5.8GHz Circularly Polarized Rectennas Using Schottky Diode and LTC5535 Rectifier for RF Energy Harvesting

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Abstract— **5.8GHz circularly polarized single element patch antenna and 2x2 antenna array for RF energy harvesting were designed and fabricated. A comparison between Schottky diode and LTC5535 for RF energy harvesting rectenna (rectifying antenna) was analyzed at WLAN frequency of 5.8GHz. Both rectennas are printed on Rogers 4003C substrate. Maximum gain at boresight tip was measured to be 3.4dBi and 8.0dBi for circular polarized single element patch antenna and array patch antenna respectively. And the measured return loss of the two types of antennas was measured to be -10.3dB and -20.3dB respectively. The maximum output DC voltage reading is 72.5mV for Schottky diode and 428.3mV for the LTC5535 rectifier, at a distance of 15cm from the transmitting reference antenna.**

Index Terms— **Circular polarization, circularly polarized antenna, microwave power transmission, rectenna, rectenna array, rectifier, RF energy harvesting.**

I. Introduction

The use of rechargeable batteries has significantly increased as many applications impose mobility and autonomous working. These wireless devices are growing in many applications such as mp3 players, mobile phones, sensor networks, etc. Stand-alone devices such as wireless sensor nodes located in difficult access environments have to work without the human intervention for many years. In these situations, many troubles arise such as battery replacement or recharging, in addition to the size and weight. The problem increases tremendously when the number of devices is large and distributed in a wide area or located in inaccessible places. Therefore, a feasible method is needed to supply energy to remote sensors.

There are digital systems and sensor devices with ultra low power consumptions for energy harvesting purposes [1]. This makes feasible the development of low power harvesting systems. Research work have been conducted on electromagnetic energy scavenging on high frequencies, from 2GHz to 18GHz, the unlicensed 2.4GHz and 5.8GHz ISM band [2][3]. Also, technologies such as RFID use similar technology to work at 13.56MHz or UFH-ISM frequencies [4][5][6]. Most of them use their own RF transmitter to supply power. In addition, the distance between the RF transmitter and the harvesting unit is relatively short [7]. And in the ISM band, the transmitted power allowed is low. Generally, this type of devices harvest RF energy, as shown in Figure 1. The system comprises of an antenna, impedance matching network, rectifier circuit, low pass filter, storage element and control unit [2][8]. Most of the rectennas and their matching networks are designed to have a large bandwidth [9][10]. Recently, circular polarized (CP) antennas have become one of the important characteristics in designing rectennas [11][12] as it avoids changes in the output voltage due to the rotation of the transmitter or receiver.

In this paper, a new 5.8GHz circularly polarized single element and 2x2 rectenna array have been designed and fabricated. The Schottky diode and LTC5535 RF detector are used for the rectification and their performances compared in terms of the output DC voltage.

II. Rectenna Structure

The block diagram for the rectenna is shown in Figure 1. The antenna and rectifier circuits were first designed and measured separately. Finally, they are combined to form the complete rectenna.

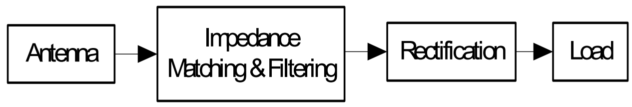


Fig. 1. Block diagram of the rectenna circuit

A. Antenna Design

The circular polarized single patch antenna is designed on RO4003C substrate with a dielectric constant of 3.38, loss tangent 0.0027, and a thickness of 32mils as shown in Figure 2. The dimensions of the 50Ω feed line is 12.7mm by 0.2mm and it is matched to a 50Ω line via a quarter wave transformer.

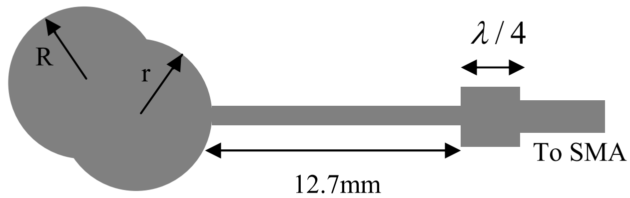


Fig. 2. Schematic of the single element CP antenna

The radius, r of the first patch is 4.2mm and the second circular patch, R is 5.1mm, this is added to optimize the CP performance and return loss of the antenna. The simulation result of the antenna shows a return loss of -11dB in Figure 3 at 5.8GHz.

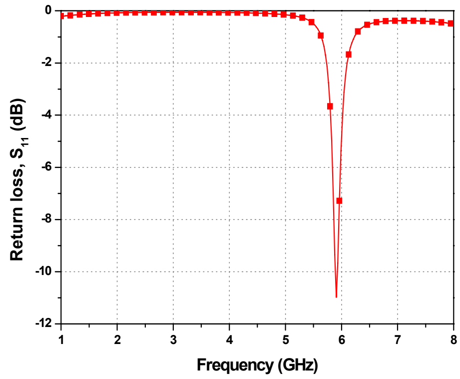


Fig. 3. Simulation result of the single element CP antenna

The antenna array configuration is designed to increase the gain of the single element antenna. This increase in gain corresponds to improved power efficiency. Antenna array of 2x2 configurations is designed as shown in Figure 4. The characteristic impedances of each line are calculated to give the widths for the transmission lines. T1 and T2 are essentially the same power combiner. The 100Ω line bodies of T1 and T2 form the arms of T3 resulting in the final combination of all power from the antennas.

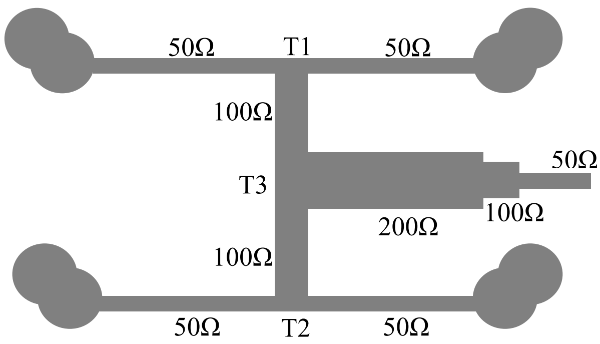


Fig. 4. Schematic of the 2x2 CP array antenna

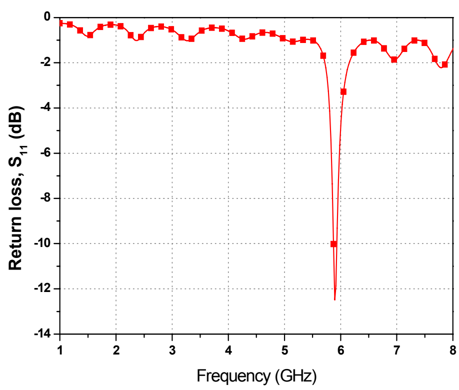


Fig. 5. Simulation result of the 2x2 array CP antenna

The 100Ω line between the 50Ω and 200Ω strips is a quarter wave transformation to match the lines so that no power is reflected away from the output. Length of the microstrip lines on the T-junction had no bearing on the matching. The simulation result of 2x2 array shows return loss of -12.2dB at 5.8GHz as shown in Figure 5.

B. Rectifier Circuit

The purpose of the rectifier is to directly convert microwave RF energy into DC electrical energy. Schottky diodes are preferred because of the low voltage drop and higher speed. In addition, Schottky diodes consume the least amount of power due to conduction and switching.

Agilent's HSMS-286x family of DC biased detector diodes have been designed and optimized for use from 915MHz to 5.8GHz. They are ideal for RFID and RF tag applications as well as for large signal detection, modulation, RF to DC conversion or voltage doubling. HSMS-2862 diode of the series has been chosen for this rectifier circuit. This circuit required the parasitics of up to about 6GHz. This was simply carried out by modifying the parasitic values and comparing against the return loss graph supplied in the datasheet. The next step was to create a matching input circuit for the diode. One diode is grounded while the other diode is directly connected to the matching network. The matching is done for a 5.8GHz input.

The second rectifier circuit as shown in Figure 6 makes use of a Linear Technology IC chip, LTC5535. The LTC5535 is an RF power detector with adjustable gain and 12MHz baseband bandwidth for RF applications operating in the 600MHz to 7GHz range. A temperature compensated Schottky diode peak detector and output amplifier are combined in a small thin SOT package.

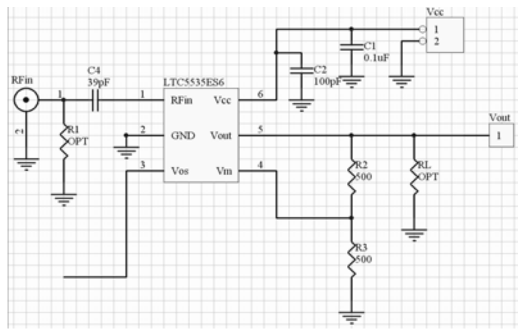


Fig. 6. Schematic of the rectifying circuit using LTC5535

The supply voltage range is optimized for operation from a single cell lithium-ion or three cell NiMH battery. The RF input voltage is peak detected using an on-chip Schottky diode. The detected voltage is buffered and supplied to the Vout pin. The LTC5535 output amplifier gain is set via external resistors. The initial starting voltage of 200mV can be precisely adjusted using Vos pin. The LTC5535 operates with input power levels from -32dBm to 20dBm.

III. MEASUREMENTS RESULTS & DISCUSSIONS

The fabricated single element and 2x2 array are shown in Figure 7, and Figures 8(a) and (b) respectively. The return loss, S11 is measured with a vector network analyzer (VNA) which is calibrated using the short-open-load-thru (SOLT) calibration kit. At 5.8GHz, the measured return loss S11 for the single element is -10.3dB and for the array is -20.3dB. These are shown in Figures 9(a) and (b) respectively.

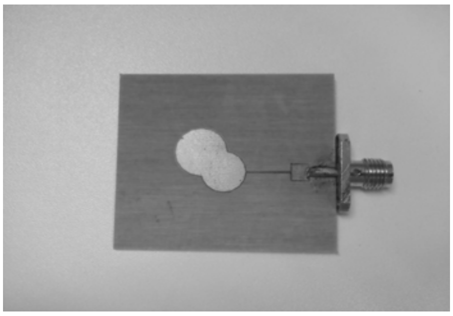
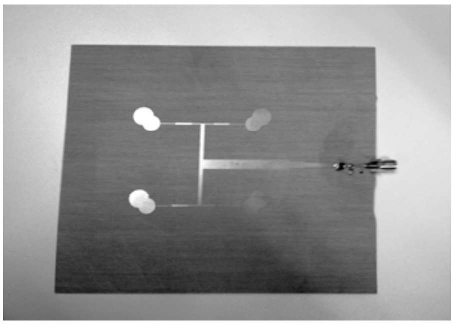
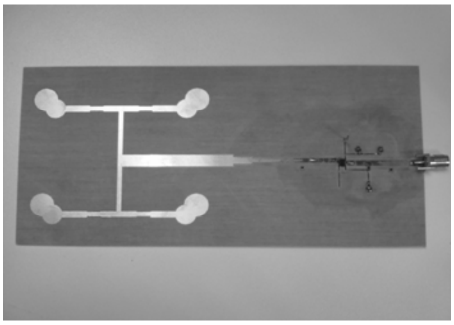


Fig. 7 Single element antenna



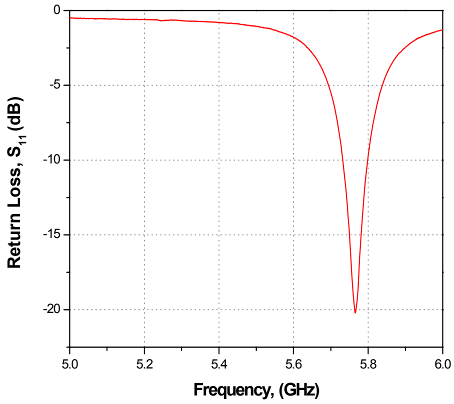
(a)



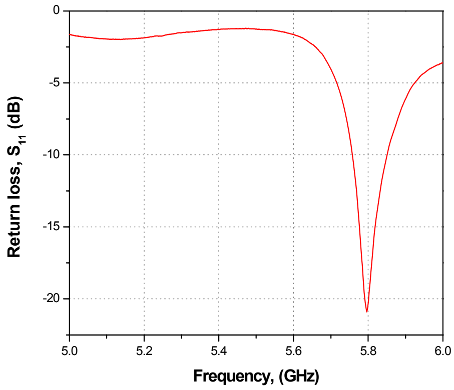
(b)

Fig. 8. Fabricated structures of the rectennas; (a) Schottky diode, and (b) LTC5535 IC

The radiation pattern of the circular polarized patch antenna was measured in an anechoic chamber as shown in Figures 10(a) and (b). Since it is a circular polarized antenna, the radiation patterns are nearly identical on both planes of the antenna. A standard gain horn antenna was used as a reference transmitter. The rectenna was rotated at the azimuth plane from -180° to 180°. The maximum gains at boresight measured are 3.4dBi and 8.0dBi respectively for the single element patch and circular polarized patch array antenna.



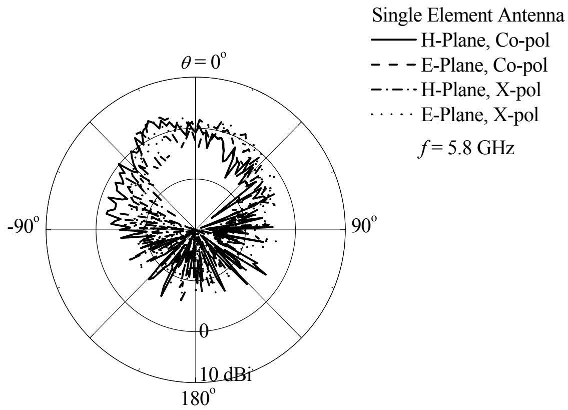
(a)



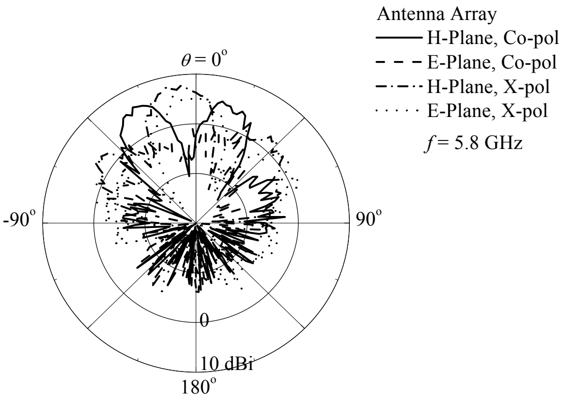
(b)

Fig. 9. Measured results of the antenna; (a) single element, and (b) 2x2 array antenna

The setup for the DC voltage measurement from the rectenna is shown in Figure 11. The input RF power is generated by the Agilent signal generator E4438C which is connected to the reference horn antenna. The rectenna is connected to the voltmeter which converts the RF power to DC output voltage. The input power levels are measured from -10dBm to 16dBm at a distance of 15cm. The maximum output from the 2x2 patch antenna array is 72.5mV and 428.6mV using the Schottky diode and LTC5535 respectively. Table I shows the RF input power and DC output voltages for both the Schottky diode and LTC5535.



(a)



(b)

Fig. 10. Measured radiation pattern of; (a) single element, and (b) 2x2 array antenna.

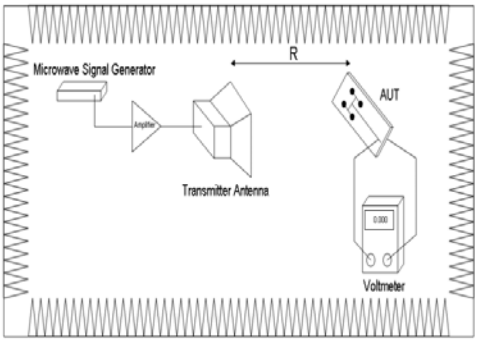


Fig. 11. Measurement setup for the DC voltage output from the rectenna in Anechoic Chamber

TABLE I

Power Input (dB m)	Schottky Diode (mV)	LTC5535 (mV)
16	72.5	428.3
14	60.2	362.5
12	48.8	305.2
8	26.5	227.6
4	13.7	188.7
0	3.8	167.9
-5	16.1	161.5
-10	1.1	158.1

IV. CONCLUSIONS

A circularly polarized single element and 2x2 rectenna arrays for RF energy harvesting at 5.8GHz have been designed and fabricated on a thin low-loss microwave laminate. The measured return loss of the single element is -10.3dB and the 2x2 antenna arrays is -20.3dB. The maximum gain at boresight measured is 3.3dBi and 8.0dBi for the circular polarized single element patch antenna and patch array antenna respectively. The 2x2 array rectenna outputs a DC voltage of 72.5mV over a distance of 15cm when 16dBm microwave power was transmitted at 5.8GHz. Using the same method, LTC5535 array rectenna outputs a DC voltage of 428.3mV. Therefore, its performance was better in terms of higher DC output voltage.

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