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A New Triple Band Microstrip Fractal Antenna for C-band and S-band Applications

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***Abstract*— Recently research show that some parameters such as the shapes of antenna patch and the ground plane when geometrically altered produces changes in the current density distribution of the planar structure and consequently in the resonant modes. This paper presents a new microstrip fractal antenna using the technique of inserting slots of shape fractal in ground plane in order to increase the bandwidth and insertion discontinuities in the feed line to reach specific behaviors in three resonant modes. The FR-4 substrate with dimensions 85.0 x 85.0 x 1.57 mm³ is used. Also, it used different techniques of impedance matching in feed line of antenna with changes of the width of the transmission line in order to obtain a variation in the current distribution and consequently of the impedance bandwidth for S11 ≤ -10dB for C-band (3.625 GHz – 4.2 GHz) and S-band (2.0 GHz – 4.0 GHz). Good agreement between measured and simulated results is achieved. Proposed fractal microstrip antenna can be easily designed, built and applied in wireless communication.**

Index Terms— Feed line discontinuity, microstrip fractal antenna, printed slots ground, wireless communication system.

I. INTRODUCTION

Nowadays, the microstrip antennas are especially attractive because of its low cost, low profile and ease of integration with other circuit elements. The patch and the ground plane may have various geometric configurations and input impedances are usually 50 Ω or 75 Ω. Some devices in wireless communications require broadband transmission and even ultra-broadband. In order to obtain the desired resonant modes is employed the addition of slots in microstrip antenna, both in the patch and the ground plane [1-3]. The removal of ground plane parts for various applications has been studied, as curve fractal-shaped for communication systems [4]. Studies of monopole antennas have been considered in order to find resonant modes for WLAN/WiMAX applications [5]. Investigation of radiation characteristics for microstrip antennas using geometries such as the island and the curve of Minkowisk as well as fractal-shaped slots in the ground plane is shown in [6]. Several studies have shown that the impedance bandwidths for printed antennas can be controlled by coupling between the patch and the slot in the printed ground plane [7-9]. In [10], the author suggests variation in width of

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the antenna's feed line, in order to obtain other resonant modes. Reference [11] shows different levels fractal geometry can increase the electrical length of the slot sides that help in controlling the resonant modes and makes the antenna resonates between 2 GHz and 6 GHz. Slots with fractal-shape and the use of fractals geometry defects in ground plane producing two resonant modes in 2.5 GHz and 5.5 GHz is reported in [12]. Studies of microstrip patch antenna with defected ground structure (DGS) for WLAN/WiMAX applications are shown in [13].

In this paper, a new triple band antenna fractal microstrip for C-Band and S-Band applications is proposed. The methodological technique consists initially design and optimize a microstrip patch antenna with full ground plane fractal with resonate modes at 4.3 GHz and 8.1 GHz. As a second step, it's inserted two defects in ground plane and then the microstrip patch fractal antenna adds two resonant modes at 5.0 GHz and 6.8 GHz, besides having controlling of resonant modes and impedance in the operating range of interest. In this way, the antenna with fractal defect and feed line discontinuity (¼ wavelength transformer) starts to resonate in three modes: 2.2 GHz, 3.7 GHz and 5.0 GHz for dimensions of specific parameters. The behavior of the resonant modes of the structure and the influence they suffer due to the level of fractal geometry and defects in the ground plane structure are important factors to be considered in this paper. Good agreement is obtained between the simulation and experiment as such as results for resonant modes, far-field E-plane and H-plane radiation patterns, and gain of the designed antennas. It's important to note that these resonant modes include frequency range of communication systems such as WLAN (2.4 GHz / 5.2 GHz / 5.8 GHz) and WiMax (3.5 GHz / 5.5 GHz). In order to validate the technical proposals is realized a comparison of the optimized antenna in this paper with another of the literature [13], observing best performance for the antenna here reported.

The remainder this paper is organized as follows. Section 2 describes the proposed antenna with resonant modes in terms of the discontinuities of feed microstrip line, patch of antenna and defects in ground plane. Parametrization analysis is presented and analyzed in Section 3. Section 4 shows the results and discussion for simulated and measured data are presented and analyzed for the resonant modes, the linear current density, the radiation patterns and the gain. The conclusion is given in Section 5.

II. Proposed Antenna: Analysis and Design

In this section are analyzed the microstrip fractal antenna techniques and the effects of partial ground plane removal and of discontinuities of feeding microstrip line on the transmission characteristics of the proposed antenna. Some tests were performed with various forms of ground plane and patches in analysis of the antennas and it was choosing the shaped-fractal for these structures. Fractal geometry offers almost unlimited ways of describing, measuring and predicting the resonant modes for planar structures of transmission. In computational numerical simulations was used Ansoft HFSS® Vs. 13 software using finite element method, for optimization of planar

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microstrip antennas. After the optimization, the antennas were built and measurements carried out in UFRN laboratories using an analyzer Vector network of Rohde & Schwarz®. The topics following describe the main parameters in the proposed antenna design.

A. Discontinuities of Feed Line

Figure 1 shows a microstrip feed line with discontinuities, where the line changes the width, being shown in Fig. 1 (a). The Fig. 1(b) depicts fringing electric field and the Fig. 1(c) shows equivalent circuit. This change in the width of the microstrip line is widely used for network configuration, transformers and ¼ wavelength couplers. The main characteristics these lines are: (i) the parasite effect or fringe fields effect (due to capacitance associated with the widest line of discontinuity); (ii) the phase-shift related to the discontinuity; (iii) the parasitic effect of a step-junction that is similar to open-end circuit. These characteristics are parameters used in the analysis of microstrip antenna.

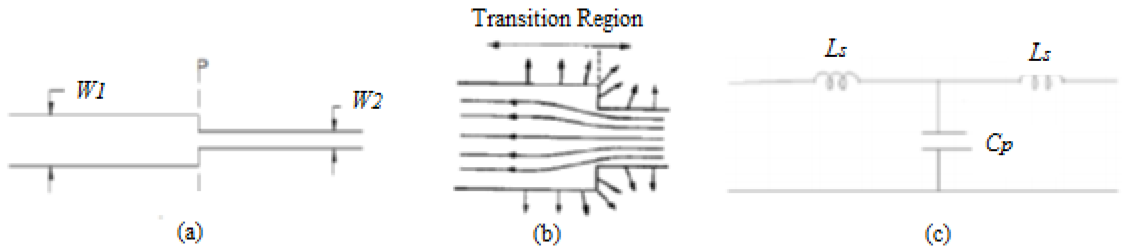

Fig. 1. Characteristics of discontinuities for microstrip line: (a) change in width; (b) appearance of fringe electric field; (c) equivalent electric circuit with two Ls inductances and one Cp capacitance.

B. Patch Antenna

In Fig. 2 are shown three situations of optimized microstrip antennas with full ground planes. For these designs were used FR-4 substrates with size 85 x 85 mm², relative permittivity 4.4, 1.57 mm of thickness, and loss tangent = 0.001. Fig. 2(a) shows the patch rectangular shape with dimensions L = 13.34 mm, W = 15 mm. Fig. 2(b) using scale factors for fractal geometry: *L/3; L/4; W/3; W/4*, for printed patch geometries. In Fig. 2(c) is used the same structure of Fig. 2(b) in order to change the width of the transmission line. The change in width of the feed line of W_1 = 3.0 mm to W_2 = 1.0 mm featuring the discontinuity in the line. The length of the discontinuity W_1 corresponds to 1/4 of the length and width W_2, and considering L_1 = 10 mm.

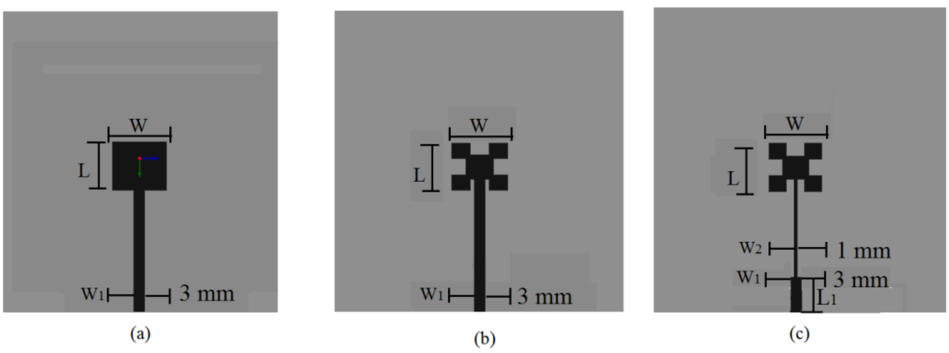

Fig. 2. Evolution of geometry of microstrip patch antenna with full ground plane: (a) rectangular patch; (b) patch fractal; (c) patch fractal with discontinuity.

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Figure 3 shows the simulation of the return loss characteristics for the structures shown in Fig 2(a)-(c). In order to do a comparative analysis, we noted that the case with the rectangular patch, it isn't satisfactory in terms of impedance matching, because it does not reach the insertion loss of -10 dB for operation of the printed antenna without discontinuities. However, for the case with patch fractal and using discontinuities results the appearance of resonance modes in 4.3 GHz and 8.1 GHz.

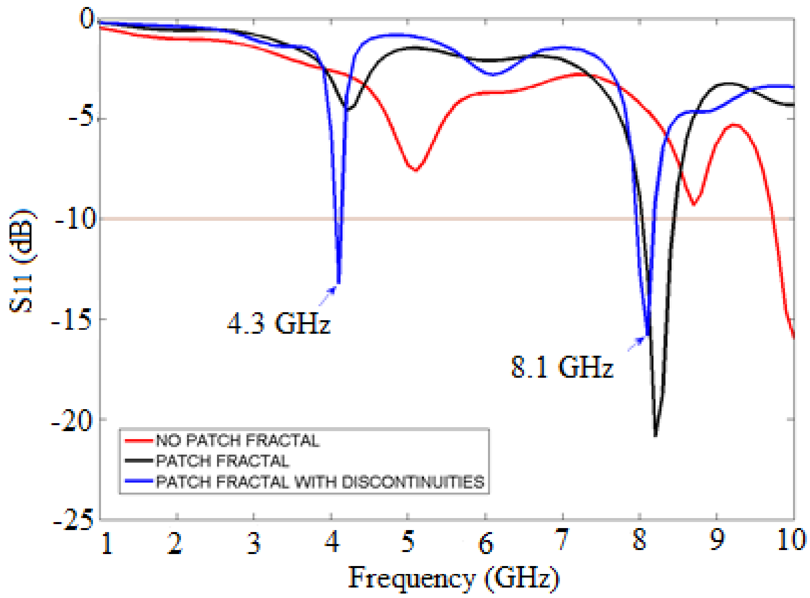

Fig. 3. Return loss for the proposed patch antenna.

Figure 4 shows the radiation pattern for E-plane and H-plane for the structures of Fig. 2. Fig. 4(a) depicted the planes $\phi = 0^o$ and $\theta = 90^o$ with geometry of full ground plane of the rectangular patch antenna and resonant mode of 10 GHz, whereas for the Fig. 4(b) shows the fractal patch antenna with resonant mode of 8.2 GHz. Fig. 4(c) shows the patch fractal with discontinuity and resonant modes in 4.3 GHz and 8.1 GHz.

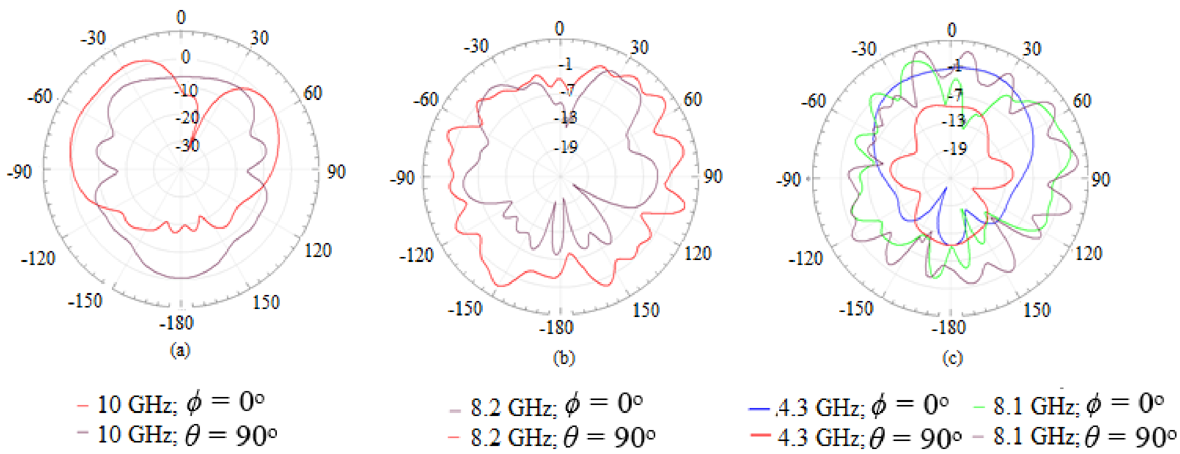

Fig. 4. E-Plane and H-plane for the full ground plane and patch: (a) rectangular; (b) fractal; (c) fractal with discontinuity.

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Figure 5 shows the gain of antennas for variations of frequencies between 1 GHz and 10 GHz, and values less than 0 dBi. This implies in no antenna radiating. Therefore, we have that considering the insert of defects in the ground plane and realize the analysis on the gain of the antennas.

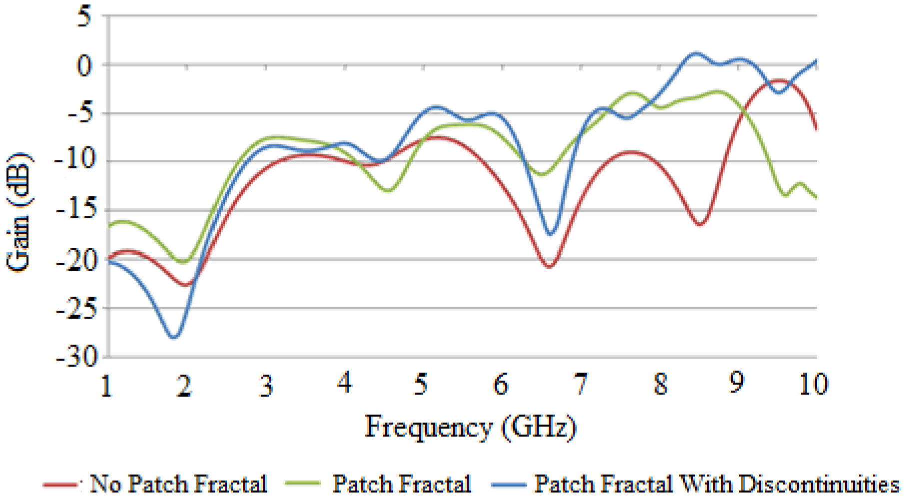

Fig. 5. Gain simulated for $\phi = 0$ ° and θ = 90º considered for cases of geometry with full ground plane.

C. Defect on the Ground Plane

The defects on ground plane are used with the optimized patch antenna in order to investigate the effects of fractal slots in the characterization of printed antennas in search of better behavior. We tested different shaped-slots on ground plane, as seen in Fig. 6. In Table I is shown the dimensions of proposed antenna. These values used in the slots are: *Lg/3; Wg/3; Lg/4; Wg/4*, as seen in Fig.6(c).

TABLE I. OPTIMIZED PROPOSAL ANTENNA

Antenna Dimension	Value
W	15 mm
L	13.34 mm
W_1	3 mm
W_2	1 mm
L_1	10 mm
W_g	40 mm
L_g	45 mm
$L_g/3$; $W_g/3$	15 mm; 13.34 mm
$L_g/4$; $W_g/4$	11.25 mm; 10 mm

The fractal antenna seen in Fig. 6(c) was used for the physical construction and measurement.

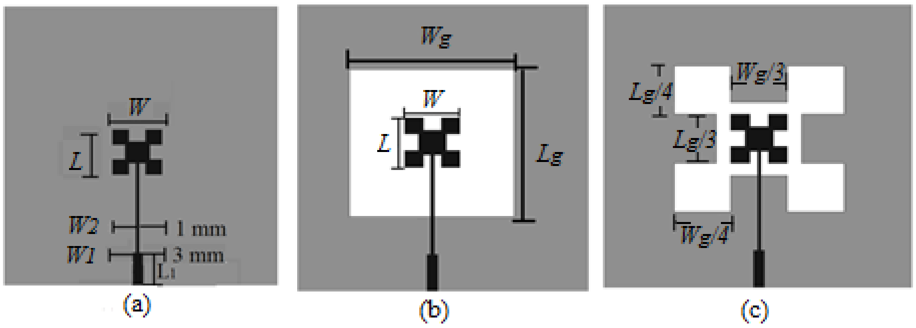

Fig. 6. Evolution of the geometry of printed ground plane, for: (a) geometry with full ground plane; (b) rectangular-shaped slot on the ground plane; (c) fractal-shaped printed slot on ground plane.

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Figure 7 shows the return loss curves for the case of antennas with ground plane defects (as seen in Figure 6 (a) - (c)) for the resonant modes in 2.2 GHz, 3.7 GHz, and 5.0 GHz, demonstrating the operation under triple band. In this case, it was used feed discontinuities in microstrip line and fractal-shaped slots in the ground plane.

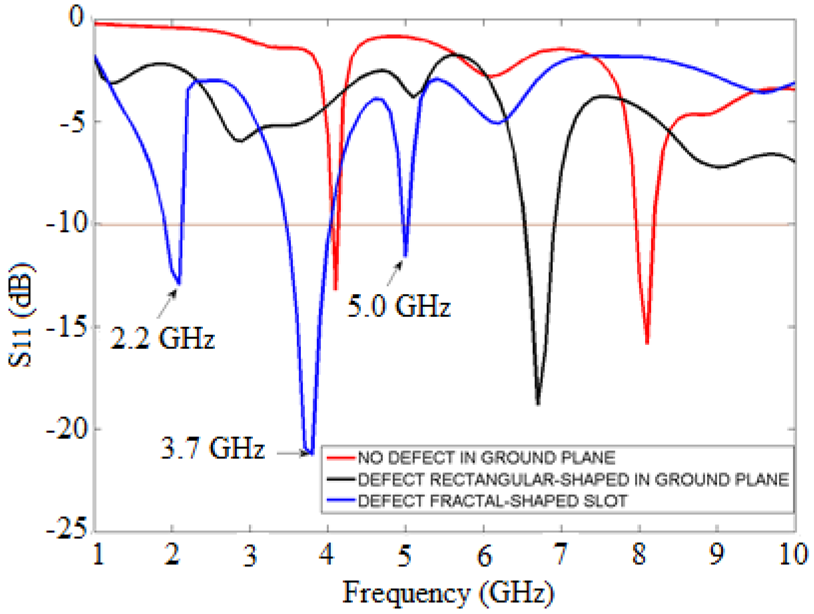
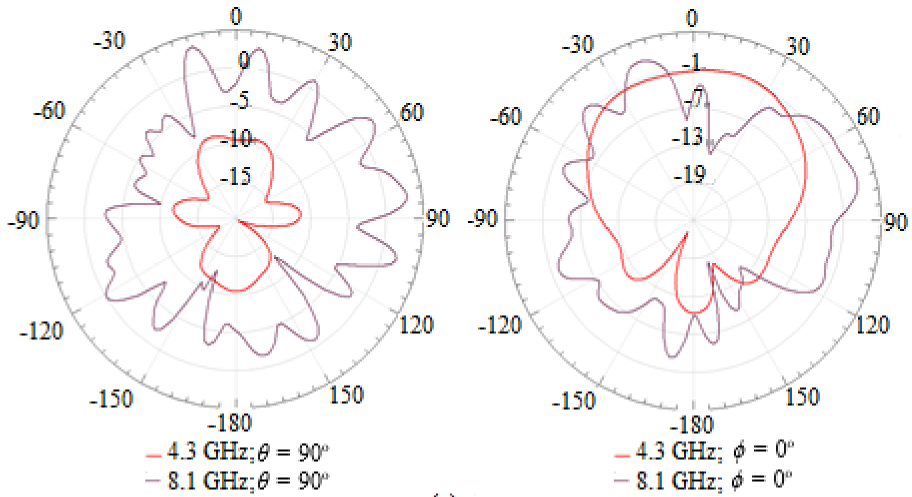


Fig. 7. Return loss for the tested cases of defect ground plane.

Figure 8 shows the measured radiation patterns in H and E planes of the proposed antenna for the resonant modes in 4.3 GHz and 8.1 GHz with geometry full ground plane (a), with resonant mode in 6.8 GHz for rectangular-shaped slot on the ground plane (b), and resonant modes in 2.1 GHz, 3.8 GHz and 5.3 GHz for fractal-shaped printed slot on the ground plane (c).



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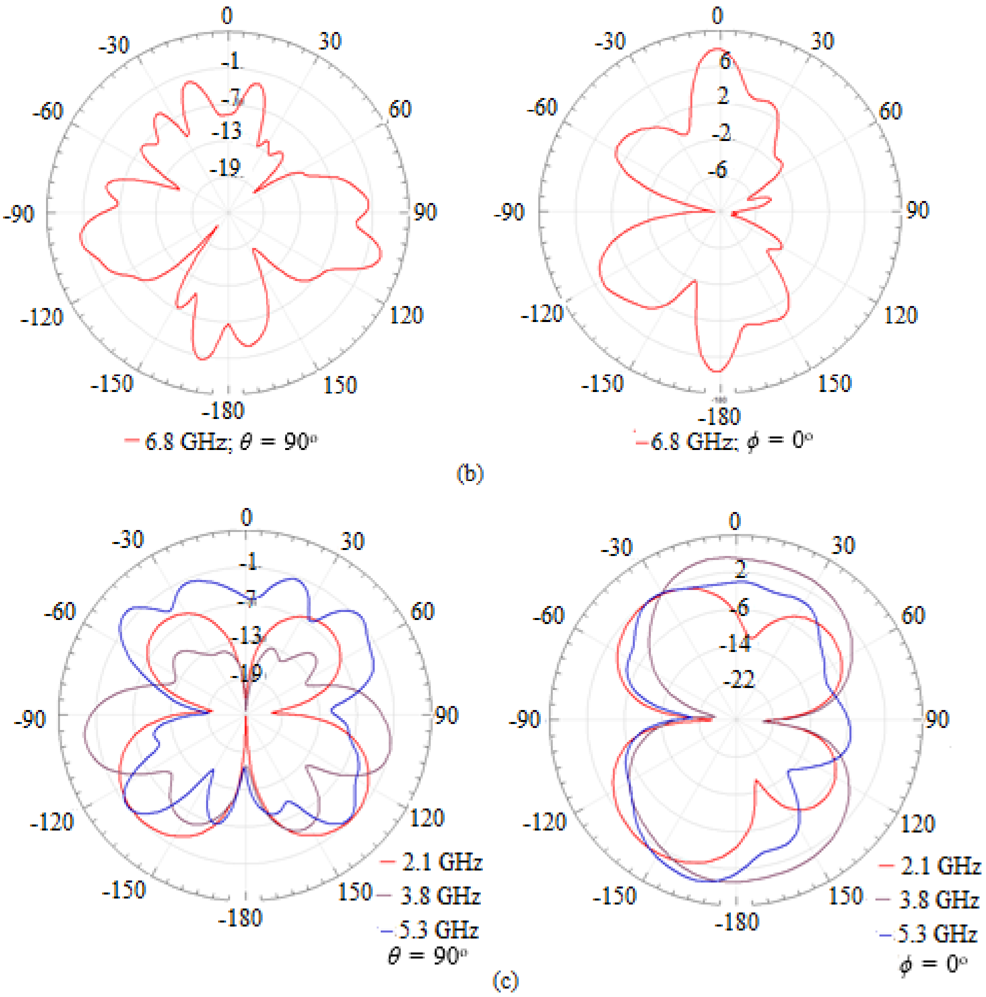

Fig. 8. Radiation patterns of E-Plane and H-plane for cases of defects on ground plane for its resonant modes.

Figure 9 shows the gain peaks in dB in range between 1 GHz and 6 GHz for the proposed antenna. In this case, fractals elements inserted by Minkowisk curve changed the formation of the fields in antenna and therefore the insertion of resonant modes for antenna operation to frequencies band of WLAN and adjusting the gain for a better propagation of the signal.

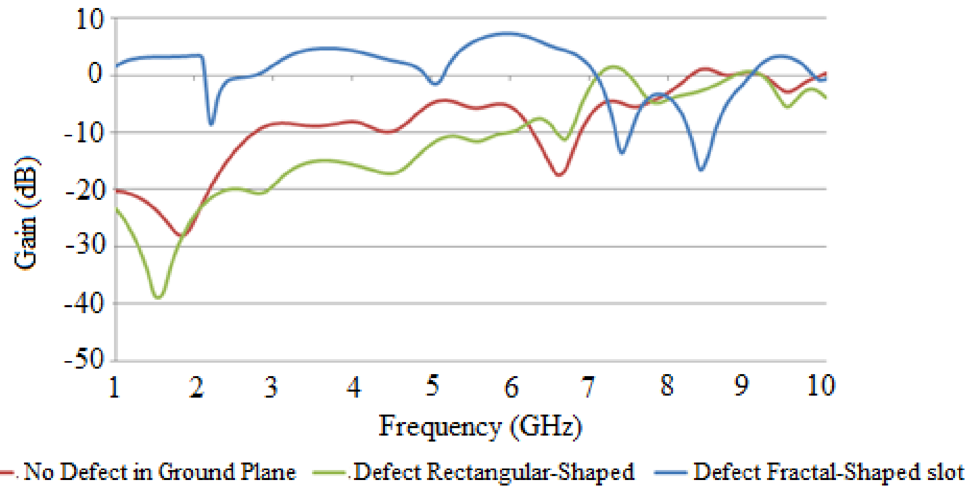

Fig. 9. Gain simulated, $\phi = 0$ ° and $\theta = 90$° considered for cases of defects on ground plane.

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III. Parametrization Analysis

Variations were performed to investigate the relationship of influences on the antenna response as function of the L_1 e W_2 parameters. The variation of parameters L_1 and W_2 have direct influence on the impedance ratio given by 1/4 wavelength transformer, which causes direct change in the reflection coefficient and control of frequency. For this test were considered the values of W_2 = 0.9 mm; 1.0 mm; 1.1 mm. For L_1, were used 7 mm; 9 mm; 10 mm; 11 mm; 13 mm, as shows the Table II. First it was considered L_1 = 10 mm and variations W_2 as seen in Fig. 10. After this, it was done simulations considering W_2 fixed in 1.0 mm and variations in L_1 as seen in Fig. 11.

Table II. Parametrization

Fixed Parameter	Variety Parameter
L_1=10 mm	W_2 = 0.9 mm W_2 = 1.0 mm W_2 =1.1 mm
W_2 = 1.0 mm	L_1=7 mm L_1=9 mm L_1=10 mm L_1=11 mm L_1=13 mm

Figure 10 shows the variation of W_2, considering fixed L_1 = 10 mm. Thus, it can change the simulated reflection coefficient and the bandwidth for S11 < -10dB practically unchanged. It happens for resonant modes in 2.2 GHz, 3.7 GHz and 5.0 GHz.

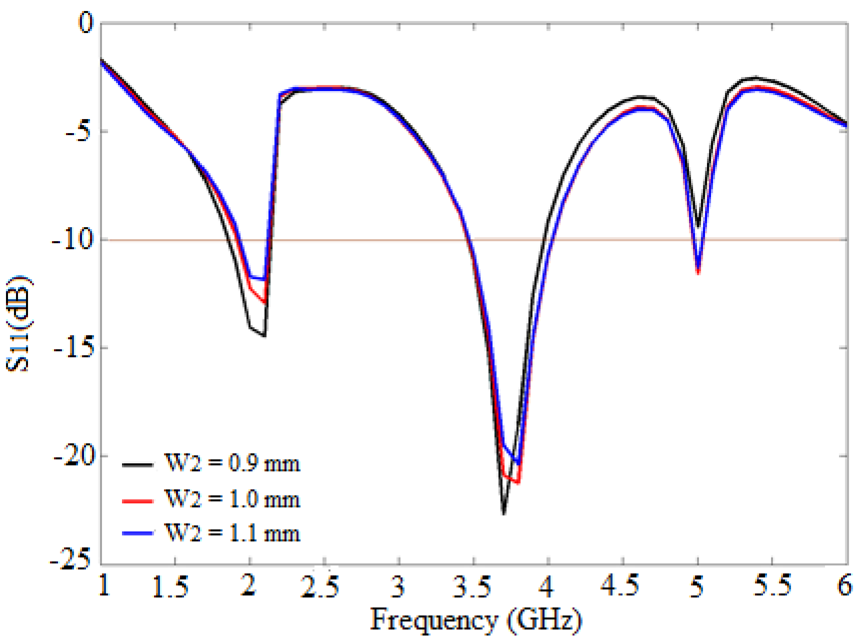

Fig. 10. Variation W_2 Fixed L_1 = 10 mm.

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However, in Fig. 11 are varied L_1 and fixed W_2 in 1.0 mm. Thus, it is shown a frequency control up to 500 MHz. Thus, we can make application the control of bands down link and up link for communication satellites applications.

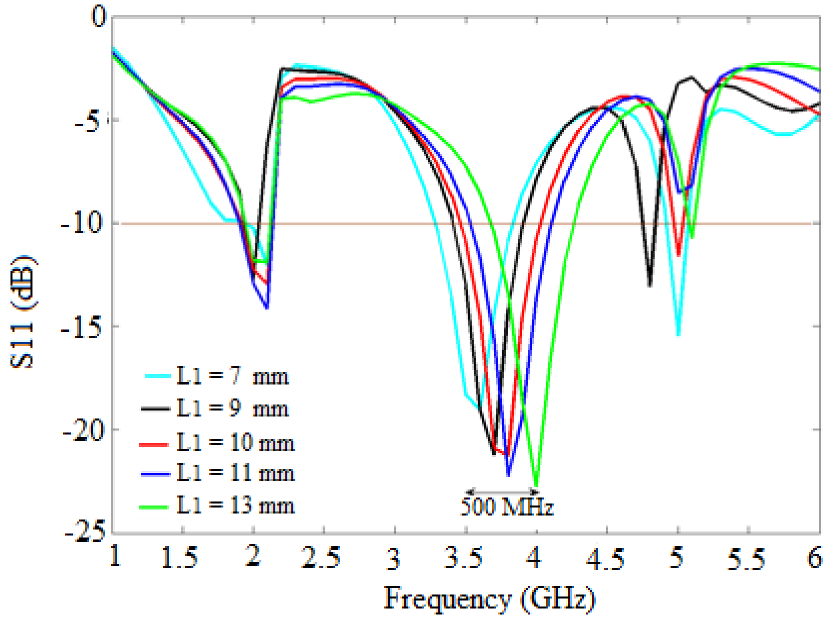

Fig. 11. Variation L1 Fixed W2 = 1.0 mm

Figure 12 considers different values of W_2 and L_1 for simulated return loss. It is observed for the second frequency band a control for the range of 500MHz of bandwidth for the case when W_2 = 0.5 mm, L_1 = 5 mm. The parametrization shows that changes in the parameters L_1 and W_2 has effects on the resonant modes and operation of the microstrip antenna for WLAN application.

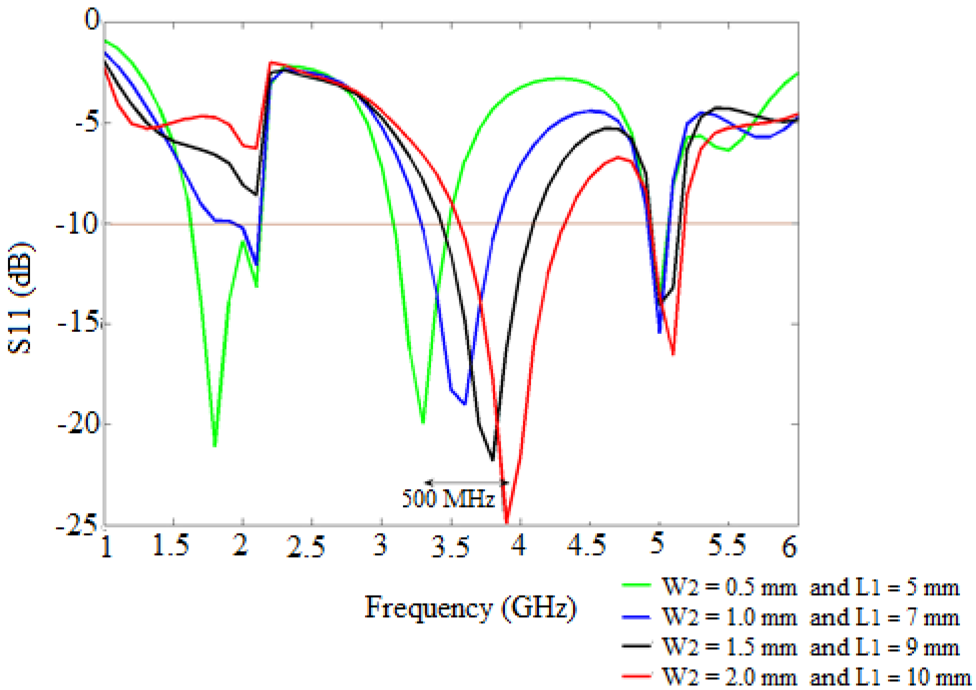

Fig. 12. Variation of L_1 and W_2 pairs in mm.

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IV. Results and Discussion

Figure 13 shows the geometry optimized while the Fig. 14 shows a photograph of the fabricated antenna. For the physical construction and measurement model was used to analysis W_2 = 1.0 mm, and L_1 = 7.0 mm. Thus, the results showed que the three bands for reflection coefficient were less than -10dB, for the bandwidths of the proposed antenna. The numerical values for these three resonant modes were 2.1 GHz, 3.8 GHz and 5.3 GHz.

Next, we analyze the parameters: (A) return loss, (B) current density distribution, (C) radiation patterns and gain, and (D) the comparative study between the proposed antenna and the antenna reported in [13].

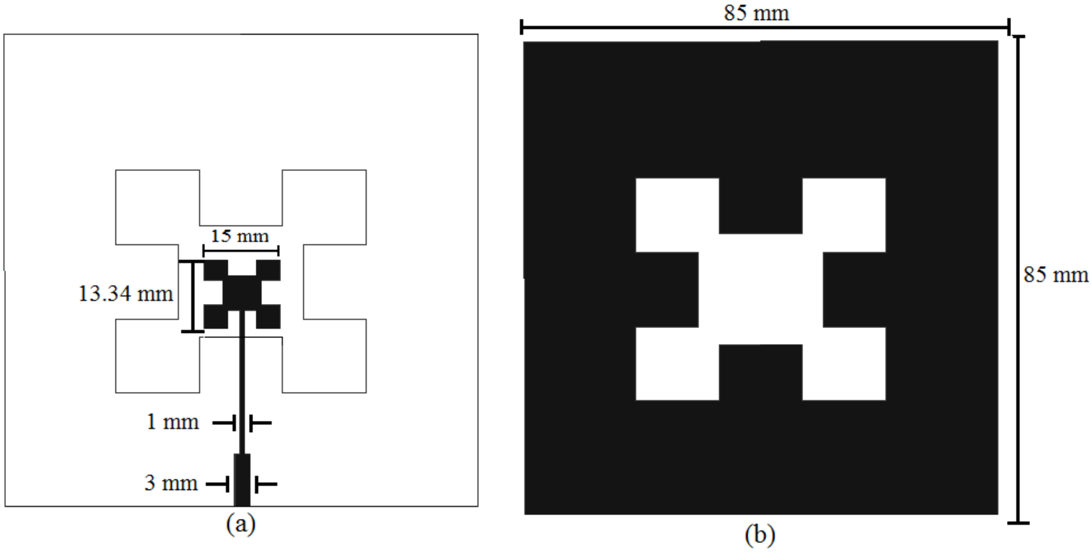

Fig. 13. Schematic of the proposed antenna: (a) Patch antenna (b) Ground plane.

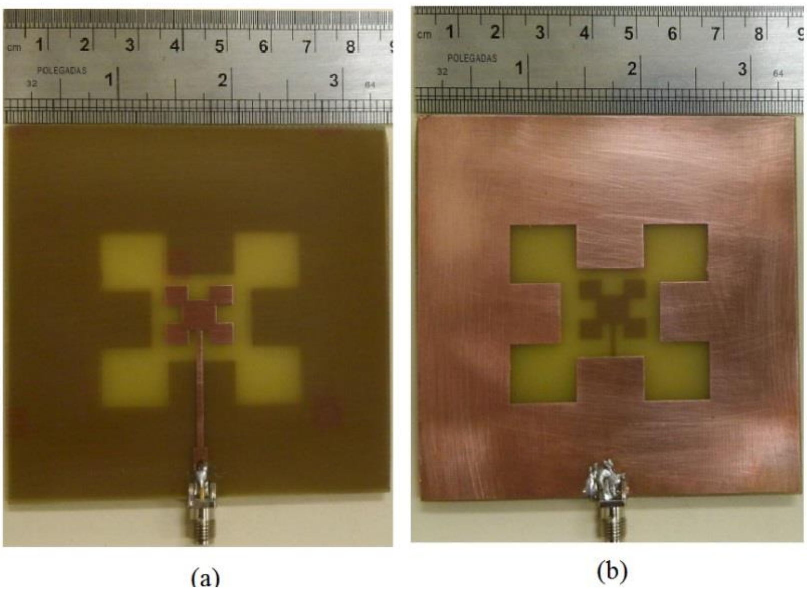

Fig. 14. Photograph of the fabricated antenna proposal: (a) microstrip patch; (b) ground plane.

A. Return Loss

The behavior three bands have remained, as seen in Fig. 15. Simulations and measurements were performed to assess the behavior of antennas in terms of the S_{11} scattering parameter. For the analysis

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were collected values from the return loss of -10dB. Thus, the bandwidth is for the case with discontinuity in feed line, bandwidth was BW_1 = 75 MHz, BW_3 = 250 MHz and BW_5 = 350MHz for measured results and BW_2 =203 MHz, BW_4 = 840 MHz and BW_6 = 100 MHz for simulated results for frequencies 2.1 GHz; 3.8 GHz; 5.3 GHz respectively.

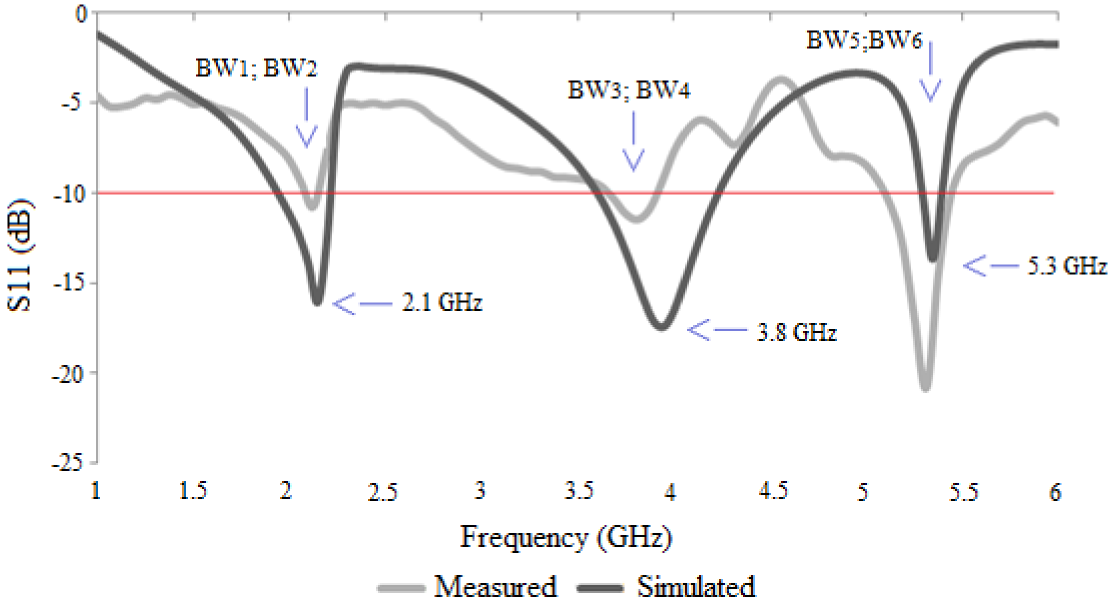
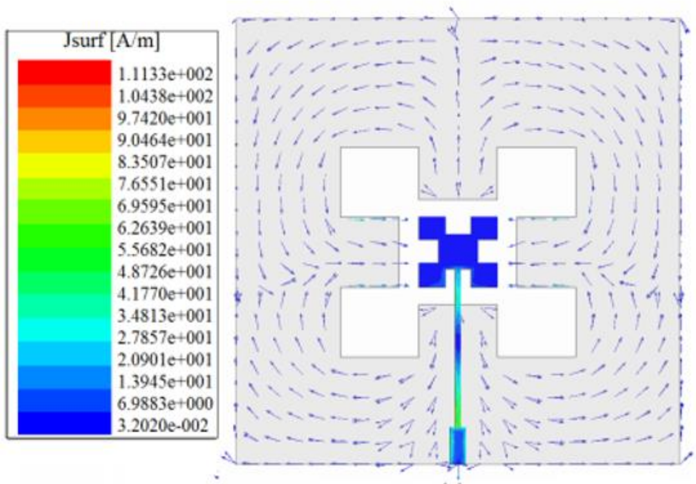


Fig. 15. Return loss measured and simulated.

B. Current Density Distribution

Figure 16 shows the distribution of current density J (A/m) for optimum antenna at frequencies of 2.1, 3.8 and 5.3 GHz. It can be observed that the antenna impedance changes due to the resonant properties of the discontinuities and ground slot shaped. The surface current concentrated on the edges of the interior and exterior of the fed by microstrip discontinues. The slits and indentations as well as the use of discontinuities in microstrip lines is much studied in order to parasitic effects and structures for linear current distributions analysis. Then observed a radiation pattern similar to a conventional patch rectangular antenna, in which the maximum radiation in the far field occurs in the direction perpendicular to the radiating element in type broadside.



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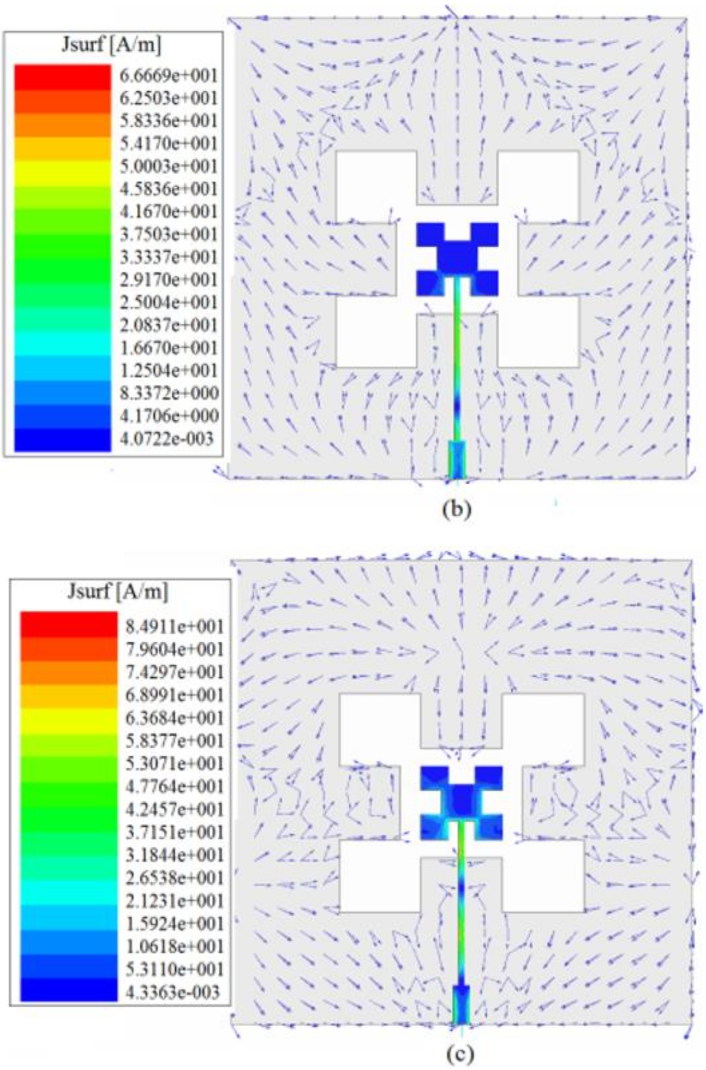

Fig. 16. Density current distribution a microstrip line with W_1 = 3 mm and W_2 = 1 mm: (a); f = 2.1 GHz (b) f = 3.8 GHz; (c) f = 5.3 GHz.

C. Radiations Pattern and Gain

The simulated radiation patterns for the resonant frequencies of the proposal antenna are shown in Fig. 17. Simulations for far fields E (ZX plane) and H (ZY plane) were obtained using the HFSS® software. Fig. 18 shows gain plot for measured antenna.

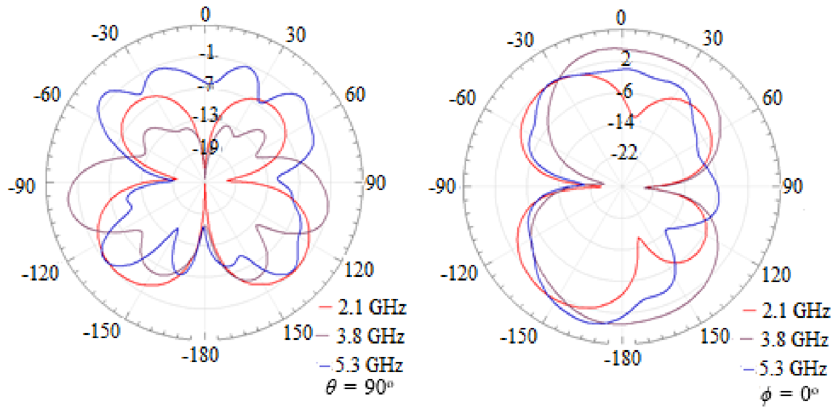

Fig. 17. Radiation pattern, ϕ = 0 ° and θ = 90º for cases: (a) E-plane (b) H-plane.

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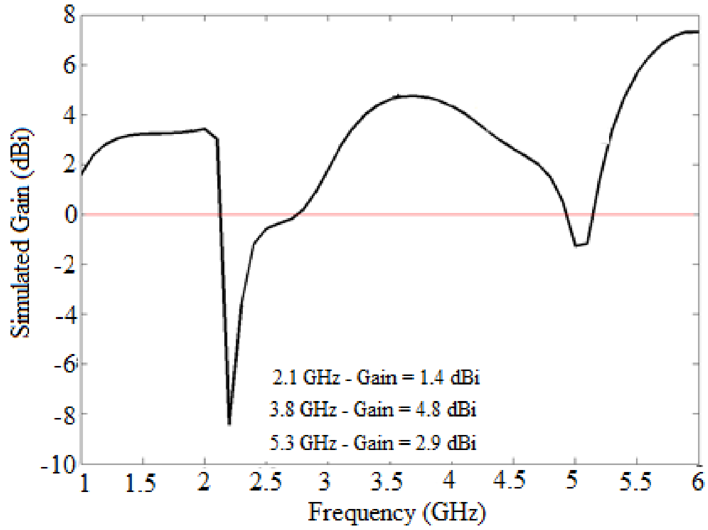

Fig. 18. Gain simulated, $\phi = 0$ ° and $\theta = 90$º considered.

D. Comparative Analysis

Figure 19 shows the comparing the simulation results of the antenna proposed in this work and results in [13]. It is evident the difference between a dual-band antenna and the antenna in this work that has three resonant modes operating in 2.1GHz, 3.8 GHz and 5.3 GHz. In this analysis the simulated bandwidths of proposed antenna were BW_1 = 1.912 GHz-2.115 GHz, BW_3 = 3.55 GHz-4.39 GHz, BW_4 = 5.39 GHz-5.49 GHz; and the gain of 1.4 dBi, 4.8 dBi and 2.9 dBi for 2.1GHz, 3.8 GHz and 5.3 GHz, respectively, while the antenna proposed by Mohammad et. Al [13], presented BW_2 = 2.276 GHz-2.553 GHz and BW_5 = 5.144 GHz-5.90 GHz bands with gain 2.053 dBi and 4.52 dBi for resonant modes 2.43 GHz and 5.52 GHz, respectively.

Note that for the two antennas in comparison were used similar techniques such as transformer 1/4 wave, fractal defects and patch geometries.

In table III is shown numerical parameters between the proposed antenna this paper and the proposed antenna in [13].

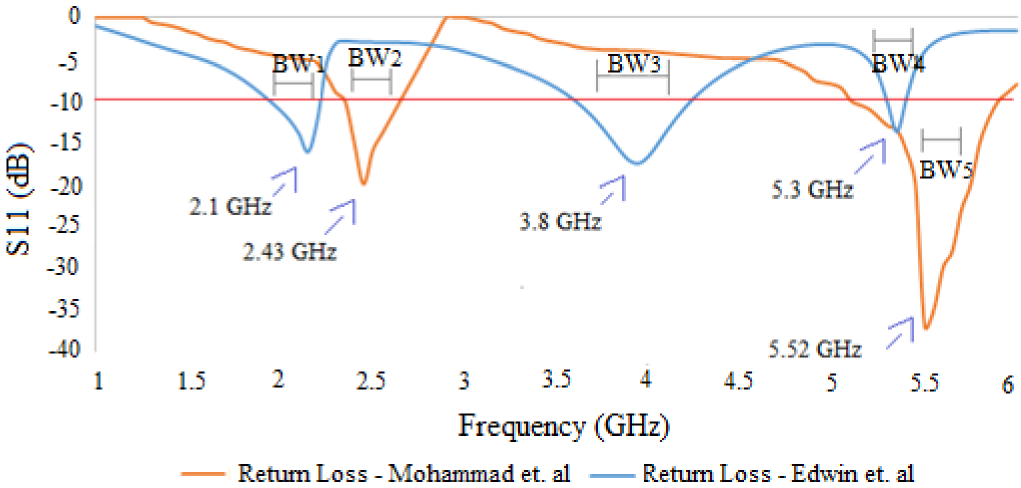

Fig. 19. Comparison between the dual band antenna proposed in [13] and the triple band antenna proposed in this paper.

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TABLE III. SIMULATION RESULTS OF THE ANTENNAS

Parameter	Proposed antenna			Mohammad et. Al [13]	
Resonant Mode	2.10 GHz	3.80 GHz	5.30 GHz	2.43 GHz	5.52 GHz
Bandwidth	BW_1 = 203 MHz	BW_3 = 840 MHz	BW_4 = 100 MHz	BW_2 = 275.5 MHz	BW_5 = 756 MHz
Gain	1.4 dBi	4.8 dBi	2.9 dBi	2.05dBi	4.52dBi

V. CONCLUSIONS

In this paper, we proposed a new tripe band microstrip patch antenna and a technique to increase its performance. The antenna is designed, optimized and fabricated for S-band (2.0 GHz – 4.0 GHz) and C-band (3.625 GHz – 4.200 GHz) for weather radar, satellites communications, WLAN and WiMAX applications. Analyzed results concluded that the proposed antenna operates efficiently for resonant modes in 2.1GHz, 3.8 GHz and 5.3 GHz. The measured bandwidths of proposed antenna were 75 MHz, 250 MHz and 350 MHz with simulated gain of 1.4 dBi, 4.8 dBi and 2.9 dBi, respectively. The maximum return loss of −11 dB, −13 dB and −23 dB is obtained for these resonant modes. The enhancement of transmission characteristics, the small size, the light weight and the cost effectiveness of the proposed antenna makes strong candidature for small and slim wireless devices in telecommunication systems.

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