

COMPACT PRINTED DUAL BAND-NOTCHED U-SHAPE UWB ANTENNA

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Abstract—In this article, a low cost, simple, and compact printed microstrip-fed U-shape monopole ultra-wideband antenna with dual band-notched characteristics is proposed and investigated. By introducing a spiral shaped $\lambda/4$ open stub in the microstrip feed line and a pair of L-shaped slots on the rectangular ground patch, dual band notched characteristics can be obtained respectively. The proposed antenna is successfully simulated, designed, fabricated and measured. The measured results show that the proposed antenna with dimensions of 24 mm (W_{sub}) \times 34 mm (L_{sub}) \times 1.6 mm (H) has a large bandwidth over the frequency band from 2.75 GHz to 10.6 GHz with VSWR less than 2, except 3.27–4.26 GHz and 5.01–5.99 GHz frequency bands. The proposed antenna exhibits nearly omnidirectional radiation pattern, stable gain, and small group delay variation over the desired frequency bands.

1. INTRODUCTION

UWB technology has received an impetus and attracted academia and industrial attention in the wireless world ever since FCC released a 10 dB bandwidth of 7.5 GHz (3.1–10.6 GHz) with an effective isotropic radiated power (EIRP) spectral density of -41.3 dBm/MHz. UWB systems have been allocated for the merits of high transmission rate, high capacity, and low power consumption for indoor communication applications [1]. Printed monopole antennas are good candidates for UWB communication because of its ease of fabrication, simple structure, low profile and lightweight. Over the designated bandwidth of UWB system, there are some other existing narrowband services that already occupy frequencies in the UWB band, such as

Received 9 January 2012, Accepted 12 February 2012, Scheduled 20 February 2012

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World interoperability for Microwave Access (WiMAX) IEEE802.16 operating in the 3.3 to 3.7 GHz frequency range, C band satellite communication in the 3.7 to 4.2 GHz frequency range and Wireless Local Area Network (WLAN) IEEE802.11a and High Performance Local Area Networks (HIPERLAN/2) operating in the 5.15–5.825 GHz frequency range. In some applications, UWB antenna uses filters to suppress dispensable bands. However, the uses of filters increase the complexity of the UWB system and lead to increase in cost. It is desirable to design the UWB antenna with dual notched frequency bands to minimize the potential interferences between UWB system and narrowband systems. So far, several design methods and structures have been reported [2–8]. These UWB antennas with filtering property have been proposed not only to diminish the potential interferences but also to remove the requirement of an extra band-stop filter in the system.

Recently, more and more band-notched UWB antenna designs have been proposed [9–17, 21, 22]. In this paper, we propose a low cost and compact microstrip line fed printed U-shape monopole UWB antenna with dual band-notched characteristics. The dual band-notched operations are achieved by introducing a spiral shaped $\lambda/4$ open stub in the microstrip feed line and a pair of symmetrical L shaped slots on the ground patch. The spiral stub in the radiating patch is used to reject the frequency band (3.27–4.26 GHz) limited by WiMAX and C-band systems while the symmetrical L-shaped slot on the Defected Ground Structure (DGS) is used to reject the frequency band (5.01–5.99 GHz) limited by HIPERLAN/2 and WLAN systems. The dual band rejections are thus mutually uncorrelated due to the placement of structure in different places namely in the radiating plane and the ground plane. Details of the antenna design and simulation are presented and the measured results are given in order to demonstrate the performance of the proposed antenna.

2. ANTENNA GEOMETRY AND DESIGN

The proposed UWB antenna is a variation of circular monopole antenna. Initially a circular monopole antenna of radius ' R ' is designed and optimized to achieve the desired UWB response. Since the current is mainly concentrated along the periphery of the circular monopole antenna, therefore, central portion of the circular monopole of radius ' r ' can be removed with negligible effect on impedance bandwidth or radiation characteristics and resulting in an annular ring monopole antenna. Thereafter U-shape monopole antenna is designed without affecting the UWB impedance bandwidth. The additional

space available in the central portion of the monopole provides design flexibility.

To reduce the interferences from the WiMAX systems, the band-notched function is desirable in the UWB system. By inserting a spiral shaped $\lambda/4$ open stub in the microstrip feed line, the frequency band notch for WiMAX is created. The notch frequency given the dimensions of the WiMAX band-notched feature can be postulated as

$$f_{\text{WiMAX-notch}} \cong \frac{c}{4w\sqrt{\varepsilon_{\text{eff}}}} \text{ GHz} \quad (1)$$

where $w = [t_1 + t_2 + t_3 + t_4 + t_5 + t_6 + t_7]$ is the total length of the spiral stub, ε_{eff} is the effective dielectric constant, and c is the speed of light ($= 3 \times 10^{10}$ cm/s.).

Similarly, by etching a pair of symmetrical L-shaped slots and a pair of symmetrical step slots in the rectangular ground plane of antenna, a frequency band notch for WLAN is created. L-shaped slot filter has negligible effect at other frequencies in UWB. The ground plane is beveled which results in a smooth transition from one resonant mode to another and ensures good impedance match over a broad frequency range. The dimensions of quarter-wave resonating (L shaped) slot at central band-notched frequency [11] can be postulated as

$$f_{\text{WLAN-notch}} \cong \frac{c}{4(L + 2\Delta l)\sqrt{\varepsilon_{\text{eff}}}} \text{ GHz} \quad (2)$$

$$\varepsilon_{\text{eff}} = \frac{(\varepsilon_r + 1)}{2} + \frac{(\varepsilon_r - 1)}{2} \left(\sqrt{1 + \frac{12H}{W_g}} \right)^{-1} \quad (3)$$

$$\Delta l = \frac{0.412H (\varepsilon_{\text{eff}} + 0.3) \left(\frac{W_g}{H} + 0.262 \right)}{(\varepsilon_{\text{eff}} - 0.258) \left(\frac{W_g}{H} + 0.813 \right)} \text{ cm} \quad (4)$$

where $L = [(w_L + L_L) - 0.5(w_s + l_s)]$ is the total length of the L-shaped slot and H is the substrate height in cm, ε_{eff} and ε_r are the effective and relative dielectric constants, respectively.

The physical length of spiral shaped open stub at central notched frequency 3.5 GHz is calculated using Equations (1) and (3). $\varepsilon_{\text{eff}} = 3.3$, and $w = 11.85$ mm. The length of the spiral stub using simulation is equal to $w = [t_1 + t_2 + t_3 + t_4 + t_5 + t_6 + t_7] = 12.5$ mm which is close to the calculated value. Similarly, the physical length of L-shaped slot at central notched frequency 5.5 GHz is calculated using Equations (2), (3) and (4). $\varepsilon_{\text{eff}} = 3.3$, $\Delta l = 0.18$ mm and $L = 7.14$ mm. The length of the L-shaped slot is equal to $L = [(w_L + L_L) - 0.5(w_s + l_s)] = [(4.5 + 3.75) - 0.5(0.75 + 0.75)] \text{ mm} = 7.5$ mm which is close

band notched characteristics are discussed and their parametric studies are reported in this section.

The gap between the radiating patch and the ground plane ' g ' affects impedance bandwidth because it acts as a matching network. The optimum UWB impedance bandwidth with dual band notched characteristic is obtained at $g = 3$ mm. The simulated VSWR at different g is shown in Figure 2. The WiMAX band rejection can be tuned by changing the dimensions of w and l of spiral shaped open stub. Stub spacing ' S ' also affects the frequency rejection bandwidth. The central band rejection frequency increases with decrease in w and rejection bandwidth decreases with decrease in l . These two parameters can be tuned separately to fine tune the notched band. The simulated VSWR at different S , w and l are shown in Figures 3, 4, and 5, respectively. Similarly, the WLAN band rejection can be tuned by changing the dimensions of w_L and L_L . These also

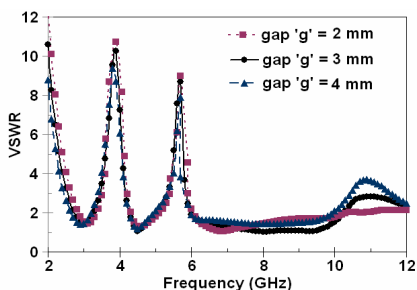


Figure 2. Simulated VSWR vs frequency at different gap ' g '.

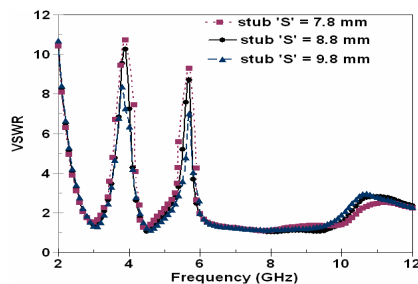


Figure 3. Simulated VSWR vs frequency at different stub spacing ' S '.

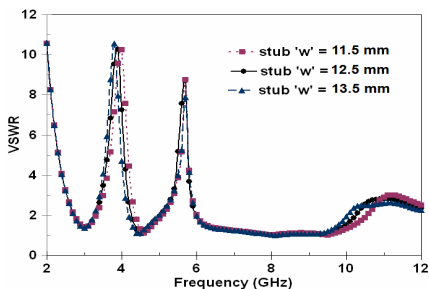


Figure 4. Simulated VSWR vs frequency at different stub length ' w '.

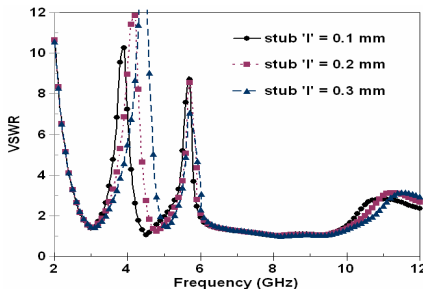


Figure 5. Simulated VSWR vs frequency at diff. stub width ' l '.

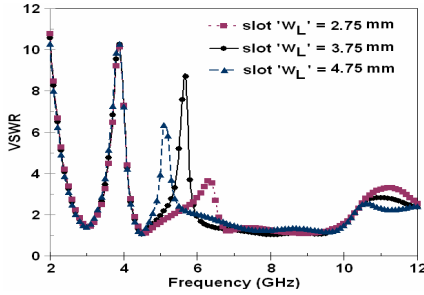


Figure 6. Simulated VSWR vs frequency at diff. ' w_L '.

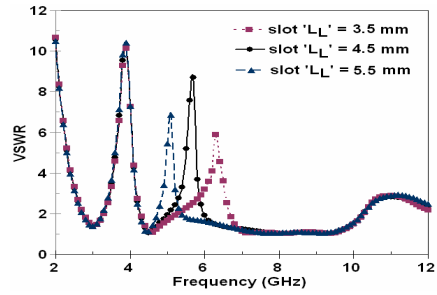


Figure 7. Simulated VSWR vs frequency at diff. ' L_L '.

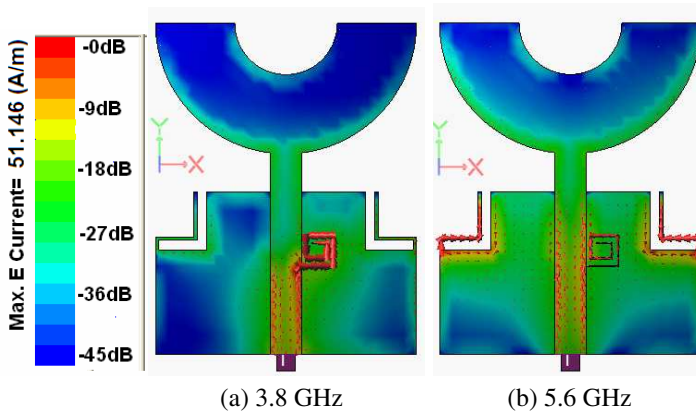


Figure 8. Surface current distribution of proposed dual band-notched U-shape UWB antenna.

affect the frequency rejection bandwidth. The central band rejection frequency increases and rejection bandwidth decreases with decrease in the dimensions of w_L and L_L . These two parameters can be tuned separately to fine tune the notched band. The simulated VSWR at different w_L and L_L are shown in Figures 6 and 7, respectively. Besides these, W_{gps} , L_{gps} , w_s , l_s , w_1 and l_1 also affect impedance matching and therefore these parameters are optimized to achieve UWB response. The symmetrical step slots on the both edge of ground plane not only enhance impedance bandwidth but also improve omnidirectional radiation pattern characteristics for UWB applications.

Figure 8 shows the simulated surface current distributions at different frequencies. At 3.8 GHz, the current mainly flows in the stub as shown in Figure 8(a) which acts as short circuit resonator.

There is little current in the radiating patch and therefore it does not radiate. The ground plane has considerable surface current which causes the antenna to be non-responsive at that frequency. At 5.6 GHz, the surface current is concentrated around the L-shaped slots as shown in Figure 8(b) which act as resonators. There is little current in the radiating patch and therefore it does not radiate. Also the ground plane has considerable surface current flowing through it which causes the antenna to be non-responsive at that frequency. Thus, the impedance of the structure is not well matched and caused large reflections which in turn result in increase in return loss and decreases in radiation efficiency and gain in stop bands. Further destructive interference between radiating patch and ground plane excited surface currents results in decrease in antenna efficiency and gain in stop bands.

4. FABRICATION AND MEASURED RESULTS

Based on the optimized parameters, the antenna structure is fabricated on an FR4 epoxy substrate with dimensions of $24\text{ mm} (W_{\text{sub}}) \times 34\text{ mm} (L_{\text{sub}}) \times 1.6\text{ mm} (H)$, a relative dielectric constant of 4.4 and loss tangent of 0.02. The proposed antenna is fed by a 50 Ohm microstrip transmission line which is terminated with a SMA connector for measurement purpose. The fabricated antenna is shown in Figure 9. The measured VSWR using Agilent 8722ET VNA and simulated VSWR of the proposed structure are shown in Figure 10. The measured results reasonably agree with simulated results. The proposed antenna shows good impedance matching over the desired bands.

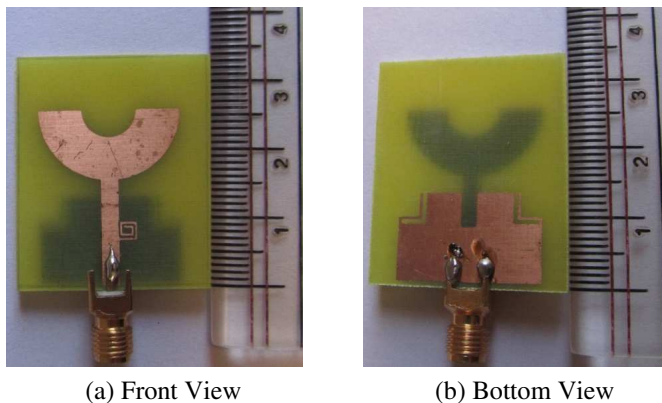


Figure 9. Photograph (prototype) of printed dual band-notched U-shape UWB antenna.

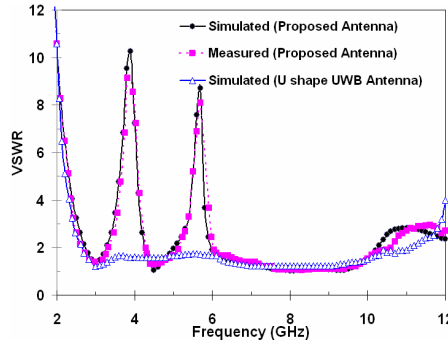


Figure 10. Simulated and measured VSWR of dual band-notched U-shape UWB antenna.

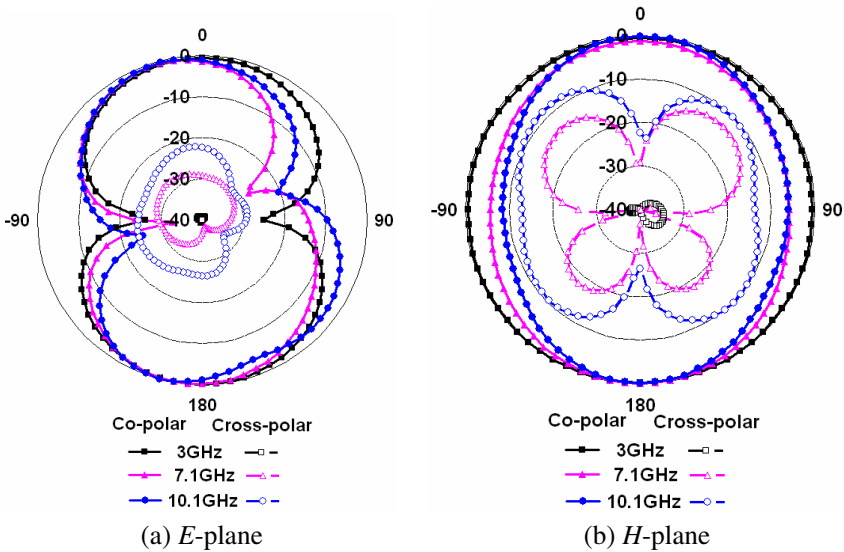


Figure 11. Radiation pattern of proposed antenna at 3, 7.1 and 10.1 GHz frequencies.

Radiation pattern and gain are measured using standard horn antennas. The normalized measured radiation patterns at 3, 7.1, and 10.1 GHz in the *E*- and *H*-planes are shown in Figure 11 while the measured gain of proposed antenna structure is shown in Figure 12. The antenna exhibits a stable omnidirectional radiation over UWB bands except in notched frequency bands. At higher frequencies, the radiation pattern deteriorates because the equivalent radiating area changes with frequency over UWB [18]. Unequal

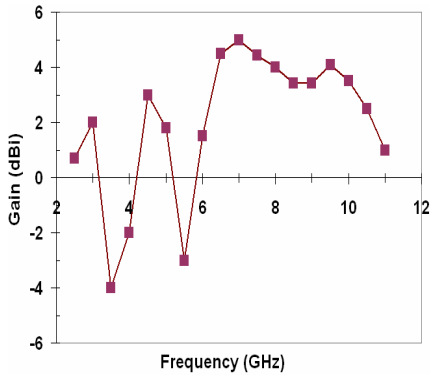


Figure 12. Measured gain vs. frequency.

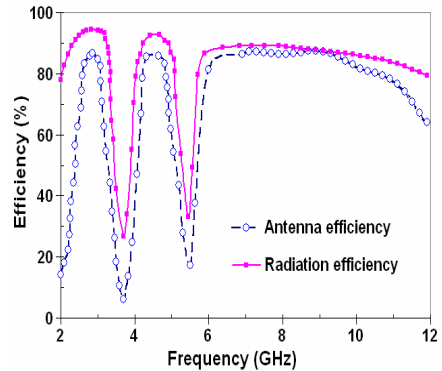


Figure 13. Simulated efficiency vs. frequency.

phase distribution and significant magnitude of higher order modes at higher frequencies also play a part in the deterioration of radiation pattern at higher frequencies. Omnidirectional characteristics and radiation bandwidth can be improved if the ground plane length is approximately the same size as that of the radiating structure width [18]. Omnidirectional characteristics and radiation bandwidth can further be improved by using a thin substrate or a substrate with low dielectric constant [19]. The proposed antenna has nearly omnidirectional radiation characteristic in the H plane and a figure of eight radiation pattern in the E plane over the desired band. The proposed antenna provides more than 85% antenna efficiency and 90% radiation efficiency except at the notched frequency bands as shown in Figure 13. The gain varies between 2 dB and 5 dB over the 2.75–10.6 GHz frequency range except in the 3.27–4.26 GHz and 5.01–5.99 GHz notched frequency bands.

The time domain performance of UWB applications is important for pulsed systems. The antenna features can be optimized to reduce their inherent pulse spreading effect. In order to evaluate the pulse transmission characteristics of the proposed dual band-notched antenna, two configurations (face to face and side-by-side orientations) were chosen. The plot of Gaussian pulse source waveform to excite the transmitting antenna, and the received pulse for both orientations are shown in Figure 14. The Gaussian pulse was generated using Tektronix AWG 7122B arbitrary signal generator and the received signal was captured by Tektronix DPO 70804 digital phosphor oscilloscope at the receiving side. The received pulses in both face to face and side-by-side orientations were almost similar. There was reduction in the amplitude and broadened in the received pulse compared to source pulse. The

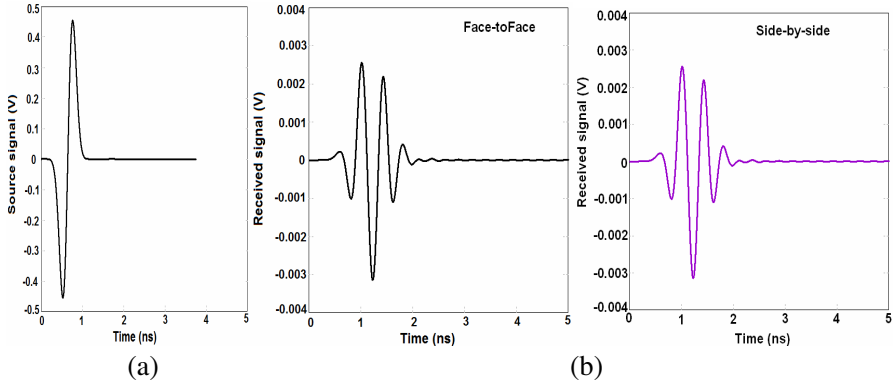


Figure 14. (a) Gaussian source pulse. (b) The received pulse (face-to-face and side-by-side orientations) at the receiving antenna.

reason for the disturbance in the received signal may be due to the noise and other disturbances present in the air channel in between the two antennas.

The group delay gives an indication of the time delay of an impulse signal at various frequencies. For group delay measurement, a pair of the proposed identical antennas used as the transmitting and receiving antennas were connected to the two ports of network analyzer. They were positioned face to face with a distance of 0.3 m and aligned in the azimuth planes at $\phi = 0^\circ$. To avoid any ground reflections, absorbing materials were being placed between the antennas. S_{21} and group delay were measured using Agilent E8364B PNA Network Analyzer. Figure 15(a) shows little variation in the measured magnitude of transfer function and Figure 15(b) shows constant group delay over the operating band except in notched frequency bands.

The fidelity factor is given by [21]

$$\rho = \max_{\tau} \left\{ \left| \frac{\int_{-\infty}^{+\infty} p(t)s(t-\tau)dt}{\sqrt{\int_{-\infty}^{+\infty} p^2(t)dt} \sqrt{\int_{-\infty}^{+\infty} s^2(t)dt}} \right| \right\} \quad (5)$$

where, τ is a delay which is varied to make the numerator in Equation (5) a maximum. It determines the correlation between the excited pulse signal $p(t)$ and received pulse signal $s(t)$. Using Equation (5), the fidelity factor for the face-to-face and side-by-side configurations were calculated and the obtained values were 0.82 and 0.80, respectively.

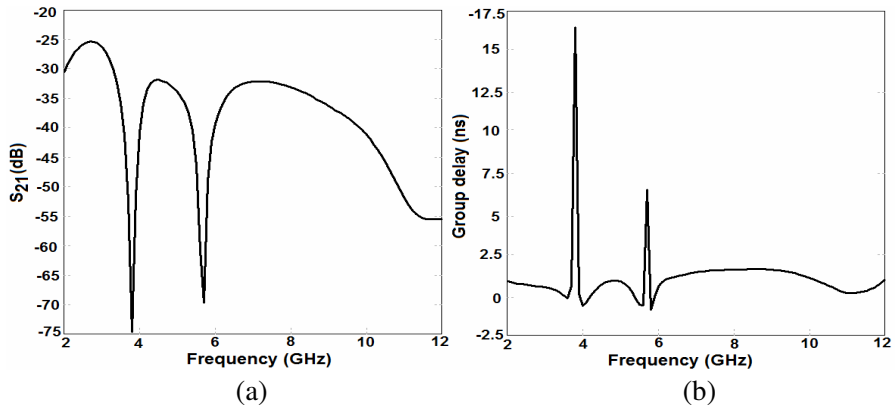


Figure 15. (a) Measured transfer function. (b) Group delay of the proposed antenna.

5. CONCLUSION

To minimize the potential interferences between the UWB system and the WiMAX-WLAN systems, a simple, low cost and compact printed U-shape monopole antenna with dual band notched characteristics is proposed and investigated. The proposed antenna can be easily integrated within the PCBs of various systems. By simply adjusting the total length of the stub in the radiating plane and the L-shaped slot on the ground plane, the desired frequency band can be controlled. The proposed antenna provides more than 85% antenna efficiency and gain varies between 2 dB and 5 dB over the 2.75–10.6 GHz range except in 3.27–4.26 GHz and 5.01–5.99 GHz notched frequency bands. The radiation patterns are nearly omnidirectional over UWB range except in the notched frequency bands. The proposed antenna, which has a simple structure, excellent performance and easy to fabricate, is suitable for various UWB applications.

ACKNOWLEDGMENT

This work is supported in part by the Department of Science and Technology (DST), India. The authors thank the efforts of the team of PCB Lab, IIT Bombay for fabrication of the structure. The authors also thank Mr. V. Srinivas Rao, Scientist, RCI, DRDO, Hyderabad, INDIA for providing measurement facilities.

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