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Design of RF Energy Harvesting Patch Antenna for Wireless Communications

N. Rajesh Kumar, P.D. Sathya

Abstract: ***In this paper a single fed microstrip patch rectenna for harvesting ambient radio frequency energy is presented. The antenna comprises of a clover shaped radiating patch operating at 2.4GHz ISM band. The rectifier circuit is placed in the same plane of radiating patch to minimize the overall antenna profile. The antenna is modelled and are fabricated on low loss roger dielectric substrate. Measured results show that the antenna achieves a peak gain of 7.19 dB in the operating ISM band with maximum RF conversion efficiency of 79%. The proposed antenna is suitable for wireless energy harvesting applications operating in ISM band.***

Keywords: Energy harvesting, microstrip antenna, rectenna, rectifier.

I. INTRODUCTION

Wireless power transfer is one of the promising ideas to charge miniature devices. This includes transfer of energy in space in a desired direction and then the RF energy gets collected by means of antenna operating in that desired band. Later the RF energy is rectified to DC energy by means of rectifier circuit in the receiver antenna collectively called rectenna (antenna along with rectifier circuit). Recently these concepts are used to harvest free radio frequency energy that are available in the ambient environment to charge handheld devices [1]. In order to have a better performance the gain of the antenna is improved by utilizing antenna arrays in place of single antenna [2]. However addition of rectifying circuit along with antenna arrays makes the overall profile of the antenna bulkier and makes it difficult to integrate with other miniature devices. These antennas are most widely designed in GSM-900, GSM-1800, ISM and UMTS-2100 bands because of widely available energy band in the immediate environment [3-4]. In some of the designs rectenna operating at multiple bands is proposed. The adds difficulty in matching antenna impedances in multiple bands and costs the efficiency of the antenna. Hence a separate matching network is needed in these multi band rectenna [5].

A multiport rectenna operating at multiple bands is demonstrated [6]. This includes multiple substrates separated by air layer makes it bulkier. A compact rectenna for harvesting energy for charging low power applications is presented [7]. The rectenna designed though compact fails to address antenna RF to DC conversion efficiency. In [8-9] a rectenna with better conversion efficiency are discussed. However the antennas suffer from poor gain performance. Due to popularity in rectenna for charging handheld devices, a 2.45-GHz power harvesting wristband rectenna is designed [10]. The antenna is made flexible to make more comfortable around the wrist and gives a good gain performances. However most of the antenna in the literatures fails to address RF-DC conversion efficiency of achieves poor conversion efficiency [11]. Hence there is need to design a rectenna of compact size operating at widely available band proving a better gain performance along with better conversion efficiency.

In this paper a clover shaped rectenna operating at ISM band is presented. The antenna is modelled using Ansoft high frequency structure simulator and are fabricated to validate the performances. The simulation and measured results are plotted and are compared with other traditional rectenna to show the merits of proposed rectenna.

II. ANTENNA DESIGN PROCEDURES

A. Antenna Geometry

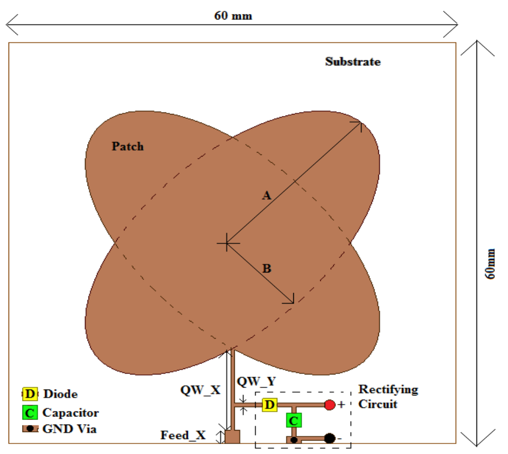

Fig. 1.Structure of proposed rectenna

The geometry of the proposed rectenna is shown in Fig.1. The rectenna comprise of clover shaped radiating patch fed by single port 50ohm SMA connector. The entire rectenna is modelled on low loss dielectric substrate of permittivity of 2.2 with loss tangent of 0.0002. The length and width of the rectenna is taken as 60mm x 60mm having a thickness of 1.6mm. In order to rectify the RF energy collected from the ambient environment a separated rectifier is placed in the feed strip line in the same plane of radiating element. This reduces additional space required for rectifying unit and hence reduces the antenna profile.

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*Correspondence Author(s)
N.Rajeshkumar, Department of Electronics and Communication Engineering, Annamalai University, Chidambaram, Tamil Nadu, India.
P.D. Sathya, Department of Electronics and Communication Engineering, Annamalai University, Chidambaram, Tamil Nadu, India.

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B. Rectifying circuit components

The circuit components used in the rectifying network is given in Table I.

Table- I Circuit Components used in the Device

Components	Value	Manufacturer
D	Schottky diode	SMS7630-079LF, Skyworks
C	100 nF chip capacitor	GRM188R71H104JA93D, Murata

In order to have a simplified rectifying network a single schottky diode having better conversion efficiency along with chip inductor is used. The schottky diode is chosen in such a way that it operates at high frequency especially above 1 GHz applications. A 100 nF chip capacitor after the diode is used to store DC power and smooth the DC output waveforms.

C. Parametric analysis

The circuit components are modelled in ansoft high frequency structure simulator (HFSS) based on the manufacture datasheet. The performance of the rectenna is largly depends on the dimension of the main clover shaped radiating element. Hence parametric analysis is carried to find the optimum dimension of the structure. The main factor that affects the dimension is the eccentricity E of the clover structure as given below.

$$E = \frac{A}{B} \tag{1}$$

Where E = Eccentricity

A= Radius of Major axis

B= Radius of Minor axis

The effect of E over operating band of the rectenna is given in Fig. 2.

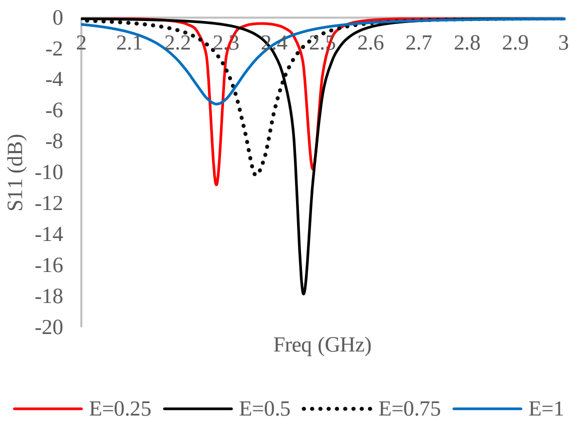


Fig. 2.Effect of Eccentricity over frequency (GHz)

It is observed from Fig. 2, with increase in eccentricity, the radiating element reshapes close to circular shape and hence increases the operating bandwidth of the rectenna. Similarly effect on eccentricity over antenna gain is given in Fig.3 given below

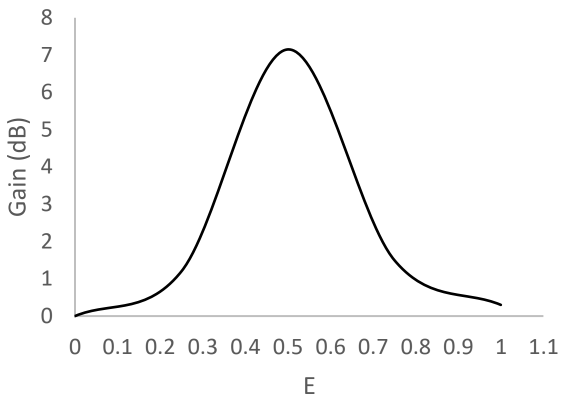


Fig. 3.Effect of Eccentricity over Gain

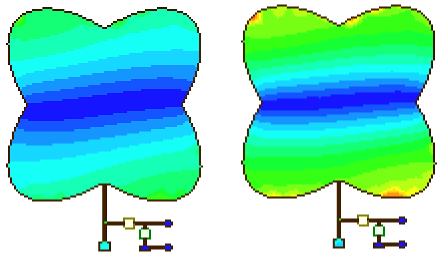
Based on the parametric analysis the optimum dimensions of the rectenna is given in Table II.

Table- II Antenna dimensions

Specification	Value
A	25
B	12.5
QW_X	20
QW_Y	0.5
Feed_X	2
Feed_Y	0.5

D. Electric field Distribution

The electric field distribution of the proposed rectenna at different instance of the time is given in Fig. 4.



(a) T=t/4 (b) T=2t/4

(c) T=3t/4 (d) T=t

Fig. 4.Electric field distribution

III. RESULTS AND DISCUSSIONS

In order to validate the performance of the antenna, the proposed model is fabricated and are measured. The reflection coefficient curve of the proposed antenna model is shown in Fig. 5. It is inferred from above figure that the antenna gives -10 impedance bandwidth of 100MHz (2.4GHz-2.5GHz) in the ISM band.

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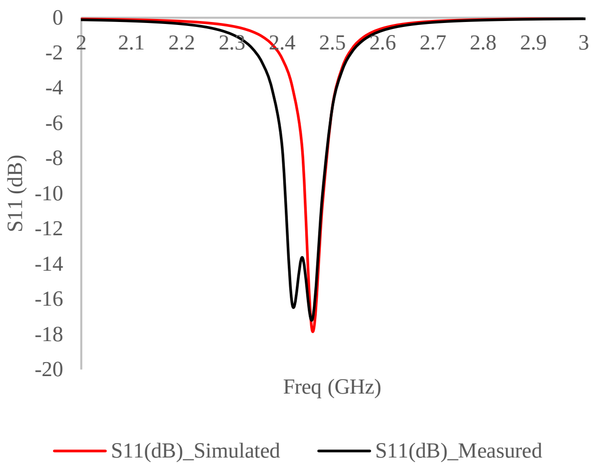
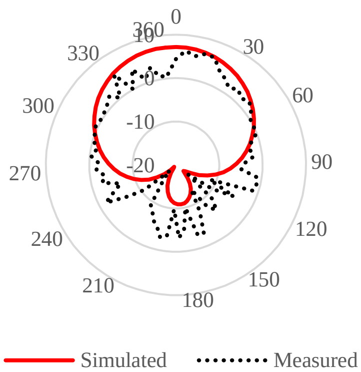
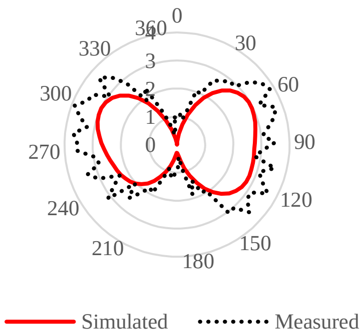


Fig. 5.Reflection coefficient (dB)

The simulated and measured gain characteristics of the antenna is plotted and are given in Fig.6. It is observed that the antenna gives symmetrical radiation with a peak gain of 7.19 dB in the operating band.



(a) E Plane



(b)H Plane

Fig. 6.Antenna Gain Characteristics

The entire performance of the rectenna depends on how well a rectenna converts collected RF energy in to DC components which is given by RF to DC conversion efficiency. It is calculated based on the equation given below.

$$RF - DC_{efficiency} = \frac{V_{out}}{P_{in}} \times 100 \qquad (2)$$

Where V_{out} = DC Power measured at rectifier output

P_{in} = RF Power measured at rectifier input

The RF to DC conversion efficiency measured for the proposed rectenna is given in Fig.7.

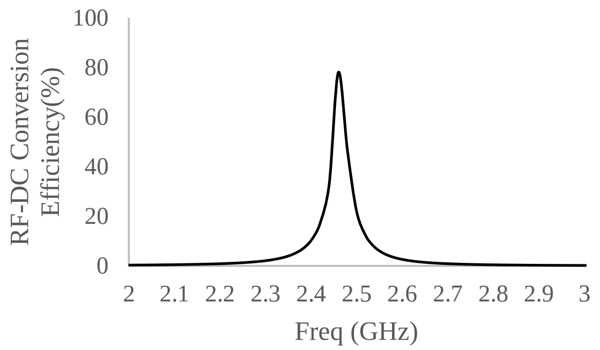


Fig. 7.RF to DC Conversion Efficiency

It is observed from the above plot that the proposed model gives better conversion efficiency at the resonant frequency since the impedance of the antenna is better matched at that frequency and received maximum power from the ambient environment. Similarly the End to end conversion efficiency of the proposed antenna is given in Fig. 8.

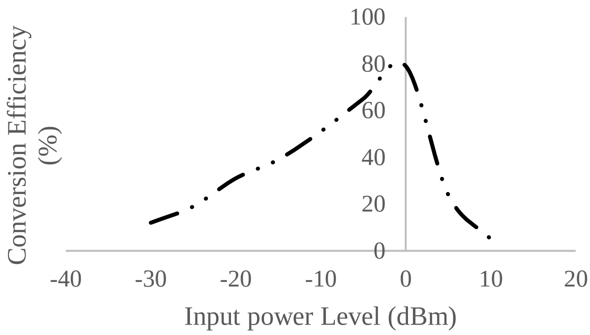


Fig. 8.End to end Conversion Efficiency

It is observed from the above figure that the antenna gives maximum conversion at 0dBm at the input power of around 0 dBm. This is because the selected diode (SMS7630) has reached its reverse breakdown voltage. Since the diode used is normally applied in low input power (e.g., from -30 to 0 dBm) applications. For high input power applications (e.g., >10 dBm) other diodes with a higher breakdown voltage could be selected. Table III gives overall performance comparison of the proposed rectetanna with other tradiational rectenna.

Table- III Performance Comparison Of Proposed Antenna

Parameter	Size (mm^3)	Band	Gain	η (%)
[3]	137x137x 21.2	GSM 900	8.5dBi	65.3%
[6]	175x 200x 46.6	GSM-900, GSM-1800, and UMTS-2100 bands	8.15, 7.15, and 8.15 dBi	40%
[8]	18x30x 1.6	ISM Band	5.6dB	68%
[10]	64x70x 3.9	ISM Band	6.8dBi	28.7%
Proposed	60x60x1.6	ISM Band (2.4-2.5) MHz	7.19 dB	79%

It is observed from the Table III, that the proposed antenna has better gain and efficiency characteristics when compared to other traditional antenna.

IV. CONCLUSION

A compact rectenna for harvesting RF energy is presented. The antenna comprises of clover shaped radiating element with rectifying unit near to feed strip. The antenna is designed to operate at ISM band and gives a measured impedance bandwidth of 100MHz (2.4GHz-2.5GHz) with a peak gain of 7.19dB. The antenna achieves maximum conversion efficiency of 79% in the operating band which makes it more suitable for energy harvesting applications.

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AUTHORS PROFILE

N Rajesh Kumar is a Research Scholar pursuing his PhD degree at Annamalai University, Chidambaram, India.. His current research interest includes antenna design and RF circuits.

P.D.Sathya is an Assistant professor with the faculty of engineering and technology Annamalai University, Chidambaram, India. Her current research interest includes digital image processing, heuristic optimization technique.

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