Radiations from double notched square patch antenna on FR4 substrate

Dheeraj Bhardwaj, D. Bhatnagar,

Microwave Lab., Department of Physics, University of Rajasthan, Jaipur -302004 (India)

Email: dbhatnagar_2000@rediffmail.com

S. Sancheti

National Institute of Technology Karnataka, Surathkal, Mangalore-575025 (India)

Brijesh Soni

Indian Space Application Center, Bangalore, Karnataka (India)

***Abstract* - This paper presents the radiation performance of a square patch antenna having two triangular notches on opposite edges designed on glass epoxy FR4 substrate and its performance is compared with a simple square patch antenna without any notch. The simulated results for this antenna are obtained by varying notch angle and compared with the measured results. The results indicate that square patch antenna with both notch angles equal to 168^{o} resonates not only at two different frequencies but also offers a much higher bandwidth in comparison to a normal square patch (without notches). Both these resonance frequencies lie in the median band (3.25 to 3.85 GHz) allotted by IEEE 802.16 working group for WiMAX systems. The performance of antenna is optimized considering different conditions to obtain an antenna with dual band and high bandwidth performance. The radiation patterns, gain and radiation efficiency of antenna are also determined.**

Index Terms— Microstrip antenna, dual band operation, bandwidth and gain

I. INTRODUCTION

Microstrip antennas have many advantages over conventional antennas such as low profile, ease of integration with active and passive devices, ability of mounting on planar, nonplanar and rigid exteriors to form MICs and low manufacturing cost due to use of printed circuit technology [1-3]. In case of planar antennas designed for wireless communication systems, it is necessary to have a compact size antenna configuration that can be integrated with other devices. Since the physical area of the microstrip antenna is inversely proportional to the frequency, it is difficult to achieve a compact size antenna for modern communication systems for WLAN, WiMAX and WiFi applications, particularly with normal patch geometries having acceptable efficiency and isolation values. There is often a tradeoff in realizing compact antennas while maintaining their performance characteristics. Traditional patch antenna using rectangular, circular or triangular geometries under normal conditions resonate at a single frequency and have inherent low bandwidth and gain values limiting their potential applications. Present day communication systems need dual or triple frequency operation with higher bandwidth. Microstrip antennas for dual frequency applications have been realized by exciting patch geometry by using a single [4] or dual feed [5] arrangements. Several researchers have studied the performance of bow-tie microstrip antennas and have reported either enhancement in bandwidth [6-8] or possible operation at two or more frequencies [9]. Some other works [10–12] applied different kind of notches in regular shaped microstrip antennas to improve their impedance bandwidth or to obtain multiple resonant frequencies with same antenna. Chen and Chia [11] applied suspended notched square probe fed plate over the ground plane to attain impedance bandwidth around 20 %. Shackelford et al. [12] considered a probe fed notched square patch antenna with a shorting post to attain bandwidth of the order of 13 %.

In the present communication, we have considered a more simplified antenna structure by applying triangular notches on opposite edges of a square patch antenna and changed the depth of notch tip to optimize and attain best performance. This geometry is somewhat like a bow-tie antenna which are planar equivalents of the biconical antenna [13] that has wideband characteristics. However, in this communication, variations are made in the simple rectangular patch geometry where the notch tips are relatively far away than that in bow tie antenna.

II. ANTENNA GEOMETRY AND RESULTS

In the present paper, radiation performance of a square patch antenna with two nothes on its opposite edges is considered and is compared with a normal square patch antenna. The antennas are simulated using IE3D [14] and later designed on glass epoxy FR4 substrate (ϵ_r = 4.4, tanδ = 0.002, substrate thickness 0.158 cm) with copper as its ground plane [15]. The patch size of 2cm x 2cm is considered for the present work. First the theoretical analysis of simple square patch antenna was carried out using an inhouse CAD tool [16] which is based on cavity model based modal expansion technique [17]. The square patch antenna with coordinate system considered during theoretical analysis and the designed antenna geometry with notches, for experimentation are shown in figure 1. The analysis reveals that the square patch antenna when fed from point (1.36 cm, 1.39 cm) resonates at a single frequency 3.46 GHz as shown in figure 2.

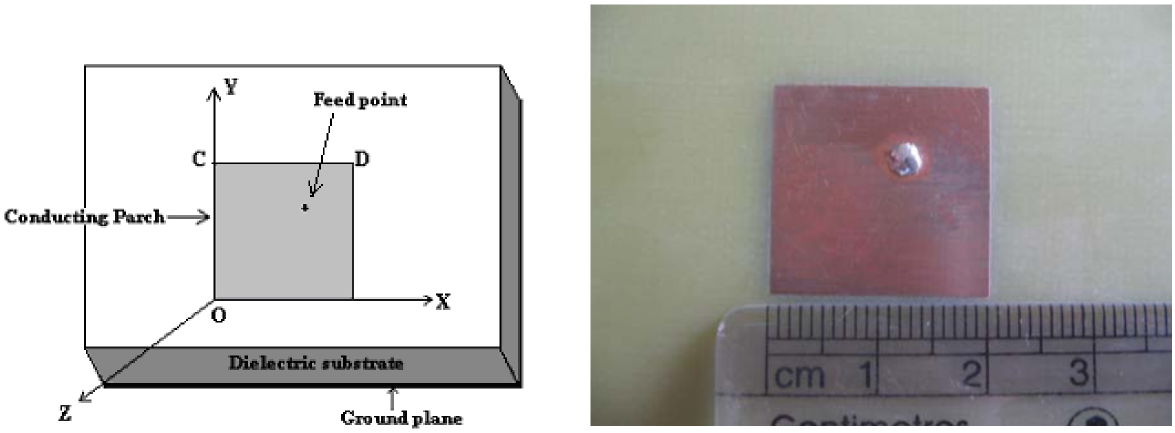


Fig. 1: (a) Normal square patch antenna (b) Square patch antenna with double notches

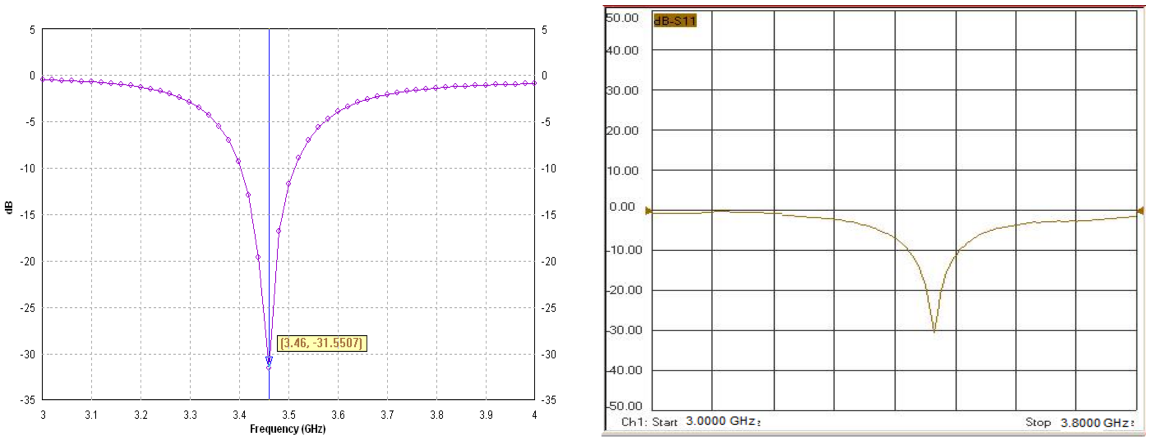


Fig. 2: (a) Simulated return loss of square patch antenna (b) Measured return loss of square patch antenna

The simulated and measured resonance frequencies are in excellent agreement. The impedance bandwidth (corresponding to -10 dB return loss) of antenna determined from figure 2 is narrow (2.09 %). Since antenna is designed on a high permittivity substrate having high loss tangent value, low gain (2.4 dbi) and low antenna efficiency (38.5 %) were obtained.

For the next phase of work the patch geometry considered is shown in figure 3. Two notches are applied in the square patch opposite to each other and notch angle are varied in two steps. In the first step, both notch angles varied simultaneously keeping both notch angles identical and in the next step, one notch angle θ_1 is kept constant and other notch angle θ_2 is varied. The antennas are again simulated using IE3D [14] software and later designed on glass epoxy FR4 substrate with copper as its ground plane retaining the patch size of 2cm x 2cm. Based on analysis, different patch antennas considered under first step are designed and tested experimentally. Representative example of designed antennas with notch angles $\theta_1 = \theta_2 = (168 \pm 0.05)^o$ is shown in figure 3(b).

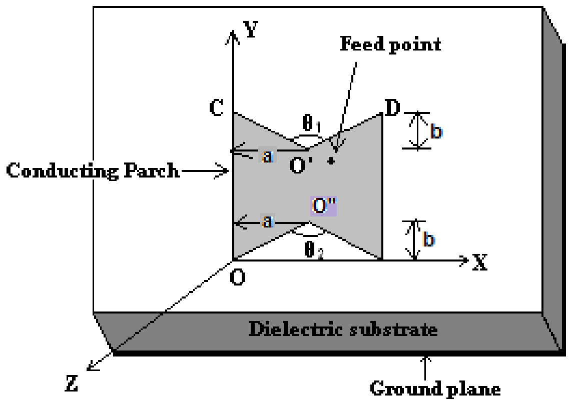


Fig 3(a) Square patch antenna geometry having identical notch angles

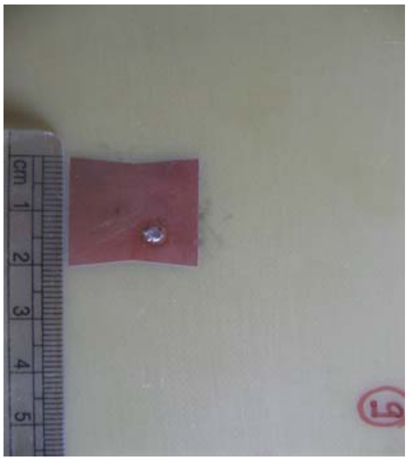


Fig 3(b) Designed square patch antenna with identical notch angles

The simulated and measured return loss results of antenna having notch angle $\theta_1 = \theta_2 = 168^o$ are shown in figures 4(a) and 4(b) respectively. The simulated return loss curve is drawn on the reduced scale (3 GHz to 4 GHz) to make results clear. These figures clearly indicate that not only shapes of return loss curve are almost identical but resonance frequencies are also in good agreement. The measured resonance frequencies are $f_1 = 3.29$ GHz and $f_2 = 3.475$ GHz respectively while simulated resonance frequencies are $f_1 = 3.39$ GHz and $f_2 = 3.58$ GHz respectively. Both these measured resonance frequencies lie in the median band (3.25 to 3.85 GHz) allotted by IEEE 802.16 working group for WiMAX [18] systems. These results also indicate that the impedance bandwidth for antenna having notch angle $\theta = 168^o$ is 9.1 % which is much higher than that of a normal patch antenna geometry [3].

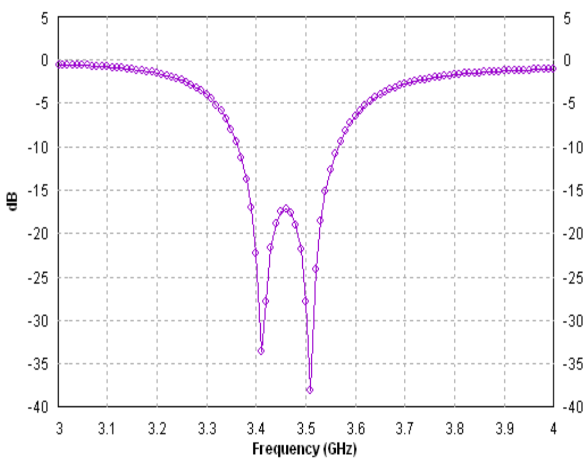


Fig. 4 (a): Simulated return loss of square patch antenna with two notches. Both notch angles are $\theta = 168^o$

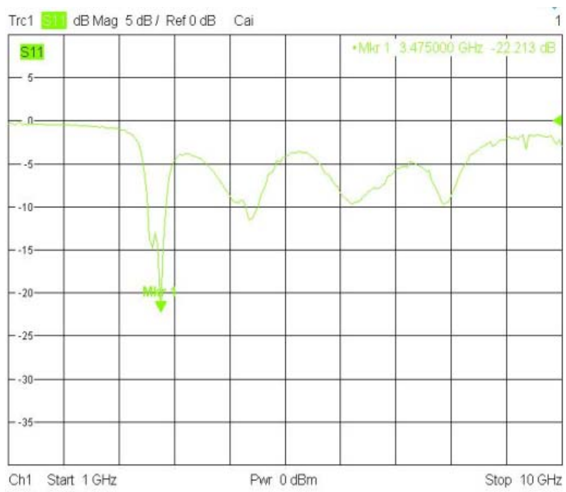
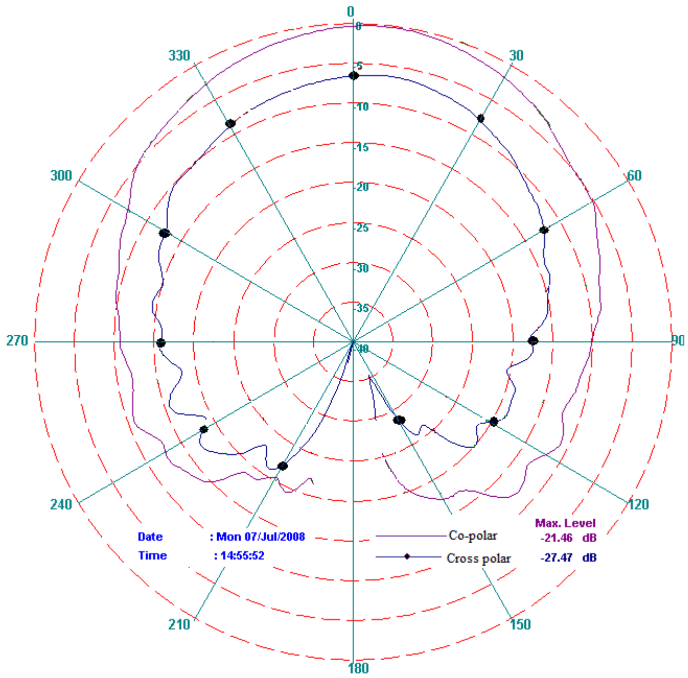
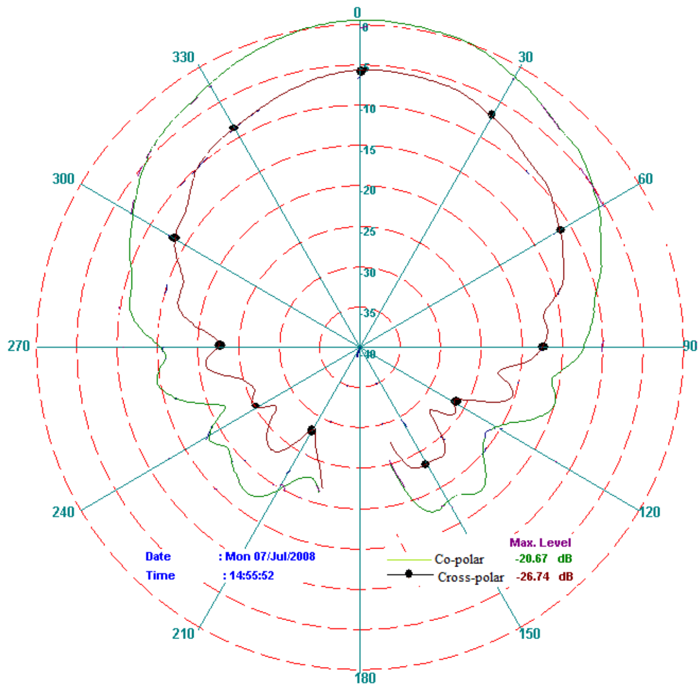


Fig. 4 (b): Measured return loss of square patch antenna with two notches. Both notch angles are $\theta = 168^o$



(a) E-plane



(b) H-plane

Figure 5: Measured far-field radiation pattern for the square patch antenna with double notch antenna at 3.29 GHz.

The E-pane and H-plane measured co-polarized and cross-polarized far-field antenna radiation patterns at 3.29 GHz are shown in figure 5. Both radiation patters are more or less identical. The co-polar radiation pattern in E-plane indicates that the 3dB beam width of antenna is ~58^{o}. The cross polarization radiation in the principal plane is seen to be less than -6dB in comparison to co-polar radiation. These patterns are almost identical to that observed for square patch antenna without notch except that the direction of maximum radiations of antenna is slightly shifted away from broadside direction ($\theta = 0^o$) i.e. in $\theta \sim 5^o$. This indicates that the presence of notches does not cause much effect on the shape and polarization level of radiation patterns of the antenna.

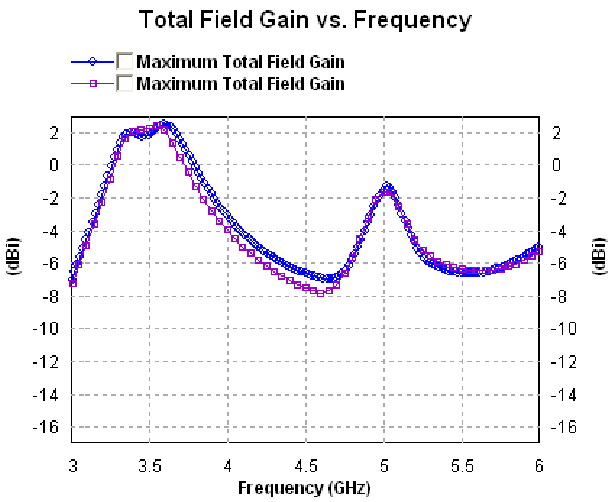


Figure 6: Simulated total gain of antenna as a function of frequency

The simulated gain of antenna as a function of frequency for this antenna is shown in figure 6. The total gain at resonance frequency 3.39 GHz is 2 dBi and the measured gain at resonance frequency of 3.29 GHz is 3 dBi. Both these values indicate low gain of the antenna. It is known that the gain bandwidth product of antenna remains constant and during present work the effort is concentrated on bandwidth enhancement at the cost of gain of antenna.

The measured results shown in figures 7(a) indicate that on reducing notch angles from $\theta = 180^o$ to $\theta = 172^o$, antenna resonates at a single frequency similar to normal patch antenna geometries. On reducing notch angle further, antenna starts resonating at two different frequencies. One of these frequencies (f_1) is lower while the other frequency (f_2) is more than that of the square patch antenna resonant frequency without any notch. The ratio of these frequencies (f_2 / f_1) shown in figure 7(b) indicating that ratio marginally increases on decreasing the notch angle. A simple square patch antenna operates at its resonance frequency corresponding to its dominant mode of excitation. As soon as notches with appropriate notch angles are applied (typically 168º in the present case), other modes near the edge of the patch geometry gets excited and hence antenna starts resonating at the new resonant frequency corresponding to new mode of excitation in addition to the resonance frequency of the dominant mode of excitation. As these two resonance frequencies are quite close to each other their return loss curves overlap each other to give wide bandwidth. The simulated gain and radiation efficiencies of antennas as a function of notch angle are shown in figures 8(a) and 8(b) respectively. Like the simple square patch antenna, both gain and efficiencies of these antennas are low.

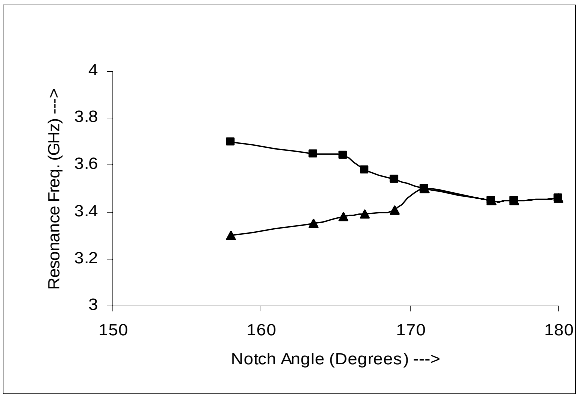


Fig.7a: Variation of resonance frequency with notch angle.

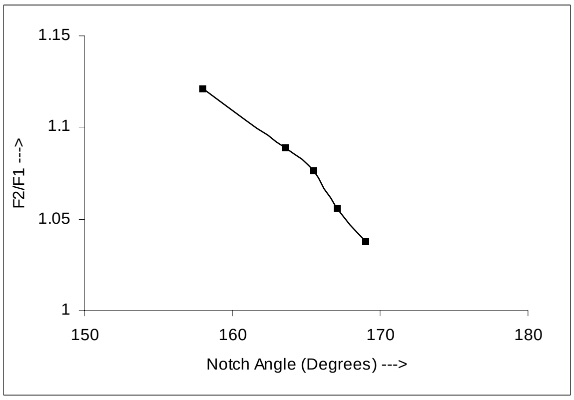


Fig.7b: Variation of frequency ratio (f_2 / f_1) with notch angle

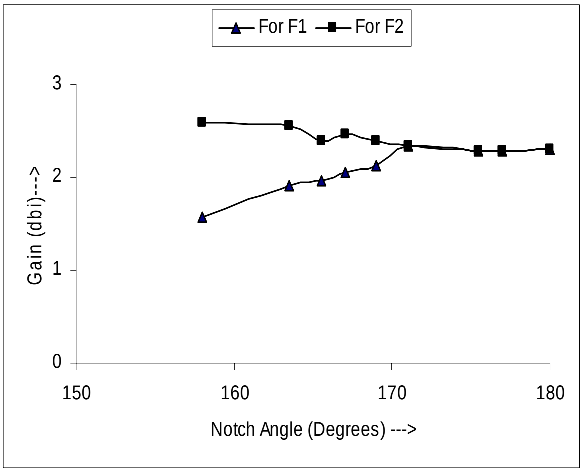


Fig.8a: Variation of antenna gain with notch angle

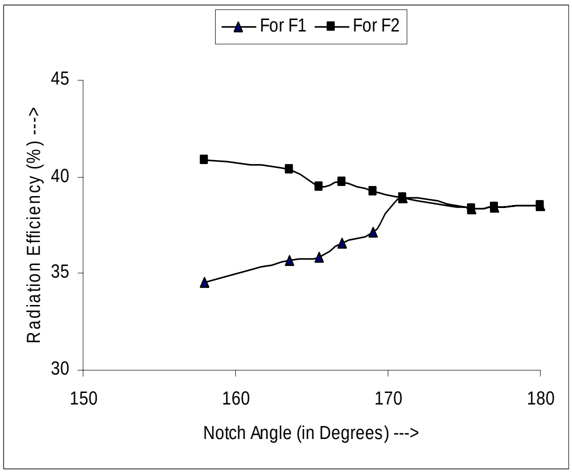


Fig.8b: Variation of frequency ratio (f_2 / f_1) with notch angle

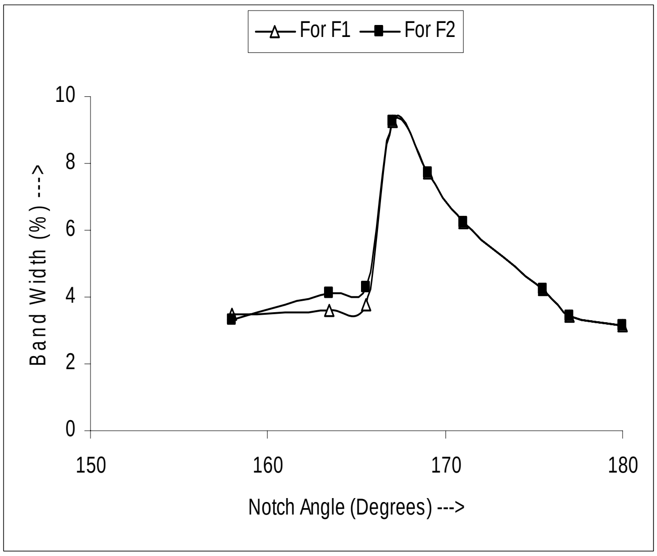


Fig. 9: Variation of bandwidth of square patch antenna with notch angle

The reason for these low values is obvious because the substrate which has large dielectric constant with high loss tangent. In this work the bandwidth of antenna is optimized by varying notch angle. The variation of bandwidth of antenna with notch angle is shown in figure 9. This figure indicates that maximum bandwidth of 9.1 % may be achieved by making both notch angles 168^o. This bandwidth is significantly higher than that of a simple patch antenna. These results are very encouraging and it is felt that bandwidth may be further improved by applying techniques such as varying air gap between the radiator and the ground plane (or reducing effective dielectric constant of the substrate) [19] and by applying parasitic patch at close vicinity to the radiating patch [20].

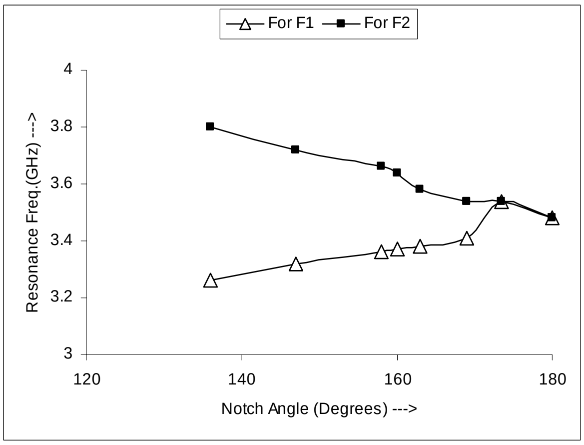


Fig.10a: Variation of resonance frequency with variation of notch angle θ_2 keeping θ_1 fixed

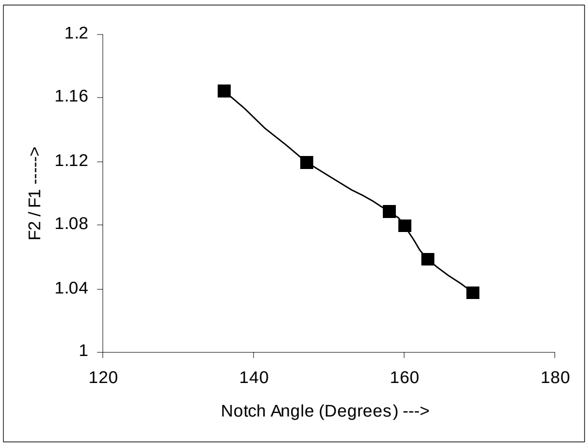


Fig.10(b): Variation of frequency ratio (f_2 / f_1) with variation of notch angle θ_2 keeping θ_1 fixed

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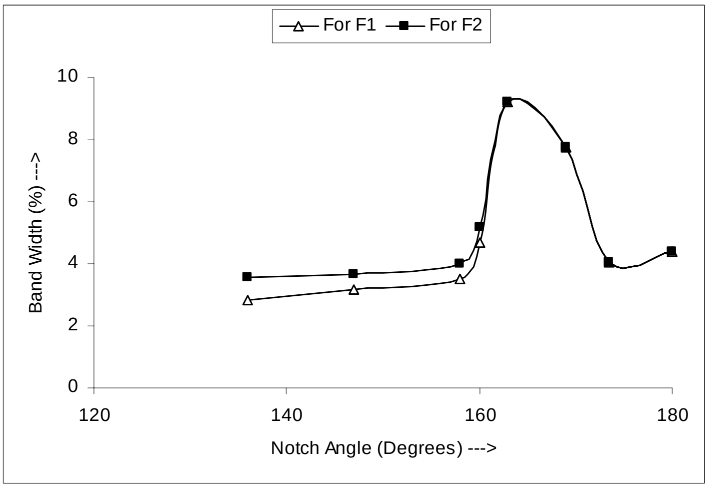

Fig.11: Variation of bandwidth of antenna with variation of notch angle θ_2 keeping θ_1 fixed

In the next step, one notch angle $\theta_1 = 168^o$ is kept constant (the notch angle where we chieved maximum bandwidth) and other notch angle θ_2 is varied from 180^o to 136^o and this time only simulation of each antenna is carried out to estimate the performance of these antennas. Results reveals that on reducing notch angle θ_2 from 180^o to 173.5^o, the antenna continues to resonate at a single frequency. On reducing notch angle θ_2 further, antenna starts resonating at two different frequencies as shown in figure 10(a). The ratio of two resonance frequencies (f_2 / f_1) corresponding to several notch angles are calculated and are shown in as shown in figure 10(b). The obtained variation indicates that this ratio marginally increases with reduction in notch angle θ_2 and approaches to 1.165 when the notch angle approaches to 136^o. This indicates that frequency splitting increases with reduction in notch angle. However an important result shown in figure 12 indicates that maximum bandwidth of antenna of 9.1% may be achieved by making both notch angles equal with θ_1 = θ_2 =168^o.

III. DISCUSSION AND CONCLUSION

Radiation performance of a double notched square patch antenna is presented in this paper. The simulated and measured results indicate that a dual frequency antenna with higher bandwidth may be achieved by cutting two triangular notches in the opposite arms of a square patch antenna. When both notch angles are made equal to 168^o, the optimum bandwidth (9.1%) is achieved with resonance frequencies 3.29 GHz and 3.475 GHz respectively. Both these resonance frequencies lie in the median band (3.25 to 3.85 GHz) allotted by IEEE 802.16 working group for WiMAX systems. The gain of antenna is low (~3dBi) and maximum radiations are normal to the patch antenna geometry. Further work on these antennas is being carried out to enhance the performance further.

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