# Analysis of Slits Loaded Compact Printed Antenna for Multifrequency Operation

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**Abstract.** In this paper, investigation of a single layer, single feed printed antenna has been carried out using method of moment based IE3D software. Triple narrow slits are introduced on the radiating patch to reduce the size of the antenna by lowering the resonant frequency. Multiple resonant frequencies are also obtained by cutting the narrow slits. The proposed antenna offers 63% size reduction in comparison to the conventional microstrip antenna with same patch area. A detailed analysis of reflection coefficient, gain, directivity, radiation efficiency and radiation pattern including surface current distribution is presented in this paper.

Keywords: Slits, multi-frequency, size reduction, wireless communication

## 1. Introduction

In recent years, the need for compact multi-frequency antennas is increased due to the rapid decrease in the size of wireless communication devices [1–2]. A number of techniques have been reported on the compactness of a microstrip antenna such as using high dielectric material as substrate [3], increasing the electrical length of antenna by optimizing its shape [4], by applying resistive or reactive loading [5-6], by using shorting pin [7], by implementing fractal geometry [8], by using electromagnetic bandgap structure [9], Several compact microstrip antenna designs have been reported over the years by embedding various shapes of slots on microstrip patch and ground plane [10-11]. Rezvani et al. reported that 34% antenna size can be reduced by using slotted microstrip patch antenna with defected ground plane [10]. A maximum antenna size reduction of 41% with multi-frequency operation was achieved by varying the positions and dimensions of the rectangular slots on the patch [11]. The use of slot in a microstrip patch perturbing the $TM_{10}$ has also been used to make the patch smaller [12]. The use of slots has also been considered in the design of small multiband antennas for handset [13]. Other techniques such as optimization with genetic algorithm are also used for designing triple band antenna [14]. In this paper, a compact multi-frequency microstrip patch antenna is presented by cutting triple slits on the radiating edges of the patch. The size reduction of 63% is achieved in comparison to conventional rectangular microstrip antenna with same patch area.

## 2. Antenna design

### *2.1. Antenna 1 (conventional antenna)*

The structure of the conventional antenna is shown in Figure 1(a). The conventional antenna is a 12 mm ×16 mm rectangular patch. The dielectric material chosen for this design is an FR-4 substrate with dielectric constant ($\varepsilon_r$) = 4.4 and substrate height h = 1.5875 mm. Coaxial probe-feed of radius 0.5 mm with simple ground plane arrangement is located at a position W/2 (8 mm) and L/3 (4 mm) from right side edge of the patch for best impedance matching.

### *2.2. Antenna 2 (proposed antenna)*

The configuration of the proposed antenna is shown in Figure 1(b). This is achieved by making slits on the three sides of the Antenna 1 which provides miniaturization of the antenna by reducing the lower order resonant mode and also offers multi-frequency operation. The feed point is located at an optimized position of (X = 2 mm, Y = 2 mm) from center of the patch to achieve multiple resonant frequencies with best impedance matching condition,. Any further alteration in feed position results in narrower −10 dB bandwidth and less sharp resonances at the respective frequencies. The analysis of the proposed antenna is carried out by using the method of moment based electromagnetic simulator IE3D [15]. The dimensions of the proposed antenna parameters are manually optimized by parametric study to meet the design goal. The optimal values of the structural parameters of the proposed antenna are given as: W = 16 mm, L = 12 mm, $W_1$ = 1 mm, $L_1$ = 5 mm, $W_2$ = 0.5 mm, $L_2$ = 4 mm, $W_3$ = 1 mm, $L_3$ = 4 mm, $L_4$ = 6.5 mm, $L_5$ = 5.75 mm, $L_6$ = 3.5 mm. The fabricated structure of the proposed antenna (antenna 2) is shown in Figure 2.

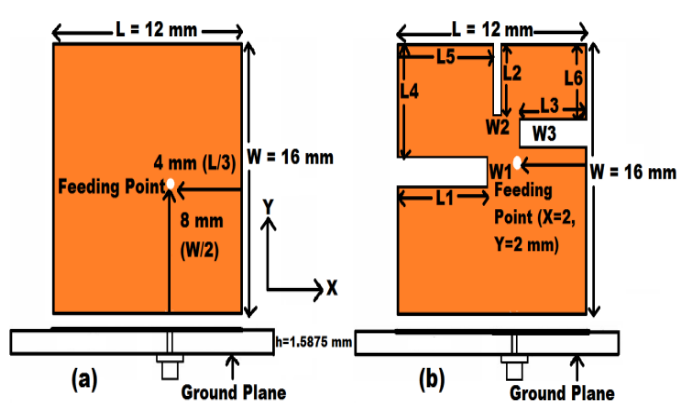


Fig.1. Configuration of (a) Antenna 1 (b) Antenna 2

Fig.2. Fabricated structure of the proposed antenna

## 3. Analysis of the proposed antenna

The effect of each optimized slot on the resonant frequency of the proposed antenna is analyzed using IE3D software. Figure 3 shows the different cases of evolution of the proposed antenna and corresponding reflection coefficients. The geometry of the proposed antenna is achieved by four different modifications. The conventional antenna resonates at 5.5 GHz. But the resonance characteristics of the antenna changes drastically due to incorporation of slits. The results of Figure 3 are shown in Table 1.

## 4. Parametric study

The effective parameters are investigated by simulating the antenna with one geometry parameter slightly changed from the reference design while all the other parameters are fixed. The parametric studies are carried out by simulations without altering the feeding location of the antenna.

### *4.1 Effect of parameter $L_1$*

The variations of $S_{11}$ parameter and resonant frequency of the proposed antenna as a function of design parameter $L_1$ is shown in Figure 4. With the increase of $L_1$ than proposed

**Table1**: Simulated results in different cases

| Different Cases | Resonant Frequency (GHz) | $S_{11}$ (dB) |
|---|---|---|
| Case I (conventional) | $f_1 = 5.5$ | −26.5 |
| Case II | $f_1 = 3.7$<br>$f_2 = 5.47$<br>$f_3 = 6.71$ | −7<br>−24<br>−16 |
| Case III | $f_1 = 3.68$<br>$f_2 = 4.92$<br>$f_3 = 6.23$ | −9.8<br>−6.71<br>−3.95 |
| Case IV (Proposed) | $f_1 = 3.51$<br>$f_2 = 4.82$<br>$f_3 = 5.90$ | −15.17<br>−11.01<br>−19.15 |

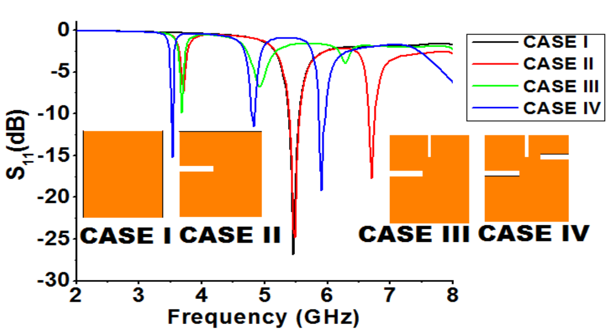


Fig.3. $S_{11}$ variations of the antenna in different cases

dimension, the first resonant frequency is further shifted to 3.31 GHz and that is due to the fact that the current path at this frequency increases. But the value of reflection coefficient at 3.31GHz decreases to −8.5 dB due to impedance mismatching. The value of $S_{11}$ should be at least −10 dB, which is the main criterion for an antenna to radiate in the far field region. The second and third resonant frequency remains unchanged with different impedance matching due to variations of parameter $L_1$.

### *4.2. Effect of parameter $W_1$*

The impact of design parameter $W_1$ is shown in Figure 5. It is clearly seen that further increase of $W_1$ than proposed dimension will slightly shift the first resonant frequency but impedance matching is very poor. The second and third frequency band remains stationary with the variation of $W_1$ slit parameter. So, an optimum value of $W_1$ = 1 mm is selected for antenna design.

### *4.3. Effect of antenna parameter $L_2$*

It is seen from Figure 6 that first resonant frequency remains unaffected due to change in $L_2$ but best $S_{11}$ value is achieved for the proposed dimension $L_2$ = 4 mm. The third resonant frequency appears almost stationary. The second resonant mode is greatly influenced by the variations in slit length $L_2$ and shifts to 4.43 with increasing value of $L_2$ but $S_{11}$ parameter is only −5.4 dB. So, an optimum value of 4 mm is selected for the proposed antenna.

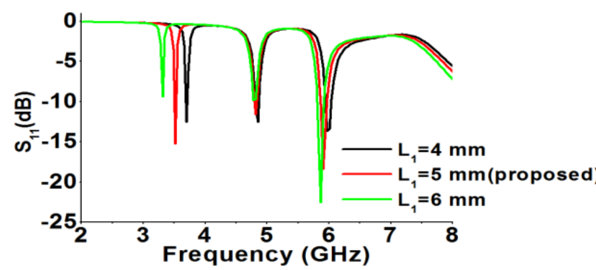


Fig.4. $S_{11}$variations for different values of $L_1$

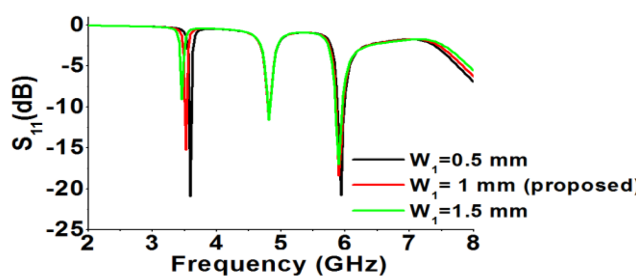


Fig.5. $S_{11}$variations for different values of $W_1$

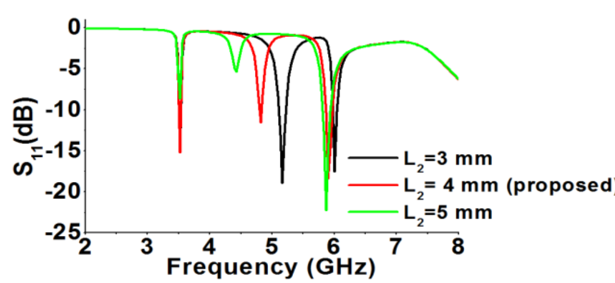


Fig.6. $S_{11}$variations for different values of $L_2$

### *4.4. Effect of antenna parameter $W_2$*

Figure 7 illustrates the $S_{11}$ for different values of second slit width $W_2$. It is observed from the figure that further shifting of first and third resonant frequency is not possible by changing the dimension of the slit width. The second frequency band is tuned by increasing or decreasing the dimension of the slit. But good impedance matching is obtained for the proposed dimension, which is found in the $S_{11}$ graph.

### *4.5. Effect of antenna parameter $L_3$*

Similarly, according to Figure 8, triple frequency operation with best impedance matching condition is noticed for the proposed dimension. Any further change in $L_3$ leads to triple frequency operation with very poor impedance matching.

### *4.6. Effect of antenna parameter $W_3$*

The $S_{11}$ variation of the proposed antenna for different values of $W_3$ is shown in Figure 9. It is observed from the figure that further frequency shifting is not possible by changing the dimension of the third slit width. But the values of $S_{11}$ parameter changes due to variations in width.

So, the first resonance frequency mainly changes due to variation in first and third slit parameters ($L_1$, $W_1$) and ($L_3$, $W_3$). The second resonant frequency varies due to change in second and third slit parameters ($L_2$, $W_2$) and ($L_3$, $W_3$). The third resonant frequency is mainly function of third slit parameters ($L_3$, $W_3$) and also depends on second slit parameters ($L_2$, $W_2$).

The parametric investigation can be validated by observing the surface current distributions of the proposed antenna at respective frequencies. The surface current distribution of the conventional and proposed antenna is shown in Figure 10 (a) – (d). It is clearly observed from the figure that the surface current distribution of the antenna changes due to introduction of slits. It is clearly seen from Figures 10 (b) that the surface current circulates strongly around both horizontal slits ($L_1$, $W_1$ and $L_3$, $W_3$) for 3.51 GHz operation for which it is generated and controlled.

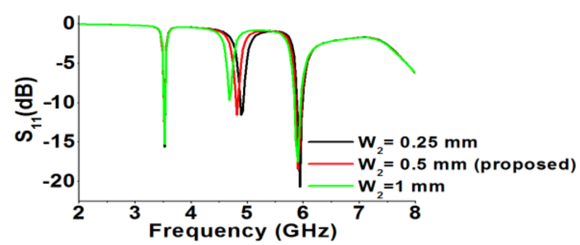


Fig.7. $S_{11}$variations for different values of $W_2$

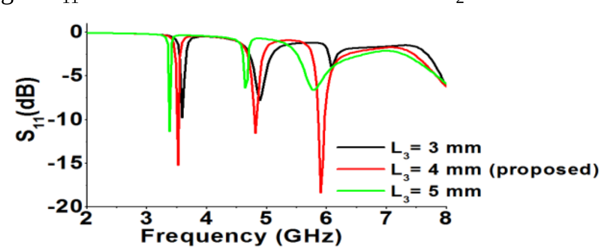


Fig.8. $S_{11}$variations for different values of $L_3$

It is also observed from Figure 10 (c) that for 4.82 GHz operation, the surface current is mainly concentrated around the slit ($L_2$, $W_2$) for which it is generated but it also depends on parameter ($L_3$, $W_3$). For the 5.90 GHz operation [see Figure 10 (d)], it is observed that surface current density is much stronger around the slit ($L_3$, $W_3$) and partly influenced by the slit ($L_2$, $W_2$). Thus, both from the $S_{11}$ characteristic curves and surface current distributions, we can clearly comprehend the function of the related geometrical mechanism of the proposed antenna at three resonant modes. The three narrow slits are introduced in the patch in such a way so that the number of resonant frequency increases due to the disturbance caused to the mean current paths of any resonant mode. Due to the lengthening of the surface current around the slits, the resonant frequency decreases which leads to miniaturization of the proposed antenna.

## 5. Result and discussion

The comparison of the measured $S_{11}$ with the simulated ones of the antenna 2 (proposed) is shown in Figure 11. The reflection coefficient is measured using Agilent E5071B vector network analyzer. A significant improvement of frequency reduction is achieved in proposed microstrip antenna with respect to the conventional antenna structure. Due to the presence of slits in antenna, the simulated results show that the first resonant frequency is reduced to 3.51 GHz with $S_{11}$ of about −15.17 dB, the second resonant frequency is obtained at 4.82 GHz with $S_{11}$ of −11.01 dB,

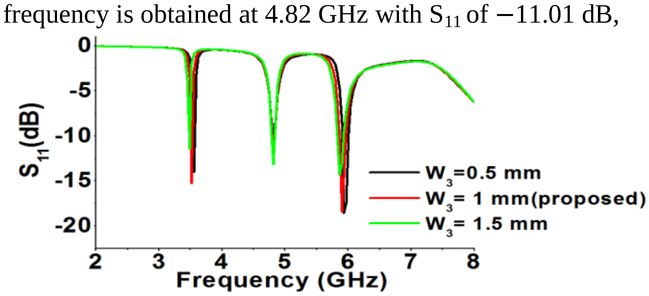


Fig.9. $S_{11}$variations for different values of $W_3$

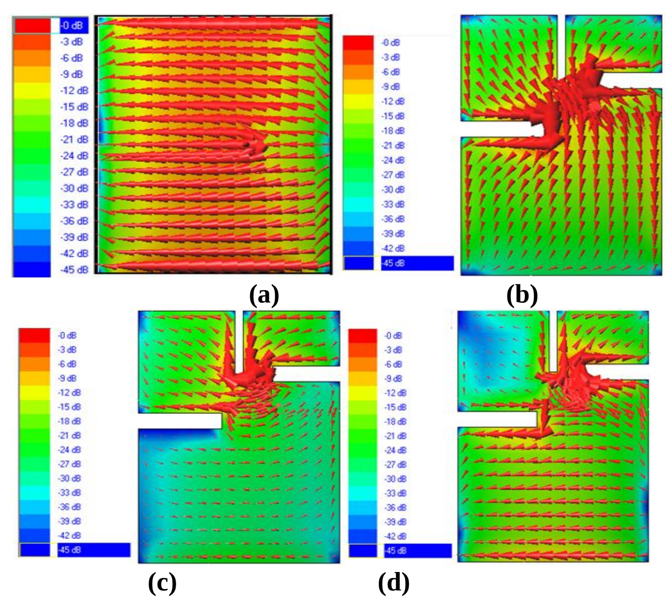


Fig.10. Current distribution of conventional antenna and proposed antenna at (a) 5.5 GHz, (b) 3.51 GHz, (c) 4.82 GHz, (d) 5.90 GHz

and third resonant frequency is obtained at 5.90 GHz with $S_{11}$ of about −19.15 dB, respectively. The measured result shows that the first resonant frequency is achieved at 3.42 GHz with $S_{11}$ of about −18 dB. The second and third resonant frequencies are measured at 4.72 and 5.85 GHz with $S_{11}$ of about −13, and −17.5 dB, respectively. The small discrepancy between the measured and simulated result is due to the effect of improper soldering of SMA connector or fabrication tolerance. The gain and directivity plot of the proposed antenna is shown in Figure 12. The proposed antenna maintains a stable gain above 4.73dBi for all the operating frequencies. The maximum directivity of 6.52dBi is observed at 4.82 GHz.

The radiation patterns of the proposed antenna are shown in Figure 13 (a) − (c). The proposed antenna offers stable unidirectional radiation patterns in both E and H plane at respective frequencies with acceptable cross polarization level. The maximum radiation is exactly concentrated along 0°. The proposed antenna shows linear polarization in the broadside direction. The total and radiation efficiency of the proposed antenna is shown in Figure 14. Radiation efficiency is used to relate the gain and directivity. The radiation efficiency, $e_{cd}$ = G/D, where, G is the gain and D is the directivity of the antenna. The total efficiency $e_0$ is used to take into account mismatch losses. The total efficiency of the antenna is the radiation efficiency multiplied by the impedance mismatch loss of the antenna. Mismatch loss, $e_r = 1-|\Gamma|^2$, and $\Gamma = \frac{VSWR-1}{VSWR+1}$, and $e_{cd}$ = gain/directivity. The total efficiency is always less than radiation efficiency. The proposed antenna offers maximum radiation efficiency of about 76 % at 3.51 GHz.

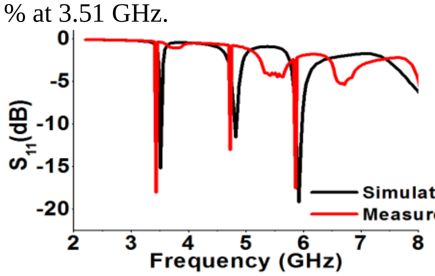


Fig.11. Simulated and measured $S_{11}$ parameter

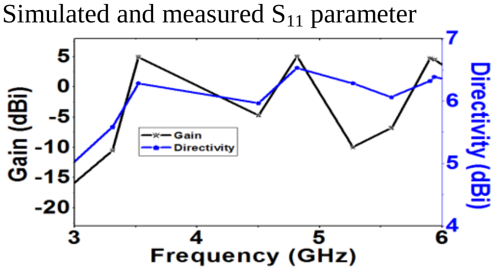


Fig.12. Gain and Directivity of the proposed antenna

## 6. Conclusion

This paper describes analysis and implementation of slits loaded multi-frequency printed antenna. The proposed antenna radiates three distinct frequencies i.e. 3.51, 4.82, and 5.90 GHz. The designed multi-frequency antenna also offers 63% size reduction. Furthermore, good stale radiation patterns and acceptable gain are also obtained across the operating frequencies. The proposed antenna is suitable for

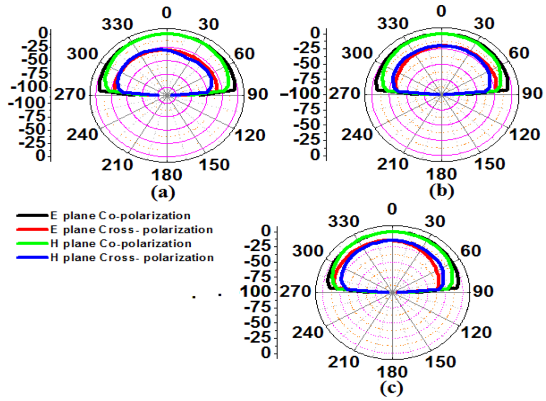


Fig.13. Radiation pattern of proposed antenna (a) 3.51 GHz, (b) 4.82 GHz, (c) 5.90 GHz

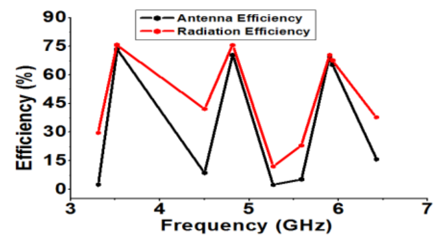


Fig.14. Antenna efficiency and radiation efficiency plot

WiMAX (3.3–3.6 GHz, 5.25–5.85 GHz), INSAT system (4.5–4.8 GHz), and Wi–Fi systems (5.725–5.875 GHz).

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