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BROADBAND SHORTED SECTORAL MICROSTRIP ANTENNA

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Abstract—The broadband microstrip antenna is realized by cutting the slot inside the patch. The slot introduces a resonant mode near the fundamental resonance frequency of the antenna and realizes broadband response. The compact variations of circular microstrip antenna are realized by placing the shorting posts along the zero field line at the fundamental mode. These shorted antennas have narrower bandwidth. In this paper, a compact half U-slot cut shorted sectoral microstrip antenna is proposed. The detailed analysis has been carried out to study the effect of the slot on various modes of the sectoral patch. It has been observed that the half U-slot does not introduce any additional mode, but reduces the resonance frequency of the higher order mode of the shorted sectoral patch and along with its fundamental mode realizes broader bandwidth. The bandwidth of more than 700 MHz, at the center frequency of approximately 2700 MHz, has been realized.

1. INTRODUCTION

The broadband microstrip antenna (MSA) is realized by cutting U-slot, V-slot and a pair of rectangular slots inside the patch [1–8]. It is assumed that the slot introduces an additional mode near the fundamental mode of the MSA (i.e., TM_{10} for rectangular MSA, TM_{11} for circular MSA and TM_{10} for equilateral triangular MSA) and thus realizes broadband response. While designing these slot cut MSAs

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for a given frequency range, the slot length is taken to be nearly half wavelength when cutting inside the patch or quarter wavelength when cutting on the edges of the patch. However, it was observed that the surface currents encircle over a finite length towards the shorted end of the slot, which adds to the additional length [9]. Thus, after adding this correction length, the slot length for the required frequency is calculated. This correction length was found to be 10% of the slot length [9]. By using the symmetry of slot cut MSAs across the feed point axis, a compact and broadband MSAs by cutting a half U-slot, half V-slot or a single slot has been realized [8, 10–12]. These compact MSAs realize 50% reduction in the patch size with nearly the same BW. When the loop formed (due to the coupling between patch mode and mode introduced by the slot) in the input impedance locus is larger (i.e., it does not lie inside VSWR = 2 circle), then a dual band response is realized using these slot cut MSAs [13–16]. While designing these dual and broad band MSAs for a given frequency band, simpler half and quarter wavelength approximations of slot length do not give closer results for various slot lengths and different slot positions inside the patch. Also, a formulation of resonant length in U-slot or half U-slot cut MSAs is not reported [17]. The frequency response in dual band U-slot and pair of rectangular slots cut inside the circular MSA (CMSA), for different slot dimensions, was studied over wide frequency range. It was observed that neither U-slot nor rectangular slots introduce any additional mode, but they reduce the higher order TM_{21} mode resonance frequency of the circular patch and thus, along with fundamental TM_{11} mode, realizes dual band response [18]. The resonant length formulation for slot mode frequency (modified TM_{21} mode) has been proposed [18].

The 90° sectoral MSA is a compact variation of CMSA and is realized by placing the shorting plate along the zero field line of CMSA at its fundamental TM_{11} mode [19]. In this paper, a broadband half U-slot cut 90° sectoral MSA is proposed. The surface current distributions at various resonant modes of the half U-slot cut 90° sectoral MSA over large frequency range have been studied. It is observed that the half U-slot does not introduce any mode but reduces the higher order TM_{31} mode resonance frequency of the shorted sectoral MSA. This mode with reduced resonance frequency, along with the fundamental TM_{11} mode, yields broadband response. This sectoral MSA gives a bandwidth (BW) of more than 700 MHz ($> 25\%$) at around 2700 MHz. The radiation pattern at shorted TM_{31} mode in sectoral MSA shows higher cross-polarization levels. Also, it shows variation in the directions of E and H-planes as compared to the radiation pattern at shorted TM_{11} mode. However, since the half U-

slot alters s of the principle planes. To optimize for the gain and to realize larger BW, the sectoral MSA is analyzed using the air substrate having substrate thickness of $\leq 1.2\,\text{cm}$ ($0.1\lambda_0$). In the present configuration, substrate thickness of 0.8 cm is used. The antenna is fed using the SMA panel type connector having inner wire diameter of 0.12 cm. The sectoral MSA was first analyzed using IE3D software followed by experimental verification [20]. The measurements were carried out using HP vector network analyzer. To realize the effect of infinite ground plane, in the measurements a larger ground plane size of $30 \times 30\,\text{cm}$ is taken. Further, the antenna response is also validated on smaller ground plane of size $10 \times 10\,\text{cm}$, which could be used in its practical applications. The radiation patterns were measured in minimum reflection surroundings with the required minimum distance between the reference antenna and the antenna under test [21].

2. FUNDAMENTAL AND HIGHER ORDER MODES OF CMSA

The resonance frequency of the CMSA is given by Equation (1) [19].

$$f_{nm} = K_{nm}c/2\pi r_e(\varepsilon_r)^{1/2} \tag{1}$$

where, f_{nm} = resonance frequency of TM_{nm} mode, c = velocity of light = 3×10^8 (m/s), K_{nm} is the mth zero of the derivative of the Bessel function of nth order, which is = 1.84118 (TM_{11}), 3.05424 (TM_{21}), 3.83171 (TM_{02}), 4.20119 (TM_{31}), 5.317 (TM_{41}), 5.3314 (TM_{12}), r_e = effective radius of the patch after accounting for the fringing fields around the periphery of the patch.

For CMSA with patch radius (r) equal to 3.2 cm and with substrate thickness (h) of 0.8 cm, as shown in Figs. 1(a), (b), the resonance frequencies of various modes calculated using Eq. (1) are f_{TM11} = 2345 MHz, f_{TM21} = 3892 MHz, f_{TM02} = 4882 MHz, f_{TM31} = 5353 MHz and f_{TM41} = 6345 MHz. This CMSA has been simulated using IE3D software, and the resonance curve for the same is shown in Fig. 1(c). The first peak, in the resonance curve, corresponds to TM_{11} mode at frequency of 2224 MHz. In this mode, the patch surface currents and the peripheral voltage distribution show one half wavelength variations along the patch diameter and a wavelength variation around the perimeter of patch, as shown in Fig. 1(d). The second peak corresponds to TM_{21} mode (3758 MHz) at which peripheral voltage shows two wavelength variations around the perimeter of the CMSA and one half wavelength variations along its diameter as shown in Fig. 1(e). The third peak corresponds to TM_{31} mode (5331 MHz) at which the peripheral voltage shows

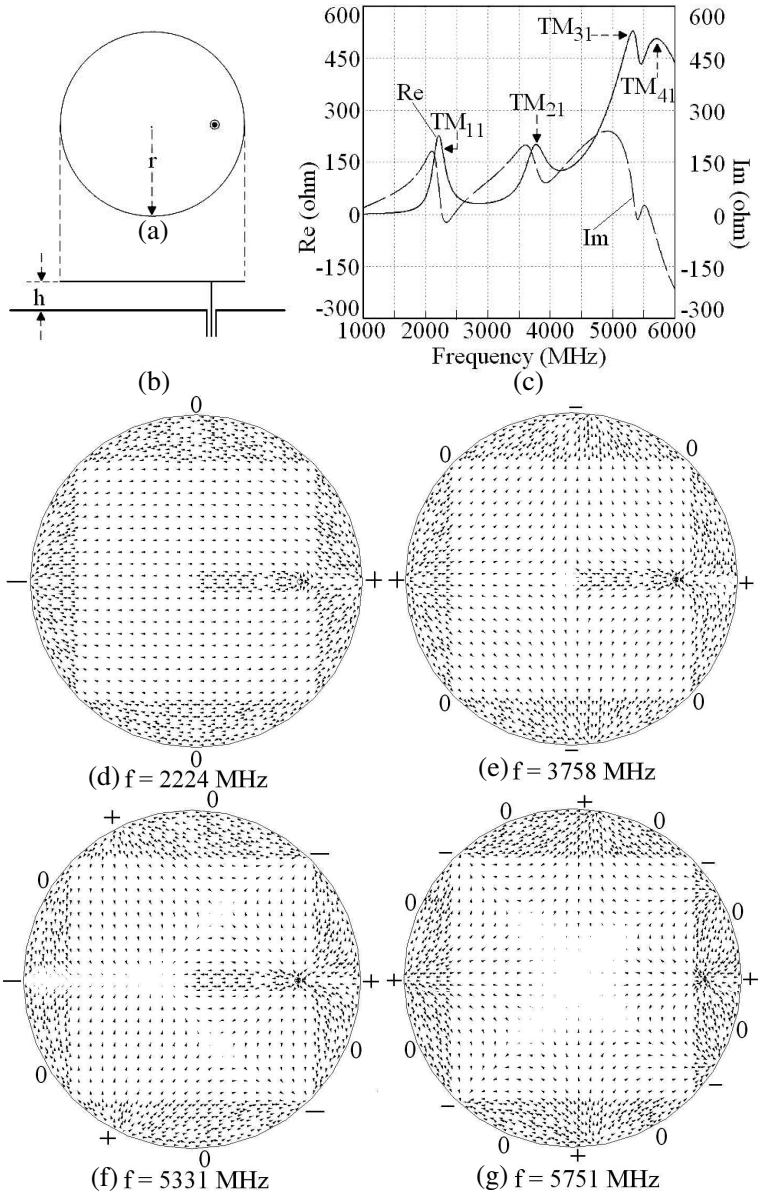

Figure 1. (a) Top and (b) side views of CMSA and its (c) simulated resonance curve plot and its surface current and voltage distributions at (d) TM_{11}, (e) TM_{21}, (f) TM_{31}, (g) TM_{41} modes.

three wavelength variations along the perimeter of the patch and one half wavelength variations along its diameter as shown in Fig. 1(f). The last peak corresponds to TM_{41} mode (5751 MHz). At this frequency, peripheral voltage shows four wavelength variations around the perimeter of the CMSA and one half wavelength variations along its diameter as shown in Fig. 1(g).

The CMSA in its TM_{11} mode has the simulated BW of 234 MHz (8.9%). The compact shorted plate 90° sectoral MSA is realized by placing the shorting plate along the zero field line of TM_{11} mode and further by using only half of the patch as shown in Figs. 2(a), (b). This compact MSA realizes 75% reduction in the patch area with nearly the same resonance frequency [19]. The resonance curve plot for shorted sectoral MSA is shown in Fig. 2(c). The first peak corresponds to TM_{11} mode at 1960 MHz. Since the CMSA is shorted in the center, in shorted sectoral MSA, the TM_{21} and TM_{02} modes do not get excited as they have maximum field in the center of the patch. The TM_{31} mode has zero fields in the center of the patch and hence along with TM_{11} mode, the TM_{31} mode (4560 MHz) is present in shorted sectoral MSA as seen in its resonance curve plot. The surface current and voltage distribution plots at shorted TM_{11} and TM_{31} modes are shown in Figs. 2(d), (e). To increase the BW of shorted 90° sectoral MSA, a half U-slot is cut inside the patch as discussed in the following section.

3. BROADBAND 90° SECTORAL HALF U-SLOT CUT MSA

A half U-slot cut shorted 90° sectoral MSA is shown in Fig. 3(a). To optimize for broader BW a parametric study by varying half U-slot dimensions were carried out. The resonance curve plots for varying half U-slot lengths (L_h and L_v) are shown in Figs. 3(b), (c). Initially L_h is increased as shown in Fig. 3(b). The L_h is orthogonal to the surface currents at TM_{31} mode whereas it is parallel to surface currents at TM_{11} mode. Hence the TM_{31} frequency reduces and TM_{11} frequency remains almost unchanged. Further when both L_h and L_v are increased then TM_{31} as well as TM_{11} frequency reduces. The length L_v is orthogonal to surface currents at TM_{11} mode and therefore its frequency reduces. Thus with increase in the slot length the TM_{31} frequency comes closer to TM_{11} frequency and the broadband response is realized when the loop, which gets formed because of the mutual coupling between these two modes, lies inside the VSWR = 2 circle. To realize this, L_v and L_h are optimized. In the optimized configuration, L_h and L_v are 2.4 and 1.0 cm, respectively. The input impedance and VSWR plots are shown in Fig. 4(a). The simulated BW is 740 MHz

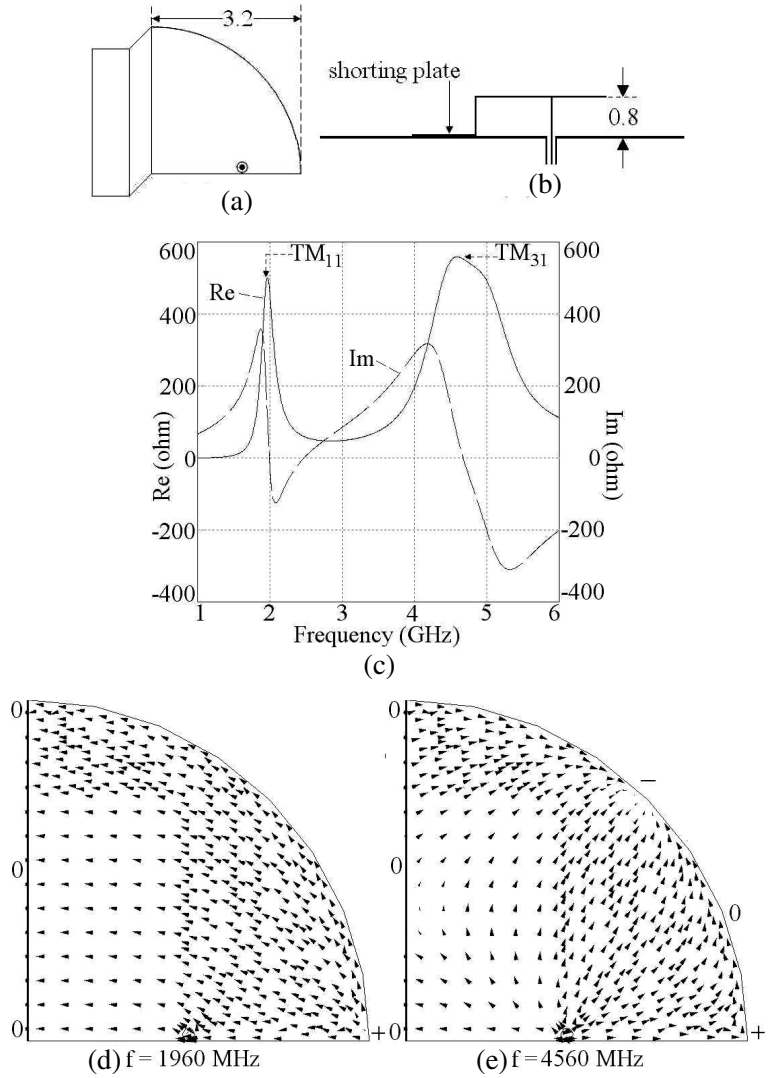

Figure 2. (a) Top and (b) side views of shorted plate 90° sectoral MSA, its (c) resonance curve plot and its surface current distributions at shorted (d) TM_{11} and (e) TM_{31} modes.

(28%). The broadband response has been experimentally verified. The measured BW is 768 MHz (29%). The variation in the measured and simulated results is due to the experimental errors. The picture of the fabricated prototype is shown in Fig. 4(b).

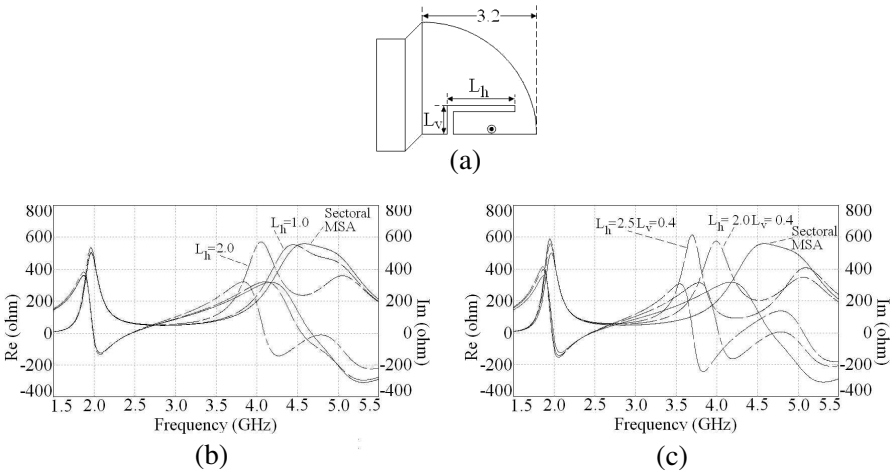

Figure 3. (a) Half U-slot cut shorted plate 90° sectoral MSA and its (b), (c) resonance curve plots for different U-slot lengths.

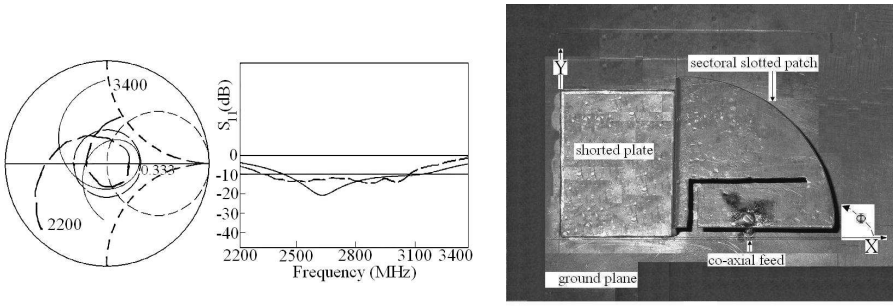

Figure 4. (a) Input impedance and return loss plots (—) simulated, (– – –) measured and (b) photograph of fabricated prototype of half U-slot cut 90^0 sectoral MSA.

The simulated surface current distribution over the BW is shown in Figs. 5(a)–(c). At the lower frequency end of the BW, shorted TM_{11} mode is dominant whereas towards the higher frequencies end of the BW, the shorted TM_{31} mode is dominant. This distribution is similar to that of TM_{31} mode distribution as shown in Fig. 2(e). The radiation pattern and measured gain over the BW are shown in Figs. 6(a)–(d). The E and H-planes are aligned along $\Phi = 0°$ and 90°, respectively over the entire BW. Due to the shorted patch and electrically thicker air substrate, the radiation pattern shows maximum radiation towards

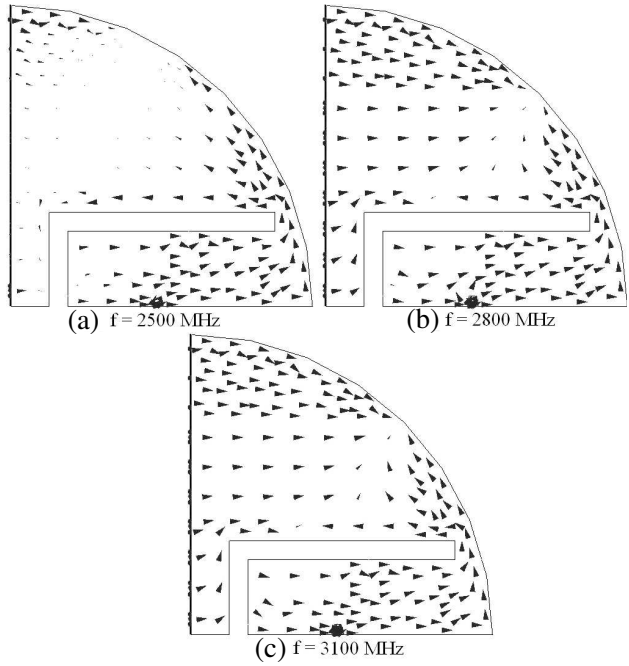

Figure 5. (a)–(c) Surface current distributions at three frequencies over the BW for half U-slot cut 90° sectoral MSA.

+90° and −90° directions with a broadside level at 3 dB down. The cross-polarization levels are less than 7 dB as compared to the co-polar levels. As the TM_{31} mode is dominant at the higher frequencies end of the BW, a higher cross-polarization level is present. In the entire BW range, due to the air substrate, the radiation efficiency is greater than 95%. The antenna gain is more than 4 dBi over the entire VSWR BW with a peak gain of nearly 6.8 dBi towards the higher frequencies end of the BW. The radiation patterns were measured using larger ground plane size, thus they do not show any back lobe radiation. The measurement was also carried out using 10×10 cm ground plane size. This reduced ground plane showed back lobe radiation 7 dB down as compared to the main lobe radiation with similar input impedance characteristics.

For the substrate thickness of 0.8 cm, the simulated BW of the CMSA is 234 MHz (8.9%) whereas the U-slot cut CMSA has the simulated BW of 464 MHz (19.7%). The shorted plate 90° sectoral MSA gives the simulated BW of 359 MHz (14.2%). Thus the proposed compact configuration gives more BW as compared to the conventional CMSA, U-slot cut CMSA and the shorted plate 90° sectoral suspended

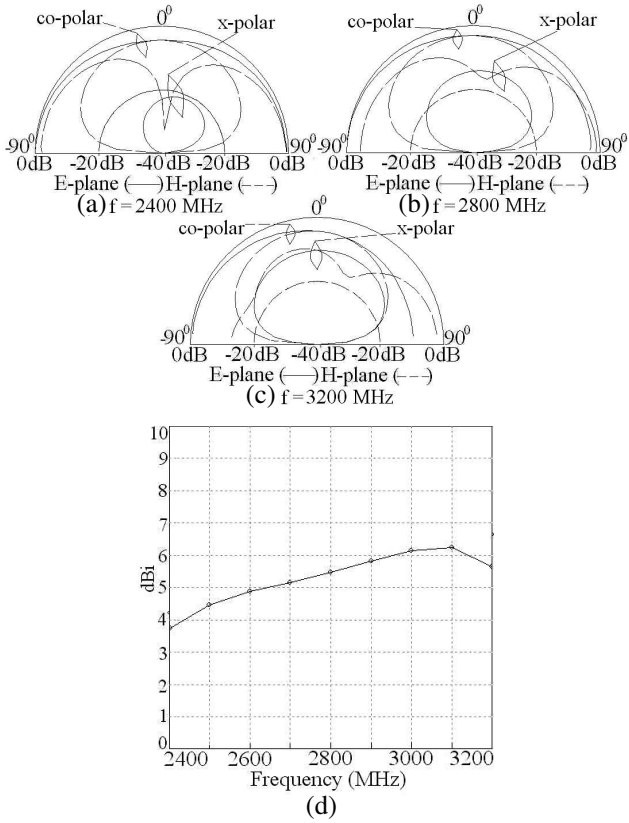

Figure 6. (a)–(c) Radiation patterns at three frequencies and (d) gain variation over BW for half U-slot cut 90° sectoral MSA.

MSA. The larger BW is due to the use of electrically thicker substrate, a shorting plate and a half U-slot which controls the TM_{31} mode frequency with respect to TM_{11} mode frequency. Although, the cross-polarization levels are higher, they are useful in applications of multi-path propagation environment wherein, these compact antennas will lead to smaller signal loss.

4. CONCLUSION

The voltage and current distributions at higher order modes in CMSA are discussed. In its compact shorted 90° sectoral MSA, the TM_{11} and TM_{31} modes are present. A broadband 90° sectoral half U-slot cut MSA is proposed. The frequency response over the wide

frequency range for varying half U-slot dimensions has been studied. It is observed that the half U-slot does not introduce any mode but alters the higher order TM_{31} mode resonance frequency of the patch. This modified higher order mode, along with the fundamental TM_{11} mode, yields broader BW. The proposed 90° sectoral half U-slot cut MSA gives the BW of more 700 MHz at around 2700 MHz. The half U-slot alters the directions of surface currents on the patch at TM_{31} mode and hence the radiation pattern shows no variation in the direction of principle planes over the BW. This antenna gives 75% reduction in the size of the patch with nearly four times the BW as compared to the CMSA and more than 1.5 times the BW as compared to that of the U-slot cut CMSA. A good agreement is obtained between the measured and simulated input impedance plots, gains and the radiation patterns.

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