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Investigations on Ultra Wide Band Probe Fed Slotted Hexagonal Patch Antenna for Wireless Communications

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Abstract: A probe Fed slotted Hexagonal patch antenna which finds application in wireless communication is presented here. The combination of hexagon stub, feed line and hexagon shape slot are used to get an operating band of 2.7 – 11.25 GHz which is more than the UWB requirement of 3.10GHz – 10.60 GHZ. A ground plane of 34 X 29 mm size is used which is suitable for portable wireless communication devices. Three different antenna designs using the straight and rotated feed lines on RT/Duroid 5880 (with loss tangent δ=0.0004, ε_r= 2.20) and FR-4 (with loss tangent δ=0.0025, ε_r= 4.4) substrates are considered. The fundamental parameters of the antenna such as return loss and 2D Gain radiation patterns were measured and found to meet standards specified for such antennas. The antenna was designed and simulated using Ansoft HFSS15.

Key words: Finite ground plane · Ultra wide band · Micro strip · Hexagon slot · Return loss · Radiation pattern

INTRODUCTION

The frequency ranges allotted by Federal Communication Commission in 2002 for commercial ultra wide band (UWB) applications are 3.10 GHz to 10.60 GHz [1]. UWB technology is still emerging and has created wide interest in UWB antennas. Communication antennas designed for UWB applications are special due to low power and very short impulse signals, which are transmitted efficiently with minimum distortion [2]. A planar form of UWB antenna is integrated between the RF front end circuitry and the radiating structure. Planar forms of antennas can be implemented using microstrip technology, which is widely used in wireless applications [3, 4]. The major advantages of UWB systems are lower power consumption and high data transmission rate. Hence, in wireless design field UWB antenna design has gained wide attention.

Narrow impedance matching bandwidth is a major disadvantage of conventional microstrip patch antenna in spite of its small size and low weight [5]. Ultra-wide bandwidth is achieved by using coplanar wave guide feed (CPW) with different types of radiating patches such as elliptical [6], crescent patch [7] etc.. The return loss of the proposed antenna is to be maintained below -10dB throughout the entire wireless band. Also the antenna is to be miniaturized so that it could easily be integrated into modern communication systems [8-13].

In this paper, a novel planar slotted hexagonal patch antenna with the ultra wide band impedance and radiation pattern characteristics are investigated. Section II presents the related works on enhancement of the band width of UWB antennas for wireless applications. The proposed antenna design, geometry and simulation models are presented in section III. The antenna performance results are discussed in section IV. Section V presents the verification of the impedance match bandwidth in addition to the UWB antenna characteristics using a simulation study. The conclusions are presented in section VI. Ansoft Corporations Designer v15.0 and High Frequency Structure Simulator (HFSS) v15.0 are employed for obtaining the simulation results.

Related Works: Microstrip slot antenna is one form of microstrip antennas, which has omni directional radiation patterns. Microstrip line fed microstrip antennas have shown wide band and ultra wide band performances [14, 15]. A quarter wave length rectangular microstrip slot antenna fed by microstrip line provided wide bandwidths of 60% and 83% respectively [16, 17]. A detailed literature

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survey has shown that among all UWB planar antenna designs, the most suitable candidate for Ultra Wide Band antenna is microstrip slot type antennas. A bandwidth of 120% and 110% are provided by a square slot (arc on one side) with a square shape feed and a triangular slot with a triangular shape feed [18]. In [19] a tuning stub of U shape was introduced to broaden the operating band width by enhancing the coupling between the elliptical/circular slots and feed line. The UWB antennas were achieved in [20] where slot antennas with U shaped tuning stub and reflector was realized using two different two different types of the feed mechanism. In [21] a large band width from 2.6 – 15 GHz is provided by a circular slot fed by a CPW line through a polygonal patch. In [22 – 26] some other types of slot antennas have been reported.

Antenna Geometry and Design: Three different antenna designs are considered in this study. Design A : straight feed line to hexagonal patch on Rogers's RT/Duroid 5880 substrate with loss tangent $\delta = 0.0004$, dielectric constant $\varepsilon_r = 2.20$. Design B: tilted feed line to hexagonal patch on Rogers's RT/Duroid 5880 substrate with loss tangent $\delta = 0.0004$, dielectric constant $\varepsilon_r = 2.20$. Design C: tilted feed line to hexagonal patch on FR-4 substrate with loss tangent $\delta = 0.0025$, dielectric constant $\varepsilon_r = 4.40$.

The geometry of the proposed antenna with straight line feed and tilted feed are shown in Fig. 1 and Fig. 2 respectively, which consists of a hexagon shape microstrip slot and tilted microstrip transmission feed line with a hexagonal stub. The dimensions of the hexagon stub and slot are kept invariant for all the designs. The dimensions were taken after parametric study. The thickness 'h' of the substrate is kept 1.6mm for all the designs. For designs B and C, the feed line is rotated by 15°.

The antenna is fed using a 50 Ω coaxial SMA connector connected to 50 Ω microstrip transmission line. The patch and feed structure are fabricated on the same plane so that only one metallic layer is present in the design. Hence, it can be easily fabricated and has low cost.

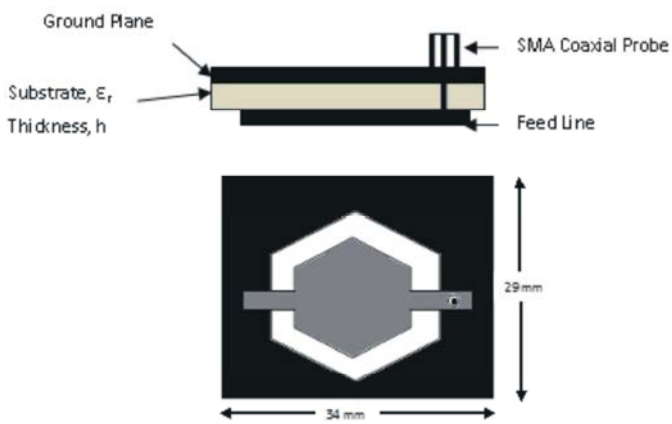


Fig. 1: The proposed Hexagon shape microstrip slot antenna with straight line feed (Design A)

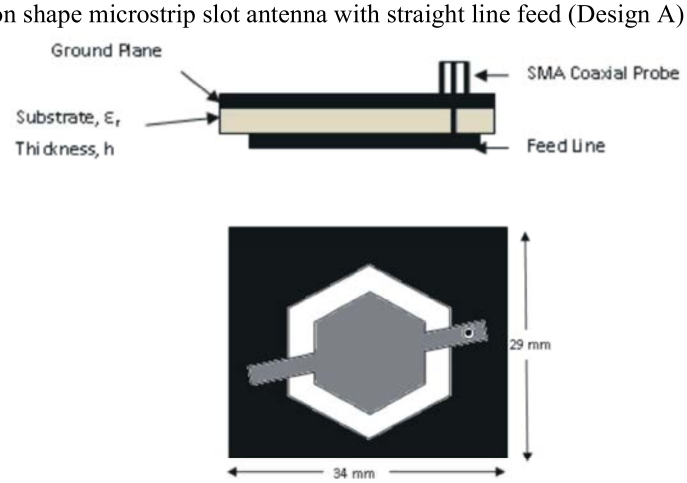


Fig. 2: The proposed Hexagon shape microstrip slot antenna with tilted feed line (Design B and C)

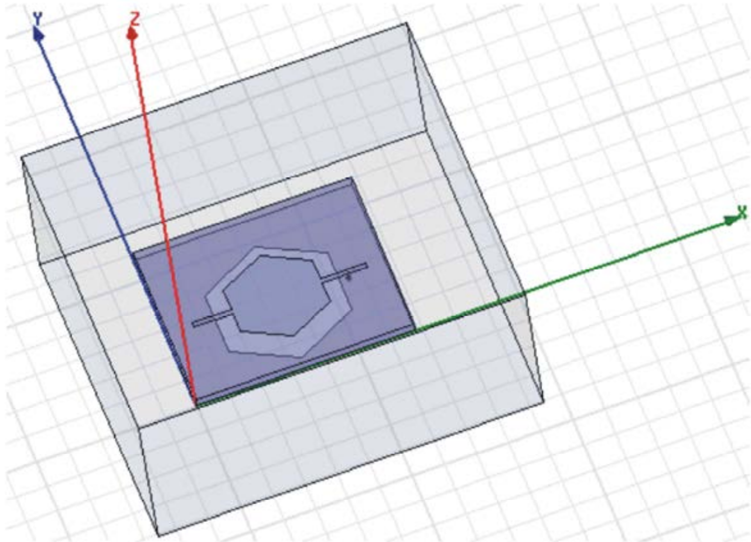


Fig. 3: Radiation setup of the antenna Design A (straight line feed)

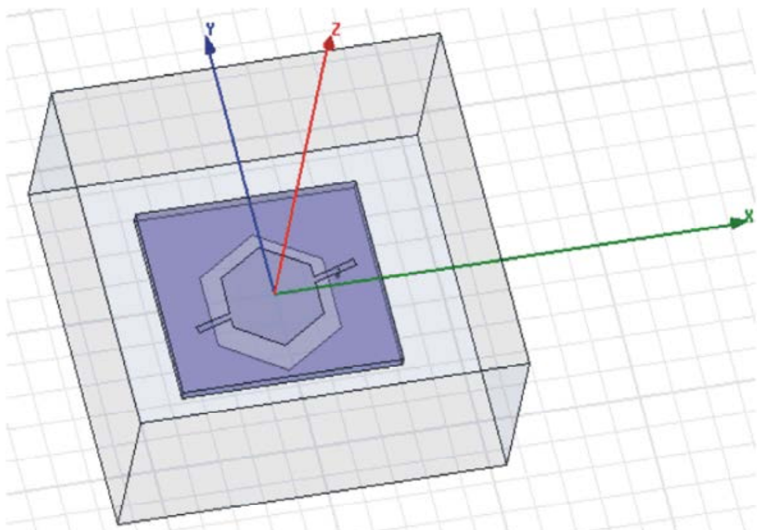


Fig. 4: Radiation setup of the antenna Design B & C (tilted feed)

The effects of various geometrical parameters are analyzed in order to provide design parameters for the antenna. The antenna has novel tuning stub in Hexagonal slot to achieve the ultra wide band property of the antenna. The size of the ground is same as that of the substrate size. The antenna is optimized with Ansoft HFSS 15. Fig. 3 shows the radiation set up of the antenna Design A for simulation and Fig. 4 shows the radiation set up of the antenna Design B & C for simulation.

The total width ‘W’ and Length ‘L’ [5] of the planar antenna are given by Equations (1) and (2)

$$W = \frac{c}{2fr}\sqrt{\frac{2}{\varepsilon r+1}} \quad (1)$$

where ‘f_r’ is the resonant frequency and ‘c’ = 3×10^8 m/s

$$L = \frac{c}{2fr\sqrt{\varepsilon reff}} - 2\,\Delta L \quad (2)$$

where $$\varepsilon_{reff} = \frac{\varepsilon r+1}{2} + \frac{\varepsilon r-1}{2\sqrt{(1+{}^{12h}/_{w})}} \quad (3)$$

$$\Delta L = h * 0.412\,\frac{(\varepsilon reff+0.3)[{}^{W}/_{h}+0.264]}{(\varepsilon reff-0.258)[{}^{W}/_{h}+0.8]} \quad (4)$$

$$L_{eff} = L + 2\,\Delta L \quad (5)$$

Width and height of CPW wave ports are given by;

$$W_{port} \geq 3 \text{ x } (2g + w) \quad (6)$$

where 'g' is the distance between the inner conductor and the ground.

$$L_{port} \geq 4 \text{ x } h \quad (7)$$

where 'h' is the height of the antenna.

Equations (1) and (2) are used to find the theoretical values of W and L for the highest resonant frequency f_r = 10 GHz. The optimized values of W and L are obtained using HFSS.

RESULTS AND DISCUSSIONS

Fig. 4 shows the reflection coefficient (S_{11}) results of the Designs A, B and C by considering a finite ground plane size of 34 X 29mm but infinite substrate material obtained using Ansoft Designer simulations.

Also simulated the Design B – tilted feed line using Ansoft HFSS to analyze the effect of finite substrate size on the performance of the antenna, in addition to other finite dimensions of the antenna. The effect of SMA connector, which is close to the antenna geometry on the antenna performance, is also included here. The simulated reflection coefficient result using HFSS is shown in Fig. 5 along with the designer simulated results. We defined the impedance bandwidth for the range of frequencies which satisfy the reflection coefficient, S_{11} = -10 dB or VSWR 2:1 criteria. It is observed that, for the antenna Design A, bandwidth is 106% covering the frequency range from 2.66GHz to 8.45GHz with respect to the centre frequency.

The antenna Design B showed a bandwidth from 2.67 – 11.32 GHz which is 124%. For the Antenna Design C, bandwidth is 116% covering a frequency range from 2.5 to 9.1GHz. Similarly Design B showed a bandwidth of 127% covering the frequency range of 2.7 to 12.5GHz while simulated using HFSS. A number of visible multiple resonances are present within the bandwidth. When these resonances are joined, a bandwidth which is more than the UWB requirement of 110% (3.10 – 10.60GHz) is obtained. It can be found that the bandwidths produced by Design B and Design C with tilted feed line are more than design A which uses straight feed. It is noted that Design B provides maximum bandwidth among all designs. Further, the antenna Design B predicted almost same bandwidths of 124% and 127% respectively when simulated using designer and HFSS.

Fig. 6(a-c) shows the Gain radiation pattern of antenna Design B within the ultra wide band range using HFSS simulations. The cross polarization ($G\theta$ at Φ = 90° plane and G_Φ at Φ = 0° plane)and co polarization ($G\theta$ at Φ = 0° plane and G_Φ at Φ = 90° plane) components of the gain radiation patterns are plotted at different frequencies. The frequencies considered for simulations are 4GHz, 7GHz and 10 GHz.

Verification of Antenna: The antenna performance was verified using the HFSS simulation for the UWB communications using the technique outlined in [28] where a transmit / receive antenna combination was considered. As suggested in [28] the transmit and receive antennas were similar (Design B) and placed 100mm apart facing each other. This combination can be considered as two port network. Fig. 7(a) and 7(b) shows the S parameters and S_{21}phase versus frequency variations respectively.

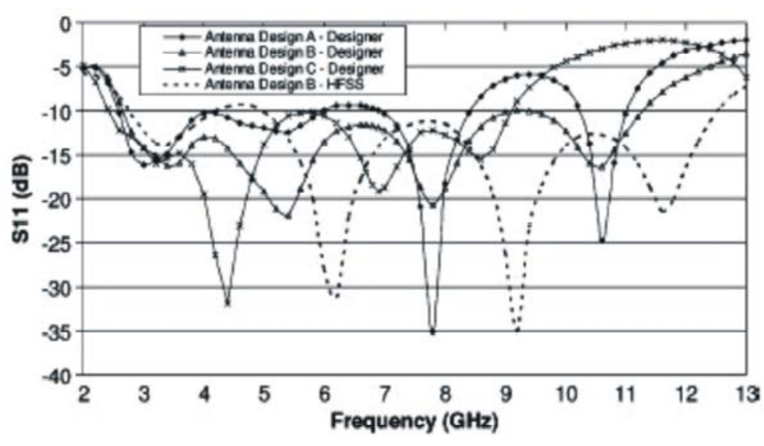
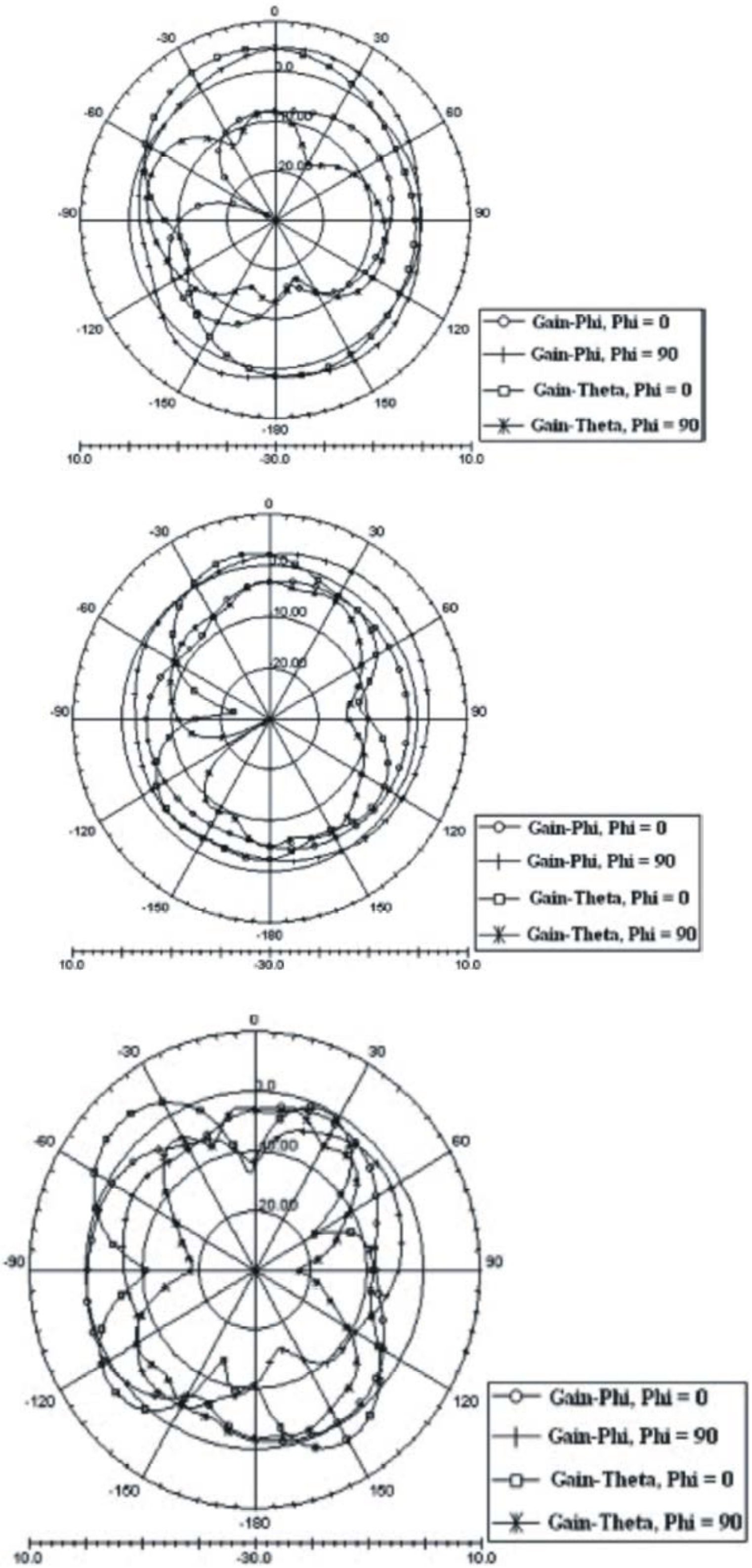


Fig. 5: The reflection coefficient $S_{11(dB)}$ versus frequency (GHz) plot for the antenna Designs A, B and C

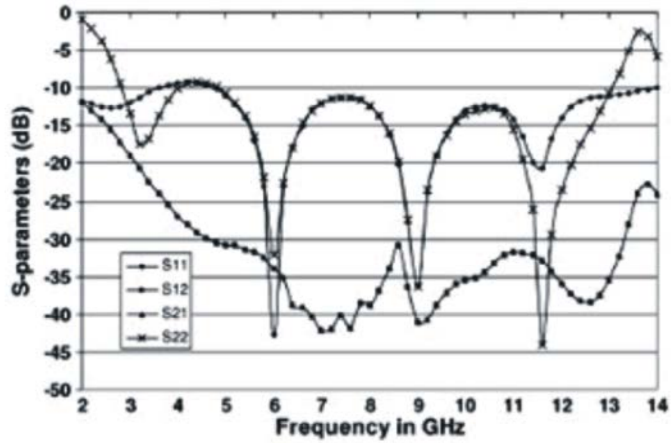


(a)

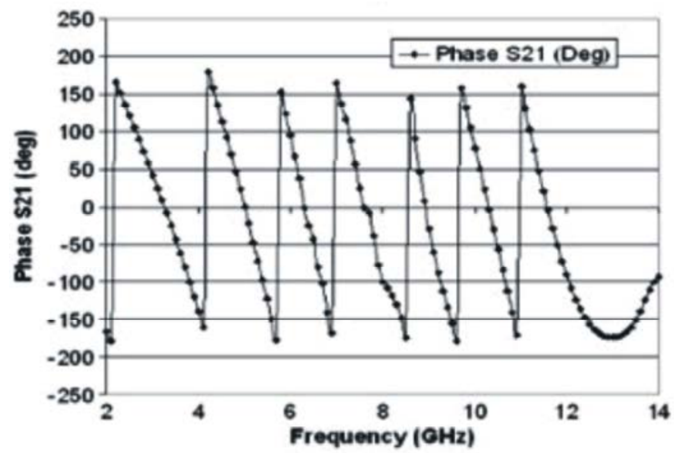
(b)

(c)

Fig. 6: Gain radiation patterns of Antenna Design B at frequencies (a) 4 GHz, (b) 7 GHz and (c) 10 Ghz with in the UWB range



(a)



(b)

Fig. 7: (a) S-parameters(dB) versus frequency (GHz) and (b) S21 phase (degrees) versus frequency(GHz) plots for the transmit-receive antenna system.

The S parameter results show that for most of the frequencies, their exist similar impedance matching behavior. They do not overlap at the start and end of bandwidths. From Fig. 7a, it can be found that, the transmission coefficients (S_{12} / S_{21}) of the system cover the ultra wide band range within near to the 10dB variation. From Fig. 7b, it is shown that S_{21} phase is nonlinear within the UWB range.

CONCLUSION

In this paper, a probe fed hexagonal shaped patch antenna with hexagonal slot cut is investigated for the impedance matching and radiation pattern characteristics. The size of the proposed antenna is 34 X 29 X 1.6mm. Both straight line and tilted feed line designs were investigated with two different substrate materials of same thickness. It was found that, antenna Design B with tilted feed line produces a bandwidth of 127% (2.7GHz – 12.5GHz) which exceeds the required UWB range of 3.10 to 10.60 GHz. Moreover all the three antenna Designs A, B and C almost met the UWB frequency range. Also all the three designs provided nearly omni directional radiation patterns. The small size, low manufacturing cost and sufficient bandwidth make this antenna suitable for Ultra wide band applications.

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