Journal of Engineering Research (ERJ)
Vol. 7 – No. 5, 2023
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ISSN: 2356-9441 https://erjeng.journals.ekb.eg/ e ISSN: 2735-4873

Design of a Circular Concentric Microstrip Patch Antenna Array for WI-FI Band Energy Harvesting

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Abstract

Wireless networks have gone through unprecedented changes in the last decade owing to the rise in the number of users. Radio frequency (RF) energy harvesting (EH) (termed as RF-EH) can be a potential solution to exploit this traffic in communication systems, one of the key issues is designing a compact antenna array while providing reliable capturing characteristics over the operating band. In energy harvesting systems, printed slot antennas have received much attention owing to their matching characteristics. In addition, they present really appealing physical features, such as simple structure, small size, and low cost. In this paper, a small circular concentric antenna array utilizing rectangular radiating patch elements and defected ground structure for RF-EH is proposed. The antenna is designed using the CST Microwave Studio software package and realized on a Roger 5880 substrate with $\varepsilon_r = 2.2$ and $h = 3.18\ mm$. The simulations demonstrated the effective performance of the proposed circular antenna array structure in terms of high gain of about $15.8\ dBi$, high efficiency, and the possibility to collect RF power from all directions.

I. Introduction

Radio frequency energy harvesting (RF-EH) is a process of extracting electrical energy from electromagnetic radiation in the radio frequency (RF) range [1]. It is used to power low-power electronic devices such as sensors, wireless transmitters and receivers, and other Internet of Things (IoT) devices [2]. RF-EH works by converting the RF signal into direct current (DC) electricity, which can then be stored in a battery or capacitor for later use. This technology has been used to power small devices such as medical implants and wearables, as well as larger systems such as smart cities [3]. (RF-EH) module would generally have four primary blocks: a receiving antenna, matching circuit, rectification circuit along with a low pass filter and finally a mechanism for energy storage [4]. a harvester process can be evaluated in term of captured ambient RF energy being translated to dc. Antenna is responsible for capturing RF signal of a particular band of interest & polarization [5]. Microstrip antennas are utilized in a variety of applications, including high data rate Personal Area Networks, cognitive radio systems, medical imaging, and radar imaging [6]. As such, the main challenge in designing antennas is to create a design that has both a good gain-bandwidth characteristic and a small size and cost. Recent advancements have seen the development of several broadband antenna designs [7]. In this paper, a new design for a concentric circular antenna array with a promising result has been introduced. It exhibits a gain with maximum value of $15.8\ dBi$, and broad band with percentage bandwidth of 33.33%. The paper introduced a simple monopole antenna with a rectangular patch on a Roger 5880 substrate. This monopole antenna can capture energy at the 2.4 GHz WI-FI band.

II. Proposed Antenna Design

The concentric antenna array design is based on a single element design that is based on rectangular microstrip patch antenna over a concentric circular of Roger 5880 substrate with relative permittivity $\varepsilon_r = 2.2$, thickness h = 3.18 mm, and loss tangent of δ = 0.0009. The dimension of the antenna is shown in Fig. 1 and Fig. 2 shows the front and back view of the antenna element.

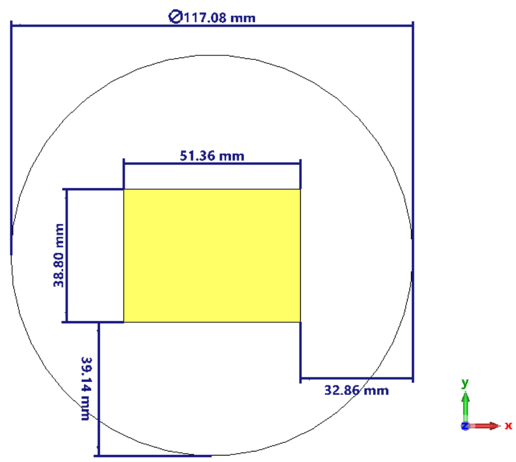
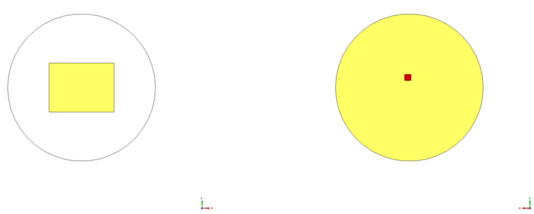


Fig. 1. Dimensions of the proposed single element antenna.



(a) (b)

Fig. 2. (a) Front and (b) back design of the antenna element.

Doi: 10.21608/erjeng.2023.237512.1253

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ISSN: 2356-9441 https://erjeng.journals.ekb.eg/ e ISSN: 2735-4873

The simulated scattering parameter $|S_{11}|$ of the antenna is shown in Fig. 3, the single element provides a promising result at the resonant frequency $f_o = 2.4\ GHz$ where $|S_{11}|$ is below $-25\ dB$.

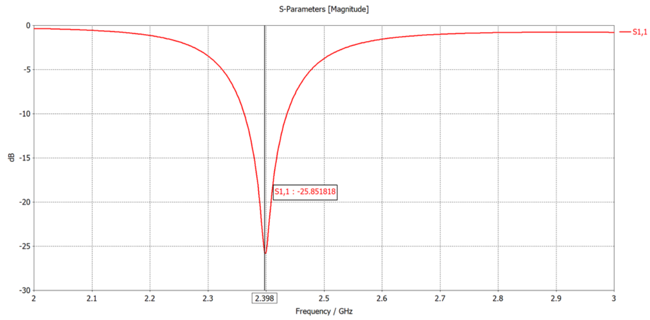


Fig. 3. Simulated scattering parameters $|S_{11}|$ of the designed single element antenna.

The single antenna provides a gain of $8.22\ dBi$ at $f_o = 2.4\ GHz$ according to far field results shown in Fig. 4.

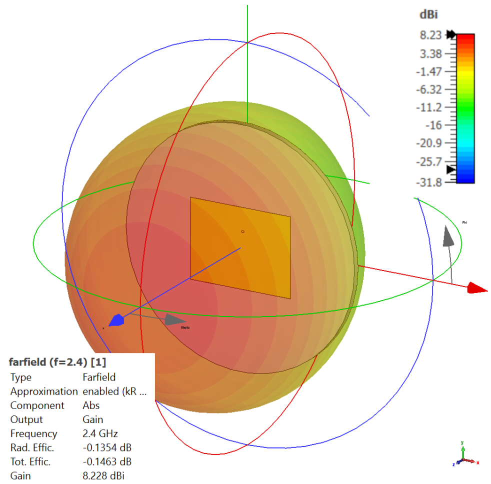
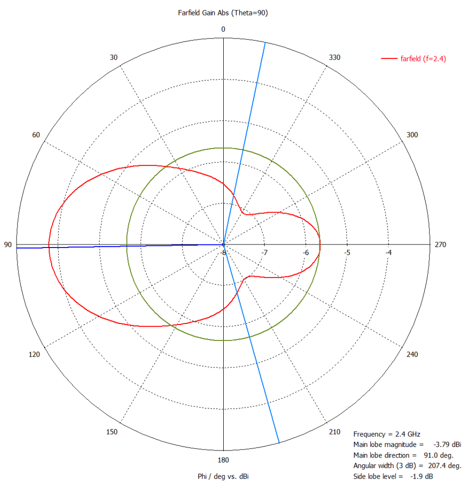
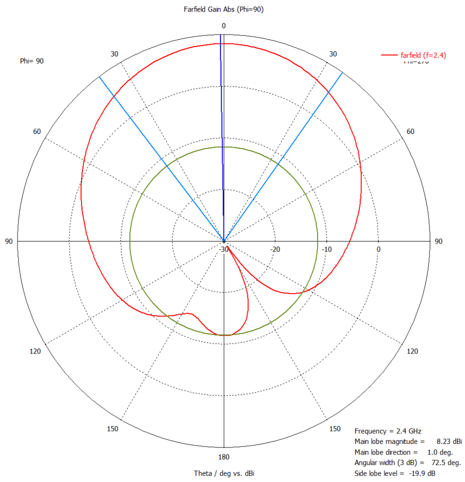


Fig. 4. Simulated scattering parameters $|S_{11}|$ of the designed single element antenna.



(a)



(b)

Fig. 5. (a) E-plane and (b) H-plane radiation patterns of the proposed single element antenna.

III. Proposed Antenna Array Design

In this section, a concentric circular antenna array is designed based on the proposed single element circular concentric single element antenna described in the previous section for Energy Harvesting application as shown in Fig. 6. The L, W, D, R, x, and y are the antenna dimensions whose values are reported in Table 1, the front and bank views of the array are shown in Fig. 7. The simulated scattering parameter $|S11|$ of the antenna is depicted in Fig. 8. It provides a promising result at the resonance frequency $f_o = 2.4\ GHz$ where $|S11|$ is below $-50\ dB$. The radiation pattern of the proposed antenna is shown in Fig. 11. Also, the radiation efficiency of the antenna is shown in Fig. 9. The entire array gain is about $15.8\ dBi$. The E-plane and H-plane radiation patterns of the proposed antenna array and 3D radiation pattern are shown in Fig. 11 and Fig. 12, respectively.

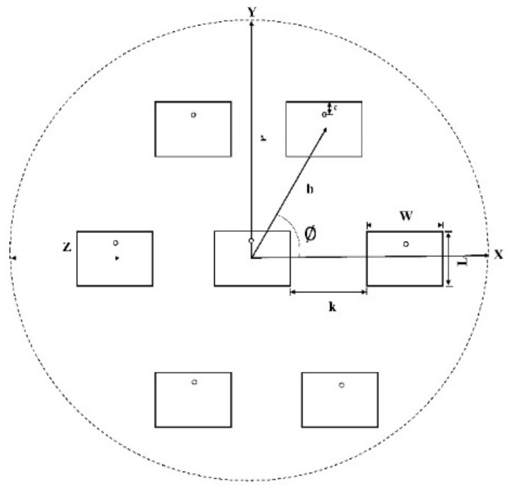


Fig. 6. Configuration of the proposed antenna array designed using the CST microwave studio software.

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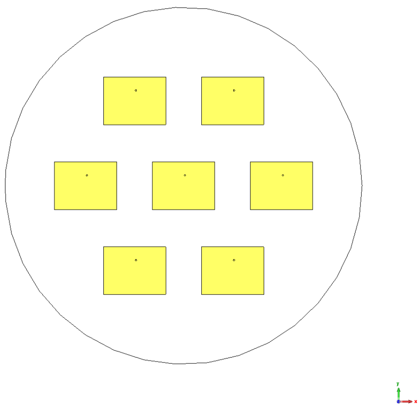
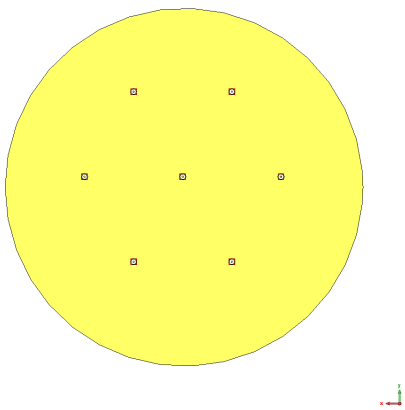
ISSN: 2356-9441 https://erjeng.journals.ekb.eg/ e ISSN: 2735-4873

Table 1. Antenna dimensions in mm.

Parameter	r	Ø	L	W	k	b	Z
Dimension	145.623	60°	38.783	50.920	33.367	84.287	61.335



(a)



(b)

Fig. 7. (a) Front view, and (b) back view of the proposed antenna array.

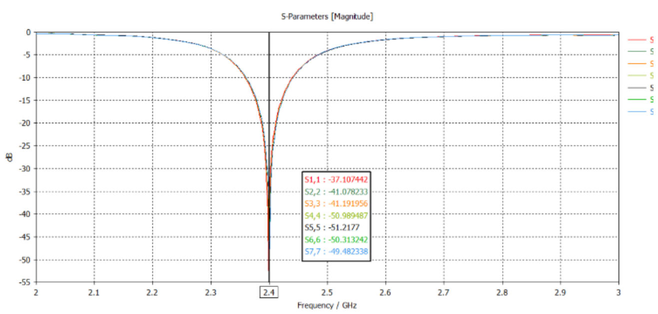


Fig. 8. Simulated scattering parameter $|S_{11}|$ of the designed antenna array.

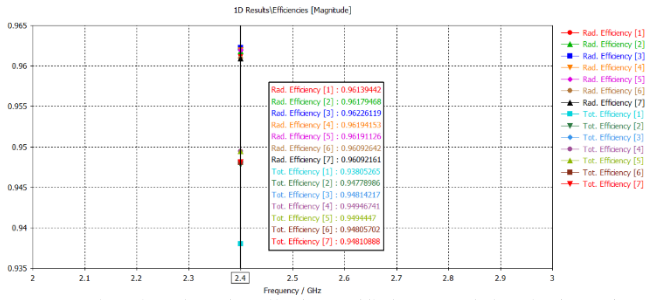


Fig. 9. The simulated radiation efficiency of the designed antenna array.

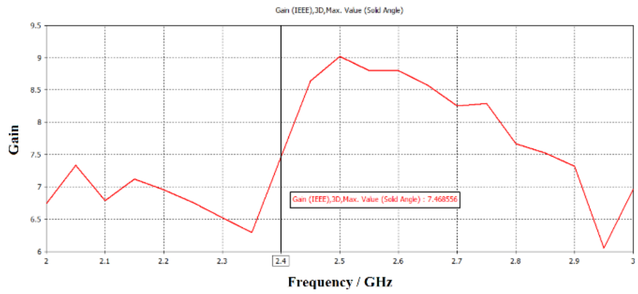
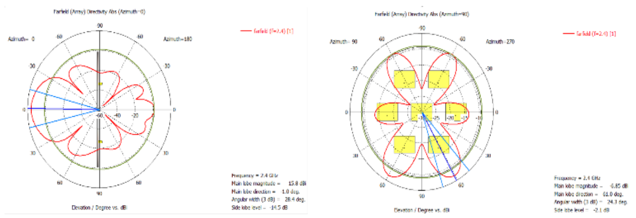


Fig. 10. Antenna array gain versus frequency.



(a) (b)

Fig. 11. (a) E-plane and (b) H-plane radiation patterns of the proposed antenna array.

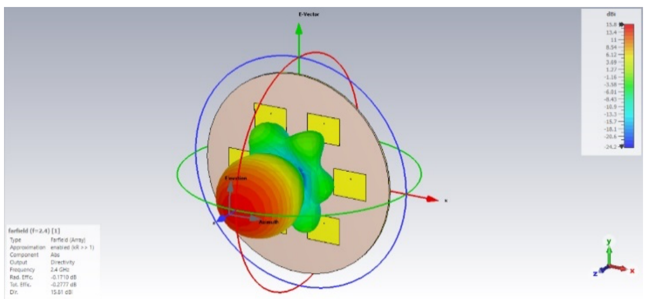


Fig. 12. 3D radiation pattern of the antenna array.

IV. Conclusion

In this paper, a small antenna array with rectangular radiating patch and defected ground structure for radio frequency energy harvesting is introduced. The antenna power capturing ability is significantly increased, and the maximum allowable antenna gain is also increased up to $\mathbf{15.8}\ \boldsymbol{dBi}$ which is 2.1067 times greater than the gain of the single antenna element. In addition, the designed antenna exhibits 51% to 95% radiation efficiency over the operating

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ISSN: 2356-9441 https://erjeng.journals.ekb.eg/ e ISSN: 2735-4873

frequency range. Good return loss and radiation pattern characteristics are obtained in the frequency band of interest. The antenna is designed using the CST Microwave Studio software using Roger 5880 substrate with $\varepsilon_r = 2.2$ and $h = 3.18$ mm. The simulation results demonstrated the effective performance of the proposed antenna array structure.

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