Design of Broadband Dual-Polarized Rectenna Array for WPT Applications

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Abstract—A broadband dual-polarized microstrip array antenna designed is proposed. To achieve wide 10 dB bandwidth for broadband operation, the technique of applying a ladder-shaped monopole antenna type with a rectangular slot insertion in the ground plane is implemented. The proposed design showed wide impedance bandwidth of the 1702-2755 MHz (47.2%). In addition, adding an open slot into the rectangular radiating element with an asymmetric ground plane was used and resulted in a slightly displacement of the radiation pattern. The 1 × 2 array type for two ladder-shaped patch array elements are arranged in symmetric feed network. By meticulously arrangement the two array antennas' positions to achieved good ports isolation, with 10 dB bandwidth for the operating bands in free-space can be achieved. This antenna is used as a rectenna (rectifying antenna), which receives the RF energy of vertical and horizontal polarization wave in free space for 2.4 GHz wireless power transmission. The rectifier circuit setup using two zero biased rectifier and voltage doubler circuit. A matching network designed with small size chip components have a significant improvement in impedance matching and eliminate high order harmonics between the antenna and rectifying circuit. The proposed dual-polarized rectenna provided the RF-to-DC conversion efficiency as high as 78.8% when 14 dBm microwave power was received at 2.4 GHz with a 1 KΩ load.

Keywords—Dual-polarized, rectenna, wireless power transmission, voltage doubler circuit.

I. Introduction

Energy harvesters take fuel from ambient sources present around environment. Types of ambient sources considered and used for energy harvesting are wind, solar, vibration, temperature gradient, thermoelectric, Radio Frequency (RF). The Wireless Power Transmission (WPT) technology is able to transfer the RF power. Some research suggests rectenna to turn on and turn off the radio nodes belonging to a Wireless Sensor Network (WSN) [1-5]. One of the most important elements in WPT is the Rectenna which is composed by a receiving antenna and rectifying circuit to covert electromagnetic energy to direct current (DC) energy.

Because of the Circular Polarization (CP) does not require the polarization alignment of the electric field at the transmitting and receiving antennas [6-8]. Unfortunately, in general the transmitting antenna is vertical or horizontal polarization wave, CP antenna as receive antenna then loss power due to polarization mismatch. One of solutions to overcome the issue have been proposed, the dual-polarization antenna receive vertical and horizontal energy respectively is which there is no power loss due to polarization matched [9-11]. Therefore, proposed a new design of a dual polarized array antenna. to achieve a good matching wideband frequency and isolation level that ensures a good diversity performance.

II. Broadband Array Antenna

A. The Antenna Array Element Structures

Fig. 1 presents the geometry of the proposed ladder-shaped monopole antenna with ladder-shaped structure. They are etched on inexpensive 0.8 mm thick FR4 substrate with relative permittivity $\varepsilon_r = 4.4$ and loss tangent tan δ= 0.0245.

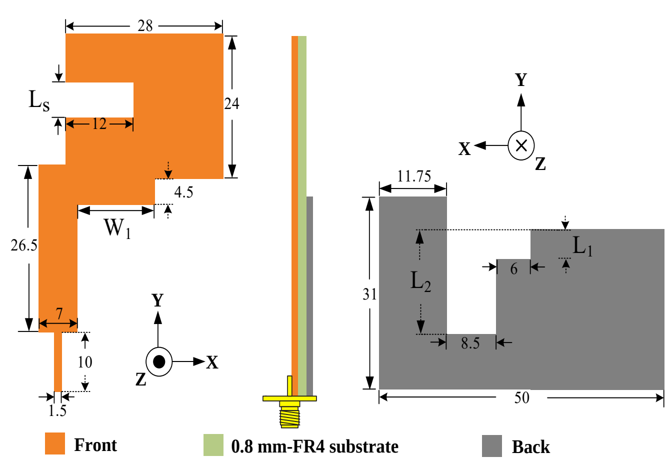

Fig. 1 Geometry of signal element broadband antenna, L1=5, LS=5, L2=17, W1=13.5 (unit: mm)

The main radiating structure of antenna is a ladder-shaped patch and consists of three sub-patches with sizes of 7 mm × 26.5 mm, W1 × 4.5 mm, and 28 mm × 24 mm. A 50 Ω microstrip line feed with dimensions of 1.5 mm × 10 mm is used to feed the patch. Embedded on the left side of the radiating element is a rectangular slot with LS × 12 mm. As for the ground plane, it is printed on the bottom side of the substrate and has an overall size of 31 mm × 50 mm. An inverted L-shaped slot vertical section is with dimension L2 × 8.5 mm, whereas the horizontal section with sizes of L1 × 6 mm is embedded behind feed-line into the ground plane. In this design, for improving the impedance matching and thus expanding good broad bandwidths [12], with a stepped slot, that is, multiple stages of an impedance transformer. In other words, the use of a multi-stage structure can generate multiple resonance modes, so that multiple similar resonance frequency points generate continuous bandwidth. Thus, this makes it possible to have a broadband impedance-matching condition.

B. Experimental Results and Discussion

Simulated and measured return loss from the two input ports are shown in Fig. 2. The impedance matching over the 1.8 and 2.4 GHz bands is seen to all better than 10 dB.

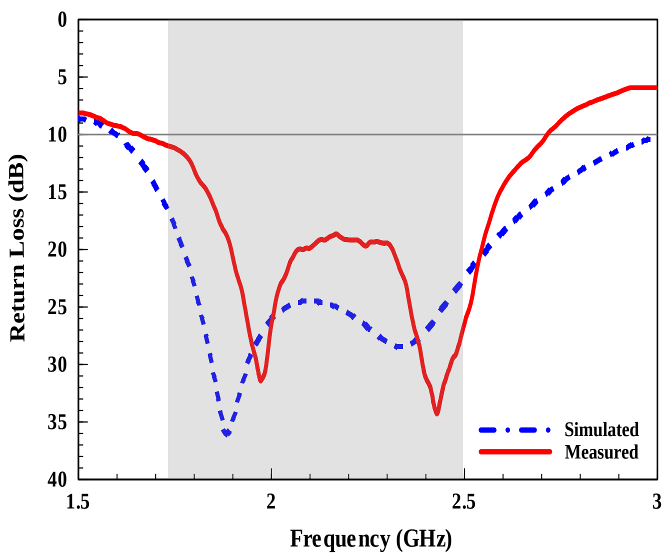

Fig. 2 Simulated and measured return loss of the proposed antenna

Fig. 3 and Fig. 4 show the measured far-field radiation patterns of the proposed antenna at 1.8 GHz and 2.4 GHz. The normalized patterns show monopole like radiations. Notably, loading an open slot into the rectangular radiating element with an asymmetric ground plane is used and resulted in a slightly displacement of the radiation pattern tends to –x direction. This structure can make the radiation pattern more concentrated when designing the array antenna, and can increase the gain of the array antenna compared with a symmetrical ground structure. The peak gain of the proposed antenna, measured within the 1.8 GHz and 2.4 GHz operating bands are shown in Fig. 5, peak gain from 0.61 to 0.8 dBi is measured between 1.8 GHz and 2.4 GHz

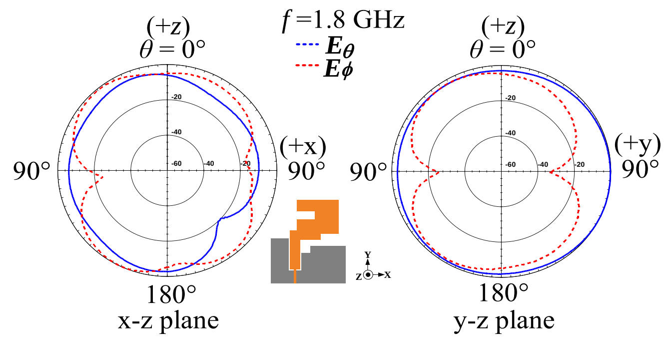

Fig. 3 Measured radiation patterns at 1.8 GHz

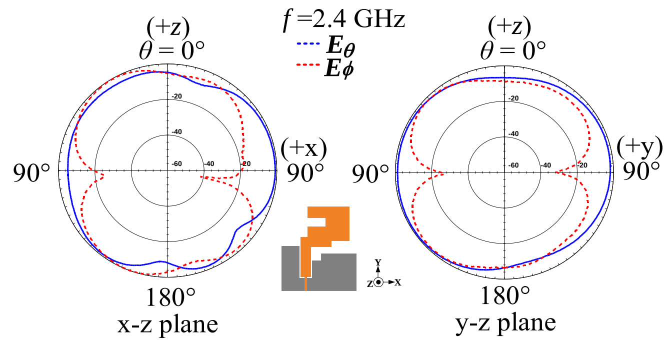

Fig. 4 Measured radiation patterns at 2.4 GHz

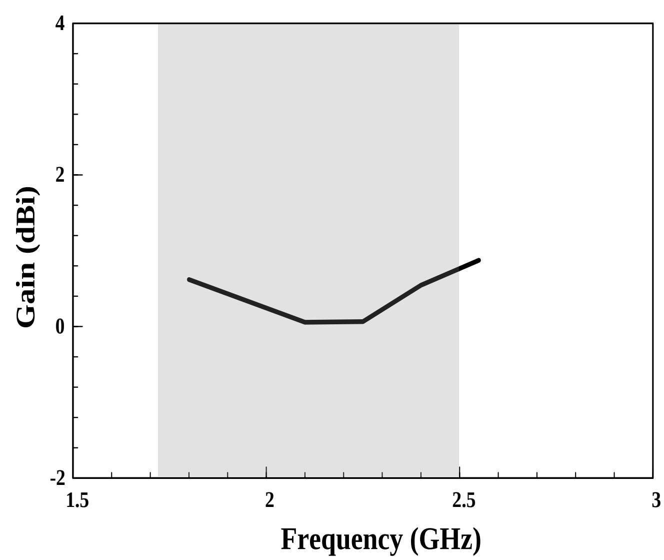

Fig. 5 Measured gain of the proposed antenna

III. Dual-Polarized Rectenna Array

A. Dual-Polarized Array Antenna

Fig. 6. It is composed of two broadband arrays aligned orthogonally and symmetrically, dual polarization performance

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of the whole array is achieved. The two monopole radiators have been separated distance (S) of 7 mm between the two radiators.

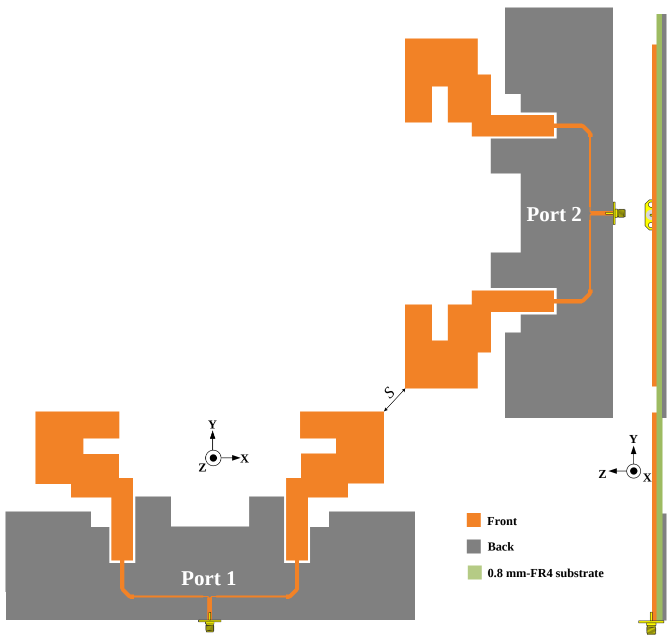


Fig. 6 Geometry of the proposed dual-polarized array antenna, S = 7 mm

Fig. 7. shows the feed network that is used to feed the two single element antennas, and the two feeding terminals (sharing the same output amplitude and phase) from B and C are individually connected to the microstrip line feed that has been described earlier.

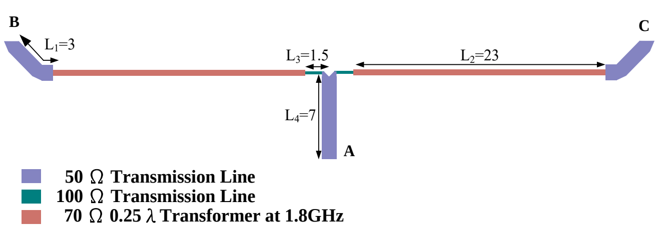


Fig. 7. Corporate feed network of proposed broadband array antenna.

In Fig. 8, one sees the improvement of the isolation across the operating band, as the S increases from 5 to 7 which can reduce the mutual coupling through separating the radiation patterns of the two radiators.

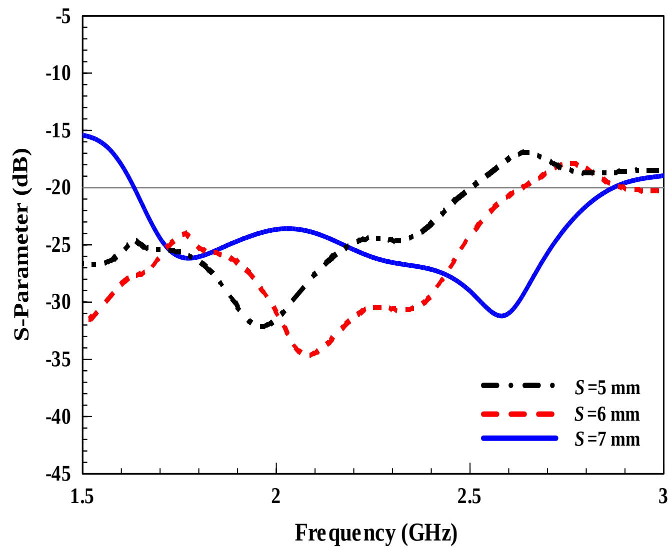
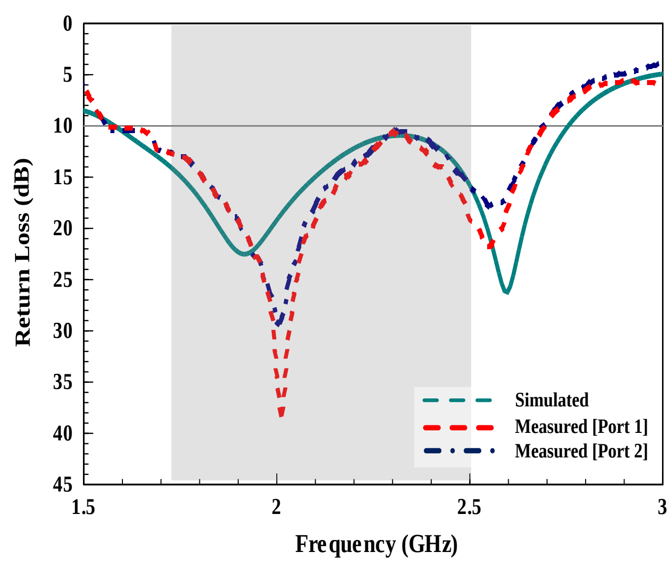
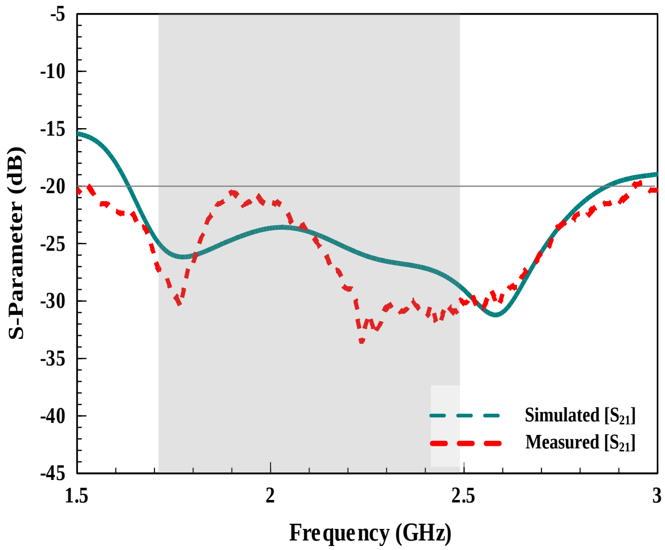


Fig. 8 Simulated S-parameters when the S varies

The return loss and isolation for both the simulation and measurement are shown in Fig. 9. The impedance bandwidth of the both port1 and prot2 are 53.4% (1555 MHz - 2693 MHz), and good agreement is demonstrated between the two results. Fig. 9 (b) show a measured isolation meet these specifications more than 20 dB in all of the band.



(a)



(b)

Fig. 9 Measured return loss and isolation of proposed structure: (a) return loss, (b) isolation

The measured far-field radiation patterns of the proposed antenna in the two principal planes for broad operating bands at 1.8 GHz and 2.4 GHz are presented in Fig. 10 and Fig. 11. In the measurement, port2 is terminated with a 50 Ω load when port1 is excited, and vice versa. Note that port2 are not shown here because their patterns resemble port1, which is result in good isolation properties. Therefore, the beam pattern of the two antennas is spontaneously divided into two different directions. The measured gains of the proposed antenna excited from the two input ports are shown in Fig. 12. The average gains are about 3.3 dBi - 6.1 dBi.

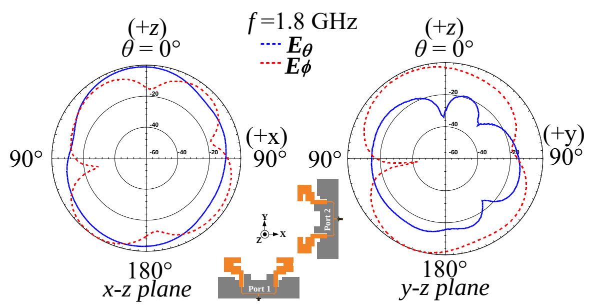


Fig. 10 Measured radiation patterns at 1.8 GHz

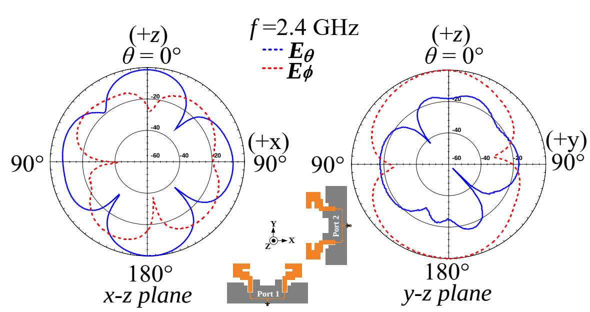


Fig. 11 Measured radiation patterns at 2.4 GHz

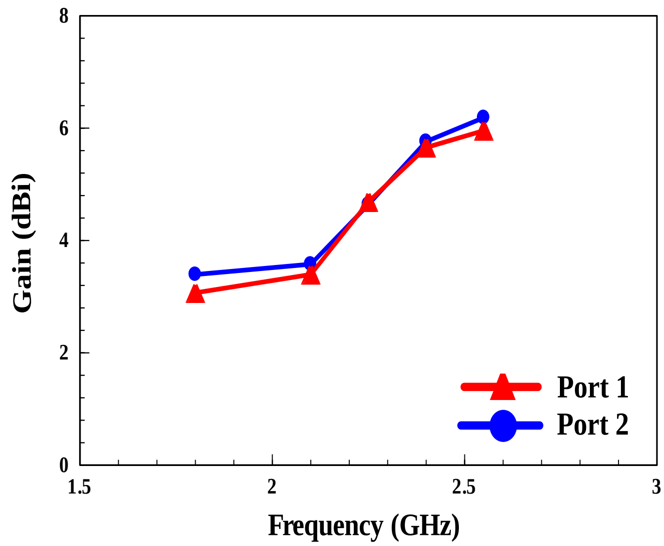


Fig. 12 Measured gain of the proposed antenna

B. Rectifying Circuit Design

The diagram of the rectifying circuit is presented in Fig. 13. The RF to DC conversion circuit is formed of HSMS-2862 zero-bias Schottky detector diode pair, a capacitor and a load resistor. The double output voltage is created by storing charge at the series capacitor (C_2) during the negative phase of RF signal through the shunt diode while charge in is accumulated with the input potential during the positive signal phase by turning on the series diode and flowed to DC filter capacitor (C_3). The impedance matching circuit has two chip components C_1 = 0.68 pF and L_1 = 3.0 nH for 50 characteristic impedance at 2.4 GHz. By the matching circuit played the role as low-pass filter, the harmonics generated by the non-linear diodes can be largely suppressed for efficiency improvement.

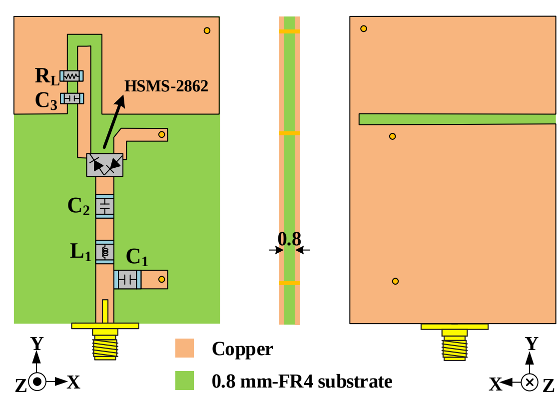


Fig. 13. Schematic and photograph of rectifier

C. Rectenna Measurement

The photographs of proposed rectenna array is shown in Fig. 14. The measurement setup refers to the approach in [13]. The rectenna is tested in an anechoic chamber. The transmitting

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terminal is composed of a vector signal generator connected to a broadband standard horn antenna, which is used as the source of RF power for WPT system. The receiving terminal is divided into two parts to receive the signal. First, in order to obtain the RF power ($P_{receiver}$) of the rectenna, a spectrum analyzer is connected to the receiving antenna that has not yet been connected to the rectifier circuit. In the second part, the antenna structure is exactly the same, but the rectifier circuit is added to the back end to form a rectenna, and a multimeter is connected to the load resistance (R_L) at the back end of the rectenna to measure the output DC voltage (V_{DC}). The conversion efficiency (η_c) is defined as

$$\eta_C = \frac{V_{DC}^2}{R_L} \cdot \frac{1}{P_{receiver}} \qquad (1)$$

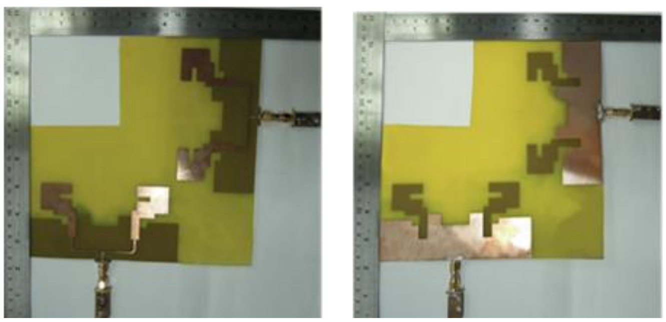

Fig. 14 the photographs of proposed rectenna

Measured voltage and the conversion efficiency are shown in Fig. 15 and Fig. 16. The RF to DC conversion efficiency is 78.8% at 30 dBm with 1 KΩ load resistance. The rectenna operating at 2.4 GHz has dc output of the maximum output DC potential is 8.2 V with 5 KΩ load resistance.

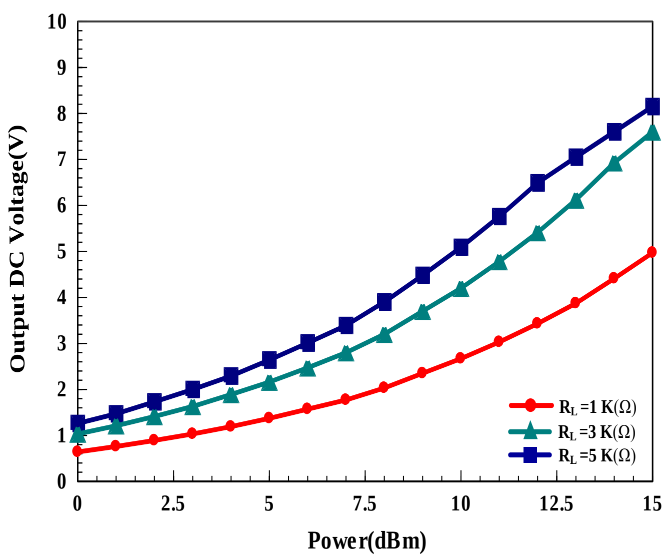

Fig. 15 Rectenna dc output voltage versus the received RF power is measured

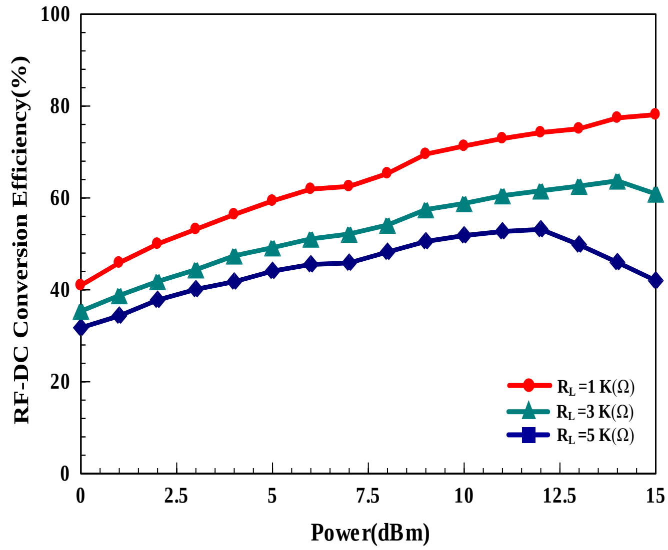

Fig. 16 Rectenna dc output voltage versus the received RF power is measured

IV. Conclusion

A broadband dual-polarized array antenna is presented. As a result, the proposed antenna meets the frequency band requirement, bandwidths are 53.4% for both polarizations, and shows good isolation performance and stable radiation patterns over the entire 1.8 GHz and 2.4 GHz bandwidth. The dual-polarized rectenna array operated at 2.45 GHz with measured gain about 3.3 dBi - 6.1 dBi. The used doubler rectifier provides optimum 78% RF-DC conversion efficiency at 15 dBm incident power and 1 KΩ load resistance.

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