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IMPROVING POWER CONVERSION EFFICIENCY OF RF ENERGY HARVESTING USING MICROSTRIP PATCH ANTENNA ARRAY WITH TWO U-SHAPED METALLIC STRIPS

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Abstract

The Radio Frequency (RF) energy harvesting has attracted research interest as a sustainable solution to power low-power electronic and Internet of Things (IoT) devices. However, the power conversion efficiency is limited by the performance of the antenna as it is the first block in RF energy harvesting. High conversion efficiency of the RF energy harvesting system demands the use of a high-gain antenna. The microstrip antennas available today are of lower gain, and this puts a big challenge for portable systems antennas. The work presented in this paper consists of the design of the 2 X 2 patch antenna array with a U-shaped metallic strip, and this antenna is verified for improvement in RF harvesting systems power conversion efficiency. This U-shaped metallic strip improves impedance matching, bandwidth, and gain The antenna and the entire RF energy harvesting module are simulated using Advanced Design System 2022. The parasitic elements formed due to two U-shaped metallic strips increase the antenna gain. The antenna attains a directivity of 11.39 dBi, a gain of 8.50 dBi, and a radiation efficiency of 51.33% under standard test condition. Incorporation of this antenna in the RF energy harvesting system resulted in improved power conversion efficiency of 89.31%.

Index Terms- Directivity, Gain, Patch antenna array, RF Energy harvesting, U shape parasitic element

I. INTRODUCTION

RF energy harvesting (RFEH) captures energy from the environment and converts it into usable DC power. The power conversion efficiency (PCE) is an important performance metric to measure the effectiveness of an RF energy harvesting system. Till time, different antennas like array antenna with parasitic elements, a defected ground structure antenna are used to enhance PCE [1]. The power conversion efficiency is directly proportional to the radiation efficiency of an antenna [2]. Microstrip patch antennas (MPA) are widely used in RF energy harvesting systems as they are compact, have a flat design, minimal weight, and are economically efficient. This type of antenna can be embedded in small devices because of its small size [2]. Using directional antennas like MPAs instead of omnidirectional ones can significantly increase the harvested power by focusing on the direction of the RF source. Despite their advantages, MPAs are constrained by factors such as limited gain, low bandwidth, and reduced power-handling capability [3]. The gain of this antenna can be increased by using resonators. The parasitic elements form due to the resonators increase the bandwidth of the antenna [3].

II. LITERATURE REVIEW

To date, many researchers have worked to improve overall system performance using microstrip patch antennas, including the impacts of parasitic elements. In [2], a broad operating frequency range is obtained as a result of parasitic elements of the U-shaped metal strip designed around the patch antenna. The antenna simulation was carried out using HFSS. A vector network analyzer is used to evaluate antenna parameters such as return loss and impedance. The resonant frequencies were

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observed at 5.12 GHz and 6.08 GHz, for a 1.5 GHz bandwidth, which represents 27.3% of the mid-band frequency. The [3] Paper presents a microstrip antenna design operating at the ISM band of 2.45 GHz. The study has investigated two methods to improve the performance characteristics of a patch antenna using parasitic elements. The conventional and shorted patch antenna were compared. Both of these antennas have considered the impact of parasitic elements. The work has focused on the performance characteristics of these antennas. The performance parameters considered are return loss and radiation pattern of an antenna. The CST Microwave Studio 2008 tool is used for simulation purposes. The antenna's bandwidth increased by 2 % from 2.9 % to 4.9 %. The work [4] has introduced an MPA with circular polarization. The design has included four L-shaped patches, which introduce parasitic elements. A broad 3-dB axial ratio bandwidth of 16.7% and a 10-dB return loss bandwidth of 25.5% were achieved by the antenna (5.5 GHz, spanning 4.8-6.2 GHz). The study in [5] presents a short antenna featuring a parasitic microstrip cap-shaped design. The antenna includes a U-shaped parasitic microstrip line that is excited by coupling from the feed line at the patch. The proposed antenna is optimized using the Particle Swarm Optimization (PSO) algorithm. The simulation tool used is the ZELAND IE3D software environment. Two-band coverage is obtained for both the C and the X band. The bandwidth increase is also obtained for both bands. The paper designs a printed microstrip patch antenna [6]. The design includes two U-shaped rectangular parasitic strips. The HFSS is used for simulation purposes. The antenna exhibits resonance at 2.6 GHz, 6 GHz, and 8.5 GHz. The paper [7] proposes a microstrip patch antenna that operates at broadband. A U-shaped metallic strip is added to the rectangular patch side to generate an additional resonant frequency. Adjusting the location and length of the metallic strip can greatly expand the bandwidth. A bandwidth of 10.3% centered at 4.85 GHz is achieved through simulation, while preserving a compact design measuring approximately 0.025 λ in free space. In the paper [8], the authors used a U-shaped metallic strip on the MPA. The full-wave electromagnetic simulator is used for simulation purposes. The input impedance bandwidth is 33% when centered at 5.68 GHz. The antenna's bandwidth shows a 6.8% and a 5.7% increase when compared with the simulation and experimental data. In the paper [9], MPA with metallic strips is proposed. The shapes used are inverted L and T. The proposed antenna operates in the multiband. The substrate used for the antenna is alumina. The simulation is done using CST MWS 2010. The paper [10] presents an MPA. The design achieves an extremely broad bandwidth. The designed antenna consists of a square patch that is U-shaped, integrated with two parasitic elements. The structure is coplanar, which is fed via a waveguide. The simulation is done using Ansoft HFSS. The Agilent network analyzer is used for measurement purposes. The designed antenna's bandwidth ranges from 2.76 to 12.8 GHz, which is 129% higher. The measured impedance, VSWR, gain, and return loss are satisfying characteristics of a UWB antenna. The gain obtained is 1.6 to 5.3 dBi. In paper [11], an MPA incorporating a U-slot is presented. The obtained bandwidth is 4.82-6.26 GHz, which is 26.2% higher. The HFSS is used for simulation purposes.

Reviewing the above literature, the rectangular microstrip antenna array of size 2 x 2 is designed and modelled using ADS 2022. This antenna array serves as a reference antenna for comparison with the 2 x 2 antenna, featuring a U-shaped metallic strip, which has been designed and modelled.

III.PROPOSED WORK

In this study, the reference microstrip array and proposed antenna are designed and simulated

A. Design of Reference antenna

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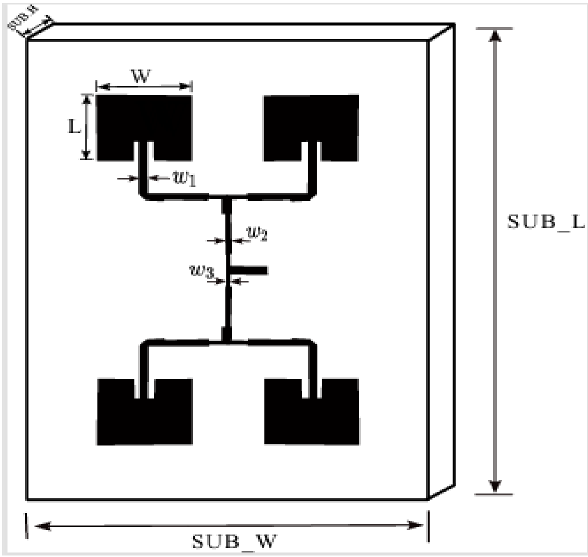

Fig.1. Microstrip patch array without parasitic element

The reference MPA array antenna of size 2 x 2 is simulated for 2.4 GHz using a transmission line model in ADS 2022, as shown in Fig.1. In ADS 2022, the TLines Microstrip tool is used to design a reference antenna. The antenna is a 2 x 2 patch, which is obtained from a single patch. The single patch is first converted into a 2 x 1 patch and then into a 2 x 2 patch in ADS 2022 softwareThe geometric parameters of the antenna are width of patch W = 37.35 mm, Length L = 28.78 mm, Line feed I = 15.136 mm, Line width W1 = 2.957 mm, W2 =1.557 mm, W3 = 0.672 mm and Inset distance S = 8.3 mm. An FR4 substrate with a dielectric constant (εr) of 4.6, loss tangent tan δ = 0.001, and a height of 1.6 mm has been used in this work. The SUB_L = 180 mm and SUB_W = 130 mm. To reduce the radiation losses, the high-conductivity material copper is introduced into the substrate. This reference antenna is connected in the RFEH system, which is depicted in Fig. 2. The Fig.2. illustrates the block diagram of RFEH simulated using ADS 2022. The antenna is the first block of RFEH, which is followed by a matching network. Following this, is the rectifier which converts the captured RF signal in to direct current (DC). This DC voltage is often too low for practical use, so it is fed into a voltage multiplier, which boosts the voltage level to meet the requirements of the load. In the layout component, any antenna can be put in and observe the results like output voltage and PCE. The L-type impedance matching network is designed using the Smith chart tool. The rectifier used is a full-wave rectifier with Schottky diodes. The Ambient RF signals are usually very weak. The Conventional diodes (like PN junction diodes) require a threshold voltage that may exceed the available RF voltage. Hence, the two low-threshold Schottky diodes HSMS285x are used. The Greinacher voltage multiplier is used to boost the signal from the rectifier.The voltage multiplier is designed using two Schottky diodes and two capacitors. The input capacitor charges from the rectifier's output voltage and switches it in a way that effectively multiply the output voltage. The output is taken across a 1 KΩ load. The microstrip patch array antenna 2 x 2 used in RF energy harvesting of Fig. 2 gives Vout of 2.903 and PCE of 84.256 % as shown in Fig.3. and Fig.4. The power conversion efficiency (PCE) is calculated using the following formulas.

$$\text{PCE} = \frac{\text{Pout}}{\text{Pin}} \text{ x } 100 \quad (1)$$

$$\text{PCE} = \frac{\text{Vout}^{2}}{\text{RL X Pin}} \text{ x } 100 \quad (2)$$

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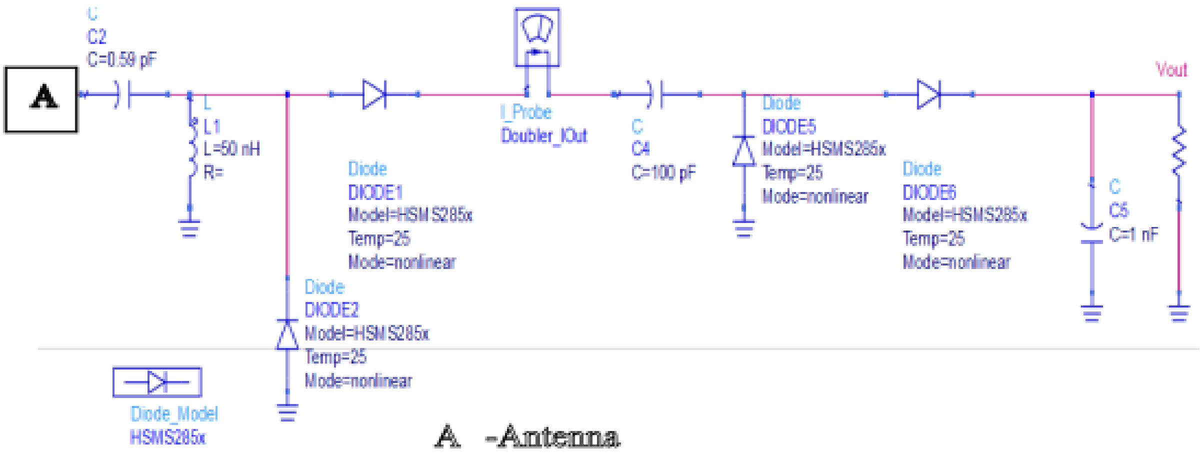

Fig. 2. Simulated block diagram of RFEH in ADS software

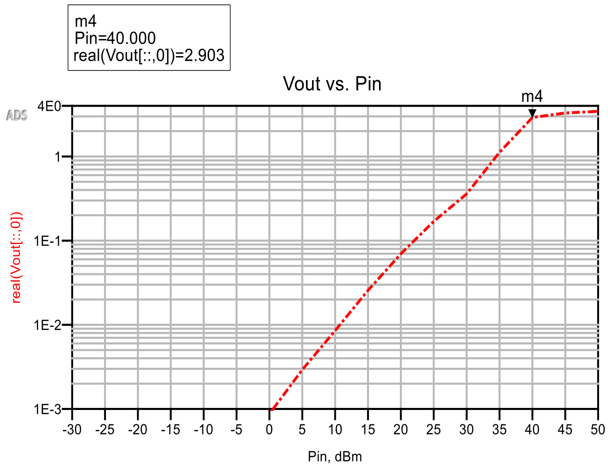

Fig. 3 Vout of 2 x 2 Patch

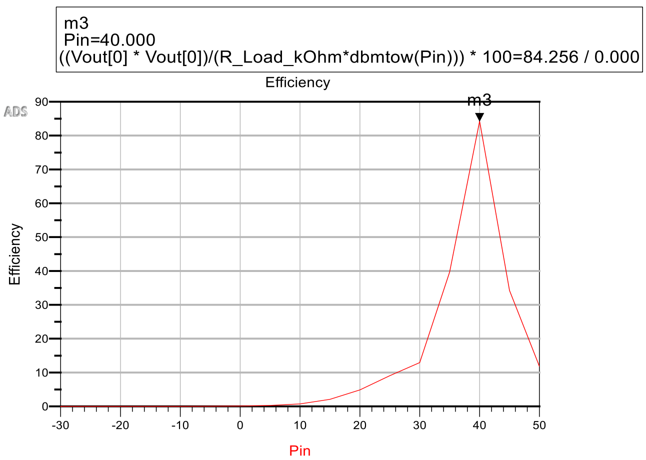

Fig. 4. PCE of 2 x 2 Patch

B. Proposed antenna design

The metallic strip element can be placed around a microstrip patch antenna which are not energized. Different shapes can be placed. In this work, we are placing two U-shaped metallic strips. Because of that shape, antenna parameters increase, which leads to an increase in the power conversion efficiency of RF energy harvesting. The 2 x 2 array with two U-shaped metallic strips is shown in

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Fig.5. The metallic strips added form the parasitic element. These parasitic elements are not excited with the feed line. Instead, they influence the radiation pattern with the driven element through electromagnetic influence. The parameters of the parasitic component are Wu = 125 mm and Lu = 83 mm. The size of the metallic strip is set as 2.957 mm. These non-radiating metallic strips are positioned surrounding the radiating array patch. Because of these U-shaped metallic strips, the antenna parameters increased. These metallic strips affect the electromagnetic field, leading to a reduction in mutual coupling. Additionally, they contribute to achieving a wider bandwidth [12]. This proposed antenna's primary feature is that it increases its gain, directivity and overall efficiency all without altering its dimensional characteristics [13]. The bandwidth is also increased due to metallic strips [14][15].

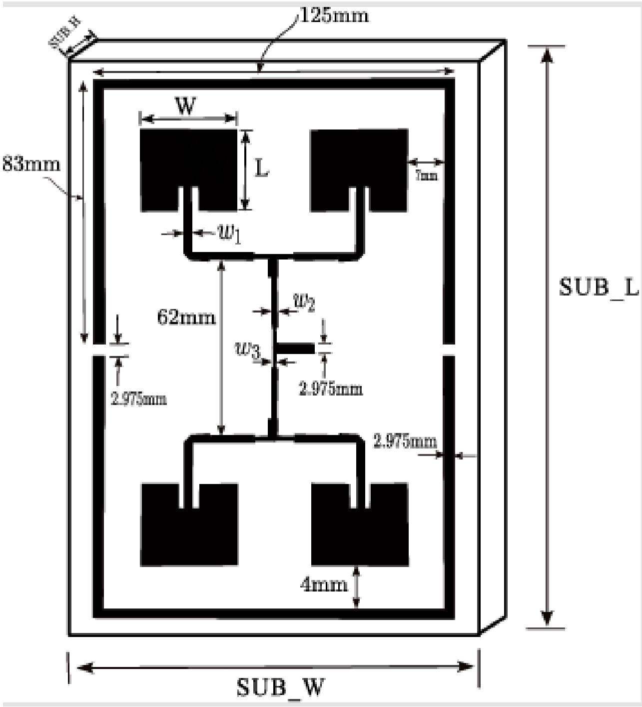

Fig.5. The Layout of 2 x 2 Patch with Parasitic Element

They improve the directivity by focusing the radiation in a specific direction. A U-shaped slot which is etched into the ground plane alter its curvature, which enhances the antenna's bandwidth by modifying the current distribution. This change, in turn, influences the inductive and capacitive characteristics of the ground plane.[16]. The radiation around the surface is suppressed due to metallic strips. By directing the energy in the desired direction, the parasitic element formed due to metallic strips contributes to higher antenna gain. The parasitic radiated power versus frequency is plotted. The parasitic element helps achieve better impedance matching, which can improve the antenna's efficiency. Radiofrequency (RF) energy harvesting provides sustainable, maintenance-free power for wireless sensors, IoT devices, and low-power electronics. Advances in efficiency have led to the development of miniaturized rectennas and multi-band antennas that capture electromagnetic energy across various frequencies [17]. The patch antenna is capable of supporting both polarization diversity and frequency diversity [18]. Besides delivering strong performance in a compact form, the proposed antenna also provides mechanical benefits like a straightforward design, low weight, and ease of manufacturing qualities that make it well-suited for future RF energy harvesting in low-power electronic applications [19].

IV. RESULTS

The proposed antenna's return loss, as illustrated in Fig.6. is -17.160 dB at 2.421 GHz. The antenna parameters obtained are depicted in Fig.7. The directivity, gain, and efficiency obtained are 11.39

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dBi, 8.50 dBi, and 51.33 %, respectively. When this proposed antenna is used in RF energy harvesting of Fig.2. it gives a Vout of 2.989 V and PCE of 89.31 %. Thus, the Vout and PCE increase due to the metallic strips added.

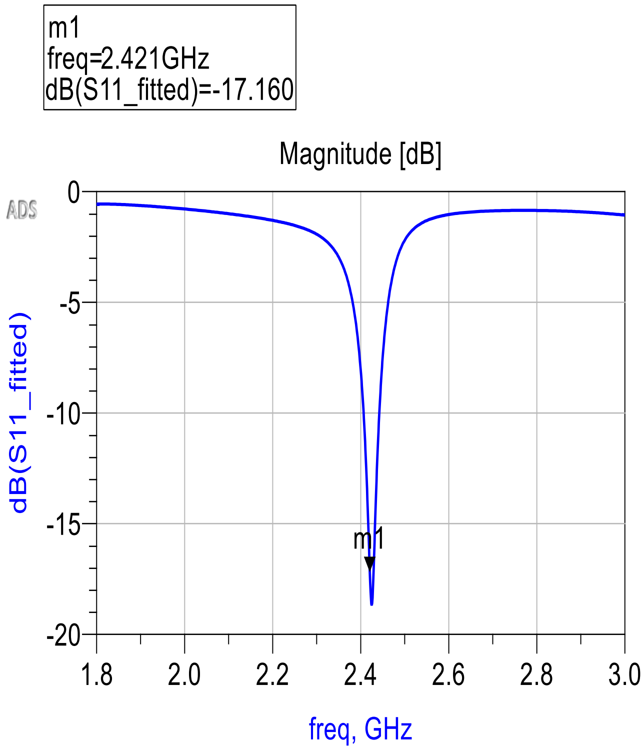

Fig.6. Return Loss of 2 x 2 Patch with Parasitic Element

Frequency (GHz)		2.43915
Input power (Watts)		0.00231497
Radiated power (Watts)		0.00118833
Directivity(dBi)		11.3974
Gain (dBi)		8.50132
Radiation efficiency (%)		51.3327
Maximum intensity (Watts/Steradian)		0.00130457
Effective angle (Steradians)		0.910903
Angle of U Max (theta, phi)	26	270
E(theta) max (mag,phase)	0.99076	-46.877
E(phi) max (mag,phase)	0.0365574	-32.1708
E(x) max (mag,phase)	0.0365574	-32.1708
E(y) max (mag,phase)	0.890489	133.123
E(z) max (mag,phase)	0.43432	133.123

Fig 7. Antenna Parameters of 2 x 2 patch with parasitic element

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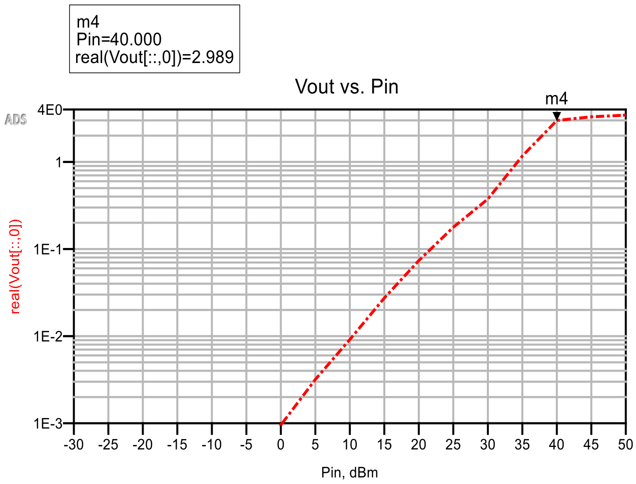

Fig. 8. Vout of 2 x 2 patch with parasitic element

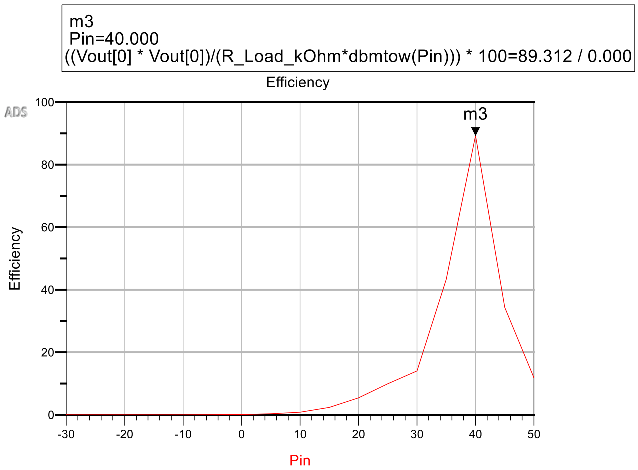

Fig. 9 PCE of 2 x 2 Patch with Parasitic element

The Vout is as illustrated in Fig.8. and PCE is as illustrated in Fig. 9. The current distribution is as shown in Fig.10. The current is induced due to parasitic coupling affecting the resonator behavior. Due to that, it alters the current path, affecting the radiation efficiency.

IV . COMPARISON WITH RECENT STUDIES

The comparison of proposed work with previously published work is shown in Table 1. It shows that our results of Vout and PCE are better than other works.

Table 1 Comparison with recent works

Ref.	Load in KΩ	Frequency in GHz	Pin in dBm	Vout in volts	PCE in %
[20]	8	0.87	0	1.25	30
[21]	25	0.95	-10	2	43.51
[22]	10	2.45	-5	--	61.4
This work	1	2.4	10	2.989	89.31

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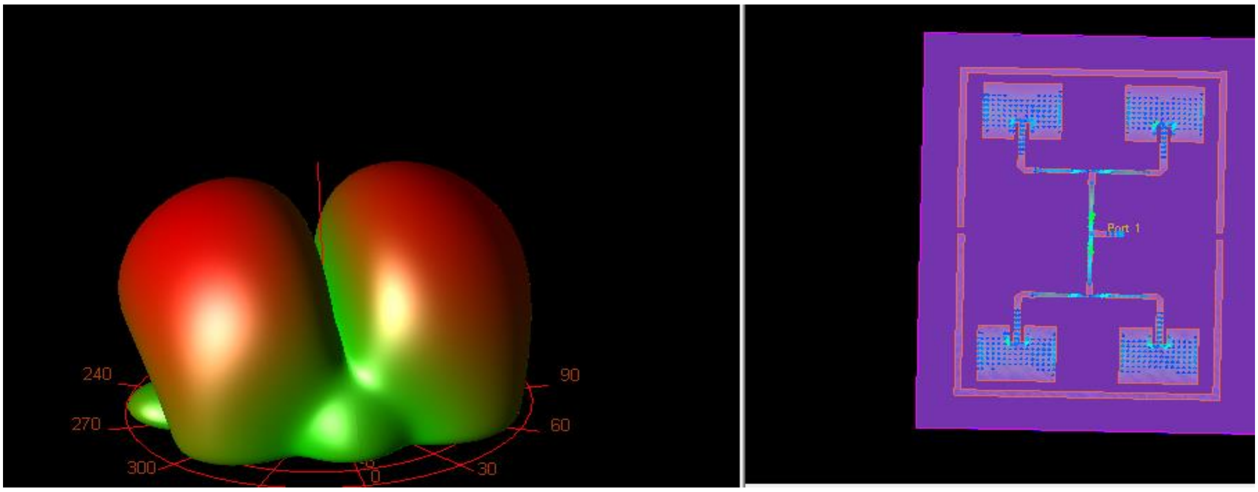

Fig. 10. Current Distribution of 2 x 2 Patch with Parasitic element

V. CONCLUSION

In this work, an MPA array with two U-shaped metallic strips, which form the parasitic elements for an antenna in RF Energy harvesting, has been proposed. This antenna works at 2.4 GHz frequency. It shows directivity, gain and efficiency as 11.39 dBi, 8.50 dBi and 51.33 %, respectively. The power conversion efficiency obtained is 89.31.% with a metallic strip, whereas the power conversion efficiency without a metallic strip is 83.271 %. Hence, the power conversion efficiency is improved due to metallic strips. Therefore, the proposed antenna is well-suited for RFEH to get higher power conversion efficiency.

REFERENCES

[1] K. N. Patil and A. D. Jadhav, "Review on Power Conversion Efficiency Improvement Strategies in RF Energy Harvesting", IEEE Wireless Antenna and Microwave Symposium (WAMS), Rourkela, India, pp. 1-6, June 2022.

[2] Wi, Sang-Hyuk, Yong-Shik Lee, and Jong-Gwan Yook. "Wideband microstrip patch antenna with U-shaped parasitic elements." IEEE transactions on antennas and propagation 55.4,1196-1199,April 2007.

[3] Dahlan, A. M. M., and M. R. Kamarudin. "Shorted microstrip patch antenna with parasitic element." Journal of Electromagnetic Waves and Applications 24.2-3, 327-339, April 2012.

[4] Su, Wei, Junkui Li, and Ren-Huai Liu. "A compact double-layer wideband circularly polarized microstrip antenna with parasitic elements." International Journal of RF and Microwave Computer-Aided Engineering 31.1 : e22471, 2021

[5] Zaman, M. R., M. T. Islam, and Salehin Kibria. "A Novel U-Shaped Parasitic Asymmetric Microstrip Cap Loaded Compact Patch Antenna." The Applied Computational Electromagnetics Society Journal (ACES), pp.191-203,2015.

[6] Asif, Sajid, et al. "A compact multiband microstrip patch antenna with U-shaped parasitic elements." IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting. IEEE, April 2015.

[7] Chen, Xin-Peng, Neng-Wu Liu, and Guang Fu. "A Compact Wideband Microstrip-Fed Patch Antenna Using a U-shaped Parasitic Element." 2019 IEEE International Conference on Computational Electromagnetics (ICCEM). IEEE, 2019.

[8] Dong, Jiawei, et al. "A novel stacked wideband microstrip patch antenna with U-shaped parasitic elements." 8th International Symposium on Antennas, Propagation and EM Theory. IEEE, 02-05 November 2008

[9] Kim, Jun-Won, et al. "Compact multiband microstrip antenna using inverted-L-and T-shaped parasitic elements." IEEE Antennas and Wireless Propagation, October 2013.

[10] Koohestani, Mohsen, and M. Golpour. "U-shaped microstrip patch antenna with novel parasitic tuning stubs for ultra wideband applications." IET microwaves, antennas & propagation 4.7: 938-946, 2010.

[11] Lu, Hua-Xiao, et al. "Design and analysis of wideband U-slot patch antenna with U-shaped parasitic elements." International Journal of RF and Microwave Computer-Aided Engineering 28.2,e21202, Nov 2017.

[12] Tran, Huy Hung, and Nghia Nguyen-Trong. "Performance enhancement of MIMO patch antenna using parasitic elements." IEEE Access 9: 30011-30016, Feb 2021.

[13] Hajlaoui, El Amjed. "New triple band electromagnetic band gap microstrip patch antenna with two shaped parasitic elements." Journal of Computational Electronics 17.1: 452-457, 2018.

[14] Ketineni, R. V., Uma Balaji, and A. Das. "Improvement of bandwidth in microstrip antennas using parasitic patch." IEEE Antennas and Propagation Society International Symposium, Digest, IEEE, 1992

[15] Peng, Lin, et al. "Bandwidth enhanced l-shaped patch antenna with parasitic element for 5.8-GHz wireless local area network applications." Wireless Personal Communications 91: 1163-1170, 2016.

[16] Kayed, Somaya I., et al. "Multiband microstrip rectenna using ZnO-based planar Schottky diode of RF energy harvesting applications. Micromachines 14.5: 1006, May 2023.

[17] Thanh, Tu Duong Thi, et al. "A Penta-band Antenna using Symmetrical DGS for RF Energy Harvesting in IoT Applications." Engineering, Technology & Applied Science Research 15.2: 22028-22034 , 2025.

[18] Shrestha, Sika, Sun-Kuk Noh, and Dong-You Choi. "Comparative study of antenna designs for RF energy harvesting." International Journal of Antennas and Propagation 2013.1: 385260, Jan 2013.

[19] Koohestani, Mohsen, Jérôme Tissier, and Mohamed Latrach. "A miniaturized printed rectenna for wireless RF energy harvesting around 2.45 GHz." AEU-International Journal of Electronics and Communications , 127 : 153478., 2020

[20] Alex-Amor, Antonio, et al. "RF energy harvesting system based on an archimedean spiral antenna for low-power sensor sensors 19.6 : 1318 .applications.", 2019/

[21] Yusoff, Saiful Syazwan, Syed Abdul Malik, and Taib Ibrahim. "Simulation and performance analysis of a dual GSM Band rectifier circuit for ambient RF energy harvesting." Applications of Modelling and Simulation 5: 125-133, 2021.

[22] Chen YS, Chiu CW. Maximum achievable power conversion efficiency obtained through an optimized rectenna structure for RF energy harvesting. IEEE Transactions on Antennas and Propagation. March 2017.