A Miniaturized Microstrip Antenna for Ultra-wideband Applications

Nivedita Mishra¹, Saima Beg²

¹Department of Electronics and Communication Engineering, Integral University Lucknow, India - 226026.
Corresponding author: Nivedita Mishra (e-mail: nivimini01@gmail.com, saimabeg@iul.ac.in)

ABSTRACT In this paper, the authors present an ultra-wideband (UWB) planar antenna with defected ground structure (DGS) for various wireless applications. The operating frequency of the proposed geometry is in the range of 3.1 to 10.6 GHz. The proposed compact geometry antenna is applicable for the UWB applications. In order to optimize the dimensions of the antenna, a parametric analysis has been performed. The measured magnitude is less than -10 dB over the band, and it has an impedance bandwidth of 10.60 GHz. The designed UWB antenna gives maximum radiation efficiency and gain of 96.5% and 3.30 dBi, respectively. Also, it gives good time-domain characteristics over the entire resonating band. The designed UWB antenna is simple geometry, and it is applicable for numerous wireless applications.

INDEX TERMS Microstrip Patch Antenna, Monopole, Ultra-wideband, Wireless Applications

I. INTRODUCTION

Recently, Ultra-wideband antennas (UWB) are playing a vital role in designing wireless communication frameworks, especially for the wireless local area (WLAN) and World interoperability for microwave access (WiMAX) network [1]. Microstrip patch antenna (MPA) is mainly used as a UWB antenna with its miniaturized size, multiband, and omni-directional patter [2] for these applications. MPA is also exceptionally well known because of its straightforwardness design and adaptability of enhancement to meet the antenna performance [3].

For better antenna design, a few strategies such as partial ground, increasing substrate thickness, and different slots consolidated on the antenna [4]. Utilizing the fractional ground plane, UWB transferable speed can be effectively acquired, and further, with various spaces, the band notch attributes can be handily gotten [5]. As of late, a few methods have been formed at UWB frequency with double band-notch attributes for various sorts of utilizatations in [6]. The UWB antenna is implemented for dual-band rejection using the coplanar waveguide (CPW) feeding method in [7]. Two balanced spaces are added on the ground plane by planning a ring-opening on the transmitting patch to accomplish the primary band-notch. Nonetheless, just two frequency bands were engaged in [8-9]. The implemented antenna in [10] was persuaded by TL-MTM work and an L-formed space on the ground. In literature, many antennas are proposed, but the lack of compactness is the main problem in [11-13].

In [14], a smaller shape UWB monopole antenna is proposed for WLAN applications. A C-shaped slot has obtained the dual notch bands. It has accomplished a minor component of 34 × 30 mm² nearby with UWB transmission capacity for the upper WLAN band. A fascinating UWB antenna with a blend of U-shape stab on the patch and W-shape slots on the implemented ground was proposed in [15]. Hence, the developed radio wire has acquired 8.61 GHz data transmission alongside a double band-dismissal trademark for UWB applications. The antenna has disposed of the WiMAX and WLAN frequency band separately. A monopole antenna with the improvement for WLAN applications has been proposed in [16-17]. The fabricated antenna has a wide working data transmission of 3.1 - 11 GHz with satisfactory VSWR esteem (< 2) for the full transfer speed. The antenna has an area of 35 × 24 mm². In [18-22], a CPW-took care of material radio wire is presented for UWB application with the double band rejection for Bluetooth and WiMAX applications. The implemented design has a wide working transmission capacity of is 8.9 GHz capacities. The accomplished double bands are 2.3 – 2.5 GHz and 3.3 - 3.7 GHz for Bluetooth and WiMAX applications. Two split ring resonator spaces have been planned on the radiating component to get double band rejection qualities. Notwithstanding, it has a wide area dimension of 43 × 40 mm². It is seen from the literature that the more significant part of the antenna has a somewhat enormous measurement that necessities to lessen by proposing an antenna for the application.

This paper proposes a triple-band microstrip patch antenna for WiMAX/LWLAN/UWLAN and downlink C-band sat beneficiary applications. A new plan of the UWB work has been proposed by embedding strips on wideband printed open space antenna by picking the legitimate boundaries of the strips to dismiss single, double band operation. Further, the proposed geometry is single layer and compact. The simulated and measured impedance bandwidth of 10.45 GHz and
II. PROPOSED ANTENNA DESIGN

A. STEP FORMATION OF PROPOSED DESIGN

The step-by-step formation of the proposed antenna geometry is depicted in Fig. 1. First, the conventional square-shaped geometry with a half-ground plane is considered, and its corresponding reflection coefficient is plotted in Fig. 2. From Fig. 2, it can be seen that the designed conventional square geometry resonates at around 7 GHz with low impedance bandwidth. In step-2, the truncated corner has been introduced in a top patch with the same size ground plane, and corresponding $S_{11}$ is depicted in Fig. 2. It can be seen that after introducing the truncated corner, the resonating frequency is shifted lower side. After introducing a truncated corner, the current path has been stretched which leads to electric travel for long distances. In step-3, the curve on the top patch is added, and it resonates at a lower band with good bandwidth. In step-4, the simple rectangular notch is added and its shown in Fig. 1(d). After adding a notch on the ground plane, the designed antenna resonates with a wideband. Finally, in step-5, the curve on the ground plane notch has been introduced and illustrated in Fig. 1(e). The corresponding $S_{11}$ (Solid Blue Line) magnitude of the proposed design is given in Fig. 2. It can be seen that the designed antenna resonated in the UWB range (3.1 - 10.60 GHz). Inspired from results, the step 5 design is considered for UWB wireless applications.

B. SINGLE ELEMENT

The proposed design on step 5 is etched on top of the substrate material, shown in Fig. 3. The FR-4 substrate material has been utilized for the implemented antenna. The reason is that the FR-4 substrate material is easily available in the market as well as it is low-cost material. The overall substrate size is $40 \times 50$ mm$^2$. The defected ground surface (DGS) is employed to the proposed antenna instead of the full substrate material, shown in Fig. 3. The FR-4 substrate material is easily available in the market as well as it is low-cost material. The overall substrate size is $40 \times 50$ mm$^2$.
the notch is taken 1.66 mm. The top-view and bottom view of the proposed UWB antenna are illustrated in Fig. 3(a) and (b), respectively. Further, the detailed optimized dimensions is given in Table 1. In the radiator, the patch is connected with a feed line to feed power in the patch. The 50Ω inset feed line is used to feed power in the patch. The dimension of the feed line is taken 3.50 × 24 mm². Both sides of the patch are cut with a 6.66 mm radius curve. The printed design of the proposed microstrip patch antenna can create an ultra-wide frequency band. UWB data transfer potency is accomplished by changing the radiuses of the curves in a patch and the size in DGS. The proposed antenna structure is easy to design for practical purposes, and it can provide an excellent stable impedance bandwidth in UWB operation. In designing the antenna, the lowest operating f₁ is predicted, as in [20].

\[
f₁ = \frac{c}{4\sqrt{\varepsilon_{eff}} \times \frac{l}{2}}
\]

Where \(c\), \(\varepsilon_r\), and \(\varepsilon_{eff}\) are the velocity of light, a dielectric constant, and effective dielectric constant of the substrate, respectively. As a result of this changing the length (L) of the patch antenna, the impedance matching property can be altered to the desired range. In this antenna, the length of an antenna is taken 23 mm to get better impedance matching.

III. PARAMETRIC ANALYSIS

At first, numerical simulation of the proposed UWB MPA is conducted in the CST software using the transient solver assessment and then experimentally verifying the simulated result. Then, a designed antenna is simulated from 0 GHz to 14 GHz to observe the reflection coefficient, voltage standing wave ratio (VSWR), radiation patterns, gain, and radiation efficiency. The comparative study for different sizes (\(G_l\)) of DGS, top patch curve (\(R_1\)), and ground notch (\(R_2\)) are also examined to observe the change of bandwidth using \(S_{11}\) magnitude.

The parametric analysis and effect on the \(S_{11}\) magnitude are illustrated in Fig. 4. The ground plane length (\(G_l\)) variation from 20 to 28 mm with a 4 mm gap and its effect on the reflection coefficient is presented in Fig. 4(a). It can be seen that for particular \(G_l = 24\) mm, the proposed UWB gives good performance and achieve wideband as compared to other values. Similarly, the top patch notch (\(R_1\)) variations from 4.44 to 8.88 mm have been performed, and its effect on the reflection coefficient is depicted in Fig. 4(b). Similarly, the bottom notch (\(R_2\)) variations and effect on \(S_{11}\) magnitude is illustrated in Fig. 4(c). Thus, the UWB antenna gives wide bandwidth and good performance results for wireless applications for optimized and perfect value.

IV. SIMULATION AND MEASUREMENT RESULTS

The photograph of the manufactured model proposed UWB antenna is portrayed in Fig. 5. From Fig. 5, it can be seen...
that the proposed antenna is a compact and straightforward geometric configuration. Fig. 5(a) and (b) provide the top and back-view of the proposed geometry. The proposed antenna is fabricated and etched on top of the low-cost FR-4 material.

A. REFLECTION COEFFICIENT AND E-FIELD

The proposed UWB designed antenna simulated and measured $S_{11}$ magnitude comparison is depicted in Fig. 6. It is seen from Fig. 6 that the measured and simulated $S_{11}$ magnitude is approximately similar. The simulated antenna resonates from 1.93 – 12.38 GHz while the measured reading is obtained at 2.1 – 12.70 GHz. Also, the sharp $S_{11}$ notch of -39.66 dB at 2.26 GHz in simulation and -42 dB at 2.50 GHz in measurement. Further, the simulated impedance bandwidth from CST software is 10.45 GHz, and the resultant impedance bandwidth from the prototype antenna is 10.60 GHz. Besides, the return loss of the measurement section is lower compared to the simulated section. Also, the resultant VSWR is fewer than 2 between 1.93 to 12.38 GHz frequency ranges. With the goal that reception apparatus coordinate thought about generally excellent.

The E-field distribution at 3, 6, and 10 GHz frequencies are given in Fig. 7. Fig. 7(a) shows that at 3 GHz frequency, the highest E-field at the bottom side notches, which indicates the lower resonating notch is achieved due to the back notch. Similarly, for 6 GHz and 10 GHz, the designed patch
truncated sides and $R_1$ curve are responsible for the middle and higher bands, respectively. The most extreme E-field is noticed in the upper and lower layers of the patch. The proposed antenna gives good resonance at 6 GHz, as shown in Fig. 6. Also, the same can be seen in Fig. 7 which is electric field distribution where the more electric field is distributed at the edges of the radiating patch.

B. RADIATION PATTERNS

In Fig. 8, the polar plot for the far-field directivity is given. These are simulated at 3, 6, and 10 GHz at both E-plane ($\phi = 0^\circ$) and H-plane ($\phi = 90^\circ$). It is observed that the side lobe of the E-plane reduced with increasing frequency. As observed, the E-plane is not similar in shape as the frequency increases. The same case is also for H-plane. Overall the radiation pattern reflects the omni-directional and bi-directional for H-plane and E-plane by taking the characteristics of monopole antenna. So that, it can be seen that the primary beam tilts at upper recurrence. The sidelobe level is also changed in the antenna radiation with increasing frequency. The simulated gain of the proposed UWB antenna at 3, 6, and 10 GHz is 3.30, 1.86, and 1.10 dBi, respectively. The proposed antenna can provide enough gain for the WiMAX/LWLAN/ UWLAN, and downlink C-band sat receiver.

The output of the 3D radiation pattern is given in Fig. 9. The 3D radiation pattern is simulated at 3, 6, and 10 GHz to observe the change of directivity over the broadband. The radiation pattern of the antenna, without a doubt, emanates from the entire worked frequency range. The simulated directivity is 3.85 dBi at 3 GHz frequency. At 6 and 10 GHz, the directivity gain reduced slightly. The antenna provides enough directivity gain for the applications such as WIMAX, LWLAN, UWLAN, and downlink C-SAT receiver. Directivity depicted by the simulated UWB MPA is shown as a good possibility for this application.

C. GAIN AND RADIATION EFFICIENCY

The simulated gain and radiation efficiency plot of the designed UWB antenna is given in Fig. 10. From Fig. 10, it can be found that the designed UWB gives a gain of 0.5 - 3.30 dBi variations over the resonating band. The maximum gain of 3.30 dBi is achieved at 3.50 GHz. Further, the radiation efficiency analysis results are illustrated in Fig. 10. The radiation efficiency of the proposed UWB antenna varies from 87 – 96%. The maximum radiation efficiency of 96.5% has been achieved at 5 GHz.

The impedance variations over the resonating band plot are illustrated in Fig. 11. From Fig. 11, it can be noted that the antenna has an almost constant impedance of 50Ω over the resonating band. However, the impedance varies between 40 – 60Ω over the resonating band. Further, it can be seen that the impedance is not matched at lower 1 GHz and higher 14 GHz, which is due to the current being interrupted at a particular resonating frequency.
The mathematical formula for the group delay is given below [23]:

$$\tau_g(\omega) = -\frac{d\phi(f)}{2\pi df}$$  (3)

Where $\phi$ is the phase response of the received signal, and the group delay versus frequency plot of the proposed UWB antenna is depicted in Fig. 13. From Fig. 13, it can be observed that the designed antenna has a group delay variation in the side-by-side condition is less than 0.06 nsec, and in the face-to-face condition, the variation is 0.75 nsec. The transfer function of the UWB antenna is given as [23]:

$$H(\omega) = \sqrt{\frac{2\pi c_0 DS_{21}^{(1)}(\omega)e^{j\omega D}}{j\omega}}$$  (4)

Here, D is the distance between the antenna, and the coupling between two ports can be identified using the isolation parameter. The isolation defined the ratio of power incident to the power delivered to another port. The isolation parameter ($S_{21}$) of the proposed geometry is given in Fig. 13. It can be noted that the designed geometry gives good isolation in both conditions, which is greater than -20 dB. Thus, the designed UWB antenna gives good time-domain characteristics over the entire resonating band and gives suitable performance parameters over the resonating band. Therefore, the proposed geometry is applicable for UWB wireless applications.

V. CONCLUSION

A microstrip antenna is designed with DGS for the UWB frequency range. The antenna size is a small, easy fabrication and provides the operation band of frequency over 3.1 – 10.6 GHz. The measured impedance bandwidth of the proposed geometry is 2.1 – 12.70 GHz. The designed prototype antenna performance is close to the simulation part from CST. The VSWR is also in the acceptable range. The radiation characteristics also provide some excellent properties. The measured maximum gain of the proposed geometry is 3.30 dBi at 3.50 GHz. Also, the radiation efficiency variations from 87 – 96% over the resonating band. The operating far-field directivity is also very good for the application in WIMAX/LWLAN/ UWLAN, and downlink C-band sat receiver. Also, it gives good time-domain characteristics performance over the resonating band. Moreover, the experimental results matched well with the numerical antenna characteristics. Overall, the proposed antenna provides much better performance regarding the UWB application.


