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Tetra band inverted L-shaped planar antenna for WLAN, WiMAX, and X-band applications

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***Abstract*— A novel design for WLAN, WiMAX, and X- band applications is proposed in this paper. The proposed antenna consists of an inverted L-shaped slot with a rectangular slot in the circular radiating patch and a hexagon slot being included in the ground plane. The measured results show that the proposed structure holds the directivity of 2.02 dBi, 2.65 dBi, 4.30 dBi, and 5.52 dBi for lower WLAN, WiMAX, upper WLAN, and X-band frequency bands. The significant feature of this structure is that it can be operated in traffic light crossing detectors since it resonates at 10.4GHz in X-band. The proposed structure also exhibits Omni-directional radiation pattern with considerable measured gain in the lower and upper WLAN bands being 1.25 dBi and 3.58 dBi respectively and for WiMAX and X- band applications the measured gains are 2.09 dBi and 4.05 dBi respectively. The fabricated antenna resonates at 2.45 GHz, 3.52 GHz, 5.5 GHz, 10.4 GHz with the fractional band width of 12.65 % (2.24 GHz-2.55 GHz), 24.74 % (3.409 GHz - 4.28 GHz), 44.01 % (4.394 GHz - 6.815 GHz), 42.29 % (6.815GHz - 11.214GHz) respectively. The proposed structure having the dimensions 39mm (length), 25mm (width), and 3.2mm (thickness) is simulated with the help of CST Microwave Studio version 2010 by Finite differential time domain (FDTD) technique.**

***Index Terms*— Tetra band; planar antenna; circular patch; wide bandwidth**

I. Introduction

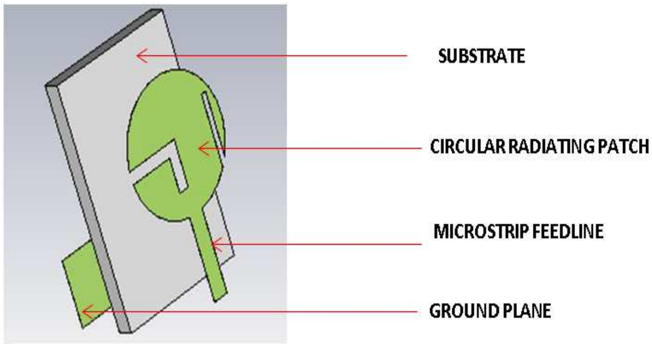
Advancement in the wireless communication technology has led to the advent and development of wireless devices like mobile phones, headphones, printers etc., and subsequently they found wide application in WLAN. It helps the users to extract their optimum performance to transmit the information in a wireless medium which becomes inevitable. The free spectrum available in ISM (Industrial, Scientific, and Medical) band increases the probability of interest in designing the antenna for WLAN applications. But designing an antenna which operates in multiple frequency bands becomes challengeable. Antenna can be designed and constructed for WLAN by using Planar Inverted-F antenna (PIFA) [1, 2] , L and U shaped slots [3], dual frequency electromagnetic bandgap (EBG) structure [4], two square shaped defected ground structure (DGS) [5], and ultra wide band rose leaf microstrip patch antenna[6]. However, designing a patch antenna for multiband operation is a trivial task.

The internet services at home, mobile phones, business plans make the WiMAX (Worldwide Interoperability for Microwave access), IEEE 802.16 one of the indispensable and inescapable wireless services. It also acts as a substitute for wired medium applications like broadband access for Digital Subscriber Link. The WiMAX operates in 3.3–3.7GHz radio frequency bands. Sectoral M-EBG antenna [7] is commonly employed in WiMAX application. A disadvantage of using sector antennas is that more wireless interfaces are needed and that interference can be a problem. Transparent antenna [8], Dual U-Shape microstrip patch antenna [9] can also be used to produce WiMAX application oriented antenna but they fail to produce X-band frequency bands. In [10], although the antenna is compact, it shows a high level of cross polarization. In [11], [12], and [13] antennas with meandered split-ring slot [11], rectangular ring and an S-shaped strip with a crooked U-shaped strip [12], and asymmetric coplanar strip (ACS)-fed structure[13], respectively, are designed to cover desirable bands. However, most of these antennas are designed for single/dual, or triple band operation. A multi resonator-loaded compact antenna for multiband operation is discussed in [14]. X-band radio spectrum lies in 8-12 GHz used in satellite communication, traffic light crossing detectors, experimentation in RF and Microwave laboratory etc. X-band patch antenna can be produced using various structures that have been explained in the literature [15-17] but these structures have failed to produce multiband patch structures and also they limit their application to X-band. The patch antenna for wireless communication can also be created with slotted [18], stacked [19], Complementary split ring [20], and also broadband and high gain antennas that have been explained in detail in [21, 22]. But these structures failed to operate in tetra band. In most cases, the size of the antenna is too large, and the antenna geometry is also complicated.

A novel design is proposed in this paper which enables the patch antenna to operate in WLAN (IEEE 802.11 a/b/g), WiMAX, and X-band frequency spectrum with desirable directivity and sufficient bandwidth. In this paper, the propounded structure is explained in Introduction in section 1, Antenna design and Parametric Analysis in sections 2 and 3 and in sections 4 and 5 presenting Results and Measurements and Conclusions .

II. ANTENNA DESIGN

The proposed microstrip patch antenna consists of three layers, namely ground, substrate, and patch stacked one above the other. The 3D view and the diagrammatic structure of the proposed antenna is illustrated in Figure 1 and Figure 2.



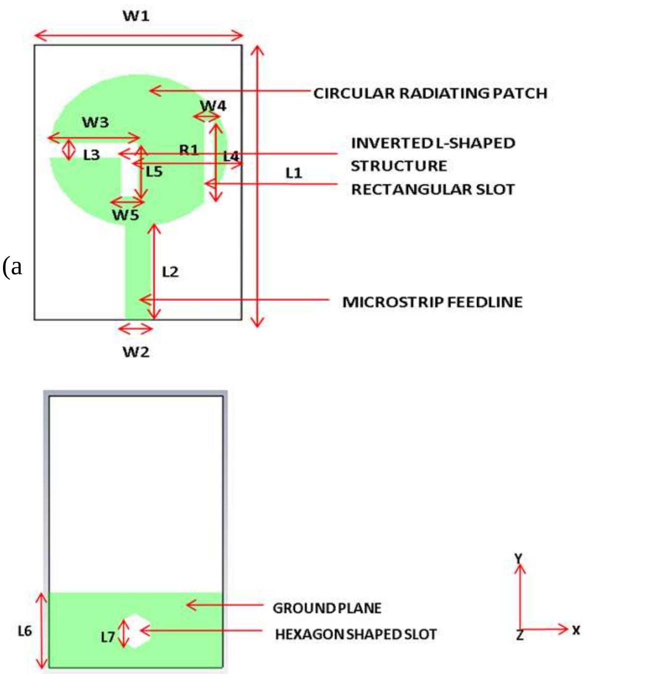


Fig. 2. Schematic structure of the circular patch antenna : (a) Top view and (b) Bottom view

The antenna was constructed using FR-4 substrate with dielectric constant (εr) of 4.4 and 0.02 of loss tangent. The substrate acts as dielectric insulator between the ground and the patch and also helps in providing sufficient mechanical strength to bear the stress and the strain faced during operation. To make the antenna operate for WLAN, WiMAX and X-band, the dimension of the substrate was chosen as L1 x W1. The length L6 for the ground plane was chosen because L6 provided considerable return loss and gain for the desired frequency spectrum of operation. The circular radiating patch rests on FR-4 substrate with the calculated radius of R1. The patch also included inverted L-shaped structure followed by rectangular slot positioned at right most corner of the patch. The inverted L-shaped structure consisted of two arms i.e., horizontal and vertical. The horizontal arm of L3 x W3 was so chosen as to make the structure operate at X- band and lower WLAN frequency spectrum. The vertical arm of length L5 and width W5 account for the operation of antenna in WiMAX spectrum. The rectangular slot of L4 x W4 enables the microstrip patch structure to work in the upper WLAN frequency bands. A hexagon slot is provided at the ground plane which tunes the frequency of operation of the proposed antenna. The size of the hexagon slot increases as L7 increases which in turn affects the return loss of the antenna. The microstrip feed line measuring L2 x W2 was so chosen as to achieve the impedance matching .The interspace between the circular patch and the ground plane also affects the |S11| of the structure.

III. PARAMETRIC STUDY

The parametric analysis was done with the help of microwave studio developed by computer simulation technology, version 2010. The analysis was performed on various lengths of the horizontal arm of the inverted L-shaped structure (L3), width of the vertical arm (W5), and width of the rectangular slot (W4). The results of this analysis helped in obtaining the optimum values of the structure.

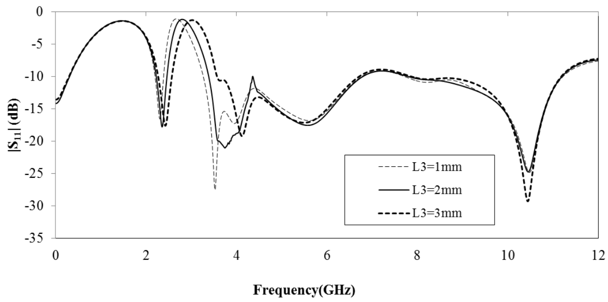


Fig. 3, $|S_{11}|$ plots for various values of L3

Figure 3 shows the |S11|, return loss plot for different values of L3, which is the length of the horizontal arm of the inverted L- shaped slot. From the plot it is evident that at length L3=2 mm desired resonant frequency is achieved which enables the antenna to work in a multiband spectrum. On variation, it is observed that there is a significant shift in the resonant frequency of WiMAX as values deviate from 2mm.

Figure 4 explains the results of parametric analysis on different values of W5, which is the width of the vertical arm of the inverted L- shaped slot. The plot clearly shows that on varying W5, drastic variation occurs in the frequency spectrum like variation in return loss and bandwidth making the antenna operate in the undesirable frequency spectra. At W5=2mm, the antenna can produce the four different resonant frequencies which make the designed structure work effectively for upper and lower WLAN, WiMAX, and X-band applications, thus making the width of the vertical arm of 2mm optimum.

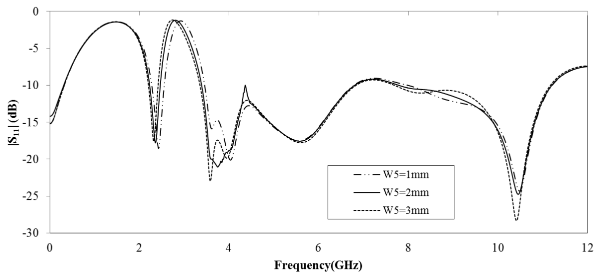


Fig. 4. $|S_{11}|$ plots for various values of W5

From Figure 5, it is evident that on varying W4, that is, the width of the rectangular slot, the resonant frequency is predominantly changed in upper WLAN and WiMAX. The bandwidth also reduces when the value of W4=1 mm increases, thus making 1mm as the value of W4 optimum. The final parameters of the antenna are listed in Table 1.

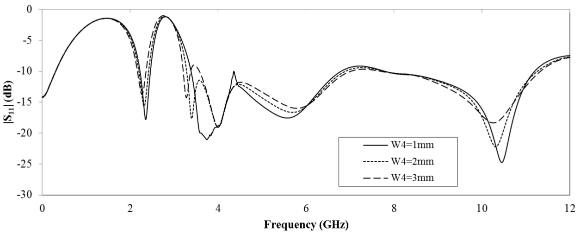


Fig. 5. $|S_{11}|$ plots for various values of W4

TABLE 1 FINAL PARAMETERS OF THE ANTENNA

Parameter	Optimum Value (mm)
L1	39
W1	25
L2	13.36
W2	3
L3	2
W3	10.75
L4	5.5
W4	2
L5	11.46
W5	1
L6	10.8
L7	2.5
R1	10.75

IV. RESULTS AND MEASUREMENTS

The proposed structure was fabricated using the dielectric substance, namely Flame Retardant (FR)-4, which was chosen as a substrate with 4.4 as relative permeability (Єr), loss tangent 0.02, and a thickness h of 3.2 mm. Figure 6 shows the photographs of the fabricated antenna.

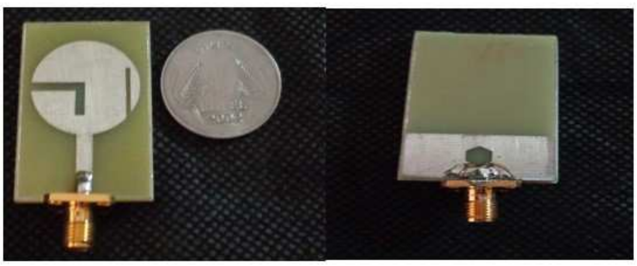


Fig. 6. Top view and Bottom view of the fabricated antenna

The return loss, fractional bandwidth, and resonant frequency were measured using vector network analyser and the radiation pattern was plotted with the help of anechoic chamber.

Figure 7 shows the simulated and the measured return loss plot of the propounded structure. From the graph the simulated antenna resonates at four different frequencies i.e., 2.35 GHz, 3.74 GHz, 5.60 GHz, and 10.43 GHz and the measured antenna resonates at 2.45 GHz, 3.52 GHz, 5.5 GHz, and 10.4 GHz which helps the proposed structure to operate in lower WLAN, WiMAX, upper WLAN, and X-band applications.

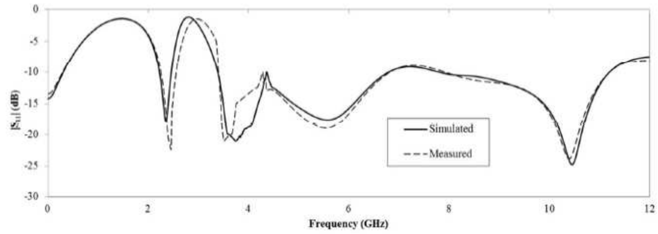


Fig. 7. $|S_{11}|$ plots for measured and simulated antenna

The simulated results explicitly show that the formulated structure resonates at 2.35 GHz, 3.74 GHz, 5.60 GHz, and 10.43 GHz with the fractional bandwidths of 9.111 % (2.2542 GHz - 2.4685 GHz) , 26.04 % (3.38 GHz - 4.355 GHz), 42.32 % (4.368 GHz - 6.74 GHz), and 33.37 % (7.727 GHz - 11.207 GHz) respectively. On measuring, the multiband compact structure resonates at 2.45 GHz, 3.52 GHz, 5.5 GHz, and 10.4 GHz with fractional bandwidths of 12.65 % (2.24 GHz - 2.55 GHz), and 24.74 % (3.409 GHz - 4.28 GHz) ,44.01 % (4.394 GHz - 6.815 GHz), and 42.29 % (6.815 GHz - 11.214 GHz) respectively. Reasonable concordance between the results of simulation and measurement has been achieved. The small variation is due to the innate fallacy of the EM simulator and measurement sufferance. The return loss (|S11|) values of the measured structure at 2.45 GHz, 3.52 GHz, 5.5 GHz, and 10.4 GHz are -21.75 dB, -20.88 dB, -18.96 dB, and -23.8 dB indicating that the structure has less effect on the reflected waves.

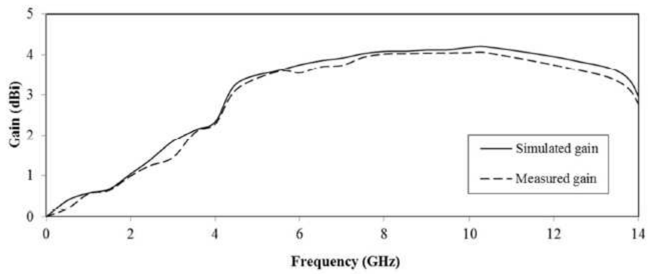


Fig. 8. Gain plot of simulated and measured antenna

Figure 8 shows the comparative graphs on gains of the simulated and the proposed structure. The simulated gains at 2.35 GHz, 3.74 GHz, 5.60 GHz, and 10.43 GHz are 1.38 dBi, 2.14 dBi, 3.60 dBi, and 4.20 dBi respectively. The measured gains are 1.25 dBi, 2.09 dBi, 3.58 dBi, and 4.05 dBi at 2.45 GHz, 3.52 GHz, 5.5 GHz, and 10.4 GHz. This helps the proposed structure to efficiently operate in lower WLAN, WiMAX, upper WLAN, and X-band applications.

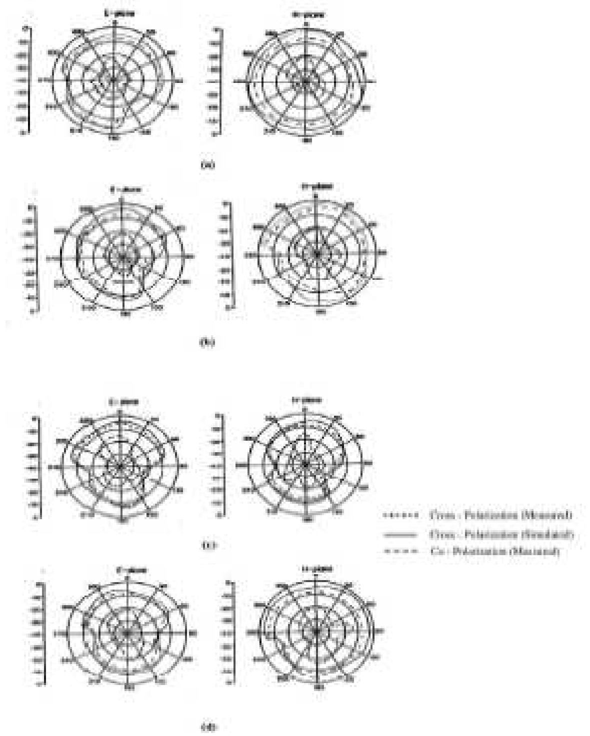


Fig. 9. Co and cross polarization at (a) 2.45GHz (b) 3.52GHz (c) 5.5GHz and (d) 10.4GHz

The measured directivity values are 2.02 dBi, 2.65 dBi, 4.30 dBi, and 5.52 dBi at 2.45 GHz, 3.52 GHz, 5.5 GHz, and 10.4 GHz respectively which indicates that the antenna can efficiently act as both transmitter and receiver. The VSWR (Voltage Wave Standing Ratio) at 2.45 GHz, 3.52 GHz, 5.5 GHz, and 10.4 GHz are 1.15, 1.05, 1.25, and 1.11 respectively. For a better operation the VSWR value should be less than 2. From the values it can be observed that the proposed structure can operate efficiently.

Figure 9 explains the co and cross polarization of the simulated and the measured patterns. From the patterns it is understood that the structure exhibits the omni-directional radiation pattern at four different resonant frequencies for lower WLAN, WiMAX, upper WLAN, and X-band applications.

V. RESULTS AND MEASUREMENTS

In this paper, a tetra band circular patch antenna has been proposed. The proposed structure consists of an inverted L-shaped structure with a slot being cut in the form of a hexagon present at the ground plane and a rectangular slot in the circular radiating patch. By increasing the thickness of the substrate from the conventional value to 3.2 mm the wide operating bandwidth has been achieved. The antenna features such as structural simplicity, low cost, wide operating bandwidth and passable gain have been achieved in the propounded design and therefore the antenna is a promising candidate for WLAN, WiMAX, and X-band applications.

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