International Journal of
Science and Engineering Investigations vol. 7, issue 79, August 2018
ISSN: 2251-8843

Circular Dual-Band Slot Patch Antenna with Defected Ground Plane for Wireless Communication

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Abstract- The focus of this paper is the design and simulation of circular dual-band slot patch antenna with defected ground plane for wireless communication at 2.4 GHz and 5.2 GHz using inset fed technique on an RT Duroid substrate (ε_r=2.2). Basic microstrip antenna (MSA) equations were used to obtain the physical parameters of the patch such as the radius, effective radius, radial length, and inset gap and the values obtained were 1.0541 cm, 1.1448 cm, 0.48915 cm and 0.26578 cm, respectively. Computer Simulation Technology (CST) Studio was used for simulating the designed antenna showing voltage standing wave ratio (VSWR) of 1.218 and 1.780, and impedance bandwidth of 69.2 MHz and 144.9 MHz at 2.4 and 5.2 GHz, respectively. The proposed antenna may find suitable applications in devices operating in the Industrial, Scientific and Medical (ISM) band as well as the wireless local area network (WLAN) band.

Keywords- *Antenna, Slot Patch, Dual-Band, Compact, Inset Feed*

I. INTRODUCTION

With the advent of advancement in the field of wireless communication, miniature antenna has gained huge popularity. This is partly due to sophistication required in modern communication gadgets which is evidenced in the rapid progress being made in various fields of technology. Most of these innovations are geared towards having a more compact, efficient, highly automated and reliable means of communication. Based on these specifications, microstrip antennas (MSAs) fit perfectly into the trend judging from its characteristics. As a matter of fact, MSAs can meet these requirements as they are lightweight and have low profile, it is feasible for them to be structured conformably to the mounting hosts. Moreover, they are easy to fabricate, have low cost and are easily integrated into arrays or into microwave printed circuits for bandwidth augmentation [1].

Due to the flexibility of microstrip antennas, multi-frequency operation is made possible. This eliminates the need for repeated design and implementation of independent antennas at different desired frequencies within a single device. Various applications require covering both transmitting and receiving frequency bands which are spaced apart. Providing multiple antennas to handle multiple frequencies and polarizations becomes difficult if the available space is limited as with airborne platforms and submarine periscopes [2]. Dual band operation can be realized from a single feed using slot loaded or stacked microstrip antenna or two separately fed antennas sharing a common aperture [3]. Before the advent of the use of slots and defected ground plane to realize dual frequency operation, single band microstrip antennas were outlined in arrays to achieve multi-frequency operation. This however had limitations like complicated beam forming or duplexing network and difficulty in realizing good radiation patterns at designed frequency bands. The second technique provides more flexibility with separate feed system as beams in each frequency band can be controlled independently. Another desirable feature of a dual band antenna is easy adjustability of upper and lower frequency bands [4].

II. REVIEW OF RELATED WORKS

Circular dual-band patch antenna has been proposed by several authors as a way of mitigating the narrow bandwidth capacity that is inherent with MSAs. The authors in [5] proposed a similar configuration to the one proposed in this paper but they used an elliptical defective ground structure (DGS) with a circular slot on the patch to taper the current and field distribution around the patch leading to dual-frequency resonation at 2.48 GHz and 5.32 GHz with a combined bandwidth of 207 MHz at both bands. [6] worked on a tunable and dual-band circular microstrip antenna with single and double stub of different length to achieve single and dual-band resonation. [7] introduced a novel dual band circular patch for wireless applications at 2.2875 GHz and 2.475 GHz, respectively. The geometry of the authors' proposed antenna is such that it has a T-shaped slot on the patch which performed within designed specifications. Also, [8-10] all proposed circular dual-band patch with similar configurations and achieved a good measure of bandwidth enhancement.

III. ANTENNA DESIGN PROCEDURE

The first step to every microstrip antenna design is to specify some parameters as stated by [11] such as the substrate to be used, the substrate height (0.1588 cm), dielectric constant of the substrate (ε_r=2.2) and the first operating frequency of the patch (2.4 GHz), respectively. The final optimization for the dual band resonation was done using CST Microwave Studio. The procedures are outlined as follows:

A. Determine the Loss due to Surface Waves

The loss due to surface waves can be neglected when h satisfies the following condition given by [12] as follows:

$$h \leq 0.3 \times \frac{\lambda_{air}}{2\pi\sqrt{\varepsilon_r}} \tag{1}$$

$$\lambda_{air} = \frac{c}{f_r} \tag{2}$$

where h is the height of substrate, ε_r is the dielectric constant, λ_{air} wavelength in free space (air), c is the speed of light = 3×10^{10} cm/s, f_r is the selected resonant frequency = 2.4×10^9 Hz, tan δ is the loss tangent, = 0.025, Z_o is the transmission impedance = 50 Ohms

Evaluating (1) and (2) given that $\varepsilon_r = 2.2$, yields;

$$\lambda_{air} = \frac{30}{2.4} = 12.5 \text{ cm}$$

$$h \leq 0.3 \times \frac{12.5}{2\pi\sqrt{2.2}} \approx 0.402 \text{ cm}$$

Hence the chosen height of 0.1588 cm is consistent with specified condition.

B. Calculate the Radius and Effective Radius of Patch

Calculate the radius, a and effective radius, a_e of the patch using equations adopted from [11] as follows:

$$a = \frac{F}{\left\{1+\frac{2h}{\pi\varepsilon_r F}\left[\ln\left(\frac{\pi F}{2h}\right)+1.7726\right]\right\}^{1/2}} \tag{3}$$

$$F = \frac{8.791\times 10^9}{f_r\sqrt{\varepsilon_r}} \tag{4}$$

In order to take care of the fringing effect which makes the patch electrically larger, the effective radius of the patch is therefore calculated to take care of this fringing thus;

$$a_e = a\left\{1+\frac{2h}{\pi\varepsilon_r a}\left[\ln\left(\frac{\pi a}{2h}\right)+1.7726\right]\right\}^{1/2} \tag{5}$$

$$F = \frac{8.791\times 10^9}{2.4\times 10^9\sqrt{2.2}} = 2.4695$$

$$a = \frac{2.4695}{\left\{1+\frac{2\times 0.1588}{\pi\times 2.2\times 2.4695}\left[\ln\left(\frac{\pi\times 2.4695}{2\times 0.1588}\right)+1.7726\right]\right\}^{1/2}} = 2.3627 \text{ cm}$$

The effective radius becomes;

$$a_e = 2.3627\left\{1+\frac{2\times 0.1588}{\pi\times 2.2\times 2.3627}\left[\ln\left(\frac{\pi\times 2.3627}{2\times 0.1588}\right)+1.7726\right]\right\}^{1/2}$$

=2.4733 cm

C. Calculate the radial distance, ρ of the patch thus:

$$\rho = \frac{2(2a)}{\lambda_{air}} \tag{6}$$

$$\rho = \frac{2(2\times 2.3627)}{12.5} = 0.75606 \text{ cm}$$

D. Calculate the width of the transmission line, W_f using equation adopted from [13]:

$$W_f = \left(\frac{2h}{\pi}\right)\times\left[\frac{60\pi^2}{Z_o\sqrt{\varepsilon_r}} - 1 - \ln\left[2\times\left[\frac{60\pi^2}{Z_o\sqrt{\varepsilon_r}}\right]-1\right] + \left(\frac{\varepsilon_r - 1}{2\varepsilon_r}\right)\ldots \times\left(\ln\left[\left[\frac{60\pi^2}{Z_o\sqrt{\varepsilon_r}}\right]-1\right]+0.39-\frac{0.61}{\varepsilon_r}\right)\right] \tag{7}$$

$$W_f = \left(\frac{2\times 0.1588}{\pi}\right)\times\left[\frac{60\pi^2}{50\times\sqrt{2.2}} - 1 - \ln\left[2\times\left[\frac{60\pi^2}{50\times\sqrt{2.2}}\right]-1\right] + \left(\frac{2.2-1}{2\times 2.2}\right)\ldots \times\left(\ln\left[\left[\frac{60\pi^2}{50\times\sqrt{2.2}}\right]-1\right]+0.39-\frac{0.61}{2.2}\right)\right]$$

$$= 0.48915 \text{ cm}$$

E. Calculate the notch width, g using equation from [14]:

$$g = \frac{c\, f_r \times 10^{-9} \times 4.65\times 10^{-9}}{\sqrt{2\varepsilon_r}} \tag{8}$$

$$g = \frac{30\times 4.65\times 10^{-9}\times 2.4\times 10^{-9}}{\sqrt{2\times 2.2}} = 0.19594 \text{ cm}$$

F. Calculate the minimum permissible length of transmission line, L_f is using the equation from [14]:

$$L_f = \frac{6h}{2} \tag{9}$$

$$L_f = \frac{6\times 0.1588}{2} = 0.48 \text{ cm}$$

A summary of the dual-band antenna design parameters after optimization in CST MW Studio is given in Table 1 and the geometry of the proposed circular dual-band antenna is given in Fig. 1 while the design of the dual-band antenna in CST Microwave Studio is given in Fig. 2.

TABLE I. SUMMARIZED DESIGN PARAMETERS OF THE PROPOSED ANTENNA

Parameter	Value (cm)
Radius, a	1.68059
Effective radius, a_e	1.74067
Radial length, ρ	0.74086
Notch width, g	0.16438
Substrate height, h	0.15880
Radius of slot on patch, b	0.50000
Length of slot on ground plane, p	0.40000
Width of slot on ground plane, v	0.20000

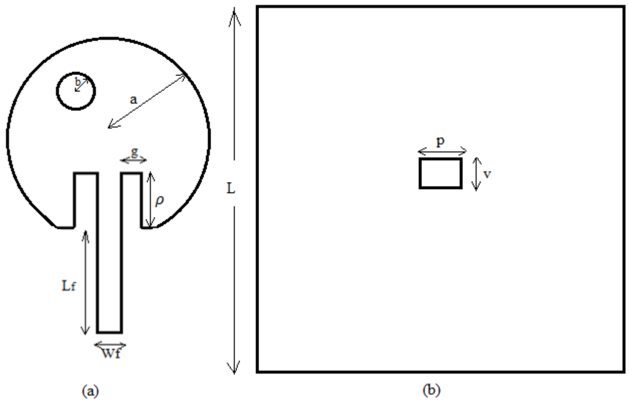


Figure 1. Geometry of the proposed dual band antenna (a) top view (b) bottom view

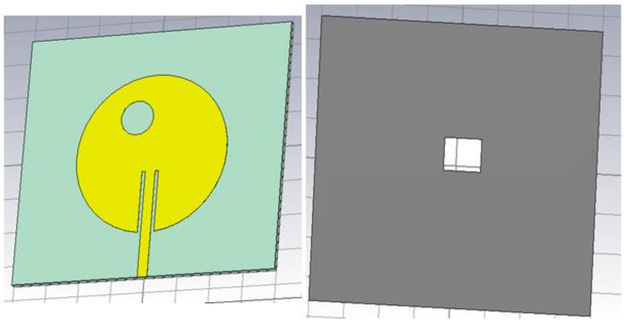


Figure 2. Top and bottom view of dual band CMSA antenna designed in CST MW studio

IV. RESULTS AND DISCUSSION

The simulation results using CST Microwave Studio are presented in Fig. 3 to Fig. 9. The return loss of the proposed antenna as can be seen from Fig. 3, shows that at -21.1608 dB, the resonance frequency is 2.4089 GHz and at -17.0214 dB the resonance frequency is 5.2129 GHz, respectively. An impedance bandwidth of 69.2 MHz at 2.4 GHz and 144.9 MHz at 5.2 GHz was realized.

The percentage bandwidth of the antenna was calculated using equation from [15] thus;

$$\text{Bandwidth at 2.4 GHz} = \frac{2.445\text{-}2.3758}{2.4} \times 100\% = 3.30\ \%$$

$$\text{Bandwidth at 5.2 GHz} = \frac{5.2874\text{-}5.1425}{5.2} \times 100\% = 2.8\%$$

Fig. 4 and Fig. 5 show the VSWR of the proposed antenna indicating that the resonated within the allowed specification for good design ($1 \leq \text{VSWR} \leq 2$). It is seen from Fig. 4 that VSWR of 1.218 at 2.4 GHz was achieved while a VSWR of 1.780 at 5.2 GHz was achieved.

The directivity of the dual band antenna at 2.4 GHz and 5.2 GHz is shown in Figures 6 and 7. From Figure 6, the Half Power Beam Width (HPBW) of the antenna at 2.4 GHz is 83.2°, main lobe magnitude and direction are 7.11 dBi and 0.0° with a side lobe level of -14.1 dB, respectively. At 5.2 GHz as seen from Fig. 7, the HPBM of the antenna is 45^{0}, main lobe magnitude and direction are 3.06 dBi and 40^{0} with a side lobe level of -2.5 dB.

Antenna gain was presented in Fig. 8 and Fig. 9; it is observed that the proposed antenna achieved gains of 6.39 dB and 6.91 dB at 2.4 GHz and 5.2 GHz, respectively.

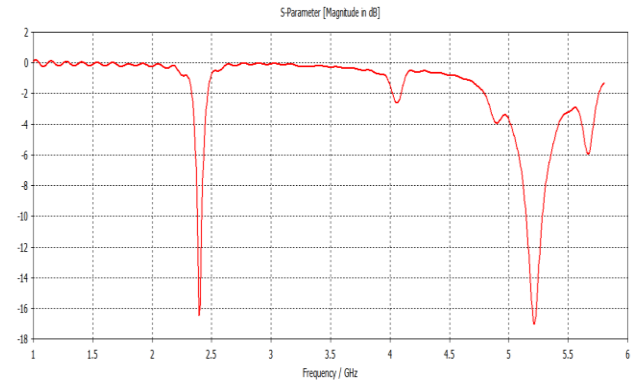


Figure 3. Return loss plot of the proposed antenna

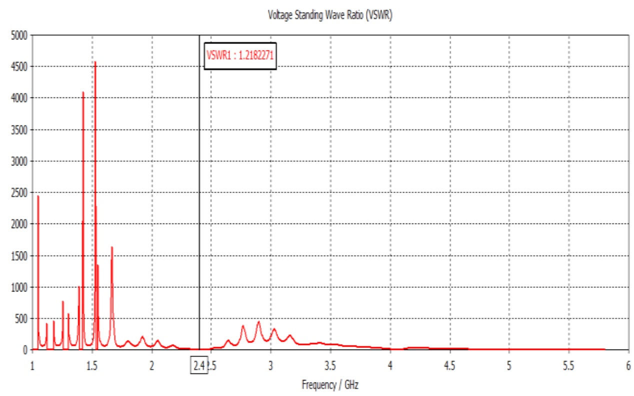


Figure 4. Voltage Standing Wave Ratio (VSWR) of the proposed antenna at 2.4 GHz

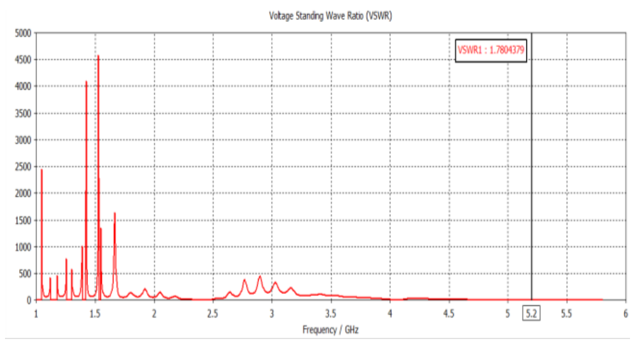


Figure 5. Voltage Standing Wave Ratio (VSWR) of the proposed antenna at 2.4 GHz

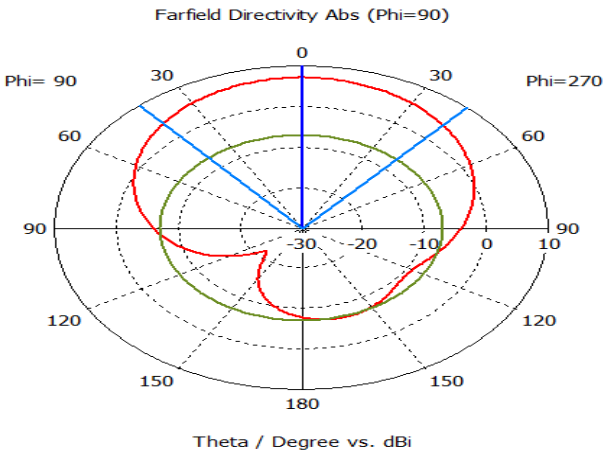


Figure 6. Directivity of the dual band antenna at 2.4 GHz

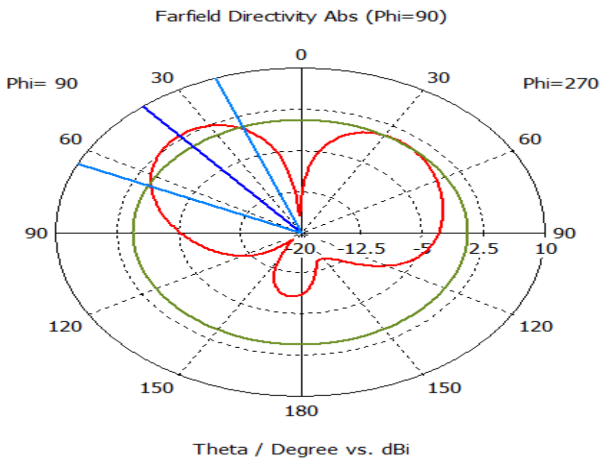


Figure 7. Directivity of the dual band antenna at 2.4 GHz

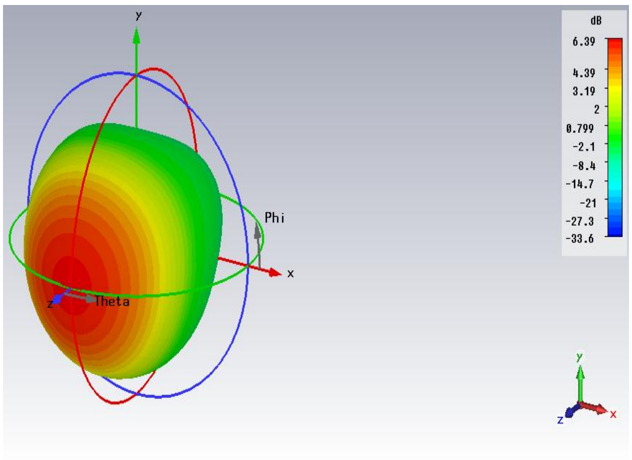
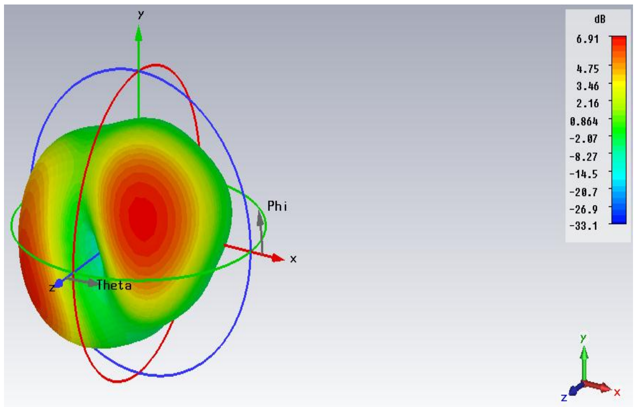


Figure 8. Gain of the proposed antenna at 2.4 GHz



V. CONCLUSION

In this article, the design and analysis of circular dual-band slot microstrip antenna for wireless communications on an RT Duroid substrate ($\varepsilon_r = 2.2$) has been presented. The structure of the proposed antenna is such that it has a circular slot on the patch and a rectangular slot on ground plane, this aided the realization of dual frequency resonation using a single patch. The proposed antenna resonated at specified frequencies of 2.4 GHz and 5.2 GHz having VSWRs within accepted limits ($1 \leq \mathrm{VSWR} \leq 2$) with gains of 6.39 dB and 6.71 dB at 2.4 GHz and 5.2, GHz respectively.

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