Proximity fed shorted 135^0 Sectoral Microstrip Antenna

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ABSTRACT

Compact shorted 135^0 Sectoral microstrip antenna derived from 270^0 Sectoral microstrip antenna is proposed. On thicker air substrate ($h > 0.1\lambda_0$) it yields bandwidth of more than 350 MHz (35%). To increase the bandwidth, its rectangular slot cut variation is proposed. The slot 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 bandwidth of more than 500 MHz (>50%). The realized bandwidth in shorted slot cut Sectoral microstrip antenna is nearly the same as that given by 270^0 Sectoral patch, but with 50% reduction in patch area. Due to shorted patch, proposed antenna gives gain of around 3 dBi over the entire bandwidth.

Keyword

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

1. INTRODUCTION

The broadband microstrip antenna (MSA) is realized by using multi-resonator configurations in which additional resonant mode is either introduced by parasitic MSA which is gap-coupled or stacked on to the fed MSA or by cutting the slot inside the MSA [1 – 8]. These broadband configurations are optimized with respect to fundamental patch mode and slot cut method is more preferred as it does not increase the patch area. The coaxially fed slot cut MSAs are optimized on lower dielectric constant substrate (for e.g. air) of thickness 0.06 to 0.08□ 0. Further increase in their bandwidth (BW) is obtained by cutting additional slot inside the slot cut MSA or by optimizing them on substrate thickness more than $0.08\lambda_0$, in conjunction with 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 and further by using only half of the configuration [1 – 3].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]. The compact slot cut MSAs gives more than 50% reduction in patch area with slightly reduced BW. While designing slot cut MSAs in desired frequency range, slot length is either taken equal to half wave or quarter wave in length. Based on half wave length approximation, formulation in slot resonant length is reported [15, 16]. However the effects of slot parameters like its position inside the patch and slot width, on the slot resonance frequency is not explained. To understand the effects of slot, an analysis of slot cut broadband MSA has been carried out [17, 18]. It was observed that slot does not introduce any additional resonant mode but it 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 broadside radiation pattern over the complete BW without 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) [19]. In 300^0 S-MSA, Sectoral angle tunes the spacing between first two patch resonant modes to yield BW of more than 400 MHz (>35%) [19]. The BW of 270^0 S-MSA is increased by cutting rectangular slot inside the patch which yields BW of nearly 500 MHz (>40%) [20]. In 340^0 S-MSA, Sectoral angle tunes the spacing between first three patch resonant modes to yield BW of more than 700 MHz (>50%) [21]. However in all these S-MSAs, radiation pattern shows higher cross polar level towards lower and higher frequencies of BW, which is due to orthogonal surface currents at first and third resonant modes. This leads to variation in co-polar gain by more than 3 dBi over the VSWR BW.In this paper, a new 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 proposed. Firstly fundamental and higher order modes of shorted 135^0 S-MSA for different proximity feed positions and their comparison with the modes of 270^0 S-MSA is presented. At fundamental mode, shorted 135^0 MSA yields simulated and measured BW of more than 350 MHz (~35%). To increase its BW, its rectangular slot cut variation is proposed. The rectangular slot 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 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. The proposed MSAs were first simulated and optimized using IE3D software [22]. For experimental verifications the patch were fabricated using copper plate having finite thickness and were supported in air using foam spacer support place towards the antenna corners. The measurement was carried out using R & S vector network analyzer (ZVH – 8) on finite square ground plane of side length 30 cm. The radiation pattern was measured in minimum reflection surroundings with required minimum far field distance between reference antenna and antenna under test whereas gain was measured using three antenna method [23]. Thus as compared to 270^0 S-MSA and its slot cut compact variation, yields higher % BW and with 50% reduction in patch size.

2. SHORTED 135^0 S-MSA

The air suspended proximity fed 270^0 S-MSA is shown in Fig. 1(a, b). The dimensions shown in all the figures and their captions are in cm. The formulation for patch radius in S-MSA at desired TM$_{10}$ and TM$_{11}$ mode frequencies is reported [24].

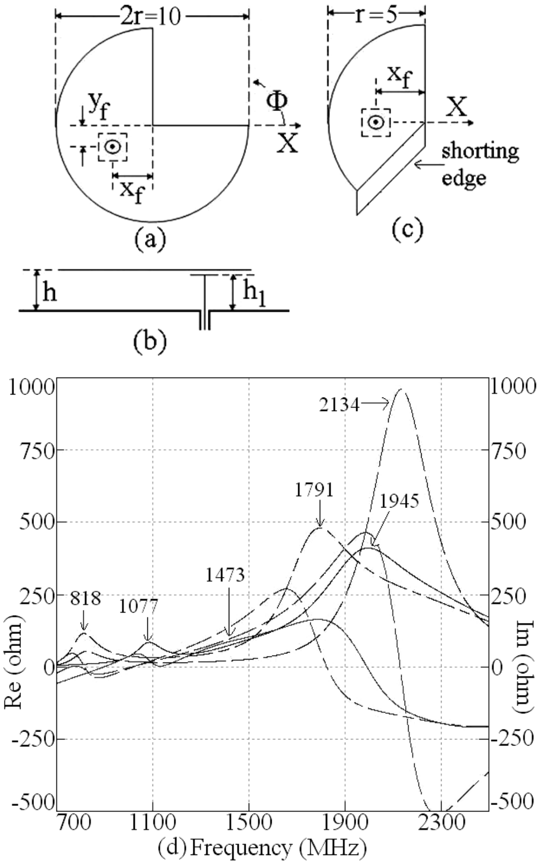
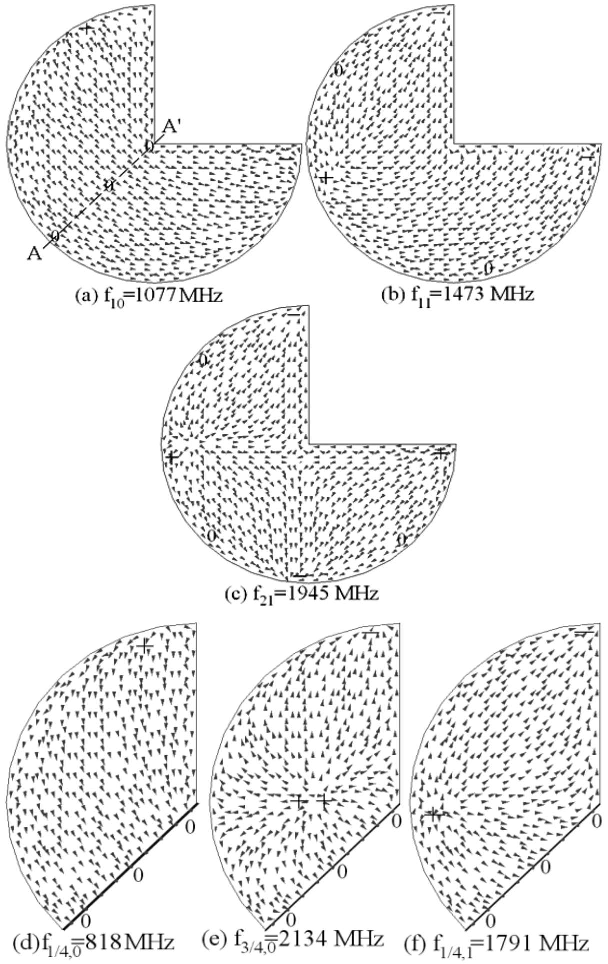


Fig. 1 (a) Top and (b) side views of 270^0 S-MSA, (c) shorted 135^0 S- MSA and (d) resonance curve plots for, (—) 270^0 S-MSA, shorted 135^0 S-MSA for (— —) x_f = 2.0 and (– – –) x_f = 4.5 and y_f = 0

Using them, patch radius for TM$_{10}$ mode frequency to be around 1000 MHz, is calculated. The thicker air substrate is used as it helps in realizing larger BW. The 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 [19 – 21]. The surface current distributions at them are shown in Fig. 2(a – c).



(a) f_{10}=1077MHz
(b) f_{11}=1473 MHz
(c) f_{21}=1945 MHz
(d) $f_{1/4,0}$=818MHz
(e) $f_{3/4,0}$=2134 MHz
(f) $f_{1/4,1}$=1791 MHz

Fig. 2 Surface current distributions at various resonant modes for (a – c) 270^0 S-MSA and for shorted 135^0 S-MSA for (d, e) x_f = 2.0 and (f) x_f = 4.5

At TM$_{10}$ mode, current shows half wavelength variation along patch perimeter and has zero field in the patch center (A – A'). At TM$_{11}$ mode, surface current shows two half wavelength variations along patch perimeter. At TM$_{21}$ mode, currents show two half wavelength variations along half of the patch perimeter. 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(d – f), respectively. The first peak for x_f = 2.0, corresponds to shorted TM$_{10}$ mode as current shows quarter wavelength variation along shorted patch length. Due to this variation this mode is also referred to as TM$_{1/4,0}$ mode. Here the first index refers to multiples of quarter wave length variation along shorted length and second index refers to multiples of half wavelength variation along the orthogonal patch dimension. At second peak current shows three quarter wavelength variation along shorted patch length and this mode is referred to as TM$_{3/4,0}$ mode. When the feed point is placed at x_f = 4.5 cm, an additional prominent peak is observed at 1791 MHz in the resonance curve. The surface current distribution at this mode shows one quarter wavelength variation along shorted length and one half wavelength variation along the orthogonal dimension. Due to this variation this mode is referred to as TM$_{1/4,1}$ mode. 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 $\Phi = 90^0$. At $TM_{1/4,1}$ mode, as majority of the surface current contribution is along the horizontal direction, E-plane is directed along $\Phi = 0^0$. 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 as shown in Fig. 3. The simulated BW is 350 MHz (38.1%) whereas the measured BW is 374 MHz (40.7%).

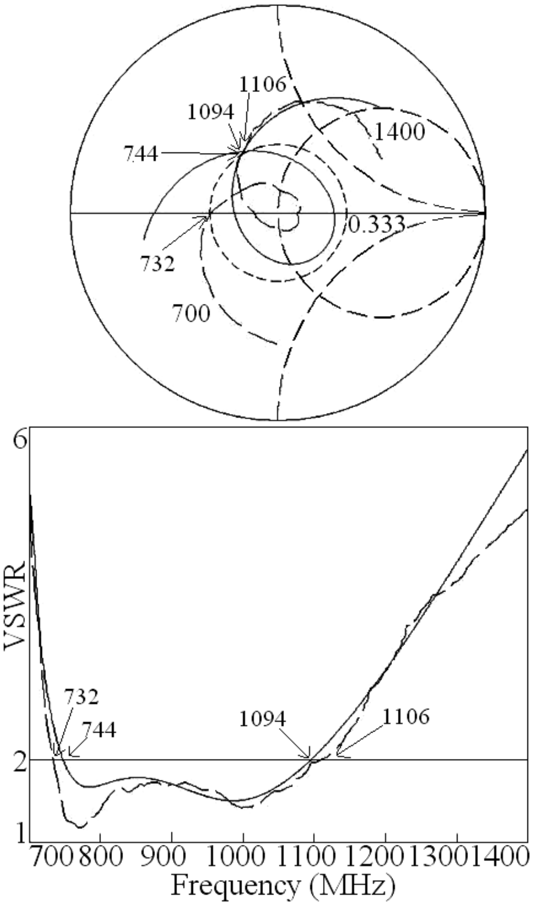
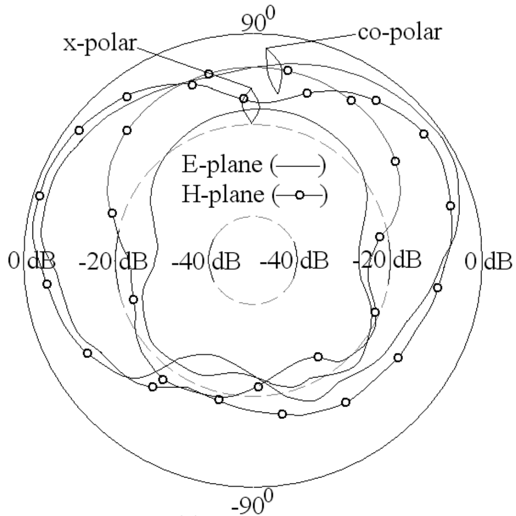
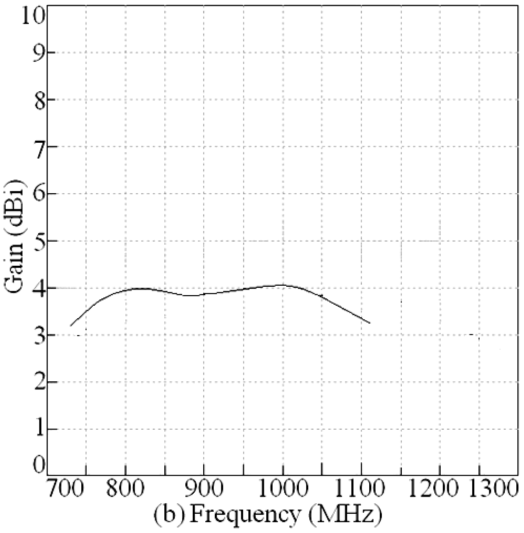


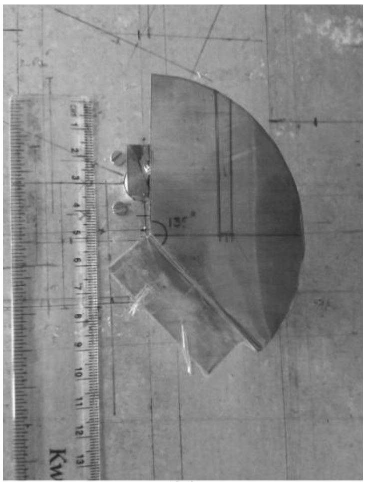
Fig. 3 Input impedance and VSWR plots for proximity fed shorted 135^0 S-MSA, (——) simulated, (— —) measured

Using finite ground plane, measured radiation pattern at center frequency and gain variation over the BW are shown in Fig. 4(a, b). Due to shorted patch, pattern shows higher cross polar levels with gain of more than 3 dBi over a complete BW. The fabricated prototype of the configuration is shown in Fig. 4(c).



(a) f = 910 MHz





(c)

Fig. 4 (a) Radiation pattern at center frequency, (b) gain variation over BW and (c) fabricated prototype of proximity fed shorted 135^0 S-MSA

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. 5. The rectangular slot reduces the resonance frequency of $TM_{1/4,1}$ mode of the shorted patch and along with $TM_{1/4,0}$ mode yields broader BW. For $x_f = 1.2$ and $y_f = 1.5$ cm, the simulated BW is 522 MHz (52.2%) whereas the measured BW is 535 MHz (51.9%). The slot modifies the surface current distribution at $TM_{1/4,1}$ mode to yields radiation pattern with no variations in the directions of principle planes. Since effective patch area has not increased, the antenna gain is more than 3 dBi over most of the BW.

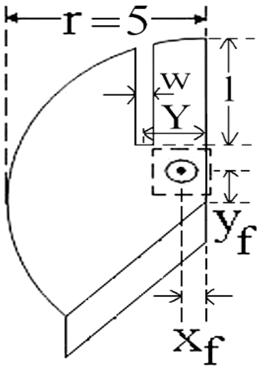


Fig. 5 Proximity fed shorted rectangular slot cut 135^0 S-MSA

4. CONCLUSIONS

A new compact shorted 135^0 S-MSA derived from 270^0 S-MSA is proposed. For the same patch radius fundamental mode resonance frequency in shorted 135^0 S-MSA is lower than the fundamental mode frequency in 270^0 S-MSA. This is due to additional shorted length in shorted MSA. On thicker air substrate it yields BW of more than 350 MHz (>30%). To enhance its BW, a rectangular slot cut variation is proposed. 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 radiation pattern in slot cut MSA shows higher cross polar levels, thereby realizing elliptical polarization over entire BW. Due to which the proposed antenna can find application in mobile communication environment wherein antenna with lower cross polar level will lead to higher signal loss. In further study to improve upon the gain and BW of shorted 135^0 S-MSAs, their gap-coupled variations will be studied. Also the detailed study to understand the broadband response realized in shorted 135^0 S-MSA, will be presented.

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