Compact Antenna with 3.5 GHz band-notched characteristics using a split ring resonator

HUMBERTO C. C. FERNANDES
ALMIR SOUZA E SILVA NETO
Department of Electrical Engineering
Federal Institute of Education, Science and Technology of Maranhão (IFMA)
Av. Getúlio Vargas, 4 - Monte Castelo, São Luís - MA, 65030-005
São Luís/MA - BRAZIL
almir.neto@ifma.edu.br

Abstract: - A design of the compact antenna with band-notched characteristic using a Split Ring Resonator (SRR) etched at the ground plane, is proposed. The proposed antenna has a bandwidth of 4.3 GHz from 2.09 to 6.39 GHz, except one notched band from 3.19 GHz to 3.93 GHz for Worldwide Interoperability for Microwave Access (WiMAX) application. A good agreement was observed between the simulated and measured results.

Key-Words: - Band-notched, Split Ring Resonator (SRR), Worldwide Interoperability for Microwave Access (WiMAX).

1 Introduction

The authorization for the commercial use of ultra-wideband (UWB), in 2002, was approved by Federal Communications Commission (FCC). The FCC and the International Telecommunication Union Radio communication Sector (ITU-R) defined the UWB with bandwidth larger than 500 MHz or 20% of the center frequency, in the frequency range from 3.1 to 10.6 GHz. The UWB technology is a short-range wireless technology, for transmitting large amounts of data, at high-speed with very low power. Generally, the Effective Isotropic Radiated Power (EIRP) must be smaller than -41.3 dBm/MHz between 3.1 to 10.6 GHz [1]–[2].

Some challenges presented by UWB antenna are: the impedance matching, radiation stability, antenna size, and the low manufacturing cost. In the indicated bandwidth by UWB system from 3.1 to 10.6 GHz, the UWB overlaps with the traditional narrow band systems, such as: IEEE 802.16, World Interoperability for Microwave Access (WiMAX) service operates from 3.3 to 3.7 GHz.

To solve this problem, it is desirable to design of UWB antennas with a band-notched characteristic to minimize potential interference. Numerous technologies are used to design notch-band UWB antennas, such as slots, parasitic elements and stubs [3]–[6]. Recently another techniques with resonators have been developed for the obtain band-notched characteristics such as: the spiral loop resonators resonating located in both sides of the circular radiating patch and resonators [7], the slot type Split Ring Resonator (SRR) that is inserted in the radiating part [8] and the microstrip slot antenna with a square ring resonator embedded in the tuning stub [9].

In this paper an UWB antenna with band–notched characteristic using the slot in ground plane combined with the Split Ring Resonator (SRR) etched on the ground plane, is proposed. The proposed antenna covers the requirements the UWB frequency band except (3.19– 3.93 GHz) for WiMAX to avoid possible interferences with existing communication systems running over it. The antenna was fabricated and characterized experimentally.

2 Antenna Design

The proposed antenna is constructed on a 30 (L) × 30 (W) mm2 RT DUROID 3006 substrate of 1.27 mm thickness, dielectric constant ε_r = 6.15 and loss tangent tan δ = 0.0025. A circular slot centered at the origin of radius R = 13.5 mm is etched off the ground plane. The SRR is composed of a pair of rings with openings in opposite ends and this opening controls the resonant frequency. To implement the band–notched property, a SRR is inserted non– concentrically inside the circular slot of the ground plane, underneath the radiating patch.

Figure 1 show the geometry of the proposed antenna and circular slot etched on the ground plane, the dimensions are: L = 30 mm, W = 30 mm, lx = ly = 13 mm, lf = wf = 3 mm, R = 13.5 mm, coupled to microstrip line of 50 Ω.

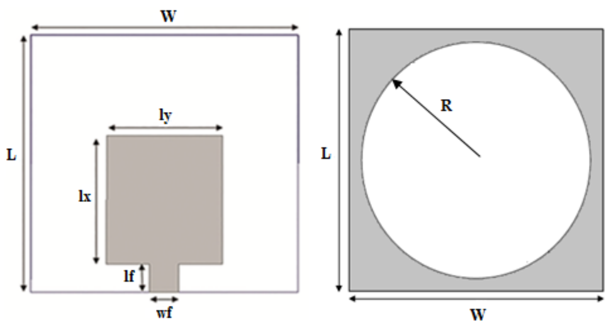


Fig.1. Geometry of the proposed: (a) Antenna; (b) Circular slot

For simulation of the proposed antenna was used the software ANSYS HFSS® (High Frequency Structure Simulator) [10].

An LC resonator can describe the SRR, and the resonant frequency given in equation (1), where L0 is the inductance per unit length between the ring slots, C is the total capacitance, and r0 is the average radius of the two rings [11]:

$$\omega_0 = \sqrt{\frac{2}{\pi r_0 L_0 C}} \qquad (1)$$

The SRR was projected for a resonant frequency of 3.5 GHz. The geometry of the proposed unit cell of the SRR is shown in Figure 2.

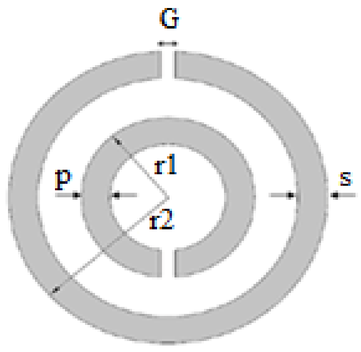


Fig.2. Geometry of the proposed SRR.

To optimize the SRR, four different configurations were tested, with: G = 0, 9 mm, r1 = 4.5 mm and r2 = 7.5 mm, altering only the s and p. Table I shows the dimensions of the SRR 1, SRR 2, SRR 3 and SRR 4.

TABLE I. DIMENSIONS OF THE PROPOSED SRR`S.

SRR	s (mm)	p (mm)
SRR 1	1.5	1
SRR 2	1	1
SRR 3	1	0.5
SRR 4	1.5	0.5

Figure 3 shows the comparison of simulated return loss (S11) between the four configurations of the SRR.

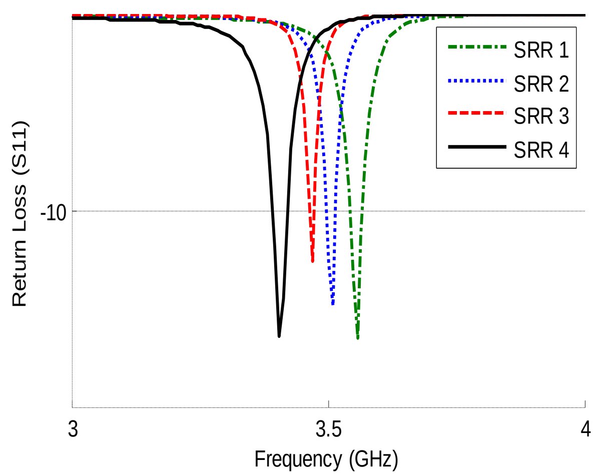


Fig. 3. Return Loss (dB) of the SRR 1, SRR2, SRR3 and SRR4.

Table II shows the resonant frequency and return loss of SRR`s.

TABLE II RESONANCE FREQUENCY AND RETURN LOSS.

SRR	Resonant Frequency (GHz)	Return Loss (dB)
SRR1	3.55	-16.49
SRR2	3.50	-14.85
SRR3	3.46	-12.58
SRR4	3.40	-16.36

From the Table II, it is evident that the SRR 2 presents the better results for the frequency of interest (3.5 GHz). Then the dimensions of the SRR for proposed antenna are: G = 0, 9 mm, s = p = 1 mm, r1 = 4.5 mm and r2 = 7.5 mm.

The magnitude of the S-parameter of the SRR is shown in Figure 4 [12].

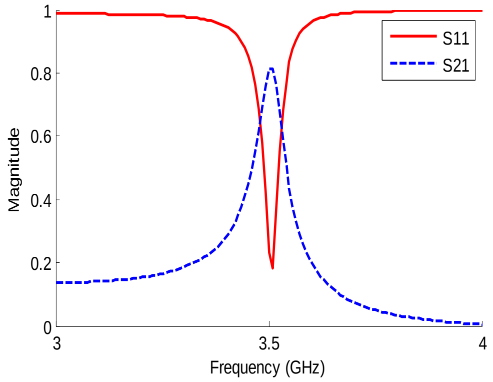


Fig. 4. Magnitude (dB) of the S-parameter of the SRR.

The S parameters extracted from HFSS are used to calculate the curves for the permittivity and the permeability. The permittivity and permeability curves obtained are shown in the Figure 5 and Figure 6. These curves shown that the permittivity and permeability are negative in the frequency of 3.5 GHz, showing double-negative metamaterial characteristics [12].

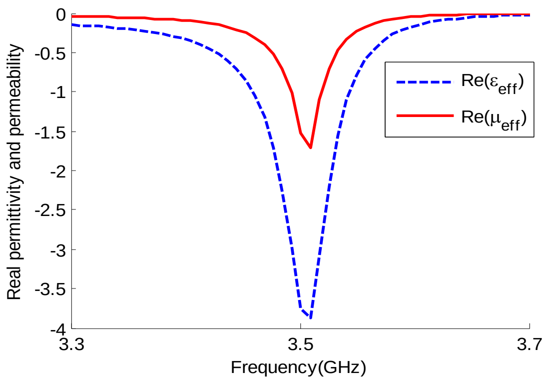


Fig. 5. Real values of permittivity and permeability of metamaterial.

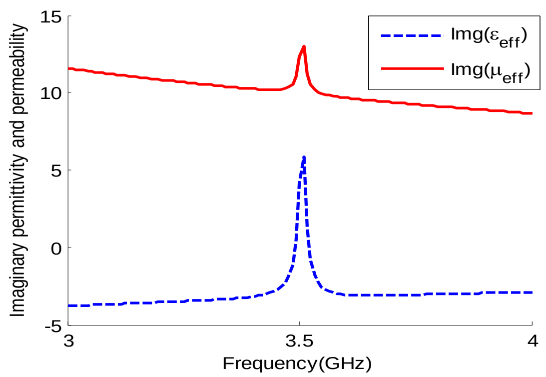


Fig. 6. Imaginary values of permittivity and permeability of metamaterial.

The refractive index and the impedance are shown in the Figure 7 and Figure 8. From these curves is showed the negative real refractive index and positive impedance, showing the metamaterial characteristics in the region of interest [12].

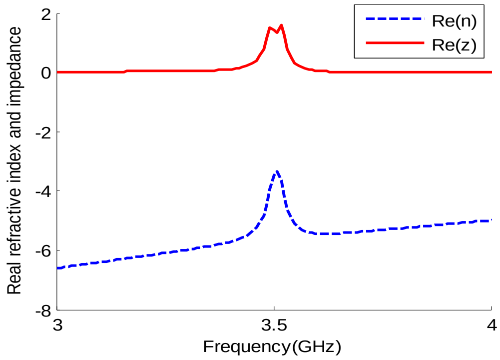


Fig. 7. The real curves for refractive index and impedance.

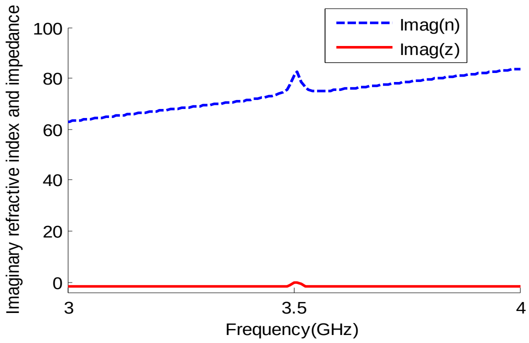
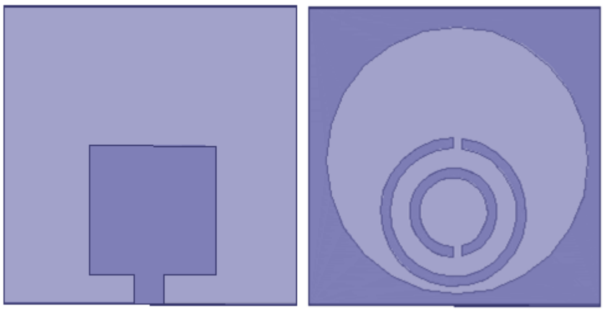


Fig. 8. Imaginary values for refractive index and impedance.

The geometry of proposed antenna is shown in Figure 9.



(a) **(b)**

Fig. 9. Design of proposed antenna: (a) Front; (b) Back.

3 Results and discussions

Figure 10 shows a comparison of the return loss (S11) for the antenna with SRR and without SRR etched on the ground plane. The antenna without SRR presented a bandwidth of 4.8 GHz from 2.08 to 6.88 GHz and the antenna with SRR presented a bandwidth of 4.3 GHz from 2.09 to 6.39 GHz, except one stop band from 3.19 GHz to 3.93 GHz.

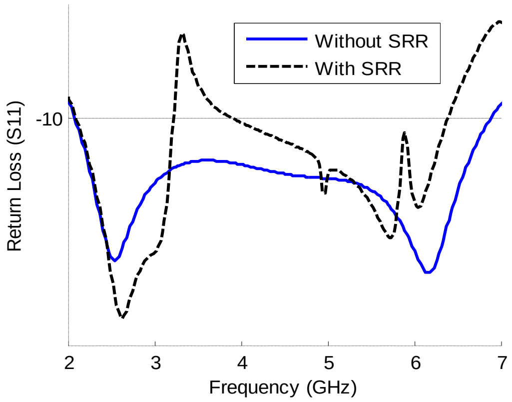
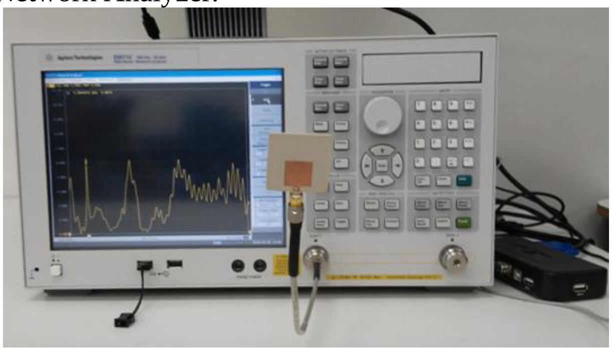
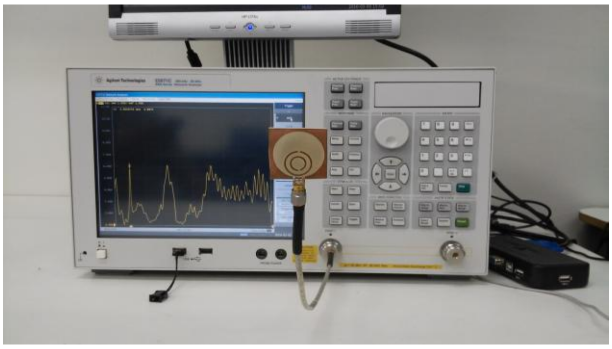


Fig. 10. Return loss (S11) for the antenna with SRR and without SRR etched on the ground plane.

Figure 11 shows the photograph of the fabricated antenna, using E5071C (300 KHz - 20 GHz), Network Analyzer.



(a)



(b)

Fig. 11. Photograph of the fabricated antenna using Network Analyzer. (a) Front; (b) Back.

The comparison of the return loss (S11) between simulated and measured results is shown in Figure 12.

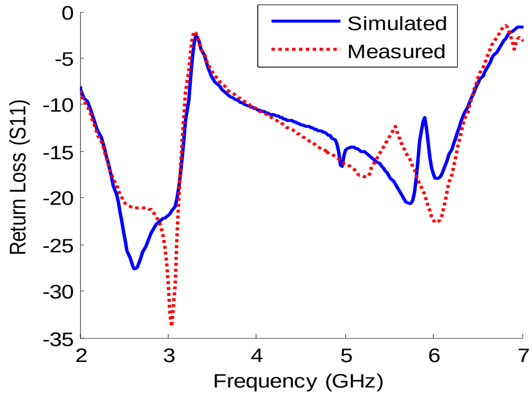


Fig. 12. S_{11} plot of comparison between simulated and measured results

The measured result presented a bandwidth of 4.3 GHz from 2.09 to 6.39 GHz, except one stop band from 3.19 GHz to 3.93 GHz. Differences between the two curves are inaccuracies in dimensions and misalignment during the manufacturing process. The simulated and measured results of the proposed antenna show a good agreement.

The simulated and measured results of VSWR of the proposed antenna are shows in Figure 13.

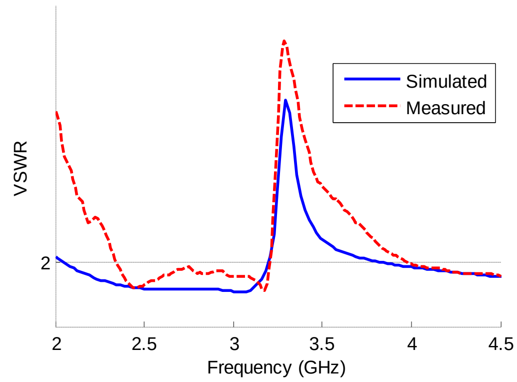


Fig. 13. Simulated and measured VSWR of proposed antenna

The measured result presents a stop band from 3.19 GHz to 3.97 GHz and the peak value of the UWB antenna is observed at frequency of 3.3 GHz.

The Figure 14 shows the surface current distribution at the peak value 3.3 GHz.

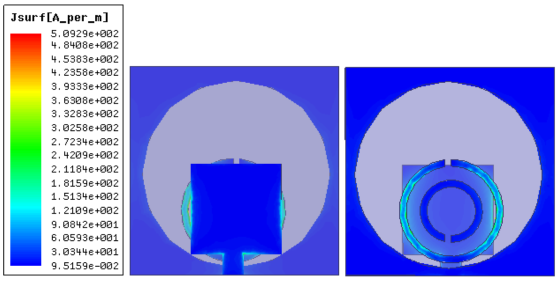
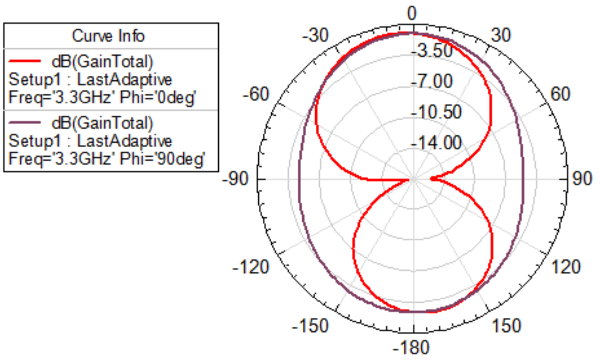


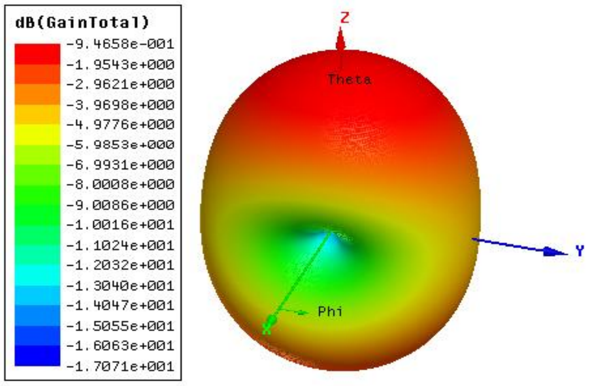
Fig. 14. The surface current distribution at the notch frequency at 3.3 GHz

Note that at the notched frequency 3.3 GHz the current density is concentrated particularly in the SRR. For this case, the destructive interference for the excited surface currents in the proposed antenna will occur, causing the proposed antenna to be nonresponsive in the frequency of interest.

The radiation patterns in 2D on the E-plane (φ = 0°) and H- plane (φ =90°) and 3D at 3.3 GHz are shown in Figure 15.



(a)



(b)

Fig. 15. Simulated results of radiation patterns at 3.3 GHz in: (a) 2D; (b) 3D.

Notice that the energy at the notched frequency band, at 3.3GHz, is not radiated, thus, the gain decreases indicating the band rejection of the proposed antenna.

4 Conclusion

An ultra-wideband (UWB) antenna with split ring resonator (SRR) etched on the ground plane, with rejection bands for worldwide interoperability for microwave access (WiMAX) at frequencies from 3.3 to 3.7 GHz, has been proposed and discussed. The proposed antenna presents a bandwidth of 4.3 GHz from 2.09 to 6.39 GHz, except one stop band from 3.19 GHz to 3.93 GHz. The proposed antenna meet specifications defined for UWB antenna, with bandwidth larger than 500 MHz or 20% of the center frequency, in the frequency range from 3.1 to 10.6 GHz. A good agreement for measurement and simulation has been observed.

References

[1] J. Kim, N. Kim, S. Lee and B. Oh, Triple band-notched UWB monopole antenna with two resonator structurees, Microwave Opt Technol Lett 55 (2012),4–6.

[2] First Report and Order, “Revision of Part 15 of the Commission’s Rule Regarding Ultra-Wideband Transmission System FCC 02–48,” Federal Communications Commission, 2002.

[3] Y. Yau, and B. Z. Huang, A novel ultra–wideband microstrip–line fed wide–slot antenna having frequency band notch function, in Proc. International Conference on Microwave and Millimeter wave Technology, Guilin, China, April 2007, 1–4.

[4] C. B. Kim, J. S. Lim, J. S. Jang, Y. H. Jung, H. S. Lee and M. S. Lee, Design of the wideband notched compact UWB antenna, International Journal of Applied Electromagnetics and Mechanics, Vol. 28, no. 1, 101–110, 2008.

[5] I. J. Yoon, H. Kim, H. K. Yoon, T. J. Yoon and Y. H. Kim, Ultrawideband tapered slot antenna with band cutoff characteristic, Electronics Letters, Vol. 41, no.11, 629–630, 2005.

[6] H.G. Schantz, G. Wolenec and E.M. Myszka, Frequency notched UWB antennas, in Proc. IEEE Conference on Ultra Wideband Systems and Technologies, Reston, Virginia, USA, November 2003, 214–218.

[7] D. Kim, N. Jo, D. Choi, C. Kim, Design of the Novel Band Notched UWB Antenna with the Spiral Loop Resonators, PIERS Proceedings, March 2010, 878 – 881.

[8] D.B. Brito, X. Begaud, A.G. D'Assuncao, and H.C.C. Fernandes, Ultra-wideband monopole antenna with Split Ring Resonator for notching frequencies, EuCAP 2010, 4th European Conference on Antennas and Propagation, Barcelona, Espanha, April 2010, pp.15.
[9] W. J. Lui, C.H. Cheng, and H.B. Zhu, Improved frequency notched ultrawideband slot antenna using square ring resonator. IEEE Trans Antennas Propag 55 (2007), 2445-2450.
[10] HFSS, ANSYS Corporation.
[11] R. Marqués, F. Mesa, J. Martel, and F. Medina, "Comparative analysis of edge- and broadside-coupled split ring resonators for metamaterial design—Theory and experiment," IEEE Transactions on Antennas and Propagation, vol. 51, no. 10, 2572–2581, October 2003. doi:10.1109/TAP.2003.817562.
[12] A. B. Numan and M. S. Sharawi, "Extrection of material parameters of metamaterials using a full-wave simulator", IEEE Antenna and Propagations Magazine, vol. 55, no. 5, pp. 202-2011, 2013.
[13] H.C.C. Fernandes, O. P. Lavor, C. G. de Moura and M. P. Sousa Neto, "Analysis of a UWB Planar Antenna with Split Ring Resonator", Journal of Communications and Information Systems, vol. 30, No.1, 30- 34, march 2015. doi: 10.14209/jcis.2015.4