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Reduced Sized Triple frequency Microstrip Antenna with Dual Frequency Tuning Characteristics

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Abstract: A compact slot loaded rectangular microstrip patch antenna has been designed which shows triple resonant frequency. The effect of slot on reflection coefficient, resonant frequency tuning and antenna size reduction has been investigated in this paper. It has been shown, how the variation of length of the slot embedded in the patch results in shifting of resonant frequencies. By changing the length of the slot, the lower resonant frequency (f_1) of the proposed antenna can be tuned from 4.275 GHz down to 3.75 GHz and the higher resonant frequency (f_3) can be tuned from 7.10 GHz down to 6.65 GHz. The ratio of the fixed fundamental frequency (f_2) to the tunable lower resonant frequency (f_1) can be varied from 1.453 to 1.274. If the ratio of this fixed fundamental frequency (f_2) to the tunable higher resonant frequency (f_3) is considered, then the ratio can be varied from 1.302 to 1.22 by varying the slot length. A significant size reduction of about 58% is achieved compared to conventional rectangular reference antenna. The simple configuration and low profile nature of the proposed antenna leads to easy fabrication and make it suitable for the applications in wireless communication system.

Keywords: Compact; dual frequency tuning; micro strip patch antenna; slot; wireless communication system

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I. INTRODUCTION

Microstrip antennas are now extensively used in various communication systems due to their compactness, economical efficiency, light weight, low profile and conformability to any structure. There is an increase in demand for compact multifrequency antennas with improved performance for wireless communication systems. Frequency agile communication systems must be able to receive signals over a large frequency range and therefore, requires tunable antennas. Tunable microstrip antennas (MSAs) are used for changing to another nearby frequency for a specific application. Tunable narrow-band antennas can be advantageous if small efficient antennas are required to cover a large frequency range. Some of the works for tuning the resonant frequency have been made by reactive loading of the microstrip patch using varactor diode [1], switching diode [2-3] and changing the external DC bias voltage [4]. Although these electrical reconfiguration techniques have been widely used, they have some undesired performance characteristics when they are not designed carefully. Their impedance mismatch with the antenna structure creates a challenge for antenna designers. However, external circuit is required for shifting the resonant frequency in these works, and the antenna which is working as a system becomes more sensitive to the different external parameters. So, slot loaded tunable microstrip antenna has been studied and reported in [5] but the antenna offers small single frequency tuning range 1.41 to 1.45 with larger antenna dimension ($50\times54\times1.6\ mm^3$) . Again, due to recent advancements in mobile and wireless communication system, the increasing demands for wireless connectivity necessitate a single antenna to cover several allocated wireless frequency bands. So, the demand for the design of an antenna with multifrequency operation has increased since such an antenna is vital for integrating more than one communication standards in a single compact system. Likewise, triple frequency compact antennas are used largely as they eliminate the need for a separate antenna for three different frequencies and at the same time provide good isolation. A number of techniques have been reported to increase the compactness of a microstrip antenna such as using high dielectric material as substrate [6], increasing the electrical length of antenna by optimizing its shape [7], by applying resistive or reactive loading [8]. Several compact microstrip antenna designs have been reported over the years by embedding various shapes of slots and slits on microstrip patch and ground plane [9-24]. The size reduction of about 50% was achieved by the insertion of printed inductive elements [8]. It was reported by Rezvani that antenna size reduction of 34% can be achieved using slotted microstrip patch antenna with defected ground plane [9]. A maximum size reduction of about 10% was achieved by meandered circular patch with shorting pin [10]. Mitra et al. reported a split ring resonator-loaded CPW-fed antenna with 26% reduction in antenna size [11]. It was reported by Gautam et al.[12] that with four slits and a pair of truncated corner, the size of the antenna can be reduced by 39%. Antenna size reduction of about 20% with dual frequency operation was achieved by cutting a circular slot on the microstrip patch [13]. A maximum antenna size reduction of 41% with multifrequency operation was achieved in [14] by varying the positions and dimensions of the rectangular slots on the patch. It was also reported by Singh [15] that by using cross slot on the rectangular and trapezoidal patch, the size of the antenna can be reduced by 34% and 41% respectively. In Ref. [16], a maximum size reduction of 46.2% was achieved by introducing a triangular slot at the upper edge of the patch. A maximum size reduction of less than 40% was reported in [17] for slotted edge fed microstrip antenna. It was reported by Malekpoor [18] that by cutting the different slots length on the patch and using unequal resonance arms, the size of the microstrip patch antenna can be reduced by 37% with multi-frequency operation. It was reported by Chatterjee [19] that by cutting unequal rectangular slots at the edge of the patch, the size of the antenna can be reduced by of 46.13%. A maximum size reduction of 47.4% has been achieved in Ref. [20] by embedding three unequal rectangular slots at the edge of the patch. Kaya designed and studied rectangular microstrip antenna with a pair of parallel slots loaded close to the radiating edge of the patch and three meandering narrow slots embedded in the antenna surface resulted in a size reduction of 34% and 45% [21]. Antenna size reduction of 41.8% with dual frequency operation was also reported by Chatterjee [22]. A compact equilateral triangular patch antenna with maximum size reduction of 43.47% was reported by Dasgupta [23]. A novel compact probe-fed microstrip patch antenna is studied by etching out a symmetric pattern of crossed slots from the surface of a square probe-fed patch which results in 51 % antenna size reduction [24]. In this paper, a single layer probe feed size reduced slotted rectangular patch antenna with dual frequency tuning and having triple frequency operation is proposed. Authors have tried to investigate the effect of slot on the following characteristics of the antenna:

(i) Reflection coefficient (S_{11})
(ii) Gain
(iii) Size reduction
(iv) Resonant frequency tuning

The proposed modified antenna covers three important design issue of microstrip patch antenna, such as compactness, frequency tuning and multifrequency operation. The advantage of our work is that we have achieved triple frequency operation with dual frequency tuning in compact size without using defected ground structure, fractal geometry, external DC bias, shorting pin, high dielectric material, varactor diode or switching (PIN) diode. The proposed slotted microstrip patch antenna is designed with thin, inexpensive, low dielectric constant FR-4 substrate. The tunable microstrip antennas reported in [1-5] do not provide multifrequency operation. The compact microstrip antennas reported in [6-24] do not provide frequency tuning characteristics. The advantages of the proposed antenna in comparison to the reported antennas [1-24] are as follows:

(i) The structure of the proposed antenna is less complex.
(ii) The proposed antenna provides better size reduction.
(iii) The proposed antenna provides dual frequency tuning with better frequency tuning capability.
(iv) The proposed antenna provides better tuned frequency ratio.
(v) The radiating patch area of the proposed antenna is much less.

The proposed antenna could be promising for a number of modern wireless communication applications such as 3.7 GHz Wi-MAX, due to its small size, light weight, low cost and good working characteristics.

II. ANTENNA DESIGN

Antenna 1 (Conventional Antenna):

The width (W) and length (L) of Antenna 1 is calculated from Conventional equations [25].

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{1+\varepsilon_r}} \qquad (1)$$

$$L = L_{eff} - 2\Delta L \qquad (2)$$

$$\frac{\Delta L}{h} = 0.412 \times \frac{(\varepsilon_{reff}+0.3)(\frac{w}{h}+0.264)}{(\varepsilon_{reff}-0.258)(\frac{w}{h}+0.8)} \qquad (3)$$

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{w}\right]^{-1/2} \qquad (4)$$

$$L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}} \qquad (5)$$

Where, f_r = Resonant frequency, W= Width of the antenna, L_{eff} = Effective length of the patch, $\frac{\Delta L}{h}$ = Normalized extension of the patch, ε_{reff} = Effective dielectric constant. The length and width of Antenna 1 (conventional antenna) operating at frequency 5.5 GHz are 12 and 16 mm, respectively, with substrate thickness h = 1.5875 mm and dielectric constant ε_r = 4.4 (FR-4). The width and length of the conventional patch antenna in terms of wavelength are $0.293\lambda_r$ and $0.22\lambda_r$, respectively, where, λ_r is the wavelength of the resonant frequency (i.e., 5.5 GHz). Figure 1 shows the structure of the conventional rectangular microstrip patch antenna with length (L) = 12 mm and width (W) = 16 mm. Coaxial probe-feed (radius = 0.5 mm) 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 structure of Antenna 2 (proposed antenna), designed with simple ground plane is shown in Figure 2. The FR-4 substrate chosen for realizing the antenna has dielectric constant, $\varepsilon_r = 4.4$ and thickness (h) of 1.5875 mm. The proposed antenna is incorporated with one horizontal and one small vertical connected slot. The horizontal slot $(L_1 = 5\,mm, W_1 = 1\,mm)$ is introduced to generate triple frequency. The addition of small vertical slot $(L_2 = 0.5\,mm, W_2 = 1\,mm)$ improves the reflection coefficient and hence impedance matching of the proposed antenna at respective frequencies. The parameter "L_1" is considered to vary which is the length of the horizontal slot where all other dimensions are optimized to obtain best miniaturization value with frequency tuning for the proposed design. The method of moment based electromagnetic simulator IE3D [26] is applied for numerical investigation in the proposed antenna design. The dimensions of the proposed antenna parameters are 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, L_1 = 5 mm, W_1 = 1 mm, L_2 = 0.5 mm, W_2 = 1.5 mm.

The antenna is excited by a coaxial probe (radius = 0.5 mm), and the feed point is located at the distance of (−1.5 mm, −1.5 mm) away from the centre of the rectangular patch [Figure 2]. Alteration of location of the feed point results in narrower −10 dB bandwidth and non tuneable frequencies. The prototypes of the fabricated antenna 1 (conventional antenna) and antenna 2 (proposed antenna) are shown in Figures 3-4.

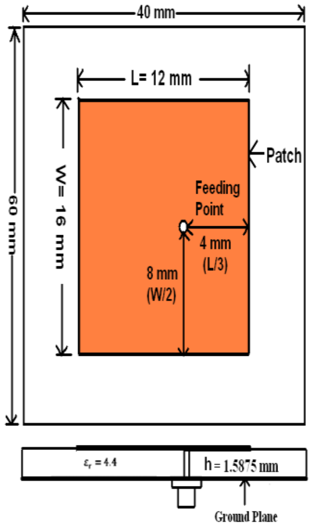


Figure 1: Geometry of Antenna 1

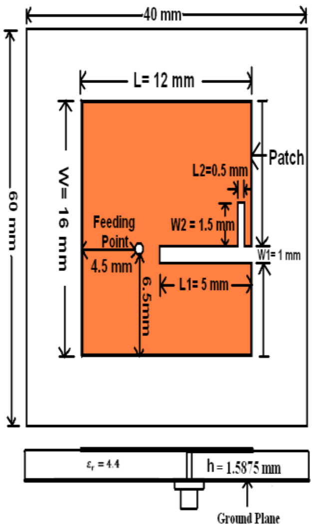
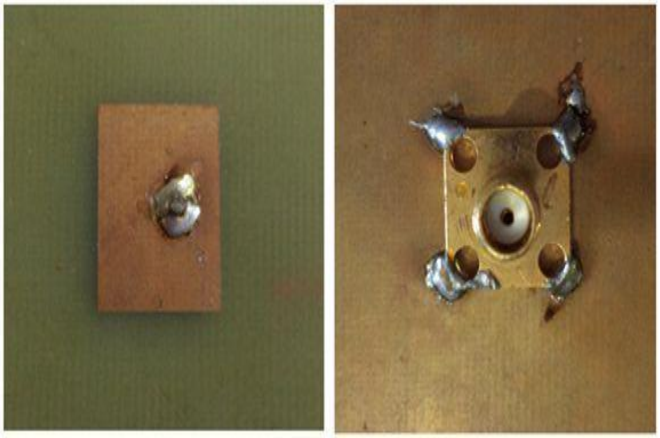
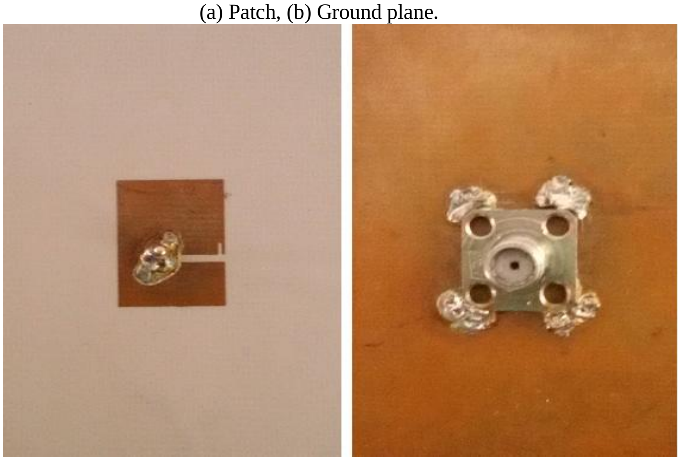


Figure 2: Geometry of Antenna 2



(a) (b)

Figure 3. Photograph of fabricated prototype of the conventional antenna (a) Patch, (b) Ground plane.



(a) (b)

Figure 4. Photograph of fabricated prototype of the proposed antenna (a) Patch, (b) Ground plane.

III. FREQUENCY CONTROL

Effect of Antenna Parameter L_1

The effects of varying the dimensions of the slots on the resonant characteristics of the proposed antenna are investigated by 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 variations of reflection coefficient and resonant frequency of the proposed antenna as a function of design parameter L_1 is shown in Figure 5. The parameter L_1 has great impact on resonant frequency of the first and third mode. The resonant frequency of the first mode can be tuned from 4.275 GHz down to 3.75 GHz with $S_{11} \leq -10$ dB. With further increase in L_1 parameter than proposed dimension (L_1 = 5 mm), the first resonant frequency is further shifted to 3.34 GHz and that is due to the fact that the current path at this frequency increases. But the value of reflection coefficient at 3.34 GHz decreases to −4 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 resonant mode remains unchanged with the variations of parameter L_1. The third resonant frequency can be easily tuned by adjusting the value of the design parameter L_1. The resonant mode for 6.65 GHz can be tuned from 7.10 GHz to 6.485 GHz by adjusting the slot length from 2 mm to 7 mm. But if L_1= 7 mm, the resonant frequency of first resonant mode appears with poor impedance matching. So, it is clear from Figure 5 that L_1= 5 mm is the optimum value for the proposed antenna to achieve dual frequency tuning with best impedance matching. The variation of two resonant frequencies as a function of slot length L_1 is shown in Figure 6. It is observed that the shifting of resonant frequencies depend inversely on dimension of L_1 parameter of the proposed antenna.

The relationship between the length (L_1) of the slot and first resonant frequency f_1 (in GHz) is formulated by the Eq. (6) given below. By the help of this equation first resonant frequency (f_1) can be calculated for a particular length (L_1) of the slot.

$f_1 = -0.014{L_1}^2 - 0.045L_1 + 4.334$ ……………… (6)

Similarly, the relationship between the length (L_1) of the slot and third resonant frequency f_3 (GHz) is formulated by the Eq. (7) given below. By the help of this equation third resonant frequency (f_3) can be calculated for a particular length (L_1) of the slot.

$f_3 = 0.005{L_1}^2 - 0.182L_1 + 7.432$ ………………... (7)

Effect of Antenna parameter W_1:

The impact of design parameter W_1 is shown in Figure 7. The changes in slot width (W_1) yields very limited tuneablity at f_1 and f_3. The second frequency band remains stationary with the variation of W_1 slot parameter. It is seen from Figure 7 that when the parameter W_1 is varied from 0.25 mm to 1.5 mm, the resonant frequency of the first mode moves from 3.88 GHz to 3.75 GHz. In this case resonant frequency of the third mode varies slightly from 6.74 GHz to 6.65 GHz. Maximum reflection coefficient i.e., best impedance matching is achieved for W_1 = 1 mm. So, W_1= 1 mm is selected for the proposed antenna.

Effect of Antenna parameter L_2 and W_2:

The S_{11} variations of the proposed antenna for different values (L_2 and W_2) of small rectangular notch are shown in Figures 8-9. It is observed from the figures that further frequency shifting or tuning is not possible by changing the dimension of the parameters. But the values of S_{11} parameter changes due to variations in notch dimensions. Furthermore, good impedance matching is obtained for the proposed dimensions, which is found in the respective S_{11} graphs.

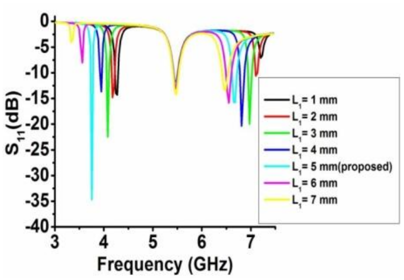


Figure 5: S_{11} variations for different values of L_1 parameter

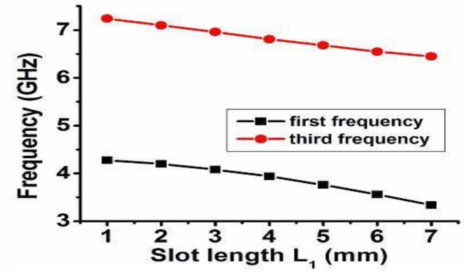


Figure 6: Frequency variation as a function of slot length L_1

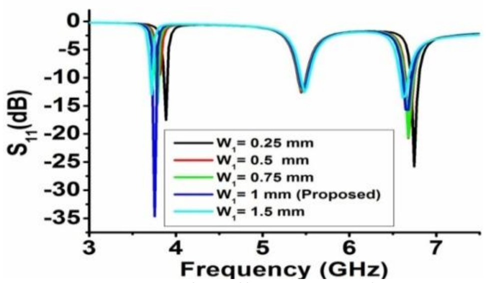


Figure 7: S_{11} variations for different values of W_1 parameter

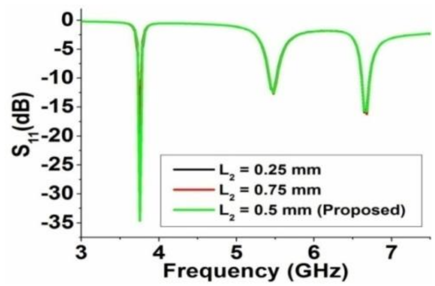


Figure 8: S_{11} variations for different values of L_2 parameter

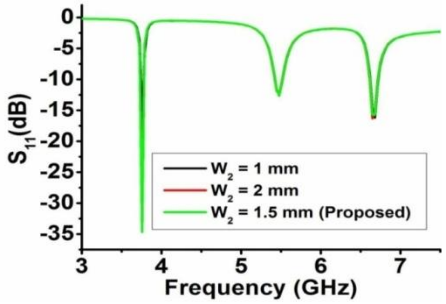
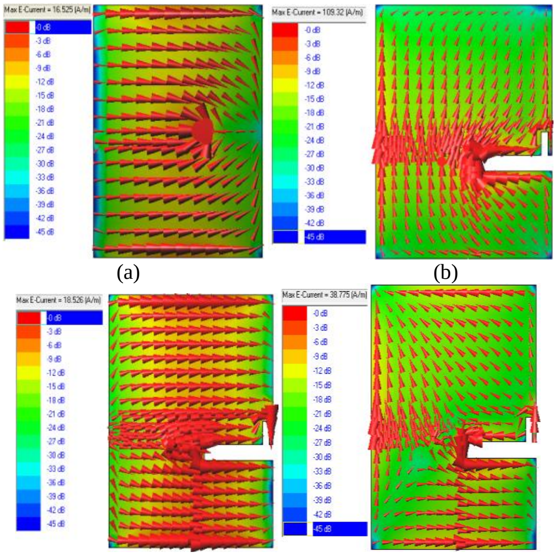


Figure 9: S_{11} variations for different values of W_2 parameter

For better understanding the excitation behavior of the proposed antenna, the simulated surface current distributions at different resonant frequencies are displayed in Figure 10. It is clearly observed from Figure 10 (a) that the surface current density of the conventional patch antenna is much less 16.52 A/m. So, the current density of the patch at that radiating edge can be increased by introducing additional slots [27]. In comparison to surface current density of conventional antenna, the surface current density increases to 109.32 A/m for the proposed antenna at 3.75 GHz operation [see Figure 10 (b)]. The fundamental resonant mode at 5.45 GHz is not dependent on the variation of slot parameters. It is mainly generated due to dimensional parameter of the patch. It is verified from

Figure 10 (c) that for 5.45 GHz operation, the direction of surface current is almost similar to current distribution of conventional antenna. For the 3.75 and 6.65 GHz operation [see Figure [10 (b) & (d)], the surface current density is mainly concentrated around the slot (W_1, L_1) for which it is generated and controlled. The current mainly concentrates at edges of the slot and thereby increases the current path. Due to the lengthening of the surface current around the slot, the resonant frequency decreases.



(a) (b)

(c) (d)

Figure 10: Surface current distribution of Antenna1 (Conventional) and Antenna 2 (Proposed) at different frequencies (a) 5.45 GHz (b) 3.75 GHz (c) 5.45 GHz (d) 6.65 GHz

IV. RESULTS AND DISCUSSION

The prototype of the antenna 1(conventional) and antenna 2 (proposed antenna) was fabricated and tested. The reflection coefficient and VSWR was measured using Agilent E5071B vector network analyzer. The simulated and measured reflection coefficient of antenna 1(conventional antenna) is shown in Figure 11. Both the measured and simulated value shows that the obtained frequency is 5.45 GHz with S_{11} of about −23 and −35 dB, respectively. The comparison of the measured S_{11} with the simulated ones of the proposed antenna is shown in Figure 12. The measured value shows that the antenna resonates at 3.71, 5.45, and 6.45 GHz with S_{11} parameter of about $-19, -14.5, -19.5$ 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. In comparison with a conventional patch antenna, 58% size reduction is achieved by the proposed structure. The measured VSWR and mismatch loss of the proposed antenna is shown in Figure 13. The VSWR of the proposed antenna is within 2:1 which signifies less reflected power and practically considerable mismatch loss throughout different resonant frequencies. Figure 14 shows the total field gain versus frequency plot for the proposed antenna. It is observed that peak gain of about 5.25 dBi is achieved at 3.75 GHz. Efficiency of the proposed antenna (radiation efficiency and antenna efficiency) with the variation of frequency is shown in Figure 15. It is found that for the lower band of operation, efficiency of the proposed antenna is about 78 %. The simulated E plane and H plane radiation patterns for antenna 2 (proposed antenna) are shown in Figures 16-17. As shown in the figures, radiation pattern of the antenna is broadside. It is observed from Figure 16 that the cross polarization is almost 25 dB less than co polarization values. Similarly, it is seen from Figure 17 that the cross polarization level is 14 dB less than the co polarization level in the E plane, and its values in the H plane are acceptable in the region of $-20^{\circ} \leq \theta \leq 20^{\circ}$.

Calculation of Mismatch loss (ML):

The mismatch loss (ML) is calculated from the measured VSWR using the following expression

$$ML = -10\log\left\{1-\left[\frac{VSWR-1}{VSWR+1}\right]^{2}\right\} \ldots\ldots\ldots\ldots \ (8)$$

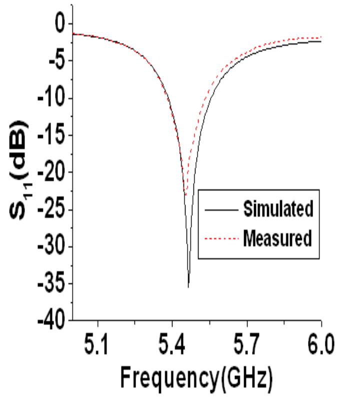


Figure 11: S_{11} of Antenna 1 (Conventional Antenna)

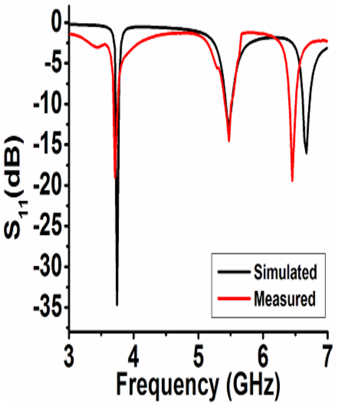


Figure 12: S_{11} of Antenna 2 (Proposed antenna)

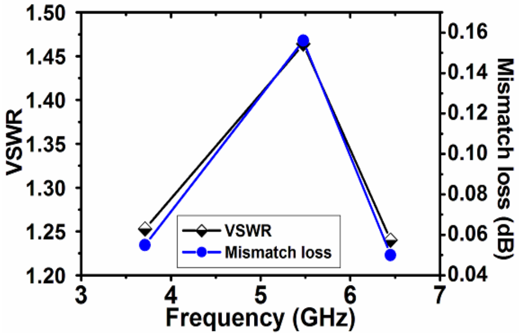


Figure 13: Measured VSWR and mismatch loss.

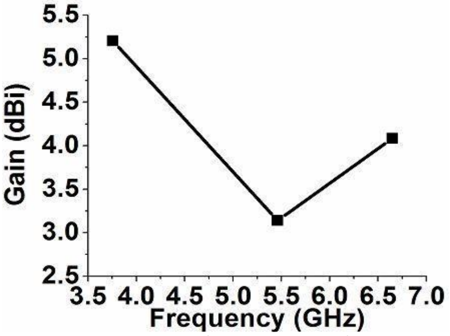


Figure 14: Gain versus frequency plot of Antenna 2

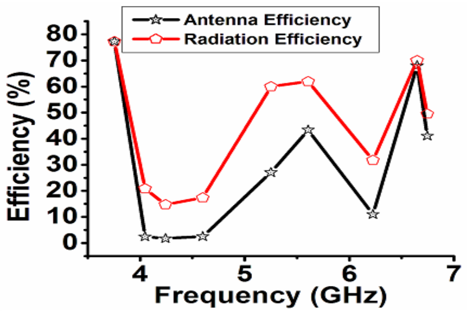
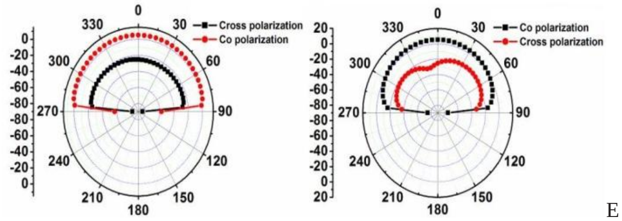


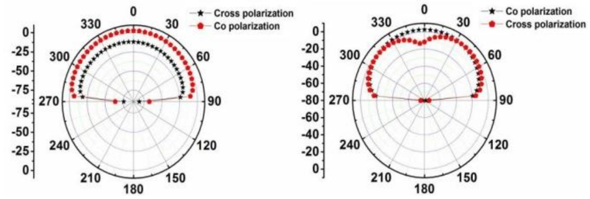
Figure 15: Efficiency versus frequency plot for the proposed antenna



E

field pattern H field pattern

Figure 16: Simulated radiation pattern at 3.75 GHz



E field pattern H field pattern

Figure 17: Simulated radiation pattern at 6.65 GHz

V. CONCLUSION

A single layer single feed slot loaded microstrip patch antenna is proposed in this paper. It is shown that the proposed antenna can operate in three frequency bands. An optimization between frequency tuning and impedance matching is maintained in this work. For antenna 2 (proposed antenna), the effect of slot has reduced the lower resonant frequency from 5.45 GHz to 3.75 GHz which shows an area reduction of about 58%. Overall, the lower resonant frequency can be tuned to any value between 4.275 GHz and 3.75 GHz. Similarly, the higher resonant frequency can be tuned to any value between 7.10 GHz and 6.65 GHz. Furthermore, good stable radiation patterns with wider 3 dB beam-width and acceptable gain are also obtained across the operating frequencies. The proposed antenna could be promising and suitable for 3.7/5.5 GHz WiMAX and 5.5 GHz HiPERLAN.

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