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Design of Monopole Antenna with Band-Notching Function for UWB Applications

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ABSTRACT— A monopole antenna is a resonator antenna and has omni-directional radiation pattern. Slots used in monopole antenna for performing band- notching function by eliminating the interference in wireless communications. This letter presents a novel printed monopole antenna for ultrawideband applications with dual band-notched function. The antenna structure consists of a square radiating patch with an inverted T-shaped ring slot surrounded by a C-shaped slot for single band notching function. By inserting an inverted T-shaped parasitic structure inside the inverted T-shaped slot dual band-notching is achieved. A small ground slots are inserted to increase the bandwidth of planar monopole antenna with microstrip-fed. The antenna has an operating range of 3.05-11.5 GHz. The effect of slot is studied for varying the notch band operation of the antenna without changing the nature of omni-directional radiation characteristics in its operating band. The issue on monopole antenna with effects of slots and feed line is obtained.

KEYWORDS— C-shaped slot, inverted T-shaped parasitic structure, ground slot, printed square monopole antenna (PSMA).

I. INTRODUCTION

A planar monopole antenna is extremely used for wireless communications, because of its simple structure, low cost and omni-directional radiation pattern. Due to all these interesting characteristics, planar monopoles are very attractive to be used in emerging UWB applications. Consequently, a number of planar monopoles with different geometries have been designed [1, 2]. This letter focuses on a square monopole antenna for UWB applications, which combines the square-patch approach with a truncated ground plane and achieves a fractional bandwidth. For typical monopole antennas, the lower edge of the impedance bandwidth is inversely proportional to the overall length of the element. In the

case of planar monopoles, the overall length includes the feed gap. A significant increase in impedance bandwidth can be achieved by trimming the square edge near the ground plane by either a symmetrical or asymmetrical pentagonal monopole. Planar monopoles are realized by replacing the wire element of conventional monopole with a planar element. The planar element may be square, circular, triangular, diamond and bow-tie like plates which have the same heights. The input impedance of the monopoles is measured when the planar element deviates from vertical. A monopole antenna consists of a straight rod-shaped conductor, often mounted perpendicularly to some type of conductive surface called a ground plane. Common types of monopole antenna are whip, rubber ducky, helical, random wire, umbrella, inverted-L and T-antenna and ground plane antennas. The monopole is a resonant antenna; for radio waves the rod functions act as a resonator and it oscillates standing waves of voltage and current along its length. The length of the antenna determines the wavelength of the radio waves used.

According to Federal communication commission (FCC) rules, the 3.1 - 10.6 GHz is allocated to ultrawideband applications and it will cause interference to the existing wireless communication systems, such as wireless local area network (WLAN) for IEEE802.11a operating in 5.2/5.8 GHz and 5.725-5.825 GHz bands, WiMAX (3.3-3.6 GHz), and C-band (3.7-4.2 GHz). So the UWB antenna with single and dual band-stop performance is required. Compact antennas with various dimensions have been studied and implemented to enhance this effect. Many techniques like, using a pair of U-shaped slots and a notched ground plane with a T-shaped sleeve [3], pair of T-shaped strips protruded inside the square ring and a coupled π-shaped strip in the ground plane [4], inserting a two rod-shaped parasitic structures and two V-shaped slots in the ground plane [5], pair of L-shaped slits and an E-shaped slot and a ground plane with a V-shaped protruded strip [6] and other techniques [7,8] have been reported to obtain wideband and small size of printed monopole antennas.

In this letter, a new dual band-notched monopole antenna with improved multiresonance performance is presented. In the proposed structure, single band-notched function is provided by cutting an inverted T-shaped slot which is surrounded by a C-shaped slot in the radiating patch, and dual band-notch characteristic is obtained by adding an inverted T-shaped parasitic structure inside the T-shaped slot and also by inserting small ground slots helps to improve the bandwidth of the antenna. The proposed antenna has wider impedance bandwidth in the frequency band of 3.05-11.5 GHz with two rejection bands around 3.21-4.55 and 5.15-6.74 GHz. Compact size, wide bandwidth, and omni-directional radiation pattern with low cross-polarization level are some of the other features of this antenna. Good return loss and radiation pattern characteristics are obtained in the frequency band of interest.

II. Printed Monopole Antennas

Ultra wideband technology should have bandwidth ranging from 3.1GHz to 10.6GHz in which practical efficiency and suitable omni-directional radiation patterns are necessary. In this ultra-wide bandwidth, an extremely low emission power level should be ensured. The Federal Communication Commission (FCC) has specified the emission limited to −41.3 dBm/MHz. The antenna propagates minimum distortion with short-pulse signal over the frequency range. UWB communication having ultra-wideband characteristic has many advantages for the short-distance wireless communication such as high data rates and large channel capacity, Excellent immunity to multipath interference, Low complexity and cost and Low power consumption.

The square monopole antenna fed by a 50-Ω microstrip line is shown in Fig. 1. The basic antenna structure consists of a square patch, a feed line, and a ground plane which is printed on a FR4 substrate of thickness 0.8 mm, permittivity 4.4. The square patch has a width W. The patch is connected to a feed line of width W_f and length L_f, as shown in Fig. 1. On the other side of the substrate, a conducting ground plane of width W_{sub} length L_{gnd} is placed. The proposed antenna is connected to a 50-Ω SMA connector for signal transmission. The parameters of this proposed antenna are studied by changing one parameter at a time and fixing the others.

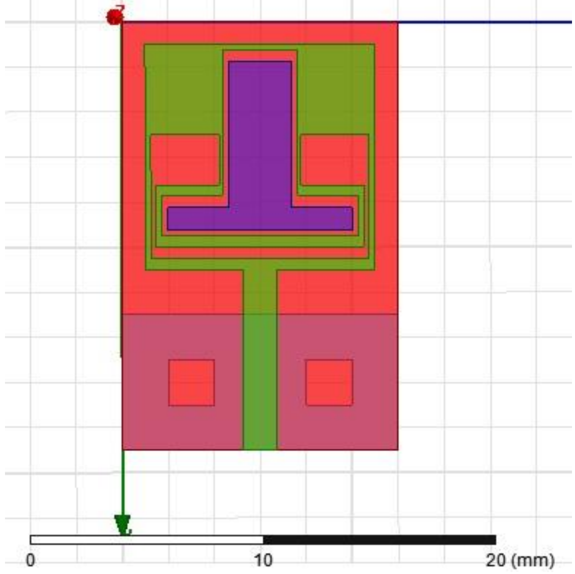

Fig.1 Design structure of proposed antenna.

The simulated results are obtained using the Ansoft simulation software high-frequency structure simulator (HFSS) [22]. The printed monopole antennas give very large impedance bandwidth with reasonably good radiation pattern in azimuthal plane.

III. Antenna Analysis

A. Inserting the slots

To obtain the frequency band notched function in UWB antenna, it is the most known method to insert the slots. Various frequency notched UWB antennas studied by many researchers can be classified according to slot's locations such as radiating element, ground plane, feeding line and vicinity of the radiating element. In this case, the notched frequency is determined by the total length of the slot which is equal to nearly half wavelength. By inserting slots in the radiating patch we able to achieve band notching function. Similar with inserting slots, it is also good method to remove narrowband resonant structure. We would like to insert narrowband resonant structure on the UWB antenna element to notch the specific frequency bands. By doing so, we can realize the frequency notched UWB antenna.

B. Design of dual band-notched UWB antenna

In this letter the proposed structure consists of C-shaped slots and inverted T-shaped parasitic structures and small ground slots. Generally band notching function is obtained by etching slots and employing parasitic strips in the radiating patch of the antenna. In the radiating patch, single band-notching function is provided by cutting an inverted T-shaped slot which is surrounded by a C-shaped slot and dual band-notch characteristic is obtained by adding an inverted T-shaped parasitic structure inside the T-shaped slot and also by inserting small ground slots towards the feed line the bandwidth is improved with respect to the multi-resonance performance. The antenna structure is shown in Fig.1.

The current mainly concentrates on the interior and exterior edges of these slots at notch frequency. Based on electromagnetic coupling, the T-shaped parasitic structure that is placed inside the inverted T-shaped slot acts as a parasitic half-wave resonant structure that is electrically coupled to the radiating patch. The current flows are more dominant around the parasitic element and they are directed oppositely between the parasitic elements and radiating patch, as a result high attenuation can be produced near the notch frequency. To control the impedance bandwidth of the antenna, the modified inverted T-shaped coupled strip can be used. Therefore, additional resonance and wider impedance bandwidth can be achieved at higher band. The designed antenna has a small size area of 12×19 mm^2. The designed antenna is fed with microstrip feed. In microstrip feed, the conducting strip is smaller in width as compared to the patch and this kind of feed arrangement has the advantage that the feed can be etched on the same substrate to provide a planar structure.

The optimal dimensions of the antenna are as follows: W_{Sub} = 12 mm, L_{Sub} = 19 mm, h_{sub} = 0.8 mm, W_f = 1.5 mm, L_f = 4 mm, W = 10 mm, W_S = 8.5 mm, L_S = 6.5 mm, W_{S1} = 3.25 mm, L_{S1} = 2 mm, W_{S2} = 2 mm, W_C = 9.5 mm, L_C = 5.5 mm, W_{C1} = 9 mm, L_{C1} = 1.75 mm, W_{C2} = 3.5 mm, L_{C2} = 2.75 mm, W_{C3} = 3.25 mm, W_T = 8 mm, L_T = 6.5 mm, W_{T1} = 3.5 mm, L_{T1} = 1 mm, L_d = 3 mm, L_{gnd} = 4 mm, W_G=2mm, L_G=2mm.

C. Effects of ground slots

Ground plane has different shapes of slots such as triangle, rectangle, circle and hexagonal slots which are placed under the feed line of the radiator are applied for achieving good impedance matching. By using these type of slots on the ground plane under the feed line, a patch antenna can achieve a bandwidth of 3.1-11.5 GHz for S_{11} < -10dB. To improve the impedance matching of the antenna, a small slot is cut on the upper edge of the ground plane under the feed line. The bandwidth improvements can be obtained by using with slots in the antenna.

D. Notch frequency

The gap distance between the radiating patch and ground plane is another effective parameter for impedance matching. The notched band frequency is controllable by adjusting the length of the slot. The band rejected frequency can be assumed as

$$fnotch = \frac{c}{2Lslot\sqrt{Eff}}$$

$$Eff = \frac{Er+1}{2}$$

Where L_{slot} is the length of the slot;
ε_{eff} is the effective dielectric constant;
c is the speed of light.

We can use this equation to predict the notch frequency of the antenna. The band-notched frequency can be adjusted by varying the lengths of the slots. However, the widths of the slot also affect the notched bandwidth. At the desired notch frequency, the current distribution is around the interior and exterior of the slots. The dielectric loading of a microstrip antenna affects both its radiation pattern and impedance bandwidth. The dielectric constant of the substrate increases with decreasing the antenna bandwidth and increases the Q factor of the antenna and therefore the impedance bandwidth gets decreased. To improve the impedance bandwidth of the antenna ground planes with slots are required.

E. Microstrip line feed

In this type of feed technique, a conducting strip is connected directly to the edge of the microstrip patch as shown in Fig.2. The conducting strip is smaller in width as compared to the patch and this kind of feed arrangement has the advantage that the feed can be etched on the same substrate to provide a planar structure.

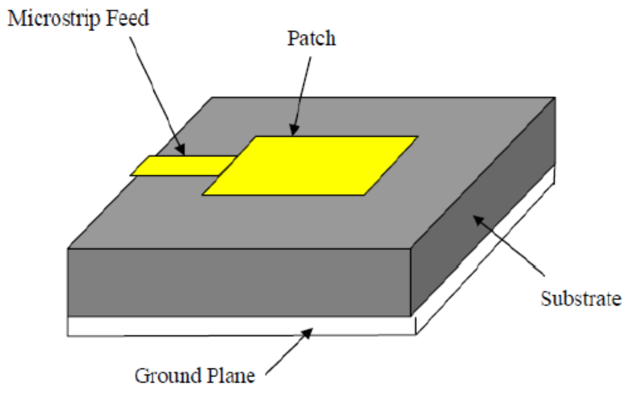

Fig. 2 Microstrip line feed

The microstrip feed has a conducting strip, dielectric substrate and a ground plane. The dielectric substrate affects both radiation and impedance bandwidth and helps to improve the impedance bandwidth of the antenna.

IV. Results and Discussions

The antenna is constructed with optimal dimensions of the designed structure. The simulated results for input impedance, s-parameter and radiation pattern are presented and discussed. The simulated results are obtained by using the Ansoft High Frequency Structure Simulator (HFSS) simulation software.

A. Return loss and VSWR

Fig.3 shows the simulated S-parameter for the antenna. In order to understand the band notching function of the antenna the simulated S-parameter results are discussed with dual notched bands. The single notched band is obtained by using a C-shaped slot in the bottom of the radiating patch and by adding inverted T-shaped parasitic structure surrounded by C-shaped slot we can achieve dual band notched characteristics. The simulated S-parameter has multiresonance performance at three frequencies. The simulate S-parameter has the resonance values at 3.1GHz, 4.8GHz and 7.15GHz. The simulated return loss shows the first resonance at 3.1GHz with S_{11} value of -13.75. The second resonance at 4.8GHz with S_{11} value of -20.64 and the third resonance at 7.15GHz with S_{11} value of -25.97 and it show a multiresonance property of the antenna.

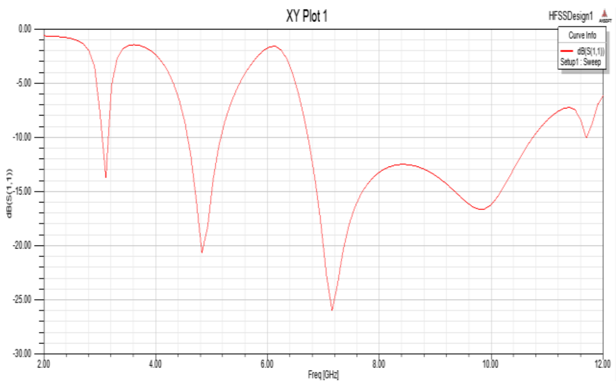

Fig.3 simulated S-parameter of the antenna

The VSWR value with < 2 is shown in Fig.4. By using the slot structure in the radiating patch of the antenna we obtain an impedance bandwidth with a frequency band of 3.05–11.5 GHz with two rejection bands around 3.21–4.55 and 5.15–6.74 GHz. When the VSWR plot which is less than 2 help to improve the radiation performance of the antenna.

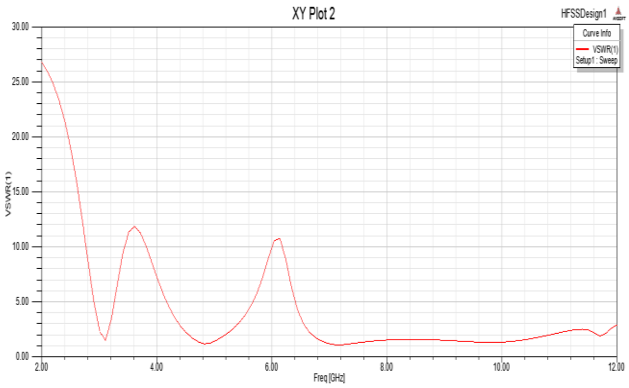

Fig.4 simulated VSWR characteristics of the antenna

At the notch frequency, the current flows are more dominant around the parasitic element, and they are directed oppositely between the parasitic element and the radiation patch. As a result, the desired high attenuation near the notch frequency can be produced. The generated notched bands avoid interference at the existing WiMAX and WLAN applications.

H. Gain

Fig.5 shows the simulated gain of the antenna for the wide frequency band. It can be observed that the square radiating patch with suitable slots achieve dual band notched frequency at 3.21GHz and 5.15GHz. The resulting gain of the antenna shows that the sharp decrease at the notched bands helps to avoid interference at the existing wireless systems such as WiMAX and WLAN bands.

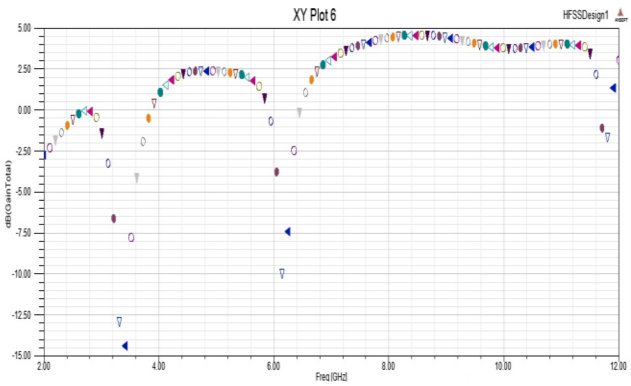

Fig.5 simulated gain of the designed antenna

C. Radiation pattern

Co-polarization and cross polarization exist only in the case of linearly polarized antennas. The designed monopole antenna shows an omni-directional radiation pattern to demonstrate that the antenna has a wide frequency over the operating band and it radiates equally in all directions. The obtained radiation patterns including the co-polarization and cross polarization in the H-plane and E-plane.

Fig.6 shows the simulated radiation patterns for the H-plane (xz-plane) and E-plane (yz-plane) at 3.1GHz, 4.8GHz and 7.2GHz respectively. It can be seen that the radiation patterns in xz-plane are nearly omni-directional for the three resonant frequencies. The receiver antenna will receive maximum power at θ= 0 and 90 degrees.

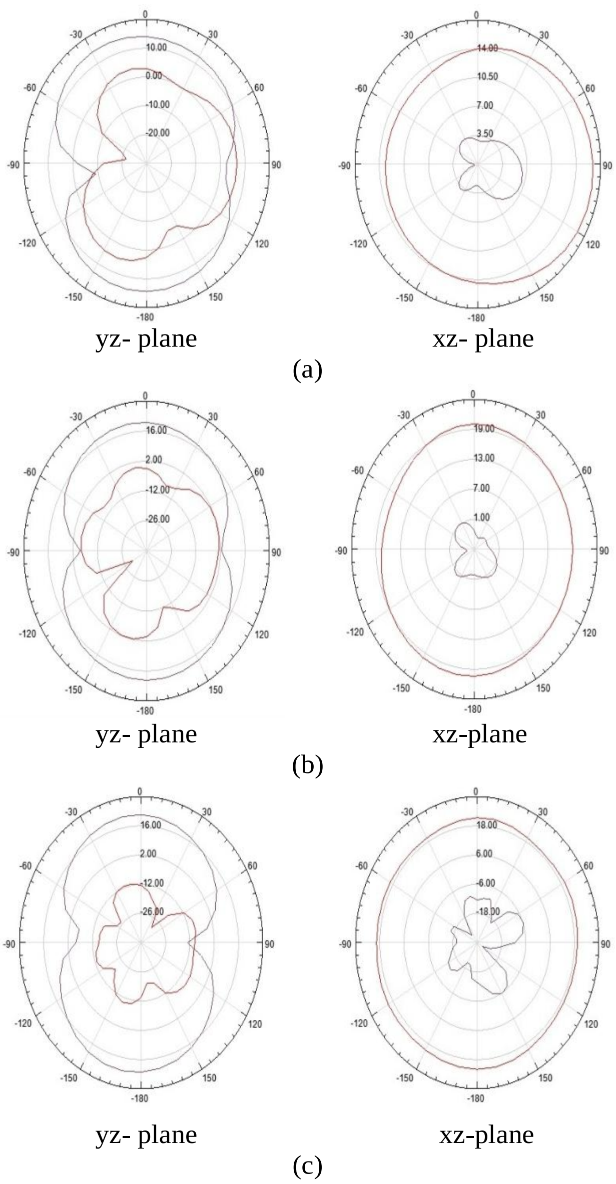

Fig.6 Radiation patterns of the antenna. (a).3.1GHz, (b).4.8GHz and (c) 7.2 GHz.

The radiation patterns of the designed antenna radiated equally in all directions when the receiver antenna has a maximum power of θ= 0. The cross polarization results are obtained when the receiver antenna has maximum power of θ= 0 and co-polarization results are obtained when the receiver antenna has minimum power of θ= 90. Hence the proposed antenna will obey the characteristics of ultra wideband applications and make it suitable to avoid interference which occurs in the existing wireless communication systems.

V. Conclusions

In this letter, a small square monopole antenna with single and dual band-notched characteristics with wide bandwidth for UWB applications is proposed. In this design, single band-notch is obtained by cutting an inverted T-shaped slot surrounded by C-shaped slot in the radiating patch and also dual band-notch is obtained by adding an inverted T-shaped parasitic structure inside the inverted T-shaped slot. Additional impedance bandwidth can be obtained by using a small square slot at the ground plane. The proposed antenna can operate from 3.05 to 11.5 GHz with two rejection bands around 3.21-4.55GHz and 5.15-6.74 GHz. Therefore, the ground slot can be used for increasing the impedance matching at higher frequencies. The designed antenna has small size and is suitable to use for ultrawideband applications.

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