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An Ultra-wideband Dual Frequency Notched Circular Monopole Antenna for Ground Penetrating Radar application

Surajit Kundu
Dept. of Electronics and Communication Engineering, National Institute of Technology Sikkim, Ravangla, South Sikkim, Sikkim, India, http://www.nitsikkim.ac.in

Abstract

A compact printed ultra-wideband (UWB) antenna of dimension 35×30×0.8 mm3 that provides wide impedance band from 2.78 to 16.58 GHz with dual frequency stop bands at 3.3-3.81 and 5.05-5.52 GHz to eliminate WiMAX and lower WLAN interferences is proposed in this article. The antenna also provides monopole like radiation pattern with an average radiation efficiency of about 87% and gain variation of 2-5 dBi in its pass bandwidth. One possible application of the proposed antenna could be found in ground penetrating radar (GPR) to scan thin sub surfaces as it can provide better lateral resolution due to very wide impedance bandwidth. The proposed antenna performance is simulated in close proximity of dry soil and wood test bed that has thickness of half inch and it is found that the antenna transfer function and group delay responses are stable in the 3.1-10.6 GHz UWB except the dual notch bands.

1. Introduction

Ground penetrating radar (GPR) is an electromagnetic tool that is widely used to scan the sub-surface to identify buried metallic and non-metallic objects hidden underneath [1]. Usually low frequency antenna that has wide operational band is preferred for such application. Broader bandwidth of GPR antenna implies better lateral resolution where lateral resolution indicates the ability of GPR to extricate between two different neighbor objects [1]. Printed ultra-wideband antenna in the 3.1-10.6 GHz unlicensed band [2] could be a useful candidate for GPR applications where better lateral resolution is main concern. However one possible drawback in this wide unlicensed band is poor depth resolution as the penetration ability of EM wave through sub-surface reduces with increase in operational frequency. This drawback can compensate by increasing the transmitting signal power but it also increases the possibility of interference with other wireless technologies such as IEEE 802.16 WiMAX (3.3-3.8 GHz), and IEEE 802.11a WLAN (5.15-5.35 GHz and 5.725-5.825 GHz) that collide in the same band. Additional filter circuitry can be integrated with GPR antenna to reduce the possibility of interference but it affect the antenna compactness and portability of the device. Therefore creation of frequency stop band in the antenna operational band to reject interfering bands is preferred now a days [3, 4]. Notch band can be created in various ways where inserting slots on the radiating patch [5-7] and embedding resonators and parasitic elements [8, 9] are some of the very common method among them. Notch generation using slot is very popular as the design and fabrication process is very simple. Different slot shapes such as C [5], L [6], inverted U [7] etc. were proposed earlier, mainly to eliminate the 5-6 GHz WLAN band. Losses of valuable spectrum because of unmatched band rejection is one of the serious drawback of these works.

In this work, a bandwidth enhanced circular disk monopole antenna is proposed. Very sharp dual frequency stop bands are realized using two co-directional rectangular split ring shape slots on the circular patch. The dual notched antenna performance is evaluated in CST MWS by keeping it in close proximity of soil and wood test beds of varying thicknesses.

2. Antenna Design

The proposed antenna design parameters are premeditated from the wavelength (λ_L) corresponding to 3.1GHz which is the lower frequency of unlicensed UWB. The equations that are considered to find the design parameters are given below.

Length (L), width (W) and thickness (H) of the substrate can be find out using the equation (1), (2) and (3) respectively.

$$\frac{\lambda_L}{4} \le L \le \frac{\lambda_L}{2} \qquad (1)$$

$$W = 2R \qquad (2)$$

$$H \approx 0.01\lambda_L \qquad (3)$$

In the above equation (2), R represents radius of the circular patch which can be determined using:

$$\frac{\lambda_L}{4} \le R \le \frac{\lambda_L}{2} \qquad (4)$$

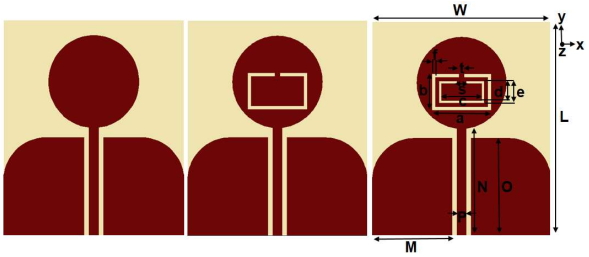
The feed length N can be calculated using:

$$(2R + N) \approx \frac{\lambda_L}{3} \qquad (5)$$

Feed gap can be calculated by subtracting the maximum length of co-planar ground plane (O) from the feed length (N) and the optimal value of feed gap can be calculated from:

$$0.01\lambda_L \leq (N - O) \leq 0.02\lambda_L \qquad (6)$$

The upper edges of co-planar ground plane is bended in both the corners as by doing so a flare angle is created in between the patch and ground. Such geometrical configuration helps to create additional resonances at high frequency and thus broaden the antenna impedance band. The antenna schematic is shown in Fig.1.a.



(a) (b) (c)

Figure 1. Schematic of proposed antenna geometry. (a) Reference antenna (b) antenna with single slot (c) Proposed antenna with dual slots.

Rectangular split ring shaped slot is embedded on the circular patch to generate the WiMAX frequency stop band. The slot dimension can be calculated from equation (7), considering the notch center frequency of 3.55 GHz.

$$f_n = \frac{c}{4(a+b-2f-2t)\sqrt{\varepsilon_e}} \qquad (7)$$

$$\varepsilon_e = \frac{\varepsilon_r+1}{2} \qquad (8)$$

Here c represents speed of light, ε_r indicates the permittivity of substrate material which is taken as 4.4, a, b, f and t can be seen in Fig. 1.c.

Another similar shaped co directional slot is also etched out to get the lower WLAN notch band. The optimal dimension of this 2nd slot can also be calculated from equation (9) considering notch center frequency of 5.3 GHz.

$$f_n = \frac{c}{[4C+d)-\frac{3S}{2}]\sqrt{\varepsilon_e}} \qquad (9)$$

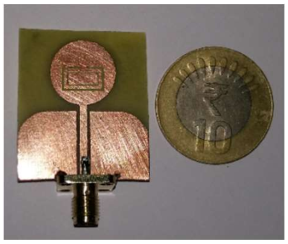


Figure 2. Fabricated prototype of proposed dual notched antenna.

Optimal values of antenna parameters are: L=35mm; W=30mm; M= 13.4mm; N= 17.54mm; O= 15.9mm; P=1.6mm; a=9.8mm; b=5.8mm; C=6.6mm; d=2.6mm; e=3.4mm; f=0.6mm; s=1.6mm; and t=0.8mm. The proposed dual notch antenna is fabricated on cheap and easily available substrate material FR 4 epoxy that has thickness of 0.8 mm, permittivity of 4.4 and loss tangent of 0.018. The fabricated antenna prototype is shown in Fig. 2.

3. Results and Discussion

The antenna without notch (ref. antenna), antenna with single notch and the proposed dual notched antenna are simulated in CST microwave studio suite simulator [10] and their respective VSWR are compared in Fig. 3. The CPW fed circular disk monopole antenna with bending in the ground plane, mentioned as reference antenna in Fig. 3, provides a wide impedance band (VSWR ≤ 2) from 3.1 to more than 20 GHz. The antenna with single slot provides impedance band from 2.9 to 17.36 GHz with notch band at 3.34-3.96 GHz whereas the antenna with dual slots provides an impedance band from 2.95 to 17.18 GHz with stop bands at 3.3-3.78 and 5-5.6 GHz as per the simulation result. The dual notched antenna VSWR is measured and plotted in Fig. 3. As per the measurement, the antenna provides an impedance bandwidth from 2.78 to 16.58 GHz with dual frequency notch bands of 3.3-3.81 and 5.05-5.52 GHz.

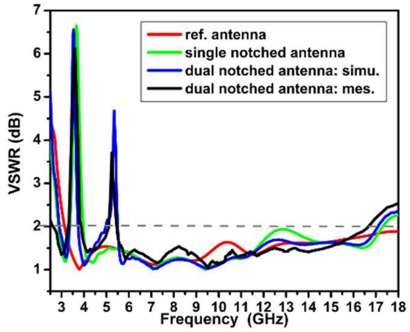
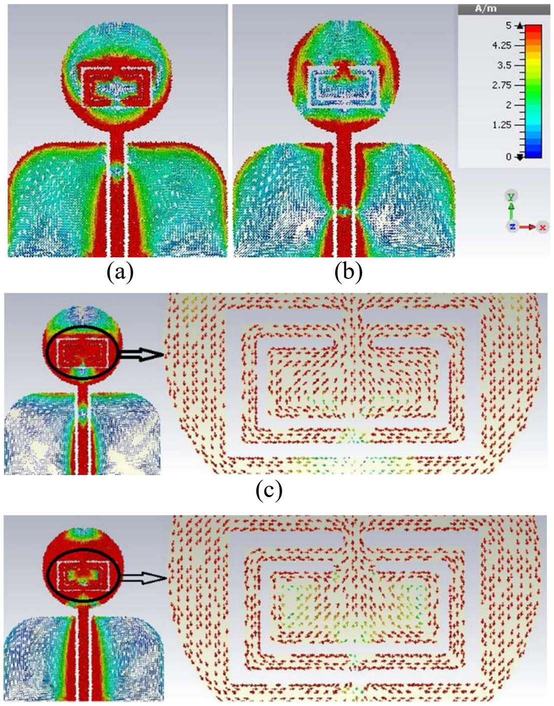


Figure 3. VSWR comparison plot of reference antenna, single notched and dual notched antenna.

The simulated surface current at WiMAX notch center frequency of 3.55 GHz and at WLAN notch center frequency of 5.3 GHz are shown in Fig. 4. Surface current at 4 and 7.2 GHz are also shown in Fig. 4. Clearly the current flow is symmetric along y-axis and more current concentration in the bended edge of ground plane along with neighbor patch portion can be seen. This observation justifies the creation of additional resonances due to the bending of ground plane upper edges. Also one half-cycle current variation along peripheral can be seen at 4 GHz that indicates the fundamental mode. At 7.2 GHz, the current distribution has more half-cycle variations but with reduced amplitude. High current concentration around slots can be seen at notch center frequencies. The current is mainly flowing in the opposite direction inside and outside the slots and thus total current become zero that indicate the creation of strong frequency resonance at those frequencies.



(a) (b)

(c)

(d)

Figure 4. Simulated surface current at (a) 4 (b) 7.2 (c) 3.55 and (d) 5.3 GHz.

Co-polarized antenna radiation patterns in E and H-plane is simulated at four different pass band frequencies of 4, 6, 7.2 and 9.5 GHz and plotted in Fig. 5. The antenna provides monopole like E-plane and omnidirectional H-plane pattern. Usual pattern starts degrading at higher frequencies (≥ 10 GHz), however the pattern band is almost covering the unlicensed UWB.

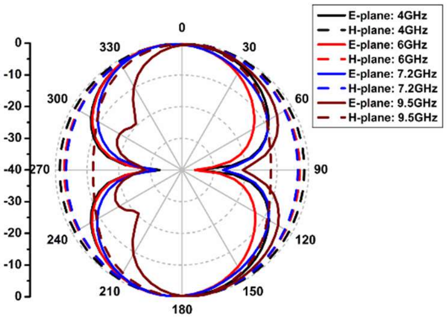


Figure 5. E-plane and H-plane co-polarized antenna radiation patterns at different pass band frequencies.

Antenna gain and radiation efficiency responses are also compared in between the reference antenna and dual notched antenna and plotted in Fig. 6 and 7 respectively. The reference antenna provides a stable gain variation of 2-5 dBi whereas the proposed dual notched antenna has similar response in pass band with major deviation in gain value in the notch bands. The reference antenna has an average radiation efficiency of about 87% in its operational band whereas the dual notched antenna provides almost similar efficiency in its pass band. Strong reduction in efficiency value can be seen in the notch bands which suggest the creation of frequency notch at that frequency bands.

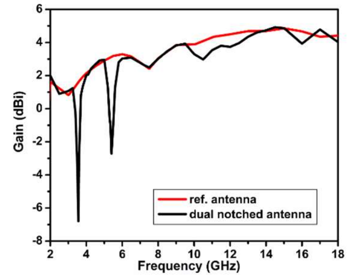


Figure 6. Simulated gain response over frequency plot.

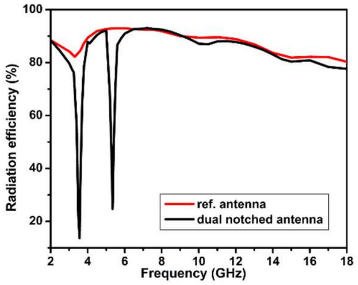


Figure 7. Simulated radiation efficiency plot of reference antenna and dual notched antenna.

The dual notched antenna performance such as its transfer function and group delay responses are studied in close proximity of ground coupling GPR test bed of dimension 34×5×1.27 cm3 using CST studio suite. A thin aluminium sheet is kept at the bottom of test bed and the test bed is then filled with dry sand and wood for two different set of investigations. The test set-up simulation model is shown in Fig. 8.

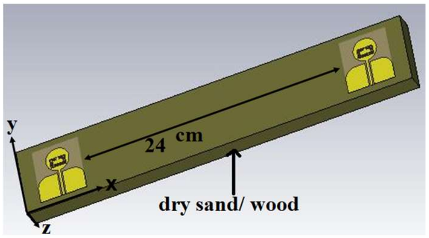


Figure 8. Schematic showing the antenna test set-up in ground coupling mode of GPR.

Transfer function (S21) and group delay response of the proposed dual notched antenna is studied without any GPR test set-up and with GPR-test set up. Two similar antenna prototype is taken where one act as transmitting and another as receiving antenna. Both the antennas are kept at a distance of 24 cm which is much more than their far field distance.

A variation of S21 not more than 10-15 dB can be considered as linear whereas a variation in group delay within 2 ns can be considered as flat. As can be seen in Fig.

9 and Fig. 10, the antenna provides linear S21 response and non-varying group delay response in the 3.1-10.6 GHz unlicensed band except in the notch bands. The responses varies significantly in the notch bands and beyond 10.5 GHz. Good agreement between the results for varying surface medium can also be seen which establish the ability of proposed antenna to work in GPR ground coupling application.

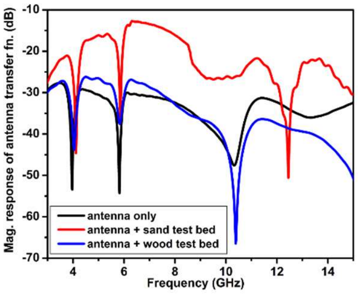


Figure 9. Magnitude response of antenna transfer function (S21) without GPR test bed and with GPR test beds.

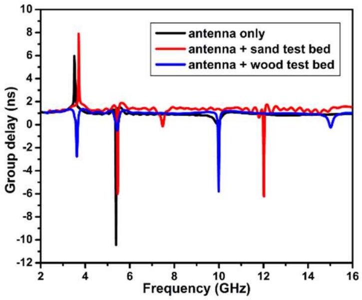


Figure 10. Antenna group delay response without GPR test bed and with GPR test beds.

4. Conclusion

A circular monopole antenna that provides wide impedance band from 2.78 to 16.58 GHz with dual frequency notch bands of 3.3-3.81 and 5.05-5.52 GHz is proposed in this article. The antenna provides monopole like radiation pattern with flat gain variation between 2-5 dBi and average radiation efficiency of 87% in its pass bandwidth. The antenna performance is suitable for scanning of thinner sub-surfaces where lateral resolution is a significant requirement. The antenna transient performance such as mag. response of transfer function (S21) and group delay is studied in close proximity of sand and wood test beds. The antenna is suitable for such ground coupling GPR application as it provides linear S21 and non-varying group delay response in the pass band, covering 3.1-10.6 GHz unlicensed ultra-wideband.

5. Acknowledgements

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6. References

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