International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878, Volume-8 Issue-3, September 2019

Design of Ultra Wideband Rectenna for Ambient RF Energy Harvesting Applications

N. Rajesh Kumar, P.D. Sathya

Abstract*: In this paper a single fed microstrip patch ultra-wideband rectenna for harvesting ambient radio frequency energy is presented. The rectenna comprises of a rectangular shaped radiating patch operating at L band frequencies. The rectifier circuit is placed in the same plane of radiating patch to minimize the overall rectenna profile. The rectenna is modelled and are fabricated on low loss roger dielectric substrate. Measured results shows that the rectenna attains a maximum gain of 5 dB in the operating L band with maximum RF conversion efficiency of 81%. The rectenna designed is appropriate for harvesting wireless RF signals operating in L band.

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

I. INTRODUCTION

With the developments and enormous deployment of modern communication devices, huge amount of rich RF energy from surrounding regions are available in our atmosphere. By means of a suitable rectenna, these EM signals are harvested and are rectified into electrical energy. Wireless power transmission is one of the hopeful concepts 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 rectenna operating in that desired band. Later the RF energy is rectified to DC energy by means of rectifier circuit in the receiver rectenna collectively called rectenna (rectenna 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 rectenna is improved by utilizing rectenna arrays in place of single rectenna [2]. However addition of rectifying circuit along with rectenna arrays makes the overall profile of the rectenna bulkier and makes it difficult to integrate with other miniature devices. These rectennas 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 rectenna impedances in multiple bands and costs the efficiency of the rectenna. 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 rectenna RF to DC conversion efficiency.

In [8-9] a rectenna with better conversion efficiency are discussed. However the rectennas 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 rectenna is made flexible to make more comfortable around the wrist and gives a good gain performances. However most of the rectenna 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 rectangular shaped rectenna operating at L band is presented. The rectenna 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. RECTENNA DESIGN PROCEDURES

A. Structure of Rectenna

The physical dimensions of the proposed rectenna is given in Fig.1. The rectenna comprise of rectangular shaped radiating patch fed by single port 50 ohm 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 100mm x 80mm 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 rectenna profile.

Manuscript published on 30 September 2019
* Correspondence Author
N.Rajeshkumar*, Department of Electronics and Communication Engineering, Annamalai University, Chidambaram, Tamil Nadu, India. Email: rajeshavc2004@gmail.com
P.D. Sathya, Department of Electronics and Communication Engineering, Annamalai University, Chidambaram, Tamil Nadu, India. Email: p.d.sathya@yahoo.in

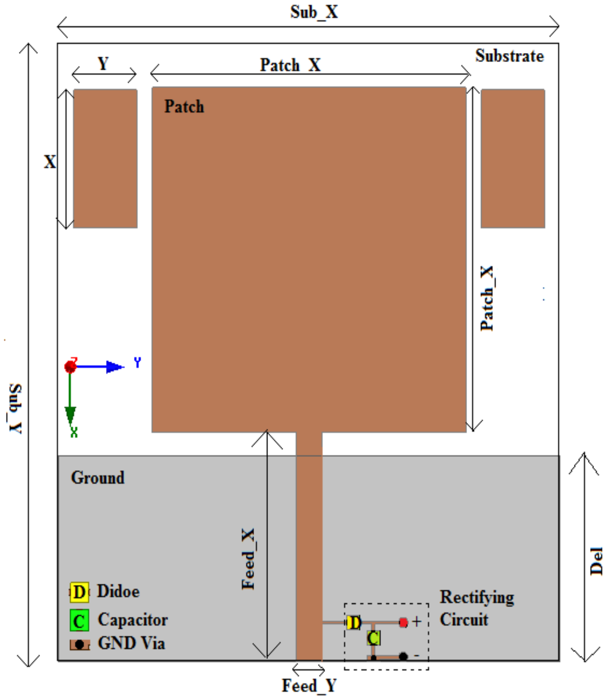


Fig. 1.Structure of proposed rectenna

B. Rectifying circuit components

The EM energy trapped from ambient environment is converted into a DC power by means of suitable rectifier circuit and are integrated with rectenna for receiving EM waves from the various ambient RF transmitters, which are broadly available in the surrounding like mobile phone signals, FM station signals, Satellite dish signals and several other wireless systems. Research on RF energy harvesting is going on in several areas such as low power wireless sensors, RFID (radio frequency identification) tags, and biotelemetry. 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. In order to have smooth DC power output, a 100 nF chip capacitor is placed next to the diode in the rectifying circuit.

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 largely depends on the length of the defected ground structure (Del). Hence parametric analysis is carried to find the optimum dimension of the structure.

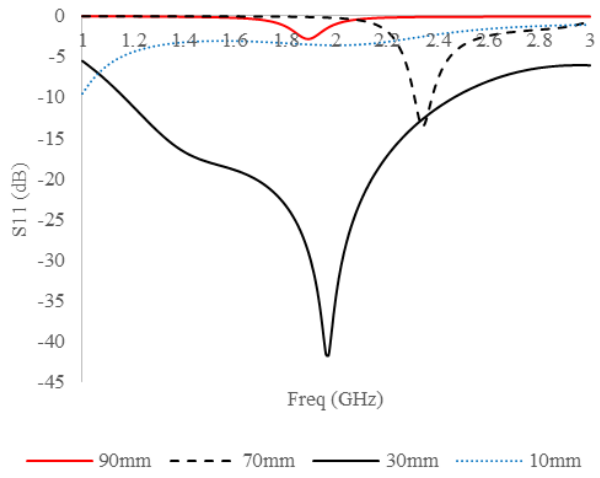


Fig. 2.Effect of ground length over frequency (GHz)

It is observed from Fig. 2, with increase in ground length, the rectenna resonant frequency shifts towards higher band and gives narrowband frequency range. Hence an optimal dimension of 30mm is considered as length for defected ground for the proposed design. Based on the parametric analysis the optimum dimensions of the rectenna is given in Table II.

Table- II Rectenna dimensions

Specification	Value
Sub_X	80mm
Sub_Y	100mm
Patch_X	50mm
X	20mm
Y	10mm
Feed_X	33.3mm
Feed_Y	4mm
Del	30mm

D. Electric Field Distribution

The electric field distribution of the proposed rectenna at different instance of the time is given in Fig. 3.

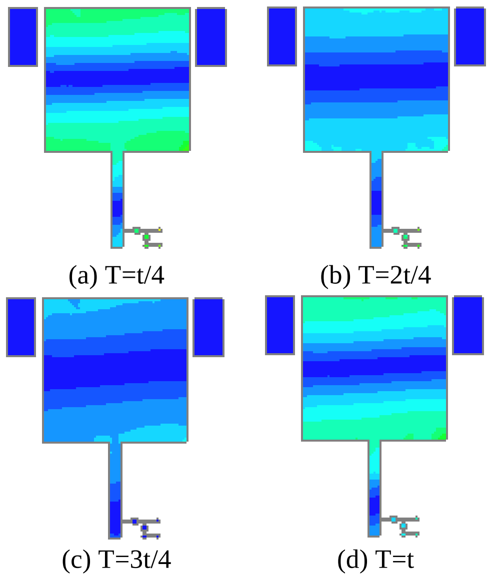


Fig. 3.Electric field distribution

Retrieval Number: C4574098319/19©BEIESP
DOI:10.35940/ijrte.C4574.098319
Journal Website: www.ijrte.org

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878, Volume-8 Issue-3, September 2019

III. RESULTS AND DISCUSSUIONS

The rectenna is fabricated and its performances are measured for analyzing its characteristics. The impedance bandwidth curve of the proposed rectenna design is depicted in Fig. 4.

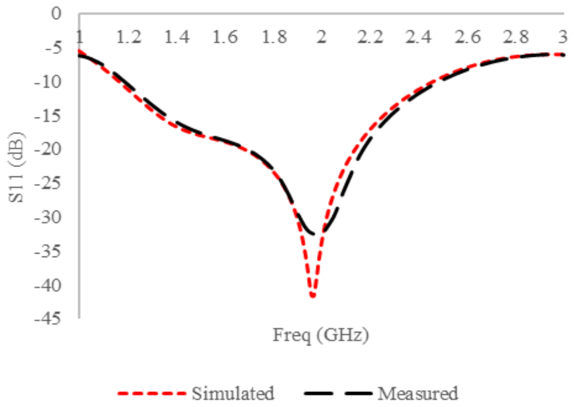


Fig. 4.Reflection coefficient (dB)

The simulated impedance characteristics closely agrees with measured impedance characteristics of the proposed rectenna. The fractional bandwidth of the rectenna is calculated from

$$FractionalBandwidth(\%) = \frac{f_h - f_l}{f_c} \quad (1)$$

Where f_h = High frequency component

f_l = Low frequency component

f_c = Center frequency component

It is noted from Fig. 4 that the rectenna attains -10dB impedance bandwidth of 1200MHz (1.2GHz-2.4GHz) in the L band with a fractional bandwidth of 66.6%. The simulated and measured gain characteristics of the rectenna is plotted and are given in Fig.5. It is observed that the rectenna gives symmetrical radiation with a peak gain of 5dB in the operating band.

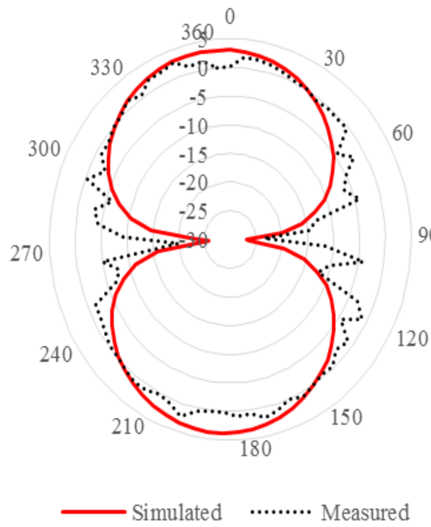
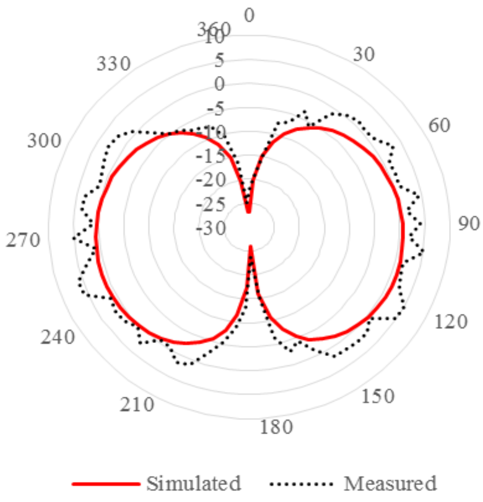


Fig. 5.(a) E Plane



(b)H Plane

Fig. 6.Rectenna Gain Characteristics

It is noted from Fig. 5, that rectenna gives bidirectional radiation characteristics in both E and H plane. This is due to presence of defected structure in the ground plane which allows spurious radiation on other side of the radiating patch. This allows the proposed model to receive RF energy in both sides of the radiating patch which significantly increases the amount of energy harvested from ambient source. The rectenna gives a measured peak gain of 5dB in the operating band.

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.

$$RF - DC_{Efficiency} = \frac{V_{out}}{R_{in}} \times 100 \quad (2)$$

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.6.

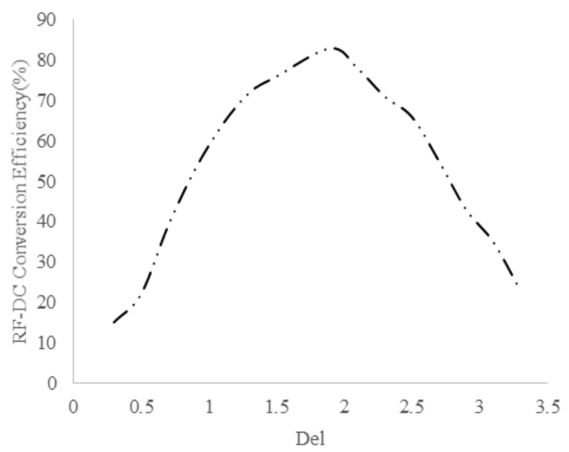


Fig. 7.RF to DC Conversion Efficiency

Retrieval Number: C4574098319/19©BEIESP
DOI:10.35940/ijrte.C4574.098319
Journal Website: www.ijrte.org

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

It is observed from the above plot that the proposed model gives better conversion efficiency of 81% at the resonant frequency since the impedance of the rectenna is better matched at that frequency and received maximum power from the ambient environment. Similarly the End to end conversion efficiency of the rectenna designed is given in Fig. 7.

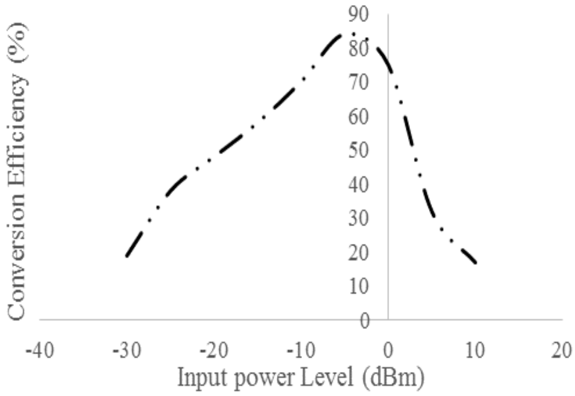


Fig. 8.End to end Conversion Efficiency

It is observed from the above figure that the rectenna gives maximum conversion at 0dBm at the input power of around 0 dBm. This is due to the fact that the chosen RF diode (SMS7630) falls in reverse break down after 0dBm. This puts limitation of usage of this diodes to operate at low power applications operating in the range from -30 to 0 dBm. For high input power applications (e.g., >10 dBm) other diodes with a higher breakdown voltage could be selected. Table III gives overall performance evaluation of the proposed rectenna with other traditional rectenna.

Table- III Performance Comparison of Proposed rectenna

Parameter	Size (mm^3)	Band width	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	80x100x1.6	L Band (1.2-2.4) MHz	5 dB	81%

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

IV. CONCLUSION

An ultra-wideband rectenna for RF energy harvesting in the ambient energy is presented. The rectenna comprises of rectangular patch along with a rectifier circuit at its bottom of same plane. The rectenna gives a -10dB wide impedance characteristics of 1200MHz (12GHz-2.4GHz) in the L band with a peak gain of 5dB in the operating band. 81% in the operating band which makes it more suitable for energy harvesting applications.

REFERENCES

1. F. Xie, G. Yang and W. Geyi, "Optimal Design of an Rectenna Array for Energy Harvesting," in IEEE Antennas and Wireless Propagation Letters, vol. 12, pp. 155-158, 2013.
2. A. Mavaddat, S. H. M. Armaki and A. R. Erfanian, "Millimeter-Wave Energy Harvesting Using 4 x 4 Microstrip Patch Antenna Array," in IEEE Antennas and Wireless Propagation Letters, vol. 14, pp. 515-518, 2015.
3. M. Arrawatia, M. S. Baghini and G. Kumar, "Differential Microstrip Antenna for RF Energy Harvesting," in IEEE Transactions on Antennas and Propagation, vol. 63, no. 4, pp. 1581-1588, April 2015.
4. A. Bakkali, J. Pelegri-Sebastia, T. Sogorb, V. Llario, and A. Bou-Escriva, "A Dual-Band Antenna for RF Energy Harvesting Systems in Wireless Sensor Networks", Journal of Sensors, Vol 2016, Article ID 5725836, pp.1-8, 2016.
5. C. Song, Y. Huang, J. Zhou, P. Carter, S. Yuan, Q. Xu, and Z. Fei, "Matching Network Elimination in Broadband Rectennas for High-Efficiency Wireless Power Transfer and Energy Harvesting," in IEEE Transactions on Industrial Electronics, vol. 64, no. 5, pp. 3950-3961, May 2017.
6. S. Shen, C. Chiu and R. D. Murch, "A Dual-Port Triple-Band L-Probe Microstrip Patch Rectenna for Ambient RF Energy Harvesting," in IEEE Antennas and Wireless Propagation Letters, vol. 16, pp. 3071-3074, 2017.
7. R. Krishnamoothy and K. Umapathy, "Design And Implementation Of Microstrip Antenna For Energy Harvesting Charging Low Power Devices," 2018 Fourth International Conference on Advances in Electrical, Electronics, Information, Communication and Bio-Informatics (AEEICB), Chennai, 2018, pp. 1-3.
8. Q. Awais, Y. Jin, H. T. Chattha, M. Jamil, H. Qiang and B. A. Khawaja, "A Compact Rectenna System With High Conversion Efficiency for Wireless Energy Harvesting," in IEEE Access, vol. 6, pp. 35857-35866, 2018.
9. K. Shafique et al., "Energy Harvesting Using a Low-Cost Rectenna for Internet of Things (IoT) Applications," in IEEE Access, vol. 6, pp. 30932-30941, 2018.
10. S. Adami et al., "A Flexible 2.45-GHz Power Harvesting Wristband With Net System Output From −24.3 dBm of RF Power," in IEEE Transactions on Microwave Theory and Techniques, vol. 66, no. 1, pp. 380-395, Jan. 2018.
11. L. Yang, Y. J. Zhou, C. Zhang, X. M. Yang, X. Yang and C. Tan, "Compact Multiband Wireless Energy Harvesting Based Battery-Free Body Area Networks Sensor for Mobile Healthcare," in IEEE Journal of Electromagnetics, RF and Microwaves in Medicine and Biology, vol. 2, no. 2, pp. 109-115, June 2018.

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.