Super-Wideband Antenna with Triple Band Notched Functionality Through L-X Bands

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***Abstract*—In this paper a super-wideband (SWB) monopole antenna design is presented with integrated triple-band notching characteristics. The proposed antenna comprises a standard circular patch which is loaded with various slot artifacts that include multiple split-ring resonators (SRR), a rotated Γ-shaped slot, and embedded in the feedline is a rotated S-shaped slot. The ground-plane of the antenna is truncated. The SSR slots excite band stop function at the WiMAX bands. The Γ-shaped slot and the S-shaped slot in the feedline introduce band notches in the L, S and X-bands. With this technique notch bands can be inserted at low frequencies such as L-band without affecting the antenna size. The proposed planar antenna is relatively small having a surface area of 20 × 24 mm². The measured results confirm the proposed antenna has an impedance bandwidth between 0-14 GHz for which the return loss ≤-10 dB, and in the non-notch regions of the spectrum the antenna has a gain of 5.5 dBi and efficiency of 92%. The radiation pattern of the antenna however varies with frequency but maintaining a wide coverage. The radiation pattern in the E-plane is partially omnidirectional at lower frequencies however become progressively multidirectional with increase in frequency. The H-plane radiation pattern is quasi-bidirectional and with increase in frequency the pattern changes but remains essentially quasi-bidirectional.**

***Keywords*—Super wideband, Planar antenna, Notched antenna, 5G, WiMAX, C-Band, X-Band.**

I. INTRODUCTION

Wireless communication is made possible with antennas without which it's not possible to interface radio waves propagating through space and the transmitter/receiver. This makes antennas a fundamental component of wireless systems. Two decades ago in 2002, the federal communications commission (FCC) made available the electromagnetic spectrum covering the frequency range from 3.1 to 10.6 GHz for ultra-wideband (UWB) technology [1]. The large bandwidth of the UWB systems provides high data rates of up to 1 Gbit/s within a 10-meter radius for wireless personal area communications.

With the deployment of fifth generation (5G) mobile systems there is now an increasing demand for much higher data rate, capacity and resolution. As a result, super wideband (SWB) systems with enhanced radiation characteristics are capturing great importance [2]. Moreover, SWB systems can offer a pervasive service by covering both short and long-range data transmission [3]. In comparison to UWB, the SWB technology can offer significantly increased channel capacity and a superior resolution [2]. As SWB systems are multi-functional and operate with multiple wireless communications standards, the stringent requirement for such systems is to have a low-profile antenna that can simultaneously accommodate various technologies including global positioning system (GPS) and radio frequency identification (RFID). However, such systems pose a significant challenge due to the exceedingly stringent regulations about efficiency, size and bandwidth.

Interference is a serious problem for both UWB and SWB systems. It is therefore necessary to notch-out portions of the band to avoid interference with the existing wireless networking technologies such as WiMAX [4]. This is due to the fact that UWB and SWB transmitters should not cause any electromagnetic interference and vice versa. Therefore, UWB and SWB antennas with notched characteristics have been implemented with various techniques.

Numerous techniques have been employed in the development of antennas to block unwanted frequencies. Examples of various techniques to do this reported in literature include the use of split-ring resonators (SRR) [5, 6], complementary split-ring resonators (CSRR) [7], open-loop resonators [9] and discreet filters [9]. The use of discrete filters is undesirable as it introduces an additional component which increases the size of the antenna. In [10] the frequency between 5.2-5.8 GHz is suppressed by etching an omega-shaped slot on the planar antenna. Similarly, in [11] U-shaped slots are embedded on the patch antenna to block multiple frequencies. In [12] the authors use a curved-shaped slot to notch the WiMAX and WLAN bands. To realise notching feature over 5.10-5.94 GHz, an S-shaped slot is applied in the feedline of the monopole antenna in [13]. In [14] filter characteristics of band stop and bandpass are created using SSR. In [6] uplink and downlink satellite frequency bands are rejected with a single SRR slot implemented in the patch antenna. Three different frequency bands are notched in [15] by embedding multiple split rings near the feedline of the antenna model. In [16] a triple band notched UWB monopole antenna is realized by embedding elliptic CSRR and rectangular split rings in the antenna structure. The antenna has impedance bandwidth covering the entire UWB range (3.1–10.6 GHz), along with notch-bands in the WiMAX, WLAN, and X-band frequencies. The issue with the above techniques is that they cannot be used to block much lower frequencies in the L-band without affecting the overall antenna size.

This paper presents a singular SWB monopole antenna with three integrated stop bands. This is achieved using a combination of slots and split-ring resonators that are strategically located on the patch antenna to suppress unwanted signals in the L, S and X-bands. This is achieved loading the antenna with split-ring and Γ-shaped slots and inserting an S-shaped slot in the feedline. The antenna's performance was verified through simulation and measured results. The rest of the paper is organised as follows: Section II gives details on the antenna's geometry and the implementation of the notched bands. In Section III, the proposed antenna's salient features are discussion and compared with other similar type of antennas reported in literature. The work is finally concluded in Section IV.

II. Proposed Antenna Design

The proposed antenna is based on a circular-shaped monopole antenna with a truncated ground plane. The antenna is constructed on a standard dielectric substrate (Rogers RO3003) with a thickness of 1.6 mm, a relative permittivity of 3 and thickness of 1.6 mm. Radius of the circular monopole antenna is 14 mm. The patch antenna is defected with three different shaped slots that are strategically located on it, as shown in Fig. 1. The slots on the patch include five split-ring resonators and a rotated Γ-shaped slot. These slots are used to reject signals in the L, S and X-bands. Embedded in the feedline is a rotated S-shaped slot that is used to suppress signals in the X-band. The evolutionary steps taken to design the proposed SWB antenna are shown in sequence in Fig. 2. The geometry and locations of the slots on the monopole antenna are important in determining the impedance bandwidth and the selectivity of the notching bands. The antenna was optimised using CST Microwave Studio. The optimised dimensions of the antenna are given in Table I. The overall antenna has dimensions 20×24×1.6 mm^3.

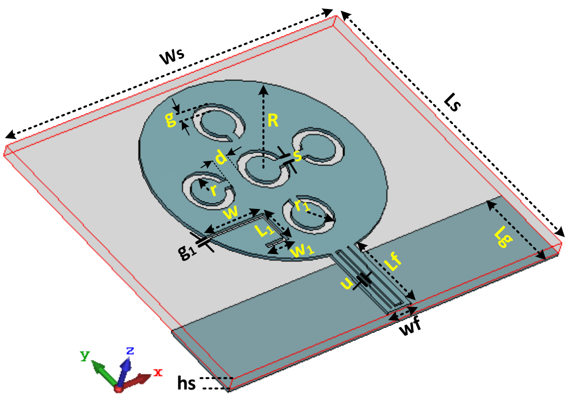


Fig. 1. Geometry of the proposed UWB monopole antenna.

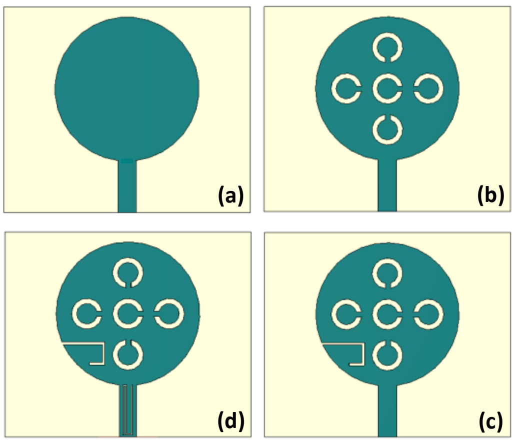


Fig. 2. Design iterations taken to design the proposed SWB monopole antenna, (a) Antenna 1 is a standard circular patch, (b) Antenna 2 is modification of Antenna 1 with SRR, (c) Antenna 3 is Antenna 2 with slot line, and (d) Antenna 4 is Antenna 3 with feedline slot.

The proposed SWB antenna design was simulated using CST Microwave Studio. It is evident from the simulation results in Fig. 3 that Antenna 1 provides super wideband performance for $S_{11} \leq$ -10 dB. By inserting the five split-ring resonators in Antenna 2, rejection characteristics are achieved in the X-band. By applying a rotated Γ-shaped slot in the lower left-hand quadrant of the circular patch the signals in the WiMAX band across 3.3-3.7 GHz are strongly suppressed. Finally, by inserting a rotated S-shaped slot in the feedline of the antenna, rejection characteristics are achieved in L and S-bands. The length of the various slots are determined using the following approximate expression

$$L_s = \frac{\lambda_o}{2\sqrt{\varepsilon_r}} \qquad (1)$$

Where L_C is the length of the rotated Γ-shaped slot, L_S is the length of the rotated S-shaped slot, λ_o is the wavelength in free-space at the required notch frequency of interest, and ε_r is the dielectric constant of the substrate.

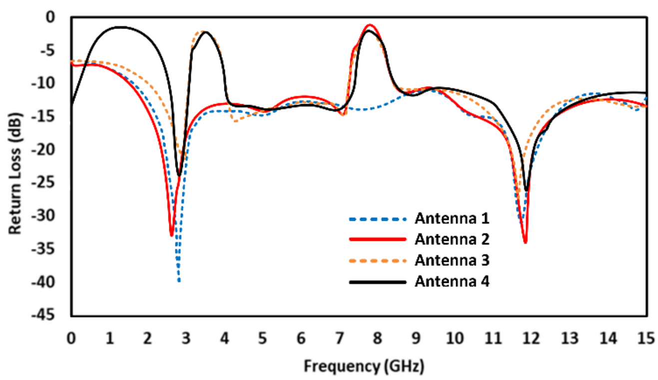


Fig. 3. Simulated return loss comparing the four antenna iterations.

Table I. Dimensions of the proposed UWB monopole antenna.

Parameters	Value (mm)	Parameters	Value (mm)
s	1.3	g_1	0.5
Ls	41	*R*	14
d	2	r_1	2.3
g	1	*Lf*	15
L_1	7	*u*	0.2
hs	1.6	*Lg*	10
r	2	*wf*	3
W	12	w_1	4

III. Results and Discussion

The simulated and measured reflection coefficient of the proposed SWB antenna with triple-band notching is shown in Fig. 4. It is evident from the plots that the impedance bandwidth of the antenna extends from 0-14 GHz for $S_{11} \leq$ -10 dB with notching at the L-band & partially S-bands (0.5-2.5 GHz), WiMAX bands (3.3-3.6 GHz), and partially X-band (7.3-8.4 GHz). There is excellent agreement between the simulated and measured results.

The measured gain and efficiency of the proposed SWB antenna is shown in Fig. 5. It shows that with the exception over the notched bands, the gain of the antenna varies from 2 to 7 dB. The peak gain of the antenna in the notched bands is less than 0 dB. In the non-notch regions, the antenna gain is 5.5 dBi and efficiency is 92%.

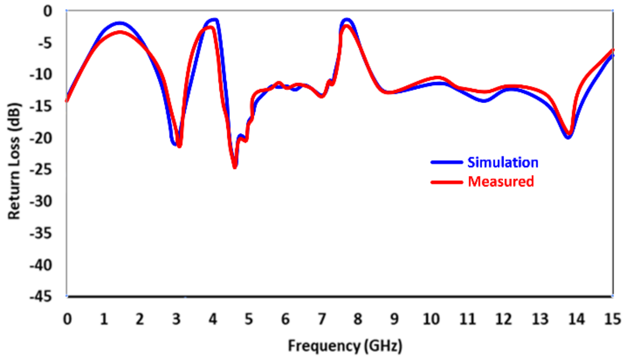


Fig. 4. Simulated and measured return loss of the proposed SWB antenna.

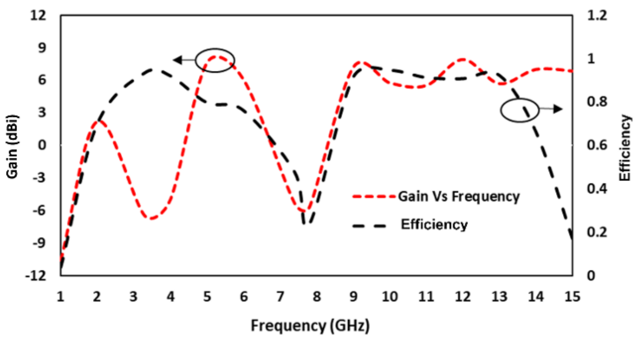
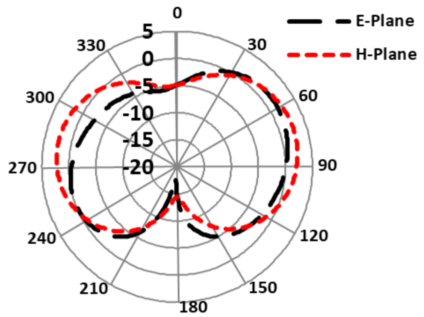
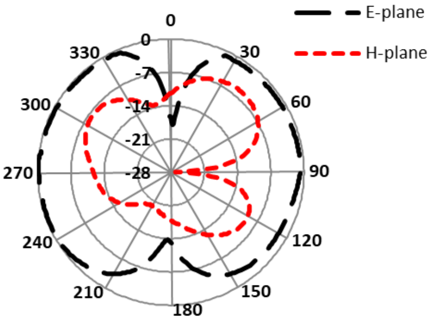


Fig. 5. Gain response of the proposed UWB monopole antenna.

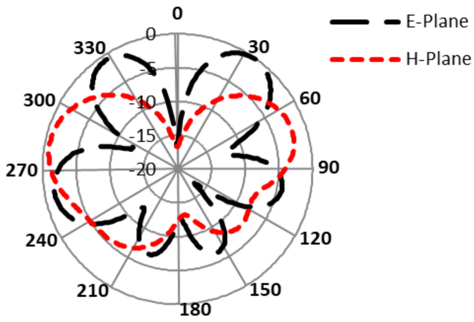
The measured polar radiation plots of the proposed SWB antenna in the E- and H-planes at 3.7 GHz, 4 GHz, and 7.6 GHz are shown in Fig. 6. The plots show the radiation pattern of the antenna varies with frequency. The radiation pattern in the E-plane is partially omnidirectional at lower frequencies however become progressively multidirectional with increase in frequency. The H-plane radiation pattern is quasi-bidirectional and with increase in frequency the pattern changes but remains essentially quasi-bidirectional.



(a)



(b)



(c)

Fig. 6. Polar plots of the UWB antenna with frequency notches at (a) 3.7 GHz, (b) 4 GHz, and (c) 7.6 GHz.

The simulated 3-dimensional plot of the antenna at the un-notched frequency of 6 GHz is shown in Fig. 7. It shows that at this frequency the antenna strongly radiates bidirectionally with a peak gain exceeding 5 dB.

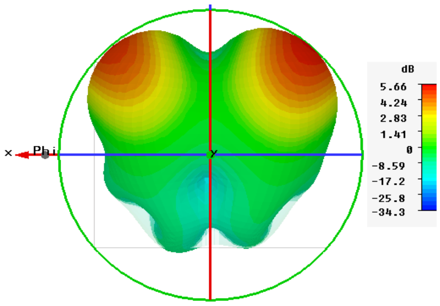
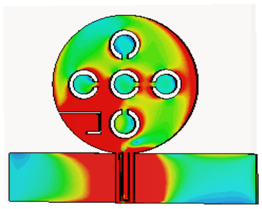
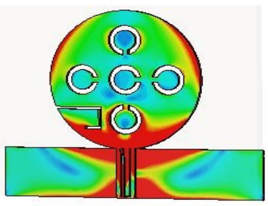


Fig. 7. 3D view of the proposed radiating SWB antenna at 6 GHz.

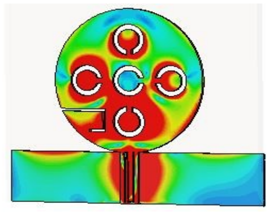
The surface current distribution over the antenna at the three notched bands is shown in Fig. 8. The red shaded regions show areas over the antenna where the current concentration is the heaviest. Fig. 9 shows the front and back photographs of the antenna.



(a)



(b)



(c)

Fig. 8. Surface currents over the SWB antenna at (a) 3.7 GHz, (b) 4 GHz, and (c) 7.6 GHz.

The proposed SWB antenna is compared with similar type of antennas reported in literature. From the table it can be observed the size of the proposed antenna is comparable to [17] however the proposed antenna can accommodate much lower frequency using a relatively small structure.

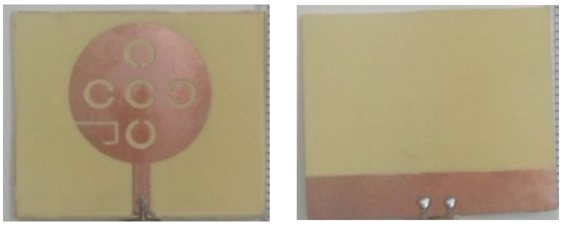


Fig. 9. Photograph of the proposed SWB antenna, (a) front view, and (b) back view.

Table 2. Comparison table of the proposed antenna with other UWB monopole antennas reported in literature

Ref.	Size (mm^2)	Notched band ranges (GHz)	Remarks
[17]	20 × 26	3.4 - 3.9 5.2 - 5.8 7.25 - 7.8	Three notched bands
[18]	35 × 35	2.9 - 3.7 5.1 - 6.0	Two notched bands
[19]	25 × 29	3.3 - 3.8 5.0 - 5.8	Two notched bands
[20]	70 × 80	2.4 - 2.5 4.0 - 6.0 8.0 - 8.4	Two notched bands
This work	20 × 24	0.5 – 2.5 2.3 – 3.7 7.3 – 8.4	Novel configuration with three notched bands

IV. Conclusion

A novel monopole antenna with super wideband capability and triple-band notching function is presented. The patch antenna includes slots of different geometries and sizes that can be configured to block the required frequency bands. The proposed antenna is shown to suppress unwanted interfering signals as low as L-band and as high as X-band. The measured results confirm the antenna radiates with an average gain of 5.5 dBi and efficiency of 92% in the in the un-notched bands. The proposed technique does not affect the size of the antenna.

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