UWB performance of planar printed monopole antennas have been analyzed in the previous chapter. The objective of this chapter is to introduce low profile and light weight antenna with wide impedance bandwidth. Wide bandwidth is achieved by exciting rectangular slot with a C shaped stub. The study includes all aspects of systematic design, performance analysis of antenna with respect to reflection coefficient, surface current distribution and radiation characteristics.

4.1 INTRODUCTION

In Chapter 2, antennas classified based on the frequency of operation had been reviewed. Another way of classifying it is as electric and magnetic antennas. Antennas such as dipoles and horns that have intense electric field close to the antenna are electric type antennas. In contrast antennas characterized by intense magnetic field are magnetic antennas. Slot antennas and loop antennas fall under the category of magnetic antennas. Conventional dipole and monopole antennas display large values of input reactance when the wavelength is much greater than the antenna dimensions. The impedance of the electric dipole approaches open circuit value. Whereas, small magnetic dipoles display large value of input susceptance and the impedance tends towards a short circuit value as frequency decreases [Mayes et al 1972]. Magnetic slot antennas have been developed in the late 1940s to early 1950s. Small magnetic antennas lends themself best for embedded applications because their magnetic near fields are less vulnerable to undesired coupling than the near electric fields of small electric field antennas [Schantz, (2005)]. Compared to other magnetic antennas, slot antennas are attractive because of their low profile, high efficiency and multiband operation capabilities. A wide variety of slot antennas has been proposed in the literature. Discussion of slot antenna is largely based on a generalization and extension of Babinet’s principle by Henry Booker [Krauss, (2010)]. A monopole slot
antenna with a small radiating structure over a large ground plane had been proposed with 10:1 bandwidth, stable input impedance and unidirectional beam pattern [Mayes, et al 1972]. A microstrip line fed slot antenna operating at X-band was proposed by Yoshimura (1972). The dependence of input impedance and radiation pattern on slot to reflector spacing was tested. Exciting the slot antenna array using microstrip line had the disadvantage that both sides of the substrate had to be photolithographically treated and required a complicated network. To overcome this disadvantage a new concept of coplanar waveguide (CPW) excitation was proposed by Nesic (1982). Bandwidth of conventional microstrip slot antenna is ten percent or less. Bandwidth can be increased up to 127% by crossed flared slot antenna [Povinelli (1987)]. Thus, slot antenna with CPW feed is preferred rather than microstripline feed line due to the misalignment error caused by etching on both sides of the substrate.

4.2 UWB SLOT ANTENNA

Printed UWB slot antenna has been widely used in UWB systems. Round corner rectangular slot and partial circular patch introduces five resonant modes enhancing the bandwidth ratio to more than 7.2:1 [Chen, et al (2007)]. Planar elliptical/circular slot antenna using tapered feed line with U-shaped tuning stub has been demonstrated to exhibit ultra wideband characteristics [Li et al (2006)]. Wide bandwidth of 110% has been achieved by the combination of the rectangular slot and U-shaped tuning stub [Chair et al (2004)]. A significant bandwidth enhancement of 120% was reported with an arc shaped slot and square patch feed [Liu et al (2004)]. A rocket shaped slot antenna with two parasitic strips for dual band notch characteristics was proposed by Qing, et al (2010). Rectangular slot antenna with fork shaped tuning structure has been presented by Chen, et al (2006). The slot and fork shaped feeding structure were positioned symmetrically with respect to the centerline. Several such antennas are seen in the literature [Cheng, et al (2008), Krishna, et al (2008), Rajagopal, et al (2009), Moghadasi, et al (2009). Alternate to the slot antenna monopole like slot antenna have been developed [Qing, et al (2009), Gopikrishna, et al (2009), Qing, et al (2008), Sharma, et al...
These consist of an open slot and feeding structures. The ground plane surrounding the slot is open and offers more freedom in design and also reduction in size.

In this chapter a CPW fed slot antenna with ultrawide bandwidth is presented. The rectangular slot is excited with C shaped stub to achieve ultrawide bandwidth.

4.2.1 ANTENNA GEOMETRY

The geometrical configuration of the proposed rectangular slot antenna with C shaped stub is depicted in Figure 4.1. A 50 Ω CPW line having a signal strip of thickness $W_f = 3$ mm and a gap of $g_p = 0.5$ mm between the signal strip and the coplanar ground plane is used to capacitively excite the rectangular slot. The proposed antenna is located in x-y plane and the normal direction is parallel to z-axis. The antenna $34 \times 29$ mm$^2$ ($L_G \times W_G$) is fabricated on FR4 substrate with relative permittivity of $\varepsilon_r = 4.4$, thickness of 1.6 mm. The antenna fed with a CPW line and the metallization is on single side only, making the antenna low profile and cost effective.

![Figure 4.1 Slot antenna geometry](image-url)
4.2.2 PARAMETRIC STUDY

The dimension of the primary slot \((L_{st} \times W_{st})\) and the gap between the ground and primary slot \((g_p)\) are the key parameters that control the bandwidth in lower frequency band. In addition to the bandwidth enhancement, the uniplanar nature of the slot antenna provides for simple integration of active or passive lumped components into the topology of the antenna without the need for via holes.

![Graph showing simulated reflection coefficient for different gap positions \((g_p)\)](image)

**Figure 4.2** Simulated reflection coefficient for different gap positions \((g_p)\)

The effect of varying the gap between the patch and primary slot \((g_p)\) is shown in Figure 4.2. The slot spacing is varied from 1-2.5 mm in steps of 0.5 mm. The resonant resistance increases as spacing is less than 2 mm which affects the low frequency band and affects the high frequency band when it is greater than 2 mm. Hence good impedance matching for the proposed design is obtained by enhancing the coupling between the patch and the ground plane. The optimal spacing is found to be 2 mm.
The effect of varying the slot length ($L_{s1}$) is shown in Figure 4.3. Slot length is increased from 22 mm to 24 mm in steps of 1 mm. The slot length mainly affects the upper frequency band. When the length is 22 mm, a notch band appears between 6.5 GHz to 8.5 GHz as noted from Figure 4.3. As the length increases to 24 mm, higher resonant frequency shifts from 9.32 GHz to 9 GHz and lower frequency band reduces. A steep decrease in reflection coefficient is observed due to mismatch. A slot of length of 23 mm is chosen as the optimum value.

**Figure 4.3** Simulated reflection coefficient for different slot length ($L_{s1}$)
Figure 4.4 Simulated reflection coefficient for different slot width ($W_{s1}$)

The slot width ($W_{s1}$) is varied in steps of 1 mm from 13.2 mm to 15.2 mm. A width of 13.2 mm affects the lower band whereas the width of 15.2 mm affects the upper frequency band as illustrated in Figure 4.4. Hence 14.2 mm is chosen as optimum value for slot width.

4.2.3 SURFACE CURRENT DISTRIBUTION

The antennas behavior was further analyzed by investigating the surface current distribution. Figure 4.5 shows the surface current distribution plot at three different resonant frequencies, 3.95 GHz, 6.3 GHz and 9.3 GHz respectively. It can be seen that the current concentrates mainly on the CPW line and the slot. This shows that the dimension of the slot is a critical parameter in achieving wide bandwidth.
Figure 4.5 Surface current distribution of the antenna at (a) 3.95 GHz (b) 6.3 GHz (c) 9.3 GHz
4.2.4 RADIATION CHARACTERISTICS

The radiation characteristics of the antenna at three different resonant frequencies 3.95 GHz, 6.3 GHz and 9.3 GHz respectively are shown in Figure 4.6. It was observed that the gain increases with frequency. Also the number of lobes increased and the antenna became more directional.

Figure 4.6 Simulated radiation characteristics at (a) 3.95 GHz (b) 6.3 GHz (c) 9.3 GHz
4.2.5 BAND NOTCHED SLOT ANTENNA

In general, frequency notched UWB antennas can also be used in multiband systems, where the use of a single antenna that can function at potentially widely separated narrow bands of interest, is relevant for economic and cosmetic reasons [Schantz et al (2007)]. Today’s communication environment changes constantly and there is a need for reconfigurable designs which will utilize environmental changes in order to achieve higher performance [Wang et al (2007)]. Therefore, there is a need for UWB antenna with reconfigurable band rejection characteristics in the aforementioned frequency bands.

Reconfigurable antennas are similar to conventional antennas, but one or more of its specifications or characteristics could be varied or tuned using RF Switches (PIN diodes) [Wang, et al (2007), Khidre, et al (2009)], fast switching diodes, MEMS switches [Nikolaou, et al (2009)], variable capacitors or inductors [Yang, et al (2008), Behdad, et al (2006)]. Though PIN diodes are reliable and provide high speed switching, they introduce non linearity and complex bias circuitry needs to be integrated with the antenna. On the other hand MEMS switches have lower insertion loss, easier integration, less static power consumption and have high linearity, but it needs high static bias voltage. Capacitance is likely to change due to the presence of air gap and soldering points when varactors are employed.

In this section UWB printed monopole wide slot antenna with reconfigurable band notch is studied. In this study, ideal switch models are used to mimic the PIN diode switches for proof of concept. Reconfigurable capability is achieved by changing the operational state of the integrated switches. The role of the switch is to reconfigure the antenna between WiMAX and WLAN notch bands. During ON state, the antenna exhibits band notch covering the bandwidth of the WLAN band and OFF state it covers the WiMAX band. The simulated and experimental VSWR, radiation characteristics are presented over the entire band.
The band notched characteristic of CPW fed slot antenna is obtained by etching another slot (secondary slot) on the ground plane as shown in Figure 4.7. A rectangular slot of dimension 27 mm × 3.7 mm \((L_{s2} \times W_{s2})\) is etched on top of the ground plane to produce notch band in the vicinity of 3 GHz and thus prevent the interference with the WiMAX band. The width of the slot is fixed based on the dimension of the real PIN diode switch BAR 63(1.54mm × 3.77mm).

**Figure 4.7** Geometry of slot antenna with secondary slot \((L_{s2}\times W_{s2})\)

**Figure 4.8** Effect of secondary slot length on frequency
The effect of varying the secondary slot length \( (L_{s2}) \) is shown in Figure 4.8. An increase in slot length from 20-27 mm shifts the notch band from 4.4 - 4.63 GHz to 3.43 - 3.7 GHz. Therefore increasing the slot length decreases the notch band operating frequency. The length of the slot can be determined from,

\[
L = \frac{c}{2f_n \sqrt{\varepsilon_{\text{eff}}}}
\]  

(4.1)

Where,

\[
\varepsilon_{\text{eff}} = \frac{\varepsilon_r + 1}{2}
\]  

(4.2)

\( f_n \) - notch center frequency

\( \varepsilon_{\text{eff}} \) - effective dielectric constant

![Figure 4.9 Comparison of VSWR with and without secondary slot](image)

Figure 4.9 Comparison of VSWR with and without secondary slot
The VSWR of the antenna with and without the secondary slot is shown in Fig 4.9. Antenna with secondary slot introduces band notch characteristics at WiMAX band. Reconfigurable band notch characteristic is obtained by placing a metal pad of dimension 1.54 mm × 3.7 mm ($L_{SW} \times W_{SW}$) across the secondary slot. The open or closed state of the switch is simulated in the presence or absence of metal pad. The geometry of the antenna with metal pad is shown in Figure 4.10. During the ON state (with metal pad) the antenna presents band notch covering the bandwidth of the WLAN (5.15 -5.52 GHz) and OFF state (without metal pad) WiMAX (3.43 - 3.7 GHz) notch band is obtained. Position of the metal pad is determined from Eqn (4.1), where the length corresponds to the center of the notch frequency. The VSWR of the antenna with and without the metal pad is shown in Figure 4.11.

![Figure 4.10 Geometry of the antenna with metal pad](image)

**Figure 4.10** Geometry of the antenna with metal pad

![Figure 4.11a Simulated VSWR with and Without metal pad](image)

**Figure 4.11a** Simulated VSWR with and Without metal pad
Band notch behavior of the antenna was investigated using current distribution at four different frequencies. Investigation reveals that current is concentrated more on the CPW line, stub and the slot as shown in Figure 4.12a. At the notch frequency, the concentration is more on the slot. Also the current flow is in opposite direction on the interior and exterior of the slot. Concomitant the impedance changes and makes the antenna non responsive at notch frequency as presented in Fig 4.12 (b) - (d).

Figure 4.11b. Measured VSWR with and without metal diode
4.2.6 MEASUREMENT

Slot antenna measurement in anechoic chamber is shown in Figure 4.13. The measured reflection coefficient of the slot antenna is depicted in Figure 4.14. A wide bandwidth of 111.7% is achieved covering 3 - 10.1 GHz. A slight deviation in the result is seen which may be due to the soldering of the connector.
Figure 4.13 Slot antenna measurements in anechoic chamber

Figure 4.14 Measured and simulated reflection coefficient
Measured radiation characteristics of the slot antenna in the y-z plane and x-z plane at 3.2, 6 and 7.5 GHz are shown in Figure 4.15. The H-plane pattern is nearly omnidirectional and E-plane pattern is monopole like. Increase in frequency increases cross-polar radiation pattern in the H-plane. This may be due to the horizontal components of the surface current and E-field which becomes stronger with increase in frequency.
4.3 SUMMARY

CPW fed C-shaped printed antenna with rectangular slot was designed and implemented. UWB bandwidth of 3.01 - 10.4 GHz was obtained using rectangular slot and C shaped stub. The antenna is modified to have band rejection at WiMAX band (3.43 - 3.7 GHz) by etching a half wave length slot on the ground plane. In addition reconfigurable notch band capability was achieved by integrating a metal pad across the slot, which changes the notch band from WLAN band and WiMAX band. Omni directional radiation pattern and constant gain were observed over the entire band. Planar configuration of this antenna with reconfigurable band rejection characteristics makes it attractive for UWB devices like USB dongle and laptops.