International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-9 Issue-2, December, 2019

Design of an Elliptical Patch Antenna for RF Energy Harvesting Application in 2.4 GHz Frequency band

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***Abstract:** In this paper, the design and prototype of an elliptical patch antenna is presented, which operates at the frequency of 2.4 GHz frequency band. It harvests energy from 'Radio Frequency' waves. The elliptical antenna has an antenna substrate made with FR4 board with dielectric constant of 3.95. The paper presents the simulation results of the basic parameters of the antenna such as: return loss, input impedance, bandwidth, gain, directivity and efficiency. The experimental results for return loss, band width and input impedance was also presented in the paper. The antenna has a gain of 5.84 dB, directivity of 6.25 dBi, return loss of -43.35 dB, bandwidth of 373 MHz, input impedance of 50.35 Ω and efficiency of 90%. The high gain, properly matched impedance for minimum return loss and high efficiency of the antenna make it eligible for energy harvesting application.*

Keywords: Patch antenna, Energy harvesting, Radio Frequency, Antenna design

I.INTRODUCTION

An investigation of remote power transmission by microwave signals was cultivated in the mid 20th Century in United States of America [1]. In the background of microwave vitality reaping framework [2-4] for low utilization remote sensors, many microwave vitality gathering framework have been practiced in most recent couple of years. The concept of energy harvesting is to get vitality from surroundings sources and convert it into a helpful structure to control any applications or store the energy for future use. In wireless (RF) energy harvesting, electromagnetic electricity from more than one sourcesobtained by way of an antenna, converts it into an electric power and use as a power source for different devices.

There are generally three factors in a regular RF power harvesting device. An antenna designed and flawlessly tuned to a specific frequency which receives signals from its surroundings,is very important for the system. Antenna converts electromagnetic waves into low power electrical indicators which will be feed to an AC to DC converter. DC voltage will be controlled by means of a controlling unit which regulates the output to the load or storage.

Revised Manuscript Received on December 30, 2019.
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With the quick development in cell correspondence and remote innovation, there has been an enormous increment in the quantity of portable base stations and WiFi routers [5]. Thus, remote Energy Harvesting from radio frequency has turned into a prevalent and dependable substitute wellspring of vitality. The essential segments of the RF vitality gathering unit are the reception apparatus and rectifier [6]. As RF energy harvesting is a wireless process the antenna is a very important part of the system. The antenna has to be perfectly tuned for the specific band. Considerable researches have been done to design specific antennas for energy harvesting. Several Designs of the antennas for the application of energy harvesting has been presented in the papers [6-11]. An array of antenna for the energy harvesting has been presented in [12]. The antenna for energy harvesting application must have high efficiency and should be compact enough to fit inside the devices from latest technologies.

The 2.45 GHz band is worldwide used for wifi purpose. This band is highly used because of its availability. The RF energy harvesting can also use the available 2.4GHz band to harvest and transfer data from wifi sources [6].

This paper is composed of three main segments. In first section, a short illustration of the design of the antenna has been discussed. Second section discusses the simulation and experimental results of the antenna. Finally, a comparison of the simulation result and experimental result was presented experimental result was presented

II.ANTENNA DESIGN

The verifiable formulas for calculation of dual resonance frequency using approximated Mathieu function [13-15] are given below.

$a_{eff} = a[1+\frac{2h}{\pi \mathcal{E} a}\{ln\ ln\left(\frac{a}{2h}\right) + (1.51\mathcal{E} + 1.71) + \frac{h}{a}(0.268\mathcal{E} + 1.65)\}]^{1/2}$ **(1)**

$f_{11}^{e,o} = \frac{15}{\pi e a_{eff}}\sqrt{\frac{q_{11}^{e,o}}{\varepsilon_r}}$ **(2)**

$q_{11}^{e} = -0.0049e + 3.7888e^2 - 0.727$ **(3)**

$q_{11}^{o} = -0.0063e + 3.8316e^2 + 1.1351e^3 + 5.2229e^4$ (4)

Where,
a_{eff} =Effectual semi-major axis,
a= Semi-major axis,
h =Height of antenna substrate,
e = Irregularity of elliptical patch,
Ɛ=Permittivity of antenna substrate,

$f_{11}^{e,o}$ =Dual-Resonance frequency,
$q_{11}^{e,o}$ =Approximated Mathieu function of the dominant (TM_{11}^{eo}) mode.

In this research, we have designed an elliptical antenna at 2.4 GHz for the application of RF energy harvesting application. Initially the antenna was designed using the CST microwave studio software. For designing the antenna substrate in CST, a rectangular box of FR4 with dielectric constant Ɛr=3.95 was used. The substrate height is 1.6 mm with respect to Z- axis. The antenna consists of the radiating element on a side and the ground plane on the other side. For designing the radiating elements of the antenna, copper was used. For more accurate simulation we have also designed the connecter using perfect electrical conducting material. The designed model of the antenna is shown in Figure. 1

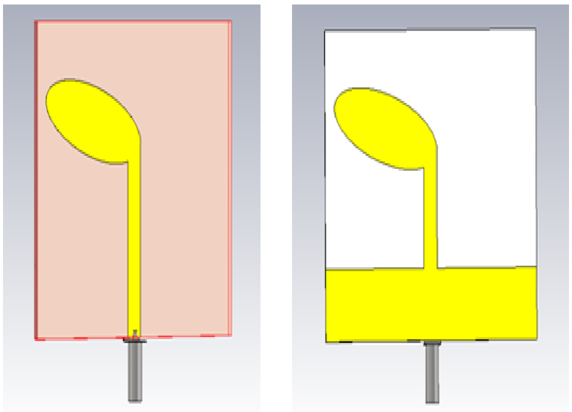

Fig. 1Front &Back vision of the designed antenna in CST microwave studio

The parameters of the designed antenna are shown in the Table 1 below.

Table. 1 Parameters of the designed antenna

Parameter	Measurement
Major axis Radius of ellipse	13.5 mm
Minor axis Radius of ellipse	5 mm
Feeding line Length	27.25 mm
Feeding line Width	3.4 mm
Width of partial ground plane	10.5 mm
Rotation angle of the ellipse	105˚
Thickness of the patch	0.035 mm
Substrate length	45 mm
Substrate width	54mm
Substrate height	1.6mm

III.RESULTS & DISCUSSIONS

4.1 Results

The basic performance parameters such as: S-parameter, impedance, VSWR, gain, directivity and efficiency of the antenna at 2.4 GHz has been analyzed using the CST Microwave Studio. The S-parameter have been also measured for the fabricated prototype (Fig.6). A comparison of the performance for the simulated antenna and the fabricated prototype has been discussed in this part of the paper.

Simulation Results

The different performance parameters of the designed antenna have been accurately observed from the CST Microwave Studio. This part of the paper illustrates the parametric results of the antenna.

S-parameter:

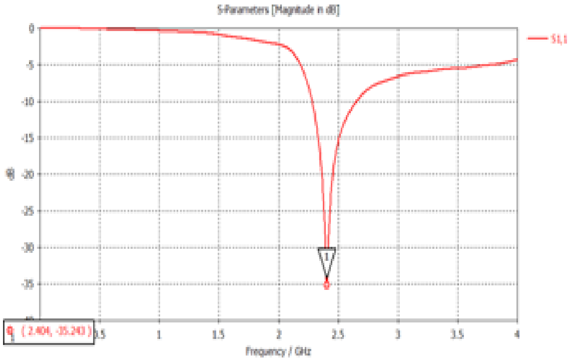

Fig. 2The return loss of the designed antenna

Figure 2shows that the designed antenna has a signal reflection coefficient of -35.243 dB at the frequency of 2.4 GHz.

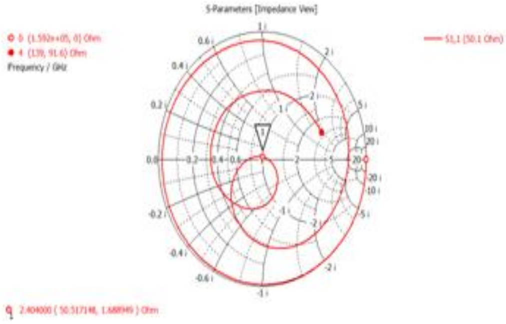

Fig. 3Impedance view of the S-parameter

From Figure 3 we can observe that the matched input impedance of the antenna is Z=(50.52+j1.69) Ω, which is a quite good match with the 50 Ω line impedance. The good matched input impedance causes the lower return loss.
Gain:

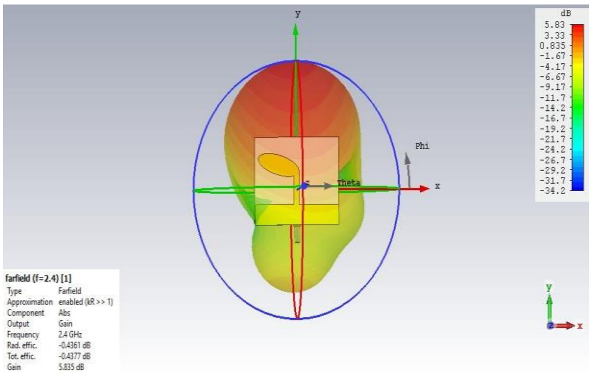

Fig. 4 Gain of the antenna

From Figure 4 it can observed that the gain of the designed antenna is 5.85 dB

Directivity:

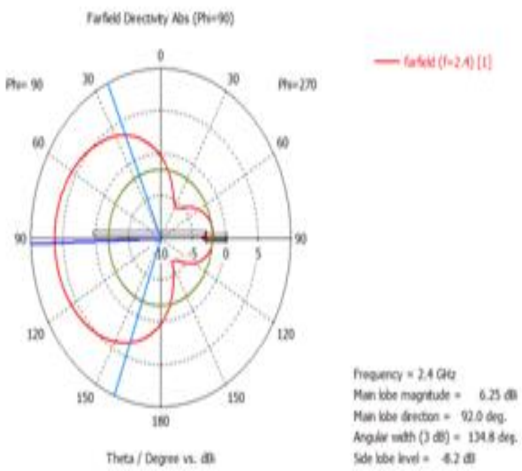

Fig. 5 Radiation pattern of the antenna in polar form

From Figure.5 it is indicated that, the main lobe of the radiation of the antenna is situated at 92 degrees in Phi plane. The dimension of the main lobe is 6.25 dBi. Angular width of the radiation is 134.8 degrees.

Parameter	Value
Resonance Frequency	2.403 GHz
Return Loss	-43.35 dB
Input Impedance	(50.35+j0.63)Ω
Band Width	373 MHz
VSWR	1.04
Gain	5.84 dB
Directivity	6.25 dBi
Efficiency	90.41%

Experimental Results:

The fabricated prototype of the antenna is shown in Fig. 6.

Fig. 6(a)Front vision of the prototype antenna (b)Back vision of the prototype antenna

The S-parameter, bandwidth and The input impedance of the fabricated prototype of the antenna were observed using a VNA.

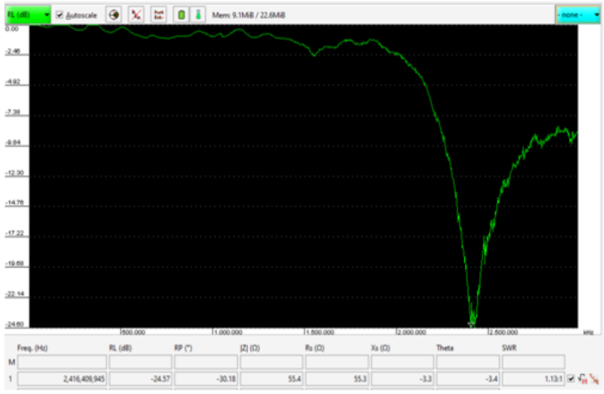

Fig. 7 The S-parameter of the fabricated antenna

The return loss of the antenna is -24.6 dB at the frequency of 2.42 GHz. The bandwidth of the antenna is 457 MHz.

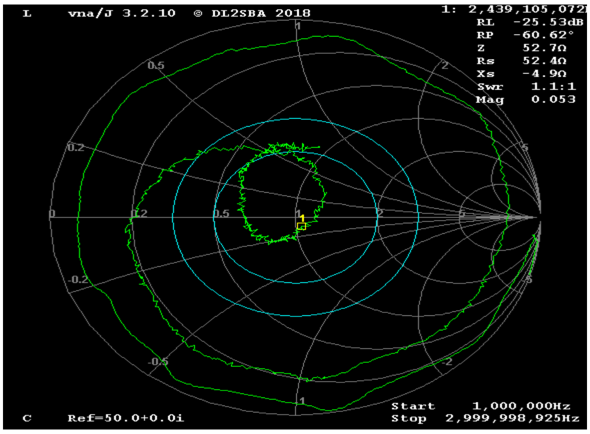

Fig. 8 Input impedance of the fabricated antenna

The input impedance of the fabricated antenna is Z= (52-j4.9) Ω, which is fairly matched with the line impedance.

4.2 Discussions

Simulated and Measured Return loss of the antenna is shown in Fig 9.

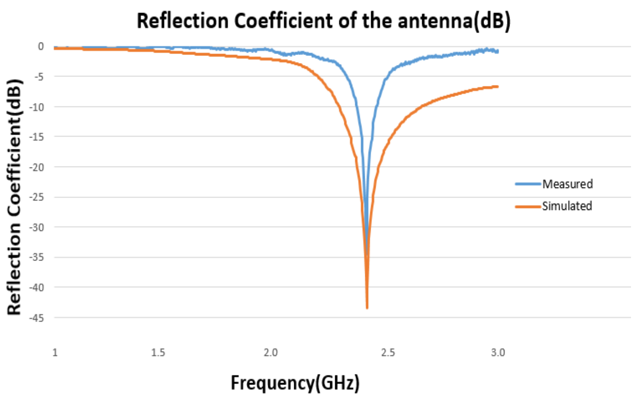

Fig. 9 Simulated and measured return loss of the proposed antenna

The comparison of the results of the simulated antenna and fabricated antenna is given in the Table 3.

Table. 3 Simulation Results of the antenna

	Resonance Frequency	S-Parameter	Input Impedance	Band Width
Simulation	2.403 GHz	-43.35 dB	(50.35+ j0.63)Ω	373 MHz
Fabrication	2.394 GHz	-34.62dB	(49-j1.5)Ω	360 MHz

The comparison exhibits little difference between the simulation and experimental results. The difference can cause by a lot of reasons. Fabrication error and mismatching loss, generated by the network analyzer can be the reasons. Also the parameter tolerance and the inhomogeneity of the FR4 board can cause the difference in the results.

IV.CONCLUSION

An elliptical shaped antenna with partial ground, which operates at 2.4 GHz frequency band is introduced in our work. Structured using a FR4 substrate with CST Microwave Studio software. The first step of the designing procedure was to tune the patch elements. The design prototype of the antenna persuades the specifications of the RF power harvesting application. The antenna gain 6.25 dBi is quite high for a single element antenna. Also, maximum −34.62 dB return loss and a 49 Ω was achieved from the fabricated antenna for highest transferred energy to the load. The antenna has a high efficiency of 90.41% For higher directivity, in future array can be made from the design.

ACKNOWLEDGMENTS

The primary work and elementary research was supported and funded by “Ministry of Higher Education (MOHE), Fundamental Research Grant Scheme (FRGS) 2015 (Flood Disaster Management)”, Grant No. FRGS/1/2015/TK06/UNITEN/02/1, entitled “Exclusively Allocated Wireless Power Transfer to Flood-Affected Areas for Emergency Needs Rapidly”. The research work is proceeding and publication is assisted by ‘Innovation and Research Management Centre, Universiti Tenaga Nasional’.

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