Phi Shape UWB Antenna with Band Notch Characteristics

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***Abstract*—In this paper a novel band notch antenna in UWB frequency range is designed using split rings. Split rings are overlapped with designed monopole to give phi shape. The slit gap gives band-notch operation from 5.1GHz to 6.29GHz and from 4.94GHz to 5.91GHz for SPSSR and SPSCR antennas respectively. Simulated and measured results are in good agreement.**

Keywords-monopole; split ring resonator; band-notch; UWB antenna; VSWR

I. INTRODUCTION

For a wireless communication system, large bandwidth is an important requirement. Although UWB antenna gives large bandwidth of 7.7GHz (3.1GHz to 10.6GHz), it faces many challenges of interference with existing systems in UWB range. To avoid this interference with existing systems like WLAN, HIPPERLAN, WiMAX, C-band satellite communication etc., band notch antennas are nowadays becoming popular and necessary for communication. In this paper a novel band notch antenna is designed by merging a monopole antenna with a square or circular split ring resonator. This proposed antenna shape looks like the Greek letter Phi (φ) hence is named as split Phi shape square ring (SPSSR) antenna and split Phi shape circular ring (SPSCR) antenna. Both antennas give single band notch operation in UWB band. Monopole is designed at 3GHz. The parameters for the SPSSR antenna are designed, optimized and applied to the SPSCR antenna. It is found that both antennas give the same response hence the same design can be extended to any other shape as well. In proposed antennas, by varying the split gap of rings, band notch frequency can be tuned to the desired band. The length and width of split ring resonator gives inductance, and the gap between two rings and the slit gap of the rings gives the capacitance. The gap between the rings and the slit gap is optimized to give UWB antenna with notch band characteristics. At slit gap of 1.1mm the UWB operation in with band notch at 5.87 and 5.47GHz is achieved for SPSSR and SPSCR respectively.

Many antennas with band-notch characteristics are reported. Band-notch characteristics are achieved by inserting different slots in the radiating patch [1-3]. In [4, 5] antennas with etching slots shapes such as H, M, W etc. slots in the ground plane are reported. A band notch antenna by etching a narrowband dual resonance fractal binary tree in the radiation element of the conventional UWB antenna is reported in [6], but the antenna manufacturing and structure are complex. The band-notched characteristics are obtained by adding a stepped impedance resonator (SIR) or a split ring resonator (SRR) on the feed line or cutting slots in the ground plane [7, 8]. A band-notch antenna is designed by etching a nested CSRR inside the ground plane in [9].

Another technique to obtain band-notch characteristics is by adding the parasitic elements in the form of printed strips placed in the radiating aperture of the planar antenna at the top and bottom layer. They are employed to suppress the radiation at certain frequencies within an ultra-wide frequency band [10, 11]. By inserting the U-shaped parasitic element on the bottom plane of the basic planar monopole antenna [12] or by using a pair of arc shaped parasitic elements around the patch, an excellent notched frequency band for rejecting the WLAN band (5-6GHz) can be obtained [13]. The electromagnetic coupling of the SRR with the CPW yields the frequency notch [14]. There are many more techniques used to obtain band-notch operation in UWB range. The proposed antenna is simple to design and implement. By changing the slit gap of the antenna the desired band-notch frequency can be tuned. Additional varactor diode can be implemented with the antenna as a future scope to give variable capacitance and the same antenna can be used to tune different frequency bands. The proposed antenna was carefully fabricated and measured. The return loss, VSWR, and impedance are measured to certify the performance. Results show acceptable discrepancy between simulation and measurement due to the influence of the SMA connector for testing and the indoor measurement environment.

II. PHI SHAPE UWB ANTENNA WITH BAND NOTCH CHARACTERISTICS

Initially a monopole antenna at 3GHz frequency is designed. The height of monopole antenna will be λ/4. Heights of monopole antenna and ground plane dimensions are fixed by optimization. Designed square and circular shape split ring resonators are overlapped with monopole to form the proposed phi shape antennas. The proposed SPSSR and SPSCR antennas for band notch applications in UWB range are shown in Figure 1. The length of the outer ring is 38mm and the ring width is

1.1mm. Outer and inner rings are separated by 0.7mm. Both antennas have a split gap of 1.1mm. Detailed dimensions are shown in Table I. The length of rings with specified width gives the inductance and the spacing between the two rings and their slit gap gives the capacitance. The inductance can be changed by changing the length and width of rings whereas the capacitance by changing the spacing and slit gap of rings. Resonance frequency is a function of inductance and capacitance. Hence the resonance frequency for the square and circular ring is given as in (1) [15]

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{1}{L_e C_e}} \qquad (1)$$

Le and *Ce* are the equivalent inductance and capacitance values of square and circular split rings.

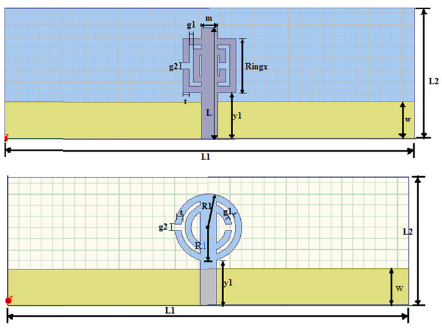

Fig. 1. SPSSR antenna and SPSCR antenna

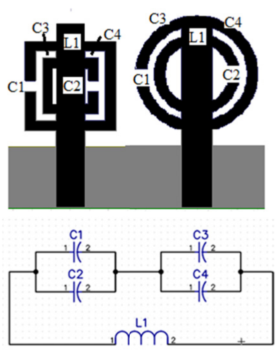

Fig. 2. Empirical antenna equivalent circuit.

From the empirical equivalent circuit diagram shown in Figure 2, L1 is the total equivalent inductance of the circuit, C1 and C2 are capacitance because of the slit gap in outer and inner rings and C3 and C4 are capacitance between the ring and monopole on left half and right half of antenna. Resonance frequency of the proposed antenna is calculated by taking (1) into consideration. The total equivalent capacitance of the circuit is given by (2) [16] as

$$C_e = \frac{(C_1+C_3)(C_2+C_4)}{(C_1+C_3)++(C_2+C_4)} \qquad (2)$$

Considering $C_1=C_2=C_a$ and $C_3=C_4=C_g$, (2) can be written as:

$$C_e = \frac{C_a+C_g}{2} \qquad (3)$$

Metal thickness of copper is p=35μm, ring width is t, gap between rings is g_1 and $\varepsilon_0=8.854187817\times10^{-12}$F/m. C_g can be written as

$$C_g = \frac{\varepsilon_0\, tp}{g_1} \qquad (4)$$

C_a for square rings is given by (5) [13, 16] as

$$C_a = (4a_{avg} - g_1)C_p \qquad (5)$$

C_a for circular rings is given by (6) [15] as

$$C_a = (\pi r_{avg} - g_1)C_p \qquad (6)$$

a_{avg} , πr_{avg} and C_p are calculated as in [13, 15-17].

Equivalent inductance *Le* calculation for rectangular/circular cross section of wire with finite length *l* (mm) and thickness of ring *t (mm)* is proposed in [18]. The same concept is used to calculate the equivalent inductance *Le* of SPSSR and SPSCR antenna for band notch applications in UWB range. The equivalent inductance *Le* for SPSSR antenna is:

$$L_e = 0.0002l\left(2.303log_{10}\frac{4l}{c} - \Upsilon\right)\ microH \qquad (7)$$

where, ϒ is the constant for wire loop of square geometry,

$$l = 8a_{ext} - g_1;\ \ a_{ext} = \frac{Ringx}{2};\ \Upsilon = 2.853 \qquad (8)$$

The equivalent inductance *Le* for SPSCR antenna is the same as in (7) but with different (ϒ) constant for wire loop of circular geometry and:

$$l = 2\pi r_{ext} - g_1;\ \ r_{ext} = R_1;\ \Upsilon = 2.451 \qquad (9)$$

Using (2)-(9) in (1) gives the ring resonance. The proposed concept in [13, 15-18] is used to design the proposed SPSSR and SPSCR antennas for band notch applications in UWB range. Calculated dimensions with some optimization are used to simulate the proposed antenna.

TABLE I. ANTENNA DIMENSIONS

Parameter	SPSSR antenna dimensions	SPSCR antenna dimensions
L1	72mm	72mm
L2	23mm	23mm
L	19.5mm	19.5mm
M	3mm	3mm
y1	7.9mm	7.9
W	6.5mm	6.5mm
Ring length	38mm (ringx=9.5mm)	38mm(R1=6.05mm)
T	1.1mm	1.1mm
g1	0.7mm	0.7mm
g2	1.1mm	1.1mm
H	1.6mm	1.6mm

III. RESULTS AND DISCUSSION

The performance of the proposed antennas is investigated by parametric analysis and the simulated results are validated by measuring the s-parameters and VSWR. The proposed antennas are fabricated using an FR4 substrate of 1.6mm thickness, 4.4 dielectric constant and 0.02 dielectric loss tangent. The dimensions of both SPSSR and SPSCR antennas are optimised as shown in Table I and the antennas are as shown in Figure 1.

Both antenna designs are simulated with electromagnetic solver based on finite element method. The simulated antennas give good impedence characteristics for both designs. The input impedance is quite close to 50Ω for both antennas as reflected in Table II. Initial antenna design is done for SPSSR antenna and is applied to SPSCR antenna by using the same optimised dimensions, because of this there may be a slight mismatch in input imedence of SPSCR comapred to SPSSR antenna and results are not exactly matching with each other. To understand the antenna response in better way S_{11} verses frequncy simulated curves are ploted for both designs in Figure 3.

TABLE II. SPSSR AND SPSCR ANTENNA SIMULATED RESULTS

Band	Parameters	SPSSR antenna	SPSCR antenna
UWB range	Frequency Range (GHz)	2.75-11.4	2.63-11.42
	S11 in dB	Less than -10dB	Less than -10dB
	VSWR	Less than 2	Less than 2
	Band width in GHz	8.65	8.8
	Impedance	Around 50Ω for said range	Around 50Ω for said range
Notched Band	Center frequency (GHz)	5.874	5.47
	VSWR	6.27	4.7
	Freuency Band	5.1-6.29	4.94-5.91
	Notvh-Band BW in MHz	1190MHz	970MHz
	Impedance	140 Ω	117 Ω

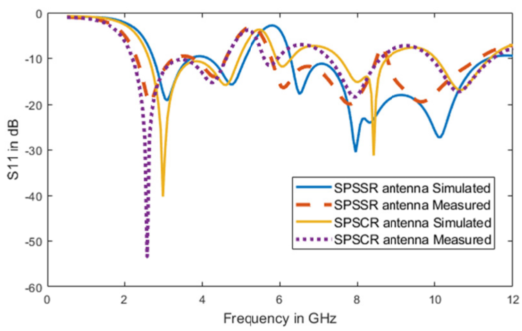

Fig. 3. Simulated and measured S_{11} SPSSR and SPSCR antenna

From Figures 3 and 4 it is clear that both antennas resonate very close to each other. Simulated and measured results show good agreement with each other for both antennas. Figure 4 shows the simulated and measured VSWR for SPSSR and SPSCR antennas. Figure 5 shows the simulated radiation patterns for the specified bands of SPSSR and SPSCR antennas at 3.4GHz and 8.GHz respectively. From the radiation pattern it is clear that both antennas are behaving in similar ways in their respective bands. E-plane pattern resembles with dipole antenna and H-plane pattern is omnidirectional. Radiation pattern gets disturbed at high frequencies. This change in radiation pattern is caused by the change in current distribution at high frequencies.

Figure 6 shows the current distribution for both antennas. From the current distribution pattern at 5.47GHz and 5.87GHz for SPSSR and SPSCR in Figure 6(b) and 6(c), it is clear that the current is distributed only in one side and flowing in opposite directions giving band-notch operation.

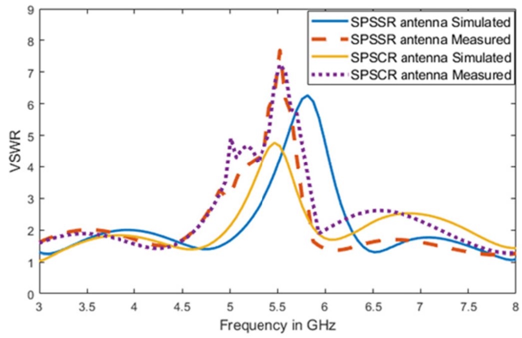

Fig. 4. Simulated and measured VSWR for SPSSR and SPSCR antennas giving band-notch.

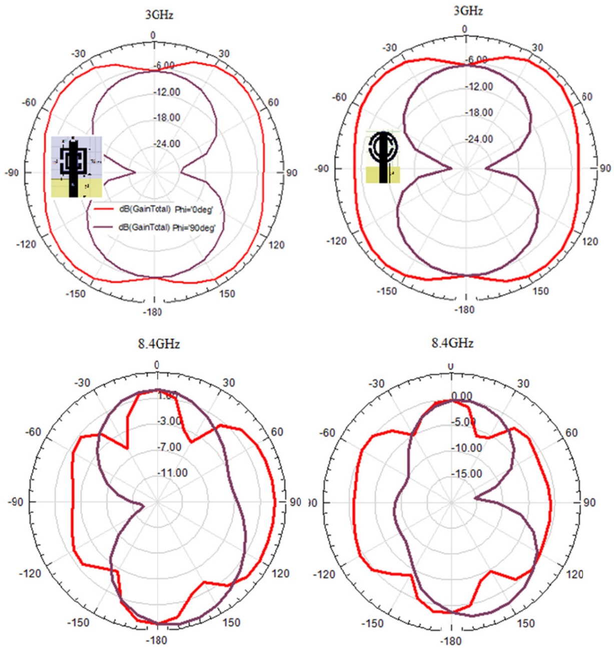

Fig. 5. SPSSR and SPSCR antenna radiation pattern at 3.0GHz and 8.4GHz

Figure 7 shows the effect of slit gap on band notch frequency. As the slit gap is increased the overall equivalent capacitance decreases and as an effect the notch-band center frequency is increased in both antennas. Hence, desired frequency tuning is possible by changing the slit gap or by connecting varactor diode in between slit gap. The slit gap is optimised to 1.1mm which gives band notch operation in WLAN frequency band. Figure 8 shows the gain for both antennas. The gain for both shapes is constant and equal at all frequencies. Figure 9 shows the fabricated antennas.

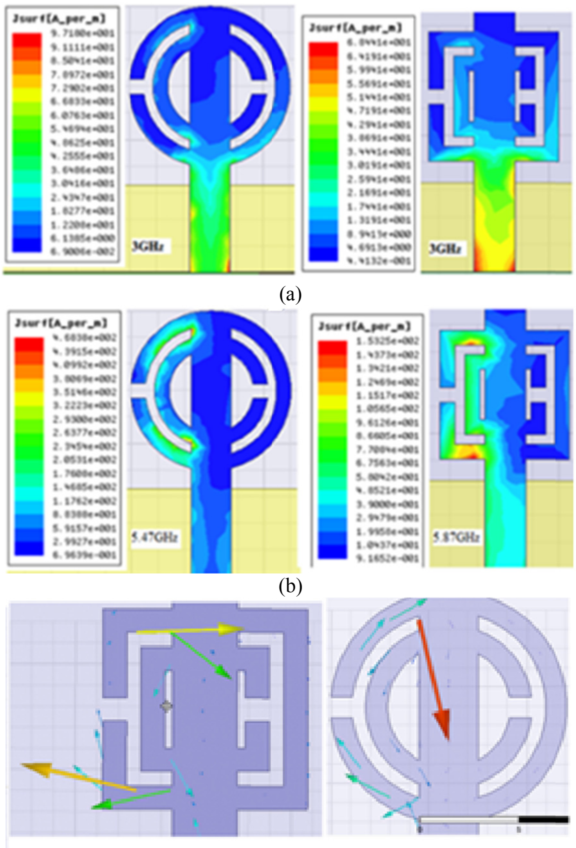

Fig. 6. Current distribution for SPSSR and SPSCR antennas (a) for radiating patch at frequency of 3GHz and (b) (c)for notch-band center frequency 5.87GHz and 5.47GHz for SPSCR and SPSSR respectively.

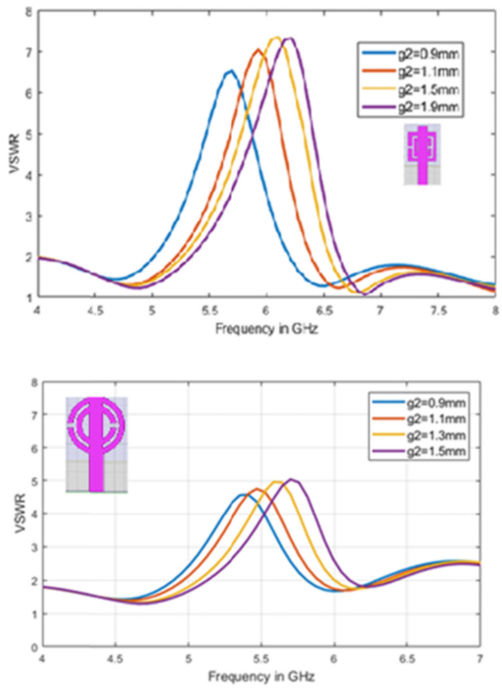

Fig. 7. Effect of slit gap on notch-band frequency.

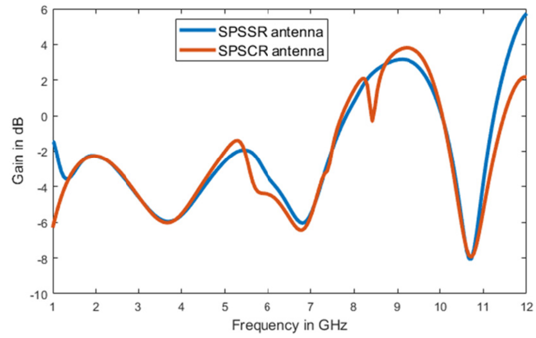

Fig. 8. Gain of SPSSR and SPSCR antenna

Fig. 9. Fabricated antennas.

IV. CONCLUSIONS

Applications of UWB antennas find difficulties in avoiding interference with existing systems like WLAN and WiMAX. Band notch antennas are playing an important role in today's wireless communications in UWB range. In this paper, a novel SPSSR antenna is designed and the same design is applied to SPSCR antenna in UWB frequency range. Both designs are giving similar response in terms of S_{11}, VSWR, radiation pattern and gain. It is observed that by increasing the slit gap the equivalent capacitance increases which in turn increases the band-notch center frequency. As future work, a varactor diode can be connected between the slit gap in order to tune the desired frequency. Both antennas are capable of giving band notch at WLAN and WiMAX system frequencies. The notch bands are from 5.1GHz to 6.28GHz for SPSSR and 4.94GHz to 5.91GHz for SPSCR antenna. Both notch bands are covering the WLAN and WiMAX systems. Interference with WLAN and WiMAX will be avoided by using the proposed antennas. The theoretical design results are verified by simulation for both antennas. Simulated and measured results are in good agreement with each other.

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