Analysis of complimentary notch loaded multifrequency compact printed antenna

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Abstract: A single layer single feed rectangular microstrip antenna is designed and parametrically studied. Multifrequency operation is achieved along with the compactness. Complimentary symmetrical slots have been added at the edges of the patch with an extra slot placed diagonally at its top right corner to achieve multifrequency with a reduced size. It has been found that modifying the length and the width of the slots result in a rapid change in the prospect of frequency, gain, VSWR etc. The simulated result of the proposed antenna shows that it resonates at 3.79 GHz, 5.43 GHz, 5.83 GHz and 6.44 GHz. The proposed antenna has achieved 56.52% size reduction as compared with the conventional rectangular microstrip patch antenna. A profound evaluation of the radiation pattern, gain, voltage standing wave ratio, reflection coefficient (S_{11} parameter) and radiation efficiency of the proposed antenna is discussed in this paper.

Keywords: Compact antenna, complimentary Slots, microstrip patch antenna, multifrequency antenna, Wireless Communication

1. Introduction

In the field of microstrip patch antenna, the size reduction of the antenna is a major concern because all the wireless communication systems are becoming compact in size. As the systems are getting cheaper the size of the components integrated into it must be reduced in that manner. As antenna is one of the components being used, the design of compact microstrip patch antenna is a topic of intense research. Numerous authors have achieved compactness by various methods [1-9]. Gautam et al. [1] designed a compact microstrip patch antenna with 39% reduction in size by inserting 4 slits on the square shaped patch. Kuo and Wong reported compactness of 56% by introducing meandered slots on the ground plane of the radiating patch antenna [2]. A single feed microstrip antenna with a reduction of 40% was reported by inserting slots of optimum dimensions on the radiating edges of the patch and parallel to the non-radiating edge [3]. A multi-frequency microstrip antenna with compactness of 41% was reported by varying the position and the dimensions of the rectangular slots of the patch [4]. Song et al. [5] reported a 43.9% miniaturized printed antenna using perturbation of radiating slot. Xue et al. [6] reported that a size reduction of 50% was achieved on a window shaped microstrip patch antenna. It was reported by Chakraborty et al. [7] that a maximum miniaturization of 46.2% could be achieved by embedding a triangular slot at the upper edge of the radiating patch. A miniaturization of 47.4% was reported by cutting three unequal rectangular slots on the edge of the radiating patch [8]. A coaxial probe-fed printed antenna results in 51% size reduction by etching out a symmetrical pattern of crossed slots from the surface of the patch [9]. The work presented in this paper is also related to a miniaturized multifrequency microstrip patch antenna to satisfy the wireless LAN or WLAN and worldwide interoperability microwave access or WiMAX. The antenna is constructed with an FR4 substrate. Our main objective is to reduce the size and to achieve multiple resonating frequencies by modifying only the patch of the antenna. By introducing complimentary symmetrical slots to the patch and truncating the top right corner, multiple resonating frequencies are acquired and the size of the antenna is reduced to 56.52% as compared to the conventional rectangular patch antenna. The proposed antenna resonates at multiple frequencies such as 3.79 GHz, 5.43 GHz, 5.83 GHz and 6.44 GHz. The proposed antenna configuration was optimised by MOM based EM simulator IE3D [10].

2. Antenna configuration:

The structure of the conventional and proposed antenna is designed and analyzed using IE3D software. The configuration o antenna 1 (conventional antenna) is shown in Figure 1. The antenna 1 operates at 5.5 GHz. The length (L) and the width (W) of the conventional antenna are 12mm and 16mm respectively. The dielectric material chosen for this antenna is an FR4 epoxy with a dielectric constant (ε_r) = 4.4 and the height of the substrate is (h) = 1.5875mm. The width (W) and the length (L) of the conventional patch antenna in terms of wavelength are $0.293\lambda_r$ and $0.2\lambda_r$ respectively where λ_r is the wavelength of the resonating frequency i.e., 5.5GHz. A coaxial probe feed of radius 0.5mm with an unmodified ground plane arrangement is located at a position of W/2 (8mm) and L/3 (4mm) from the right side edge of the patch to match the impedance to its best level.

The antenna 2 (proposed antenna) is also designed with the similar substrate and same dimensions of 16mm × 12mm as shown in Figure 2. Four complimentary symmetrical slots along the edge have been introduced to the patch, among which one is at the right bottom side and the other one is at the top left side and two slots at the centre right and left side of the patch with an extra slot placed diagonally at the top right corner. The addition of this extra slot led us to an improvement of the reflection coefficient of the proposed antenna for multiple resonating frequencies. The coaxial probe (radius = 0.5mm) feed location has been changed to (X=−2 mm, −2 mm) from the centre (X = 0 mm, Y = 0 mm) of the rectangular patch for best impedance matching. The alteration of the feed location of the proposed antenna structure results in a less sharp resonance and high impedance matching at the corresponding frequencies. Electromagnetic simulator IE3D which is based on the method of moment has been used for the numerical investigation of the proposed antenna. The optimal dimensions of the patch have been achieved through the parametric study of the proposed patch which is given as: L=12 mm, W=16 mm, L1=L2=6mm, L3=L4=3 mm, L5=2 mm, L6=4 mm, W1=W2=W3=W4=W5=0.5 mm, W6=6 mm.

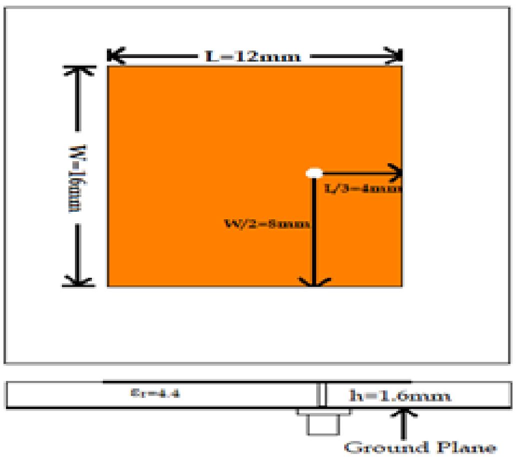

Figure 1: Configuration of Antenna1 (Conventional Antenna)

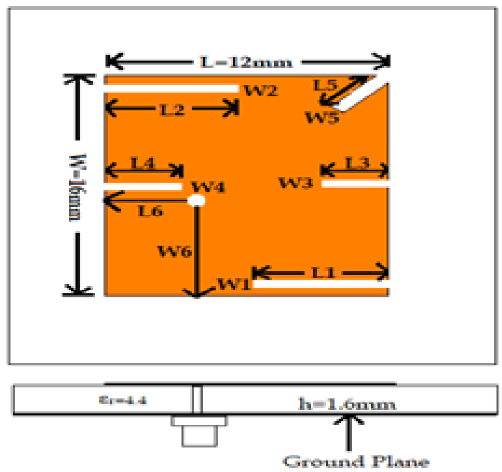

Figure 2: configuration of Antenna 2 (Proposed Antenna)

3. Analysis and working of the proposed antenna:

The geometry of the proposed antenna is constructed through 5 different steps of modifications which is depicted in Figure 3. The conventional antenna resonates at the frequency of 5.5 GHz whereas the proposed antenna resonates at different frequencies ranging from 3.79 to 6.44 GHz by incorporation of the slots to the proposed patch. Among the 5 cases, for the first case only having the right horizontal slot on the bottom of the patch results in resonating at three different frequencies which are 4.158 GHz, 5.408 GHz and 6.192 GHz respectively. It is seen in the case 2 which incorporates the top left slot of the patch, fundamental mode is excited at 4.080 GHz, 5.392 GHz and 5.344 GHz respectively. In case 3, it includes the centre-right slot which results in resonating 3.924 GHz, 5.44 GHz and 5.845 GHz respectively. In case 4 the incorporation of the centre-left slot on the patch results the resonance at 4 different frequencies below -10 dB which are 3.801 GHz, 5.446 GHz, 5.846 GHz and 6.802 GHz respectively. Another resonance is observed at 6.448 GHz but the impedance matching is very poor and reflection coefficient is only -8.614 dB. Finally in case 5, there (proposed) the structure is modified by inserting a diagonally placed slot on the top right corner of the patch. Now the proposed antenna resonates at 4 different frequencies which are 3.796 GHz, 5.437 GHz, 5.842 GHz and 6.442 GHz. The results of analysis for different geometrical shapes are shown in Table-1.

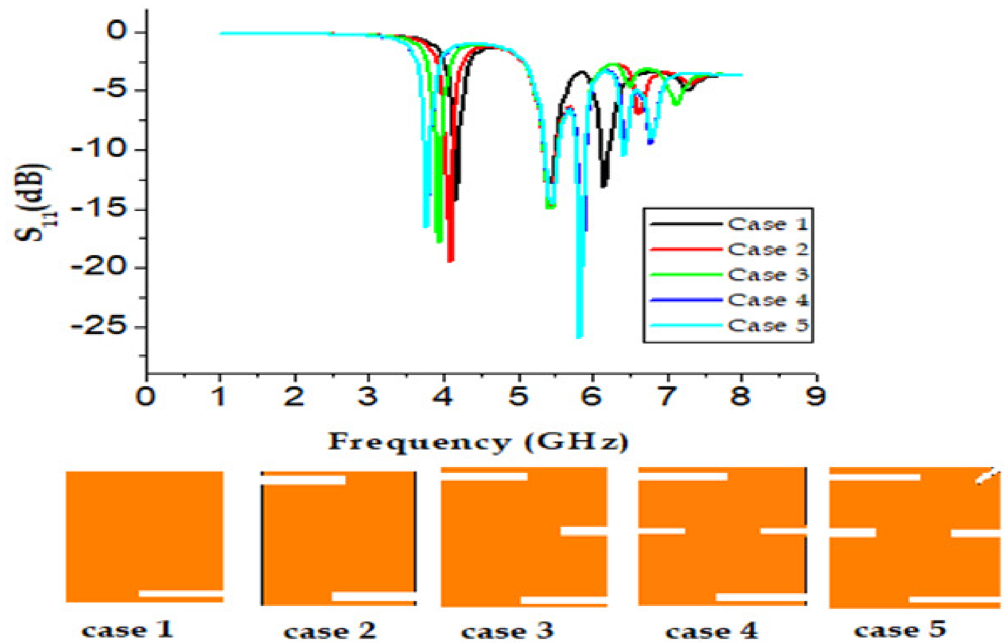

Figure 3: S_{11} parameters at different cases of the evolution of the antenna

The proposed antenna provides us advantages which are given below:

I. As the resonant frequency further reduces it offers better compactness up to 56.52 % compared to the conventional antenna.

II. Superiority in impedance matching is achieved at the corresponding frequencies because of the improvement in reflection coefficient and VSWR

Table 1: Variations of simulated results in different cases of evolution of the proposed antenna

Different Cases	Resonant Frequency (GHz)	S_{11} (dB)	Gain (dBi)	VSWR	Size Reduction (%)
Case 1	f_1=4.158	-15.229	2.252	1.4082	47.66
	f_2=5.408	-12.632	2.692	1.5974	
	f_3=6.192	-12.778	-1.701	1.6044	
Case 2	f_1=4.080	-20.165	1.483	1.2125	49.65
	f_2=5.392	-14.343	2.142	1.4786	
	f_3=5.844	-17.928	-1.923	1.2834	
Case 3	f_1=3.924	-21.469	1.593	1.1596	53.49
	f_2=5.442	-14.513	3.241	1.4535	
	f_3=5.845	-18.579	-1.703	1.2514	
Case 4	f_1=3.801	-16.147	1.153	1.3205	56.43
	f_2=5.446	-14.093	2.802	1.4707	
	f_3=5.846	-18.116	-2.472	1.2681	
	f_4=6.448	-8.614	-3.571	2.1341	
	f_5=6.802	-9.642	-0.714	2.0703	
Case 5 (Proposed)	f_1=3.796	-18.635	1.153	1.2663	56.52%
	f_2=5.437	-14.290	3.250	1.4728	
	f_3=5.842	-24.037	-2.912	1.1190	
	f_4=6.442	-10.912	-3.053	1.1910	
	f_2=6.809	-8.414	-0.071	2.2204	

4. Parametric study of the proposed antenna:

The various effects of altering the dimensions of the slots on the proposed antenna for achieving the desired resonant frequencies are investigated through parametric study. The dominant parameters are optimized by simulating the antenna by changing one geometry parameter slightly from the proposed design while all the other parameters are fixed at their proposed values. The parametric study to achieve the proposed parameters of the proposed antenna is discussed in the section below with a fixed feeding location.

4.1 Effect of Antenna parameter L_1: The variations of the reflection coefficient and the resonant frequency of the proposed antenna as a function of design parameter $L_1$is shown in Figure 4. The first resonant frequency varies a little with the increment of the proposed dimension of this parameter. The first resonant frequency is tuned from 3.69 to 3.82 GHz by the variations in the dimension of L_1 parameter. But only at the proposed value, the peak gain is observed for the first resonant frequency. The first resonant frequency

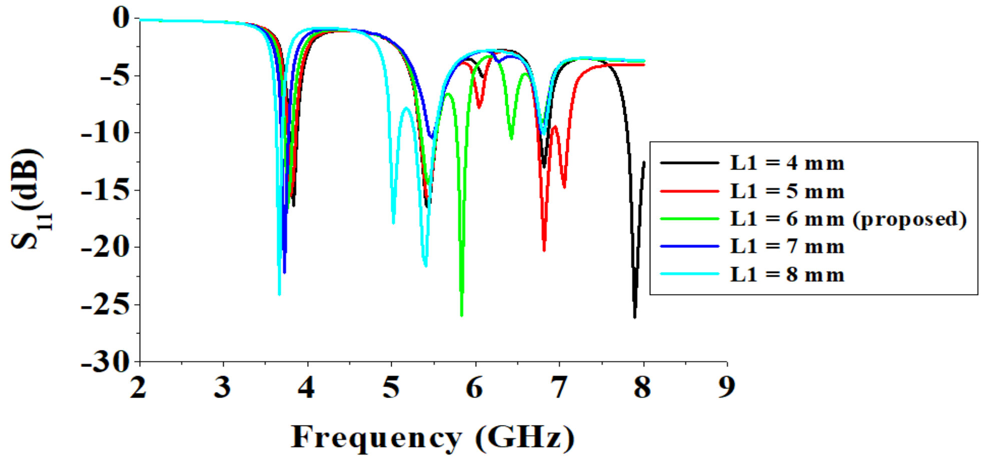

Figure 4: Variations of S_{11} for different values of L_1 parameter

4.2 Effect of Antenna parameter W_1: The effect of the parameter W_1 is evaluated throughout the parametric study shown in Figure 5, which describes that the proposed value of this parameter is the best among other values. With overall study, the first resonant frequency remains unchanged but at the proposed value, it provides the highest impedance matching at respective resonant frequencies. From the figure, it can be clearly observed that only at the proposed value second and third resonant frequencies have the highest S_{11}. As the values of the proposed parameter are changing, the S_{11} parameters are decreasing. The fourth resonant frequency is achieved using the parameter value set at the proposed dimension. Another frequency 6.84 GHz has been achieved at −8.27 dB but the reflection coefficient must be below -10 dB which is the main criterion for an antenna to radiate in the far field region.

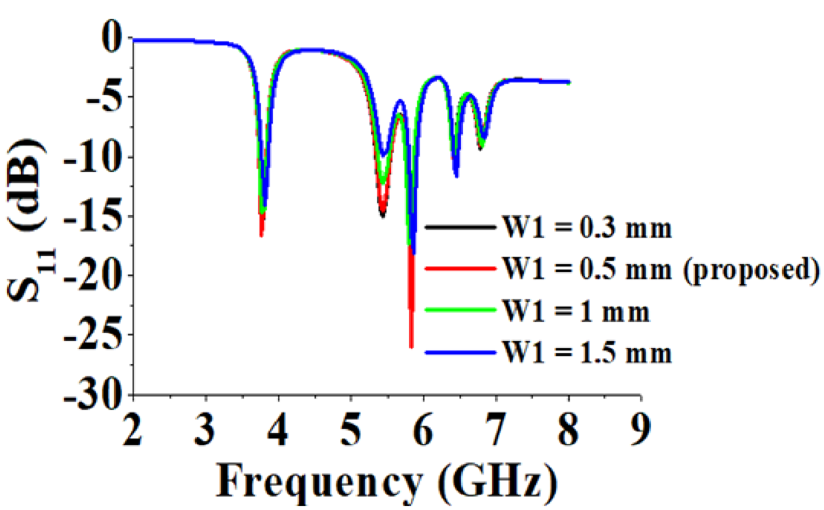

Figure 5: Variations of S_{11} for different values of W_1 parameter

4.3 Effect of Antenna parameter L_2: Various simulated S_{11} curves for the changing dimension of L_2 are illustrated in Figure 6. As we can see the first resonant frequency remains almost unchanged throughout the parametric study of the design parameter L_2. In the same way, the second resonant frequency also provides quite the same reflection coefficient as compared to the proposed dimension of the parameter irrespective of the change in slot length. The third resonant frequency only resonates at the proposed dimension of the patch. It is clearly seen from the picture that the third resonant frequency at the proposed dimension has the highest value of S_{11}. So the optimum value of L_2 is set to 6 mm.

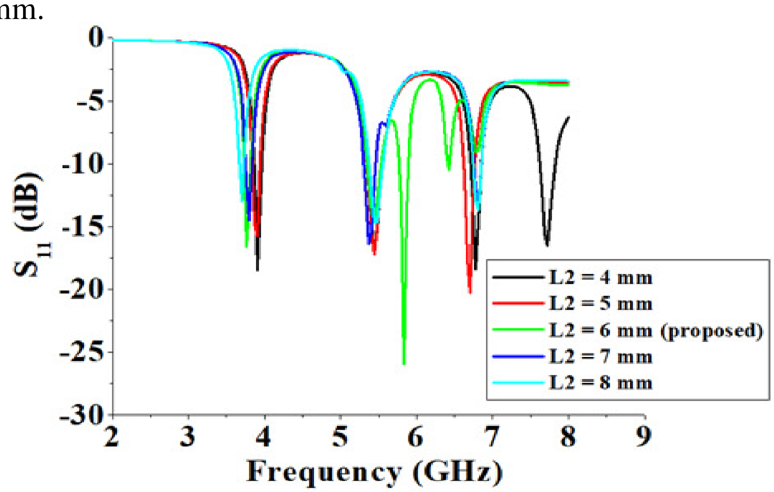

Figure 6: Variations of S_{11} for different values of L_2 parameter

4.4 Effect of Antenna parameter W_2: Figure 7 illustrates the various S_{11} _parameter curves for changing the dimension of W2. The first, second, third and the fourth frequency have same excitation mode with different S_{11} parameters. With the help of this parametric study we can say that changing the dimension of W2 does not affect the frequency shifting too much with respect to the S_{11} parameter. But only at the proposed dimension, we achieved a positive gain across the respective frequencies. Thus an optimum value of this parameter is selected at W2=0.5 mm.

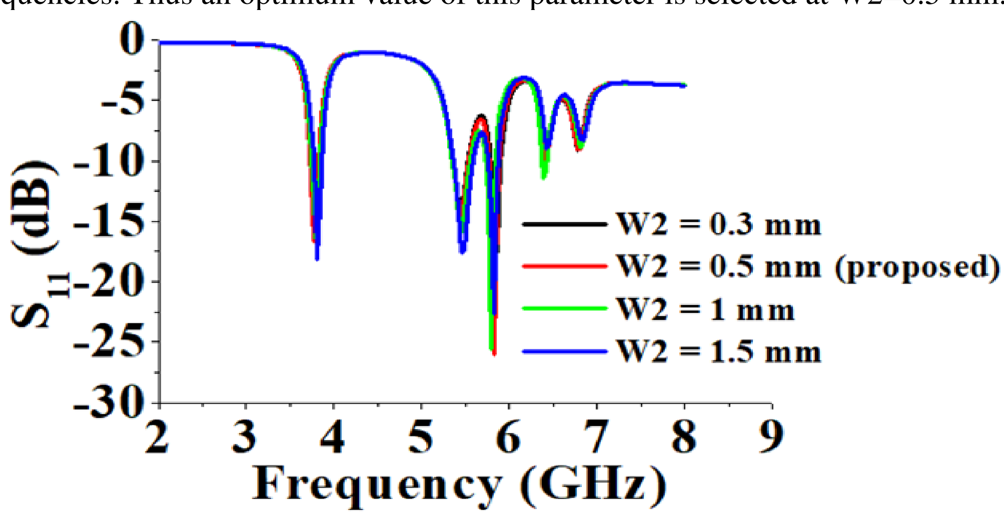

Figure 7: Variations of S_{11} for different values of W_2 parameter

4.5 Effect of Antenna parameter L_3: In Figure 8, we can see that with the increase of the parameter L_3 the first resonant frequency is reduced to 3.51 GHz with a reflection coefficient of -14.27 dB. The first resonant frequency can be further shifted by increasing the length of the slot but only at the proposed dimension the impedance matched more properly and provides a good gain. As the value of L_3 is further increased or decreased, the gain of the antenna degrades. The second and the third resonant frequencies provide the best impedance match at the proposed dimension. At L_3 = 4 mm, the fourth frequency 6.35 GHz resonates at -5.78 dB which is very poor in impedance matching but at other values of L_3 the fourth resonant frequency provides a good impedance match. Hence the optimum value for this parameter is set to L_3 = 3 mm.

4.6 Effect of Antenna parameter W_3: Similarly Figure 9 describes the S_{11} for different values of W_3. The first and second resonant frequencies remain unchanged throughout the parametric study of the various dimensions of W_3. With the value of W_3 = 1 mm the third resonant frequency has the highest S_{11}. With further increase in the value of this design parameter, the fourth resonant frequency faces a poor impedance matching. Only at the proposed value, it provides the best impedance matching except at W_3 = 1 mm which provides better impedance matching. With the overall study of W_3, the proposed value has been selected as optimum.

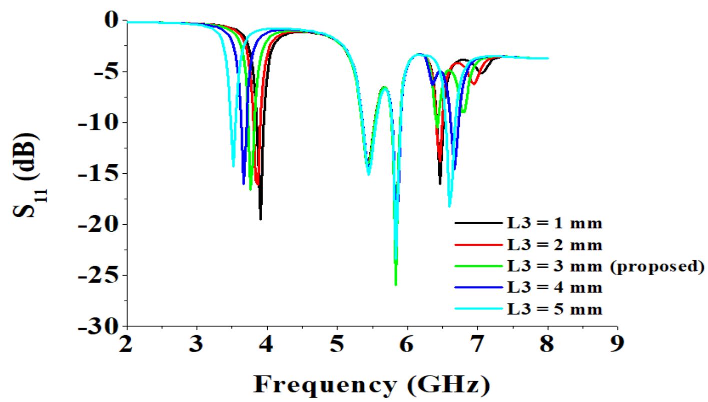

Figure 8: Variations of S_{11} for different values of L_3 parameter

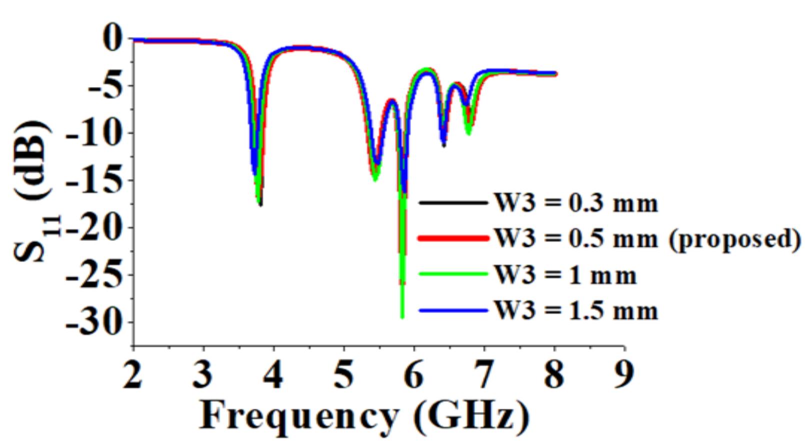

Figure 9: Variations of S_{11} for different values of W_3 parameter

4.7 Effect of Antenna parameter L_4: An illustration of the parametric study of the design parameter L_4 has been shown in Figure 10. The best impedance matching has been achieved at L_4 = 1 mm for the first and the third frequency but the first frequency has been increased to 3.92 GHz from the proposed value 3.79 GHz and the second and third frequency remain unchanged throughout the parametric study. The excitation of the fourth resonant frequency is not possible for L_4 = 1 mm and 2 mm because the S_{11} parameter at these dimensions is −5.20 dB and −6.21 dB. Only at the proposed dimension, the fourth frequency excitation is possible. Some other frequencies have been achieved too but their respective S_{11} parameters are very low.

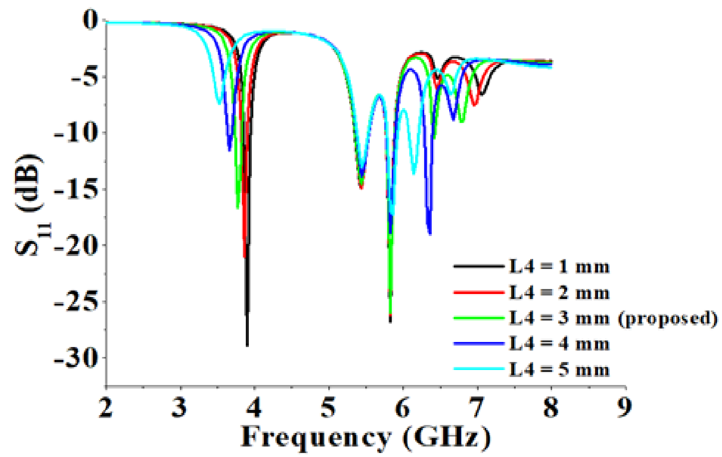

Figure 10: Variations of S_{11} for different values of L_4 parameter

4.8 Effect of Antenna parameter W_4: According to Figure 11 the first resonant frequency for the various dimensions of W_4 remains almost unalterable with different S_{11} parameters. At W_4 = 0.3 mm the highest S_{11} parameters have been achieved for the first and third frequency. The second frequency is almost same. But at the proposed value of W_4 the achieved resonant frequencies have been selected due to the peak values of gain recognized for the first and second resonant frequencies. Hence an optimum value for this is set at 0.5 mm.

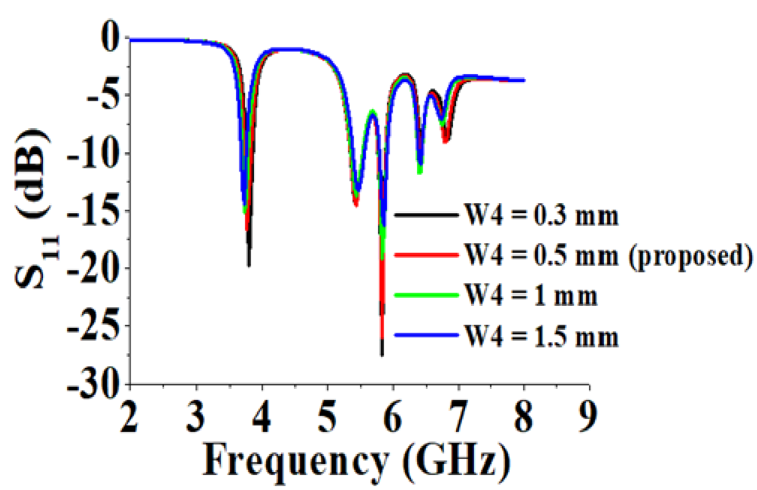

Figure 11: Variations of S_{11} for different values of W_4 parameter

4.9 Effect of Antenna parameter L_5: Figure 12 demonstrates the S_{11} curve for various frequencies achieved by changing the dimension L_5. As it is clearly seen in the Figure that the frequencies achieved by changing the dimension don't vary too much what varies is the S_{11} parameter for different frequencies. Below −10 dB there are four resonant frequencies 3.79, 5.43, 5.84 and 6.44 GHz respectively. Another frequency has been achieved at −8.41 dB level which cannot be accepted as per the reason is concerned for radiation in the far region. Only at the proposed dimension, a good size reduction with an acceptable value of gain is achieved that is why the optimum value for L_5 is set at 3 mm.

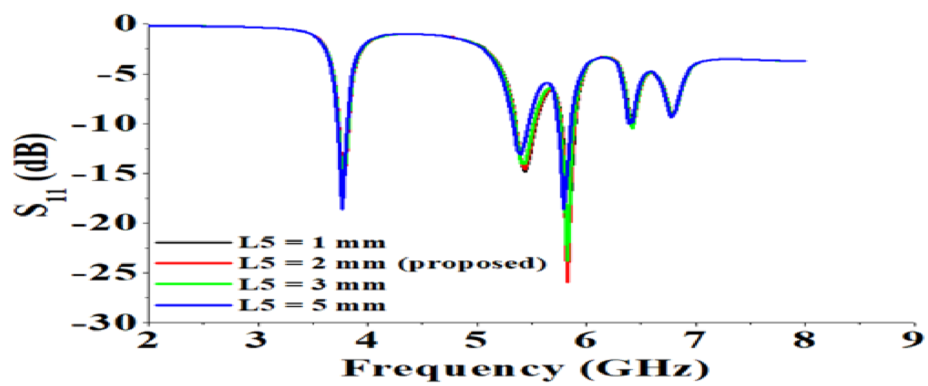

Figure 12: Variations of S_{11} for different values of L_5 parameter

4.10 Effect of Antenna parameter W_5: The parametric study of W_5 parameter is shown in Figure 13. It can be clearly observed that the frequencies are quite same throughout the parametric study of W_5 with different values of S_{11} parameter. At the proposed dimension of W_5 the gain is achieved at an optimum level for the first frequency for which the maximum size reduction is reported.

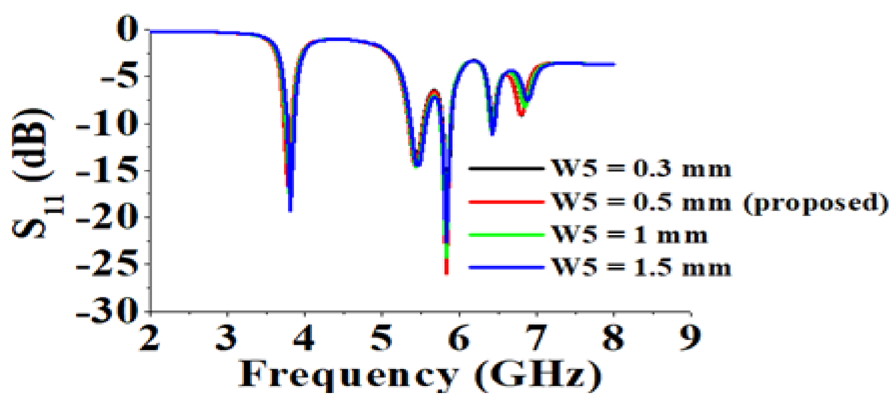

Figure 13: Variations of S_{11} for different values of W_5 parameter

5. Surface current distribution of the conventional and the proposed antenna:

Figure 14(a) to 14(e) demonstrates the excitation behaviour and surface current density for different resonant frequencies of the conventional and the proposed antenna. Figure 14(a) clearly states that the surface current density for the conventional antenna is very little at the left side of the radiating patch. Hence from [11] it can be said that by introducing new supplementary slots to the patch the surface current density can be increased. Due to the changes that have been imported by the addition of new extra slots to the patch, the surface current density has changed. Figure 14(b) clearly illustrates that for the resonant frequency operation of 3.79 GHz, the surface current density is mainly concentrated around the horizontal and vertical sections of the supplementary slots that have been added to the radiating patch. The 5.44 GHz excitation provides a bulky surface current density along the horizontal side of upper left slot and the bottom right slot has been revealed in Figure 14(c).

Finally from the depiction of Figure 14(e) it can be clearly observed that for the excitation mode of 6.44 GHz, the surface current density is huge at the arms across L_1, W_1 and L_2, W_2.

Hence through the overall study of S_{11} parameter and the surface current density it is clearly figured out that the geometrical mechanism is necessary for the four resonant frequencies. The current density mainly concentrates around the edges of the slot and in that way the current path increases. The miniaturization of the proposed antenna is due to the lightening effect of the surface current density which leads to drop off the resonant frequency.

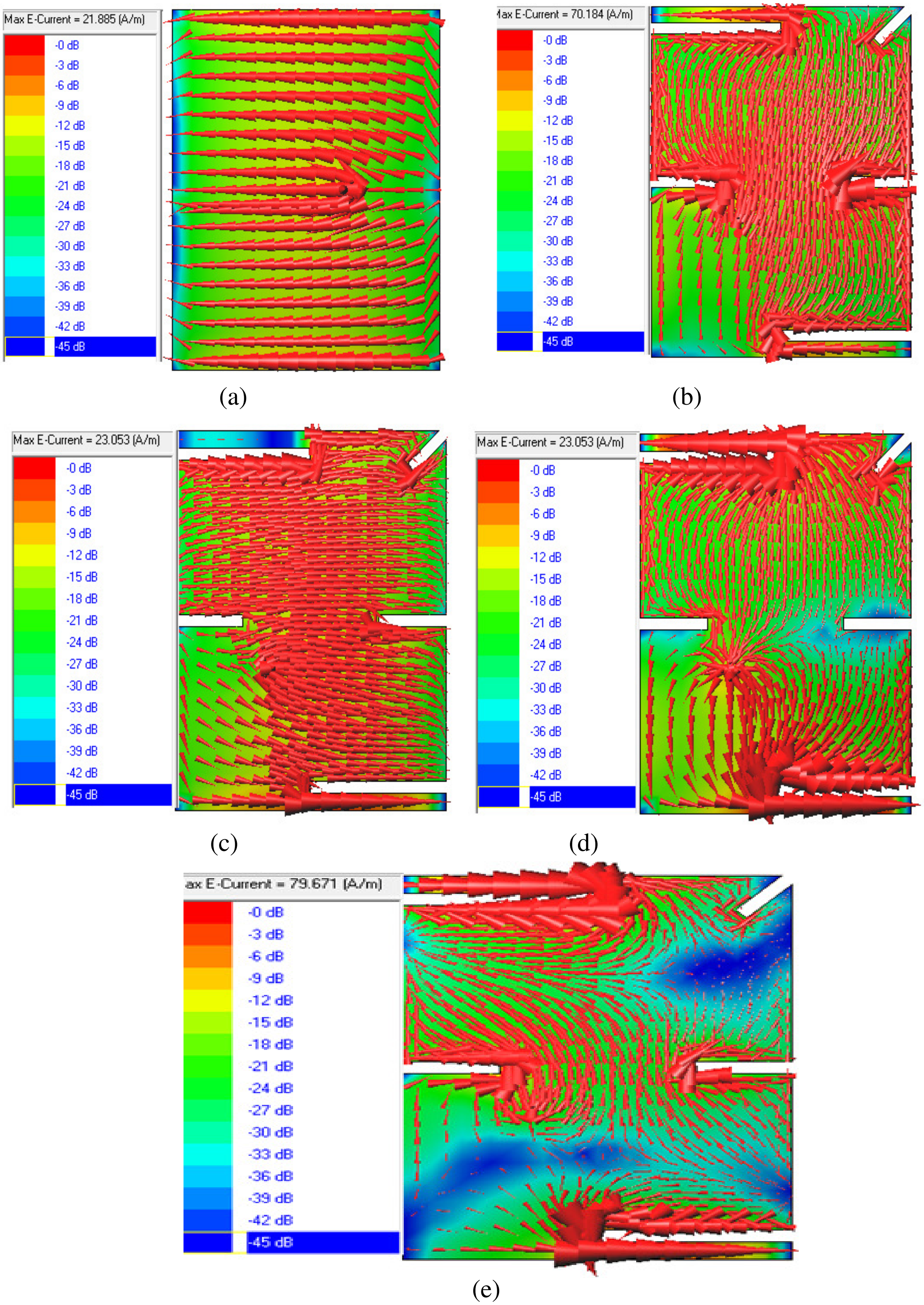

Figure 14: Surface current distribution for Conventional antenna at (a) 5.5 GHz and for the proposed antenna at (b) 3.79 GHz, (c) 5.44 GHz, (d) 5.84 GHz and (e) 6.44GHz

6. Results and discussion:

The simulated S_{11} parameter of the reference conventional antenna is shown in Figure 15. It can be observed from Figure 15 that the conventional antenna resonates around 5.5 GHz and after modification of the patch by introducing new supplementary slots to the patch, multiple resonant frequencies have been achieved [see Figure 16]. Figure 17 shows the simulated gain for the proposed antenna at its respective resonant frequencies where the peak gain for the proposed antenna is around 3.25dBi for the second resonant frequency and for the first resonant frequency we achieved a gain of around 1.15dBi. The plot of VSWR versus frequency of the proposed antenna is shown in Figure 18. The normalized E-plane radiation pattern of the proposed antenna has been shown in Figure 19. According to the figure, it can be said that nearly identical broadside radiation pattern is achieved at all of the resonant frequencies. Throughout different radiation pattern it is clearly observed that the responses are nearly steady for different resonant frequencies. There is significant separation between the co polar and cross polarization level at respective resonant frequencies, which indicates less interference.

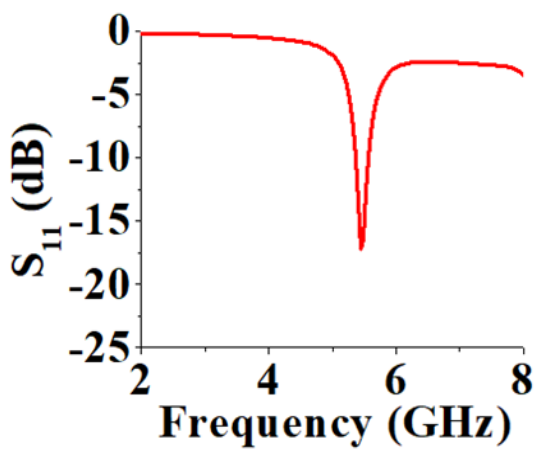

Fig. 15: S_{11} parameter of conventional antenna

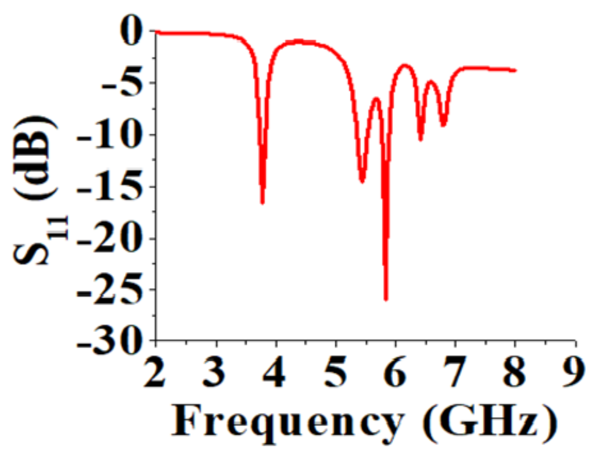

Fig. 16: S_{11} parameter of proposed antenna

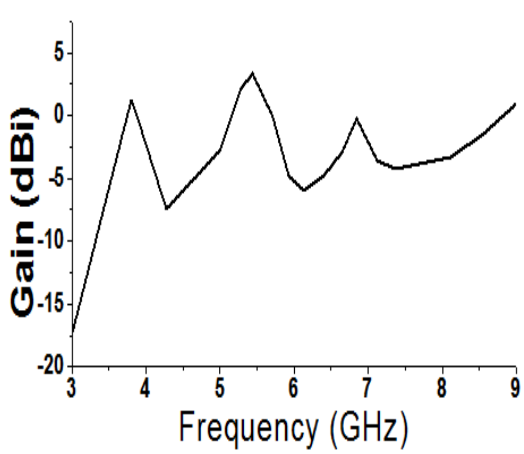

Fig. 17: Plot of Gain of the proposed antenna

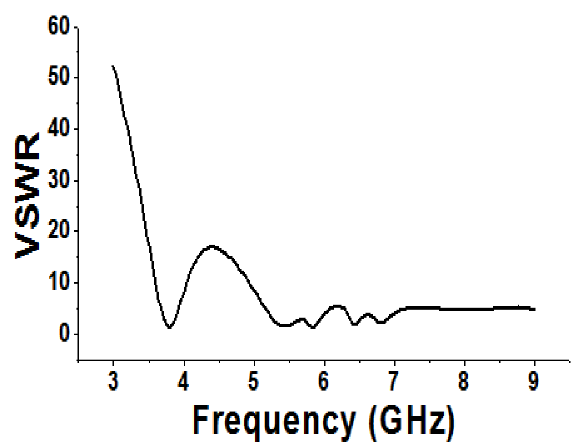

Fig. 18: VSWR of the proposed antenna

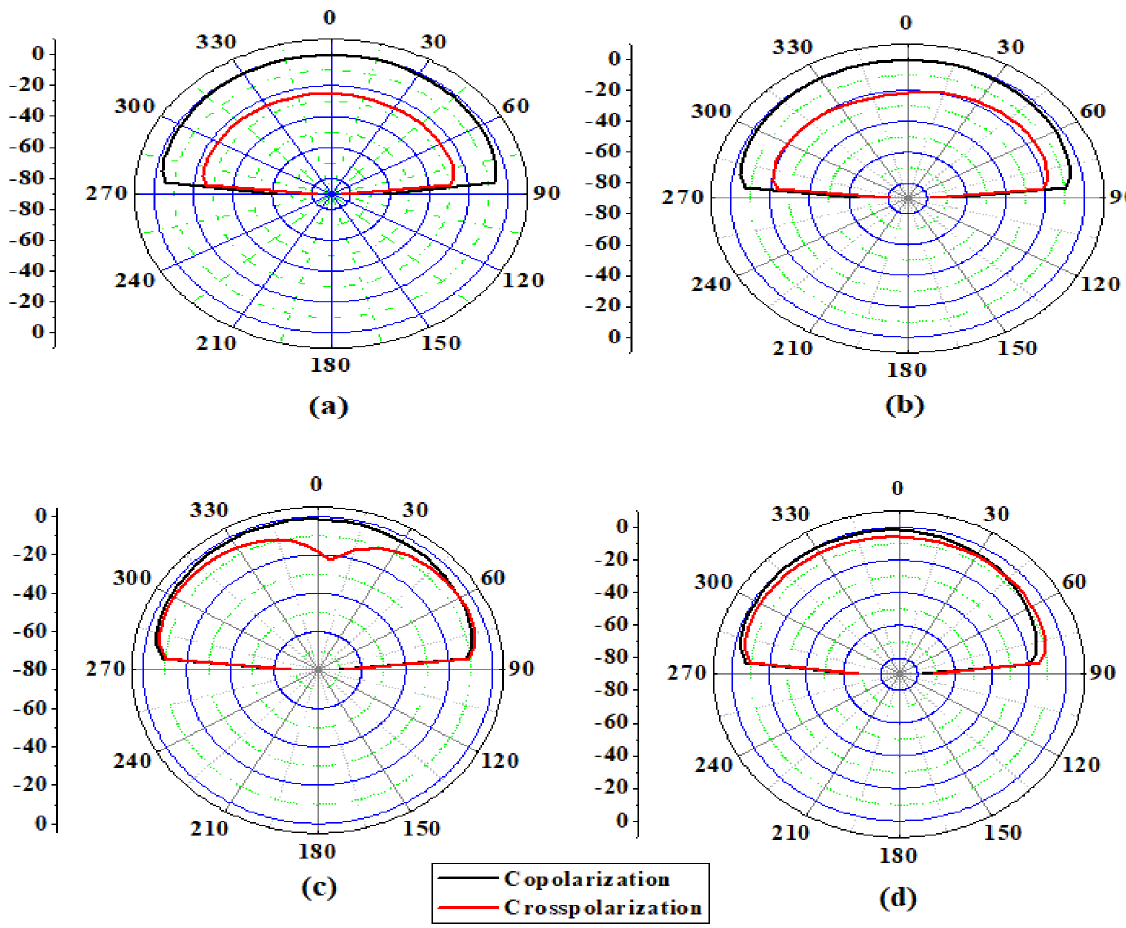

Figure 19: Normalized E-plane radiation pattern of the proposed antenna at (a) 3.79 GHz, (b) 5.44 GHz, (c) 5.84 GHz and (d) 6.44 GHz

7. Conclusion:

A single feed microstrip patch antenna with multifrequency operation has been proposed and discussed in this paper. The proposed antenna resonates at four different frequencies i.e., 3.79, 5.44, 5.84 and 6.44 GHz. The addition of the supplementary slots to the proposed patch reduced the first resonant frequency up to 3.79 GHz and a size reduction of 56.52 % is achieved. Across the resonant frequencies stability in radiation pattern is obtained along with moderate gain. The proposed antenna operates at respective resonant frequencies with very low value of VSWR. The main application of the antenna is to satisfy the wireless LAN (WLAN) and worldwide interoperability microwave access (WiMAX). The proposed antenna is also applicable for microwave L and C band applications.

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