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Design of RF Energy Harvesting Dual Band Microstrip Antenna Using Reflector

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ABSTRACT

In wireless applications, dual band microstrip antenna plays a significant role which can resonate at two frequencies. In this work, a high gain dual band microstrip antenna with electromagnetic band-gap (EBG) structure and reflector has been proposed and designed for RF energy harvesting. The antenna has been designed both with and without reflector, and simulated in CST microwave studio which operates at 3.31 GHz and 4.85 GHz. The important parameters such as gain, and reflection coefficient have been simulated for the proposed antenna by implanting a reflecting plane at a suitable distance of 15 mm. The antenna with the reflector shows higher gain of 9.14 dBi, and 7.8 dBi at 3.31 GHz, and 4.85 GHz respectively. In addition, the equivalent electrical circuit model of the proposed antenna has been designed and analyzed numerically using MATLAB to facilitate this analysis. The response of reflection coefficient from the circuit model using MATLAB shows good agreement with the simulated reflection coefficient from Computer Simulation Technology (CST).

1. Introduction

Nowadays, the demand of wireless devices are increasing, and in daily activities it becomes an undeniable part to all [1]. These devices mostly use battery that suffers from different disadvantages like low input power, shorter lifetime, and difficulty in maintenance or replacement [2]. To overcome these hindrances, RF (radio frequency) energy can be a potential solution. Therefore, rectenna (Rectifying Antenna) has been emerged that can harvest RF energy, and can be used as a suitable replacement of battery. Rectenna comprises of two parts such as a receiving antenna and a rectifying circuit, where the receiving antenna absorbs the RF ambient energy, and delivers those energy to the rectifying circuit for maximization. Also, higher efficiency can be attained by increasing the gain of receiving antenna as given in equation (1) [3].

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$$p_{in} = p_d \frac{\lambda^2 G_r}{4\pi} \quad (1)$$

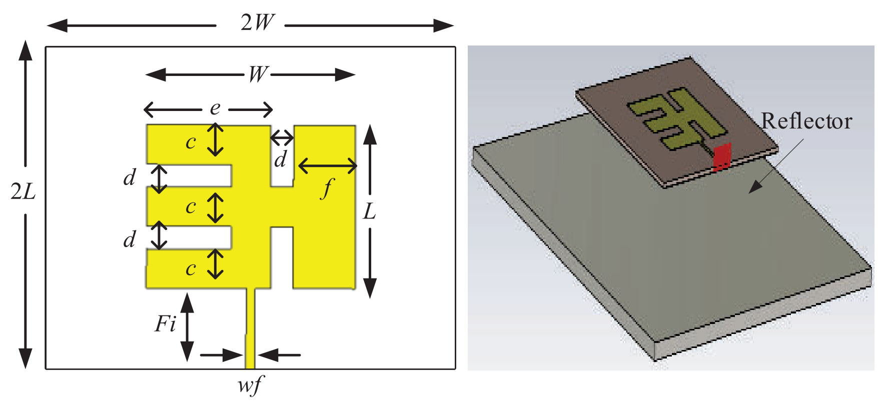
Where P_{in}, P_d, G_r, and λ are the received power, incident power density, received antenna gain by antenna, and wavelength at operating frequency respectively.

The microstrip antenna plays a significant part in wireless power transmission, and in the area of RF energy harvesting. This antenna has widely used because of its low cost, multiband facilities, and better performances. In [4], a rectangular patch antenna has been introduced at 2.45 GHz for receiving energy with a gain of 4.7 dBi. Also, WiFi energy has been harvested using a compact rectenna with a gain of 3.25 dBi at 2.45 GHz [5]. In [6], a circular patch antenna has been designed at 1.95 GHz, and 2.45GHz, and the gains are 8.3, and 7.8 dBi respectively. A compact rectenna using slot-loaded folded dipole antenna has been fabricated, and got gain of 1.87 dBi, and 4.18 dBi for 0.915 GHz, and 2.45 GHz respectively [7]. Moreover, several antennas are used for energy harvesting applications that have a gain between 3 to 7 dBi with dual frequency band [8-11]. In [12], a concentric square patch has been designed for RF energy harvesting that operates at 2.4 GHz, and 5.5 GHz, and the gains are 7.52 dBi, and 7.26 dBi respectively. Also, an aperture-coupled rectenna has been introduced for harvesting purpose with a gain 8.5 and 7.8 dBi [13]. The antenna arrays have also used to enhance the gain of receiving antennas. In [14], a planar antenna array comprising of four dipole elements has been implemented at 2.4 GHz for Wireless Power Transfer (WPT), and gets a gain of 10 dBi.

In this article, a dual band antenna has been structured with reflector to achieve high gain over operating frequencies. The antenna parameters, reflection coefficient response, surface current distribution, and antenna gain have been measured, and discussed. Moreover, the performances of the equivalent electrical circuit of the proposed antenna has been analyzed, and compared with the simulated results.

2. Geometry of Proposed Antenna

Fig. 1 shows the structure of microstrip patch antenna with EGB. Fig. 1(a) shows the front view of the radiating element, and Fig. 1(b) shows the reflector plane which has been placed at a distance of 15 mm from the ground plane.



(a) (b)

Figure 1. Geometry of proposed antenna (a) without reflector, (b) with reflector.

Here, FR-4 material has been used as substrate for the antenna with a thickness of 0.8 mm. The permittivity (ε_r), relative permeability (μ_r), and loss tangent of FR-4 are 4.3, 1, and 0.025 respectively. The dimension of the reflector used in this structure is 70 mm × 60 mm × 3 mm. The thickness of microstrip transmission line (*wf*), patch, and ground plane is 0.1 mm, and are made of copper. The designing parameters are enlisted in Table I. The initial design analysis has been performed in CST design environment.

Table 1. Antenna design specifications

Parameters	Value of proposed antenna (mm)
W	37
L	29
c	7
d	4
e	22
f	11
Fi	14.5
wf	1.568

3. Antenna Simulation and Results

Fig. 2 shows the reflection coefficient of antenna without and with reflector.

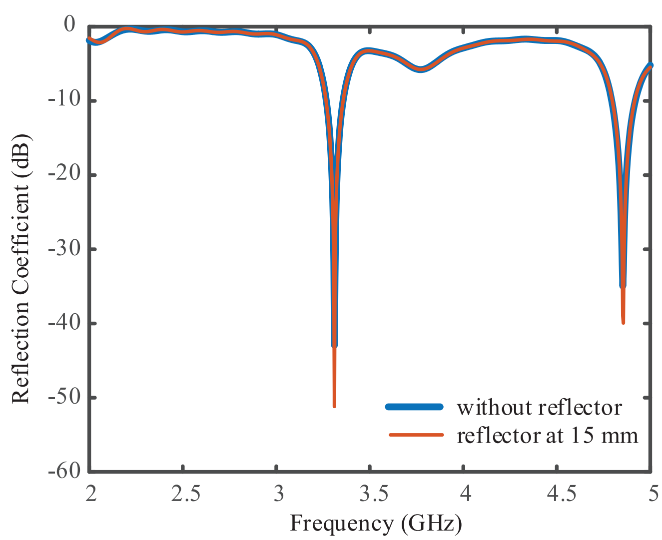
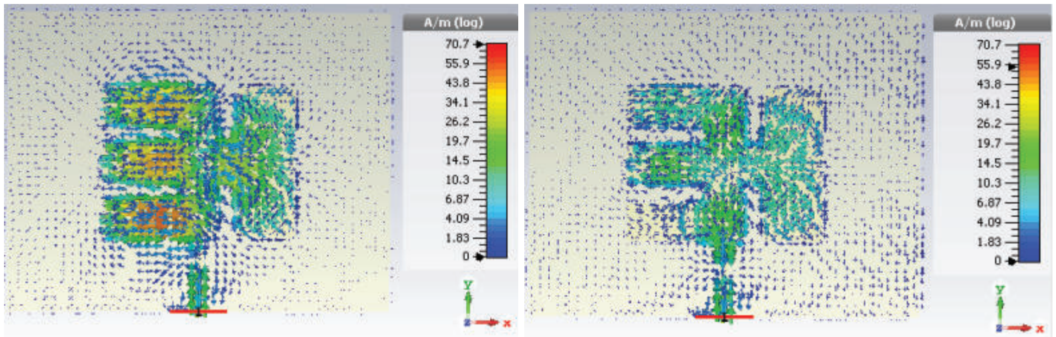


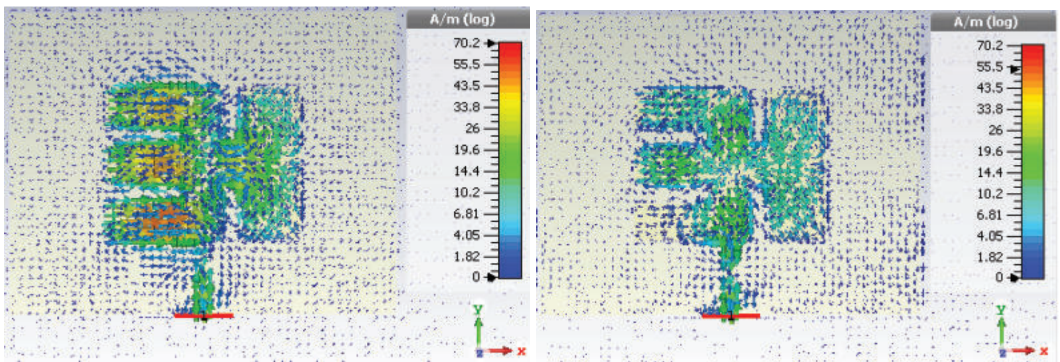
Figure 2. Reflection coefficient of proposed antenna without and with reflector.

Here, the distance between the reflector and ground plane is 15 mm which is selected by trials and error method. It is obvious that the antenna in both case (i.e. without reflector and with reflector) resonates at two frequency bands 3.31 GHz, and 4.85 GHz. In both frequencies, antenna with the reflector shows higher reflection coefficient than the antenna without reflector as well as for the antennas with reflector at other distances. The reflection coefficients of the antenna with reflector are around – 51 dB (at 3.31 GHz) and – 39 dB (at 4.85 GHz) which are 19.3% and 13.6% higher than the antenna without reflector respectively.



(a) (b)

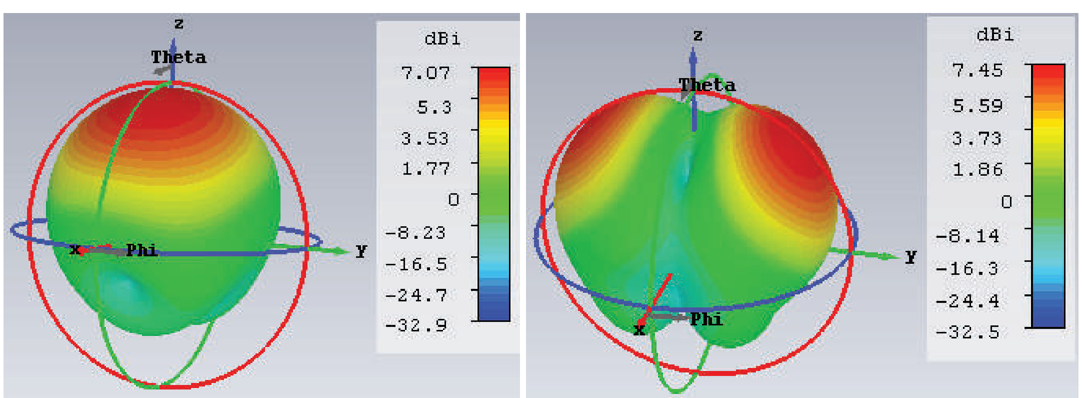
Figure 3. Surface current distributions without reflector at (a) 3.31 GHz, (b) 4.85 GHz.



(a) (b)

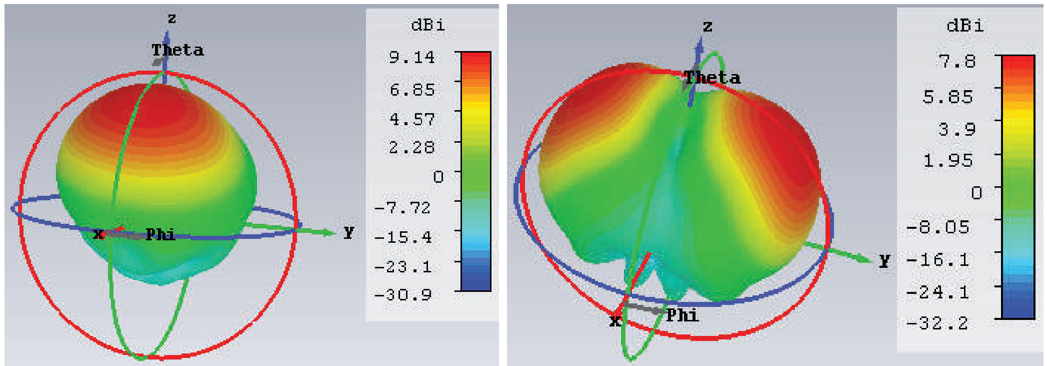
Figure 4. Surface current distributions with reflector at (a) 3.31 GHz, (b) 4.85 GHz.

Fig. 3, and Fig. 4 shows the surface current distributions at frequency bands of 3.31 GHz, and 4.85 GHz without reflector, and with reflector respectively. It is clear that most of the current at both frequencies is concentrated in the radiating element, especially at frequency 3.31 GHz. Fig. 5, and Fig. 6 shows the 3D-gain radiation patterns without, and with reflector respectively.



(a) (b)

Figure 5. Radiation patterns without reflector at (a) 3.31 GHz, (b) 4.85 GHz.



(a) (b)

Figure 6. Radiation patterns with the reflector at (a) 3.31 GHz, (b) 4.85 GHz .

Without the reflector, the gain of antenna is 7.07 dBi at 3.31 GHz, and 7.45 dBi at 4.85 GHz. But, the antenna provides an improved gain with the reflector due to the reflection of backward radiation into the forward direction. So, the resulting antenna gains with the reflector are 9.14 dBi at 3.31 GHz, and 7.8 dBi at 4.85 GHz. Moreover, it is evident that without fluctuating any frequency the gain of the antenna has been enhanced, especially at the frequency of 3.31 GHz. A comparison has been listed in Table 2 between the proposed antenna and related works. The dual band antennas in those related works provide gain from 3 dBi to 8 dBi, while the proposed antenna provides higher gain than others.

Table 2. Comparison between suggested antenna and literature works for dual-band

References	Frequency (GHz)	Types of Antenna	Gain (dBi)
[3]	1.95, 2.45	Stacked disc	8.3, 7.8
[8]	0.915, 2.45	Slot-loaded folded dipole	1.87, 4.18
[9]	2.45, 5.3	quasi-Yagi	5.7, 5.9
[10]	5.2, 5.8	Rectangular patch	4.33, 6.64
[11]	0.915, 2.45	Yagi-Uda	3, 6
[12]	2.5, 5.8	Quasi-PIFA	6.62, 6.25
[14]	2.45, 5	Coupled antenna	8.5, 7.8
This work	**3.31, 4.85**	**EGB structured patch**	**9.14, 7.8**

4. Equivalent circuit model

Fig. 7 shows the equivalent circuit model for the proposed antenna comprising of lumped elements L_1, C_1, R_1, L_2, C_2, and R_2.

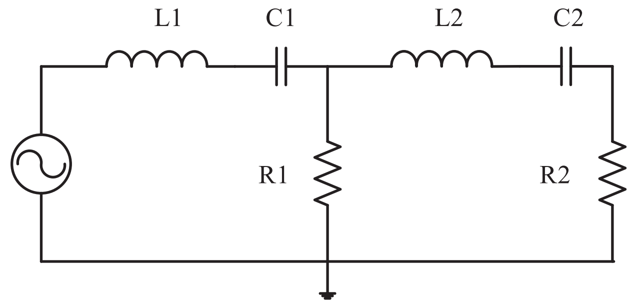


Figure 7. Equivalent lumped-elements circuit for the proposed antenna.

Here, the resistances R_1 and R_2 have been used for the radiating losses. This equivalent electrical circuit of the proposed antenna has been designed in such a way that it responses at 3.31 GHz and 4.85 GHz to an incoming RF input signal. In this model, elements L_1, C_1, and R_1 have been used for the resonance frequency of 3.31 GHz, and elements L_2, C_2, and R_2 have been used for the resonance at 4.85 GHz. The values of corresponding lumped elements are enlisted in Table 3.

Table 3. Equivalent Circuit Elements for the Proposed Antenna

Parameter	R_1 (Ω)	L_1 (H)	C_1 (μF)	R_2 (Ω)	L_2 (H)	C_2 (μF)
Value	1.18	6.26	369.32	1.33	4.23	254.36

The equivalent circuit model has been analyzed numerically using MATLAB. The response of the reflection coefficient calculated from the MATLAB platform has been compared with the reflection coefficient simulated in CST design environment as shown in Fig. 8. It is obvious that the simulated results, and the results using equivalent circuit model are in good agreement.

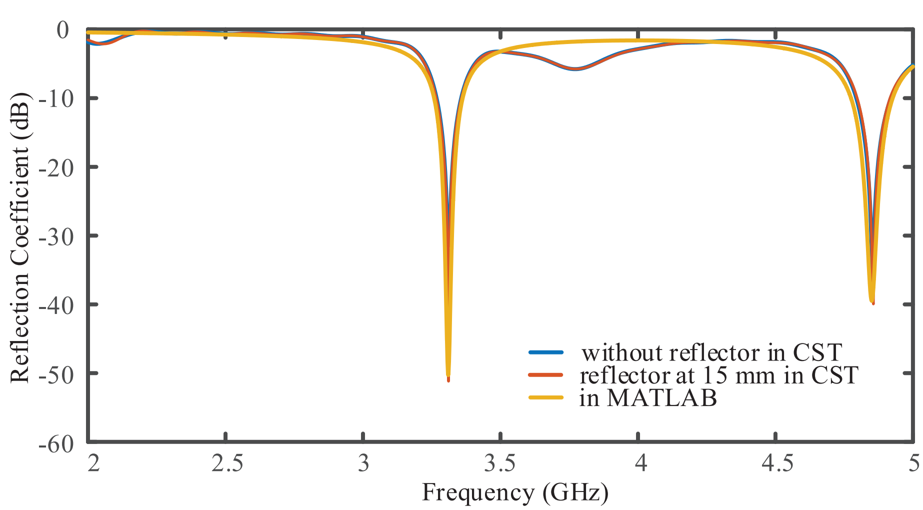


Figure 8. Comparison of reflection coefficient responses using CST and Matlab.

5. Conclusion

In this work, a dual band microstrip antenna has been successfully structured, and simulated for harvesting RF energy. The reflection coefficient of the proposed antenna has improved due to the use of reflector. Moreover, the gain of the antenna is higher than the other related works done so far, specifically at the frequency band 3.31 GHz. The equivalent lamped elements circuit model for the proposed antenna has been designed, and numerically analyzed in Matlab platform. The equivalent circuit model shows a good matching reflection coefficient response as from the proposed antenna.

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