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Shorted Gap-Coupled Variation of 135^0 Sectoral Microstrip Antenna

Amit A. Deshmukh
Professor and Head, EXTC Dept.,
DJ Sanghvi College of Engineering
Vile Parle (W) Mumbai, India

Sudesh Agrawal, A. A. Desai, S. A. Shaikh, K. A. Lele,
PG student, EXTC Dept.,
D. J. Sanghvi College of Engineering
Vile Parle (W) Mumbai, India

ABSTRACT
The compact shorted 135^0 Sectoral microstrip antenna derived from 270^0 Sectoral microstrip antenna is discussed. The slot cut shorted 135^0 Sectoral microstrip antenna is proposed. The detail analysis to understand the effect of rectangular slot to that yields broadband response is presented. The slot reduces the resonance frequency of second order $TM_{1/4,1}$ mode of the shorted patch and along with fundamental $TM_{1/4,0}$ mode yields broader bandwidth. The slot cut shorted MSA yields bandwidth of more than 500 MHz (>45%). Due to shorted patch the patch shows radiation pattern with higher cross polar levels with antenna gain of more than 2 to 3 dBi over the entire bandwidth. Further to increase the gain of shorted patch gap-coupled configuration of two shorted 135^0 Sectoral microstrip antenna is proposed. It yields bandwidth of more than 500 MHz (>45%) with antenna gain of more than 4 dBi over most of the bandwidth. The proposed configuration can find applications in multi-path propagation environment as higher cross-polarization levels will lead to lesser signal loss.

Keyword
Sectoral microstrip antenna, Compact microstrip antenna, Broadband microstrip antenna, Rectangular slot, Higher order mode

1. INTRODUCTION
Using multi-resonator configuration, in which the additional resonant mode is either introduced by parasitic microstrip antenna (MSA) or it is introduced by the slot which is cut inside the MSA, a broadband response has been realized [1 – 8]. Out of these two techniques slot cut configurations are more preferred since they maintains the same patch size. Coaxially fed broadband slot cut MSAs are optimized on lower dielectric constant substrate (for e.g. air) of thickness 0.06 to $0.08\lambda_0$. To further increase the bandwidth (BW) of slot cut MSA, an additional slot is cut inside the first slot or slot cut MSA is fed using the proximity feeding technique [9 – 12]. The proximity fed MSAs realize 5 to 10% increase in antenna BW as compared to coaxially fed MSA and they are simpler in design as compared to dual slot cut MSAs. The compact MSAs are realized by placing shorting post along the zero field line at the fundamental patch mode [1 – 3]. The placement of shorting post/plate converts conventional half wavelength resonator into a quarter wavelength resonator. The compact and broadband MSA is realized either by using symmetry of slot cut patch across the feed point axis and by using only half of the configuration or by cutting the modified slot inside the shorted MSAs [13, 14]. While designing slot cut MSAs, slot length is either taken equal to half wave or quarter wave in length. However this wave length approximation of slot length does not give closer results for varying slot dimension and its position inside the patch. To understand the effects of slot, an detail analysis of slot cut broadband MSA is reported [15, 16]. In that it was observed that, slot reduces the resonance frequency of higher order orthogonal patch mode and along with fundamental patch mode yields broadband response. The slot also modifies the surface current distribution at higher order mode to yield radiation pattern that does not show any variation in the direction of principle planes. In the above analysis, slot position was found to be an important parameter, as it decides which higher order mode is present while realizing broader BW. Without using any parasitic MSA or slot, antenna BW is increased by varying one of the antenna parameter like Sectoral angle in Sectoral MSA (S-MSA) [17]. However in S-MSAs, radiation pattern shows higher cross polar level towards lower and higher frequencies of BW, due to the orthogonal surface currents. In this paper, shorted 135^0 S-MSA, derived by placing shorting plate along the zero field line at the fundamental mode in 270^0 S-MSA is discussed [18]. At fundamental mode, shorted 135^0 MSA yields simulated and measured BW of more than 350 MHz (~35%) [18]. To increase its BW, its rectangular slot cut variation is proposed [18]. In this paper detail analysis to understand the broadband response in shorted slot cut 135^0 S-MSA is presented. The rectangular slot tunes the resonance frequency of higher order $TM_{1/4,1}$ mode of the shorted patch with respect to fundamental $TM_{1/4,0}$ mode to yield BW of more than 500 MHz (>50%). The rectangular slot also modifies the surface current distribution at $TM_{1/4,1}$ mode to yield the radiation pattern with no variations in the directions of principle planes. Due to the shorted patch, radiation pattern shows higher cross-polar levels with gain of around 3 dBi over the VSWR BW. To increase the antenna gain, gap-coupled configuration of two shorted 135^0 S-MSAs is proposed. It yields BW of more than 500 MHz with gain of around 4 dBi over most of the BW. The proposed MSAs were first analyzed using IE3D software [19]. In experimental verifications, shorted 135^0 S-MSAs were fabricated using copper plate of finite thickness. They were supported in air using foam spacers which were place towards the antenna corners. The simulations and measurements were carried out using finite square ground plane of side length 30 cm. The input impedance response was measured using R & S vector network analyzer (ZVH – 8). The radiation pattern was measured using RF source (SMB 100A) and spectrum analyzer (FSC6). Thus as compared to 270^0 S-MSA and its slot cut compact variation, yields higher % BW and with 50% reduction in patch size.

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2. SHORTED 135^0 S-MSA

The air suspended proximity fed 270^0 S-MSA is shown in Fig. 1(a, b) [18]. For the dimension shown in Fig. 1(a, b), 270^0 S-MSA is simulated for x_f = 3.5, y_f = 0, and h_1 = 2.8, and its resonance curve plot is shown in Fig. 1(d). The resonance curve plot shows peaks due to fundamental TM_{10} and higher order TM_{11} and TM_{21} modes [18].

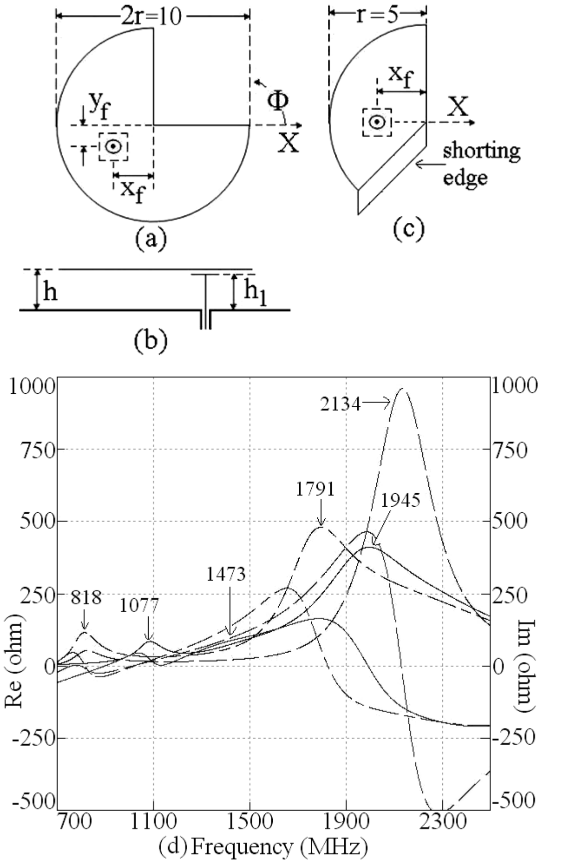

Fig 1: (a) Top and (b) side views of 270^0 S-MSA, (c) shorted 135^0 S- MSA and (d) resonance curve plots for, (——) 270^0 S-MSA, shorted 135^0 S-MSA for (— —) x_f = 2.0 and (—– –—) x_f = 4.5 and y_f = 0 [18]

At TM_{10} mode, current shows half wavelength variation along patch perimeter and has zero field in the patch center. The shorted 135^0 S-MSA as shown in Fig. 1(c) is obtained by shorting 270^0 S-MSA along the zero field line at TM_{10} mode and by using only half of the patch. The resonance curve plots for two values of 'x_f' and surface current distributions at observed resonant modes, for shorted 135^0 S-MSA are shown in Figs. 1(d) and 2(a – c), respectively [18].

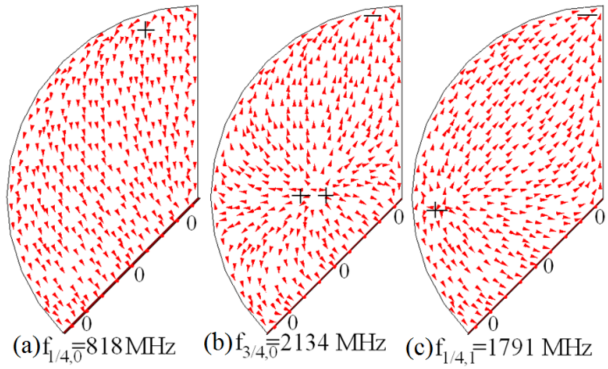

Fig 2: Surface current distributions at various resonant modes for shorted 135^0 S-MSA for (a, b) x_f = 2.0 and (c) x_f = 4.5 [18]

The first peak for x_f = 2.0, corresponds to shorted $TM_{1/4,0}$ mode [18]. The second peak corresponds to $TM_{3/4,0}$ mode. When the feed point is placed at x_f = 4.5 cm, a new resonant mode is oobserved at 1791 MHz in the resonance curve. This is referred to as $TM_{1/4,1}$ mode [18]. This mode is absent for x_f = 2.0, as at that location, feed is placed near the maximum current location at $TM_{1/4,1}$ mode. Since the surface currents at $TM_{1/4,0}$ and $TM_{3/4,0}$ modes are directed along the vertical direction, the E-plane is directed along Φ = 90^0. At $TM_{1/4,1}$ mode, as majority of the surface current contribution is along the horizontal direction, E-plane is directed along Φ = 0^0. Further by optimizing strip dimension and its position below the shorted 135^0 S-MSA, broadband response at $TM_{1/4,0}$ mode is obtained and its yields simulated and measured BW of 350 MHz (38.1%) and 374 MHz (40.7%), respectively. Further increase in the BW of shorted 1350 S-MSA is realized by cutting the rectangular slot as discussed below.

3. SHORTED RECTANGULAR SLOT CUT 135^0 S-MSA

To increase the BW of shorted 135^0 S-MSA, its rectangular slot cut variation is investigated as shown in Fig. 3(a). Since slot modifies the higher order mode resonance frequency, the slot position is an important parameter while designing slot cut broadband MSA. If the slot is cut along the horizontal direction then it will reduce $TM_{1/4,0}$ and $TM_{3/4,0}$ mode resonance frequency. Therefore to realize constant $TM_{1/4,0}$ mode frequency, vertical slot is cut which will only affect $TM_{1/4,1}$ mode frequency. The resonance curve plots for varying slot length are shown in Fig. 3(b). The plots are shown for variation in slot length (l) from 3 to 5 cm, and for slot width (w) of 0.4 cm and slot position (Y) of 2.0 cm from the patch edge. To excite $TM_{1/4,1}$ mode, proximity feed is placed at x_f = 0 and y_f = 1.2 cm. This position ensures that feed is not placed towards maximum current location at $TM_{1/4,1}$ mode. Since $TM_{1/4,0}$ and $TM_{3/4,0}$ mode frequencies remains constants, there peaks in the resonance curves remains overlapped. For slot length < 3 cm, prominent peak due to modified $TM_{1/4,1}$ mode is absent. However it is observed for slot length > 4 cm. With an increasing slot length, $TM_{1/4,1}$ mode frequency comes closer to $TM_{1/4,0}$ mode frequency. The surface current distribution at $TM_{1/4,1}$ mode with increasing slot length is shown in Fig. 3(c, d). The current contribution increases along vertical direction inside the shorted patch with an increase in slot length. Thus over $TM_{1/4,0}$ and modified $TM_{1/4,1}$ modes, surface currents are directed along the vertical direction that gives E-plane along $\Phi = 90^0$.

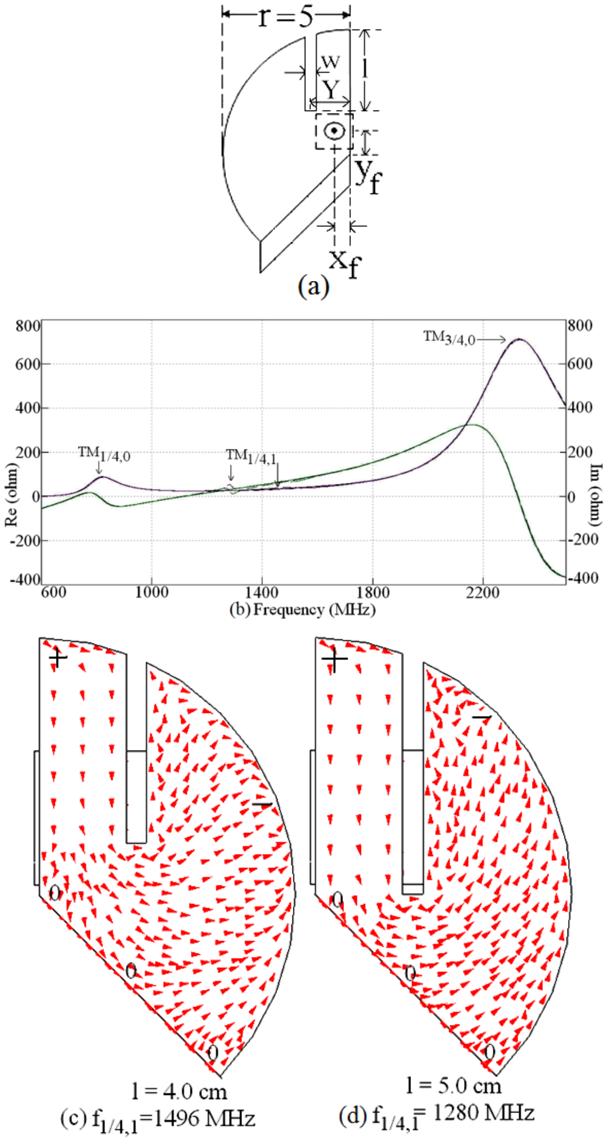

Fig 3: (a) Slot cut shorted 135^0 S-MSA, its (b) resonance curve plots for l = (—) 0, (— —) 3, (— - —) 4, (— — —) 5, and its (c, d) surface current distribution at modified $TM_{1/4,1}$ mode for two different slot lengths

For constant slot length and for variation in 'w' and 'Y', a negligible variation in modal frequencies was noticed. The broadband response is obtained when loops due to $TM_{1/4,0}$ and modified $TM_{1/4,1}$ mode lies inside VSWR = 2 circle. An important parameter for realizing this is the strip position below the patch. The input impedance plots for varying strip position are shown in Fig. 4(a, b).

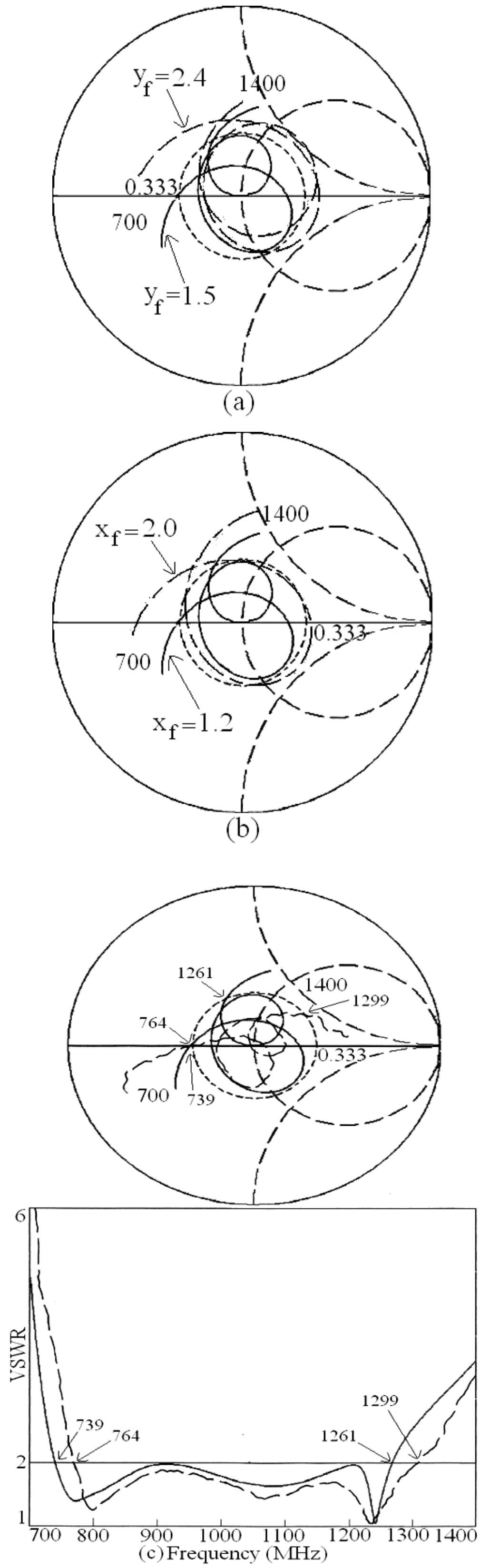

Fig 4: Input impedance plots for (a) y_f = 2.4, (b) x_f = 2.0, and (c) optimized input impedance and VSWR plots for slot cut shorted 135^0 S-MSA, x_f = 1.2, y_f = 1.5

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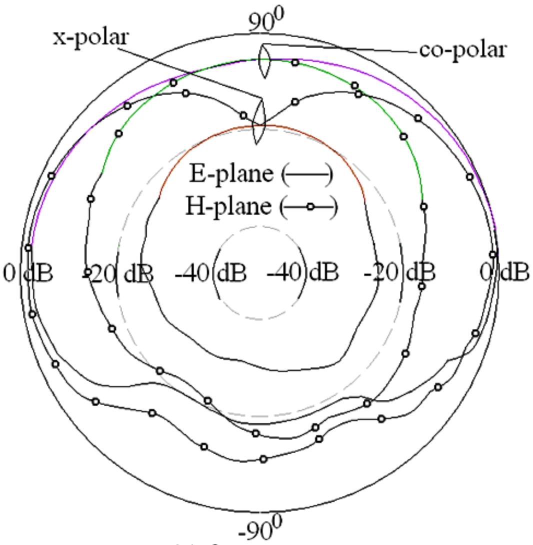
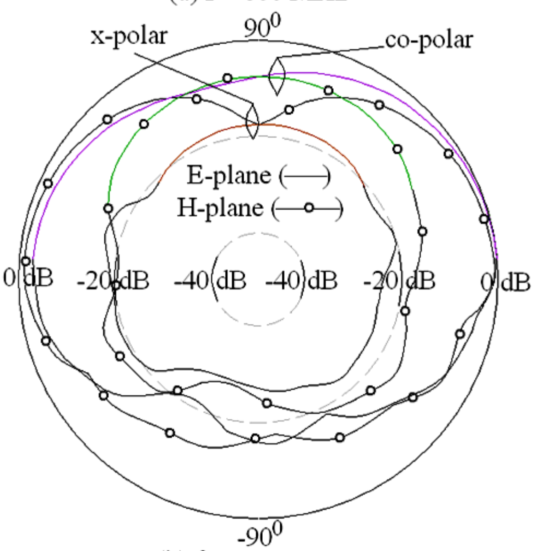
When the strip is placed away from the shorting edge (y_f = 2.4, x_f = 1.2), a larger loop size due both the modes is observed. This is because mode impedance is higher for moving away from the shorting edge. When the strip is placed closer to the shorted end of the slot (x_f = 2.0, y_f = 1.5), loop size due to modified $TM_{1/4,1}$ mode is absent as field is minimum at that point for $TM_{1/4,1}$ mode. Thus, strip position is used to control the coupling at individual modes and optimum response is obtained for x_f = 1.2 and y_f = 1.5 cm, as shown in Fig. 4(c). The simulated BW is 522 MHz (52.2%) whereas the measured BW is 535 MHz (51.9%). The radiation pattern and gain variation over the BW are shown Figs. 5(a, b) and 6(a, b), respectively. The E and H-plane are directed along $\Phi = 90^0$ and 0^0, respectively. Due to shorted MSA, radiation pattern shows higher cross polar levels with a gain of more than 3 dBi over the entire BW.



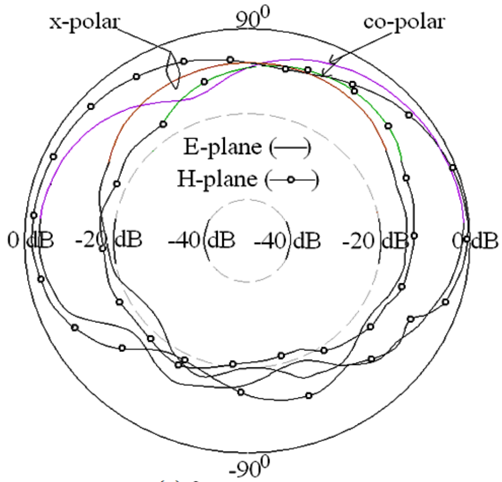
(a) f = 800 MHz



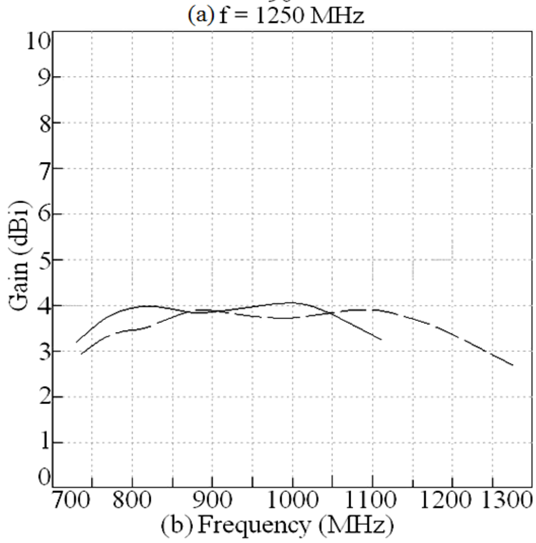
(b) f = 1050 MHz

Fig 5: (a, b) Radiation pattern plots at band start and center frequency of BW for slot cut shorted 135^0 S-MSA

The cross polar levels are higher towards higher frequencies of BW, which are due to horizontal component of surface currents at $TM_{1/4,1}$ mode. The fabricated prototype of the slot cut shorted 135^0 MSA is shown in Fig. 6(c).



(a) f = 1250 MHz



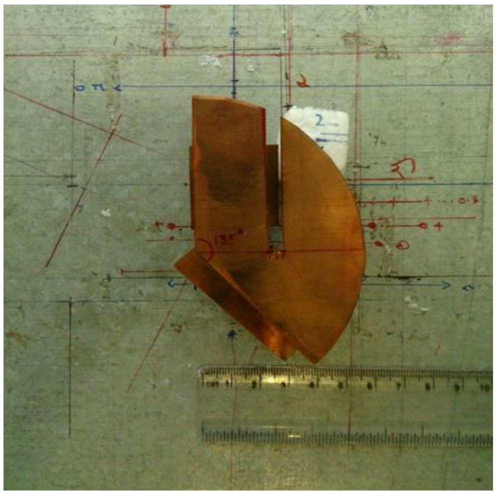


Fig 6: (a) Radiation pattern at band edge frequency, (b) gain variation over BW, (—) shorted 135^0 S-MSA, (– –) slot cut 135^0 S-MSA and (c) fabricated prototype of slot cut shorted 135^0 S-MSA

An increase in gain of shorted 135^0 S-MSA is realized by using gap-coupled configuration of two shorted 135^0 S-MSAs as shown in Fig. 7(a).

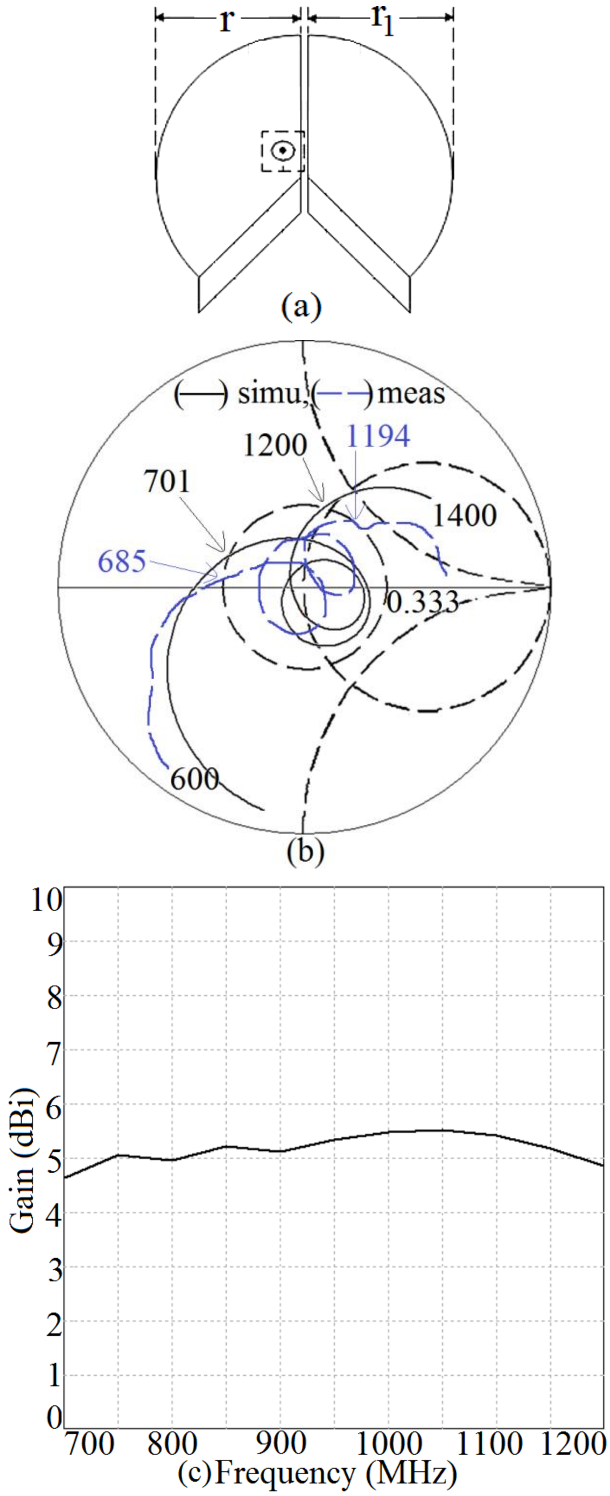


Fig 7: (a) Gap-coupled shorted 135^0 S-MSAs, its (b) input impedance plots and its (c) gain variation over the BW

The realized BW depends upon the spacing between $TM_{1/4,0}$ mode frequencies of individual patches. The optimum BW is obtained for 'r' = 5.0 and 'r_1' = 4.4 cm as shown in Fig. 7(b). The simulated BW is 499 MHz (52.5%) whereas the measured BW is 509 MHz (54.2%). Due to gap-coupled configuration antenna gain is more than 4 dBi over most of the BW as shown in Fig. 7(c). The fabricated prototype of the configuration is shown in Fig. 8.

Fig 8: Fabricated prototype of gap-coupled shorted 135^0 S-MSAs

4. CONCLUSIONS

A new compact shorted 135^0 S-MSA derived from 270^0 S-MSA is discussed which gives simulated and measured BW of more than 350 MHz (>30%). To enhance its BW, a rectangular slot cut variation of shorted 135^0 S-MSA is proposed. A detail parametric study to understand the effect of rectangular slot and coupling strip position in slot cut configuration is presented. The slot does not introduce any additional resonant mode but reduces the resonance frequency of higher order $TM_{1/4,1}$ mode of the shorted patch and along with fundamental $TM_{1/4,0}$ mode yields BW of more than 500 MHz (>50%). The realized % BW in compact shorted MSA is higher than that obtained in slot cut 270^0 S-MSA and with half the patch size. Due to shorted patch and horizontal surface current components at modified $TM_{1/4,1}$ mode, radiation pattern in slot cut MSA shows higher cross polar levels, thereby realizing elliptical polarization over the entire BW. The gap-coupled variation of two shorted 1350 S-MSA is proposed which yields nearly 500 MHz (~50%) of BW but with antenna gain of more than 4 dBi over entire BW. Due to above antenna characteristics, proposed antennas can find application in mobile communication environment wherein antenna with lower cross polar level will lead to higher signal loss. Although in the proposed work, commonly used broadband and compact MSA techniques are used. However a clear explanation for the functioning of slot cut shorted quarter wavelength resonators in terms of their operating modes in presented.

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