ABSTRACTS (PH D THESIS)

Study on novel rectifiers for microwave wireless power transfer system

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In the 1970s, W. C. Brown demonstrated the first microwave wireless power transfer system. This system adopted horn antenna as transmitter and a rectenna array as a receiver. Since then, the microwave wireless power transfer technology attracted much academic attention. The technology can be applied widely in our life. For example, it can be applied as a power harvesting technology to drive low power or tiny power sensors in IoT system. To drive mobile electronic devices such as mobile phones, laptops, and tablets, a medium-power microwave wireless power transfer system application in life is highly anticipated. In recent years, with the popularity of electric vehicles and new electrical equipment such as drones, high power microwave wireless power transfer system has also been developed.

The microwave wireless power transfer system consists of transmitter and receiver, the DC to RF conversion efficiency in the transmitter, and the RF to DC conversion efficiency in the receiver mainly affect the total efficiency of the system. However, the single shunt rectifiers which have high conversion efficiency commonly adopted in high frequency, the output voltage of single shunt rectifiers is too low to drive a digital circuit. In this paper, we discussed the GHz-band high-frequency and high conversion efficiency rectifier at the receiver in detail.

Charge pump rectifiers with class-F filter

For Tiny or low power applications, we designed a 5.8 GHz highly efficiency rectifier circuit based charge pump circuit in chapter 2 shown as Figure 1. And we introduced a class-F load that can make it on a process the third harmonic wave. To improve the conversion efficiency of the rectifier circuit, we adjusted the applied voltage of diodes. Owing to inserting the class-F load and adjusting the applied voltage of diodes in this circuit, the conversion efficiency increase to 78% at 30 mW in the circuit in the simulation, and obtained about 71% conversion efficiency in the experiment. In addition, the output voltage is higher than 5 V at an optimum voltage 1300 Ω.

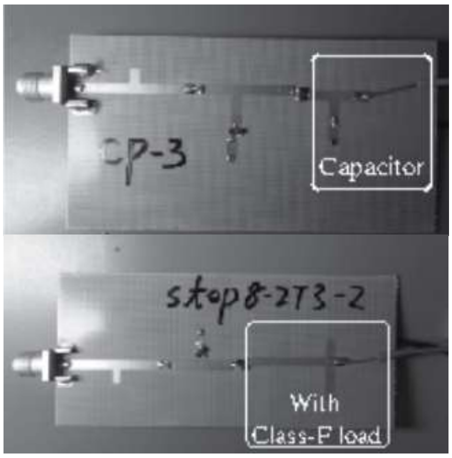

Figure 1. The photos of normal charge pump rectifier and class-F charge pump rectifier.

Charge pump rectifier array application

For medium-power applications, rectenna array often applied in a microwave wireless power transfer system. Based on chapter 2, we theoretically compare the diode losses in a charge pump and single shunt rectifier, and experimentally verify the results. Apart from this, we consider that the class-f charge pump rectifiers will be used for a rectenna array. To know the DC load change of a class-f charge pump circuits is connected as a rectenna array, we measured the conversion efficiencies of a 2 by 2 rectenna array, connected in series and parallel. The results of the experiment indicate that the optimum load of the rectifier changes to 4 times DC load when connected in series, and to 1/4 the DC load when connected in parallel.

Multistage Dickson charge pump rectifier

For medium-power applications and high voltage application, based on the class-F charge pump rectifiers, we designed multistage Dickson charge pump rectifiers shown as Figure 2. The maximum conversion efficiency of the 2-stage class-F filter Dickson charge pump rectifiers is approximately 70%, and the maximum conversion efficiency of the 4-stage rectifiers is approximately 60%. The maximum output voltage of the 2-stage charge pump rectifiers is over 9 V, and the maximum output voltage of the 4-stage charge pump rectifiers is over 15 V. Additionally, we compared the multistage class-F filter Dickson charge pump with normal multistage Dickson charge pump rectifiers. We found that the performance of the multistage class-F filter charge pump is better than the normal charge pump rectifiers. Because the charge pumps rectifiers at each stage affect each other, the harmful effects of harmonic components are amplified in multistage Dickson charge pump rectifiers.

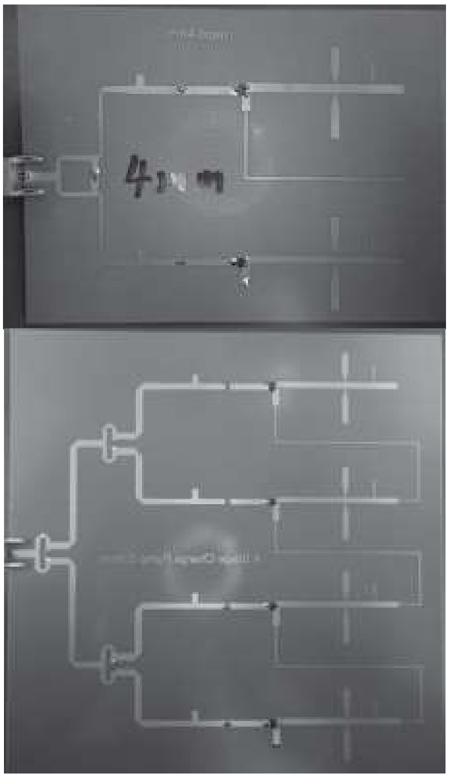

Figure 2. The photos of 2-stage and 4-stage Dickson class-F charge pump rectifier.

High conversion efficiency and high power rectifiers design

For high power application such as electric vehicle applications and drone applications, a high conversion efficiency rectifiers are required. However, a conventional silicon semiconductor hardly rectifies high power and high-frequency. In chapter 5, we applied individual GaAs Schottky diodes to design a high power high frequency rectifier. Experimental results show that the conversion efficiency of the rectifiers with GaAs Schottky diodes is 91% at optimal input power 3 W and optimal load 100 Ω. In addition, we measured the SPICE parameters and package parameters of the diodes. And we analyzed the effect of the diode SPICE parameters on the rectification conversion efficiency.

Optimal load adjustment by band-stop structure for GHz-band rectifiers design

The conversion efficiency of rectifiers affects the total efficiency of microwave wireless power transfer systems; moreover, rectifiers are load-dependent. At optimal load, a rectifier has its highest conversion efficiency; as the load increases or decreases, the conversion efficiency of the rectifier decreases. In chapter 6, we propose a method in which the optimal rectifier load is controlled by changing the band-stop structure length. We design 2.45 GHz single shunt rectifiers, 2.45 GHz charge pump rectifiers, and 5.8 GHz two-stage Dickson charge pump rectifiers to verify the method. The experimental results show that for the 2.45 GHz single shunt rectifiers, when the optimal load changes from 300 Ω to 500 Ω, the conversion efficiency is approximately 72%; for the 2.45 GHz charge pump rectifiers, when the optimal load changes from 1000 Ω to 1100 Ω, the conversion efficiency is approximately 78%; and for the 5.8 GHz two-stage Dickson charge pump rectifiers, when the optimal load changes from 1000 Ω to 1900 Ω, the average conversion efficiency is approximately 65%.

Summary

In summary, microwave wireless power transmission technology has a broad application prospect. To satisfy a variety of application conditions, we proposed the GHz-band class-f filter charge pump rectifiers for tiny or low power applications. Furthermore, the load variation of the class-F filter charge pump rectifier array and multistage Dickson class-F filter charge pump rectifiers is discussed in chapter 3 and chapter 4. For high power applications, we designed high power 2.45 GHz single shunt rectifiers by GaAs Schottky diodes in chapter 5. Finally, we proposed an optimal load adjustment design method to march the load, and we verify its validity in chapter 6.