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# Survey of Embedding MSRRs Structure on Compactness and Bandwidth Operation of UWB Antenna

F. Alizadeh*, R. Zayer, M. Dadashi

*Urmia University, Urmia, Iran*
*Corresponding's Email: st_f.alizadeh@urmia.ac.ir

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***Abstract*** *– The effect of embedding regular and modified multiple split-ring resonators on the ultra-wideband antenna is proposed and studied. By embedding the structures on the compact UWB antenna a novel method for enhancing the performance of the antenna in the desired frequencies is realized. The proposed configurations are useful for enhancing the banding by combining several resonant modes. The antenna in special conditions, in which the MSRR structures rings width are minimized and modified to avoid of notching shows good impedance matching in desired frequencies.*

***Keywords****: Compact Antennas, Monopole Antenna, Split-ring Resonators (SRRs), Ultra-Wideband (UWB) Antennas.*

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ORIGINAL ARTICLE

## INTRODUCTION

Much attention has been paid for the design of Ultra-Wideband(UWB) antennas as such since it occupies extremely wide swathes of spectrum and uses very low power to communicate. Among all various techniques for implementing UWB applications and antennas, planar monopole antenna is one of the most popular candidates because of its extra advantages such as ease of fabrications and integrations. An Omni-directional pattern in H-plane and Monopole radiation-like pattern in the E-plane, compact size, low cost and supporting an Ultra-Wideband of frequency range between 3.1_10.6 GHz with VSWR< 2 are the basic requirements for the UWB antennas. The basic shapes for implementing monopole antennas printed on the substrate are circular, rectangular, triangular, elliptical, U-shape, Vivaldi and etc. The circular patch is implemented in order to have a large impedance bandwidth [1]. However, high gain and good radiation patterns need a rectangular patch. While tapered triangular UWB with slots on the ground and on the radiating element, yields a wideband property with a relative good matching. The UWB antenna is miniaturized by using tapered feeding lines, slots in ground plane or on the patch and defected ground plane. Inserting L-strip tuning stubs, dual fed and triple fed are the other ways for impedance matching bandwidth of the antenna in both higher and lower frequencies [2]-[4].

Recently, researchers are also trying to notch the unwanted frequencies using half and quarter wave length slots in the patch radiating element, ground plane, feeding line and vicinity of the radiating element like using arc shapes around patch. These slots have various shapes but main slot shapes are U- Shape and L-shape [2]-[7].

The more compact the antenna is, the less likely these methods will be used. This is the reason for introducing sub-wave length resonator structures by using meta-materials for notching the unwanted frequencies. In order to do this, the electrically small resonators such as split-ring resonators (SRR), complementary split-ring resonators (CSRR) and spiral-loop resonators (SLR) have been used in radiating element, ground plane and even on the feeding line [8]-[12]. These structures show a band gap in their pass band in which transmission is obstructed. This gap is occurs in intrinsic resonance of this structures ($f_0 = 1/2\pi\sqrt{L_s C_s}$). These structures operate as a resonator in this frequency and disturb the current distribution on the patch by forming an inductance and capacitance qualities. While the antenna will be probably have a good matching near this frequency, namely in the $f_z$ frequency where the overall structure resonates. In this, they can also be used for enhancing the band width in the upper frequencies and increasing the matching under the main resonance frequency ($f_0$) of these structures. However the definition for these frequencies differs from each other. The transmission zero frequency ($f_z$) in this case can be easily obtained from the transmission coefficient *S*21 of the unitcell. Since at this frequency the whole power injected from the input port is reflected back and begin to flow in the outer of the metal patch surface. This will increase the amount of inductance and lead to increasing the matching in the lower frequencies and gain of antenna [13]-[14].

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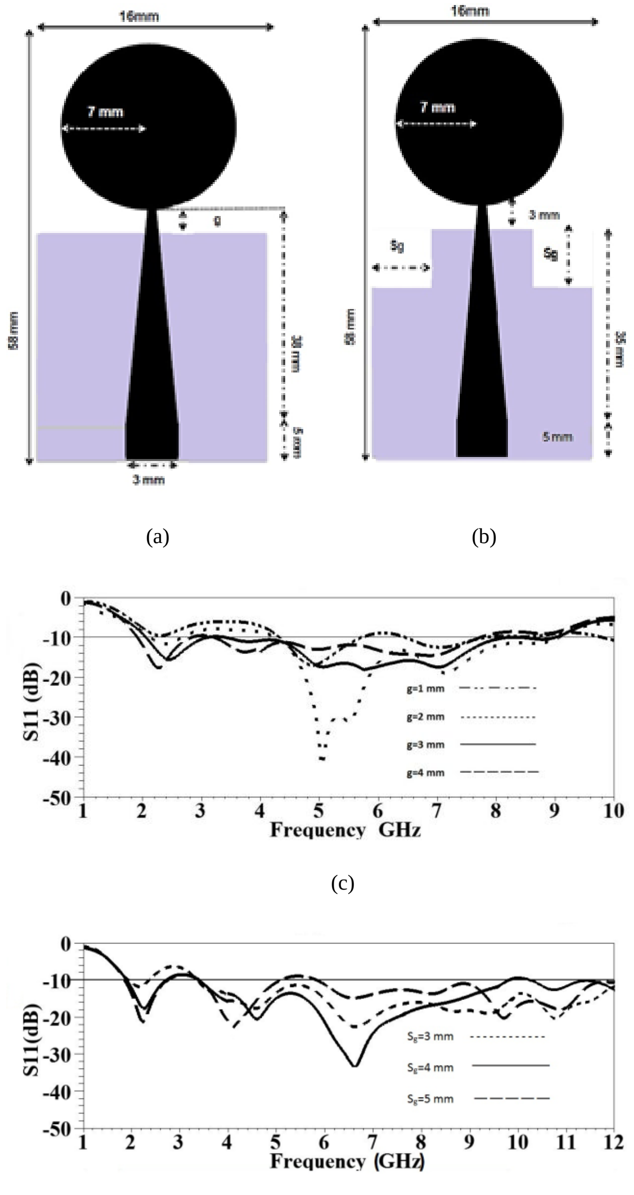
The reference antenna which is proposed here has a good bandwidth due to the large tapering line and thanks to circular shape. But one of the disadvantages of compact patches is the low matching and low gain in the desired frequencies. Because these structures represent small gain in comparison to the other shapes like rectangular and minder lines. To enhance and modifying the bandwidth of antenna both slots and electrically small resonators can be used. However, with more size reduction of the patch, using sub-wave length resonators are reasonable to enhancing the matching of antenna. At the same time, these structures cause notching, so matching or notching depends on various parameters like current distribution on patch or location of slots and length [15]-[16].

The multiple ring resonators (MSRR) and their equivalent circuit are introduced by Bilotti et al. This structure has been used for reducing the resonance frequency that gives a typical miniaturization around λ/50. Then, these resonators are employed in the designs that compacting is very important. [17]- [19]. In this paper these structures are used to increase the matching and banding of the reference antenna. For this purpose, MSRR and CMSRR are etched on the patch to provide a relativity good matching for desired frequencies.



(a) (b)

(c)

(d)

Fig. 1- Reference antenna structure with defected ground plane. (a) gap. (b) L-slots. Simulated return loss for (c) gap. (d) L slot.

## ANTENNA DESIGN

The configuration of the reference antenna is shown in Fig. 1.(a) The circular printed patch is selected as a radiating element to have a wide bandwidth. The patch has symmetric dimensions along the y and x axis. A gap between the radiator and ground plane is provided to match up microstrip line and radiating element. However the effect of the gap has been investigated by modifying different distances. A 50Ω micostrip line with a width of 3mm and length of 5 mm is connected to a tapered line. The length of the taper is 38mm with a width of 0.6 mm is connected to the patch. The tapered line provides a good match in the lower frequencies. The reference antenna is printed on a FR4 substrate, with relative permittivity $\varepsilon_r$ =4.4, loss tangent of 0.02 and thickness of 1.6 mm. The overall dimension of the substrate of the antenna is 5.8 ×1.6 $cm^2$. Which is smaller than the UWB antennas previously mentioned [8]. The reference antenna bandwidth is mainly determined by the gap between the patch and the ground plane(g) and the L-slots on the ground ($S_g$). The effect of the defected ground plane in the return loss is shown in the Fig. 1(a) with changing the gap between the ground plane and the radiating element. At low frequencies electrical current is mainly distributed over the radiator. When the gap increases, antenna inductance in the lower frequencies will also increase. In higher frequencies, as shown in fig. 1(c), the impedance bandwidth increases as the gap between ground plane and radiating element decreases. L- Shape or Square slot on the ground mainly influence on the increasing bandwidth in the higher frequencies. Fig. 1(b) shows the reference antenna with two squares in the ground plane. The effect of the slot in the ground by varying $S_g$ is displayed in Fig. 2(d). C or U-shaped slot causes to notch a special frequency due to the guided wavelength in the resonator, namely $\lambda_g/2$. For providing a complete survey, the geometry is depicted and simulation results are presented in Fig. 2 (a) and (b), respectively. The position of the arc slot is the same as [6] but the dimensions are adjusted to improve the responsiveness. Creating the arc slot on the patch also leads to increasing the bandwidth in lower frequencies and matching before the notched frequency.

The antennas with two arc slot (i.e. SRR and CSRR) have the same effect on antenna performance, but in two range of frequency, due to the dual-band features of these sub-wavelength resonators. Any slot on the patch represents a transmission line which transforms nearly zero impedance in the short circuit mode, [6], [8], [15]. Due to current distribution a slot can be used in short circuit form to provide a parallel LC resonator. This resonator shows a transition in zero impedance that yields a resonance to the operating band. Open ended slot forms infinity impedance in antenna operating band which that it can be modeled as a series LC resonator. The result is notching a special band or frequency due to the resonance mode of the series resonator. So some slots embedded on the patch can be modeled as an alternative parallel and series resonators. This will affect the bandwidth of the antenna by adding some resonances in the special frequencies. As a result, in some frequencies, smooth notching and good match must be observed. For this purpose, MSRR and CMSRR structures are used since these structures have the same features that are required in this case. For more illuminating the mechanism of the MSRR or CMSRR, these structures are studied by etching on the surface of patch and also excited by 50Ω microstrip line.

The formulas that are presented in [17]-[19] are used for calculating the intrinsic resonance of magnetic inclusion. In this frequency, the antenna must show a weak matching or the matching of the own antenna without gaps. That is based on the fact that at this state the gaps between two rings can be seen. The patch behaves like slotted-circle with the influence of MSRR. The following equations (1,2,3) are used for calculating inductance of complementary MSRR[18].

$$l_{avg} = 4\left(\frac{\pi}{2}R_{ext} - (N-1)(w+s)\right) \tag{1}$$

$$\rho = \frac{(N-1)(w+s)}{\left(\frac{\pi}{2}R_{ext} - (N-1)(w+s)\right)} \tag{2}$$

$$L_{MSRR} = 0.76 l_{ave}\left(Ln(0.98/\rho) + 1.84\rho\right) \tag{3}$$

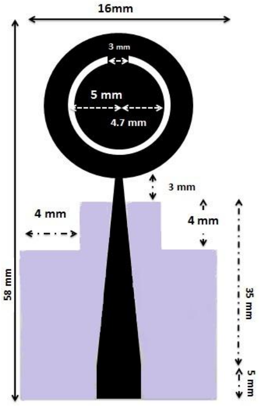
And the formulas (4,5,6) for the capacitance are also given [31]

$$\varepsilon_r^{eff} = 1 + \frac{2}{\pi}\tan^{-1}\left(\frac{h}{2\pi(w+s)}\right)(\varepsilon_r - 1) \tag{4}$$

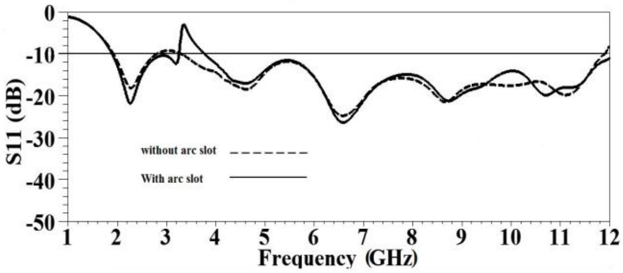
$$C_0 = \varepsilon_0 \varepsilon_r^{eff} \frac{K(k')}{K(k)} \tag{5}$$

$$C^{MSRR} = [(N-1)(\pi R_{ext} - (2N-1)(w+s))C_0]/2 \tag{6}$$

In Table. I, the $f_0$ (intrinsic resonance frequency of the MSRR) for several $R_{ext}$ and for different width and gap between two rings are calculated. While the numbers of rings are arbitrary, 6 rings are used because increasing the number of rings has no effect on the antenna performance. Also the width of split on the rings has no effect on the intrinsic frequency of the patch as long as the dimensions of split (between **w** and 3**w**) are reasonable. The amount of split is useful for increasing the matching or for widening of the bandwidth pass band under the main resonance frequency before of the zero transmission frequency [18].



(a)



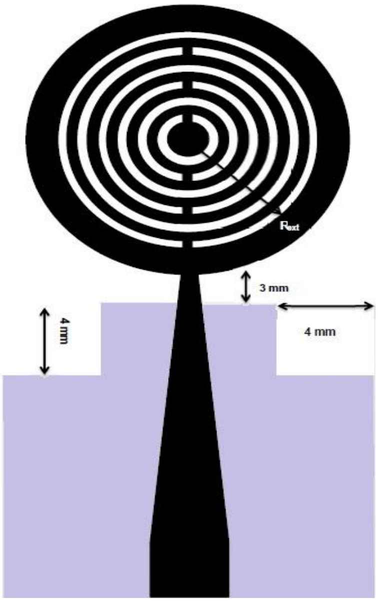
(b)

Fig. 2- The proposed antenna (a) With an arc slot for notching the WIMAX band. (b) Return loss.

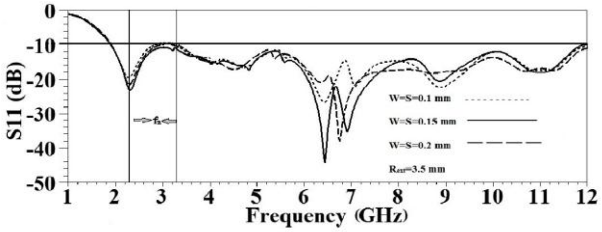
Table I. Intrinsic resonance frequency ($f_0$) of MSRR

| $R_{ext}$(mm) | W=S(mm) | C(pF) | L(nH) | $F_0$(GHz) |
|---|---|---|---|---|
| 3.5 | 0.1 | 0.09 | 26 | 3.28 |
| | 0.15 | 0.067 | 20.15 | 4.32 |
| | 0.2 | 0.05 | 17 | 5.4 |
| 4.5 | 0.1 | 0.12 | 38.6 | 2.3 |
| | 0.15 | 0.095 | 30.45 | 2.96 |
| | 0.2 | 0.075 | 25.32 | 3.65 |
| 5.5 | 0.1 | 0.15 | 52.6 | 1.76 |
| | 0.15 | 0.12 | 42 | 2.23 |
| | 0.2 | 0.1 | 35 | 2.7 |
| 6.5 | 0.1 | 0.17 | 67 | 1.5 |
| | 0.15 | 0.15 | 54 | 1.7 |
| | 0.2 | 0.12 | 46 | 2.1 |

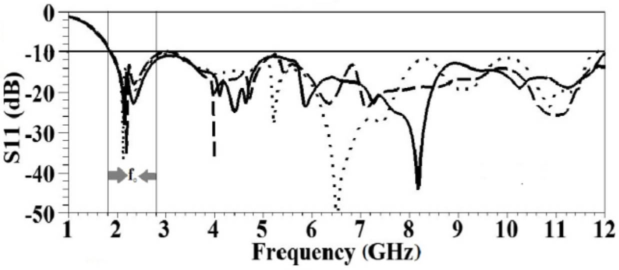
Fig.3(a) shows the proposed antenna with 6 similar arc slots which are etched on the patch. The arc slots could be realize as a single MSRR structure with width(w), separation between the ring(s) and radius of external ring($R_{ext}$). Fig. 3(b)-(e) depicts simulated return loss (S11) for the proposed antenna with MSRR, excited by a 50Ω microstrip line, for different w, s and $R_{ext}$. The simulations in fig. 3 depict that the designed antenna operates over the frequency band from 1.9 to more than 12 GHz with return loss less than 10 dB. Also simulated results for isolated MSRR prove that $f_0$ causes to mismatching while in the below frequencies the matching and the gain of antenna increases. It is also observed that the width and gap between the rings influence antenna performance. The radius of the MSRR is also changed to survey the influence of this factor on the antenna overall performance. This change will cause $f_0$ to go downwards, forcing that to operate in the lower frequencies. Interestingly, a narrow band width happens in the lower frequencies which is related to the left-hand nature of the structure. The change in the radius of MSRR also has an interesting effect which causes increasing in the band width in the lower frequencies. This happens because a narrow band width is merging with the antenna upper frequencies and increases the antenna band width from 1.9 GHz to 1.8 GHz. The reason for this increase could be observable in the Fig. 3(f) which shows that with increasing the external radius of the MSRR, the antenna will show an additional operating narrow band width between 1-2 GHz. The width of this narrow band width is controllable with the parameters of MSRR. Also it could be increased with etching more than one MSRR on the patch. This might also produce good results in larger patches. Considering the results of table. 1, it is possible to achieve a good performance and high bandwidth by using the tapering concept of width (W), separation(S) and splits of the rings (Sp). All parameters in tables and figures are in millimeter.



(a)



(b)



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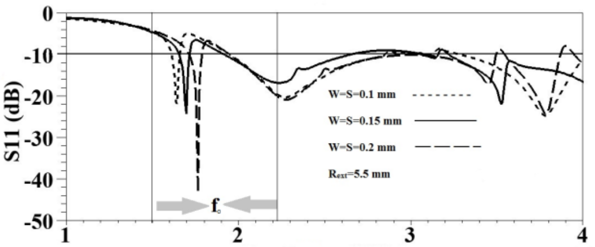

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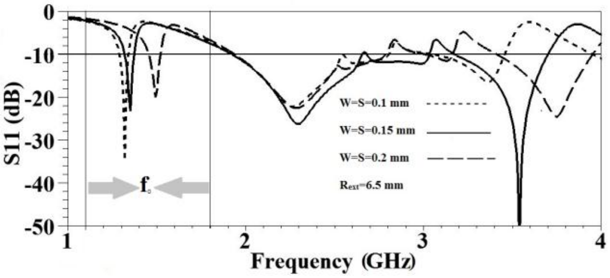


(e)

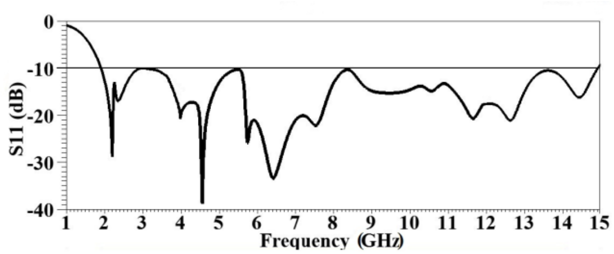
Fig. 3- (a) Geometry of the antenna with embedded MSRR. Return loss for the proposed antenna with spacing between different width for rings and $R_{ext}$ equal to (b) 3.5 mm. (c)4.5 mm. (d)5.5 mm. (e) 6.5 mm.

## SIMULATION RESULTS AND DISCUSSION

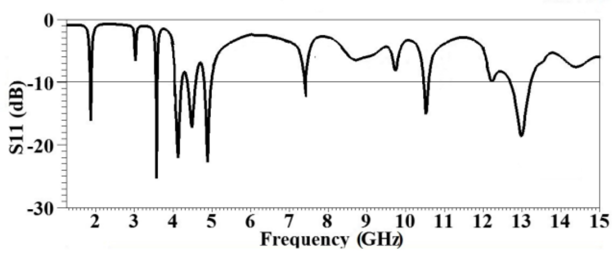
In order to implement the major results of the previous section and bring a new approach in this part of paper the dimensions of fig. 3(a) must change to the following parameters of table 2. The result of which is shown in the fig. 4(a). It can be seen from fig. 4(a) that the bandwidth of the antenna in the lower frequencies is increased. This increase is a result of the merging neighborhood resonance of MSRR of the left-hand with the bandwidth of antenna. In order to this, external radius of MSRR adjusted to reach the mentioned feature. Also other parameters of MSRR like width (W) and separation (S) of the rings and splits (Sp) of each ring are changed to satisfy the other requirements such as widening bandwidth in the upper frequencies, having good matching and high gain in the frequencies without interference like 4-5 GHz and 6-8 GHz. The small splits lead to matching while large splits cause mismatching. Also this figure shows a smooth decreasing in the matching of the operating bands like Worldwide Interoperability for Microwave Access or WIMAX (3.4 – 3.7 GHz), Wireless Local Area Network or WLAN (5.2 – 5.8 GHz) and International Telecommunication Union or ITU (7.9-8.4 GHz). In fig. 6(a) the proposed antenna are fabricated and the measurement results are shown in fig. 7, respectively.

Table. II. Optimized parameters of MSRR

| $R_{ext}$ | $W_1$ | $W_2$ | $W_3$ | $W_4$ | $W_5$ |
|---|---|---|---|---|---|
| 5 | 0.28 | 0.24 | 0.2 | 0.16 | 0.12 |
| $S_1$ | $S_2$ | $S_3$ | $S_4$ | $S_5$ | $S_6$ |
| 0.3 | 0.26 | 0.22 | 0.18 | 0.14 | 0.1 |
| $Sp_1$ | $Sp_2$ | $Sp_3$ | $Sp_4$ | $Sp_5$ | $Sp_6$ |
| 0.3 | 0.26 | 0.22 | 0.18 | 0.14 | 0.1 |



(a)



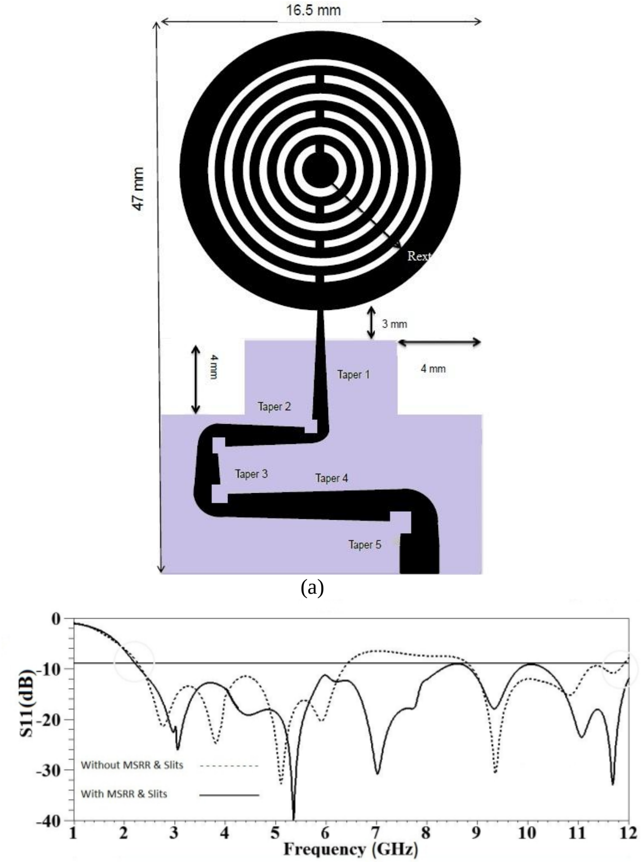
(b)

Fig. 4-Return loss of the antenna with modified MSRR structure of table II and (a) defected ground plane. (b) complete ground plane.

However, in fig. 4(b) the defected ground plane is replaced with complete ground to cover whole substrate which prove the idea of increasing band width with MSRR structures. Another point worth mentioning is changing the length of the tapered line or ground plane has no effect on the resonance frequencies of MSRR. There must be a little change in the operating band width of the antenna if the antenna feeding line and ground plane decreases. This decreasing in the taper line could be useful in reducing the dimensions of the entire antenna. For this purpose the large taper line of figure 3(a) is divided into 5 small tapers and connected to each other. Finally for decreasing the input reflection the capacitance and inductance of bends are decreased and increased with joining two tapers by curving the distance between them and making a rectangular slit in the corner of each bend, respectively, as shown in fig. 5(a). As seen in fig. 5(b), there is a little shift (around 0.2 GHz) in the band width of the antenna in comparison to direct feeding of fig. 3(a) but MSRR shows the features of matching, gain and enhancing band width regardless of these changes.

Table III. Tapered-line parameters of fig. 5(a)

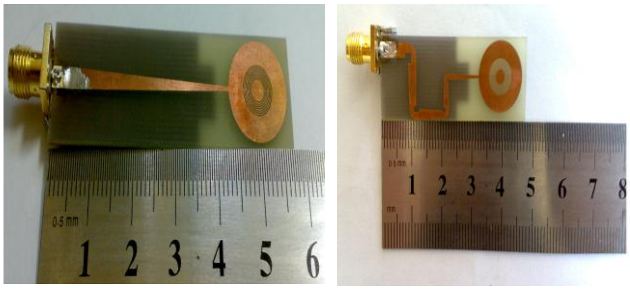
| Taper | Small edge | Large edge | Length |
|---|---|---|---|
| Taper 1 | 0.6 | 1.2 | 10 |
| Taper 2 | 1.2 | 1.6 | 6 |
| Taper 3 | 1.6 | 2.1 | 9 |
| Taper 4 | 2.1 | 2.6 | 10 |
| Taper 5 | 2.6 | 3 | 4 |
| Slit 1 | Slit 2 | Slit 3 | Slit 4 |
| 0.6×0.6 | 1×1.2 | 1.2×1.6 | 2×2 |



(a)

(b)

Fig. 5- (a) Structure of the designed compact UWB MSRR antenna with modified magnetic inclusion and bended tapered-line. (b)Return loss.



(a) (b)

Fig. 6-Antenna prototype with parameters of (a) table II. (b) table III.

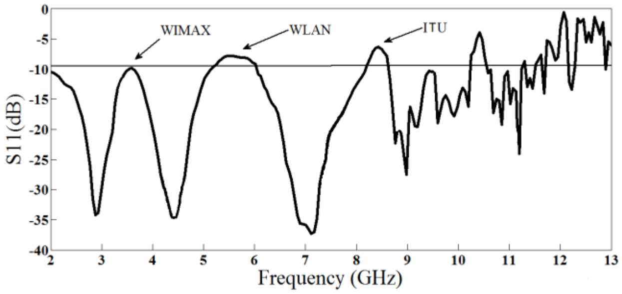


Fig. 7- Measured return loss for the designed MSRR antenna with table parameters

In fig. 6(a) and (b) the prototype of fabricated antennas with MSRR structure embedded on the patch are shown. The substrate used in both designs is FR4-epoxy with dielectric constant of $\varepsilon_r = 4.4$ and 1.6 mm height. FR4 dielectric constant is known to vary with frequency and manufacturer and is not a reliable substrate in frequencies upper than 8 GHz. In the upper frequencies as seen in the fig. 7 the measurement are distorted and the matching is affected by both substrate dielectric variation and network analyzer's the incorrect calibration.

## CONCLUSION

A new approach for enhancing the performance of compact circular UWB antenna has been demonstrated with MSRR structures. The overall dimensions of the MSRR are modified to achieve the goals that mentioned previously. The 10-dB bandwidth of the simulated and fabricated antennas are presented. The mentioned structures embedded on patch antenna under special conditions can be expected to be a good candidate for stringent UWB applications.

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