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Research paper

Enhancement of the Gain and the Bandwidth of a UWB Microstrip Patch Antenna Using Metamaterials

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Abstract

This paper designs a miniaturized size ultra-wideband microstrip antenna based on Metamaterial array. The proposed structure is consisting of ultra-wideband antenna and Metamaterial array. The antenna is characterized by dimensions of 36*38*1.58 mm^3 with a partial ground printed on the FR4 dielectric substrate. The MTM array is constructed from two triple split ring resonators located above the antenna structure. The antenna is showed an acceptable gain of 5.6 dB with a wide band of operating frequencies starting from 2.6 GHz to more than 20 GHz with an S11 value less than – 10 dB in the entire band. The gain is enhanced about 3.19 dB by adding the TSRRs. Finally, the CST MWS is used to design and simulate the antenna structure.

Keywords: *Gain; Bandwidth; Ultra Wideband Antenna; Metamaterial.*

1. Introduction

This document can be used as in continuous developments in the wireless communications industry, a need for antennas of exceptional capabilities has increased. A high gain with multiband/ wideband support antennas would be an idealistic solution. In spite of these challenges, antenna design specifications are rarely relaxed. Thus, achieving the desired antenna's performance generally becomes difficult to cope with these continuous developments in the wireless communications industry.

Microstrip patch antennas are characterized by many advantages such as slim profile, low production cost, lightweight, easy to fabricate and integrated with Microwave Circuit Board (MCB) [1]. However, microstrip antennas also suffer from inherent limitations such a narrow bandwidth, low efficiency, modest gain, low power-handling capacity and extraneous radiation due to surface waves [2].

Many techniques were proposed to overcome conventional microstrip antennas limitations and for example, high-permittivity substrates, shorting posts, meanders, spirals, truncated patches and lumped elements were proposed to reduce the antenna size [3]. While, a partial ground plane was proposed to overcome the bandwidth limitation [4]. As shown from above, the performance and the size of antennas are generally mutually related in a conflicting matrix; i.e., enhancing certain properties may affect others [5].

In last few years, a novel way was proposed to overcome these limitations. This technique is presented by using various Metamaterial (MTM) structures [6]. The metamaterial can be defined by an artificial material characterized by unique properties (-μ and -ε) which is not found in nature [6-8]. The properties of metamaterial depend on the shape, orientation, arrangement and size of the structure [8-10].

In this paper, two techniques are applied to design high bandwidth gain product antenna for wideband applications. The first one is presented by using the partial ground plane technique to achieve a wideband operating frequency, S11 < -10 dB, by reducing the energy stored in the substrates. While, the second technique is represented by adding the triple split ring resonators (TSRRs) to the proposed antenna structure in order to enhance the antenna gain in the entire band.

2. Antenna Design Principle

The Conventional Microstrip Patch Antenna design that is shown in Figure 1 consists of four main structures: a substrate, rectangular patch, ground plane and feed line where the other related details can be found in Table 1.

Table 1: Conventional microstrip patch antenna dimensions (mm).

LS	WS	LP	WP	Lf	Wf	h	t
38	36	18	20	16	2.9	1.58	17

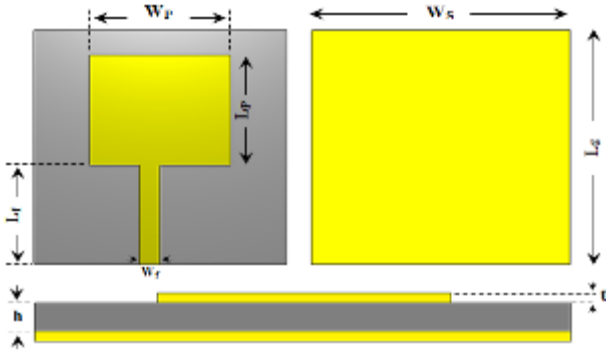


Fig. 1: Conventional microstrip patch antenna: (a) top view, (b) back view, (c) side view.

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The performance of the proposed design model based Conventional Microstrip Patch Antenna structure is tested numerically in terms of S11 spectra as seen in Figure 2. It is found that the proposed antenna model provides an S11 < -10 dB at the frequency bands: 7.445 GHz - 8.1146 GHz, 10.403 GHz - 10.775 GHz, 11.069 GHz - 11.923 GHz and from 12.941 GHz to 20 GHz.

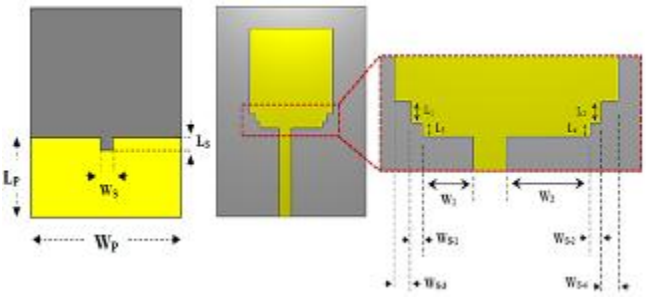


Fig. 2: S11 spectra of the conventional microstrip patch antenna.

The proposed structure design geometry is consisting of two main parts: UWB microstrip patch antenna and Metamaterials structures. The UWB antenna is shown in Figure 3. The dielectric substrate is picked as the FR4-Epoxy material of εr and tanδ equals to 4.4 and 0.02 respectively.

The substrate dimensions are 38×36 mm2 with a thickness of 1.58 mm. The patch and partial ground plane are picked as conductive material printed on the both of substrate faces, where the other related details can be found in Table 2.

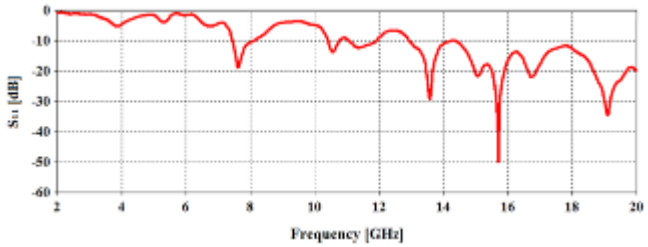


Fig. 3: UWB microstrip antenna.

Table 2: UWB microstrip patch antenna dimensions (mm).

L_1	L_2	L_3	L_4	W_1	W_2	W_{S-1}
1.5	1.5	1	1	4.55	7.55	1
W_{S-2}	W_{S-3}	W_{S-4}	L_P	W_P	L_S	W_S
1	1.5	1.5	15	36	2.7	3.8

The second part of the structure construction is presented by the metamaterial array that located above the UWB antenna with separated distance (d). The proposed array consists of two unit cells in one row separated by distance equals to 10 mm. Both of unit cells are printed on a dielectric substrate as seen in Figure 4.

The single unit cell is a Triple Split Rings resonator (TSRR) with rings with dimensions of 10×10 mm2, 8.2 × 8.2 mm2, and 6 × 6 mm^2 respectively. The materials that used to construct the TSRR structure are: the dielectric FR4-Epoxy material with εr and tanδ equals to 4.4 and 0.02 as a substrate, that seen in the Gray color, while the other material is conductive materials that picked as PEC that seen in the yellow color. The other related dimensions details of the proposed structure can be found in Table 3.

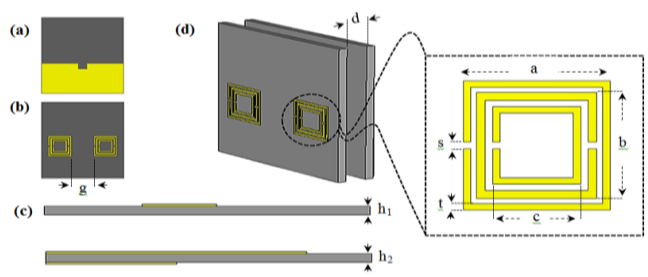


Fig. 4: Microstrip patch antenna based on triple split rings resonator: (a) Back view, (b) Top view, (c) Side view and (d) 3D view.

Table 3: UWB microstrip patch antenna based on triple split rings resonator dimensions (mm).

d	h_1	h_2	g	b	c	t	s
4	1.58	1.58	10	8.2	6	0.5	0.5

3. Results and Discussion

The performance of the UWB Microstrip Patch Antenna Based Triple Split Rings resonator structures is tested numerically in terms of S11 spectra, gain, current distribution and radiation patterns.

3.1. Antenna Performance

In Figure 5, the S11 performance of the proposed structures is tested numerically in case of with and without MTMs. It is found that the proposed antenna model provides a wideband of operating frequency with S11 less than -10 dB from 2.6 GHz and continuous to more than 20 GHz. Addition of the MTMs, whereas seen in Figure 3, the first mode is shifted down by 688.74 MHz.

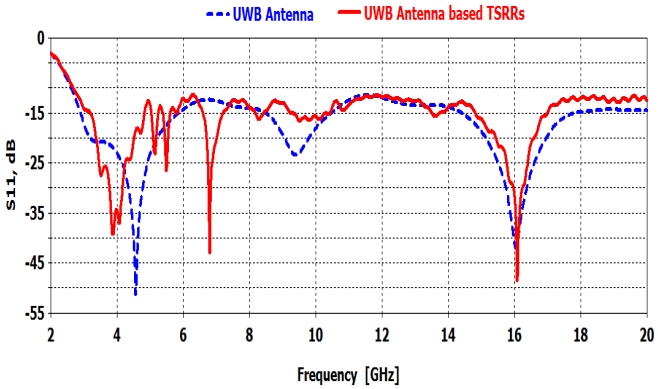


Fig. 5: S11 comparison between the UWB antenna and UWB antenna based TSRRs structures.

The gain spectra of the proposed structure are evaluated and then compared with the gain of the antenna without MTM, as seen in Figure 6. It is found that the gain spectra of the proposed structure, antenna with TSRRs are varying from 1.36 dB to 8.13 dB at a different operating frequency where the maximum enhancement in the gain is found equal to 3.19 dB at the frequency 16 GHz.

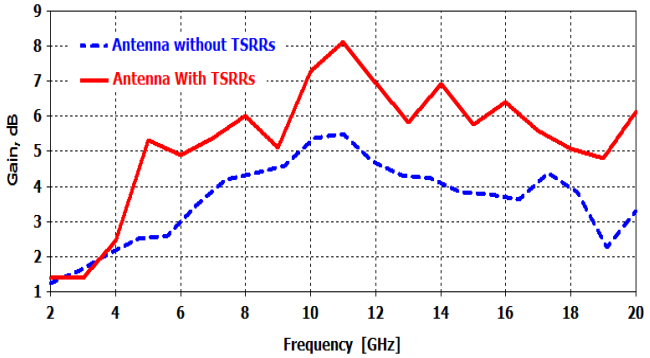
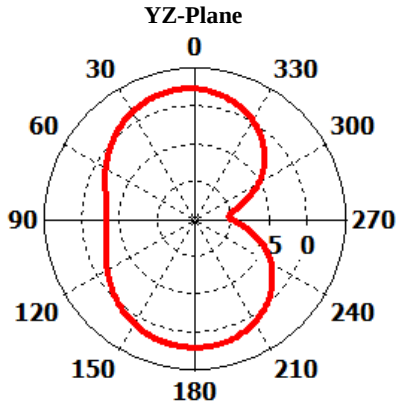
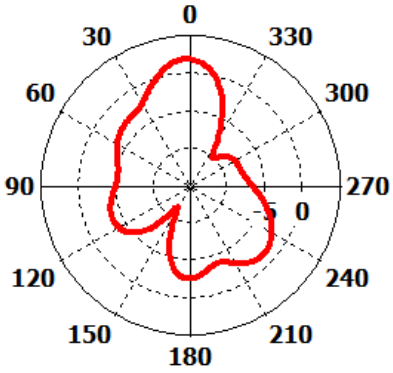


Fig. 6: Gain comparison between the UWB antenna and UWB antenna based TSRRs structures.

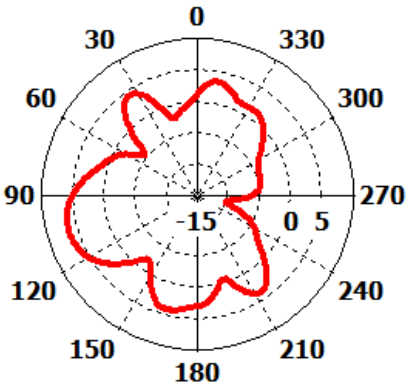
For more accuracy in define the E-filed and H-field directions of the proposed structure, the 2D radiation pattern is evaluated in terms of YZ-Plane and XZ-Plane as shown in Figure 7.



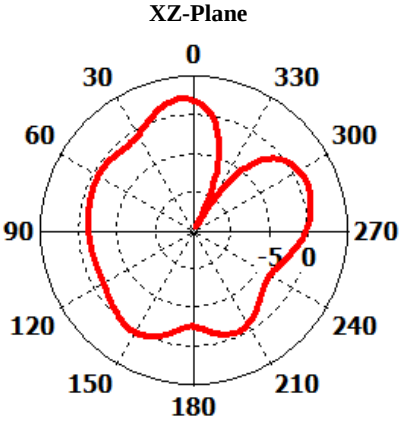
f = 3 GHz



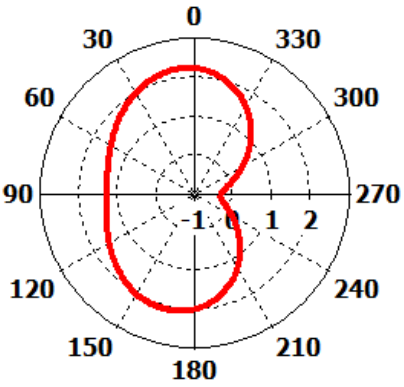
f = 10 GHz



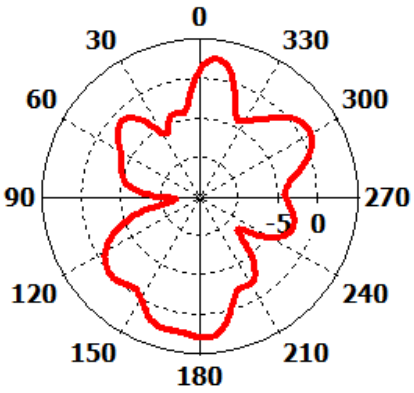
f = 20 GHz



f = 3 GHz



f = 10 GHz



f = 20 GHz

Fig. 7: YZ-plane and XZ-plane radiation patterns of the antenna based TSRR structures at the different operating frequency.

3.2. Antenna Parametric Study

The performance of the proposed structures, antenna/ antenna based TSRRs would be affected by changing the geometrical dimensions of the structure. This study is conducted to find the effects of each parameter on the antenna performance. The parametric study has been followed to arrive at the optimum design is shown below.

3.2.1. UWB Antenna

A-Effect of the Substrate Thickness (h)

The effect of substrate height/thickness (h) on the S11 spectrum is studied by fixing the substrate length and width at 38 mm and 36 mm respectively, while h is changed from 1 mm up to 2 mm with the step of 0.25 mm. In Figure 8, the S11 spectra are shown. It is found that the antenna shows the best matching bandwidth when the thickness is 1.58 mm.

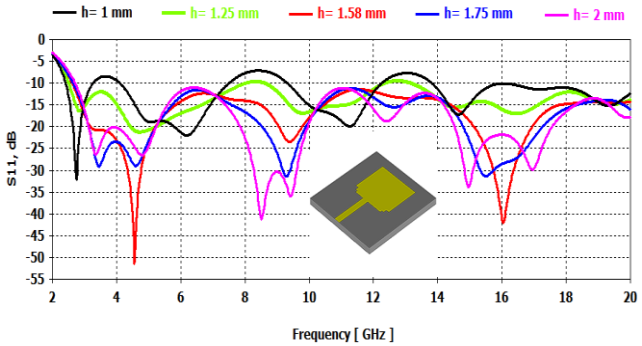


Fig. 8: S_{11} spectra with respect to changing h.

The reason of the antenna has the best matching at 1.58 mm thickness is back to the quality factor, where at this thickness the proposed antenna shows a lowest quality factor value compared with the other thickness and as a result, a low-quality factor means a high bandwidth due to the opposite relation between them.

B-Effect of the Ground Plane

The effect of varying the length of the ground plane is evaluated and presented in Figure 9. It is a clear that the length of the ground (Lg) has a significant effect on the antenna performance that presented by S11, which the best result is found at Lg equals to 15 mm after adding the slot to the partial ground.

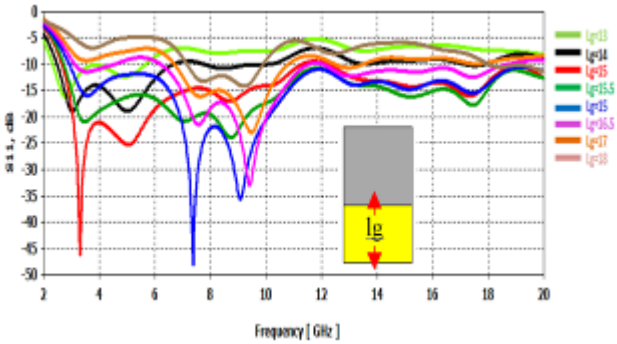


Fig. 9: S_{11} spectra with respect to changing L_g.

After achieving the best S11 with an Lg equals to 15 mm, a slot is added to the partial ground plane in order to enhance the S11 that have values close to -10 dB and reduce them to value below -10 dB. Figure 10 shows an S11 compression of the antenna in terms with and without a slot in the partial ground.

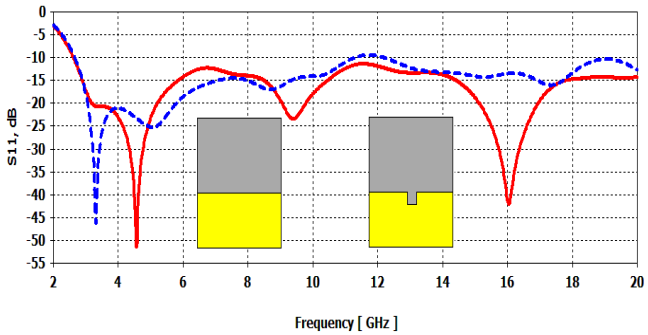


Fig. 10: Effective of the slot on the antenna S_{11} spectra.

3.2.2. Antenna Based TSRR Structures

After completing the antenna parametric study, a new study based on TSRR structures is proposed. This study is conducted to find the effects of the TSRRs separation distance (d), a number of TSRR structures, TSRRs position and g - gap on the antenna performance and as follows.

A-Effect of the TSRRs height (d)

In this section, the effectiveness of the separating distance (d) that cleared in Figure 11 on the antenna performance has been studied with considering that the optimum antenna dimensions are 38×36×1.58 mm^3.
Figures 12 and 13 show the simulated results, S11 and gain of the proposed structure with multiple separating distance values. It is a clear that the d has a significant effect on the antenna performance, which the best result is found at d equals to 4 mm that gives a higher gain with best impedance bandwidth that has S11 < -10 dB.

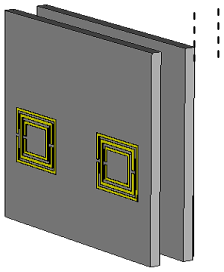


Fig. 11: The separating distance (d) between antenna and TSRR array.

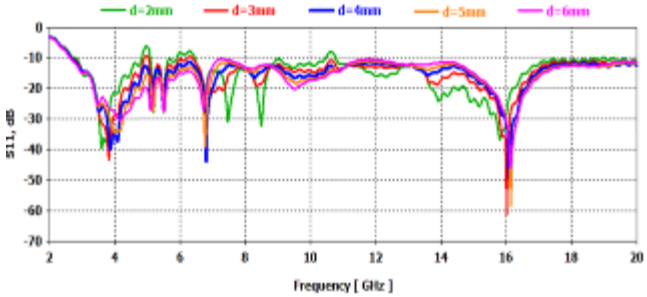


Fig. 12: S_{11} spectra of the multiple d values.

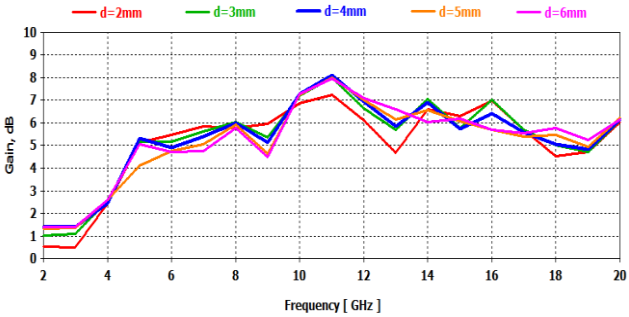
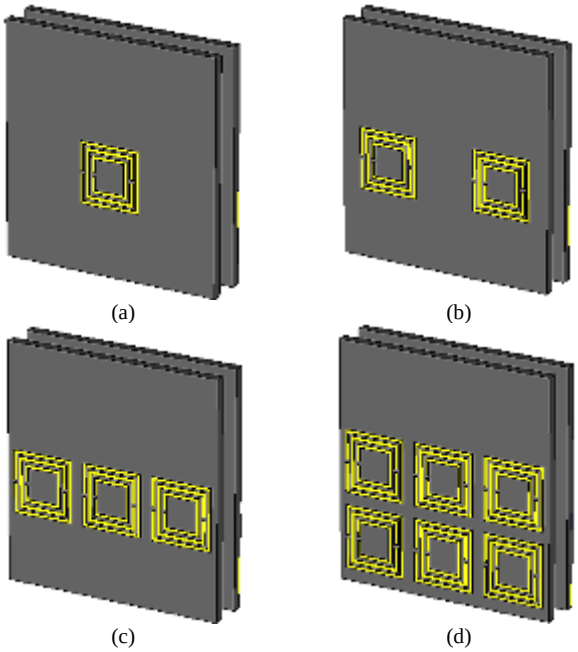
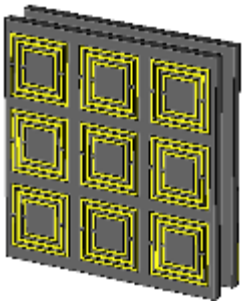


Fig. 13: Gain spectra of the multiple d values.

B-Effect of the TSRRs Number

The next study is presented by showing the effects of the TSRR number that shown in Figure 14 on the antenna performance with considering that the optimum (d) value and antenna dimensions are equal to 4 mm and 38×36×1.58 mm^3 respectively.





(e)

Fig. 14: Numbers of TSRR: (a) One TSRR, (b) Two TSRRs, (c) Three TSRRs, (d) Six TSRRs, (e) Nine TSRRs.

The simulated results that presented by S11 and gain of the different unit cell number are shown in Figures 15 and 16. It is a found that the number of the unit cell has a significant effect on the antenna performance, which the best result is found when the array is consisting of two unit cells only. At this number of unit cell, a higher gain with best impedance bandwidth, S11 < -10 dB is achieved.

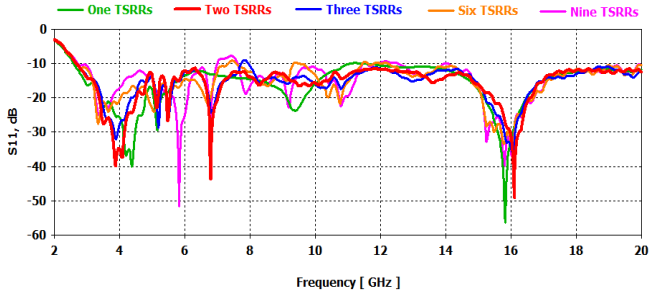


Fig. 15: S_{11} spectra of the different unit cell number.

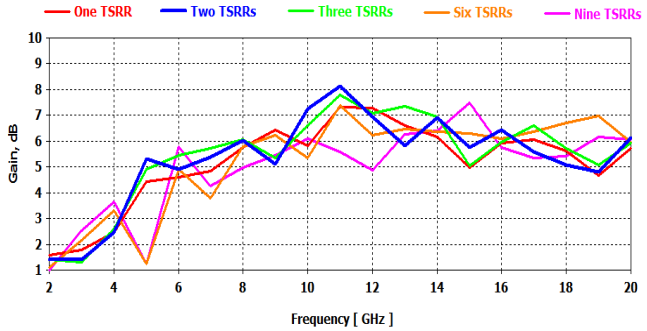
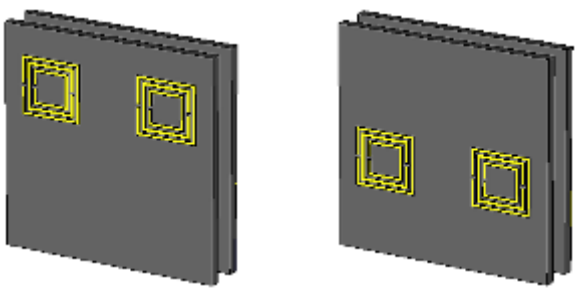


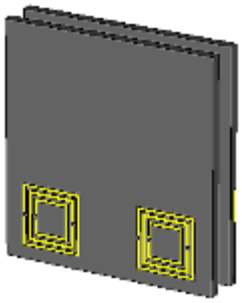
Fig. 16: Gain spectra of the different unit cell number.

C-Effect of the TSRRs Position

In addition to all previous studies, a new study based on the best TSRR unit cells position has been presented in this section. This study is focusing on finding the best TSRR position that gives higher gain with best impedance bandwidth.
As shown in Figure 17, many positions have been chosen to study with taking in the consideration that the optimum (d) value, antenna dimensions and a number of the unit cell are equal to 4 mm, 38×36×1.58 mm^3 and two TSRRs respectively.



(a) (b)



(c)

Fig. 17: Different TSRR positions: (a) Upper position, (b) Central position, (c), Lower position.

For all TSRRs positions, the structure performance that presented by S11 and gain are found as shown in Figures 18 and 19. From the obtained results, it's a clear that the unit cells position can be effected on the antenna performance where it is found that a higher gain with best impedance bandwidth, S11 < -10 dB is achieved when the unit cells are located in the center.

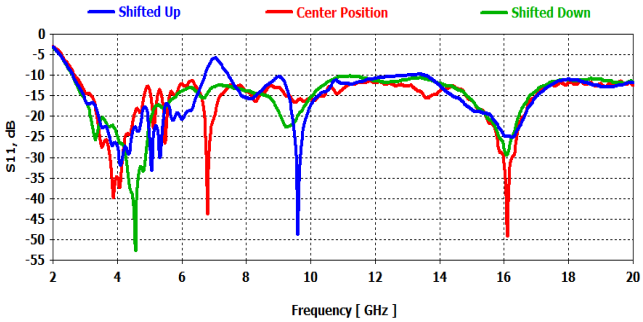


Fig. 18: S11 spectra of the different unit cells positions.

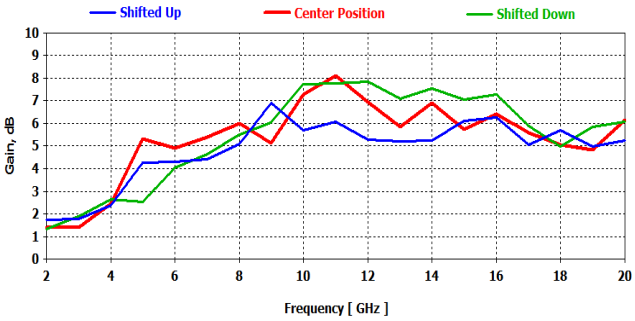


Fig. 19: Gain spectra of the different unit cells positions.

4. Conclusion

A miniaturized size UWB microstrip antenna based on TSRR MTM array was investigated. A wideband of operating frequency starting from 2.6 GHz to more than 20 GHz was achieved by applying the partial ground plane technique. Furthermore, the S11 with values close to -10 dB is reduced to less than -10 dB by adding a slot in the partial ground plane. The MTM array of Two TSRRs is added to the UWB antenna structure with separated distance (d) equals to 4 mm. The S11 value is enhanced and the first mode is shifted down by 688.74 MHz to the left after adding the TSRR array to the UWB antenna structure. Moreover, the gain is enhanced in the entire band and the maximum enhancement is found equal to 3.19 dB at 16 GHz.

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