ABSTRACTS (PH D THESIS)

Development of a Rectenna Adapted to Ultra-wide Load Range for Microwave Power Transmission

(Graduate School of Engineering, Laboratory of Laboratory of Applied Radio Engineering for Humanosphere, RISH, Kyoto University)

Yong Huang

Numerous studies have been carried out on the wireless power transmission (WPT) technologies, which transfers power to the electrical loads without man-made wires. As one mean of WPT, microwave power transmission (MPT) has attracted lots of attention due to its long-distance power transmission capability. Figure 1 shows a block diagram of a MPT system. A notable problem among these technologies is that the RF to DC conversion efficiency could be easily affected by the load resistance and the input power. Therefore, an impedance matching circuit becomes crucial to realize the wireless power transmission with high efficiency. Moreover, most of the impedance matching circuits in microwave circuits utilize distributed-constant circuits, whereas, the rectenna is a special distributed-constant circuit yielding a DC output. This present thesis aims at developing an ultra-wide load range rectenna for microwave power transmission and a resistance matching circuit from the viewpoint of DC, which is easy to design since it is unnecessary to consider high harmonics.

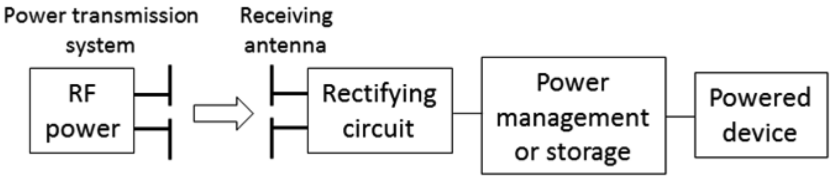

Figure 1. Block diagram of a MPT system.

Different from the conventional DC-DC converters used for voltage conversion, in the present thesis, a resistance conversion DC-DC converter is proposed and validated in the following procedures:

Firstly, with aid of the simulator of advanced design system (ADS), a common pulse-width modulation (PWM) controlled boost converter is checked as an impedance matching circuit for rectifying circuit. For the validation a simulation model of RF-DC-DC circuit is built which consists of a simple single shunt rectifying circuit and the boost converter. The simulation results show that the overall efficiency of the RF-DC-DC circuit is almost constant over 70% in the load range from 370 to 1300 Ω. Moreover, it is also found that the boost converter can prevent the reverse voltage applied on the rectifying diode from exceeding breakdown voltage and then the rectifying circuit can keep acting at the peak efficiency point. However, this PWM controlled boost converter can only convert a wide load range into a narrow input resistance range which is insufficient for an impedance matching requirement of rectenna.

Next, according to the previous simulation results, an RF-DC-DC circuit is shown to be useful for impedance matching application. Therefore, an externally powered RF-DC-DC circuit, consisting of a negative output rectifying circuit and a DC-DC converter, is designed. To choose a more suitable type of DC-DC converter, the input/output resistance relationships of three major DC-DC converter topologies (i.e. buck converter, boost converter and buck-boost converter) are investigated in continuous conduction mode (CCM) and discontinuous conduction mode (DCM), respectively. Only the DCM buck-boost converter is found to exhibit constant input resistance characteristic independent of the input voltage and the load resistance. Therefore, an inverting DCM buck-boost converter is adopted with an extra DC power supply for the control-pulse circuit, and the input resistance of the buck-boost converter is set to be close to the optimal load of the rectifying circuit. The experimental results show that the overall efficiency of this externally-powered RF-DC-DC circuit is approximately constant and over 60 %, despite the load resistance ranging from 100 to 5000 Ω.

However, the externally-powered RF-DC-DC circuit is difficult for the practical applications because of the requirement of an extra DC power supply. To solve this problem a self-powered RF-DC-DC circuit consisting of a positive output rectifying circuit and a non-inverting self-powered buck-boost converter (as shown in Fig. 2) is proposed. It can obtain a positive output voltage with a single positive input voltage. Furthermore, the input resistance of the buck-boost converter is designed to be equal to the optimal load of the rectifying circuit. The experimental results are shown in Fig. 3. We can see that the overall efficiency of the self-powered RF-DC-DC circuit is constant and over 66 %, despite an ultra-wide load ranging from 200 to 10000 Ω.

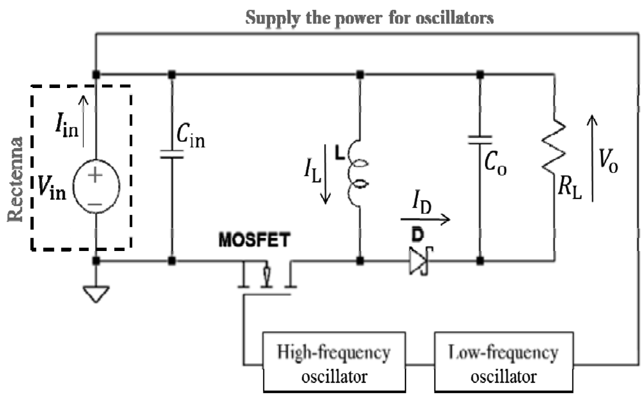

Figure 2. Block diagram of a non-inverting self-powered buck-boost converter.

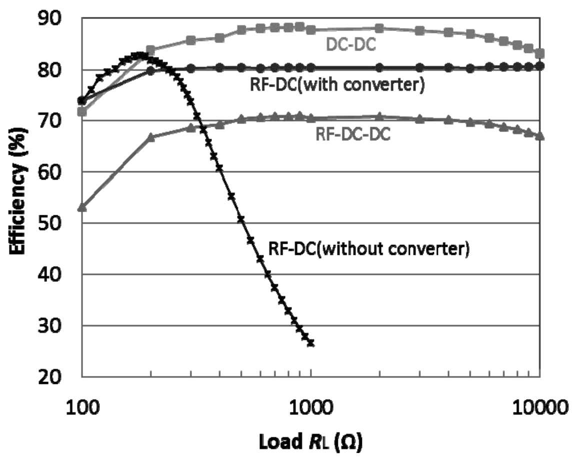

Figure 3. Experimental efficiency comparison of the RF-DC-DC circuit and the general rectifier.

Finally, several experiments are carried out on driving a DC motor using MPT with a compact designed power-receiving device which consists of a rectenna array (including antennas and rectifiers) and an improved buck-boost converter. There exits four types of power-receiving devices combined by two different rectenna arrays and two different buck-boost converters. With these four power-receiving devices, some experiments are conducted by driving a dynamic load resistance device such as a DC motor with continuous-wave (CW) power transmission and pulsed-wave power transmission. Figure 4 shows the block diagram of experiment setup for driving DC motor with pulsed-wave. In the CW case, the overall efficiency of the compact power-receiving device is above 50% in a wide power density ranging from 0.25 to 2.08 mW/cm^2. In the pulsed-wave case, the overall efficiency is above 44% in the duty ratio ranging from 0.2 to 1 for a power density of 0.98 mW/cm^2. Moreover, at a fixed duty ratio of 0.5, the overall efficiency is almost constant at 59% with the pulsed-wave frequency changing from 0.33 to 41.7 kHz.

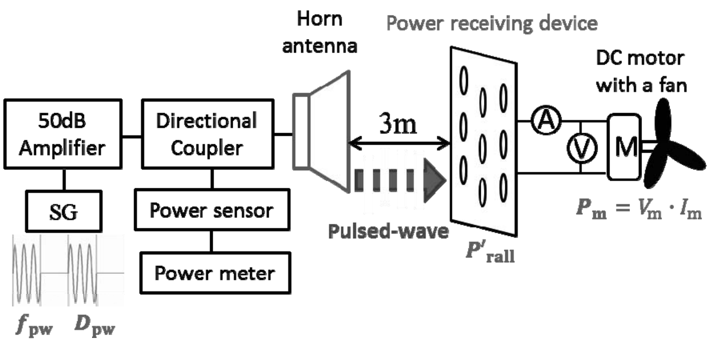

Figure 4. Experiment setup for driving DC motor by MPT using pulsed-wave.

Therefore, tested by both load resistances and a dynamic load resistance device, the proposed rectenna is found to be excellent in a relatively high efficiency for an ultra-wide load range. As a novel application of DC-DC converter, the proposed buck-boost converter, with constant input resistance characteristic, is also expected to be valuable for other WPT applications.