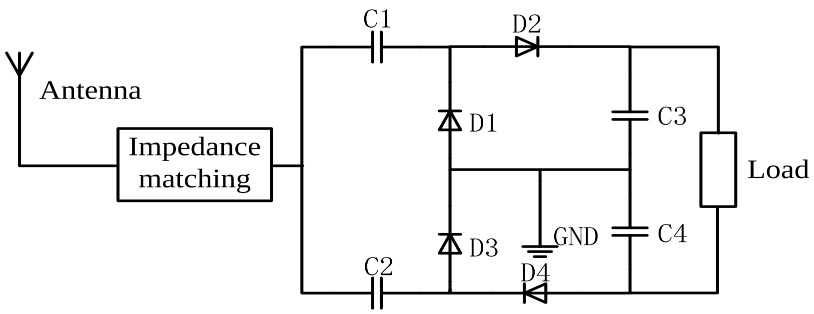

Figure 9. Quadruple voltage rectifier circuit

5. Conclusion

This paper designs a four-unit microstrip antenna. The design process from a single unit to four units is introduced in detail. And through ADS simulation, the four-unit microstrip antenna reflection coefficient S11 parameter curve and Smith chart distribution is analyzed. An antenna array with an impedance of about 50 ohms was designed. Finally, a quadruple voltage rectifier circuit is used to boost the collected radio frequency energy.

Acknowledgements

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References

[1] RONG Xun, CHEN Zhi-min, CAO Guang-zhong. Research status and developing trend of ultra low energy harvesting circuit technology [J]. Transducer and Microsystem Technologies 2015(09):6-10.

[2] FengL, Zhang Quan, Lishu. Designing and smulation of 2.4 GHz m icrostrippatch array antenna [J]. Journal of Guilin University of Electronic Technology, 2010, 30(1):5-8.

[3] Zhangkai. Design of 2.45/5.8GHz RF Energy Harvester [D]. Jiangsu University of Science and Technology, 2019.

[4] Chen Xuelin. Research and Design of Wi-Fi RF Energy Harvesting System [D]. Xiamen University, 2018.

[5] Li Mingyang. HFSS antenna design [M]. Beijing: Publishing House of Electronics Industry, 2011.

[6] Huang Mengqi. Research on Miniaturized Microwave Four-Port Power Division Device [D]. University of Electronic Science and Technology of China.

[7] Xu Tao, Yu Zhengchao. An efficient environmental WiFi energy harvesting system[J]. Radio Engineering, 2018, 048(006):492-496.