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Parametric Study of Slotted Ground Microstrip Patch Antenna

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Abstract: *In this paper, the effect of patch and ground reshaping applied to microstrip antenna have been designed, simulated and investigated in details using Finite Integral Technique (FIT) numerical method. The objective is to control the resonance frequency and to enhance the bandwidth of the microstrip antenna as well as to create an additional resonant mode where the overall patch and ground dimensions are kept constant. Three microstrip antenna configurations with a transmission line feed have been proposed and presented, and their simulated results have been investigated and compared. Furthermore, a parametric analysis is also brought out for discussion, so as to provide an insight in the design process. The proposed microstrip antenna structures have been fabricated on FR4-substrate, and their parameters have been measured. Reasonable agreement has been achieved between simulated and measured parameters. The obtained results (simulated and measured) have been verified the validity and the benefits of reshaping the patch geometry and the ground plane configuration. The presented antenna structures can be an excellent choice for LTE, WLAN and WiMax applications due to their small size and simple structure.*
Keywords: *Microstrip antenna, Parametric analysis, Slot under feeder, Slot under patch, 3G/4G applications.*

I. Introduction

Microstrip antenna structure has numerous benefits in wireless communication and radar systems applications. This is due to its small size, low cost, less weight, easy fabrication, and excellent compatibility with the typical manufacturing process of MMIC planar circuits [1-3]. Wireless local area network (WLAN) and Worldwide Interoperability for Microwave Access (WiMax) have been widely used in mobile devices such as laptops, handheld computers and mobile phones [4]. The trend in the wireless market is toward integrating multifunction into a single device. There are many reported antenna designs for wireless systems [5-7]. Also, there is various shapes of cutting slots have been designed on microstrip antennas to reduce their size and increase the surface current path [5], [8]. A dual band microstrip patch antenna using U and S slots for solution standard wireless local area network (WLAN) has been presented in [5]. Other reported works on multiresonator broadband microstrip patch antennas E-shaped antenna and T-Shape patch with slotted ground plane have been proposed in [9], [10] respectively. Considerable approaches with the equivalent circuit models of varieties of Defected Ground Structure (DGS) have been reported in [11-15]. Enhanced bandwidth was achieved by three different geometry shapes the U, E and H with a substrate has high dielectric constant of 9.4 in order to get a reduced antenna size [16]. In this paper, slotted ground plane has been applied to microstrip antenna configuration because of its size, design simplicity, robustness, adaptable to mass production using PCB technology and can be cutout of whatever surface that to be mounted. Besides, it is the least expensive to integrate into any existing system. The slots in the ground plane have been used to increase path length of surface current that lead to reduce (shift) resonance frequency to lower frequencies. The concept of inserting slots in the ground plane has been proven to give remarkable functionality due to distribution of current on the structure of antenna patch making it highly radiating at different ranges of frequency using only single feed represented by 50 SMA connector. The purpose of this paper is to provide a parametric study to analyze the effect of different patch configuration with full ground. Also, determine the effect of the slots etched at different locations in the ground plane in order to obtain the required antenna behavior which has been suitable for 3G/4G wireless applications.

The paper constructed as follows. Section II, presents a detailed description of conventional square microstrip antenna and the other proposed patch structures. Section III, illustrates a detailed parametric analysis of the proposed patch and ground configuration with their simulation results compared to the conventional square patch. Fabrication and measurement results of the three selected patch antenna configurations are presented in Section IV. Finally, section V concludes the presented paper.

II. Proposed Antenna Configuration and Description

The three antenna configurations (Conventional Square Patch, Elliptical Patch and Star Patch) have been proposed and presented as shown in Fig. 1. Each of the three proposed antenna structures has been mounted on a single FR4 substrate with relative permittivity (ε_r) 4.4, height (h) 1.6 mm, tangential loss (δ) 0.025 and conductor thickness (t) 0.035 mm. The first patch and the substrate dimensions (L_P=W_P=16 mm & L_{Sub}=W_{Sub}=30mm) were chosen to be compact in size, and then, the patch shape is optimized as well as the ground plane to operate the proposed antennas within 3G/4G frequency band. A transmission line of 50 Ohm is used to feed the microstrip patch antennas with width W_f =3.011 mm. For the presented antennas, the patch shapes have been changed but its overall dimensions are kept constant. The second design of the elliptical patch consists of adding two orthogonal ellipses together with X_{radius}=4 mm and Y_{radius}=8 mm for vertical ellipse and vice versa for horizontal ellipse, while the last patch is the star patch consists of a square patch having length 11.5 mm added to a rotated square patch by 45 degree of the same dimension. The three ground configurations which applied for each proposed patch are shown in Fig. 2 with its dimensions summarized in Table 1.

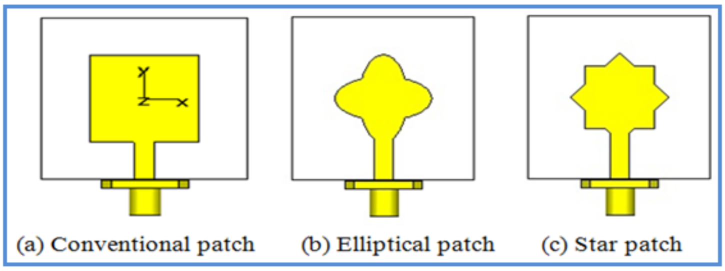


Fig. 1. Top view of the three proposed antenna configurations

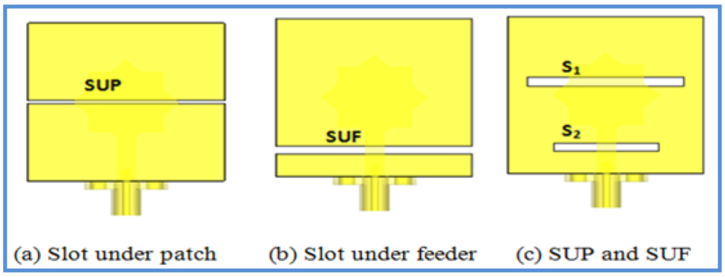


Fig. 2. Bottom view of three different ground configurations applied for each antenna presented in Fig. 1

Table 1: Dimensions of the ground configuration

Symbol	**Value in (mm)**	
	$Slot_{Length}$	$Slot_{Width}$
SUP	30	0.6
SUF	30	1.6
S1	24	1.6
S2	16	1.6

III. Simulation Results and Discussion

3.1 Patch Configuration

A detailed parametric study has been performed to investigate and evaluate the effect of different patch shapes of microstrip antenna with full ground (no added slots). The proposed patch configurations have been simulated using the CST simulator 2014, and the results are shown in Fig. 3. In this case a full ground structure is introduced for the three proposed patches. The simulated antenna parameters of the proposed patches are summarized and presented in Table 2. It can be noticed that in case of elliptical and star patches, the resonance frequency have been shifted to higher values, besides the bandwidth and efficiency have been improved as compared to conventional patch as listed in Table 2. In addition, it was observed that Star Patch achieved the better performance than the others antenna structures (VSWR less than 1.5 with enhance in bandwidth and gain). Therefore, it can be concluded that the bandwidth and efficiency will be enhanced if the outer bends of the patch edge increases, causing an improvement through the performance of the antenna.

Table 2: Simulation results for different patches with full ground

Antenna Structures	Antenna parameters				
	F_o (in GHz)	BW(-10dB) (in MHz)	VSWR	Gain (in dBi)	Efficiency (%)
Conventional patch	8.5	468	1.5	1.8	47%
	9.4	493	1.3	3	44%
Elliptical patch	10.5	852	1.37	3	53.9%
Star patch	10.6	1085	1.17	3.3	55%

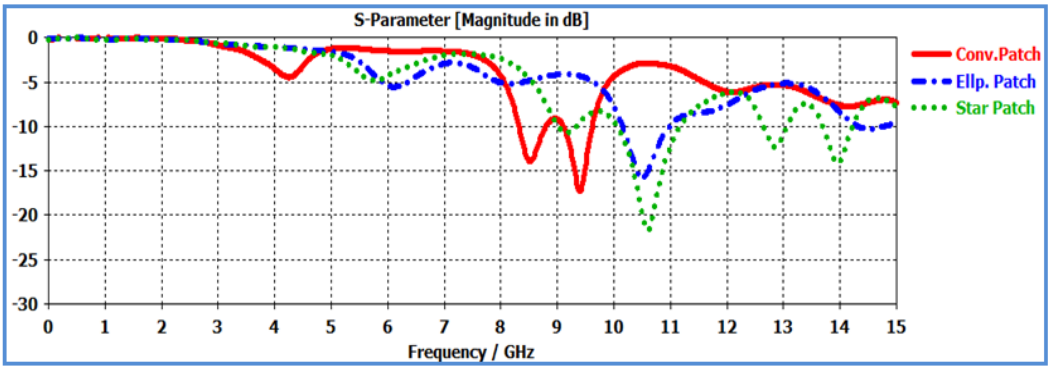


Fig. 3. S-Parameter of the three antenna structures with Full Ground

3.2 Ground Configuration

In this section, the effect of introducing slots in the ground plane for the proposed antenna structures has been investigated, and the results compared and presented. For adjusting the resonant frequency to operate within 3G/4G applications, an optimization process has been done to various parameters for achieving the best position of the slots through the ground plane. The simulated results of the three antenna configuration each of them loaded with the Slot Under Patch (SUP), Slot Under Feeder (SUF) and with both slots added together (SUP & SUF) are shown in Table 3. It is clear that with introducing SUP the resonant frequency shifted by small amount to higher frequencies and there is additional resonant frequency excited for star patch due to the creation of different current paths on the ground plane with respect to conventional patch. But when applying SUF and both slots (SUP & SUF) to the elliptical and star patch antenna structures the resonant frequency shifted to lower frequency modes with increasing in the efficiency compared to the conventional patch. It was shown that maximum VSWR value of less than 1.5 has been achieved. The dimensions and location of the slots etched in the ground plane mainly control the resonant frequency and performance of the antenna. The concept of inserting slots in the ground has proven to give remarkable functionality to the antenna. From the parametric study, it was observed that the slot length (which etched in the ground plane and perpendicular to the feeder) effects the resonant frequency as it controls the shifted range to lower or higher frequency according to the required performance. While the slot width controls the magnitude of the return loss (S_{11}) for the resonant frequency.

Three microstrip patch antenna structures have been selected for fabrication and measurement. These antennas are conventional patch with SUP, star patch with SUF and finally elliptical patch with both slots (SUP & SUF). The variation of return loss versus frequency of three selected patch antenna configuration has been shown in Fig. 4. The three selected antenna structures (conventional patch loaded with SUP, star patch with SUF and elliptical patch with both slots (SUP & SUF) have been resonated at 5.2 GHz, 5.5 GHz and 2.6 GHz with efficiency 80%, 64% and 79.5% respectively as shown in Table 3. An additional resonant frequency for each patch have been excited but neglected from the results investigation as the desired resonant frequencies should be served 3G/4G wireless applications. The proposed antenna configurations have been achieved the maximum VSWR of less than 1.5 as shown in Fig. 5 which indicated that the antenna impedance is well matched with the transmission line. The radiation patterns of the presented antennas have been illustrated in (X-Z, Y-Z and X-Y) planes as shown in Fig. 6. It is clear that the radiation pattern of conventional patch loaded with SUP at 5.2 GHz has significant value for the back lobe pattern that can be used for transmission or reception with gain of 4 dBi. Since the strength of the backplane radiation of the conventional patch antenna increased then, it can be considered as semi-omnidirectional antenna. While the radiation pattern of Star patch loaded with SUF at 5.5 GHz is completely directive antenna with gain of 4.2 dBi. In the other hand, there is omni-directional radiation pattern for Elliptical patch loaded with both slots (SUP & SUF) at 2.6 GHz which is desirable for 3G/4G wireless application because of user mobility and freedom in the transmitter or receiver position. But this implies minimizing the gain which achieved to 2.3 dBi.

Table 3: Simulation results for different patches with the proposed slots

Antenna Structures		Antenna parameters				
		F_o (in GHz)	BW(-10dB) (in MHz)	VSWR	Gain (in dBi)	Efficiency (%)
Conventional patch	**SUP**	5.2 14.2	348 3111	1.2 1	4 6.8	80% 65.7%
	SUF	8.9 10.2 12.3	299 813 930	1.4 1.25 1.02	1.2 3.2 4	54.5% 69.9% 61%
	SUP &SUF	9.9 14	514 1212	1.48 1.3	5.2 6.4	69% 64%
Elliptical patch	**SUP**	5.5	356	1.2	3	76.9%
	SUF	5.6 9.4 10.8 12.6	236 718 1089 863	1.2 1.16 1.17 1.05	4 2 2.3 3.19	61.8% 71.6% 72% 62.7%
	SUP &SUF	2.6 11	155 868	1.08 1.19	2.3 2.7	79.5% 72.7%
Star patch	**SUP**	5.4 10.1 11.4	356 1286 1674	1.10 1.08 1.09	3.27 1.79 3.3	77% 59.6% 54.6%
	SUF	5.5 9.6 12.1	299 481 813	1.13 1.38 1.30	4.2 2 3.58	64% 63% 63.8%
	SUP & SUF	2.5 13.8	139 620	1.29 1.02	2.09 7.2	76% 54.6%

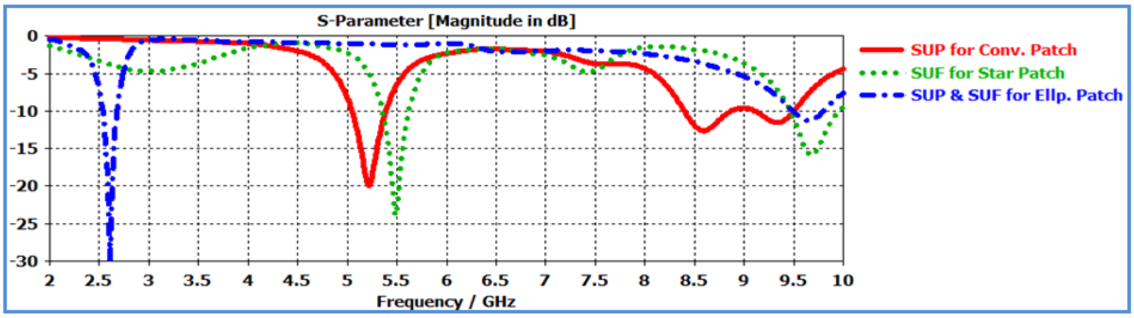


Fig. 4. S-Parameter of the three selected antenna structures

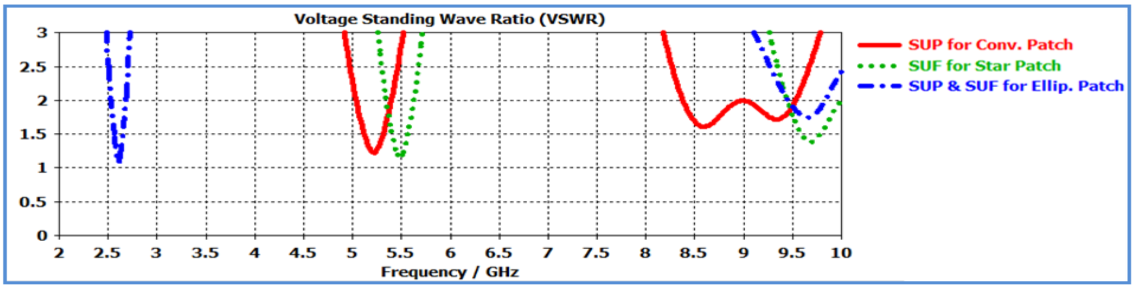
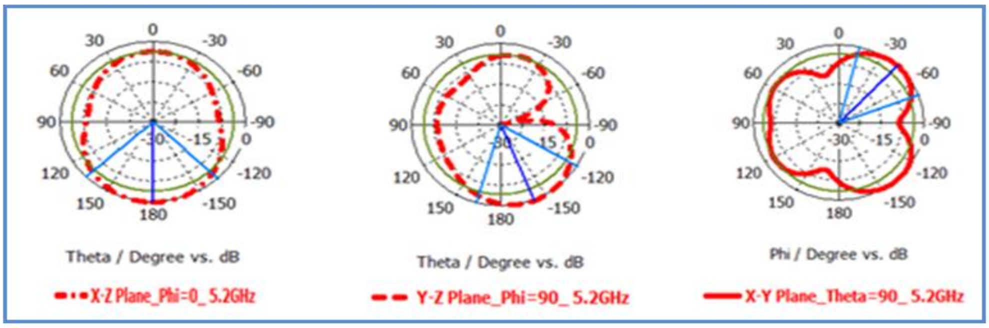
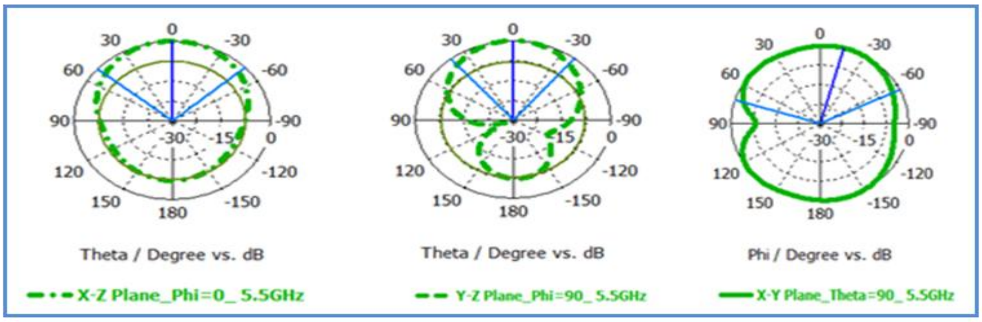


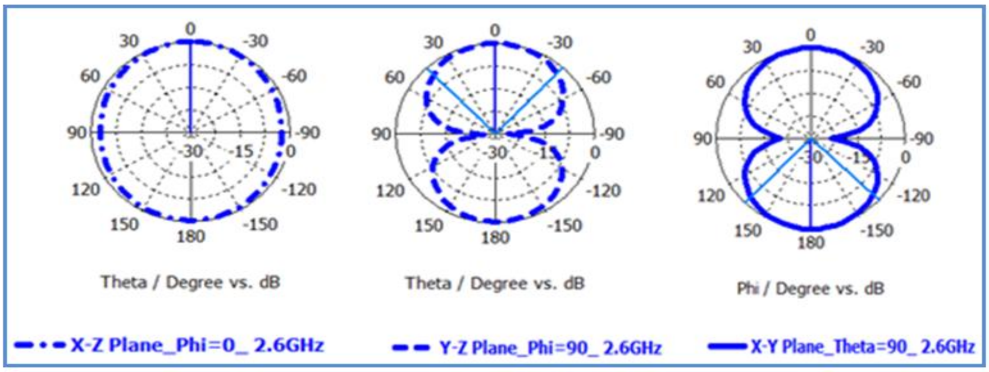
Fig. 5. VSWR of the three selected antenna structures



(a) Radiation Pattern of Conventional patch loaded with SUP at 5.2 GHz



(b) Radiation Pattern of Star patch loaded with SUF at 5.5 GHz

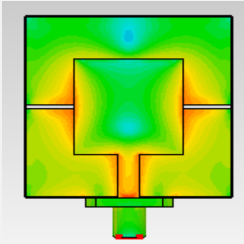
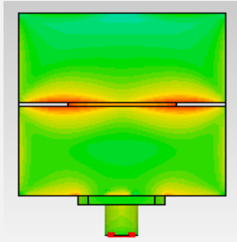
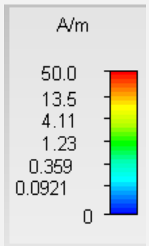
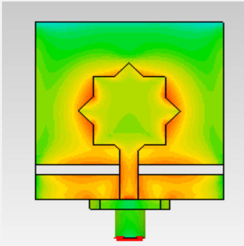
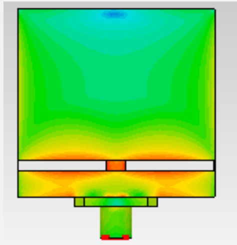
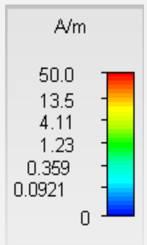
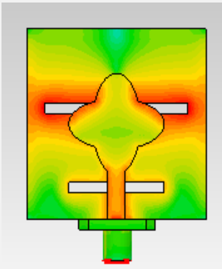
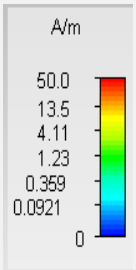


(c) Radiation Pattern of Elliptical patch with both slots SUP & SUF at 2.6 GHz

Fig. 6. Radiation Pattern of the three selected antenna structures

To fully understand the impact of reshaping ground structures on the behavior of the proposed antennas, the surface current densities distribution on the patch and ground of the three selected structures have been evaluated and investigated. Simulation results of current densities are illustrated in Table 4 with the indicated frequencies. It can be seen that different current distributions have been obtained for each patch where almost the current is distributed around the edges of the patch. These current variations have been lead to different equivalent electric patch lengths and consequently, the patch resonates differently for each corresponding electric length. Moreover, the surface current is more concentrated on the star patch as the outer bends of the patch edge increase. In addition that, the surface current on ground plane is distributed along the slots and the feeder line. This current along the edges of the slot induces an additional resonance, which added to the fundamental resonance of the radiating element. Since the linear slot forces the current to flow through a longer path, increasing the effective dimensions of the ground plane. Therefore, resonance frequencies of the proposed microstrip antennas can be tuned to specific application using the patch edges and the ground linear slots.

Table 4: The current distribution of the three selected antenna structures

Antenna Structures	Current Distribution		
	Front View	Back View	Scaling
Conventional patch loaded with SUP at 5.2 GHz			
Star patch loaded with SUF at 5.5 GHz			
Elliptical patch loaded with (SUP & SUF) at 2.6 GHz			

IV. Fabrication and Measurements

Three proposed antenna structures have been selected and fabricated on FR-4 substrate with the traditional printed circuit board (PCB) manufacturing process, thus making it a low-cost and promising design for use in size-limited 3G/4G applications. The figures of the fabricated antennas and their measured S-parameters are presented in Fig. 7 and Fig. 8 respectively. The return loss S_{11} has been measured using vector network analyzer. It is clear from the measured return loss that good agreement has been obtained between measured and simulated one. However, there are still some differences as the measured frequencies shift a little toward the higher frequencies which may be resulted from imperfection in fabrication or size error in manufacturing.

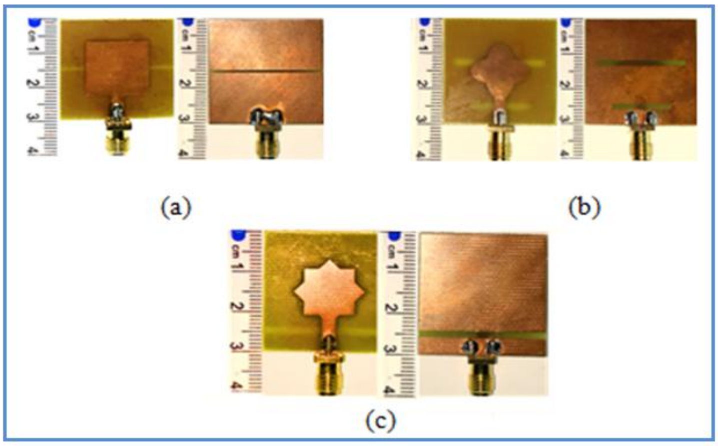
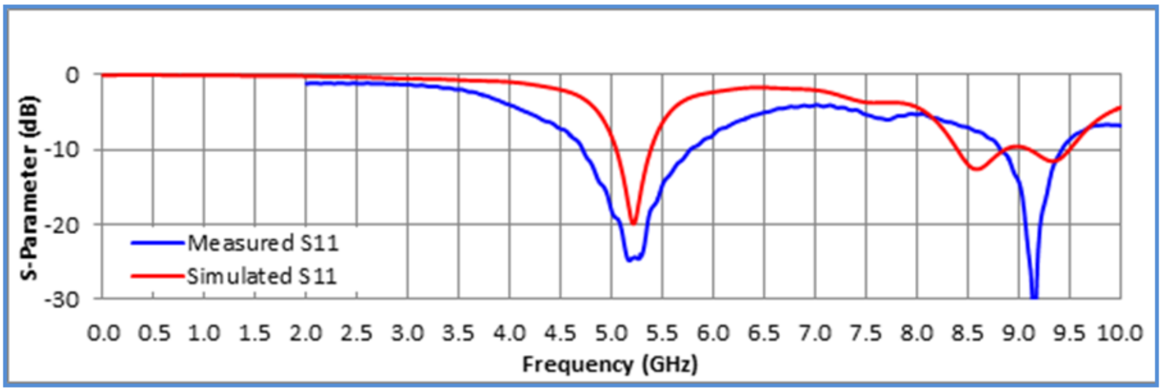
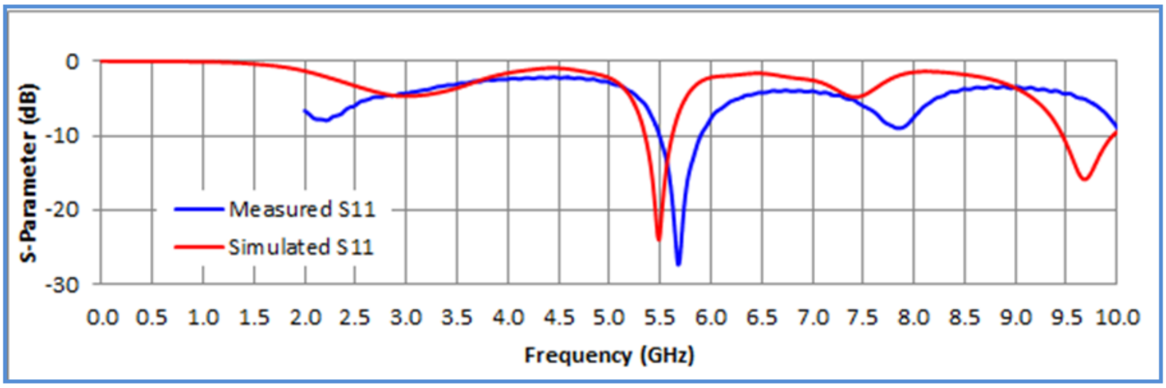


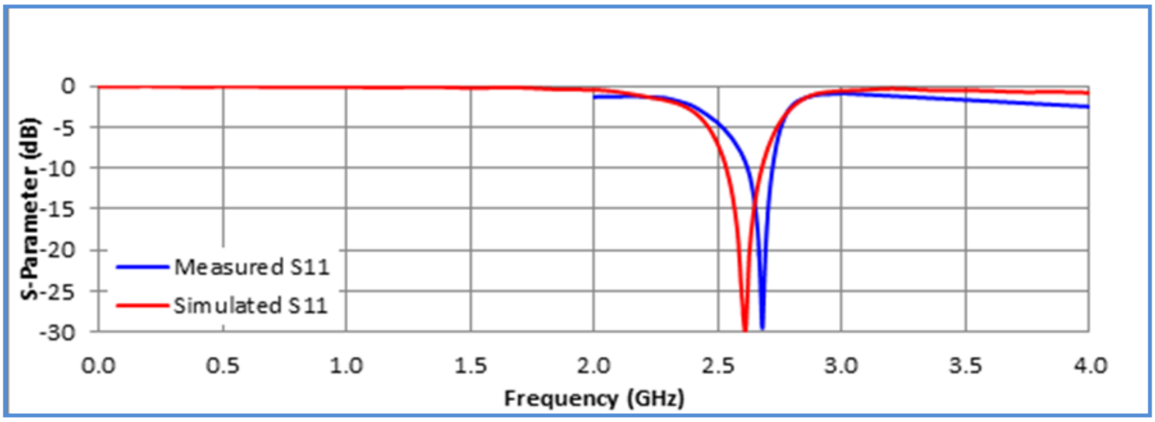
Fig. 7. The fabricated Antenna Structures Top and Bottom views:(a) Conventional patch loaded with SUP at 5.2 GHz, (b) Elliptical patch with both slots SUP & SUF at 2.6 GHz and (c) Star patch loaded with SUF at 5.5 GHz



(a) Conventional patch loaded with SUP



(b) Star patch loaded with SUF



(c) Elliptical patch with both slots SUP & SUF

Fig. 8. Simulated & Measured results for the selected antenna structures.

V. Conclusion

The presented paper demonstrates the impact of the patch and ground reshaping in order to tune and control the desired antenna specifications. The proposed antenna structures have been presented, investigated, and simulated using the CST_MW Studio 2014 to verify this design methodology. This was carried out through two main steps. The first step is to use different patch shapes with a full ground plane where the overall patch dimensions of the presented antennas have been kept constant. It can be noticed that as the outer bends of the patch edge increase this result in enhancing the bandwidth and improving the efficiency. The second one is to reshape the microstrip ground plane by adding slots at three different positions. This includes Slot Under Patch (SUP), Slot Under Feeder (SUF) and both slots added together in the ground plane. In addition that, the resonant frequency shifted to higher frequency mode with respect to conventional patch when the slot in the ground plane located away from the feeder and vice versa. Furthermore, the required performance can be obtained at the frequency of interest after realizing the concept of how to optimize the dimensions of the inserted slots. These have been applied and verified for three selected antenna structures operate at 2.6 GHz, 5.2 GHz and 5.5 GHz used for 3G/4G wireless applications. Finally, good agreement has been obtained between simulated and measured results.

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