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Analysis of Broadband Proximity Fed Gap-coupled C-shaped Microstrip Antennas

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Abstract: **The compact C-shaped microstrip antenna derived from rectangular microstrip antenna has been mainly analyzed at its fundamental mode. In this paper, fundamental and higher order modes of proximity fed C-shaped microstrip antennas are discussed. The broadband proximity fed C-shaped microstrip antenna is proposed. At its fundamental mode, it yields bandwidth of more than 230 MHz (> 23%) with broadside radiation pattern and peak gain of more than 7 dBi. Further increase in its bandwidth is realized by cutting rectangular slot on the edges of the patch. The slot reduces TM_{01} mode frequency of C-shaped patch and along with its TM_{10} mode, yields bandwidth of more than 260 MHz (> 28%). To increase the gain, gap-coupled configuration of two C-shaped microstrip antennas is proposed. This gives bandwidth of more than 300 MHz with peak gain of 7.7 dBi. Further to enhance the bandwidth, gap-coupled configuration of two rectangular slot cut C-shaped microstrip antennas is proposed. The slot reduces TM_{01} mode frequency on each of the C-shaped patches and along with TM_{10} modes, yields bandwidth of more than 400 MHz (~40%) with broadside radiation pattern and peak gain of more than 8 dBi.**

Index Terms: **C-shaped Microstrip Antenna, Compact Microstrip Antenna, Broadband Microstrip Antenna, Rectangular slot, Higher order mode, Proximity feeding**

I. INTRODUCTION

The simplest method to realize broadband microstrip antenna (MSA) is by fabricating the patch on thicker air substrate (h) [1 – 3]. Using thicker substrates (h > $0.06\lambda_0$) an impedance matching to realize broader BW, is obtained by using simpler proximity feeding technique [4, 5]. More frequently broadband MSA is realized by cutting the slot at an appropriate position inside the patch [5 – 9]. Further increase in the BW of slot cut MSA is realized by cutting an additional slot inside the patch [10, 11]. The compact MSA is realized by placing the shorting post/plate or by cutting the slot inside the patch [1 – 3]. The compact and broadband slot cut MSAs are realized by using the symmetry of slot cut MSAs across the feed point axis [12, 13]. In most of the reported literature, while designing slot cut broadband MSAs at given frequencies, slot length is taken either equal to half wave or quarter wave in length. However this simpler approximation does not give closer results. Also the closed form expressions for the resonance frequency due slot is not available. An analysis to study the effects of slot in broadband MSAs is reported [14]. It was observed that, slot does not introduce any additional mode but reduces the resonance frequency of orthogonal higher order mode of the patch and along with fundamental patch mode yields broader BW. The C-shaped MSA is a compact variation of rectangular MSA (RMSA) and it has smaller BW and gain as compared to the RMSA. In the available literature on compact C-shaped MSA, it has been mainly analyzed at its fundamental/first mode.

In this paper, fundamental and higher order modes of proximity fed C-shaped MSA are discussed. A broadband proximity fed C-shaped MSA on thicker air substrate is proposed. It gives BW of more than 230 MHz (> 23%) with broadside radiation pattern and peak gain of more than 7 dBi. An increase in the BW of C-shaped MSA is realized by cutting a rectangular slot on one of the edges of C-shaped MSA. The rectangular slot reduces the resonance frequency of orthogonal TM_{01} mode of the patch and along with fundamental TM_{10} mode yields BW of more than 260 MHz (> 28%). The slot modifies the surface current directions at TM_{01} mode and aligns them in the same direction as that of the currents at TM_{10} mode. Thereby it gives

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broadside radiation pattern over the entire BW with E-plane aligned along $\Phi = 0^0$. To increase the gain of C-shaped MSA, a gap-coupled configuration is used. First a gap-coupled configuration of proximity fed two C-shaped MSAs is proposed. This yields BW of more than 300 MHz (>30%) with broadside radiation pattern and peak gain of 7.7 dBi. Further gap-coupled configuration of proximity fed rectangular slot cut C-shaped MSAs is proposed. Due to the coupling between TM_{10} and modified TM_{01} modes on each of the C-shaped MSAs it yields BW of more than 400 MHz (~40%). The above MSAs were first analyzed using IE3D software [15]. In simulations, the antennas were analyzed using infinite as well as finite square ground planes. They were fed using N-type connector of 0.32 cm inner wire diameter. In measurements, antennas were fabricated using the copper plate having finite thickness and were suspended in air using the foam spacer supports, placed towards antenna corners. First to simulate the effect of an infinite ground plane, in measurements, a larger square ground plane of side length 100 cm is used. Further the antenna response is also validated using finite square ground planes. The antenna response was measured using R & S vector network analyzer. The radiation pattern was measured in minimum reflection surroundings with required minimum distance between the reference antenna and antenna under test [16]. The antenna gain was measured using three antenna method [16].

II. PROXIMITY FED C-SHAPED MSAs

The proximity fed C-shaped MSA is shown in Fig. 1(a, b). As against other feeding techniques of MSA, proximity feeding technique is used, as it is simpler to implement in thicker substrates. For given outer patch dimension, resonance frequency of fundamental mode of C-shaped MSA depends upon slot dimension. The formulation for resonant length of C-shaped MSA is reported [1]. Using the same and for outer patch dimension of 10 x 5 cm, the slot dimensions are calculated such that it resonates in its TM_{10} mode at frequency of around 900 MHz. The simulated resonance curve plot for C-shaped MSA is shown in Fig. 1(c). It shows two peaks and surface current distribution at them is shown in Fig. 1(d, e). At first peak, surface current shows one half wave length variation along patch length plus width, due to TM_{10} mode. At second peak, the surface currents are varying along patch length and width. This is due to close proximity of TM_{20} and orthogonal TM_{01} modes.

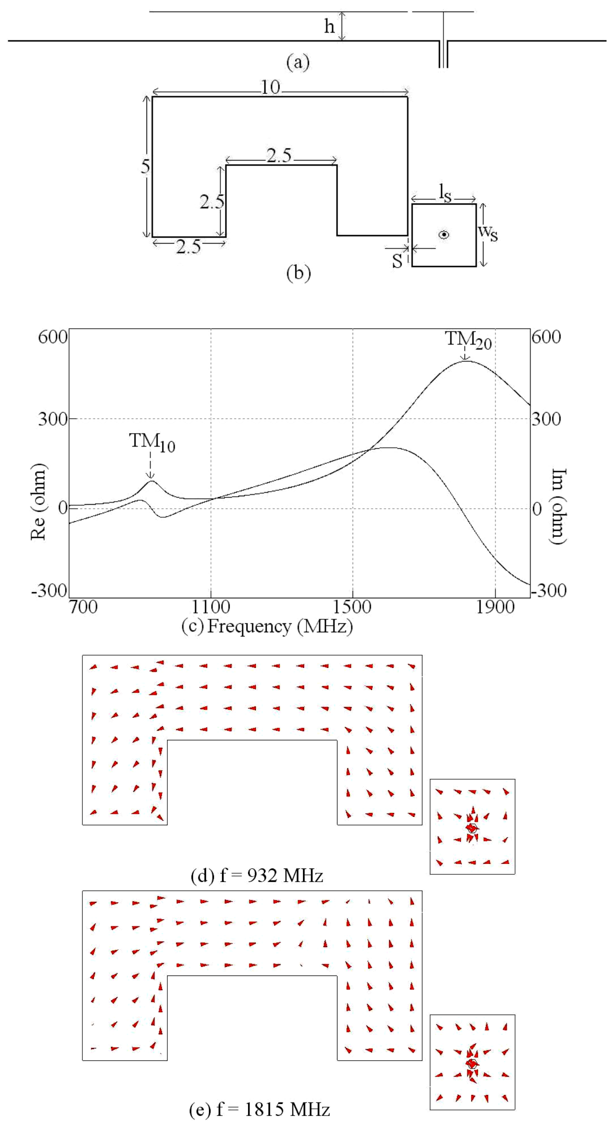

Fig. 1 (a) Top and (b) side views of proximity fed C-shaped MSA, its (c) resonance curve plot and its (d, e) surface current distribution at two modes

The broadband response at TM_{10} mode is realized by using parametric study for variations in substrate thickness for patch and coupling strip, strip dimensions and its spacing with respect to C-shaped patch. The MSA is optimized on air substrate thickness of h = 3.6 cm ($0.12\lambda_0$) and its input impedance plot, radiation pattern using finite square ground plane of side length 20 cm and gain variation over BW are shown in Fig 2(a – c), respectively. The simulated BW is 232 MHz (24 %), whereas the measured BW is 240 MHz, (25%). The radiation pattern is in the broadside direction with peak gain of more than 7 dBi.

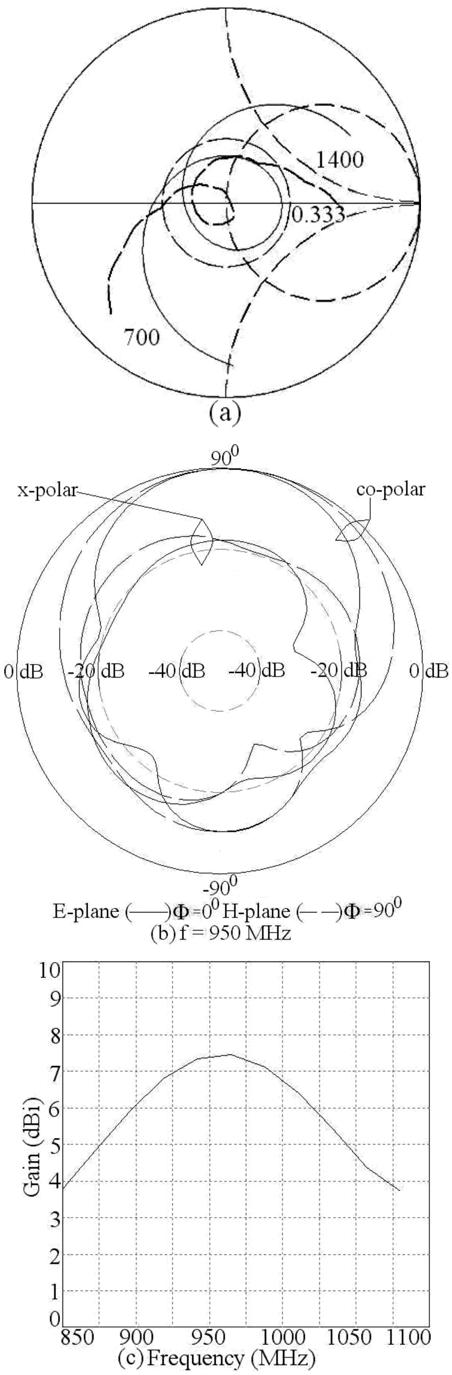

Fig. 2 (a) Input impedance plots, (—) simulated, (— —) measured, (b) radiation pattern at center frequency and (c) gain variation over BW for proximity fed C-shaped MSA

Further increase in the BW of C-shaped MSA is realized by cutting rectangular slot on one of its edges, as shown Fig. 3(a). To optimize for BW, parametric study for variations in slot length is carried out. For each of the lengths, resonance curve plots, surface current distribution and simulated radiation pattern plots were studied. The resonance curve plots for this variation at feed point location ‘A’ are shown in Fig. 3(b, c).

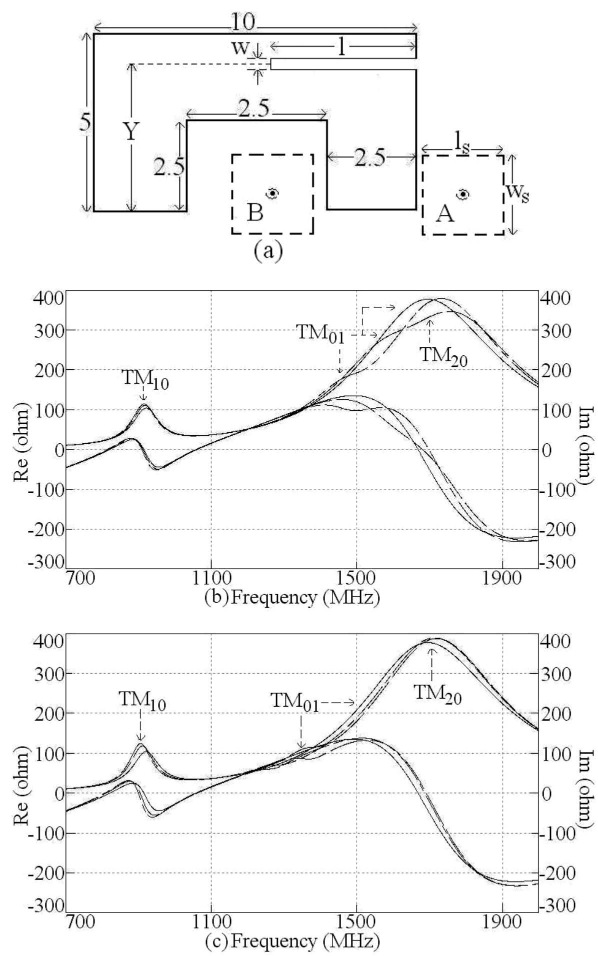

Fig. 3 (a) Proximity fed rectangular slot cut C-shaped MSA and its resonance curve plots for w = 0.4 cm, Y = 4.0 cm and (b) (—) l = 0 cm, (— —) l = 3 cm, (— - —) l = 3.5 cm, (c) (—) l = 0 cm, (— —) l = 4 cm, (— - —) l = 4.5 cm

The surface currents at TM_{10} and TM_{20} modes are parallel to the slot length hence decrease in its frequency is negligible. The currents at TM_{01} mode are orthogonal to slot length hence its frequency reduces and separate peak due to TM_{01} mode starts appearing in the resonance curve plot. The surface current distribution and

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simulated radiation pattern plots for two different slot lengths are shown in Fig. 4(a – d). With an increase in slot length, contribution of surface currents along patch length increases which changes the direction of E-plane from $\Phi = 90^0$ to 0^0. Thus rectangular slot realizes tuning of TM_{01} mode frequency with respect to TM_{10} mode frequency to realize broader BW as shown in Fig. 4(e).

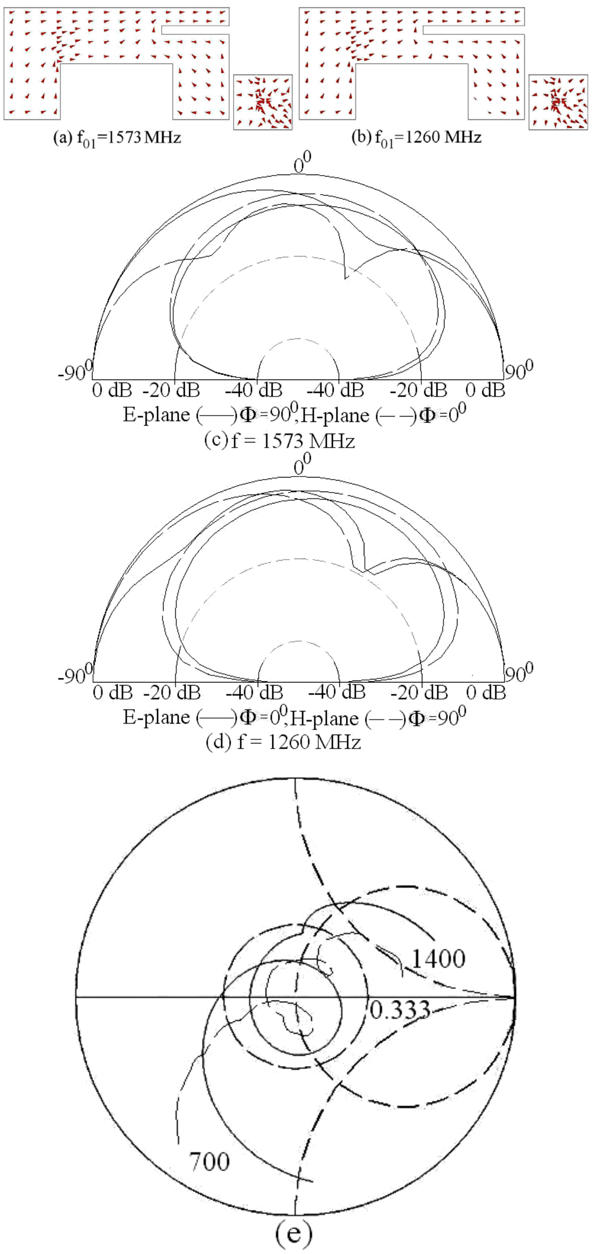

Fig. 4 Surface current distribution and simulated radiation pattern at TM_{01} mode for l = (a, c) 3.0 cm and (b, d) 4.5 cm and (e) input impedance plots, (—) simulated, (– –) measured for slot cut C-shaped MSA

The optimum coupling between strip and patch modes is realized for coupling strip at position 'B'. The MSA optimized on air substrate of 3.9 cm ($0.13\lambda_0$) has simulated BW of 267 MHz (27.1%) whereas the measured BW is 280 MHz (29.2%). The radiation pattern at centre frequency using finite ground plane and gain variation over BW is shown in Fig. 5(a, b). The pattern is in the broadside direction with peak gain of nearly 7.1 dBi. The gain reduces towards the higher frequencies of BW which is due to orthogonal surface currents due to modified TM_{01} mode. The fabricated prototype of the configuration is shown in Fig. 6.

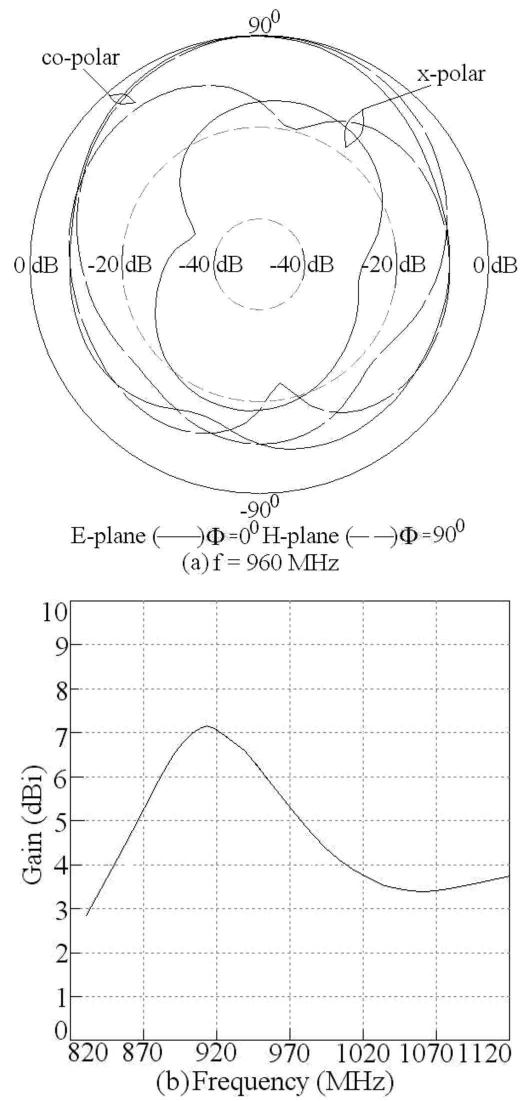

Fig. 5 (a) Radiation pattern at centre frequency and (b) gain variation over BW for proximity fed rectangular slot cut C-shaped MSA

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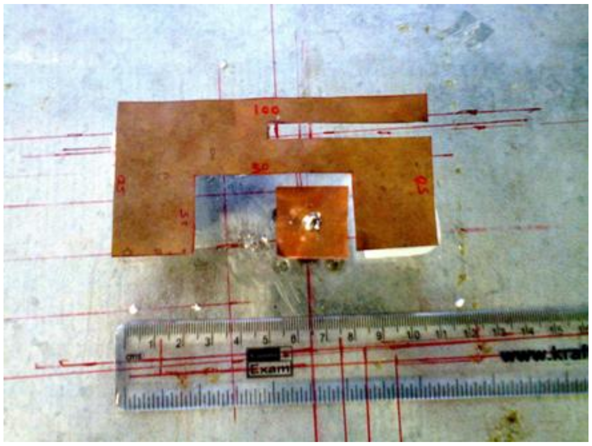

Fig. 6 Fabricated prototype of proximity fed rectangular slot cut C-shaped MSA

III. BROADBAND GAP-COUPLED C-SHAPED MSAs

To enhance the gain and BW, multi-resonator gap-coupled configuration of proximity fed two C-shaped MSAs is proposed as shown in Fig. 7(a). To realize different resonant frequencies of TM_{10} mode of individual C-shaped MSAs, patches of different lengths are used. By optimizing the gap between the two patches and their spacing with respect to coupling strip, a broader BW as shown in Fig. 7(b) is obtained. The simulated BW is 318 MHz (31.8%). The experiment was carried out and the measured BW is 320 MHz (32.4%). The radiation pattern using finite ground plane and gain variation over BW are shown in Figs. 8(a – c) and 9(a), respectively. The pattern is in the broadside direction with E and H-planes are aligned along $\Phi = 0^0$ and 90^0, respectively. The antenna gain is more than 5 dBi over most of the BW. The fabricated prototype of the configuration is shown in Fig. 9(b).

Further increase in BW of gap-coupled C-shaped MSAs is realized by cutting equal length rectangular slots on the edge of C-shaped patches as shown in Fig. 9(c). The resonance curve plot for gap-coupled C-shaped MSA and rectangular slot cut gap-coupled C-shaped MSAs is shown in Fig. 10(a). The rectangular slot on each of the C-shaped MSAs reduces its TM_{01} mode resonance frequency and brings them closer to TM_{10} mode frequencies of each of the C-shaped MSAs. The broader BW is realized when the spacing between TM_{10} and modified TM_{01} modes is optimized. The optimized input impedance and VSWR plot is shown in Fig. 10(b). The simulated BW is 414 MHz (39.8%), whereas the measured BW is 425 MHz (41.2%). The radiation pattern using finite square ground plane of side length 30 cm is shown in Figs. 10(c) and 11 (a, b). The gain variation over the BW is shown in Fig. 11(c).

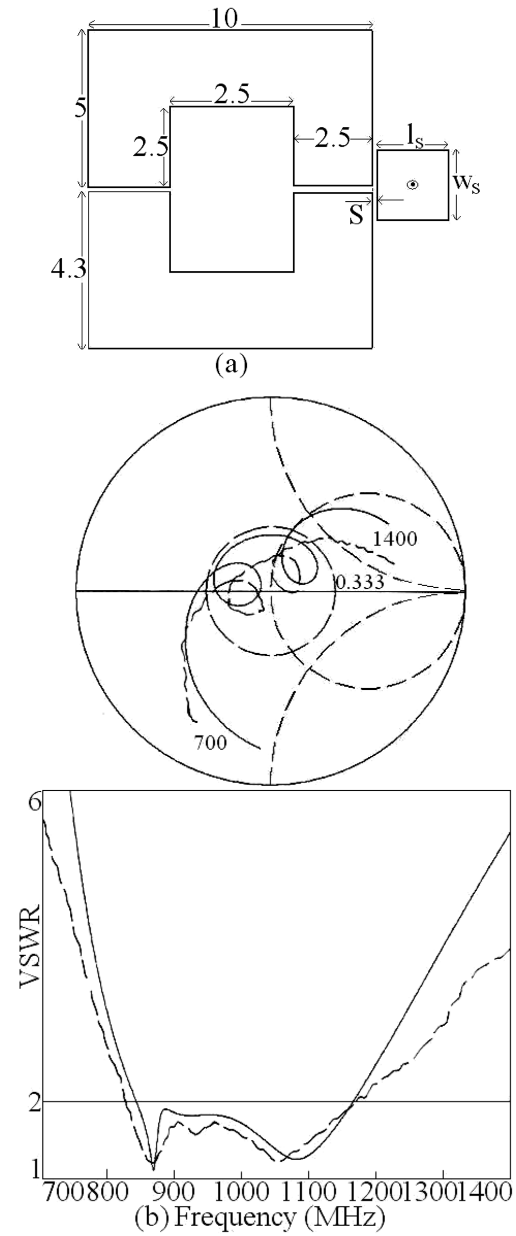

Fig. 7 (a) Proximity fed gap-coupled C-shaped MSAs and its (b) input impedance and VSWR plots, (—) simulated, (– –) measured

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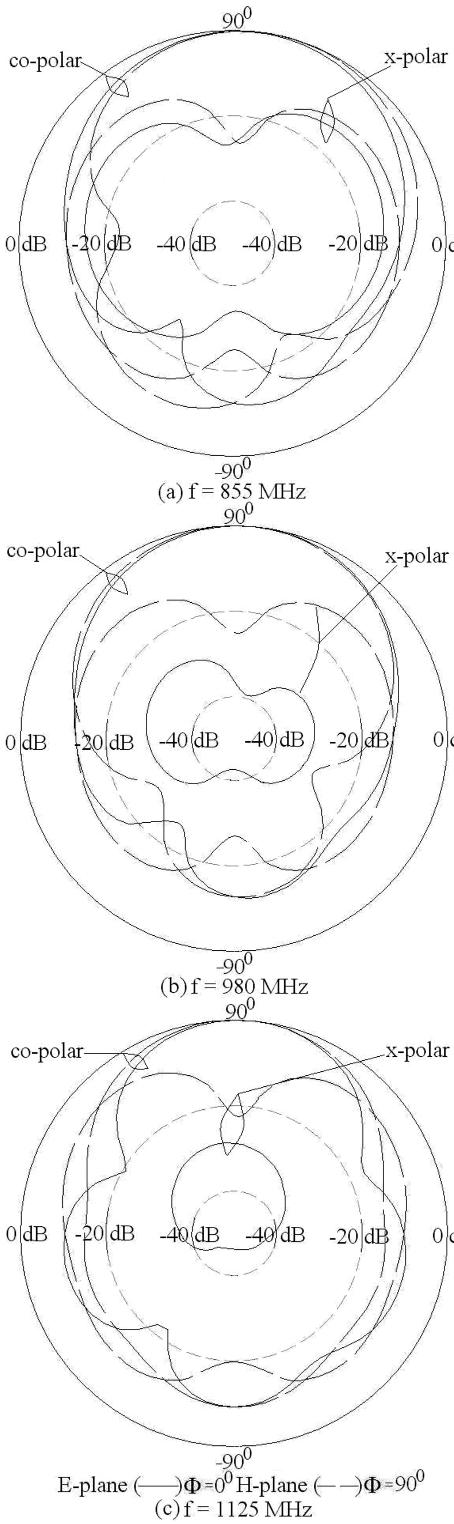
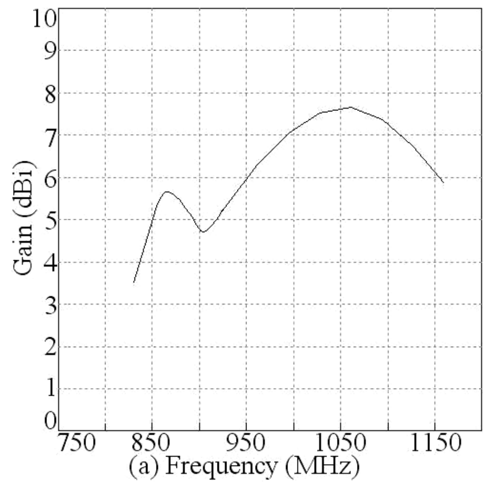
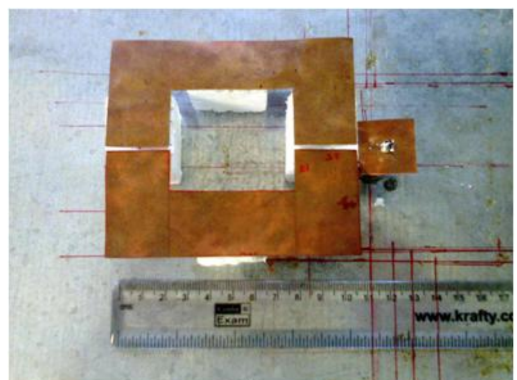


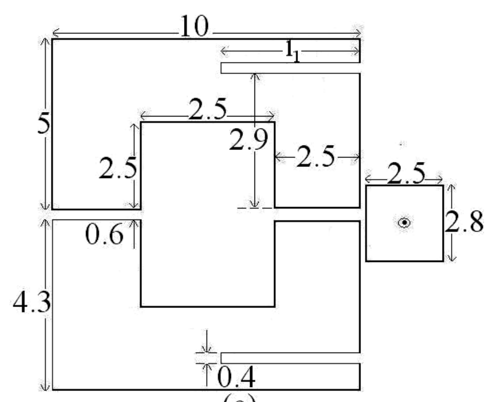
Fig. 8 (a – c) Radiation pattern over the BW for proximity fed gap-coupled C-shaped MSAs

The radiation pattern is in the broadside direction with gain of more than 6 dBi over most of the BW. Due to the multi-resonator configuration the antenna shows better gain characteristics as compared to rectangular slot cut C-shaped MSA. The fabricated prototype of the configuration is shown in Fig. 12. The results for various broadband configurations are summarized in Table 1.





(b)



(c)

Fig. 9 (a) Gain variation over BW and (b) fabricated prototype of proximity fed gap-coupled C-shaped MSAs and (c) proximity fed rectangular slot cut gap-coupled C-shaped MSAs

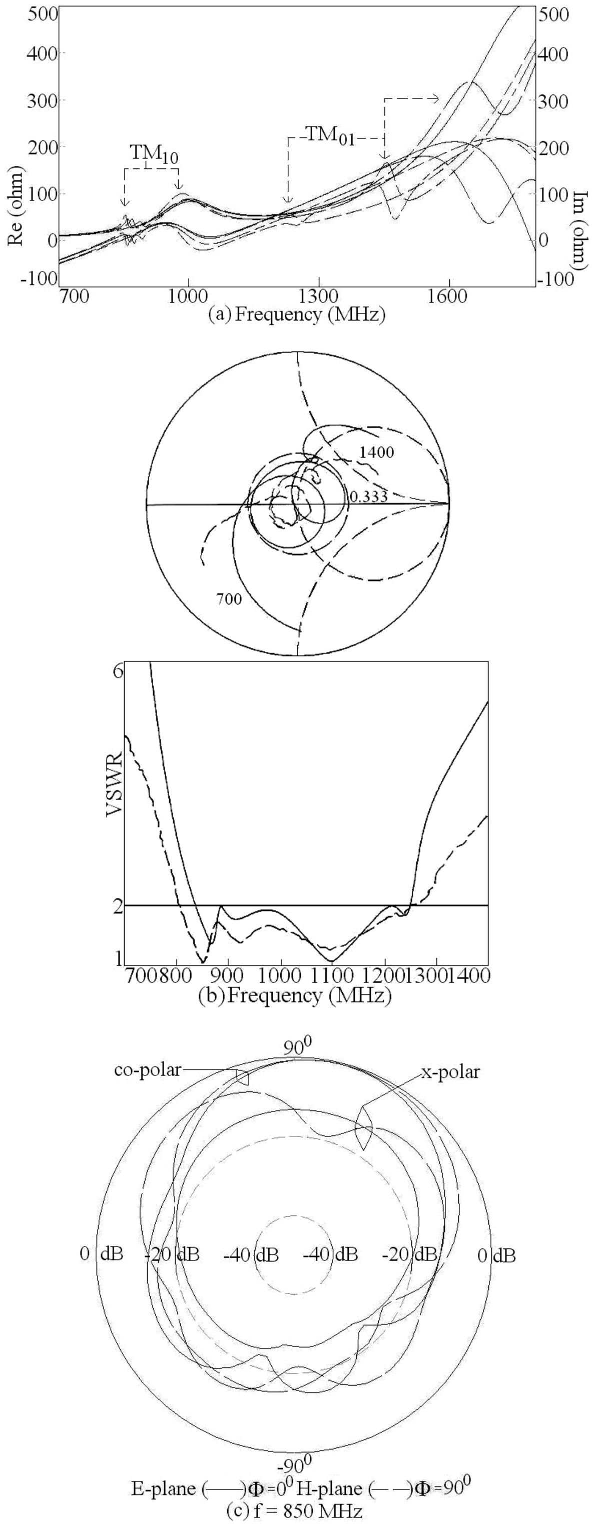


Fig. 10 (a) Resonance curve plot for l_1 = (—) 0 cm, (— —) 3.0 cm, (— - —) 3.5 cm, (— — —) 4.5 cm, (b) input impedance and VSWR plots, (——) simulated, (— —) measured and (c) radiation pattern at band start frequency for gap-coupled proximity fed rectangular slot cut C-shaped MSAs

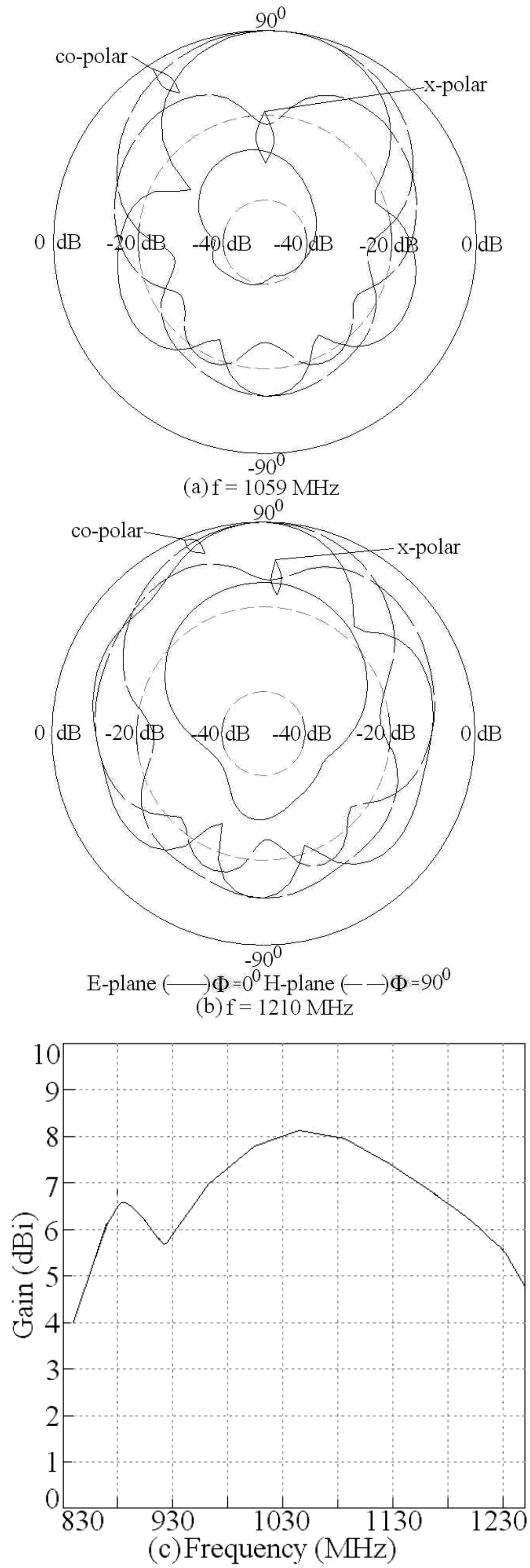


Fig. 11 (a, b) Radiation pattern and (c) gain variation over BW for gap-coupled proximity fed rectangular slot cut C-shaped MSAs

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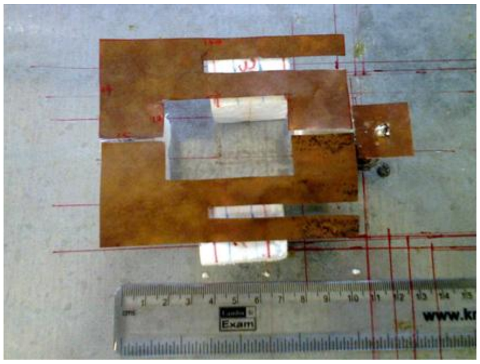

Fig. 12 Fabricated prototype of gap-coupled proximity fed rectangular slot cut C-shaped MSAs

Table 1 – Comparison of various broadband C-shaped MSAs

Configuration shown in	Simulated BW (MHz, %)	Measured BW (MHz, %)	h (cm)	Peak Gain dBi
1(a, b)	232, 24	240, 25	3.6	7.4
3(a)	267, 27.1	280, 29.2	3.9	7.1
7(a)	318, 31.8	320, 32.4	3.6	7.7
9(c)	414, 39.8	425, 41.2	3.6	8.1

V. CONCLUSIONs

The fundamental and higher order modes of compact C-shaped MSA are discussed. Further various broadband proximity fed slot cut and gap-coupled configurations of C-shaped MSAs on thicker air substrates are proposed. The proximity fed C-shaped MSA yields BW of more than 230 MHz (> 23%). Further increase in its BW is obtained by cutting rectangular slot on the edges of the C-shaped patch. The slot reduces the resonance frequency of orthogonal TM_{01} mode of the patch and along with fundamental TM_{10} mode yields broadband response. The slot also modifies surface current distribution at TM_{01} mode on the patch to yield broadside radiation pattern over the complete BW. An increase in gain and BW of C-shaped MSA is obtained by using multi-resonator gap-coupled configuration. A gap-coupled configuration of C-shaped MSAs yields BW of more than 300 MHz (>30%) with peak gain of 7.7 dBi. The gap-coupled configuration of rectangular slot cut C-shaped MSAs yields BW of more than 400 MHz (~40%) with peak gain of 8.1 dBi. Since all these gap-coupled configuration were optimized on thicker air substrate ($>0.1\lambda_0$), an error in the simulated and measured values are present. These are due to errors in maintaining the required substrate thickness as well as air gaps between C-shaped MSAs with respect to proximity feeding strip.

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