1. Introduction

In recent years, wireless power transmission (WPT) has been an interesting research topic, which means that transforms the microwave power into the DC power. The most well known application of wireless data and power transmission is radio frequency identification (RFID) which is composed by passive ICs with embedded antennas for receiving power and backscattering information wirelessly [1]. The WPT is a convenient way to send electromagnetic energy to the application specified sensors which have no physical connections [2]-[4]. In order to cover wider applications and operation ranges, WPT uses far-field electromagnetic waves to communicate with each other. Rectifiers in WPT systems using non-linear devices such as diodes can rectify RF power into a DC voltage to power up the following system. Typically, some applications have to operate at a considerable range between transmitters and receivers. While the received power decreases rapidly with the increasing separation distance, the rectifier must have optimized efficiency to supply enough output DC voltage for low input power. To achieve this, Schottky barrier diodes with low barrier potential is used with low voltage losses [5]-[6].

The key circuit in WPT system is rectenna designs. The rectenna, which consists of receive antenna, impedance matching network, rectify circuit, DC filter, and the load, is used in power transformation. It can transform the received microwave power by rectify circuit and DC filter into the DC power and deliver the DC power to the load. Power transformation efficiency, which is the ratio of the DC power in the load to the microwave power the rectenna received, is determined by the mismatch between each interface circuit. The higher of the ratio shows the better performance. Polarization mismatches would result in considerable losses between transmitting and receiving antennas [7]. In this paper, two identical helical antennas in the rectenna are used for minimizing polarization losses, and two Schottky barrier diodes in the rectifier are used for low voltage losses. Section 2 describes the design and implementation of the compact helical antenna and low-loss rectifier. Section 3 details the measurement of the rectenna module. Finally, Section 4 concludes this paper.

2. Design and Implementation of the Helical Antenna and Rectifier

A typical geometry of a helical antenna is shown in Fig. 1(a). The dimension S and D are the diameter of the helix and spacing between turns. Fig. 1(b) shows the implementation of the compact helical antenna. The turns, D, and S of the normal-mode helical antenna are 17, 0.3 cm, and 0.1 cm, respectively. The normal or broadside mode yields radiation that is most intense normal to the axes of the helix. This occurs when the helix diameters is small compared to a wavelength. This mode provides a radiation maximum along the axis of the helix, and therefore is suitable for wireless communication handsets. The advantage of the proposed antenna over a conventional straight-wire monopole of the same height is that the helix acts as a spiral inductor, tending to cancel the capacitance inherent in electrically short antennas. Fig. 1(c) shows the measured vertical and horizontal polarization patterns in XZ-plane at 925 MHz. The vertical-polarization patterns are very close to the omni-directional patterns of a dipole antenna. The measured antenna directivity and return loss is about 3 dBi and -15.6 dB.
Rectifiers are able to rectify alternating current (AC) or RF energy to direct current (DC) power. The rectifiers are usually realized by non-linear devices such as diodes, and single-shunt and doubler type are very common in the rectifier designs. The proposed rectifier with two diodes and two capacitors is shown in Fig. 2(a). C1 is a DC block capacitor between antenna and the rectifier. C2 works as a DC pass or low-pass filter to attenuate unwanted RF power to the load RL. Ideally, the filter provides RF short circuit and reflects it back to diodes for re-rectification. The rectifier consists of one shunt diode and one series diode. One advantage of the doubler type is the voltage enhancement at the load. The diodes used in this work are Agilent HSMS-2862 Schottky diodes which are suitable for RFID and RF tag applications as well as large signal detection or RF to DC conversion. The HSMS-286x family can operate from 915 MHz to 5.8 GHz, and therefore are qualified for the 925MHz wireless charging system. In order to accurately model the non-linear characteristic of the diode, the spice model of it must be included with its package for simulation. It can be observed from the simulation that many high order harmonics caused by non-linearity of the two diodes can be suppressed by the DC filter. Fig. 2(b) shows the proposed rectenna consisting of a helical antenna, matching networks, a rectifier, and a resistive load.

3. Measurement of the Rectenna Module

Fig. 3(a) shows the block diagram of the measurement set-up. The signal generator (SG) transmits a RF signal at 925 MHz. In order to minimize the junction capacitance of diodes for efficiency improvement, the RF signal is amplified by a power amplifier (PA). Then the proposed
helical antenna is after the PA as a transmitting antenna. The distance between the transmitter and rectenna is $d$. Moreover, the DC value on the resistive load (RL) is measured by a voltmeter. The output load resistor is selected as 1 KΩ to maximize RF-to-DC conversion efficiency of the Schottky diodes. Therefore, the corresponding output DC power is obtained with the known load resistor and DC values. The RF-to-DC conversion efficiency ($\eta$) is defined as

$$\eta(\%) = \frac{P_{\text{DC}}}{P_{r}} \times 100\% = \frac{V_{\text{DC}}^{2}}{R_{L} \cdot P_{r}} \times 100\% \quad (1)$$

Where $P_{\text{DC}}$ is the output DC power, $P_{r}$ is the power received by the rectifier, and $V_{\text{DC}}$ is output DC values. Fig. 3(b) demonstrates the wireless power transmission of the measurement with $d$ of 22 cm. Because the two antennas are normal-mode helical antennas, the antennas are placed parallel to each other for maximum power transfer. In this case, the 22-cm distance results in a DC value of 0.387 V as shown in Fig. 3(b). Fig. 3(c) illustrates the measured power levels at the receiver (Rx) versus power levels at the transmitter (Tx) with different distances. The distance varies from 8 cm to 22 cm, and the transmitted power level ranges from 24 dBm to 28 dBm. Typically, a closer distance and higher Tx power levels contribute higher Rx power levels. Fig. 3(d) shows the measured DC values versus Tx power levels with different distances. When Tx is 28 dBm with $d$ of 8 cm, the measured DC value across the load is about 0.66 V.

Figure 3: (a) Block diagram of the measurement set-up. (b) The wireless power transmission of the rectenna with a distance of 22 cm apart. (c) Measured Rx power versus Tx power levels with different distances. (d) Measured DC values versus Tx power levels with different distances.
4. Conclusion

In this paper, a compact rectenna module for wireless power charging systems is presented. The 925-MHz rectenna consists a normal-mode helical antenna to receive RF power and a doubler-type rectifier to convert the power into DC effectively. The rectenna is implemented, measured, and verified successfully demonstrating the feasibility of the proposed circuit. The measurement set-up and measured results are also detailed. It is convinced that the design methodology is suitable for further biomedical applications and wireless sensors.

Acknowledgments

The authors would like to thank the Chungshan Institute of Science and Technology (CSIST) for financial and technical supports. This work was supported by the CSIST under Contract XR00013P068P2.

References