Analysis of U-slot cut Equilateral Triangular Microstrip Antennas

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ABSTRACT
The broadband microstrip antenna is more commonly realized by cutting the slots at an appropriate position inside the patch. The slot when its length equals either half wave or quarter wave in length then it introduces a mode near the fundamental mode of the patch and yields broader bandwidth. However this simpler approximation of slot length against the TM_{11} mode resonance frequency of the patch and along with fundamental TM_{10} mode yields broadband response. The slot also modifies the surface current directions at TM_{11} mode in both the slot cut configurations and thereby yields broadside radiation pattern over the complete bandwidth. The proposed analysis gives an insight into the functioning of slot cut broadband microstrip antennas.

Keywords
Equilateral triangular microstrip antenna, Half equilateral triangular microstrip antenna, Broadband microstrip antenna, U-slot, Half U-slot, Higher order mode

1. INTRODUCTION
The more commonly used technique to increase the bandwidth (BW) of microstrip antenna (MSA) is by fabricating the slot cut patch on lower dielectric constant thicker substrate in conjunction with the proximity feeding technique [1 – 5]. The slot is said to introduce a mode near the fundamental mode of the patch to realize larger BW whereas the proximity feeding realizes impedance matching for substrate having thickness greater than $0.06\lambda_0$. In most of the reported configurations the patch is suspended in air thereby realizing dielectric constant of unity. The air dielectric helps in realizing maximum radiation efficiency. While designing slot cut MSAs in desired frequency band, the slot length is taken equal to be either half wave or quarter wave in length. However this simpler approximation of slot length against the wavelength does not give accurate results. An analysis to study the effect of slot in broadband MSAs is reported [6, 7]. The resonance curve plots, surface current distributions and radiation pattern plots were studied. It was observed that the slot does not introduce any additional mode but reduces the resonance frequency of higher order mode of the patch and along with the fundamental patch mode yields broadband response. Further the slot modifies the surface current directions at higher order mode of the patch and aligns them in the same direction as that of the currents at fundamental patch mode, which yields in broadside radiation pattern over the complete BW without any variations in the directions of principle planes. In this paper, fundamental and higher order modes of co-axially fed equilateral triangular MSA (ETMSA) and its compact variation half ETMSA (HETMSA) is wavelength does not give closer results. In this paper, a broadband co-axially fed U-slot cut equilateral triangular microstrip antenna and its compact variation, half U-slot cut half equilateral triangular microstrip antenna is discussed. The analysis to study the effects of slot on the broadband response is presented. It was observed that the slot reduces second order

discussed. The broadband U-slot cut ETMSA and half U-slot cut HETMSA is also discussed. To get an insight into the functioning of slot cut antennas, an analysis of U-slot cut ETMSA and half U-slot cut HETMSA for varying slot length is proposed. The resonance curve plot, surface current distribution and radiation pattern plot for different slot lengths were studied. It was observed that the slot does not introduce any mode but reduces the resonance frequency of second order TM_{11} mode of the patch and due to its coupling with fundamental TM_{10} mode, yields broadband response. The radiation pattern at TM_{10} mode is in the broadside direction whereas that at TM_{11} mode it is conical i.e. maximum in the end-fire direction. The slot alters the directions of surface currents at TM_{11} mode and aligns them in the same directions as that of the currents at TM_{10} mode. Thereby U-slot cut ETMSA and half U-slot cut HETMSA yields broadside radiation pattern over the complete BW without any variations in the direction of principle planes. The analysis is carried out using IE3D software [8]. The proposed analysis helps in understanding the functioning of slot cut antennas.

2. BROADBAND SLOT CUT ETMSAs
The co-axially fed ETMSA is shown in Fig. 1(a, b). A substrate thickness of 3.0 cm ($0.093\lambda_0$) is selected for the patch whereas ETMSA side length 'S' is calculated such that it operates in its TM_{10} mode at frequency of around 1000 MHz. The 'S' was found to be 15 cm. The patch is simulated using IE3D software and its resonance curve plot is shown in Fig. 1(d). It shows two peaks due to TM_{10} (980 MHz) and TM_{11} (1556 MHz) modes. The surface current distribution at these two frequencies is shown in Fig. 1(e, f). At TM_{10} mode, currents shows one half wave length variation along patch side length whereas at TM_{11} mode, currents shows one half wavelength variation from the patch centroid point and towards the patch edges. The radiation pattern at TM_{10} mode is in the broadside direction with E and H-planes aligned along $\Phi = 0^0$ and 90^0, respectively. The pattern at TM_{11} mode is conical, i.e. maximum in the end-fire direction as shown in Fig. 1(g). The compact variation of ETMSA, HETMSA is shown in Fig. 1(c). For h = 3.0 cm, the patch is simulated and its resonance curve plot is shown in Fig. 1(d). It shows TM_{10} and TM_{11} mode frequencies at 980 and 1466 MHz, respectively.

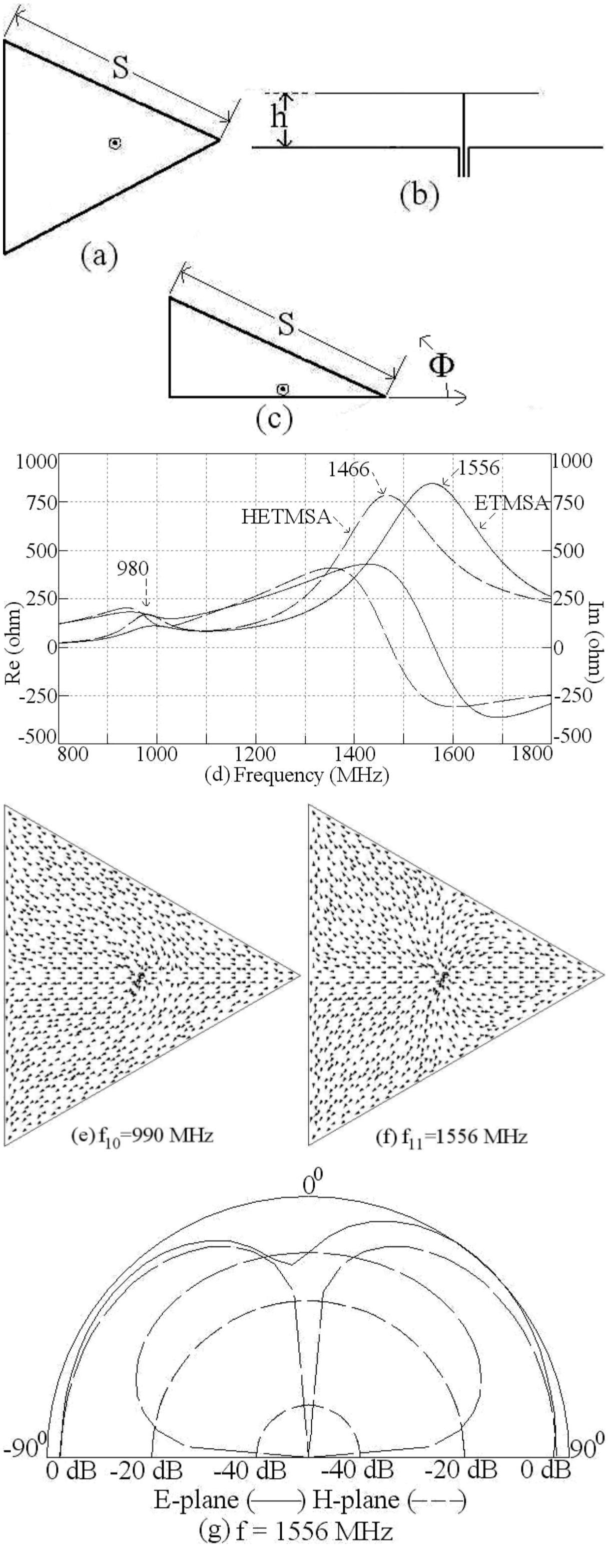

Fig. 1 (a) Top and (b) side views of ETMSA, its (c) resonance curve plots, its (d, e) surface current distribution at dual frequencies and its (f) radiation pattern at TM_{11} mode

With respect to the centroid position of ETMSA, the U-slot is cut as shown in Fig. 2(a). For L_h = 7.0 cm and L_v = 3.0 cm, an optimum broadband response is realized. The BW of 187 MHz at center frequency of 1050 MHz is obtained. The resonance curve plot for the optimum response is shown in Fig. 2(b). The resonance curve shows two peaks at 815 and 1037 MHz. The first peak is due to TM_{10} mode whereas second peak is due to the mode introduced by U-slot. In U-slot cut ETMSA, inner U-slot length nearly equals half the wavelength and it is equal to 15.8 cm in the optimized configuration. By equating this length to half wave length, the calculated frequency is 949 MHz which is smaller than the observed frequency in the resonance curve plot. Similarly the half U-slot HETMSA as shown in Fig. 2(b), is optimized for broader BW and its optimized resonance curve plot is shown in Fig. 2(d). In the optimized configuration, slot dimensions are, L_h = 8.0 cm, and $L_v/2$ = 1.5 cm. The frequency calculated by equating inner half U-slot to quarter wavelength is 842 MHz. The frequency (second peak) observed in the resonance curve is 1080 MHz which is higher than the calculated frequency. Thus in slot cut ETMSA and HETMSA, simpler approximation against wavelength does not give closer result. Hence to get an insight into the functioning of slot cut antenna, an analysis of U-slot and half U-slot cut ETMSAs is carried out as discussed in the following section.

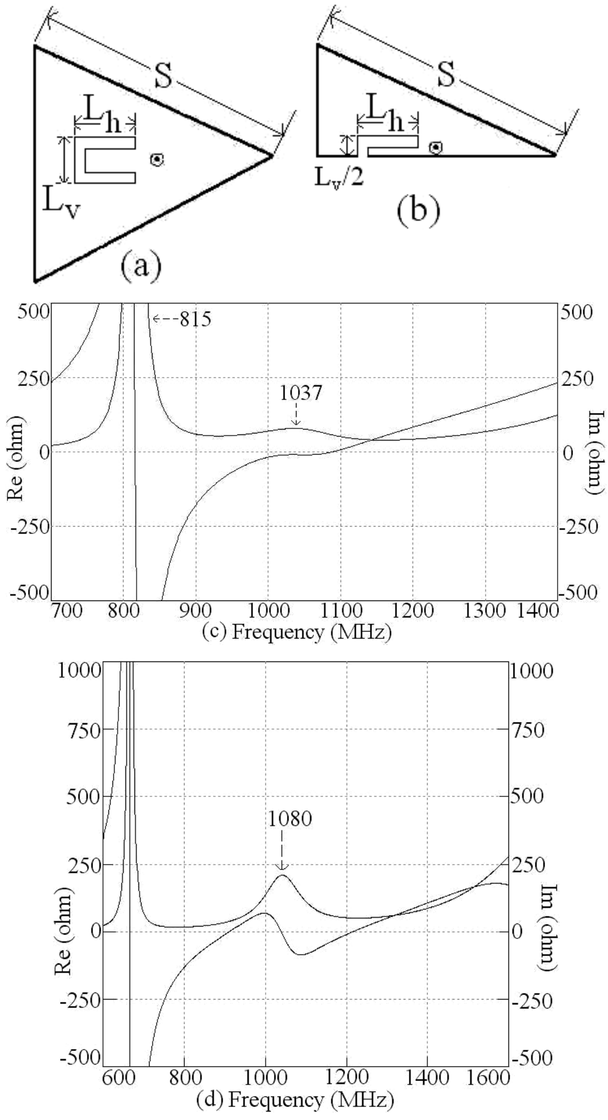

Figure 2 (a) U-slot cut ETMSA, (b) half U-slot cut HETMSA, and optimized resonance curve plot for (c) U-slot cut ETMSA and (d) half U-slot cut HETMSA

3. ANALYSIS OF SLOT CUT ETMSAs

For U-slot cut ETMSA, for L_v = 3.0 cm, the slot length 'L_h' is increased in steps of 1 cm, from 3 to 6 cm and the resonance curve plots for the same are shown in Fig. 3(a, b). The surface currents at TM_{10} mode are nearly parallel to 'L_h', hence the decrease in its frequency is smaller. The surface currents at TM_{11} mode are orthogonal to 'L_h' and hence its frequency reduces. The surface current distribution and the simulated radiation pattern plots for L_h = 3 and 4 cm are shown in Fig. 4(a – d). With an increase in L_h, vertical currents at TM_{11} mode are re-oriented along the horizontal direction inside the patch. Due to this radiation pattern at modified TM_{11} mode changes from conical direction to the broadside direction with E and H-planes aligned along $\Phi = 0^0$ and 90^0, respectively. The broadband response is realized when the loop formed due to the coupling between TM_{10} and modified TM_{11} modes lies inside the VSWR = 2 circle.

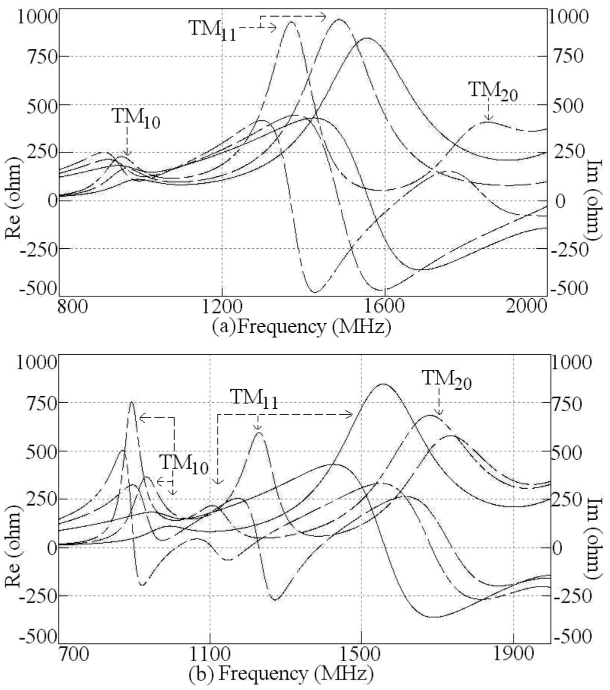

Figure 3 Resonance curve plots for U-slot cut ETMSA for (a) (——) L_h = 0 cm, (— —) L_h = 3 cm, (— - —) L_h = 4 cm and (b) (——) L_h = 0 cm, (— —) L_h = 5 cm, (— - —) L_h = 6 cm

The half U-slot cut ETMSA is realized by using the symmetry of U-slot cut ETMSA across the feed point axis and using half of the configuration as shown in Fig. 2(a, b). The resonance curve plots for variations in half U-slot length are shown in Fig. 5(a, b). With an increase in slot length, TM_{11} mode frequency reduces and it comes closer to the TM_{10} mode frequency. The surface current distributions and simulated radiation pattern plots at TM_{11} mode without the half U-slot and for two different half U-slot lengths are shown in Figs. 5(c, d) and 6(a – d), respectively. The surface current at TM_{11} mode are directed along horizontal and vertical directions inside the patch, therefore the pattern is conical with E-plane aligned along $\Phi = 90^0$. The half U-slot modifies the surface current directions at TM_{11} mode and aligns them in horizontal direction. Thereby it gives broadside radiation pattern with E-plane aligned along $\Phi = 0^0$. The broadband response is realized when the spacing between the two frequencies is optimized to realize loop formed in the impedance locus to lie inside the VSWR = 2 circle.

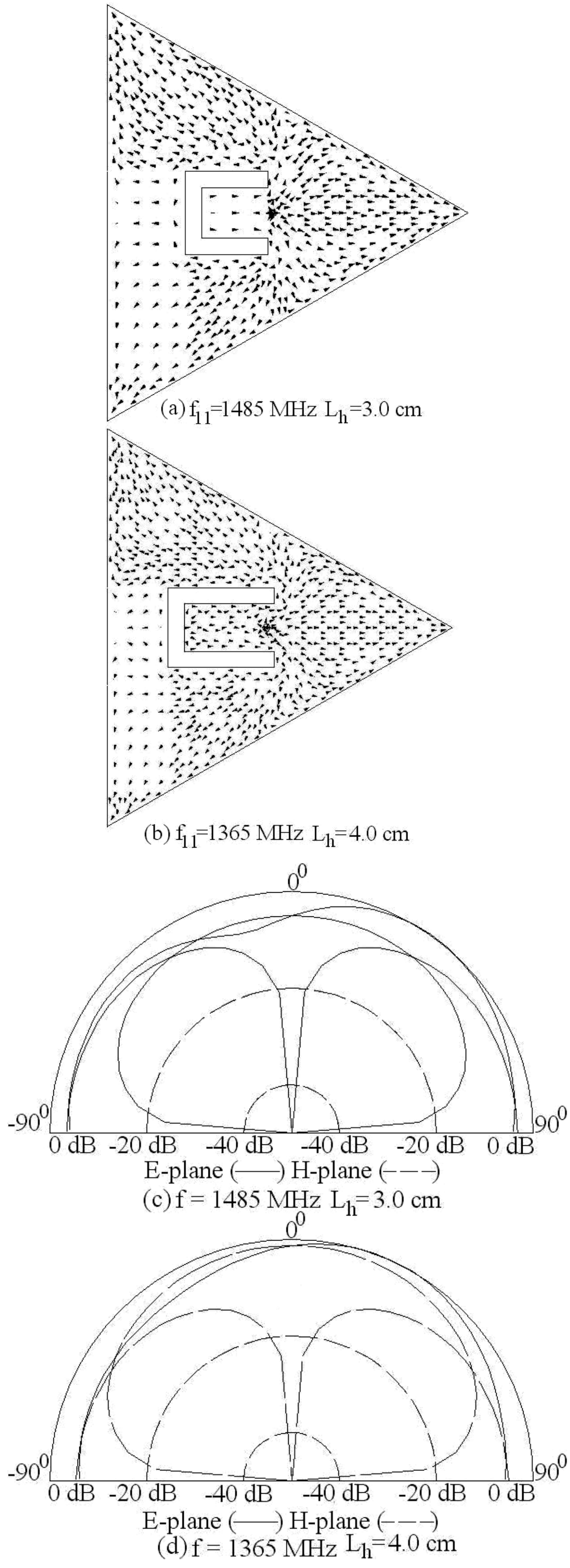

Figure 4 (a, b) Surface current distribution and (c, d) radiation pattern plots for U-slot cut ETMSA at modified TM_{11} mode

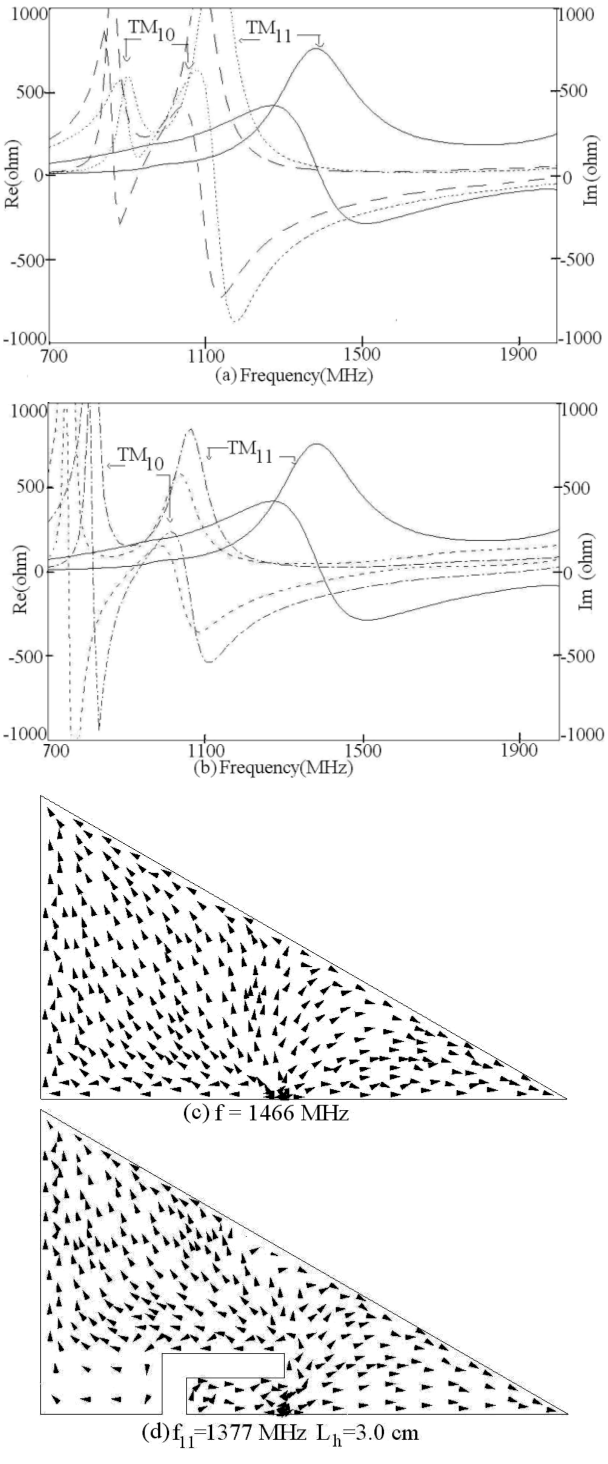

Figure 5 Resonance curve plots for half U-slot cut HETMSA, (a) (—) L_h = 0 cm, (- - -) L_h = 3 cm, (— —) L_h = 4 cm, (b) (—) L_h = 0 cm, (— - —) L_h = 5 cm, (- - -) L_h = 6 cm and (c, d) surface current distribution for two different slot lengths for HETMSA

4. CONCLUSIONS

The broadband half U-slot cut ETMSA and half U-slot cut HETMSA is discussed. The simpler approximation of slot length against the wavelength does not give closer results. Therefore an analysis of U-slot cut ETMSA and half U-slot cut HETMSA is presented. The slot does not introduce any additional mode but it reduces the resonance frequency of higher order TM_{11} mode of the patch and along with the fundamental TM_{10} mode yields broadband response. In both the slot cut configurations, slot alters the surface current directions to realize broadside radiation pattern over the complete BW.

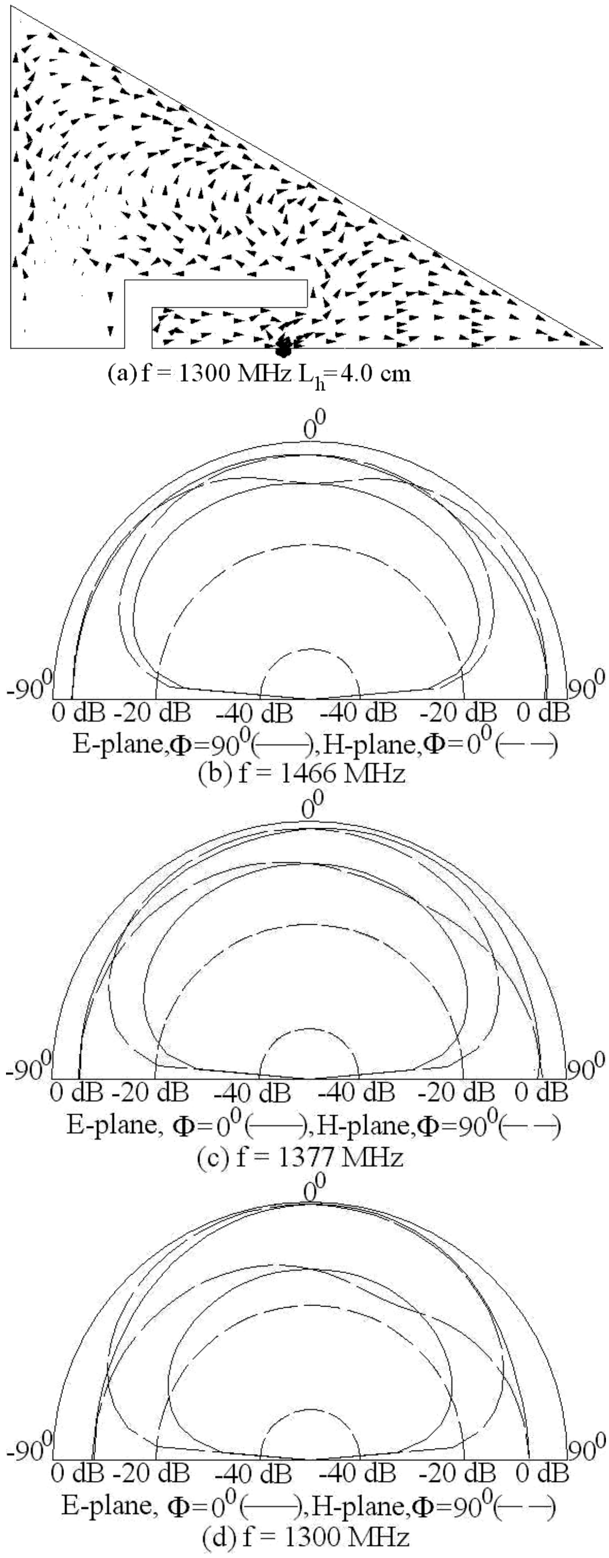

Figure 6 (a) Surface current distribution and radiation pattern for different L_h for half U-slot cut HETMSA, (b) L_h = 0 cm, (c) L_h = 3.0 cm and (d) L_h = 4.0 cm

5. REFERENCES

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