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Penta-band Elliptical Wide-slot antenna with Circular Parasitic Patch and two Inverted L-shaped slot for Wireless Applications

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Abstract: A new, compact microstrip-line fed antenna having elliptical wide-slot with similar parasitic patch and inverted L-shaped slot is discussed in this paper. The proposed antenna configuration consists of a 50Ω microstrip-line as a radiator that excites the elliptical wide-slot and gives the 10 dB return loss bandwidth (RLBW) ranging from 4.4 to 9.28 GHz (or 71.35%). To shift the operating frequency band towards lower side, a parasitic patch of similar dimensions is placed concentrically with the elliptical wide-slot. For incorporating the 2.4 GHz frequency band, two inverted L-shaped slots are also etched in the ground plane. Finally, the proposed antenna structure resonates in five different frequencies, i.e., 2.10-2.44 GHz (Band-I), 3.29-3.59 GHz (Band-II), 4.97-5.63 GHz (Band-III), 6.57-7.20 GHz (Band-IV) and 8.31-8.89 GHz (Band-V). The peak gain and maximum radiation efficiency in I, II, III, IV and V frequency bands is (1.93 dB, 98.26%), (6.51 dB, 97.53%), (3.17 dB, 99.41%), (3.87 dB, 98.34%) and (3.09 dB, 98.61%), respectively. All the simulations are performed using ANSYS Electronics Desktop ver. 17.0.

Keywords: Wide-slot, compact, multiband, inverted L-shaped slot, elliptical.

I. INTRODUCTION

Printed wide-slot antenna structures are gaining attention of the antenna researchers as they offer large operating bandwidth (or return loss bandwidth; RLBW), high gain and low cross-polarization [1]. The RLBW increases as the size of the wide-slot increases. But larger antenna sizes are not suited for modern wireless applications and have distorted radiation patterns [1]. Several ways of obtaining multiband or wideband operation with/without wide-slot antenna structures or by modifying the radiating structure have been already proposed in the literature. In [2], a meander line and semi-circular strip-lines are united with the microstrip line to obtain the tri-band operation, i.e., 2.39-2.52 GHz, 3.3-4.47 GHz and 5.15-6 GHz with the overall size of 23×20 mm^2. Another similar antenna with more compact dimensions of 18×22 mm^2 having inverted U-shaped strip line is proposed in [3]. The proposed antenna supports 2.4/3.5/5.2 GHz frequency bands. A dielectric resonator antenna (DRA) having cylindrical DRAs fed by using Y-shaped microstrip lines is proposed in [4] that gives tri-band operation ranging from 2.21-3.13 GHz, 3.4-3.92 GHz and 5.30-6.10 GHz. But the overall size of 50×70 mm^2 is too large for modern wireless applications. A CPW-fed dual-band antenna covering frequency range of both WLAN and WiMAX is discussed in [5]. The proposed antenna covers 2-2.61 GHz and 3.18-5.78 GHz frequency bands with size of 20×37 mm^2. Another CPW-fed tilted E-shaped antenna discussed in [6] shows quad band behaviour, i.e., 1.97-2.21 GHz, 3.20-3.60 GHz, 5.0-6.50 GHz and 6.94-9.44 GHz. But still the overall size of 50×58 mm^2 is too large to get accommodated inside the wireless devices. Also, the proposed antenna does not support 2.4 GHz frequency band applications. Another triple band CPW-fed antenna covering 2.4/3.5/5.2 GHz frequency bands is presented in [7] with more compact overall dimensions of 18×22 mm^2.

Fractal technology is highly popular for obtaining multiband/wideband behaviour due to their space-filling and self-symmetry features [8]. Multiband/wideband functionality can be introduced by either applying the fractalization process on the radiating geometry or on the ground plane. In [9], the radiating patch is fractalized by applying a Cantor set algorithm over it. The proposed antenna shows the triple band operation in 1.71-1.85 GHz, 3.3-3.6 GHz and 4.7-6.0 GHz frequency bands with overall size of 31×30 mm^2. In [10], again the radiating triangular patch is fractalized by adding a Spidron shape at one of its vertices that makes it suitable for C-, X- and K_u-band applications. In [11]-[13], the ground plane is fractalized (or defected) for obtaining the multiband behaviour. In [11], a dual-band response is reported by using a Spidron shaped defected ground structure. The proposed antenna operates in frequency range of 6.27-6.97 GHz and 15.73-19.38 GHz. A Sierpinski-knopp wide-slot structure with an inverted L-shaped strip for 2.4/3.5/5.2 GHz WLAN and WiMAX applications is discussed in [12]. The proposed wide-slot antenna possesses more compact size of 32×21 mm^2. In order to obtain the wider RLBW, a multilayer configuration is presented in [13] where a dual-band configuration is obtained by applying the non-linear manipulation on the parasitic octagonal patch used.

In this paper, a new compact microstrip-line fed elliptical wide-slot antenna with circular parasitic patch and two inverted L-shaped slots for 2.4/3.5/5.2 GHz WLAN and WiMAX wireless applications is proposed and investigated. The rest of the paper is organized as follows: Section II deals with the discussion of the proposed antenna configuration. Section 3 deals with the simulation results of the proposed antenna obtained via simulation using ANSYS Electronics Desktop ver. 17.0. The concluding remarks are given in Section IV.

II. DESIGN APPROACH

A. Design configuration

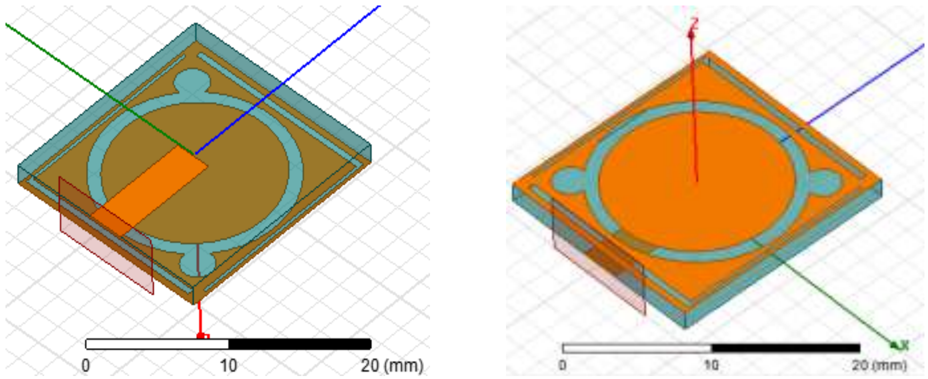
Fig. 1 shows the front and rear configuration of the proposed antenna having an elliptical wide-slot, a circular parasitic patch and two inverted L-shaped slots on both sides of the elliptical wide-slots. The proposed antenna consists of a 50Ω microstrip-line of dimensions 3×8.9 mm^2 to excite the elliptical wide-slot. The ground plane of the proposed antenna is etched with an elliptical wide-slot having a similar parasitic patch placed inside it. The overall size of the proposed antenna is 18×17 mm^2 which is compact as compared to the recently reported antenna structures. The substrate chosen for the simulation of the proposed antenna is FR-4 with dielectric constant ε_r=4.4 and thickness h=1.6 mm. Two smaller circular slots are also etched from the ground planes that help in minimizing the lowest resonating frequency of the proposed antenna.

B. Theoretical analysis and design steps

First of all, an elliptical wide-slot is etched from the ground plane which is characterized by two parameters, i.e., eccentricity (e) and semi-major axis length (D) which are related to each other by

$$e = \sqrt{1 - (\frac{b}{D})^2} \tag{1}$$

where b is the semi-minor axis length. The dual resonant frequency $f_{11}^{e,o}$ corresponding to the dominant TM_{11} mode and dimensions of an elliptical patch or wide-slot are related to each other by [14]



(a) **(b)**

Fig. 1 (a) Front view and **(b)** Rear view of the proposed antenna structure.

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

where $q_{11}^{e,o}$ is the approximated Mathieu function for even and odd mode [14]. For lower values of D, two separate frequency bands are noticed whereas for larger values, these two frequency bands eventually merge, leading to the generation of large RLBW as depicted from Fig. 2. The value of e for the elliptical wide-slot is chosen equals to 0.21.

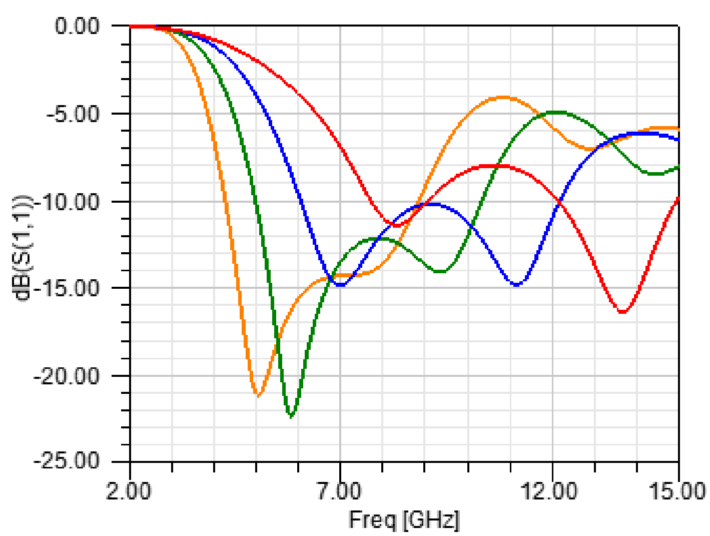


Fig. 2 Variation in reflection coefficient S_{11} for different values of D.

D=5mm, D=6mm, D=7mm, D=8 mm

It is evident from Fig. 2 that for D equals to 5 mm, two separate frequency bands are obtained whereas for D>6mm, both the frequency bands are merged and a large operating band is obtained. For D=7.7 mm, the RLBW of 4.88 GHz (or from 4.4 GHz to 9.28 GHz; 71.35%) is obtained. The lower cutoff frequency of the proposed antenna is lowered by two ways: (i) by etching smaller circular slots and (ii) placing circular parasitic patch of semi-major axis length r, placed concentrically with the elliptical wide-slot.

The variation in the matching characteristics for different values of r is shown in Fig. 3. It is clear that as the distance between the elliptical wide-slot and circular parasitic patch decreases, the resonating frequency also decreases and multiple frequency bands are obtained. This may be due to the capacitive variation between the elliptical wide-slot and circular parasitic patch.

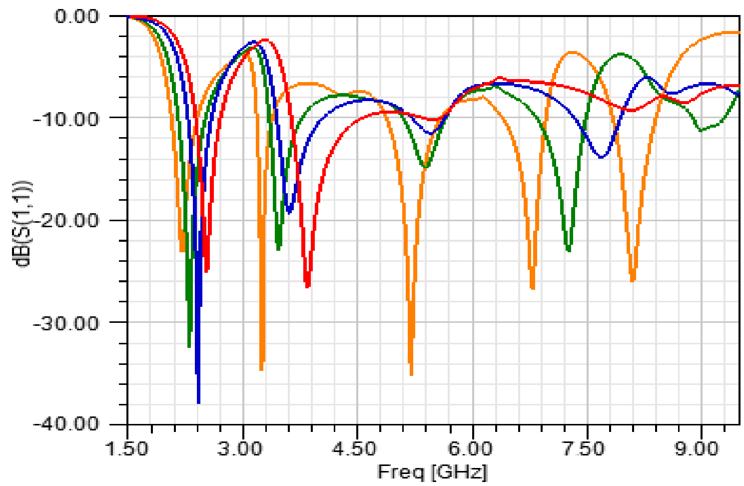


Fig. 3 Variation in reflection coefficient S_{11} for different values of r.
r=4 mm, r=5 mm, r=6 mm, r=7 mm

III. RESULTS AND DISCUSSION

A. Matching characteristics

The reflection coefficient versus frequency of the proposed antenna is shown in Fig. 4 where five different frequency bands are obtained. The five different bands are follows: Band-I (2.10-2.44 GHz; 15.0%), Band-II (3.29-3.59 GHz; 8.72%), Band-III (4.97-5.63 GHz; 12.45%), Band-IV (6.57-7.20 GHz; 9.15%) and Band-V (8.31-8.89 GHz; 6.74%). These five bands are centered around 2.24, 3.38, 5.29, 6.99 and 8.64 GHz frequency. The proposed antenna supports WLAN (2.4/5.2 GHz) and Wi-MAX (3.5/5.5 GHz) wireless applications.

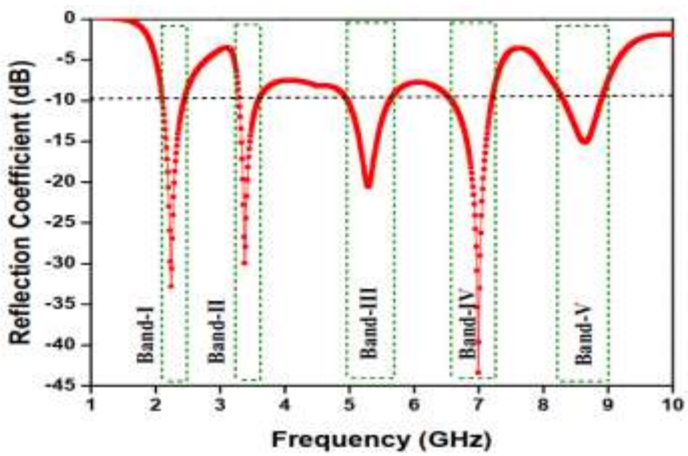


Fig. 4 Matching characteristics of the proposed antenna with five different frequency bands.

B. Gain and Efficiency characteristics

The gain variation in all five frequency bands is shown in Fig. 5(a). The gain in Band-I, II, III, IV and V varies from 5.39 to 8.99 dB, -0.84 to 4.51 dB, 0.37-4.09 dB, 1.47 to 2.11 dB and 0.03 to 1.30 dB, respectively. The average gain in all five bands is 7.12, 2.89, 1.69, 1.80 and 0.87 dB. Similarly, a good level of radiation efficiency can also be seen in Fig. 5(b). The average efficiency in all five bands is 75.07%, 81.65%, 83.73%, 90.18% and 95.45%.

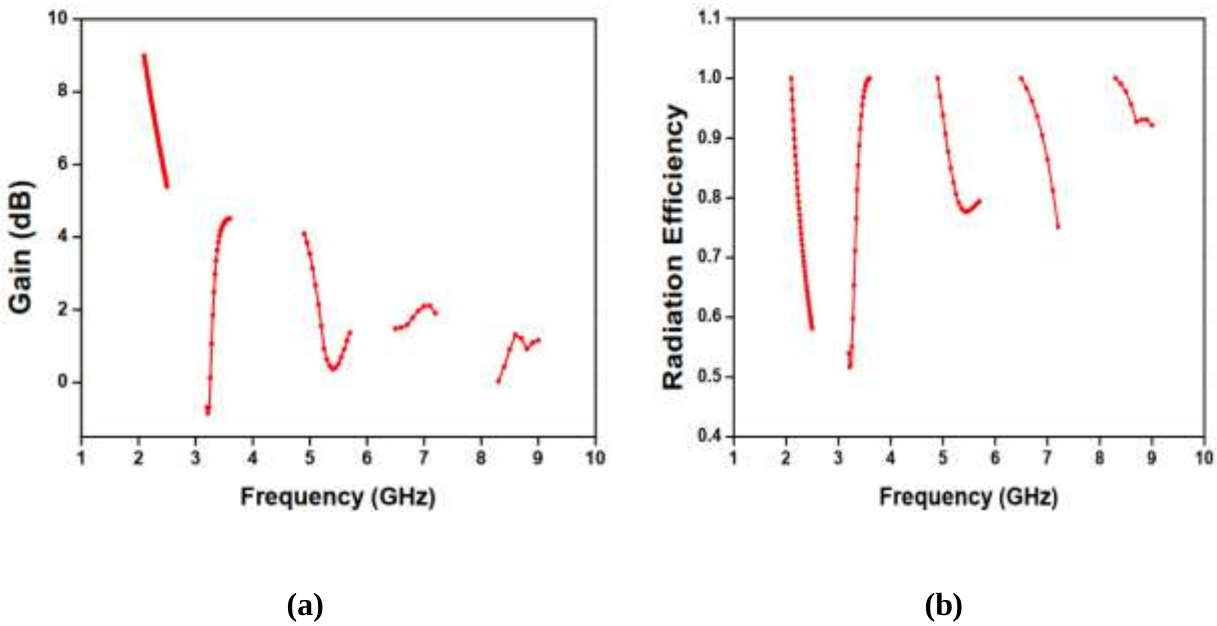


Fig. 5 (a) Gain versus frequency and **(b)** radiation efficiency of the penta-band proposed wide-slot antenna.

C. 2-D radiation patterns

Fig. 6 shows the 2D radiation pattern (both co-polarization and cross-polarization) of the proposed penta-band antenna at four different resonating frequencies. It is clear that a good level of isolation at all frequencies is obtained (difference between co-polarization and cross-polarization levels). A near omni-directional radiation patterns at all the resonating frequencies is obtained.

IV. CONCLUSION

A highly compact microstrip-line fed elliptical wide-slot antenna of size 18×17 mm^2 having circular parasitic patch and circular and two inverted L-shaped slots is designed and discussed in this paper. The proposed antenna shows five different frequency bands centered around 2.24, 3.38, 5.29, 6.99 and 8.64 GHz resonating frequencies. The proposed antenna shows a good level of gain and radiation efficiency levels in all five bands. Stable radiation patterns at all frequencies make the proposed antenna suitable for WLAN (2.4/5.2 GHz) and Wi-MAX (3.5/5.5 GHz) wireless applications.

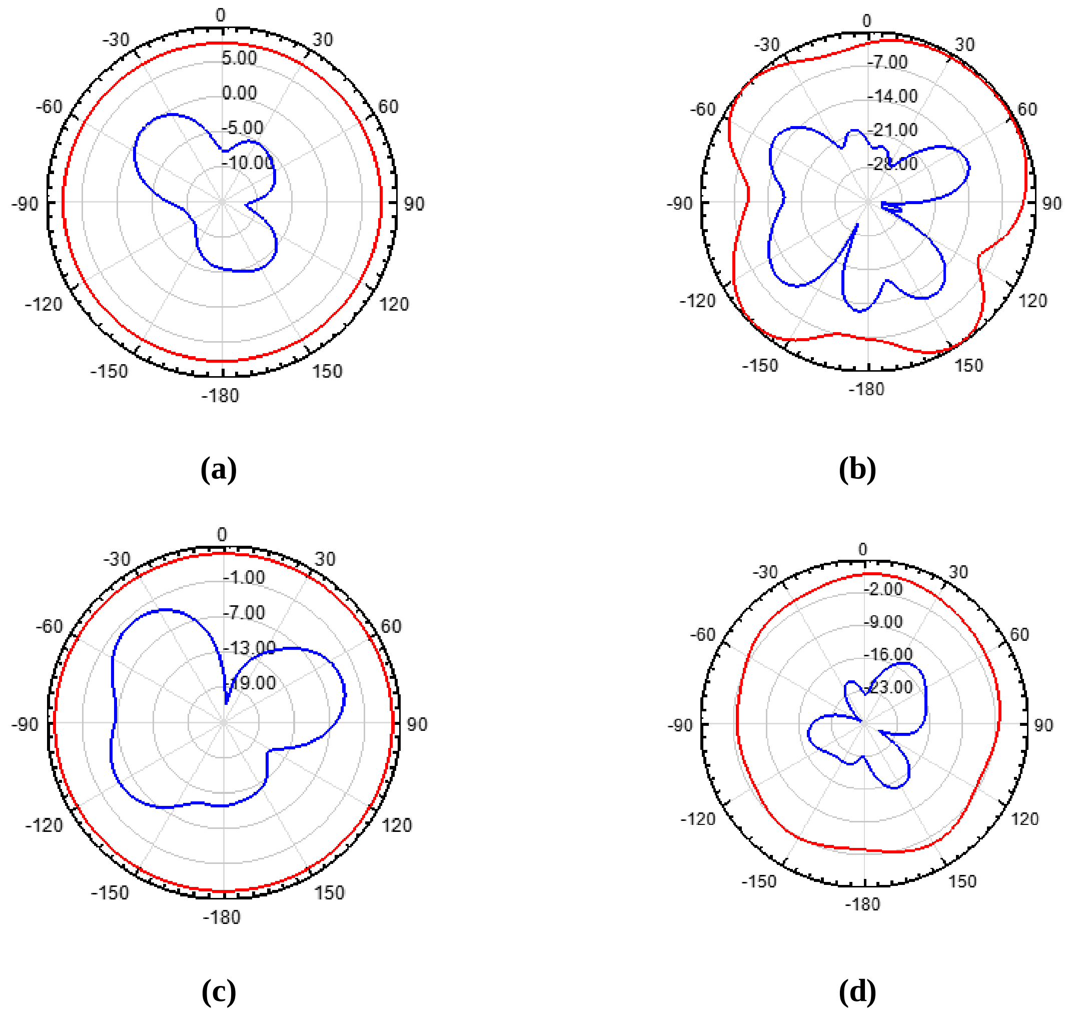


Fig. 6 2D radiation patterns at (a) 2.24 GHz, (b) 3.38 GHz, (c) 5.29 GHz and (d) 6.99 GHz.
Co-polarization Cross-polarization

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