A Compact Broadband Antenna for Civil and Military Wireless Communication Applications

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***Abstract*—This paper presents a compact broadband antenna for civil and military wireless communication applications. Two prototypes of the antenna are designed and simulated. The proposed antenna is etched on low cost substrate material with compact electrical dimensions of 0.207λ×0.127λ×0.0094λmm^3 at 2GHz frequency. The simple microstrip feeding technique and antenna dimensions are involved in the design to attain the proper impedance matching. An optimization of variables is carried out by multiple rigorous simulations. The designed antennas have achieved the broadband impedance bandwidth of 89.3% and 100% at 10dB return loss. The antennas exhibit omni directional radiation pattern at lower resonances and strong surface current distribution across the radiator. The peak realized gain of 5.2dBi at 10.9GHz resonant frequency is realized. Results reveal that the proposed broadband antenna is a better choice for WiMAX, UWB, land, naval and airborne radar applications.**

Keywords*—Compact antenna; broadband; microstrip feeding; civil and military; peak realized gain and impedance bandwidth

I. Introduction

In modern communication systems, the requirement of smart antennas is growing rapidly in the market. These antennas are economical, small in size, light weight with enhanced charactestics [1]. Recently, microstrip patch antennas with different shapes are good choice for different wireless communication systems. The narrower impedance bandwidth (BW) and larger physical and electrical dimensions are major concerns of patch antennas [2]. Therefore, antenna design engineers are working on the enhancement of important parameters of the compact patch antennas such as impedance BW, gain, stable radiation pattern and radiation efficiency.

Nowadays, researchers are paying attention on the design of simple structure antennas with enhanced features. Besides, these antennas can be used in civilian and military platforms. There are different wireless communication applications defined in the electromagnetic spectrum. These applications include WiMAX (3.5GHz-5.8GHz), H-Band (6GHz-8GHz), Ultra-Wideband (UWB) (3.1GHz-10.6GHz) and airborne, land and naval radars (8.5GHz-10.5GHz). These frequency bands are allocated for different wireless communication applications after the approval of Federal Communication Commission (FCC) [3].

Numerous studies about compact broadband antennas for different wireless communication applications have been proposed. The different shapes of radiating patch and modified ground plane were reported in [4] and [5]. Further, researchers have been proposed different techniques i.e. meta-material resonators, different shapes of slots, tuning stubs and proper selection of the feed line [6][7][8][9]. These techniques were used for the improvement in impedance BW. The existing study proposed the compact elliptical patch-based planar monopole antenna by embedding arc-shaped slot for UWB applications [10]. The Daisong Zhang and Yahya Rahmat Samii have been designed the antenna with top cross loop engraved on the compact substrate 0.345λ×0.575λ×0.02λ mm^3 at 3.43 GHz resonant frequency. The proposed antenna has achieved 91% of fractional impedance BW [11]. Another work was presented on the broadband antenna with parastic patch technique. The antenna exhibited the relative BW of 80% with compact dimensions of 0.521λ×0.521λ×0.012λmm^3 particularly at 2.32GHz operating frequency [12]. However, the designed antennas have the complex structures and larger dimensions. Moreover, Arash Valizade *et al.* demonstrated the protrude ground plane structures [13]. Jian-Feng Li *et al.* presented the idea on the isolation of antennas with T-Shaped slits in the antenna design structure [14]. Asghar Mousazadeh *et al.* presented the work on the broadband antenna with inverted L-shaped grounded strips. The antenna has the compact dimensions of 0.601λ×0.601λ×0.008λmm^3 [15]. The defected ground structure concept was utilized in [16] and [17]. Different broadband antennas were suggested in [18][19][20]. However, the employed techniques focused in the literature were complex and excessive variables utilized in the designed antennas might result in computational complexity. In the modern antenna topology, the compact size and adjustment in the designed antenna dimension in terms of variables is required. This adjustment can be achieved by electromagnetic (EM) simulation software which has the capability of the rigorous optimization.

Moreover, the authors have proposed a new palm tree structure wideband antenna. The antenna is capable to cover the 4GHz to 10.4GHz operable frequency range [21]. Kalyan Mondal *et al.* demonstrated the inverted question mark wideband antenna. The proposed antenna exhibited the good gain of 5.5dBi across the frequency span [22]. Further, the authors have presented the antennas which were capable to cover the different wireless communication applications [23].

Recently, the authors have presented the multiband antennas. The different feeding techniques were utilized and achieved the multiband characteristics [24] and [25]. A novel

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miniaturized UWB antenna has been presented. The proposed antenna has the larger physical dimensions [26]. A high gain tapered slot antenna array was reported in [27]. The authors have achieved the high gain and substantial impedance BW with Wilkinson power divider approach.

In this paper we have designed the two models of the compact antennas and analyze their performance. The antenna design topology is very simple. The proposed antenna dimensions are calculated with the standard formulation. Moreover, the parametric study of different variables has been carried out. The performance of antenna parameters at multiple resonances is observed. The simulation results of prototype-I (reference antenna) and prototype-II (proposed antenna) is compared. The broadband fractional impedance BW of 100% at 10dB return loss has been observed. Moreover, substantial impedance BW improvement of 10.7% is analyzed. Finally, the proposed antenna design achieves near monopole like stable radiation pattern, maximum gain and strong current distribution across the surface of the antennas.

The key contributions of this manuscript are explained as:

- The designed models of the antennas exhibit the broadband impedance BW, good gain, strong current distribution and stable radiation pattern across the standard planes.
- The proposed antennas possess the compact physical and electrical dimensions.

The organization of the paper is categorized mainly in five sections. The antenna layout and mathematical strategy covers in Section II. The optimization of the variables and analysis of results such as peak realized gain, return loss, radiation pattern and current distribution of the antenna is explained in Section III. Summary of proposed antenna is stated in Section IV. Future work is elucidated in Section V.

II. Antenna Layout and Mathematical Strategy

The reference and proposed antenna model and their visualization from the front, back and side view perspective are depicted in the Fig. 1(a)-(c). The antenna designs are composed of compact patch; microstrip feed line and partial ground plane (PGP). A simple shape of radiator is engraved on the top surface of thick substrate with compact dimensions 31.7×19×1.4 mm^3. Low cost FR4 Epoxy laminate is used as substrate material with dielectric relative permittivity value ε_r=4.4 and dielectric loss tangent δ=0.02. Moreover, the proposed antenna is feed by 50Ω simple microstrip feeding line. The antenna is composed of three layer sheets, i.e. the first layer sheet is dielectric substrate, the second layer sheet consists of the compact patch and feeding line etched on top of the laminate and the third layer sheet covers the PGP etched on the back side of the laminate. These all elements are made up of copper clad material. The feed line has the dimension of 16.6×2 mm^2 which have great influence to achieve the proper impedance matching. The PGP is taken as optimized value for broader impedance BW. The variables of the radiator are adopted to adjust the return loss. Moreover, L-shape slots engraved on the upper side of PGP are used to realize the improved impedance BW.

Moreover, the prototype-II of proposed antenna is depicted in Fig. 1(b). It is operated between 3.5GHz-10.5GHz centered at 6.7GHz performing the operating BW of 7GHz. It can be observed that PGP, substrate thickness and the dimensions of L-shape slots have resulted in improved impedance BW. The proposed antenna is designed and simulated by the EM solver HFSS version 13.0.

The approximated initial calculated values have been obtained from the equations explained in this section. After multiple experimental simulations the optimized values of the designed antenna are listed in Table I.

The values of dimensions of patch is calculated by the following equations (1) and (2), respectively [28].

$$L_p = \frac{F}{\left\{1+\frac{2h_s}{\pi\varepsilon_r F}\left[\ln\left(\frac{\pi F}{2h_s}\right)+1.7726\right]\right\}^{1/2}} \times 2 \quad (1)$$

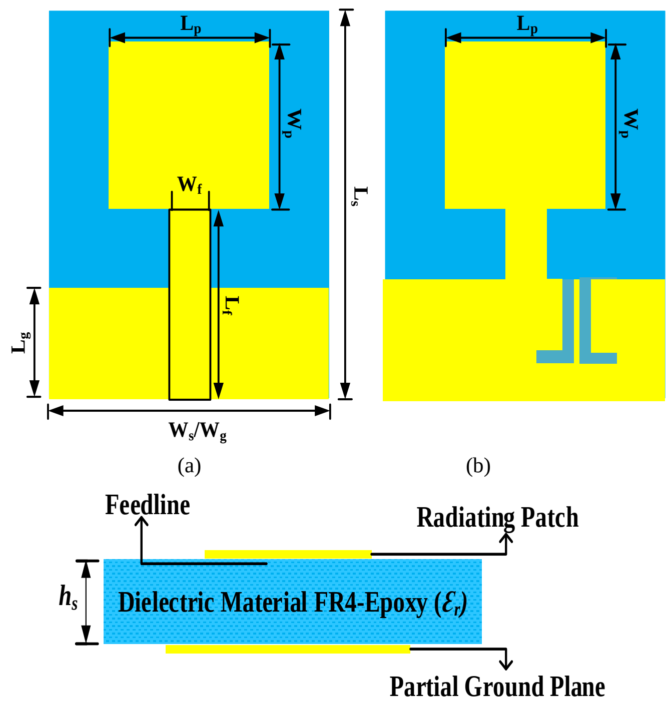


Fig. 1. (a) Top View of Prototype-I (b) Bottom View of Prototype-II (c) Lateral View of the Proposed Antenna.

TABLE. I. Proposed Antenna Defined Variables

Variable name	*Values (mm)*	*Variable name*	*Values (mm)*
L_p	9.5	L_{PGP}	14.25
W_p	9.5	W_{PGP}	19
L_{fl}	16.6	L_s	31.7
W_{fl}	2.0	W_s	19

The value of F can be calculated as follows:

$$F = \frac{8.79 \times 10^9}{f_r \sqrt{\varepsilon_r}} \tag{2}$$

In the above equations (1) and (2) variable h_s represents the thickness of dielectric substrate ε_r is relative permittivity, *F* represents the wavelength of substrate and f_r is resonant frequency.

Moreover, feedline width can be calculated by using the standard numerical equations (3) and (4), respectively [29].

$$\frac{W_{fl}}{h_s} = \frac{8e^A}{e^{2A} - 2} \tag{3}$$

Where variable A can be calculated as:

$$A = \frac{Z_0}{60}\left(\frac{\varepsilon_r + 1}{2}\right)^{1/2} + \frac{\varepsilon_r - 1}{\varepsilon_r + 1}\left(0.23 + \frac{0.11}{\varepsilon_r}\right) \tag{4}$$

Z_0 is the characteristic impedance.

III. Simulated Results and Analysis

In this section impedance matching performance related to variables used in the antenna design is explained. Moreover, the results of return loss *(S_{11})*, peak realized gain *(dBi)*, surface current distribution *(Jsurf)* and radiation pattern are also discussed and analyzed.

A. Parametric Study

This section investigates the impact of the feeding line length *(L_f)* and width of patch *(W_P)*, Effect of PGP length *(L_{PGP})* and width *(W_{PGP})*. These effects realize the matching performance of proposed antenna. Moreover, parametric study of the proposed antenna in terms of variables is accomplished by running the multiple times rigorous simulations. The effects of different values of variables are observed. Finally, the optimized values are chosen to validate the proposed antenna prototype.

1) Variation in feedline(L_f) and Patch (W_p): Microstrip feeding line is key part of the proposed antenna. The antenna radiator can be excited with the feeding line. It is very important to set the proper dimensions of feed line in order to achieve the perfect impedance matching. Fig. 2 shows the different optimetric values of feedline length ranges from 16.2mm to 16.6mm. It is analyzed that the proposed antenna achieves the good matching performance at 16.6mm value.

Moreover, the dimensions of patch also influences over the impedance matching of the proposed antenna. Fig. 3 demonstrates the variation of patch width from 9.1mm-9.5mm. It is analyzed that the optimized values for length and width of patch is achieved at 9.5mm.

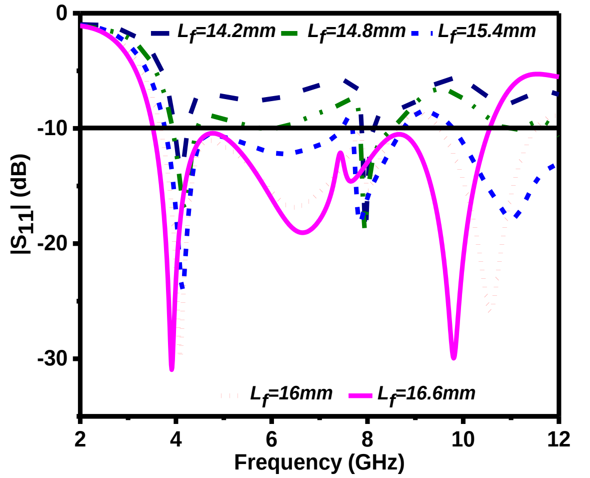


Fig. 2. Impedance Matching Analysis Related to Feed Line Length.

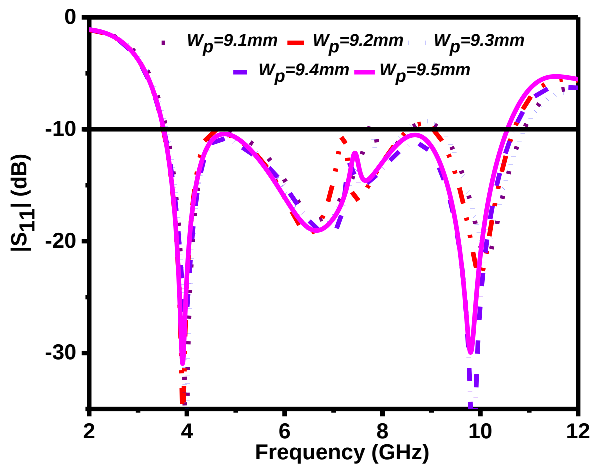


Fig. 3. Impedance Matching Analysis Related to width of Patch.

2) Variation of PGP with respect to length (L_{PGP}) and width (W_{PGP}): Length of the PGP plays a vital role to achieve broadband impedance BW. The PGP dimensions are almost half of the dimensions of the dielectric substrate. Fig. 4(a) demonstrates the optimum matched result of return loss S_{11}<10dB at 14.25mm.

Fig. 4(b) shows the optimized value of the width of PGP at 19mm. It is observed that the change in the dimensions of PGP results in the wide impedance BW and proper impedance matching**.** Finally, the simulation results of radiating patch, feed line and PGP shows the optimized antenna design geometry covers the different wireless communication application.

B. Return Loss (S_{11})

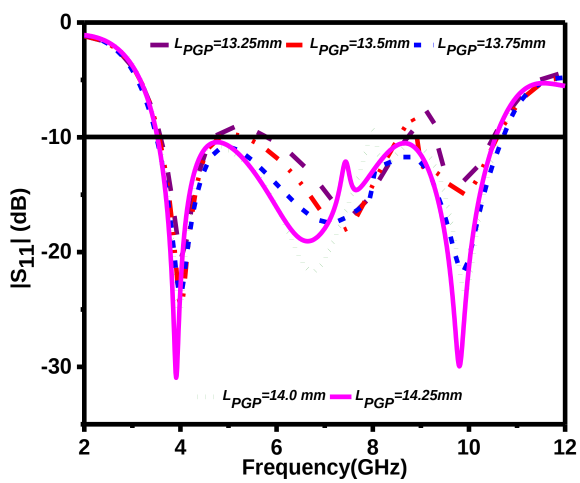
Fig. 5 delineates the return loss of prototype-I (reference antenna) and prototype-II (proposed antenna) across the operable frequency range. It is analyzed that the reference antenna achieves the broadband impedance BW of 6GHz at

10dB return loss ranging from 3.68GHz to 9.75GHz, which constitutes the fractional impedance BW of 89.3%.The reference antenna has the three resonances at 4.2GHz, 6.5GHz and 8GHz respectively. Moreover, proposed antenna achieves the 7GHz broadband BW varies from 3.4GHz to 10.5GHz which corresponds to fractional impedance BW of 100% at 10dB return loss. Furthermore, it is analyzed that proposed antenna has the three resonances at 3.9GHz, 6.6GHz and 9.8GHz, respectively.

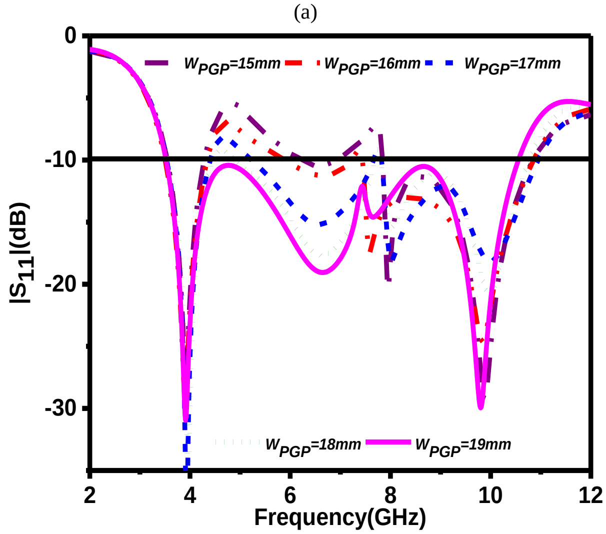
From the above analyzed results of the return loss, it is concluded that proposed antenna achieved almost 10.7% improvement in impedance BW as compared to reference antenna prototype.

C. Peak Realized Gain (dBi)

Fig. 6 shows the peak realized gain of reference antenna and the proposed antenna.It can be observed at 11.6GHz frequency reference antenna exhibits peak realized gain of 5dBi. Besides, the multiple resonances such as: at 4.2GHz the antenna exhibits the gain of 4.1dBi, at 6.5GHz the acceptable gain of 3.45dBi and at 8GHz the gain of 3.6dBi is achieved.



(a)



(b)

Fig. 4. (a) Impedance Matching Analysis Related to Length of PGP. (b) Impedance Matching Analysis Related to width of PGP.

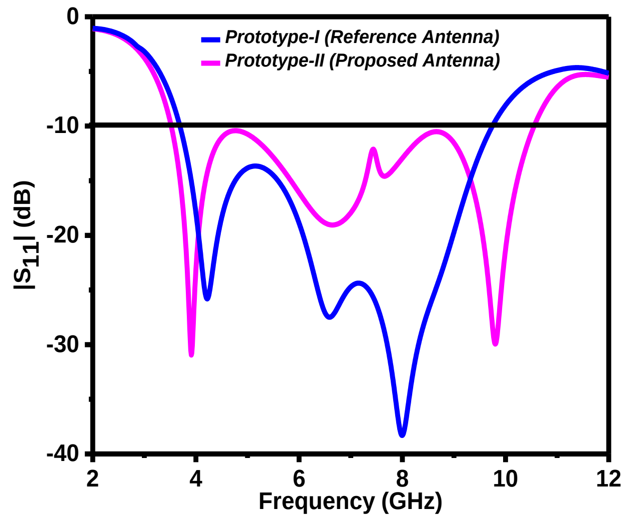


Fig. 5. S_{11} vs. Frequency Plot of Proposed and Reference Antenna Design.

Moreover, it is analyzed that the proposed antenna has achieved the high gain of 5.2dBi at 10.9GHz. However, the multiple resonances such as: at 3.9GHz, the acceptable gain of 3.7dBi, at 6.6GHz, the gain of 3.2dBi and at 9.8GHz the good gain of 4.9dBi is observed. Besides, it can also be seen that from 7.2GHz to 7.6GHz the gain is degraded upto 0.18dBi. The degradation in the gain is observed because of the L-shaped slots etched behind the feedline.

D. Surface Current Distribution (Jsurf)

The surface current distribution validates the effectiveness of proposed antenna. Therefore, it is essential to analyze a flow of current across surface of the antenna. The reference antenna current distribution simulation results are displayed in Fig. 7(a)-(c). The strong flow of current across the radiating patch, ground plane and feedline at 4.2GHz, 6.5GHz and 8GHz resonant frequencies is observed. Moreover, the proposed antenna design has almost the same current flowing effects as the reference antenna regardless of L-shape slots engraved on the conducting PGP as shown in Fig. 7(d)-(f).

E. Radiation Pattern

The 2-D Far-field radiation pattern along standard planes, i.e. E-plane (θ=0°) and H-Plane (θ=90°) of reference & proposed antenna is delineated in the Fig. 8. The reference antenna radiation pattern at multiple resonances is depicted in Fig. 8(a)-(c). It is analyzed that reference antenna possesses an stable omni directional radiation at 4.9GHz frequency, near monopole like radiation pattern at 6.5GHz and 8GHz resonant frequencies. Moreover, the proposed antenna radiation pattern at multiple resonances is illustrated in Fig. 8(d)-(f). It is analyzed at 3.9GHz frequency the proposed antenna achieved the omni directional radiation pattern. However, at 6.6GHz and 9.9GHz the radiation pattern along H-plane is near omni directional. The variation in radiation pattern is observed due to the L-shape slots inserted on the PGP. It is concluded from the above discussion that the reference antenna and proposed antenna has consistent and symmetrical radiation pattern at lower resonances and an acceptable change has been observed at higher resonances.

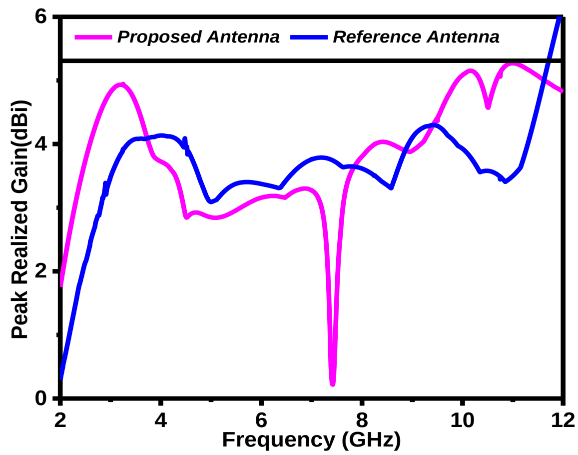


Fig. 6. Peak Realized Gain (dBi) vs. Frequency Range of Reference Antenna and Proposed Antenna.

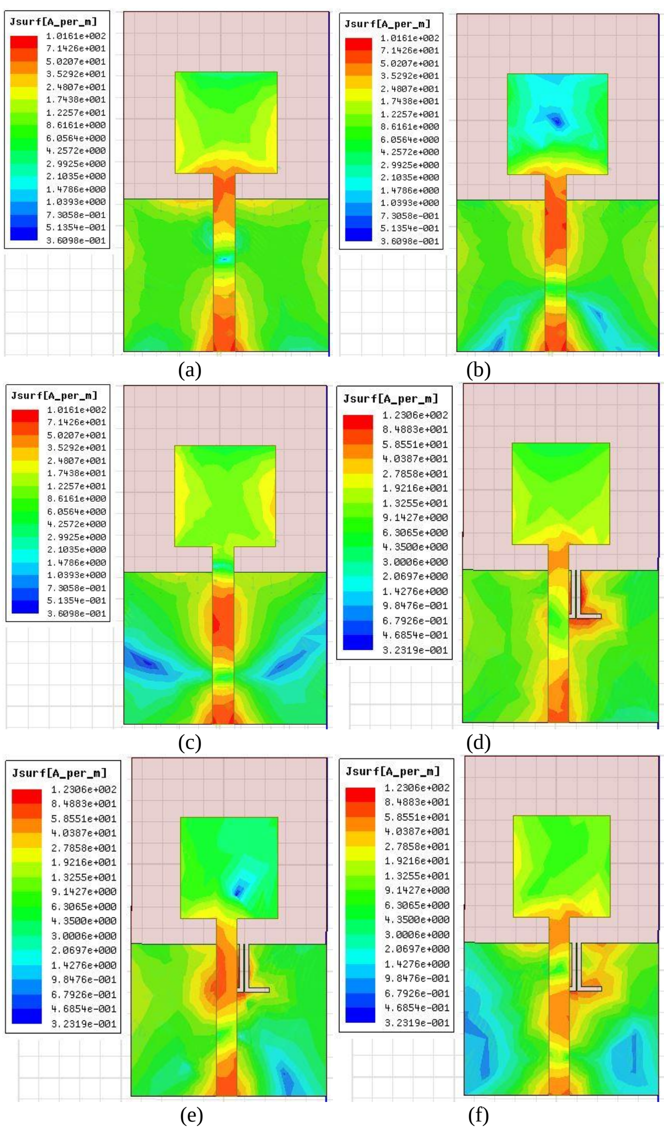


Fig. 7. Surface Current Distribution (Jsurf) of the Reference Antenna and Proposed Antenna : (a) at 4.2GHz Resonance (b) 6.5GHz Resonance (c) 8GHz Resonance (d) at 3.9GHz Resonance (e) at 6.6GHz Resonance (f) at 9.8GHz Resonance.

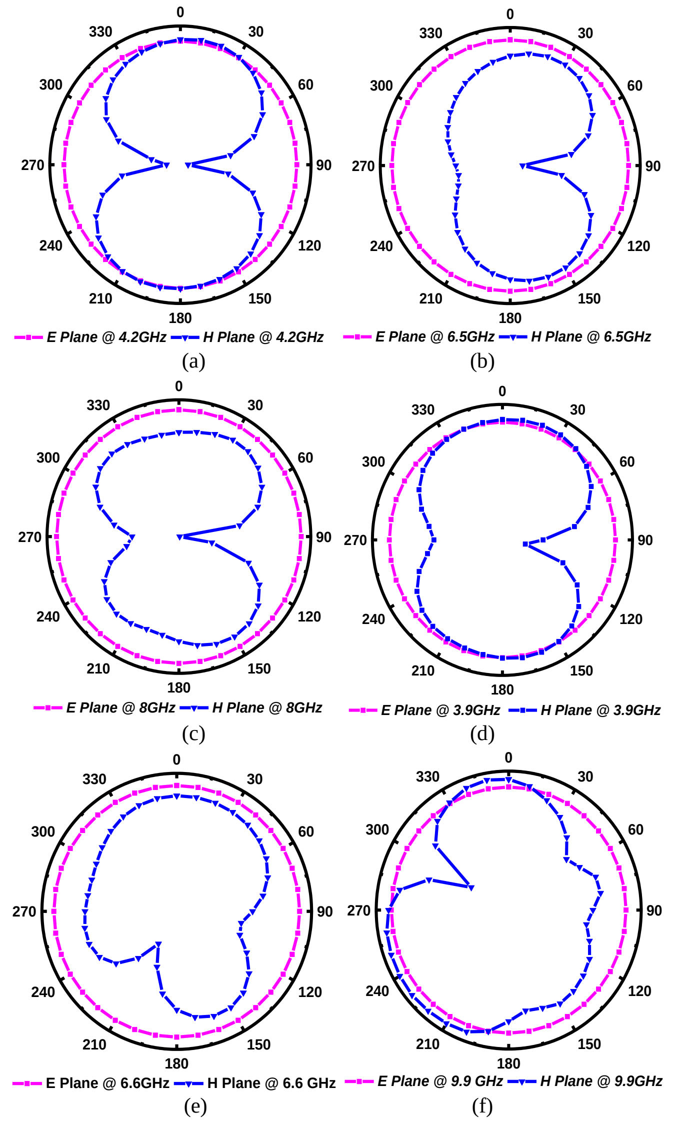


Fig. 8. Radiation Patterns at Azimuth and Elevation Plane of the Prototypes at Multiple Resonances:(a) Reference Antenna at θ=0° and θ=90°. (b) Reference Antenna at θ=0° and θ=90° (c) Reference Antenna at θ=0° and θ=90° (d) Proposed Antenna at θ=0° and θ=90° (e) Proposed Antenna at θ=0° and θ=90° (f) Proposed Antenna at θ=0° and θ=90°.

IV. CONCLUSION

In this paper two prototypes of compact broadband monopole antenna have been designed and simulated. The variables used in the designed antenna prototypes were calculated by the standard formulas. Besides, an impedance matching analysis by multiple times rigorous simulations has been carried out. The proposed antennas has been achieved the fractional impedance BW of 89.3% and 100% respectively. The designed antennas have the stable omni-directional radiation pattern at lower resonances. The peak realized gain of 5.2dBi has been observed at 10.9GHz resonant frequency. The strong visualization of current across the surface of antenna is observed at multiple resonances. The proposed antenna designs are well suitable candidate for WiMAX, UWB, land, naval and airborne radar applications.

V. Future Work

The work presented in this paper can be further extended to create the reconfigurable notch band functions at particular frequency band of spectrum. Moreover, a broadband antenna array topology will also be focused by implementing the efficient Wilkinson power divider and their performance will be analyzed in real time environment.

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