Original Research Article

Design and optimization of low power microwave rectifier circuit

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Abstract: This paper introduces the basic principle of microwave rectifier and the characteristics of low-power microwave, and analyzes the structure and performance of existing low-power microwave rectifier circuit. Based on this, a new design scheme of low power microwave rectifier circuit is proposed, including the selection of key components, parameter design and circuit simulation and optimization. In order to improve the circuit performance, the optimization strategy is also discussed, mainly from the circuit structure, component parameters, layout and process, intelligent control and adaptive optimization. Through these means, the aim is to improve the efficiency of rectification, reduce loss, for the efficient use of low-power microwave energy to provide a theoretical and technical support.

Keywords: Microwave rectifier; Low power; Circuit design; Optimization strategy; Wireless power

1. Introduction

In the environment of increasingly advanced Wireless power technology, low-power microwave rectifying circuit is a key technology in wireless charging and energy collection process, and has received widespread attention. Microwave rectifying circuit can convert the received microwave energy into DC power for a variety of low-power equipment. However, because of the special microwave energy, there are many challenges to design a high-efficient and stable low-power microwave rectifier circuit.

2. The theoretical basis of low power microwave rectifier circuit

2.1. The basic principle of microwave rectification

Microwave rectification is the conversion of high-frequency microwave energy into DC power, the basic principle is based on the nonlinear characteristics of the diode. After the microwave signal has been rectified, the rectifying diode alternately bias the microwave frequency range, using its one-way conduction characteristic to realize the conversion from AC microwave signal to DC signal. The efficiency of rectifying circuit depends on microwave frequency, input power, diode characteristics and matching network design. It is usually required to balance the input signal power and frequency characteristics in order to maximize the efficiency of the rectifier under the condition of loss and harmonic distortion. In order to achieve high efficiency of rectifier effect, it is necessary to carefully select the rectifier diode and optimize the matching network.

2.2. The characteristics of low power microwave and the requirements of rectifying circuit

Low-power microwave signal is generally referred to the power up to milliwatts to tens of milliwatts of microwave signal, it has a small signal power, frequency range, and so on, so the need for sensitive rectifier circuit. In order to convert these low power signals into DC energy efficiently, the rectifying circuit must have the characteristics of high sensitivity and high conversion efficiency. In addition, the low-power microwave rectifier circuit requires strong noise suppression, low power loss, to ensure the stability and reliability of the circuit. This requires rectifier diode selection, matching network design, circuit structure and component accuracy.

3. Analysis of existing low power microwave rectifier circuits

3.1. common rectifier circuit structure and working principle

The existing low-power microwave rectifying circuit has single-diode rectifying circuit, double-diode rectifying circuit, bridge rectifying circuit. Single-diode rectifier circuit has the characteristics of simple structure, suitable for low-frequency and low-power use, and double-diode rectifier circuit uses two reverse parallel diodes, which improves the efficiency of rectification, however, the input matching needs to be high; the bridge rectifier circuit uses four diodes to realize full-wave rectification, which is especially suitable for the applications requiring higher power and more complex microwave signal rectification. The characteristics of the input microwave signal, the requirements of output voltage and current, the complexity of circuit design and the cost of manufacture should be considered.

3.2. Evaluation of the advantages and disadvantages of existing circuits

The existing low-power microwave rectifying circuit has some performance limitations. Although single-diode and double-diode rectifying circuit is simple and easy to realize, but high-frequency loss, rectifying efficiency is limited. While improving the efficiency of bridge rectifier, the structure of bridge rectifier is complex, which needs higher component parameters and matching network to realize. In addition, the existing circuit processing low-power signal easily affected by environmental noise and signal distortion caused by the deterioration of output power quality. In order to improve the application effect of low power microwave rectifier, the circuit should be further improved in structure optimization, component selection and matching network design.

4. The design of new low power microwave rectifier circuit

4.1. Overall design proposal

The design of new low power microwave rectifier circuit should include three main contents: Optimization of rectifier module selection, reasonable matching network design and efficient structure arrangement. First, the selection of rectifier modules, need to prioritize the selection of low forward voltage, low back leakage current and fast recovery characteristics of diodes, in order to reduce high-frequency run-time energy loss, at the same time maintain high sensitivity and high conversion efficiency. Specific microwave rectifying diodes, such as Schottky diode diodes, should be considered in the design process because they have faster recovery periods and lower forward voltage drops, it is very suitable for low power microwave applications. Secondly, in the design of matching network, the new rectifier circuit must adopt multi-level, multi-segment matching network to adapt to a wide range of frequency range and power level changes. The multi-level matching network can adjust the impedance step by step, reduce the input signal reflection loss and improve the overall efficiency of the circuit. At the same time, in order to ensure the stability of signal transmission, microstrip line, balun and band-pass filter can be considered in the matching network. These components can optimize impedance matching, filter unwanted frequency components, and reduce harmonic distortion and noise interference. Thirdly, the design of the structure layout also plays a vital role in the design of the rectifier circuit. Using the compact multilayer structure can optimize the signal transmission path, reduce the parasitic capacitance and inductance, and effectively reduce the electromagnetic interference and thermal effects. For applications with high microwave frequencies, it is necessary to avoid conventional single-layer circuit board design and replace it with multi-layer printed circuit board, so as to further improve the anti-interference ability and transmission efficiency of the circuit.

4.2. Selection of key components and parameter design

The performance of low power microwave rectifying circuit depends on the selection of rectifying module and the design of parameters. First, the rectifier diode is the key component. In order to minimize the power loss and maximize the efficiency of rectification, it is necessary to select the diode with low forward voltage, low reverse leakage current and fast recovery time. The Schottky diode is ideal because of its low forward voltage drop and extremely fast switching speed. In addition, for low power microwave signal, the time of reverse recovery is one period less than that of input signal to avoid energy loss and signal distortion. Secondly, the supporting network design parameters are also critical. The main function of the matching network is to adjust the input microwave signal impedance to the optimal impedance required by the rectifier circuit, thus ensuring the maximum power transmission and the minimum reflection loss. In design, the values of capacitors, inductors and other components must be calculated accurately to achieve the optimal impedance matching target frequency. In addition, the use of low-loss capacitors, high-q inductors and other high-quality components can further reduce the loss of the circuit, improve the efficiency of rectification. For high frequency applications, the matching network design using microstrip line or coplanar waveguide can provide better frequency response and power transmission performance. Finally, high-quality microwave transmission lines and low-parasitic components should be considered in order to achieve the optimum characteristics of the rectifier circuit. When choosing microwave transmission line, it is necessary to consider its loss characteristic and matching problem under the designed frequency. By choosing the type and length of transmission line, the signal loss can be reduced to the minimum and the impedance matching can be ensured.

4.3. Circuit simulation and optimization

Circuit simulation and optimization is an important step in the design of low power microwave rectifier circuit, which can evaluate the circuit performance without actual physical manufacturing, identify potential performance bottlenecks and make improvements accordingly. When carrying out the simulation, we can use the electromagnetic simulation tools, such as HFSS or ADS, to study the performance of the circuit under various frequency and power input conditions. The simulation software can be used to measure the frequency response, reflection loss, harmonic distortion and echo loss, which is helpful for the designer to understand the efficiency and stability of the circuit. During circuit simulation, the construction of the rectifier circuit needs to be modeled in detail, covering diodes, matching networks, and other related components. The effect of the parameters on the rectifying efficiency and output power can be observed by changing the values of capacitance, inductance and load resistance. For the simulation results, the circuit parameters can be optimized step by step, such as by adjusting the capacitance, inductance and other parameters in the matching network to search the best impedance matching point; Adjust the diode bias voltage to ensure that the diode works optimally. The simulation process can also analyze the thermal effect and electromagnetic interference of the circuit under different input, optimize and adjust the circuit structure accordingly, reduce the loss and improve the performance. After the preliminary simulation, the circuit must be placed in a variety of extreme conditions to test the pressure, in order to ensure that the actual operation of the circuit stable and reliable. For example, it can simulate a variety of temperature, humidity and voltage fluctuations in the circuit's behavior to verify the adaptability of the circuit to harsh environments. The optimized simulation results can provide reliable data support for the actual circuit manufacture, shorten the development cycle and reduce the cost.

5. Low power microwave rectifier circuit optimization strategy

5.1. Circuit structure optimization

5.1.1. Using efficient rectifier diode combination

In the optimization design of low-power microwave rectifier circuit, the higher the frequency of microwave signal, the lower the power, the rectifier diode characteristics have a significant impact on the circuit performance. By using a diode with low forward voltage drop, fast recovery time and low reverse leakage characteristics, the utility model can effectively reduce loss under high frequency conditions and improve rectification efficiency. Such as low forward Schottky diode, fast recovery, suitable for low power microwave rectifier applications. In addition, multiple diodes in parallel or series can be used to form a diode array to disperse power load, reduce thermal effects, and improve the overall stability and efficiency of the circuit. The combination not only improves the rectifier efficiency but also improves the circuit endurance and adaptability.

5.1.2. Optimal matching network

optimal matching network is very important to enhance the overall performance of low power microwave rectifier circuits. The most important function of the matching network is to maximize the efficiency of microwave power transmission and reduce the reflection and loss of signal transmission. In order to achieve the optimal power transmission efficiency, the multi-segment matching network can be used to design and the input impedance matching can be optimized step by step by adjusting the parameters of the matching element. In the design, the input impedance of microwave signal is calculated accurately, and the matching inductance and capacitance are adjusted to ensure that the impedance matching state is optimal. In addition, using microstrip or coplanar waveguide technology can reduce the parasitic effect on the signal disturbance, and achieve a compact circuit structure, making the circuit more efficient and stable.

5.2. Optimization of component parameters

5.2.1. Determination of optimal load resistance

The selection of load resistance of low power microwave rectifier circuit has direct influence on output power and rectifier efficiency. Through theoretical analysis and circuit simulation, the optimal load resistance can be found to maximize power output and rectifier efficiency. If the load resistance is too high or too low, the power transmission efficiency will be reduced. The value of the load resistance must be adjusted accurately to match the output impedance of the rectifier circuit. The experiment or simulation method can be used to test and verify the optimal parameters of the load resistance under different operating conditions to ensure the stability and efficiency of the rectifier circuit in practical use.

5.2.2. Adjusting capacitance and inductance

value capacitance and inductance play a crucial role in the matching network, and their parameter adjustment directly affects the impedance matching effect and frequency response characteristics of the rectifier circuit. By adjusting the parameters of capacitance and inductance, the impedance matching can be optimized at different operating frequencies, and the efficiency and stability of the circuit can be maximized. When optimizing, the frequency response of the circuit should be analyzed with simulation tools, and the parameters of the components should be adjusted to find the best combination of capacitance and inductance. At the same time, high-quality microwave elements can reduce the parasitic effect and further improve the circuit performance.

5.3. Layout and process optimization

5.3.1. Rational layout of circuit components

Reasonable layout can not only reduce electromagnetic interference, but also effectively reduce parasitic inductance, capacitance and other effects. In low power microwave rectifying circuit, the signal transmission path should be minimized to avoid coupling and interference between high frequency signals. Through the careful design of the circuit board layout, the thermal management of the circuit is optimized to ensure that the components work in a suitable temperature range, thus promoting the reliability and efficiency of the whole circuit. In addition, reasonable layout can reduce noise interference, enhance signal stability, high rectification efficiency.

5.3.2. Option of advanced manufacturing processes

the performance and reliability of low-power microwave rectifier circuits can be significantly improved by adopting advanced manufacturing processes. The use of modern microwave circuit manufacturing techniques, such as the use of low-loss materials, the application of multi-layer printed circuit board technology and high-precision automated assembly, can significantly reduce the transmission losses and parasitic effects of the circuit, thus, the overall accuracy and consistency of the circuit can be improved. By using high quality and accurate material, the noise coefficient and power loss of the circuit are reduced, and the high efficiency and stability of the rectifier circuit are ensured. Advanced manufacturing processes can also improve circuit durability to maintain circuit performance stability in a variety of environmental conditions.

5.4. Intelligent control and adaptive optimization

5.4.1. Introduction of intelligent control algorithm

The introduction of intelligent control algorithm provides an innovative solution to the optimization design of low power microwave rectifier circuit. The intelligent algorithm can dynamically adjust the parameters such as the diode bias voltage in the circuit and the component parameters in the matching network by real-time monitoring the input/output characteristics of the circuit, so that it can adapt to a variety of input power, frequency and other conditions. The adaptive optimization can maximize the rectification efficiency, reduce the energy loss and improve the output power stability and quality. In addition, the intelligent control algorithm can also deal with the external environment changes, such as temperature and humidity fluctuations, to ensure that the circuit in a variety of conditions to maintain the best working state.

5.4.2. Adaptive matching technology

adaptive matching technology realizes the automatic adjustment of matching network parameters, which makes the performance of rectifier circuit reach the best. When adaptive matching is used in low power microwave rectifier, inductance, capacitance and other parameters can be adjusted according to the input signal to ensure the input impedance and the characteristics of the rectifier circuit. This technology not only improves the rectifying efficiency, but also strengthens the ability of the circuit to adapt to various input conditions, and ensures the stability of the output performance in the changeable application environment. The adaptive matching technology adopts the combination of software and hardware, dynamically adjusts the circuit parameters, and improves the intelligentized level and the convenience of the rectifier circuit.

6. Conclusion

A new design scheme of low power microwave rectifying circuit is given through the research in this paper, and the correctness of the scheme is proved by simulation. The efficiency and stability of the rectifying circuit have been improved successfully by designing the circuit structure, component parameters, layout and process, combining with intelligent control and adaptive optimization. These optimization strategies not only help to improve the efficiency of microwave energy conversion, but also provide new ideas for future Wireless power technology. With the development of Wireless power technology, it is believed that low-power microwave rectifying circuits will be applied to a wider range of fields, thus contributing to a more convenient and efficient way of energy utilization.

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