

Broadband Proximity Fed Modified E-Shaped Microstrip Antenna

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Abstract: Commonly used technique to realize broadband microstrip antenna is by cutting the slots at an appropriate position inside the patch. The slot introduces a mode near the fundamental mode of the patch and yields broadband response. The bandwidth of an E-shaped microstrip antenna is further increased by cutting the pair of rectangular slots on one of its edge. This increase in bandwidth is due to another mode introduced by additional pair of slots. In this paper, modal variations, for this modified E-shaped antenna are studied. It has been observed that the slot affects the resonance frequency of higher order mode, which along with modes of E-shaped patch, realize higher bandwidth. Also the broadband proximity fed variation of modified E-shaped antenna in 950 MHz frequency range is proposed. This antenna gives a larger BW of 47% with broadside radiation pattern with a peak gain of approximately 10 dBi.

Key terms: Broadband microstrip antenna, E-shaped microstrip antenna, modified E-shaped microstrip antenna, proximity coupling

I. INTRODUCTION

The microstrip antenna (MSA) has several advantages like low profile planar configuration, however its applications gets restricted because of lower operating bandwidth (BW) [1, 2]. While maintaining the same antenna size, the broader BW is realized by cutting the slots of either half wave or quarter wave in length, having different shapes like, U-slot, V-slot, and pair of rectangular slots inside the patch [3 – 7]. The slot introduces a mode near the fundamental mode of the patch and realizes broadband response. The bandwidth (BW) of rectangular MSA (RMSA) is increased by cutting a pair of rectangular slots on one of the radiating edges, leading to an E-shaped MSA [8]. Further increase in BW of an E-shaped MSA is obtained by cutting additional pair of slots on one of its radiating edge [9]. This configuration is referred as Ψ -shaped MSA [9]. The increase in BW is reported to be because of mode introduced by the additional pair of slots which forms a tuning stub. However, it is not explained that which mode is leading to increase in BW. Also the Ψ -shaped MSA gives a peak gain very close to 10.5 dBi, which reduces to as low as 3.5 dBi towards the higher frequencies of the realized BW where mode due to the tuning stub is present. In this paper, to understand the increase in BW of

Ψ -shaped MSA, the modal variations for the proposed antenna, were studied. It was observed that the additional pair of slots which forms the tuning stub alters the higher order TM_{21} mode resonance frequency of the RMSA and along with the modes of an E-shaped patch, realizes larger BW. The radiation pattern at TM_{21} mode is conical and it affects the radiation pattern of Ψ -shaped MSA towards the higher frequencies of the BW. Therefore, the Ψ -shaped MSA shows higher cross-polar radiation pattern (reduced gain) at those frequencies. Also, the broadband proximity fed design of Ψ -shaped MSA is proposed in the 950 MHz frequency band. The proximity fed antenna gives a measured BW of 524 MHz (47.7%) with a peak gain very close to 10 dBi. The modal variations for Ψ -shaped MSA and the proximity fed Ψ -shaped MSA were analyzed using IE3D software [10]. Further, the experiment was carried out to validate the result for proximity fed MSA. The proximity fed Ψ -shaped MSA is analyzed using the air substrate to realize maximum radiation efficiency.

II. Ψ -SHAPED MICROSTRIP ANTENNA

The Ψ -shaped MSA is shown in Fig. 1(a, b). The dimensions as shown in the figure are in cm. The patch is fabricated on microwave substrate ($\epsilon_r = 2.50$, $h = 0.33$ mm, $\tan \delta = 0.002$) and it is suspended above the ground plane using a foam substrate ($\epsilon_r = 1.06$, $h = 6$ mm, $\tan \delta = 0.0002$). In this configuration, the horizontal pair of slots is cut on one of the edges of the E-shaped MSA. This configuration on infinite ground plane gives a BW from 3820 to 7100 MHz, which is more than the BW of equivalent E-shaped MSA [9]. The radiation pattern is in the broadside direction with a peak gain very close to 10.5 dBi. However, towards the higher frequencies of the BW, gain reduces to less than 4 dBi. The increased BW in Ψ -shaped MSA is attributed to improved control of the current distribution on the patch by removal of the bottom side conductors (horizontal slots), resulting in a tail part [9]. This tail part acts as a tuning stub and introduces a mode near 7000 MHz and increases the BW [9]. However, a clear description of which mode is getting introduced by this stub is not been presented. To study this increased BW, the modal analysis of broadband Ψ -shaped MSA against that of RMSA is presented in the following section.

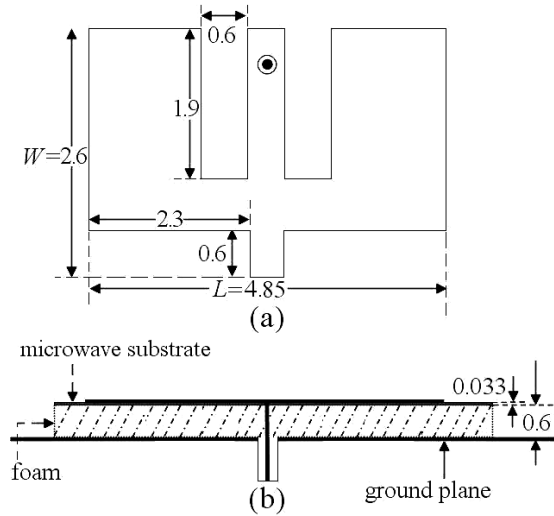


Fig. 1 (a) Top and (b) side views of Ψ -shaped MSA, [9]

III. MODAL ANALYSIS OF Ψ -SHAPED MSA

The MSA BW is increased by fabricating the slot cut MSAs on thicker substrates [3 – 7]. Since h/λ_0 is large for frequencies ≥ 5000 MHz and with respect to the center frequency of realized BW, the reported Ψ -shaped MSA is optimized on thicker substrate of $0.12\lambda_0$, the BW at the individual modes is higher and the overall configuration gives a BW in excess of 55% [1, 2]. The Ψ -shaped MSA is analyzed using IE3D and the simulated input impedance and resonance curve plots are shown in Fig. 2(a, b).

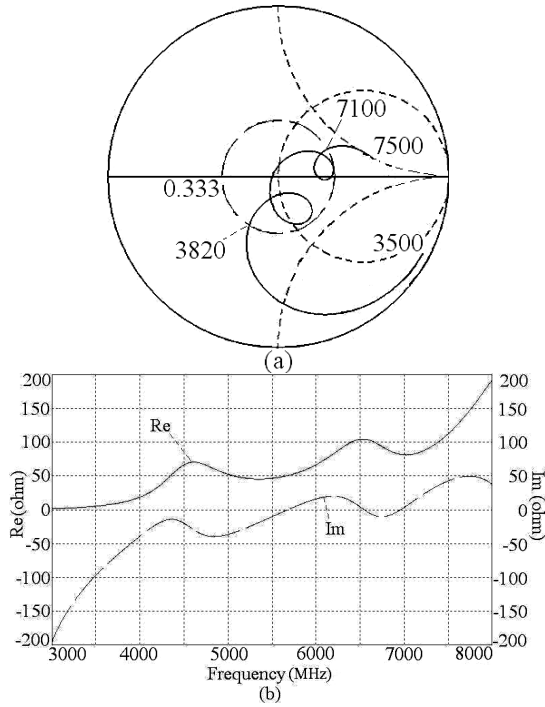


Fig. 2 (a) Input impedance loci and (b) resonance curve plots for Ψ -Shaped MSA

Two loops are observed in the impedance plot which is due to modes of the E-shaped patch and a mode introduced by

the pair slots which forms a tuning stub (tail part). The second loop is formed near a frequency of around 6500 MHz where the second peak in the resonance curve is present. The surface current distributions for Ψ -shaped MSA at three frequencies over the BW are shown in Fig. 3(a – c).

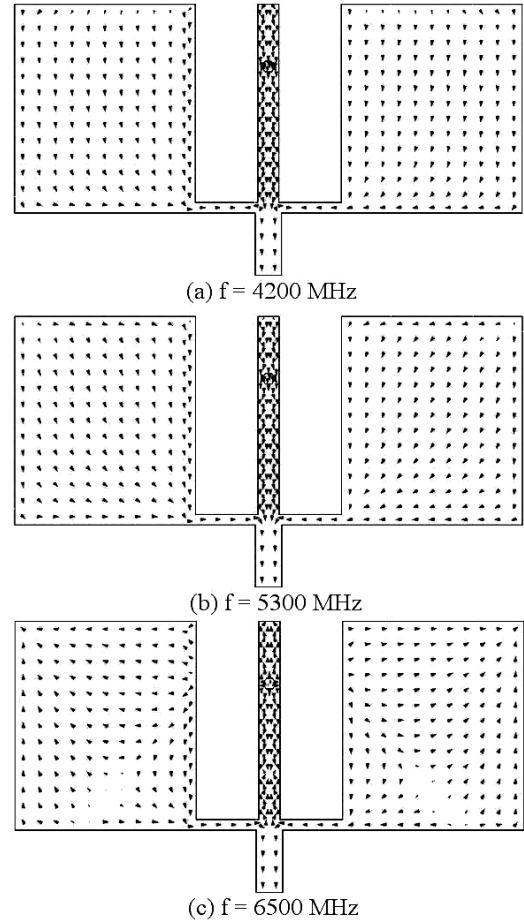


Fig. 3 (a – c) Surface current distribution over BW for Ψ -Shaped MSA

At the first two frequencies the mode distributions is similar to that observed in the E-shaped MSA [8]. The distribution at third frequency (where the second loop is present) is due to the mode introduced by the tuning stub. To understand this additional mode, a modal variations using surface current distributions for RMSA, are studied in the frequency range of 6 to 8 GHz. Further, they are compared with the current distribution at the third frequency of Ψ -shaped MSA. The equivalent RMSA dimensions in the proposed Ψ -shaped MSA are, $L = 4.85$ cm and $W = 2.6$ cm. The resonance frequency (f_{mn}) of RMSA for TM_{mn} mode is calculated by using (1).

$$f_{mn} = \frac{1}{2\sqrt{\epsilon_{re}}} \sqrt{\left(\frac{m}{L_e}\right)^2 + \left(\frac{n}{W_e}\right)^2} \quad (1)$$

Where, L_e and W_e are the effective patch dimensions after accounting for the fringing field lengths [1]. Various resonant mode frequencies of RMSA in the frequency range

of 2000 to 8000 MHz calculated using (1) are, $TM_{10} = 2497$ MHz, $TM_{01} = 4124$ MHz, $TM_{20} = 4994$ MHz, $TM_{02} = 8248$ MHz, $TM_{21} = 6476$ MHz, $TM_{12} = 8620$ MHz, and $TM_{30} = 7491$ MHz. For this RMSA, with reference to the feed point location as shown in Fig. 1(a), the L/W ratio is higher (1.865). Although this realizes higher gain but also leads to the closely spaced orthogonal higher order mode resonance frequencies. The RMSA was simulated using IE3D and its resonance curve plot is shown in Fig. 4(a). The surface current distributions at the TM_{21} and TM_{30} modes are shown in Fig. 4(b, c).

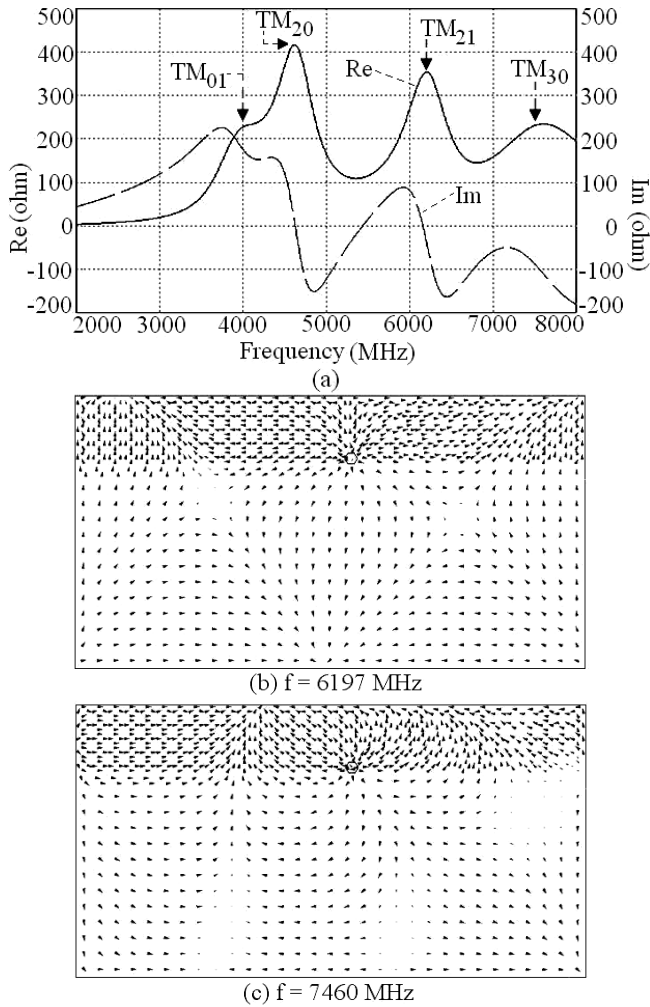


Fig. 4 (a) Resonance curve plot for RMSA and its current distribution at (b) TM_{21} and (c) TM_{30} modes

Since the RMSA is fed along the line joining the center of the patch and center of its length, it does not excite TM_{10} mode. The first peak in the resonance curve is due to the TM_{01} mode at frequency of nearly equal to 4000 MHz. The next three peaks correspond to the TM_{20} , TM_{21} and TM_{30} modes at 4642, 6197 and 7460 MHz, respectively. These frequencies are close to the frequencies obtained using (1). At TM_{21} mode, the surface current shows two half wavelengths variations along patch length and one half wavelength variations along patch width. At TM_{30} mode,

currents show three half wavelength variations along the patch length. The pair of slots is cut inside this RMSA to realize the E-shaped MSA as shown in Fig. 5(a, b). In the reported configuration, the spacing between the pair of slots is 0.25 cm ($0.05\lambda_0$). With respect to the current distribution of TM_{21} mode, these slots are placed near the current minima and therefore they do not reduce the TM_{21} frequency. However since the effective patch dimensions are altered (L_e and W_e) the TM_{21} mode frequency increases to 6600 MHz. The surface current distribution at that mode is shown in Fig. 6. To realize Ψ -shaped MSA, an additional pair of slots are cut inside this patch, as shown in Fig. 5(c).

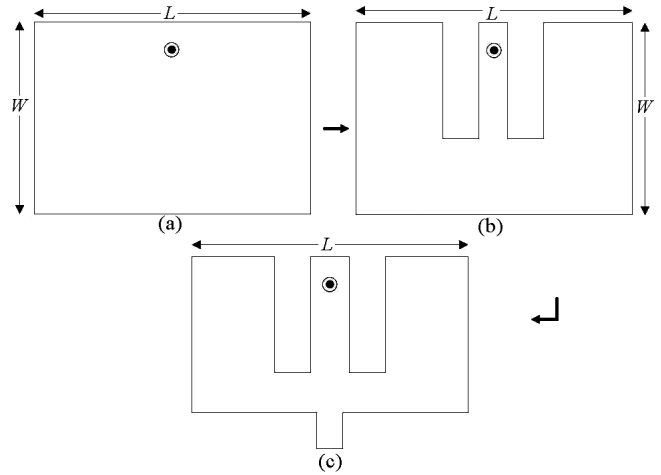


Fig. 5 (a) RMSA, (b) E-shaped MSA and (c) Ψ -shaped MSA

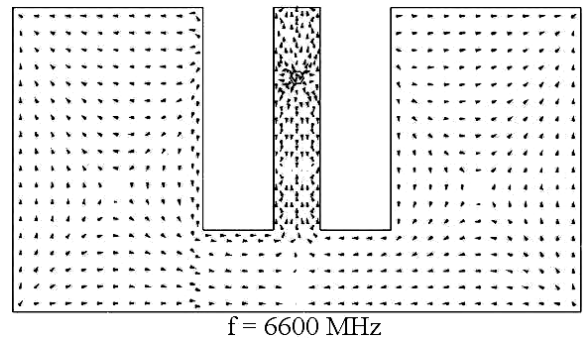


Fig. 6 Surface current distribution for E-shaped MSA at TM_{21} mode

The additional pair of slots forces the surface currents to flow along the slot length which reduces the TM_{21} mode resonance frequency from 6600 MHz to 6500 MHz as observed from the resonance curve plots of RMSA and Ψ -shaped MSA. Also the surface current distributions at the third frequency in Ψ -shaped MSA is similar to the current distributions of TM_{21} mode of RMSA and E-shaped MSA. Thus the additional pair of slot cut inside the E-shaped patch (which forms the tail part) affects the resonance frequency of TM_{21} mode. The increase in BW for Ψ -shaped MSA is realized due to the coupling between E-shaped patch modes with the modified TM_{21} frequency. The radiation pattern at TM_{21} mode in RMSA is shown in Fig. 7. The radiation

pattern is conical with higher cross-polarization levels. In Ψ -Shaped MSA, since the modified TM_{21} mode is dominant towards the higher frequencies of BW, the pattern at frequencies above 6500 MHz, shows a higher cross polarization levels which leads to the decrease in gain to as low as 3 dBi [9].

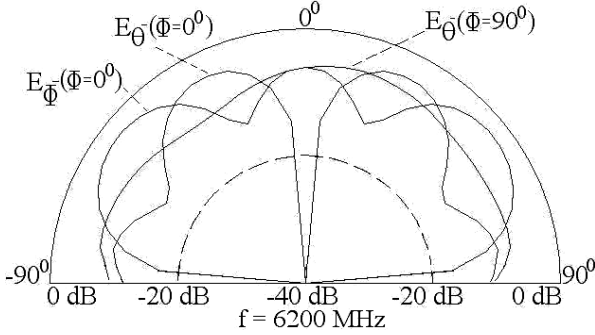


Fig. 7 Radiation pattern at TM_{21} mode for RMSA

Thus, the increased BW in Ψ -shaped MSA is attributed to thicker substrate, larger L/W ratio, larger BW at individual modes at higher frequencies and the tuning of higher order mode resonance frequency by the additional pair of slots. However, the above design is proposed on thicker substrate of $0.12\lambda_0$. This configuration can be optimized on lower substrates by using the proximity feeding technique which also adds to the BW.

III. PROXIMITY FED Ψ -SHAPED MSA

The proximity fed Ψ -shaped MSA is shown in Fig. 8(a, b). The MSA is designed using the air substrate at center frequency of around 950 MHz with the total substrate thickness of 3.0 cm ($0.095\lambda_0$). The coupling strip is placed below the patch as shown in the figure. The strip is fed using the N-type connector of 0.3 cm wire diameter. The foam spacers placed towards the antenna corners were used to support the patch. The dimensions of the equivalent RMSA in the proximity fed Ψ -shaped MSA are $W = 13.0$ and $L = 24.0$ cm. These dimensions are chosen such that a higher L/W ratio is realized. The given coupling strip position is optimized to excites TM_{01} (855 MHz), TM_{20} (1048 MHz) and TM_{21} (1372 MHz) modes of RMSA, as shown in the resonance curve plot in Fig. 8(c).

The pair of rectangular slots was cut inside this RMSA to first realize the E-shaped patch. The optimized E-shaped MSA yields simulated BW of 286 MHz (31.8%) as shown in Fig. 9. The input impedance plot for E-shaped MSA also shows a formation of another loop at higher frequency due to the excitation of TM_{21} mode. The separation between the pair of rectangular slots to realize E-shaped patch is larger ($0.19\lambda_0$). Also, these slots are placed towards the maximum current location in TM_{21} mode which has reduced the frequency from 1372 to 1280 MHz. To realize the higher BW, the position of the second loop is optimized inside the

VSWR = 2 circle, by varying the width of the additional pair of slots (w) as shown in Fig. 8(a). The optimized input impedance and VSWR plots are shown in Fig. 10.

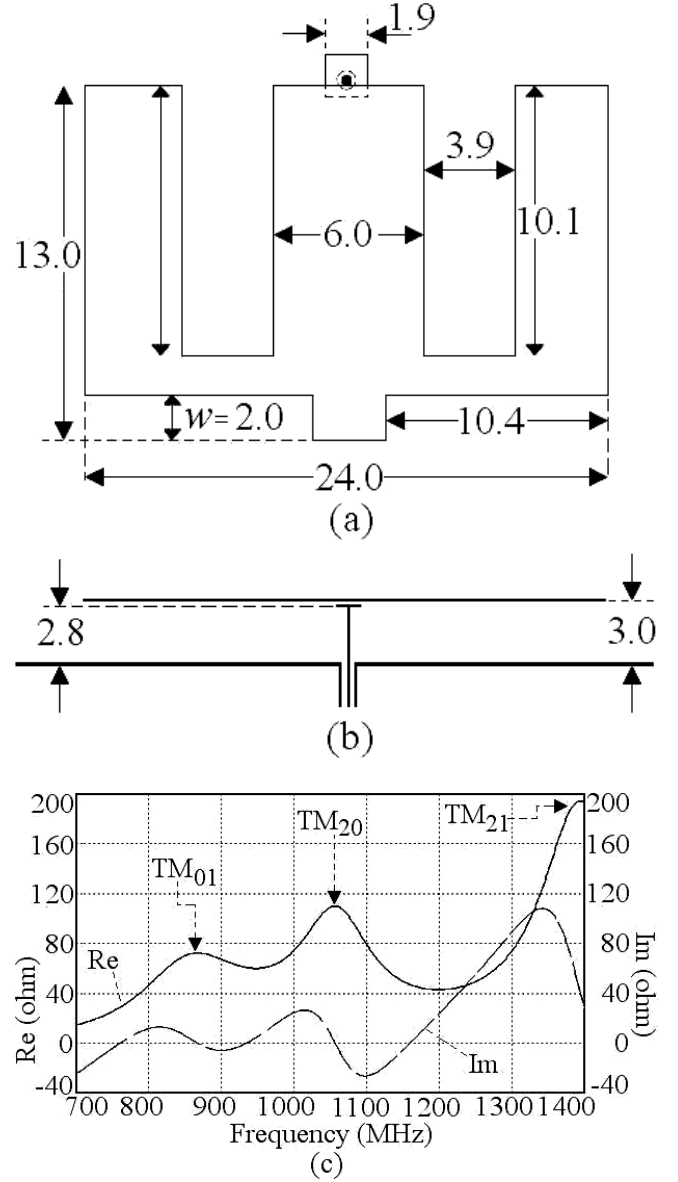


Fig. 8 (a) Top and (b) side views of proximity fed Ψ -shaped MSA and (c) resonance curve plot for RMSA of dimension 24 x 13 cm

The simulated BW is 517 MHz (47.5%), whereas the measured BW is 524 MHz (47.7%). The impedance and VSWR plots were measured using HP vector Network analyzer with ground plane size of 60 x 60 cm. The radiation pattern in the far field distance is measured over the VSWR BW. The pattern at the center frequency of 1110 MHz is shown in Fig. 11.

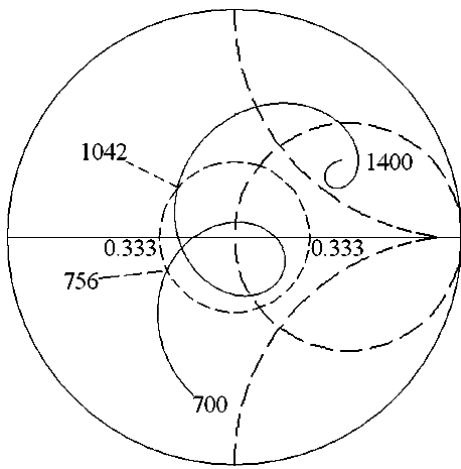


Fig. 9 Simulated input impedance plot for E-shaped MSA

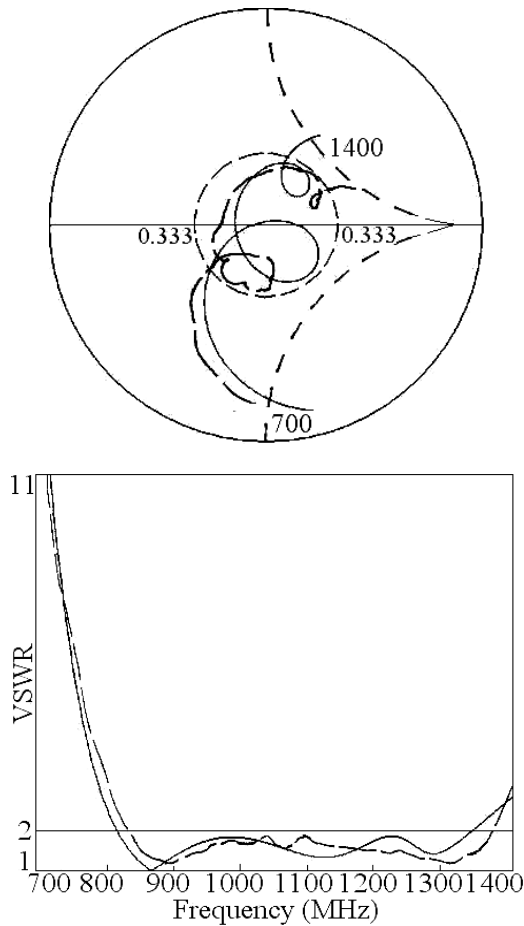


Fig. 10 Input impedance and VSWR plots for Ψ -shaped MSA, (—) Simulated, (---) Measured

The radiation pattern is in the broadside direction with cross polarization levels less than 15 dB as compared to the co-polar levels. The gain over the BW is more than 8 dBi with peak gain nearly equal to 10 dBi. Since the cross polar levels increases towards the higher frequencies of BW, at those frequencies the gain reduces to 7.8 dBi.

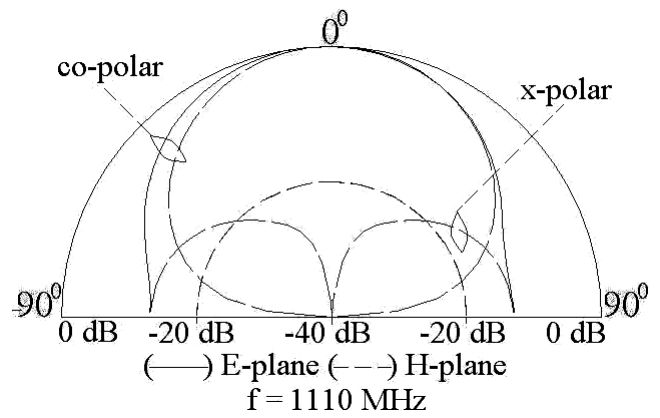


Fig. 11 Measured radiation pattern at center frequency for Ψ -shaped MSA

IV. CONCLUSIONS

The Ψ -shaped MSA is realized by cutting the additional pair of slots inside the E-shaped MSA and it gives larger BW. The modal analysis for broadband Ψ -shaped MSA is presented. It was observed the additional pair of slots do not introduce any mode but affects the resonance frequency of higher order TM_{21} mode and realizes higher BW. The broadband proximity fed Ψ -shaped MSA at 950 MHz frequency band has been proposed. This configuration is optimized with substrate with lesser thickness. The proposed proximity fed MSA gives BW of more than 500MHz ($\geq 45\%$) with broadside radiation pattern and peak gain of 10 dBi. Since the proposed configuration is optimized at lower frequency band, it has lesser % BW as compared to reported Ψ -shaped MSA.

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