

RESEARCH PAPER

Super wideband antenna with single band suppression

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In this paper, a band-notched compact printed monopole super wideband (SWB) antenna has been designed and fabricated. The SWB antenna composed of a radiating patch with a 50 Ω triangular tapered feed line which is connected through a feed region, and a chamfered ground plane (CGP), that covers the frequency band from 0.9–100 GHz (ratio bandwidth of 111.1:1) with a reflection coefficient $|S_{11}| < -10$ dB, except in the notched band of 4.7–6 GHz for Wireless local area network IEEE 802.11a and HIPERLAN/2 WLAN band. To realize the band notch characteristics a C-shape parasitic element is employed near the CGP etched with two symmetrical L-slots and placed under the radiating patch. Proposed antenna structure occupies a relatively small space ($30 \times 40 \times 0.787$ mm³) and achieved much wider impedance bandwidth as well as higher gain compared with the existing ultra wideband and SWB antennas.

Keywords: Band-notch function, Large impedance bandwidth, Super wideband (SWB) antenna, Triangular tapered microstrip feed line

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1. INTRODUCTION

With the entrance of many new wireless communication services in the new millennium, there will be a tremendous increase in the use of super wideband (SWB) printed monopole antennas (PMA), particularly owing to its low cost, small size, ease of fabrication, extremely wideband radiation characteristics, and omni-directional radiation pattern. To cater different services such as global positioning system (GPS), global system for mobile communications (GSM) 1800, the industrial, scientific and medical (ISM), wireless local area network (WLAN), ultra wideband (UWB) system, and satellite communication systems by the same devices, SWB printed monopole antennas will become more and more popular. Existing UWB [1] antenna can support limited number of wireless communication services and operates in the frequency band of 3.1–10.6 GHz with ratio bandwidth (RB) of 3.4:1. However, SWB antennas provide RB of more than 10:1. It was first supposedly reported by V. Rumsey in the late 1956, which was classified as a class of frequency independent antenna [2]. Currently a limited number of SWB printed monopole antennas have been proposed by the researchers across the globe [3–7]. In reference [3], to enhance the bandwidth concept of circular hexagonal fractal antenna was utilized. The designed SWB antenna achieved RB of 20.4:1 with overall dimension of $45 \times 31 \times 1.57$ mm³. Manohar *et al.* [4] designed tapered PMA (overall

dimension of $30 \times 40 \times 1.6$ mm³) with RB of 32:1 for voltage standing wave ratio (VSWR) ≤ 2 .

In reference [5] Liu *et al.* developed an asymmetric SWB monopole antenna by using dual-branch feed network that provides large bandwidth (RB of 31:1) with overall dimension of $74 \times 80 \times 1.524$ mm³. A semi-elliptical monopole antenna with overall dimension of $157.5 \times 112.5 \times 1.524$ mm³ was presented in [6] for SWB (RB of 19.7:1) applications. Chen *et al.* [7] designed (size of $35 \times 77 \times 1.6$ mm³) an egg shaped SWB monopole antenna with a bandwidth ratio greater than 12:1. Nevertheless, the major deficiencies of the above stated antennas are large volume and not easy to accommodate with the limited space provided by the future hand-held gadgets.

Unfortunately, one important issue to be noted for SWB antenna is that, it may cause electromagnetic interference to the existing narrow band WLAN operating in 5.15–5.35 GHz and 5.725–5.825 GHz bands. These narrow bands lie within the SWB band. To mitigate this interference issue, we have proposed SWB antennas with band-notched characteristics. In the last few years, several band-notched antennas have been reported by researchers across the globe [8–13]. But to author's knowledge, there are no band-notched SWB antennas reported in the literature.

In this communication, we propose a compact antenna structure for realization of SWB radiation characteristics along with notch capability. Here we demonstrate that by employing the triangular tapered feed line for the radiating patch, wider impedance bandwidth can be achieved. By cutting rectangular slots with same dimension on two sides of the partial ground plane, wider impedance bandwidth (frequency band of 0.9–100 GHz) of the proposed SWB antenna can be achieved. Proposed SWB antenna can achieve all critical requirements like SWB radiation characteristics, bandwidth and size

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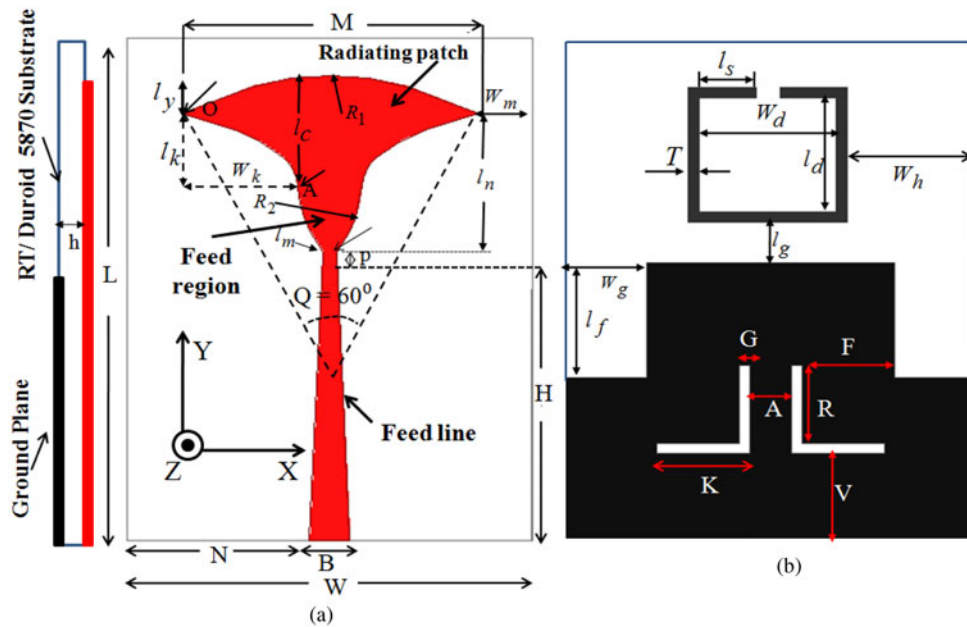


Fig. 1. Geometry of the proposed band-notched SWB monopole antenna; (a) front view and (b) back view.

reduction compared with the existing SWB antennas [3–6]. Further not to affect the band from 5 to 6 GHz used in WLAN we introduce appropriate notches at this frequency. We have used C-shaped parasitic element as well as two L slots etched in the ground plane similar to what have been reported in [10, 11]. The proposed antenna is very promising for various modern communication applications such as GSM1800 (1.71–1.88 GHz), personal communications service (PCS) (1.85–1.99 GHz), advanced wireless service (AWS)-3 (2.155–2.175 GHz), wireless communications service (WCS) (2.345–2.360 GHz), ISM (2.402–2.480 GHz), multichannel multipoint distribution service (MMDS) (2.500–2.690 GHz), UWB (3.1–10.6 GHz) and UWB vehicular radar (22–29 GHz). Due to extremely large bandwidth, the proposed SWB antenna may be used for spectrum sensing in cognitive radio [14]. The antennas were designed and optimized successfully using frequency domain three-dimensional (3D) full wave electromagnetic solver High Frequency Structure Simulator (HFSS) version 14.

II. ANTENNA CONFIGURATION

Figure 1 shows the schematic diagram of the proposed band-notched SWB monopole, which is printed on RT/Duroid

5870 substrate with a thickness (h) of 0.787 mm and a dielectric constant of 2.23 and a loss tangent of 0.0009. Proposed SWB monopole antenna structure composed of a tapered radiating patch, tapered feed region which is fed by a 50Ω triangular tapered feed line, and printed on a chamfered ground plane (CGP). Here all four parts of the proposed antenna is optimized to get large bandwidth as well as size reduction. To create the band-notched characteristics for WLAN, a C-shape parasitic element is employed, which is electromagnetic coupled to the radiating patch. To further improve the notching characteristics of the proposed antenna, two symmetrical L-slots have been placed in the CGP. To design the proposed band-notched SWB antenna we have chosen RT/Duroid substrate instead of FR4 substrate, especially for very high frequencies or millimeter wave frequencies. FR4 substrate becomes quite lossy at higher frequencies unlike RT/Duroid substrate [15]. The optimal dimensions of the proposed antennas are as follows: $L = 40$ mm, $W = 30$ mm, $H = 22$ mm, $M = 22$ mm, $l_f = 7$ mm, $W_g = 7$ mm, $l_n = 11$ mm, $l_k = 5$ mm, $W_k = 8$ mm, $R_1 = 22.7$ mm, $R_2 = 3.05$ mm, $l_y = 3$ mm, $l_c = 8$ mm, $W_m = 4$ mm, $l_m = 1$ mm, $p = 1$ mm, $N = 15$ mm, $B = 3$ mm, $T = 0.8$ mm, $W_d = 10$ mm, $W_h = 9.5$ mm, $Q = 60^\circ$, $l_d = 9$ mm, $l_g = 4$ mm, $l_s = 4$ mm, $F = 6.7$ mm, $R = 6.2$ mm, $K = 6.8$ mm, $G = 0.8$ mm, $A = 3$ mm, $V = 7$ mm.

Table 1. Comparison of the antenna size, RB, and peak gain of the proposed band-notched SWB PMA to band-notched UWB PMA.

Antenna structures	Size (mm ³)	RB	Substrate	Peak gain
Half bowtie-shaped [8]	650	5:1	FR4($\epsilon_r = 4.6$)	Around 5 dBi
Square slot-shaped [9]	1680	3.6:5	FR4($\epsilon_r = 4.4$)	Around 5 dBi
Fork-shaped [10]	1786.4	6.2:5	Not speci $\epsilon_r =$ fied ($\epsilon_r = 2.65$)	Around 6.6 dBi
Half elliptical-shaped [11]	1960	5.8:1	FR4 ($\epsilon_r = 4.4$)	Around 6 dBi
Square-shaped [12]	528	6:1	FR4 ($\epsilon_r = 4.4$)	Around 5 dBi
Rectangular-shaped [13]	1056	3.7:9	FR4 ($\epsilon_r = 4.6$)	Around 5 dBi
Rectangular slot-shaped [14]	320	3.5:1	FR4 ($\epsilon_r = 4.4$)	Around 4.5 dBi
Proposed antenna	944	111.1:1	RT/Duroid ($\epsilon_r = 2.23$)	Around 7 dBi

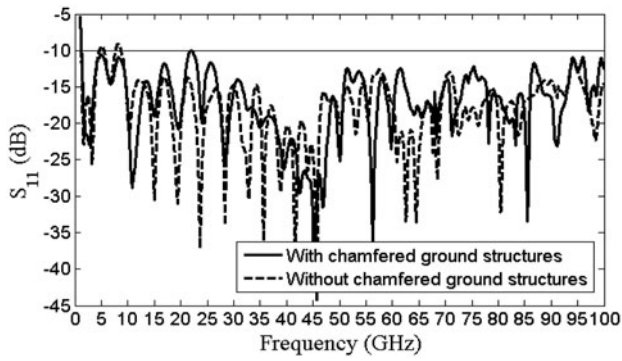


Fig. 2. Simulated return loss for the proposed SWB antenna with and without CGS.

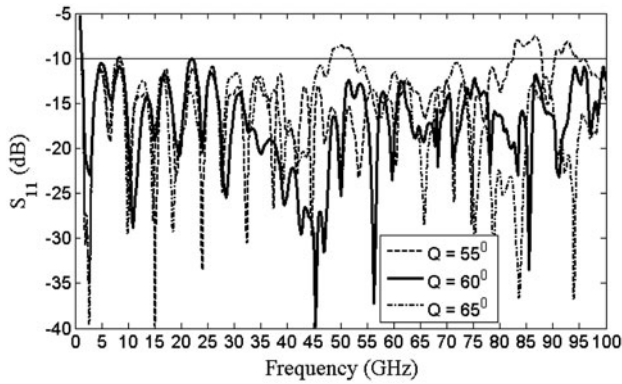


Fig. 3. Simulated return loss for the proposed SWB antenna with various circular arc angles (Q).

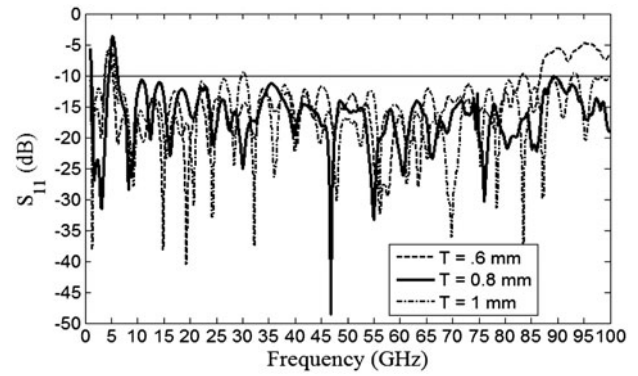


Fig. 5. Simulated return loss for the proposed band-notched SWB antenna with different arm width (T).

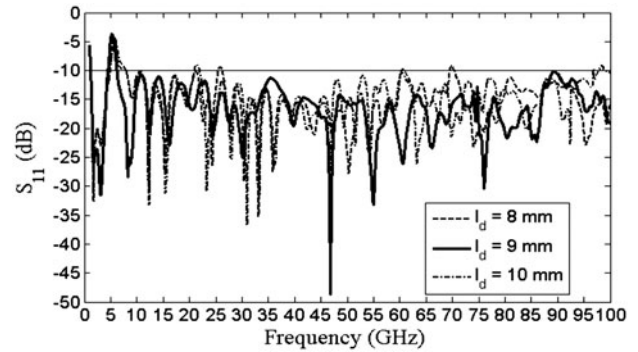


Fig. 6. Simulated return loss for the proposed band-notched SWB antenna with different arm length (l_d).

III. ANTENNA DESIGN CONCEPT

In this section, first we will explore about SWB PMA which covers the frequency range from 0.9 to 100 GHz. Then the band-notched functionality will be discussed (Table 1).

A) Methodology to achieve SWB

In the present antenna configuration i.e. Fig. 1, a feed region connection, between the feed line and, then radiating patch, was brought in to improve the antenna's performance. Due to optimal tapered [16] (Raicu's universal taper) connections

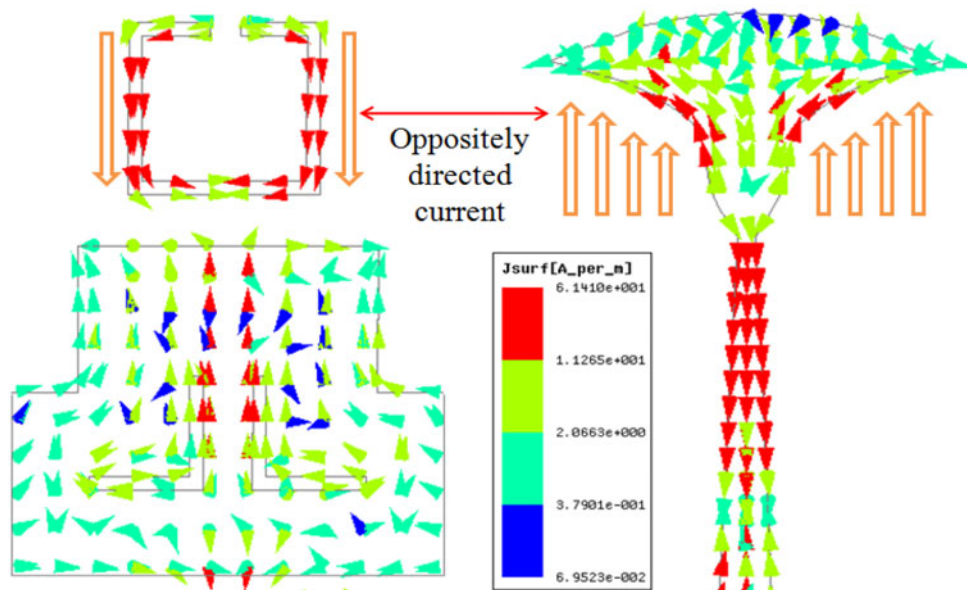


Fig. 4. Simulated current distribution at notch frequency 5.35 GHz.

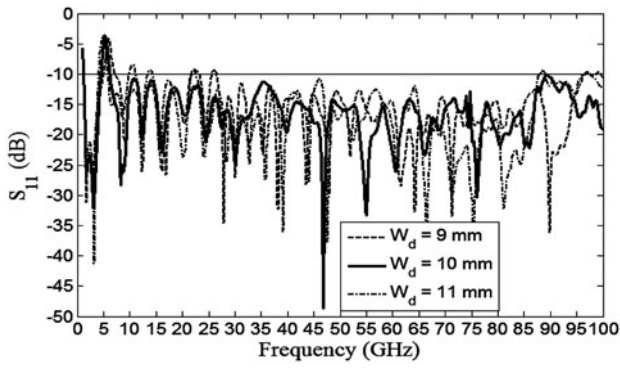


Fig. 7. Simulated return loss for the proposed band-notched SWB antenna with different arm width (w_d).

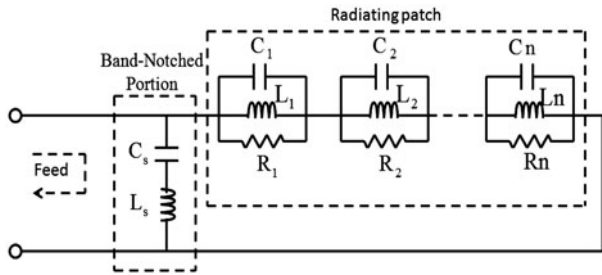


Fig. 8. Equivalent circuit model of the proposed band-notched SWB PMA.

between the feed line and the main patch, broad impedance bandwidth is obtained. The triangular tapered feed line is also used in order to improve the impedance matching. Moreover, it could be noticed that chamfered ground structures (CGS) i.e. two symmetrical rectangular slot cuts in partial ground plane are also responsible for the wider impedance bandwidth of 0.9–100 GHz (bandwidth ratio of 111.1:1) except in the notched band of 4.7–6 GHz. To get the length of the tapered line ($l_p = H + p$), method reported in [4] is followed. If Z_L and Z_o be the antenna load impedance and characteristic impedances of the feed line, then the impedance function of triangular tapered feed line is obtained from the equation given below [17, 18]

$$Z(z) = f(x) = \begin{cases} Z_o^{2(Z/l_p)^2} \ln Z_L/Z_o, & \text{for } 0 < z < l_p/2 \\ Z_o e^{\left(\frac{4z}{l_p} - \frac{2z^2}{l_p^2} - 1\right) \ln Z_L/Z_o}, & \text{for } l_p/2 < z < l_p \end{cases} \quad (1)$$

Relating this impedance function to $\Gamma(\theta)$ function will result in equation (2). A closed form solution of the Riccati equation for triangularly tapered feed line is given in [17]

$$\Gamma(\theta) = \frac{1}{2} e^{-j\beta L} \ln \left(\frac{Z_L}{Z_o} \right) \left[\frac{\sin \left(\frac{\beta l_p}{2} \right)}{\frac{\beta l_p}{2}} \right]^2, \quad (2)$$

where $\Gamma(\theta)$ is the reflection coefficient, β is the phase constant and l_p is the triangular tapered feed line length. In designing the radiating patch, an elliptical curve has been employed

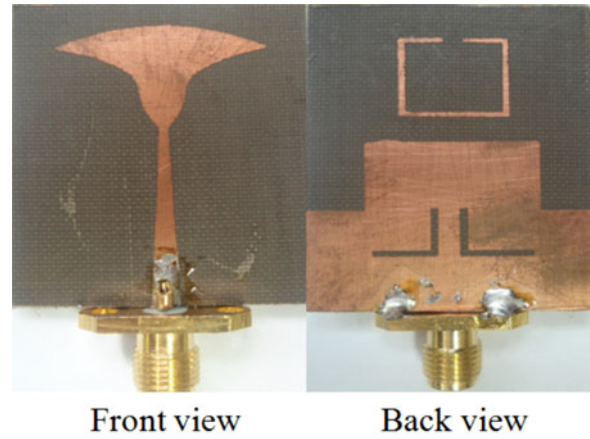


Fig. 9. Photograph of the fabricated prototype band-notched SWB antenna.

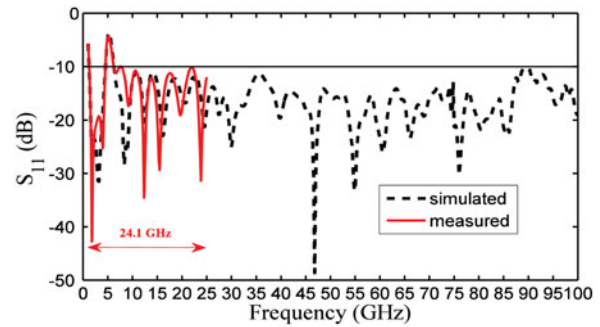


Fig. 10. Measured and simulated return loss for the proposed band-notched SWB monopole antenna.

for the design of main patch depicted in Fig. 1. The quarter elliptical arcs begin with the x and y radius and ends with the elliptical arc. The arc length of the quarter elliptical can be obtained by

$$OA = \frac{\pi}{4} \sqrt{4 \left(\frac{l_k^2}{2} + \frac{W_k^2}{2} \right)}, \quad (3)$$

where OA is the perimeter of the quarter ellipse and the value of OA = 10.5 mm with l_k and W_k as the minor and major radius. To get the SWB antenna behavior, there are many parameters that have been optimized, which can affect the impedance matching characteristics of the proposed antenna. Figure 2 demonstrates the simulated return loss for the proposed monopole antenna design of Fig. 1(a) with and without defected ground structures (DGS). It can be seen that in the absence of DGS, the behavior of $|S_{11}| > -10$ dB at frequency band (3.5–6.5 GHz). By placing two slots in the ground plane it can be observed that the slots can adjust the electromagnetic coupling effects between the monopole and the ground plane and improve its impedance bandwidth across the whole spectrum as shown in the Fig. 2. Figure 3 depicts the simulated return loss for the proposed monopole antenna with various circular arc angle (Q). When the circular arc angle (Q) increases from 60° to 65° , approximate wide impedance bandwidth is provided between 0.9 and 47 GHz, however impedance matching becomes worse between 47 and 53 GHz. As $Q = 60^\circ$, the

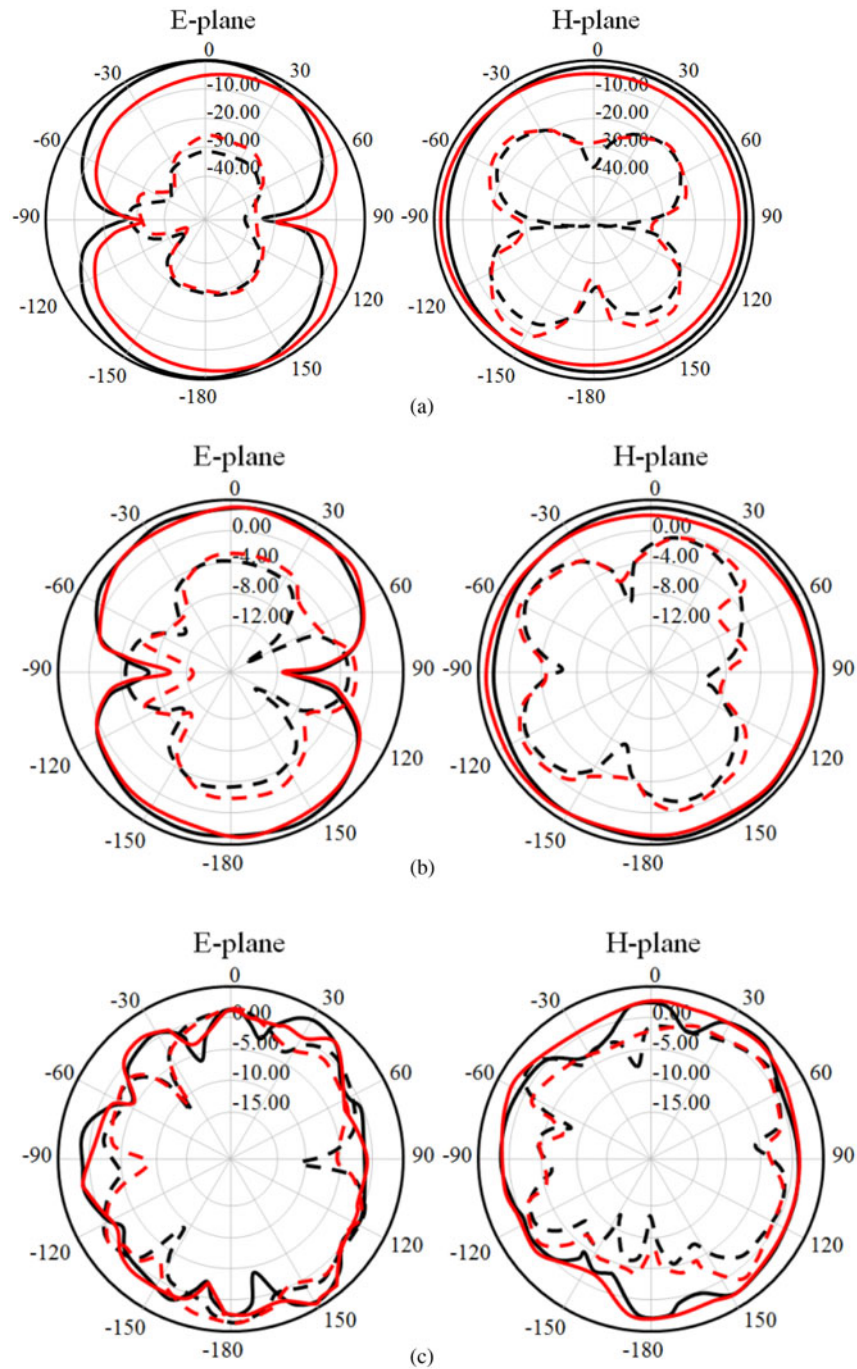


Fig. 11. Simulated and measured radiation pattern for the proposed band-notched SWB antenna (red color: simulation, black color: experimental, solid line: co-polar and dashed line: cross-polar).

super wide impedance bandwidth is achieved from 0.9 to 100 GHz. While, circular arc angle (Q) decreases from 60° to 55° , $|S_{11}| > -10$ dB between (82–87 GHz and 90–95 GHz).

B) Study of band-notched function design

Band-suppression characteristic over the whole interference band is realized by the C-shape parasitic element in the back plane of the substrate, which is electromagnetically coupled to the main patch. The C-shape parasitic element acts as a half-wave resonant structure and can perturb the

current distribution at certain frequency band (4.7–6 GHz), where the band-notched characteristics of the antenna are expected. Further increasing the strong rejection at the band-notch region (4.7–6 GHz) two symmetrical L-slots are etched with CGS. Band-notched characteristics can be achieved by tuning the parameters W_d , l_d , T , and l_s . A dimension of the C-shaped parasitic elements is selected according to the following expression

$$f_n \cong \frac{c\sqrt{\epsilon_r}}{2V} = \frac{3 \times 10^8 (\sqrt{\epsilon_r})}{2(W_d + 2l_d + 4T + 2l_s)}, \quad (4)$$

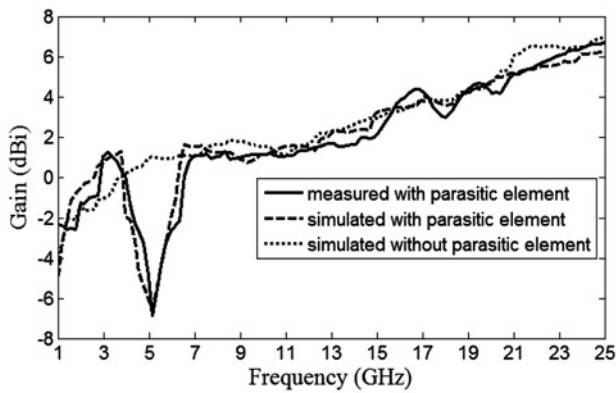


Fig. 12. Measured and simulated peak gain for the proposed band-notched SWB monopole antenna.

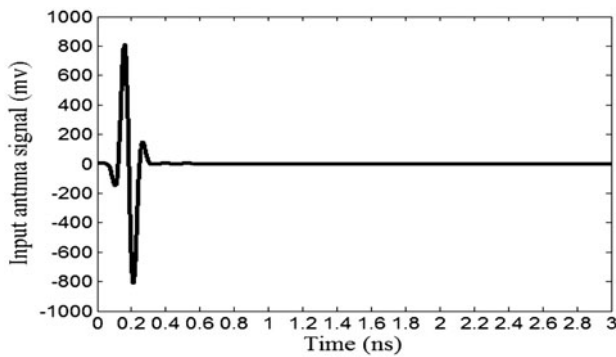


Fig. 13. Fifth-order-derivative Gaussian input.

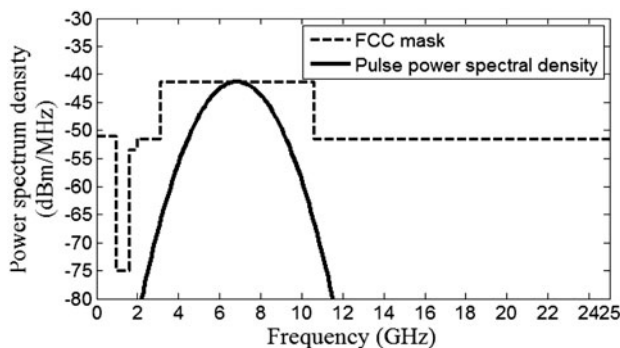


Fig. 14. Power spectral density.

where V is the physical length of C-shape parasitic element and f_n is the corresponding band-notch frequency (5.35 GHz). W_d , l_d and T is the width, length, and thickness of C-shape parasitic element. Figure 4 demonstrates the simulated surface current distribution for the proposed monopole antenna at the band-notched center frequency of 5.35 GHz. It can be seen that current flows on the C-shape parasitic element are more egregious around notch frequency and they are opposite in direction (out-of-phase) to the current flow on the main patch, which can easily cancel out the radiated field and offers strong attenuation near the notched frequency and

makes it as a non-responsive antenna at the notch frequency of 4.7–6 GHz. To understand more about antenna characteristics on the band-notched portion, we change one parameter at a time, fixing the others. Figure 5 exhibits the simulated return loss of various values of length l_d of the C-shape parasitic element. The values of l_d are varied from 8 to 10 mm. In this arrangement, center of the notched frequency changes from 5.35 to 5.8 GHz as l_d changes from 9 to 8 mm. Rejection band is tuned at $l_d = 9$ mm. The simulated return loss for different values of T for C-shape parasitic element is plotted in Figure 6. It is observed for T value greater than 0.8 mm the notch frequency shifts 0.6 GHz lower to band-notch frequency.

However, by decreasing the value of T from 0.8 to 0.6 mm center of the notched frequency decreases by 0.4 GHz. The optimum value of T is taken as 0.8 mm. The simulated reflection coefficient versus the operating frequency for different widths W_d of the C-shape parasitic element is plotted in Fig. 7. It can be seen that for W_d values smaller than 10 mm notch frequency shifts 1 GHz higher the band-notch region and provide much wider notch characteristics i.e. 4.7–7 GHz. This wide notch-band unnecessarily blocks usable frequencies from 6 to 7 GHz. However, when the width (W_d) of the C-shape parasitic element increases from 10 to 11 mm notched frequency decreases. We have also designed equivalent circuit model [20] for the band-notched SWB antenna as shown in Fig. 8. In this model SWB impedance characteristics can be achieved due to several resonances excited by the SWB antenna and each resonance can be modeled as a parallel RLC circuit [20], while the band-notched portion is modeled as a series LC circuit.

VI. SIMULATION AND EXPERIMENTAL RESULTS

In order to validate the results of the proposed band-notched SWB antenna, first we have simulated the proposed antenna using HFSS in both frequency and time domain and then compared with measured results.

A) Frequency domain performance

The photograph of the fabricated antenna is shown in Figure 9. It is simulated with the 3D electromagnetic simulation software HFSS and measured with vector network analyzer (Agilent ZVA 24). Figure 10 shows simulated and measured return loss of the proposed band-notched SWB antenna. From the Fig. 10 it is observed that the antenna provides broadband performance (frequency bandwidth from 1 to over 25 GHz) with band-notch from 4.7 to 6 GHz. Figure 11 displays three far-field radiation patterns in the E -plane and H -plane at three different frequencies (a) 3.1 GHz, (b) 10 GHz, and (c) 20 GHz. The proposed antenna has a nearly omni-directional pattern and low cross-polarization level in the H -plane radiation pattern at frequencies 3.1 and 10 GHz. E -plane radiation patterns shows a typical bidirectional (figure- of-eight) at frequencies 3.1 and 10 GHz. However, at frequency 20 GHz, antenna generates multi-nulls in the E -plane and H -plane and also the cross-polarization level increases with higher frequencies. Overall the proposed SWB monopole antenna exhibit approximately stable radiation patterns and behaves similarly to the typical planar

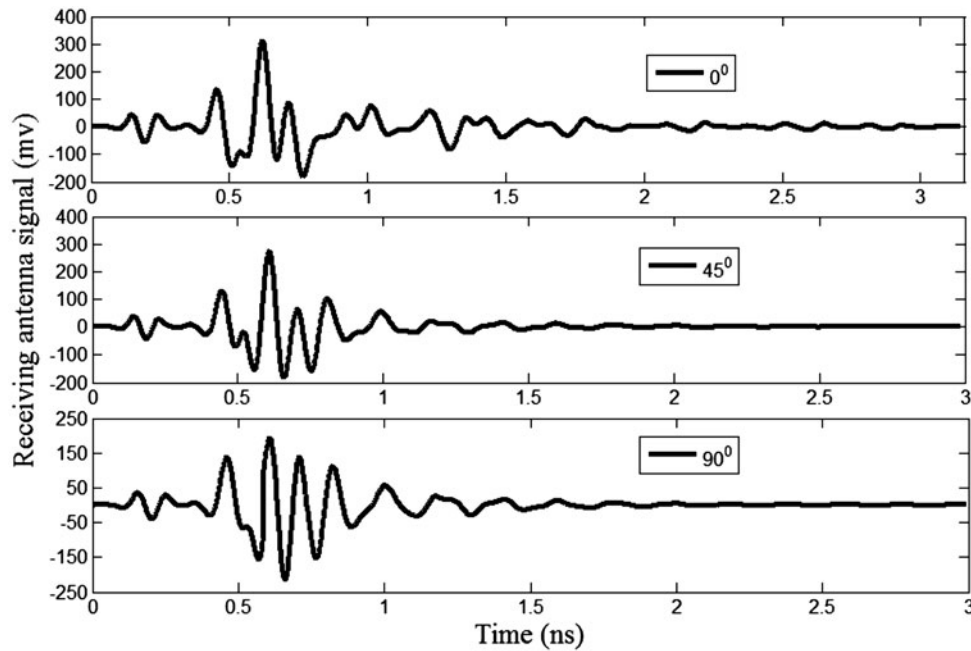


Fig. 15. Measured receiving antenna signals for the proposed band-notch antenna with different orientations $\theta = 0^\circ$, 45° , and 90° .

monopole antennas. Figure 12 presents the measured and simulated peak gain with and without parasitic element for the proposed band-notched SWB antenna. It is found that the measured antenna gain is about -2 dBi at 1 GHz. It increases with frequency and attains 7 dBi at 25 GHz. Antenna gain decreases abruptly at the center frequency of 5.35 GHz, which shows appropriate band-notch for coexistence with WLAN appliances.

B) Time domain performance

In order to comprehend the time-domain analysis, two identical antennas were utilized as transmitter and receiver. They are separated by a distance of 60 cm and kept at three different orientations 0° , 45° , and 90° . Figures 13 and 14 shows the fifth-order-derivative Gaussian input pulse waveform in time domain and its power spectral density (dBm/MHz) with reference to federal communications commission (FCC) mask. To verify the FCC spectral mask for indoor systems, the antenna is assumed to be excited by the UWB signal as suggested in [21].

This UWB signal is the fifth derivative of the Gaussian pulse and is given by (5)

$$G_5(t) = A \left(-\frac{t^5}{\sqrt{2\pi}\sigma^{11}} + \frac{10t^3}{\sqrt{2\pi}\sigma^9} - \frac{15t}{\sqrt{2\pi}\sigma^7} \right) \cdot \exp\left(-\frac{t^2}{2\sigma^2}\right). \quad (5)$$

Here, C is a constant that can be chosen to comply with peak power spectral density that the FCC will permit. σ has to be 51 ps to ensure that the shape of the spectrum complies with the FCC spectral mask. Figure 15 shows the measured receiving antenna signal for the proposed band-notched antenna with different orientations, i.e. $\theta = 0^\circ$, 45° , and 90° . Ringing distortion has been observed in the received signal

as shown in Fig. 15. At 0° orientation, received signal amplitude is 320 mV. However at 45° and 90° orientations, received signals amplitude are 300 and 200 mV, respectively.

V. CONCLUSION

A compact band-notched printed SWB monopole antenna has been proposed and extensively investigated in this paper. We have used triangular tapered feed line for broadband matching. In the feed region, we have used Raicu's universal taper for best and optimal taper. Thereby we can achieve SWB impedance matching from 0.9 to 100 GHz (bandwidth ratio of 111.1:1), except in the notched band of 4.7–6 GHz. With proper and simple C-shaped parasitic element integrated with ground plane, a band-notched performance from 4.7 to 6.0 GHz can be achieved. It helps in coexistence of SWB communication with WLAN devices. Both these devices can be deployed in the same area without any interference. The designed antenna has a simple configuration and compact in size compared with conventional structure.

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