Broadband 120^0 Sectoral Microstrip Antenna

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By

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CERTIFICATE

This is to certify that the project entitled **"Broadband 120^0 Sectoral Microstrip Antenna "**is a bonafide work of **"Pritish Y. Kamble"(Dwarkadas-177)** submitted to the University of Mumbai in partial fulfilment of the requirement for the award of the degree of **Master of Engineering** in **Electronics and Telecommunication Engineering.**

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Dissertation Approval for Master of Engineering

This dissertation entitled “**Broadband 120^0 Sectoral Microstrip Antenna**” by “**Pritish Y. Kamble**” is approved for the degree of “**Master of Engineering”** in “**Electronics and Telecommunication Engineering”.**

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Abstract

Novel configuration of 120^0 Sectoral Microstrip antenna is proposed. Compared with equivalent circular patch, 120^0 Sectoral patch has higher resonance frequency for the fundamental mode and it gives bandwidth of 1200 MHz (~59%). Resonant length formulation at fundamental mode in 120^0 Sectoral patch is proposed. Using the same, design of 120^0 Sectoral patch at resonance frequency of 1000 MHz is presented which yields more than 575 MHz (~ 50%) of bandwidth. Proposed 120^0 Sectoral patch gives broadside radiation pattern with peak co-polar gain of more than 9 dBi. Sectoral Microstrip Antennas are realized by modifying the circular microstrip antennas. It yields bandwidth of nearly 650 MHz (~49%) with antenna gain of above 8 dBi in 1200 MHz frequency range. To enhance the bandwidth and gain of 120^0 Sectoral microstrip antenna, its various gap-coupled configurations coupled along the diagonal axes are proposed. Configurations with either single patch or two patches gap-coupled along diagonal axis are discussed with variations in the coupling edges. A maximum bandwidth of more than 1000 MHz (>70%) is realized for specific configurations of 120^0 patches when they were coupled along both diagonal axes. In all gap-coupled variations, broadside MSA gain is nearly 9 dBi with pattern maximum in bore-sight direction, is observed. Further its stack variations are also studied which gives a broadband response of 890MHz. A comparative study of rectangular base desktop shaped broadband patch antenna (Antenna 1) and triangular base desktop shaped broadband patch antenna (Antenna 2).Apart from base dimensions all parameters of both antennas are constant. The broadband characteristics are achieved by introducing two parasitic ground planes and notches are etched on the radiating patch. The designed Antenna 1 shows bandwidth of 39.97% (4.95GHz to 7.42 GHz) whereas an improved bandwidth of 49.0% (4.53GHz to 7.47 GHz) is achieved through Antenna 2. The reason for the broadband response with various modes which occur where not discussed in the paper. Hence, we have made a detailed studied and found that coupling between TM_{20}, TM_{21} and TM_{03} results in broadband response further we have redesigned it 1500MHz.

Keywords: Broadband microstrip antenna; Circular microstrip antenna; Sectoral microstrip antenna; Resonant length;, Broadband Microstrip Antenna, E-shape Microstrip Antenna, Multiple Slots cut Rectangular Microstrip Antenna, Higher order modes.

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List of Abbreviations

MSA	:	Microstrip Antenna
RMSA	:	Rectangular Microstrip Antenna
CMSA	:	Circular Microstrip Antenna
VSWR	:	Voltage standing wave ratio
BW	:	Bandwidth
RF Source	:	Ratio Frequency Source
VNA	:	Vector Network Analyzer

Declaration

I, Pritish Y. Kamble , declare that this written submission represents my ideas in my own words and where others' ideas or words have been included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission. I understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

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Chapter 1

Introduction

The advent of broadband system in wireless communication area has demanded the design of antennas that must operate effectively over a wide range of frequencies. An antenna with wide bandwidth is referred to as a broadband antenna. But the question is, wide bandwidth mean how much bandwidth. The term "broadband" is a relative measure of bandwidth and varies with the circumstances. The definition of a broadband antenna is somewhat arbitrary and depends on the particular antenna. "If the impendence and pattern of an antenna do not change significantly over about an octave or more, it will classified as a broadband antenna". Wider bandwidth (BW) in microstrip antenna (MSA) is realized by using multi-resonator configurations in which additional resonant mode with respect to fundamental patch mode is either introduced by using parasitic patch or it is introduced by cutting the slot inside the patch[1-6].Broadband antennas usually require structures that do not change abruptly in its physical dimensions, but instead utilize materials with smooth boundaries. Smooth physical structures tend to produce patterns and input impedance that also change smoothly with frequency. This simple concept is very important in broadband antennas. Broadband can be obtained by cutting a slot inside the patch or it can be obtained by using parasitic patches. Wide band microstrip antenna (MSA) are obtained using techniques like, fabricating patch on thicker and lower dielectric constant substrate, using multi-resonator designs that employs stacked and gap-coupled designs, use of modified feeding techniqueslike, L-probe or proximity feed, and by using their combinations.

A patch placed closed to the fed patch gets excited due to coupling between the two patches, such a patch is known as parasitic patch. If the frequencies f_1 and f_2 of the two patches are closed to each other the broadband response is obtained. The overall VSWR will be the superposition of the response of the two resonator's resulting in a wide bandwidth. If the bandwidth is narrow for the individual patch, then the difference between f_1 and f_2 should be small. If the bandwidth of the individual patch is larger than there difference between f_1 and f_2 should be large. Radiating edge gap coupled RMSA deals with placing the parasitic patch on all the radiating and non-radiating edges. Either one or two parasitic patches can be placed along one or both the radiating edges of the fed patch with a small gap between them.
Due to rapid development of modern wireless communication technologies, low cost, light weight and small size wideband antennas are of great demand. Microstrip patch antennas are developed in response to this need. Their planer profile configurations attract commercial, industrial and medical applications. However, the main limitation of the conventional microstrip patch antennas is narrow bandwidth that restricts its operation where wider bandwidth is required. To overcome their inherent limitation of narrow bandwidth, many techniques have been proposed and investigated.

1.1 Problem Definition

Microstrip antenna (MSA) finds many applications in wireless communication system designs due to its numerous advantages like planar configuration that does disturb the properties of the hosting surface [1]. Although when it was invented, MSA was regarded as narrow bandwidth (BW) device which cannot support higher power handling requirements. However many techniques have been evolved which improves the BW and gain of MSA along with larger power handling capacity. The proposed work is primarily focused on the design and analysis of the 120^0sectoral broadband operation of the MSAs. Wideband operation of the antenna has become a necessity for many applications in recent wireless communication systems. In the reported configurations the proper explanation of the antenna modes and obtained BW and gain is not reported. The explanation of the observed broadband antenna response is not provided. In the present work we are exploring all the possible results that we obtain while introducing a single sectoral patch of 120^0 and studying its gap coupled configurations and stacked configurations. Also we have done analysis of various modes which was lacking in the reported work. These are the gaps and limitation which are identified in the similar reported work and the project aims at overcoming these limitations and bridging the gap along with the introduction of novel proposed MSA structures by analysing them and providing proper explanation on the modal frequency response along with the study of impedance curve plot, current distribution and radiation pattern characteristics.

1.2 Organisation of thesis

The report provides a detailed study of various modified shapes of antennas to facilitate broad band operation. Thus by employing modified shapes of antennas, enhancement of the bandwidth is achieved. In chapter 1 we are studying a 120^0sectoralmicrostrip antenna and the broadband response obtained with redesigning it at 1000 and 2000 MHz of frequency range. Further various gap coupled designed structures of 120^0sectoralmicrostrip antenna are stated by placing the parasitic patch on co-ordinate axis and by placing the patch on co-ordinate axis. Here coupling between the patches take place and a wide band response is obtained as one mode of feed patch get coupled with mood of second patch. In chapter 3 we have discussed gap coupled using a single and two parasitic patches. Each shape is a novel design which results in a wideband response. Also to realize broadband response, suspended dielectric structures and defected ground plane are proposed. Various configurations of MSA which are modified by introducing slots and gap coupled and stacked configurations are proposed. Chapter 4 provides detailed analysis of stack patch antenna with 120^0 sector. In chapter 5 by using a defected ground structure a broader bandwidth is realised by cutting a slot in RMSA. By incorporating slots of varying dimensions, the effective length of the path traversed by the surface current waves is increased; consequently decreasing the frequencies of the higher order modes to resonate near the fundamental mode frequency. As a result, the two or more frequencies come closer to each other and coupling between them gives a broadband response and thus meets the broadband operation. Chapter 5 also states desktop shape antenna for a wideband response using defected ground structure. The analysis of the proposed MSAs is performed by observing resonance curve plots, surface current distributions, radiation pattern plots etc. For the simulation process, IE3D software has been used.

Chapter 2

Literature Survey

The broadband microstrip antenna (MSA) is realized by fabricating the patch on lower dielectric constant thicker substrate [1]. The thicker substrate reduces the quality factor of the cavity below the patch to realize larger bandwidth (BW). In most of the reported designs the patch is suspended in air, thereby realizing dielectric constant of unity. More commonly used technique to realize broadband MSA is by cutting the slot of different shapes like, U-slot, V-slot and rectangular slot at appropriate position inside the patch [2 –4]. The slot is said to introduce a mode near the fundamental mode resonance frequency of the patch, to yield broader BW. These slot cut MSAs are optimized on substrates of thickness 0.06 to $0.08\lambda_0$. For substrate thickness more than $0.08\lambda_0$, they are optimized using proximity feeding technique.

A new 270° sectoralmicrostrip antenna derived from circular microstrip antenna is proposed. Also its variations like, 300°, 320° and 340° sectoralmicrostrip antennas are proposed. In the proposed sectoral patch a new mode below the fundamental mode resonance frequency of the equivalent circular patch is introduced. The higher order mode frequencies of sectoral patch are higher than the frequencies of equivalent circular patch. The analysis for variation in bandwidth due to the coupling between the first two modes of the sectoral patch for different sectoral angle is presented. The optimum bandwidth of 500 MHz (>50%) is realized for 320° sectoral patch. The proposed antenna yields broadside radiation pattern with gain of more than 7 dBi over the operating bandwidth

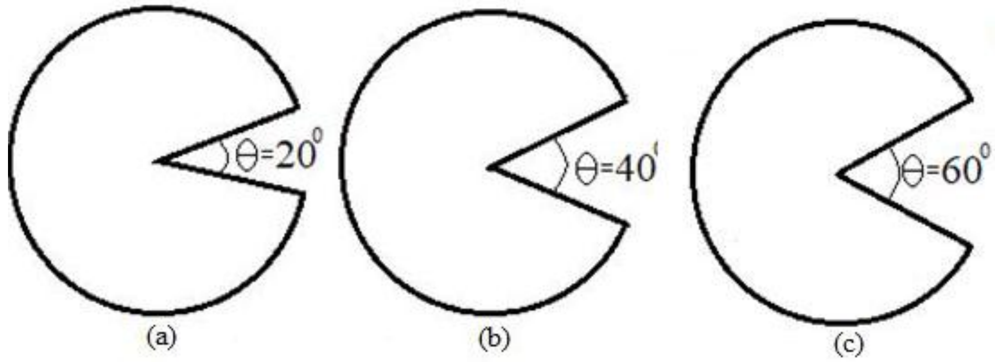


Figure 2.1. Proximity fed (a) 340°, (b) 320°, (c) 300° sectoral [9]

A new 270^0sectoral MSA which is derived from conventional CMSA is proposed. The proposed configuration has a new mode whose frequency lies below the TM_{11} mode resonance frequency of conventional CMSA. An analysis to study the effects of sectoral angle on the broader BW is presented. Along with 270^0sectoral MSA 340^0, 320^0 and 300^0sectoral MSAs were studied. Due to smaller separation between first two mode frequencies, smaller BW was realized in 340^0MSA. The optimum BW of nearly 500 MHz (50%) was realized for 320^0sectoral MSA. Although antenna shows higher cross polar levels but they may be useful in mobile communication environment.

Broadband sectoralmicrostrip antennas are proposed. The variation in sectoral angle changes the spacing between the first three patch resonant modes to yield bandwidth of more than 700 MHz (> 60%). Furthermore, the effects of variations in sector radius are presented. In a smaller sectoral angle, the sector radius optimizes the spacing between patch resonant modes to yield bandwidth of more than 850 MHz (~ 70%). Due to orthogonal surface currents at first and third resonant modes, the proposed antenna gives elliptical polarization with variation in gain from 8 to less than 4 dBi over the operating bandwidth.

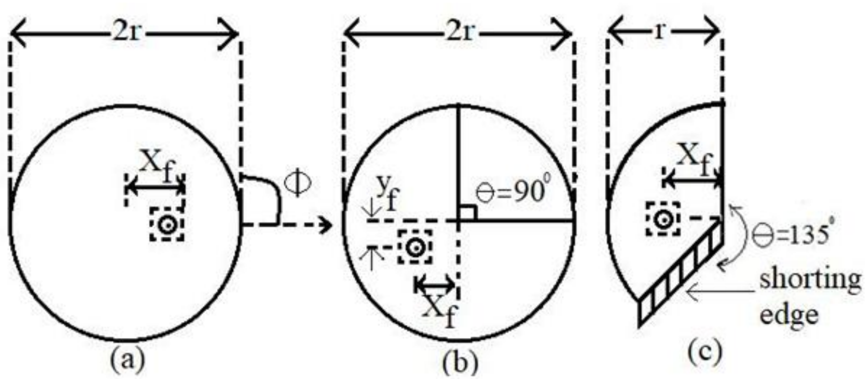


Figure 2. 2 (a) Top (b) 270° sectoral MSA, (c) shorted 135° sectoral MSA [11]

A new 270^0sectoral MSA is proposed. It has an additional resonant mode below the fundamental mode resonance frequency of the equivalent CMSA. Furthermore, by cutting a rectangular slot, broadband 270^0sectoral MSA is proposed. The position of slot is selected such that it realizes tuning of second-mode frequency with respect to first mode and yields BW of more than 500 MHz (>45%). This is more than the BW as that given by equivalent CMSA at its fundamental mode. The proposed antenna gives peak gain of nearly 8.5 dBi. This antenna can be used in 900 MHz GSM applications, whereas similar design in higher frequency range can find similar application in 1800 MHz frequency band

Analysis and design of broadband 90° Sectoralmicrostripantenna derived from 270° Sectoral patch is proposed. The formulationin resonant length at its fundamental mode and procedure to design 90° patch at different frequencies is presented. The proposed 90° patchyields higher bandwidth with better radiation pattern characteristics as compared to equivalent circular, 270° Sectoral, rectangular and their slot cut variations.

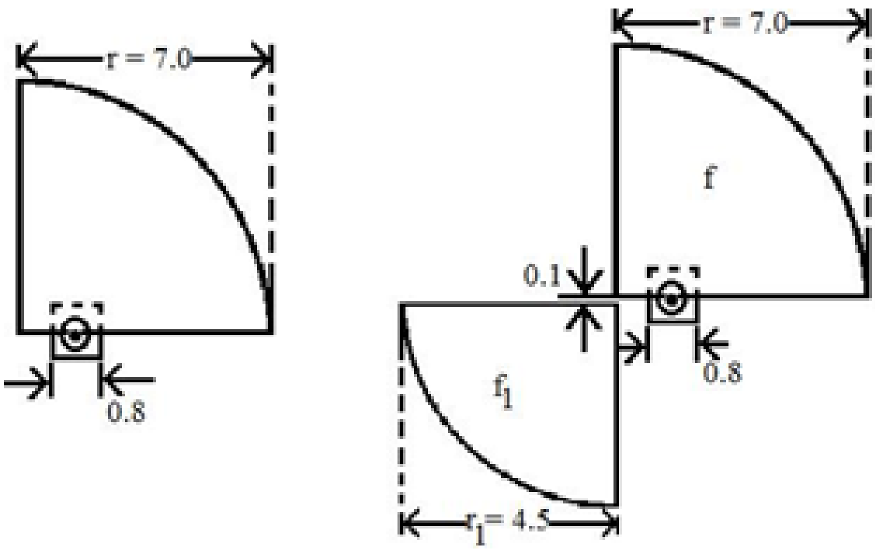


Figure 2.3 (a) Proximity fed 90° S-MSA. (b) Gap-coupled 90° S-MSAs [9]

A new proximity fed 90^0 S-MSA derived from 270^0 S-MSA is proposed. The formulation in resonant length at fundamental mode of 90^0 patch is presented. The frequency calculated using the same closely agrees with simulated result. The equivalent 90^0 S-MSA gives BW of nearly 1200 MHz (>55%) with broadside gain of more than 7 dBi. To compare, using the proposed formulations, design procedure for 90^0 S-MSA and its gap coupled variation is presented in different frequency bands, which gives broadband response. In a given frequency band, 90^0 S-MSA and its gap-coupled variation yields higher BW compared with regular and modified shape MSAs and their slot cut variations. It requires lesser patch area.A new 270°sectoralmicrostrip antenna (MSA) is proposed. It has additional resonance mode whose frequency lies below the fundamental mode of equivalent circular patch. Furthermore, slot cut 270°sectoral MSA is proposed. It gives bandwidth of more than 500 MHz (> 45%) with broadside radiation pattern and peak gain of 8.5 dBi.

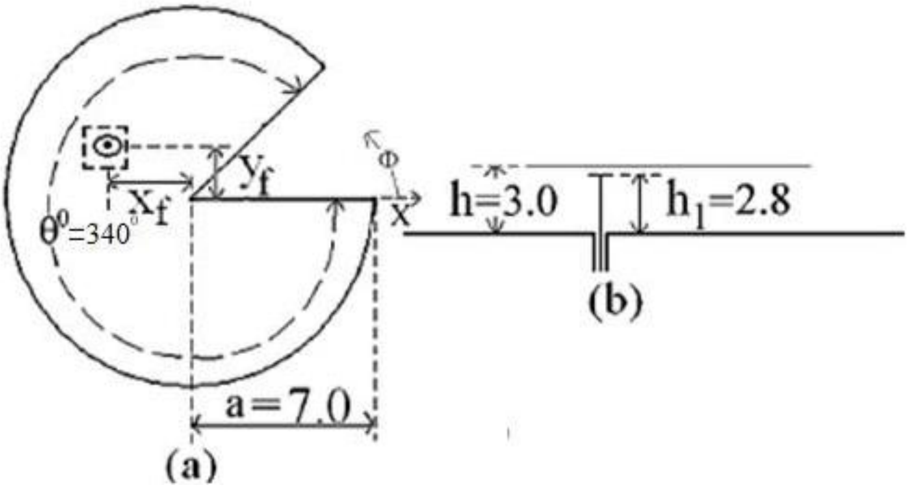


Figure 2.4 (a) Top and (b) side views of proximity-fed S-MSA [11]

A new 270° sectoral MSA is proposed. It has an additional resonant mode below the fundamental mode resonance frequency of the equivalent CMSA. Furthermore, by cutting a rectangular slot, broadband 270° sectoral MSA is proposed. The position of slot is selected such that it realizes tuning of second-mode frequency with respect to first mode and yields BW of more than 500 MHz (>45%). This is more than the BW as that given by equivalent CMSA at its fundamental mode. The proposed antenna gives peak gain of nearly 8.5 dBi. This antenna can be used in 900 MHz GSM applications, whereas similar design in higher frequency range can find similar application in 1800MHz frequency band.

Broadband variations of slot cut shorted 60^0Sectoralmicrostrip antenna using multi-resonator technique, are proposed. The slot tunes the spacing between TM1/4, 1 and TM1/4, 0 modes of the shorted patch, to yield broader bandwidth. The gap-coupled variation of slot cut shorted 60^0Sectoral patch with shorted 60^0Sectoral patch yields bandwidth of more than 900 MHz (~75%) whereas gap-coupled variation of two slot cut and shorted 60^0Sectoral patches yields bandwidth of more than 950 MHz (~78%). Due to the shorted patch, proposed configurations yields radiation pattern with higher cross polar levels with peak gain of more than 3.0 dBi.

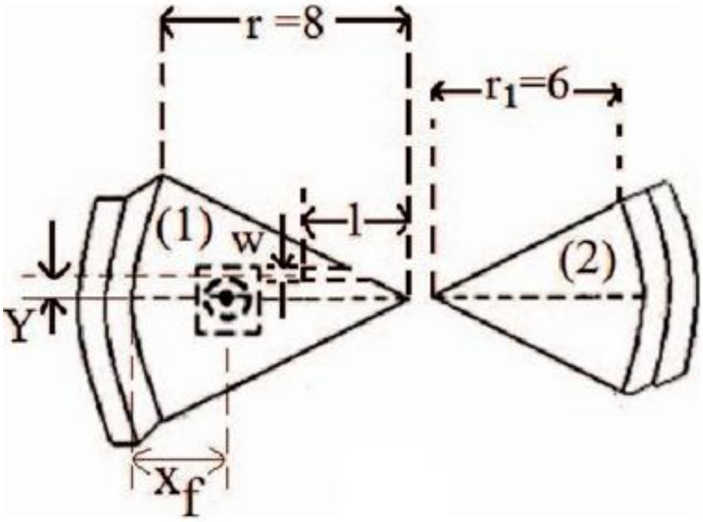


Figure 2.5 Broadband gap-coupled shorted 60^0 Sectoral MSAs [13]

The broadband gap-coupled variations of shorted slot cut 60^0Sectoral MSAs are proposed. The slot reduces theTM1/4,1 mode resonance frequency on shorted patch and along with TM1/4,0 mode frequencies yields broader BW. The slot cut shorted 60^0Sectoral MSA gap-coupled toshorted 60^0Sectoral MSA yields BW of around 930 MHz (75%) whereas gap-coupled configuration of two slot cut shorted 60^0Sectoral MSA yields BW of more than 950 MHz (~78%) . Due to shorted patches these configurations shows broad beam higher cross polar pattern thereby realizing elliptical polarization over most of the BW. The proposed antennas give gain of around 2 to 3 dBi over the BW.

A rectangular microstrip antenna with two U-shaped slots on the patch is described. Using a foam layer of thickness -9% wavelength as the supporting substrate, an impedance bandwidth of 44% is achieved. The radiation patterns are stable across the pass band.

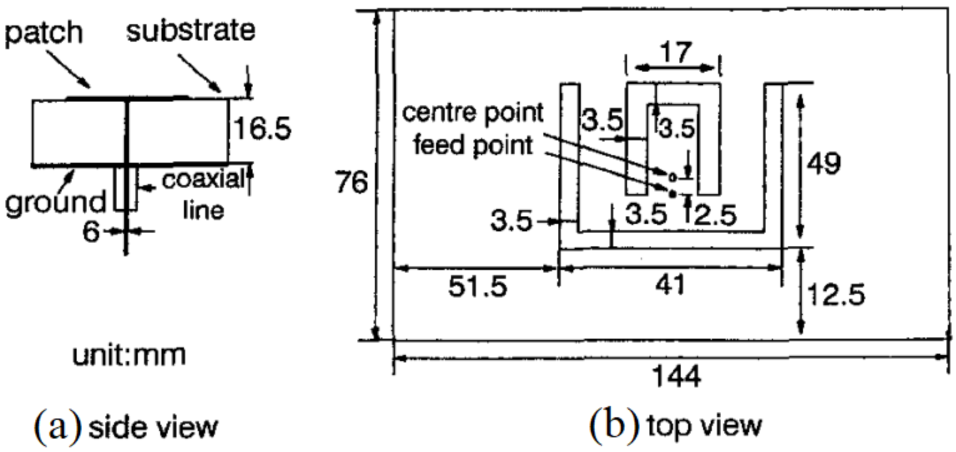


Figure 2.6 Geometry of double U slot patch antenna [12]

A double U-slot patch antenna has been described in this Letter. A third resonator is introduced by a second U-slot on the patch. The resulting bandwidth of the double U-slot patch antenna with a foam layer of thickness -9% of wavelength as a supporting substrate reaches 44% (SWR I 2). The patterns are stable across the passband.

Chapter 3

120^0 Sectoral Microstrip Antenna

Proximity fed design of CMSA, equivalent 270^0 S-MSA and 120^0 S-MSA is shown in Fig. 3.1(a – c). For h = 3.0 cm, circular patch radius is calculated for its TM_{11} mode frequency to be around 950 MHz[1]. The radius (r) is found to be 7 cm. The simulated plot showing variations in real and imaginary part of input impedance for this circular patch obtained using IE3D software is given in Fig. 3.1(d). Resonant peaks due to fundamental TM_{11} (945 MHz) and higher order TM_{21}, TM_{02} and TM_{31}modes are observed. In equivalent 270^0 S-MSA, additional resonant mode whose frequency lies below the TM_{11} mode of CMSA, is seen[13, 14] as shown in Fig. 3.1(d). In 270^0 S-MSA, across fundamental and higher order resonant modes, bi-directional variations in surface currents exist. Due to this BW realized with respect to these modes, shows higher cross polar level radiation pattern[13, 14]. To realize 120^0 S-MSA, first complementary of 270^0Sectoral patch is realized (90^0 S-MSA) and further its angle is increased from 90^0 to 120^0, as shown in Fig. 3.1(c). The 120^0 S-MSA is simulated for x_f = 3.5 cm, and its impedance plots showing variations in real and imaginary part of input impedance, is shown in Fig. 3.1(d). A resonant peak at a frequency equal to 1187 MHz is observed. Surface current distribution at the same is shown in Fig 3.2. One half wavelength variations in surface currents that is directed along $\Phi = 135^0$,is observed. This is the fundamental mode in Sectoral patch. An effect of variation in proximity feed location in 120^0 S-MSA on the excited resonant modes is studied and the same is shown in Fig. 3.2. When feed is placed towards the patch vertex point (i.e. 'x_f' is decreased), frequency of observed resonant mode increases. The surface current distribution for 120^0 S-MSA, for 'x_f' = 1.0 cm is shown in Fig. 3.3(b). At this feed location, current now shows half wavelength variation along orthogonal diagonal patch axis, i.e. along $\Phi = 45^0$. Due to current variation along patch radius here, fundamental resonant mode frequency has increased. Thus in 120^0 S-MSA, an appropriate selection of proximity feed position will give dual polarized response, i.e. E-plane is either directed along $\Phi = 135^0$ or along $\Phi = 45^0$.

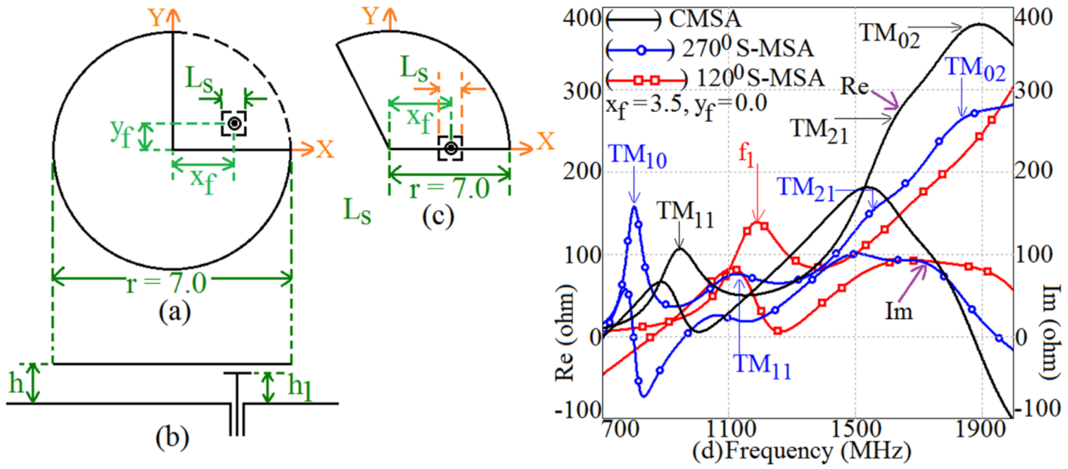


Figure. 3.1 (a) Top; and (b) side views of proximity fed CMSA and 270^0 S-MSA; (c) proximity fed 120^0 S-MSA and their (d) resonance curve plots showing impedance variations against frequency

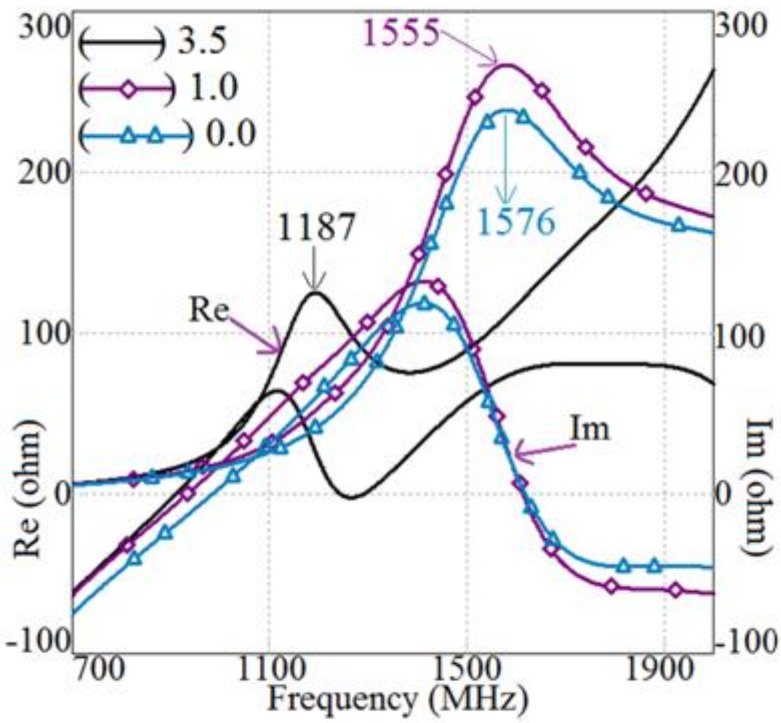


Figure 3.2 Resonance curve plots for varying feed point locations, h = 3.0 cm; h1 = 2.8 cm.

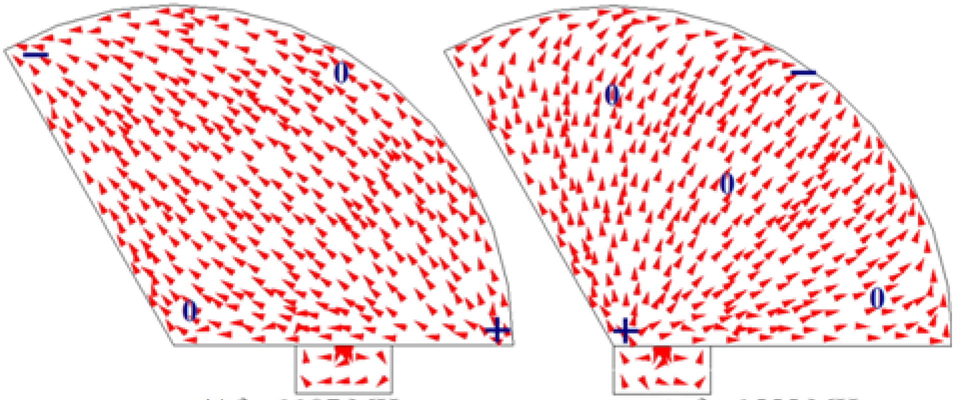


Figure 3.3 (a) (b)Their surface current distribution for xf = (a) 3.5; and (b) 1.0 cm for proximity fed 120^0 S-MSA

In the present work, proximity feed location below the vertex point of 120^0 S-MSA is chosen. For h = 3.0 cm, and h1 = 2.8 cm, by optimizing strip dimensions, broadband response in 120^0 S-MSA is realized. The input impedance plots obtained using simulations is shown in Fig. 3.4(a). The simulated BW is 1090 MHz (57.3%). Using VNA 'ZVH-8' experiment was carried out, and the measured BW is 1124 MHz (60%) as shown in Fig. 3.4(a). The air substrate thickness in 120^0 S-MSA is 3.0 cm. With respect to fundamental mode frequency of 120^0 S-MSA, here air substrate thickness is $0.16\lambda_0$. This substrate thickness is higher. Therefore, an effect of reduction in substrate thickness on fundamental mode frequency of 120^0 S-MSA is studied. Resonance curve plots showing variations in real and imaginary part of input impedance for the same are explained in Fig. 3.4(b). It is observed that frequency increases with decrease in thickness. This increment is attributed to variation in fringing field length with the thickness. By optimizing coupling strip dimension wide band response in 1200 S-MSA is obtained for h = 2.0 cm. Here, in optimum design, strip parameters are, Ls = 1.4 cm, xf = 0.9 cm and h1 = 1.6 cm. Input impedance plots for the same are shown in Fig. 3.2. Here the simulated and measured BW's are 1261 MHz (58.2%) and 1289 MHz (62%). Due to optimum placing of loop inside VSWR = 2 circle in smith chart, wider BW is obtained for h = 2.0 cm than in 3.0 cm. The fabricated prototype of Sectoral antenna is shown in Fig. 3.4(d). For Sectoral MSA with 'h' = 2 cm, radiation pattern is measured over the BW and at center frequency it is shown in Fig. 3.5(a, b). As observed from the current distribution as shown in Fig. 3.3,since effective current contribution is directed along diagonal axis, E-plane is directed along Φ = 450. Due to uni-directional current variation present over most of the patch, pattern is in the broadside direction with cross polar levels less than 10 dB.

Similarpattern characteristics are observed over the complete BW. The 120^0 S-MSA shows co-polar gain of more than 7 dBi over complete BW with peak gain of above 9 dBi as shown in Fig. 3.5(c). In pattern and gain measurements, reference Horn antenna operating in the same frequency range was used.

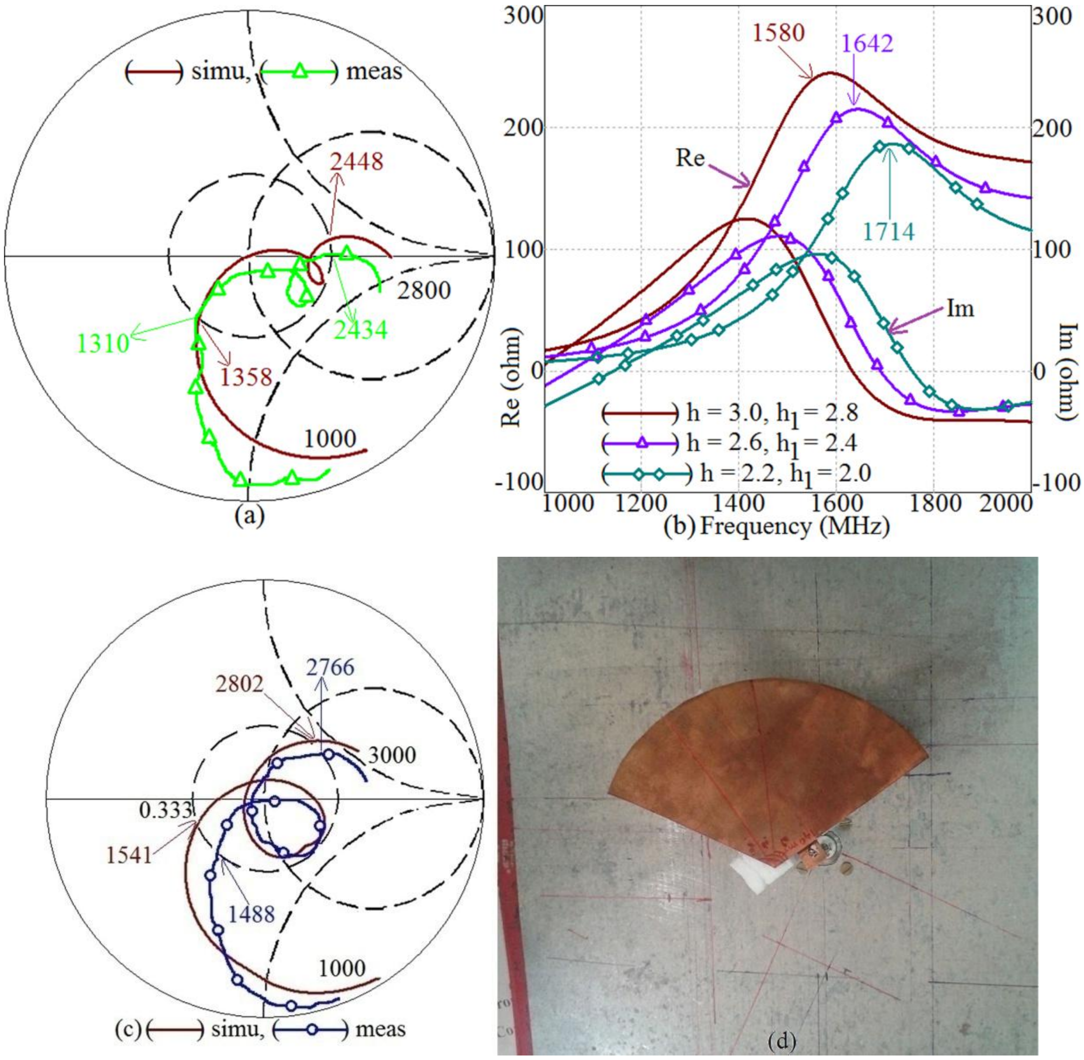


Figure 3.4 (a) Input impedance plots for h = 3.0 cm; (b) resonance curve plots for variations in 'h' and 'h1'; (c) input impedance plots for h = 2.0 cm; and (d) fabricated prototype; for proximity fed 120^0 S-MSA

Further to design 120^0 S-MSA, resonant length formulation at its fundamental mode is proposed. As seen from current distribution in Fig. 3.3(b), maximum contribution of surface currents are varying along the radial length and also it is the shortest length in Sectoral patch. Therefore resonant length formulation at fundamental mode (re) for proximity feed positionnearer the vertex point in 120^0 S-MSA is obtained by using equation (1). The second term on right hand side of equation (1) accounts for fringing field extension length. On air substrate, resonance frequency (fr) is calculated by using equation (2). For the given 120^0 S-

MSA and for substrate thickness (h) of 3.0, 2.6 and 2.2 cm, the calculated frequencies are, 1595, 1651 and 1712 MHz, respectively. These frequencies are in close agreement with simulated values, as given in Fig. 3.4(b). Further using proposed formulation 120^0 S-MSA is designed for fundamental mode frequency of 1000 and 2000 MHz, as discussed below.

$$\boldsymbol{re = r + 0.8(h + ha)(1)}$$

$$\boldsymbol{fr = \frac{30}{2re}} \qquad \textbf{(2)}$$

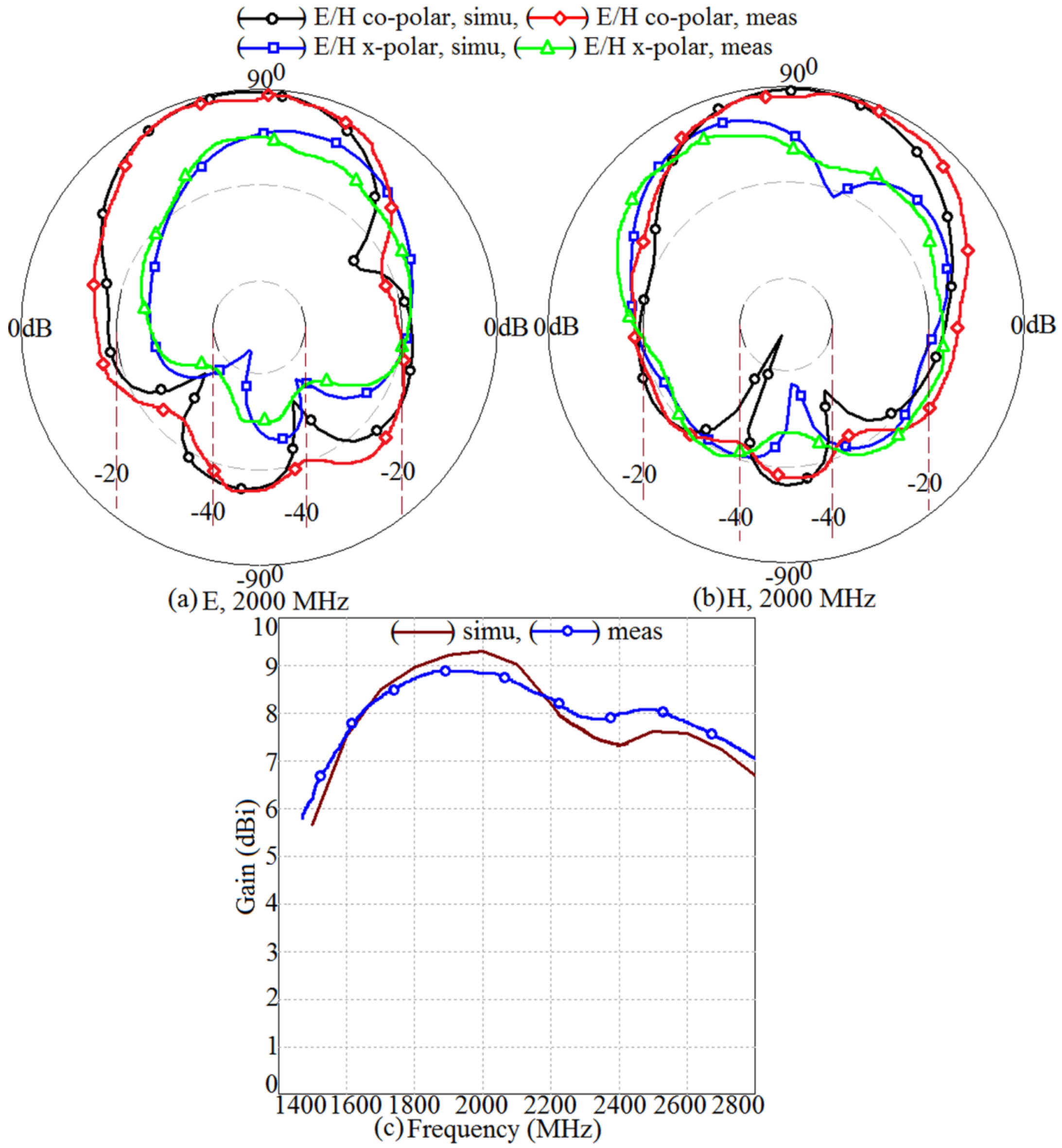


Figure 3.5 (a, b) Polar radiation pattern plot at centre frequency of BW; and (c) gain variation over the same for proximity fed 120^0 S-MSA

3.1 Design of Proximity Fed 120^0 S-MSA

A 120^0 S-MSA is designed using above formulation for fundamental mode frequency of 1000 and 2000 MHz. Since proximity feed is used, at each frequency design is presented for substrate thickness of $0.1\lambda_0$. At 1000 MHz frequency, for substrate thickness of 3.0 cm ($0.1\lambda_0$), using equation (1) and (2), radius of Sectoral patch is calculated to be 12.6 cm. This Sectoral patch when simulated shows frequency of 1037 MHz, which is closer to the desired value. Further by optimizing strip parameters, wide band response is realized. For Ls = 2.2 cm, x_f = 0.4 cm and h_1 = 2.5 cm simulated BW is 603 MHz (51%) as shown in Fig. 3.1.1(a). The experiment was carried out and measured BW is 615 MHz (52.7%). Similarly using equation (1) and (2), for fundamental mode frequency of 2000 MHz, and for substrate thickness of $0.1\lambda_0$, patch radius of 120^0 S-MSA is calculated to be 6.3 cm. This when simulated gives frequency of 2060 MHz which is closer to the desired frequency. The antenna is optimized for wider BW by tuning strip dimensions, its position below the patch and the substrate thickness. A simulated BW of 1150 MHz (48.8%) for Ls = 1.1 cm, xf = 0.5 cm and h_1 = 1.2 cm is obtained as shown in Fig. 3.1.1(b). In this case measured BW is 1175 MHz (49.9%). For 120^0 S-MSA at 1000 MHz, radiation pattern at center frequency of BW and gain variation over the same are shown in Fig. 3.1.2(a – c). The pattern remains in the broadside direction across entire BW with co-polar peak gain of more than 9 dBi. Similar pattern and gain response is obtained for Sectoral MSA at 2000 MHz. Thus proposed formulations can be used to realize broadband proximity fed 120^0 S-MSA at given resonance frequency on thicker air substrate.

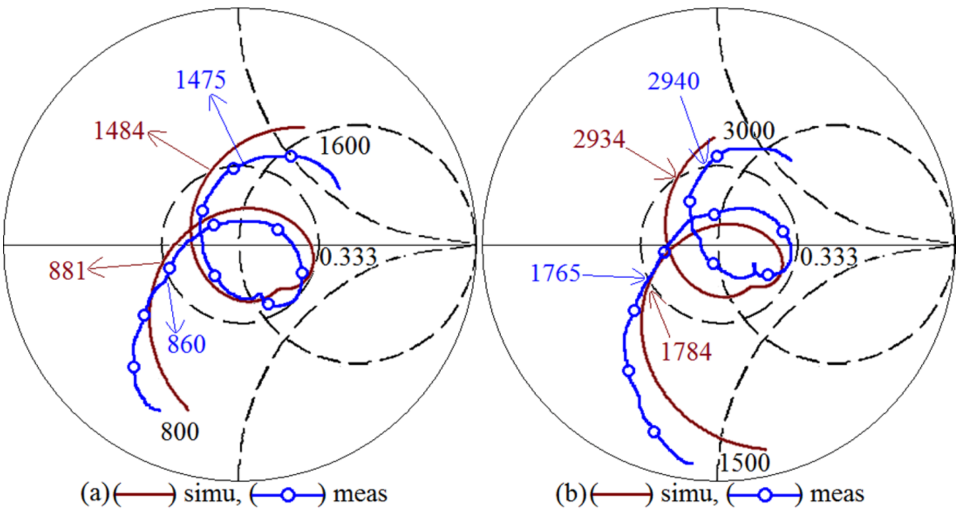


Figure 3.1.1 Input impedance plots for proximity fed 120^0 S-MSA for fundamental mode frequency of (a) 1000; and (b) 2000 MHz

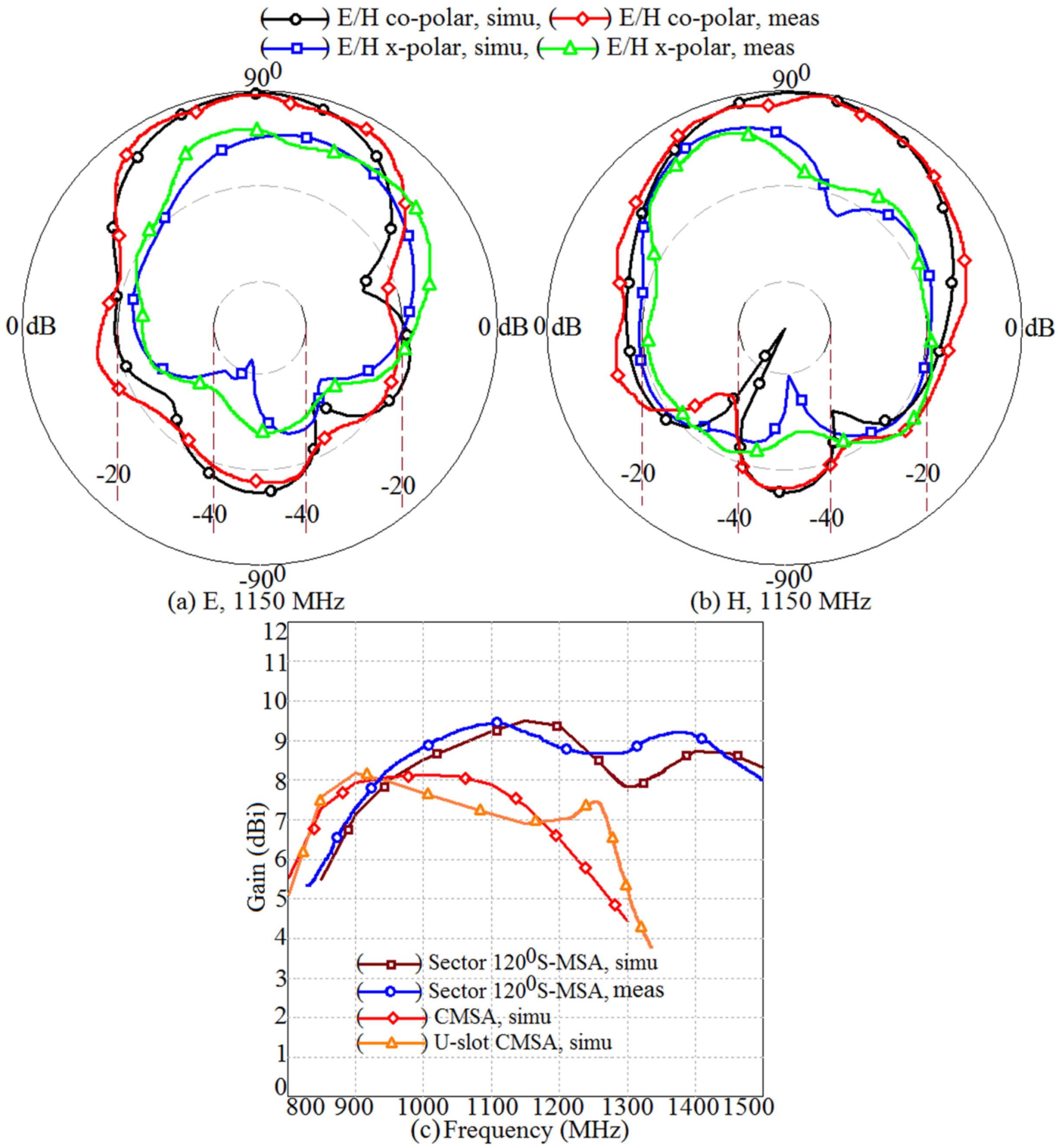


Figure 3.1.2 (a, b) Polar radiation pattern plot at center frequency; and (c) gain variation over BW for proximity fed 120^{0}S-MSA at 1000 MHz

The proximity fed CMSA for r = 7 cm, gives simulated and measured BW of 382 MHz (36.7%) whereas U-slot cut CMSA of same patch radius yields BW of 454 MHz (43.5%). Here the patch area is 154 cm^2. The simulated gain plots for CMSA and U-slot cut CMSA are also given in Fig. 3.1.2(c). The patch area for 120^0 S-MSA at 1000 MHz is 166 cm^2. Thus in comparison proposed Sectoral patch with only 7.2% increase in patch area, yields higher BW with better gain characteristics (larger peak gain) as compared to the CMSA and its U-slot cut variation.

3.2Broadband 120^0 S-MSA Variations

The proximity fed 120^0 S-MSA is shown in Fig. 3.2.1(a, b). Patch is fabricated on glass epoxy substrate (h = 0.16 cm) and it is suspended above ground plane with finite air gap 'ha'. Using formulation of resonant length as given in equation (1) patch radius (r) for fundamental mode frequency of 1200 MHz is calculated [4]. On total substrate thickness of 2.56 cm (~$0.1\lambda_0$) (ha = 2.4 cm), 'r' is found to be 10.3 cm.

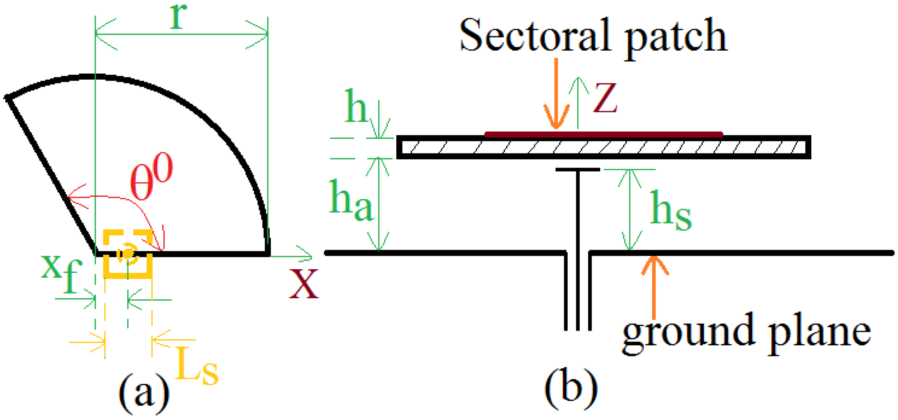


Figure3.2.1 (a, b) Proximity fed 120^0 S-MSA

$$re = r + 0.8(h + ha)(1)$$

$$fr = \frac{30}{2re} \qquad (2)$$

By optimizing position of strip (xf) and its dimension (Ls), 120^0 S-MSA is optimized for wider BW as shown in Fig. 3.2.2(a). The simulated and measured BW's are, 647 MHz (48.5%) and 662 MHz (50.1%), respectively. In 120^0 S-MSA, radiation pattern at the center frequency as shown in Fig. 3.2.2(c, d) and over the BW is in the broadside direction with co-polar antenna gain of above 7 dBi as shown in Fig. 4.2(e).

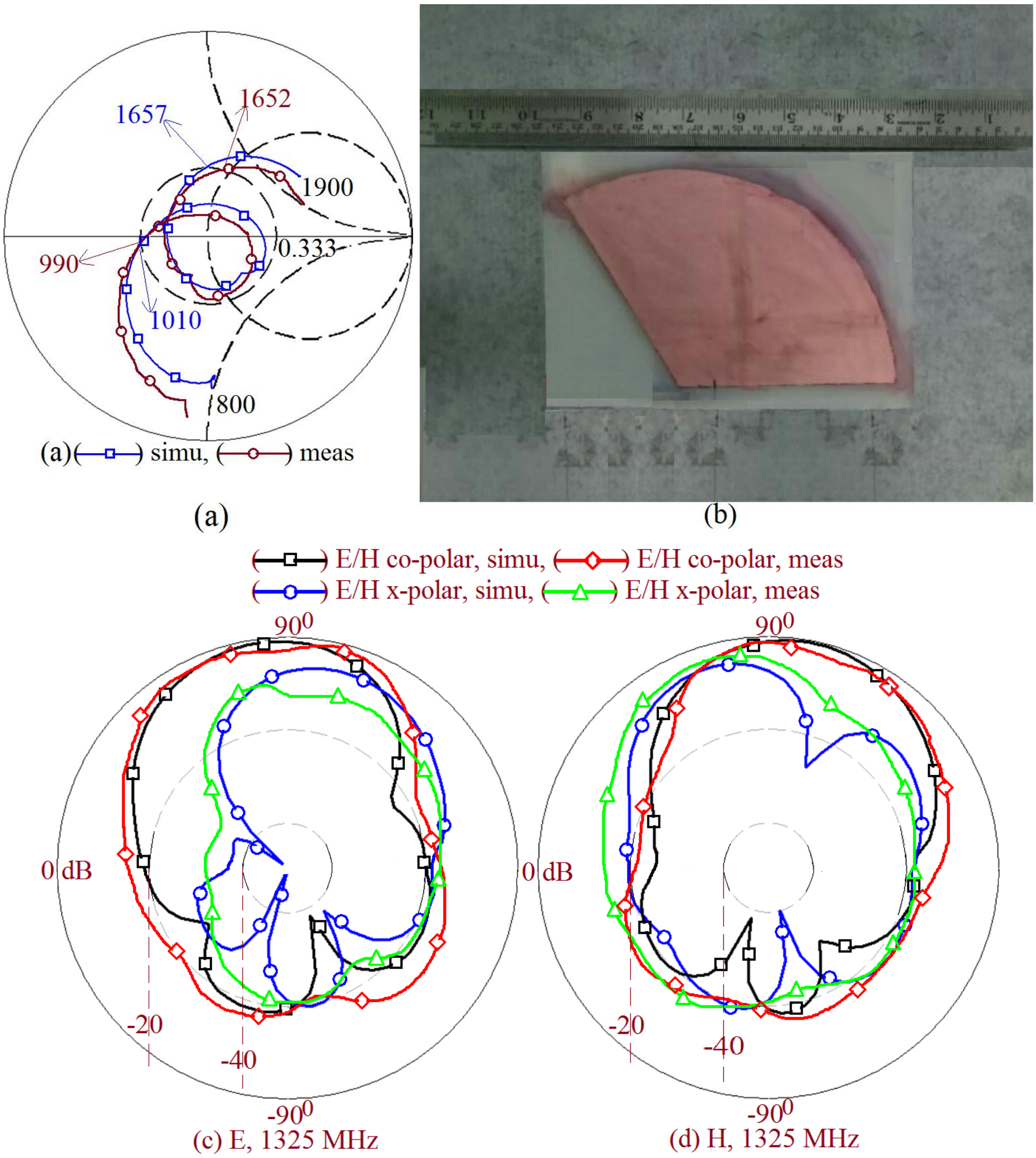


Figure 3.2.2 (a) Input impedance plots, (b) fabricated prototype, (c, d) radiation pattern at centre frequency of BW

Chapter 4

Gap Coupled Variations OfBroadband 120^0 S-MSA

To increase the BW in 120^0 S-MSA, its gap-coupled designs were studied as shown in Fig.4.1(a, b). The MSAs are coupled along two co-ordinate axes. Radius of parasitic S-MSAs is taken to be smaller to ensure larger BW. By optimizing gap between two patches, wider BW is realized in the two designs as shown in Fig. 4.1(c). For 'g' = 1.6 cm, simulated BW of 816 MHz (62.72%) is obtained for S-MSAs coupled along x-axis whereas for 'g' = 0.7 cm, simulated BW of 814 MHz (58.1%) is obtained in S-MSAs coupled along y-axis. The co-polar broadside simulated gain plots for two gap-coupled designs are shown in Fig.4.2(e). Peak gain of more than 10 dBi is observed in MSAs gap-coupled along x-axis. However, either along two axes, overall antenna size is larger. Therefore gap-coupled design along diagonal axis is studied as shown in Fig.4.1(d). This gap-coupled antenna yields BW of more than 820 MHz (~60%) with peak antenna gain of more than 9 dBi.

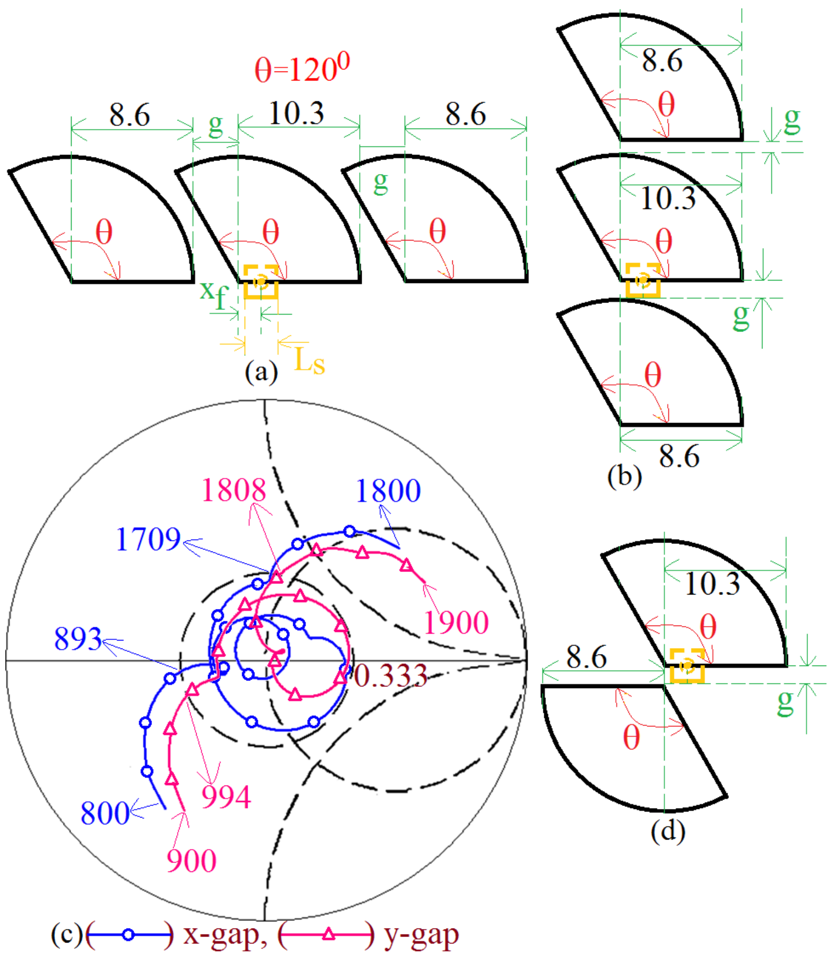


Figure 4.1 (a, b) Gap-coupled variations of 120^0 S-MSAs and their (c) simulated input impedance plots, (d) 120^0 S-MSAs gap-coupled along diagonal axis

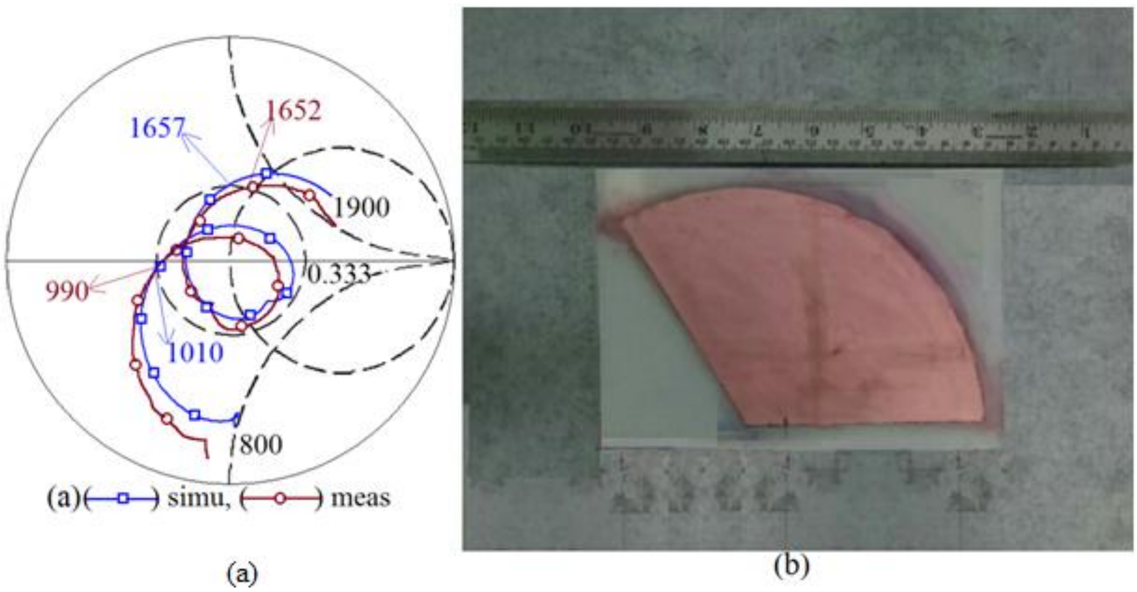


Figure 4.2 (a) Input impedance plots,(b) fabricated prototype

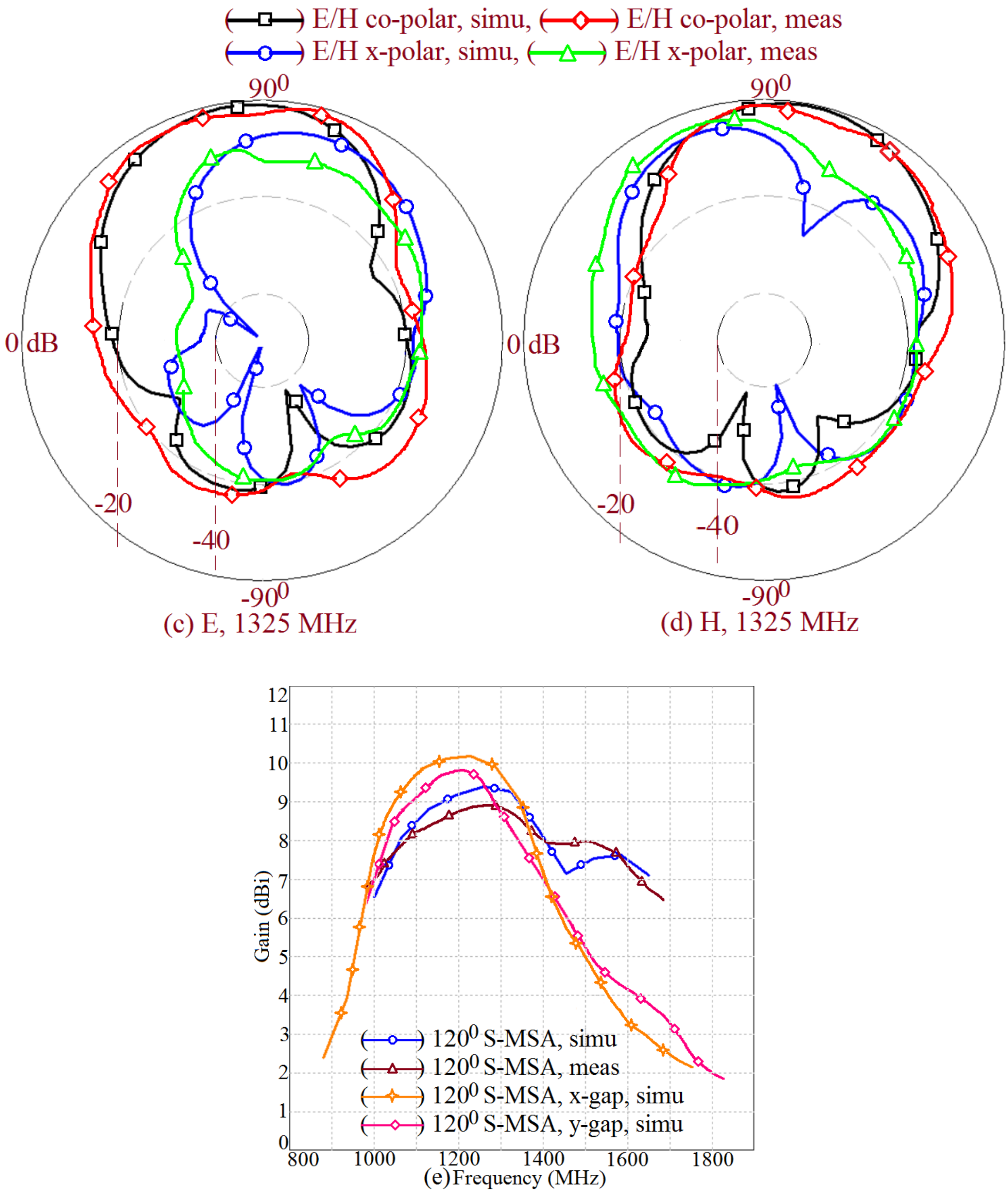


Figure 4.2 (c, d) radiation pattern at center frequency of BW and (e) gain variation for 120^0 S-MSAs

4.1 Gap-Coupled Variations of 120^0 S-MSAs

Proximity fed design of 120^0 S-MSA on suspended glass epoxy substrate (εr = 4.3, h = 0.16 cm, tan δ = 0.02) is given in Fig. 4.1(a, b). Use of air suspended configuration improves antenna's BW and gain, whereas uses of suspended substrate improves reliability of antenna parameters against substrate parameter variations. Proximity feeding technique is a variation of electromagnetic feeding method as employed in antennas [1]. Here instead of a resonating element, compact coupling strip is used to feed the energy to the radiating patch. Further it is very simpler method to be implemented for use in the thicker substrate. For fundamental mode frequency of 1200 MHz and the total substrate thickness of $0.1\lambda_0$, radius of 120^0Sectoral patch is calculated using frequency equation for same as reported in [6]. An optimized design of 120^0 S-MSA at 1200 MHz, yields two BW's namely simulated and measured, of 650 MHz (~49%). It exhibits pattern in broadside and shows gain of above 7.5 dBi. Various gap-coupled configurations of 120^0 S-MSA were further studied for enhancement in BW and gain. The patches are coupled along the diagonal axis (to reduce overall increase in size) as given in Fig. 4.1.1(a – e). In each of the gap-coupled variations radius of parasitic Sectoral patch is taken to be less than that of fed patch. For the configuration as shown in Fig. 4.1(c), variations in modal frequencies on two Sectoral patches with parasitic patch radius variations are shown in Fig. 4.1.2(a). With decrease in 'r_1' fundamental mode frequency on parasitic Sectoral MSA increases and maximum BW is obtained for 'r_1' = 8.6 cm, when two mode frequencies on fed and parasitic patches are optimally spaced. Simulated smith chart for this variation is provided in Fig. 4.1.2(b).

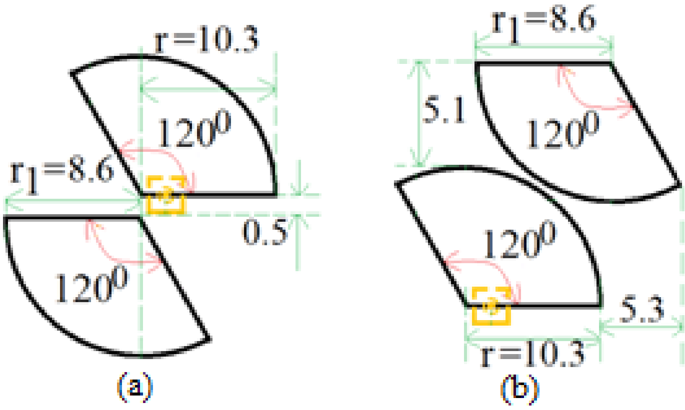


Figure 4.1.1(a – b) variations of proximity fed gap-coupled 120^0 S-MSAs using a single parasitic patch

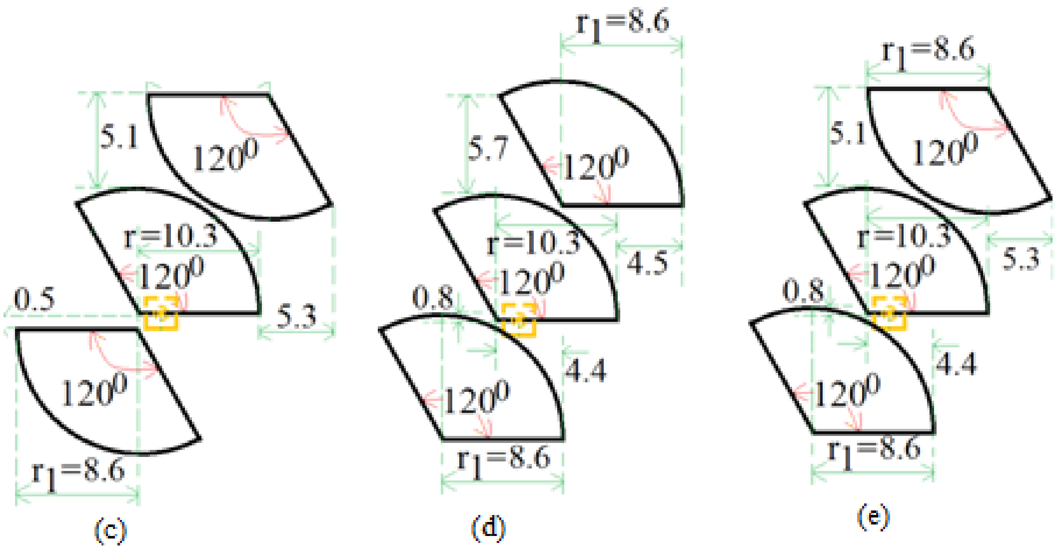


Figure 4.1.1(c– e) variations of proximity fed gap-coupled 120^0 S-MSAs usingtwo parasitic patches

For this design, BW using simulation is 829 MHz (59.2%). An experiment is carried out by fabricating MSA on suspended substrate. BW observed in experimentation is 843 MHz (61.2%). Antenna's fabricated prototype is given in Fig. 4.1.2(c). For this gap-coupled design, pattern exhibits maxima in the bore-sight direction as shown in Fig. 4.1.3(a, b). However, as position of proximity strip is not symmetrical with respect to two patches, the radiation pattern shows maxima away from the bore-sight direction. Due to radial direction surface currents, E and H-planes are aligned along $\Phi = 45^0$ and 135^0, respectively. The simulated gain plot over BW for this gap-coupled design is shown in Fig. 4.1.3(c). The peak antenna gain is more than 8 dBi. The reduction in gain towards higher frequencies of BW is attributed to the shifting of radiating pattern ways from the bore-sight direction, i.e. from along, $\Phi = 0^0$ and $\theta = 0^0$. Similarly gap-coupled variation of 120^0 S-MSA as shown in Fig. 4.1(d) is optimized for wider BW. In this variation, simulated and measured BW's are, 735 MHz (57.2%) and 755 MHz (59.6%), respectively as given in Fig. 4.1.4(a-d). This configuration also exhibits bore-sight radiation pattern but it yields peak gain of more than 9 dBi.

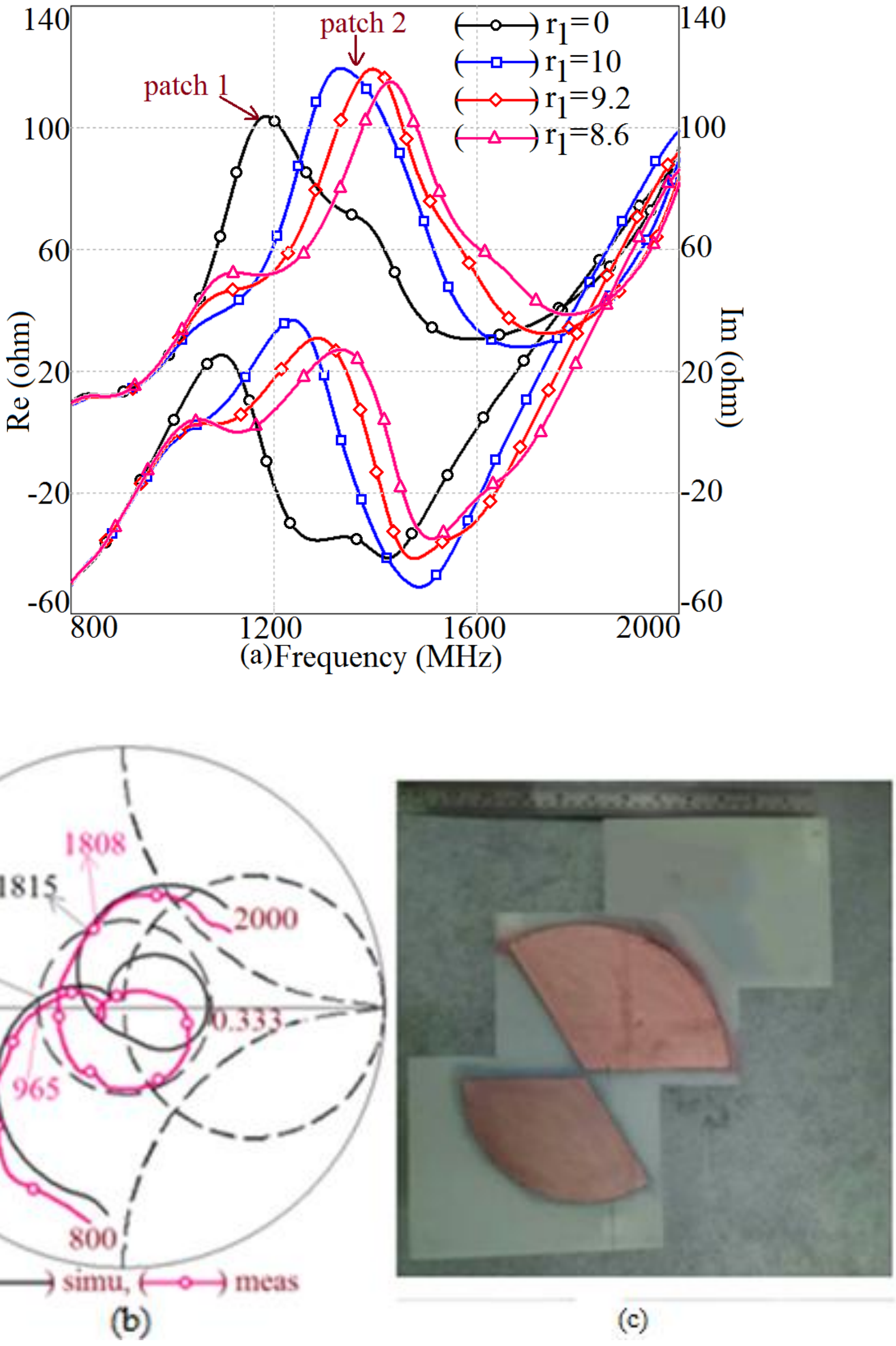


Figure 4.1.2(a) Resonance curve plots for gap-coupled proximity fed 120^0 S-MSA as shown in Fig.4.1.1(a), its (b) smith chart and the (c) fabricated prototype

Instead of using single parasitic patch, BW enhancement is also studied by using two parasitic patches as shown in Fig. 4.1.1(c – e). Here in three designs, radius of parasitic 120^0 S-MSAs is kept the same. This will yield nearly same parasitic patch resonance frequency (difference in two frequencies may be present due to varying mutual coupling between fed Sectoral patch to parasitic Sectoral patches with respect to changing field distributions around the patch periphery). The dimensions of the optimized MSAs are given in Fig. 4.1.1(c - e).

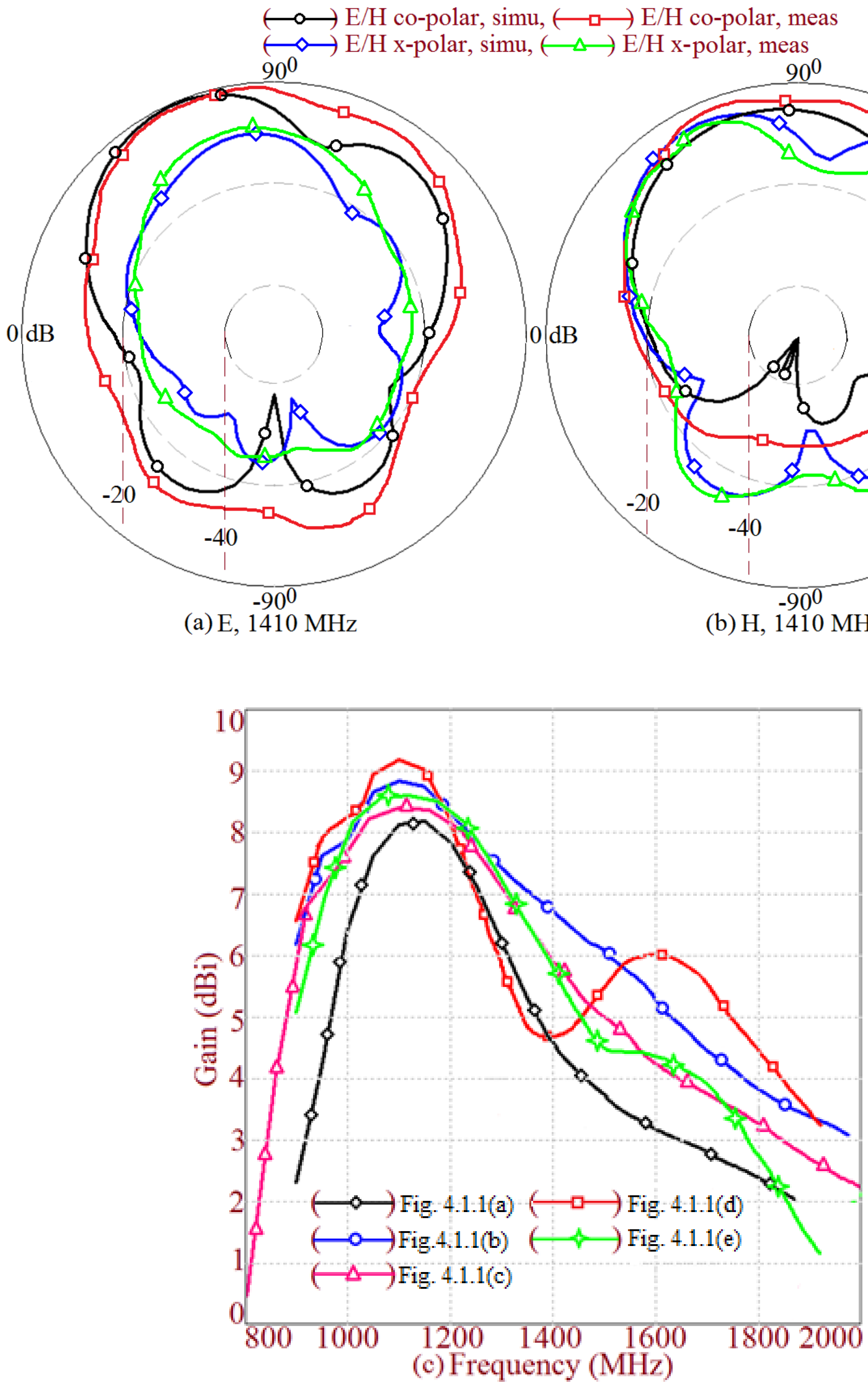


Figure 4.1.3 (a, b) Pattern plots at BW's center frequency for MSA given in Fig. 4.1.1(a) and (c) plots for gain variations across BW using simulations in gap-coupled proximity fed 120^0 S-MSAs

For the antenna as given in Fig. 4.1.1(c), BW's using simulation and measurement are, 934 MHz (67.6%) and 950 MHz (70.11%), respectively as provided in Fig. 4.1.4 (b). Similarly these two BW's for multi-resonator antenna as shown in Fig. 4.1.4(f) are, 930 MHz (65.1%) and 952 MHz (67.13%), respectively as shown in Fig. 4.1.4(c). For the antenna as shown in Fig. 4.1.1(d), a maximum BW is realized. Here the simulated BW is 1062 MHz (73.7%) as given in Fig. 4.1.4(d).

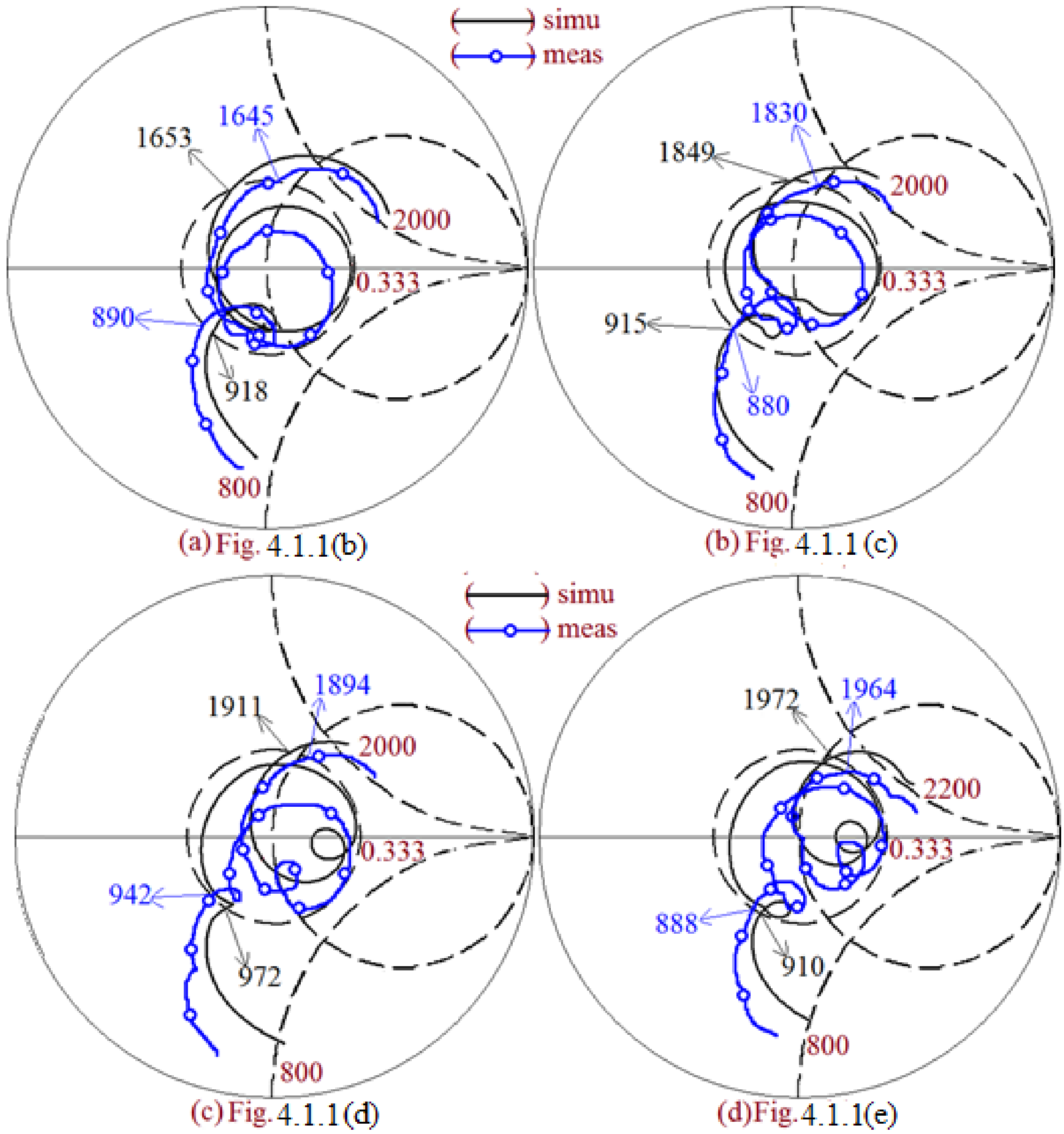


Figure 4.1.4 (a – d) Optimum smith charts highlighting the realized BW for gap-coupled designs as provided in Fig.4.1.1

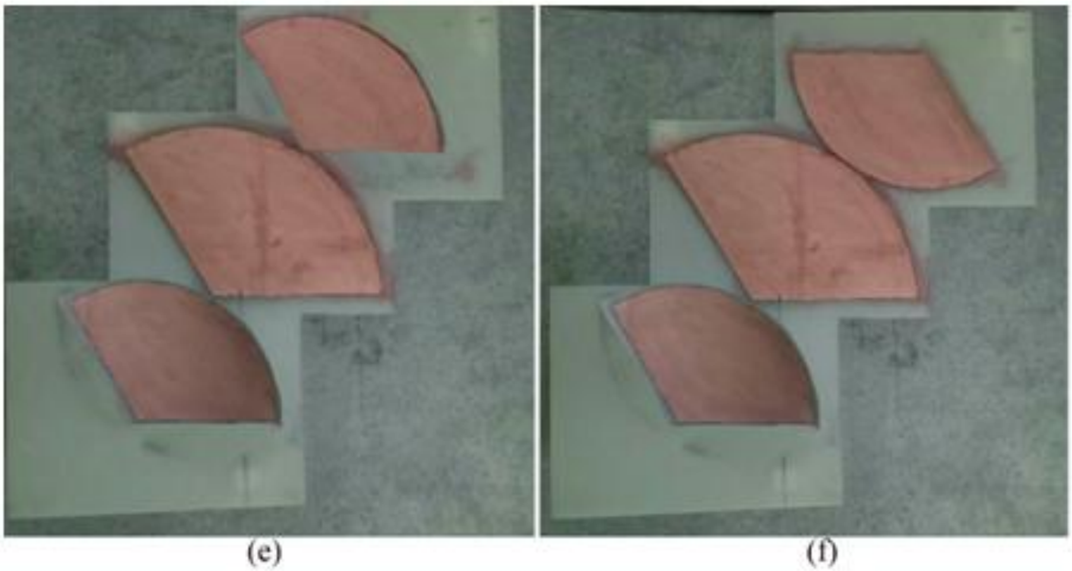


Figure 4.1.4 (e, f) respective fabricated prototypes

Experiment has been carried out and measured BW is 1076 MHz (75.2%). Fabricated prototypes for some of the gap-coupled designs are presented in Fig. 4.1.4(e, f). The pattern in these gap-coupled designs is in bore-sight directions. Due to patches present on both side of fed patch, pattern maxima variation away from bore-sight direction over BW is lower. All these designs yield peak gain of more than 8.5 dBi.

4.2 120^0 Stack Patch Antenna

We have seen bandwidth enhancement using parasitic patches which are kept along the co-ordinate axis first then along diagonal axis. Bandwidth enhancement can also be done by using stack configuration in which the feed patch is kept and above it another patch is kept at an optimum height. The radius of the feed patch is calculated by using the resonant length equation and radius of the parasitic patches is kept small. Here we have proposed two stack configurations using a single patch and two patches. The 120^0sectoral stack patch antenna is as shown in the fig.4.2.1(a),(b),(c).There are two patches kept one below the other which can be seen in the fig.4.2.1. The feed patch is of the radius r_2 and the stack patch has a radius of r_1. Proximity feed is given to the feed patch which is kept at a height of h_2 from the ground plane. Stack patch is kept at a height h_1 above feed patch. Height of the proximity feed is given by hs. Probe length is given by Ls. The feed is given at the vertex point to the patch with radius r_1. The input impedance plot for single stack patch is as shown in fig.4.2.1(a). The loop completely lies inside the VSRW=2 circle it gives a bandwidth of 890MHz. The fabricated prototype is also seen in fig.4.2.2 .

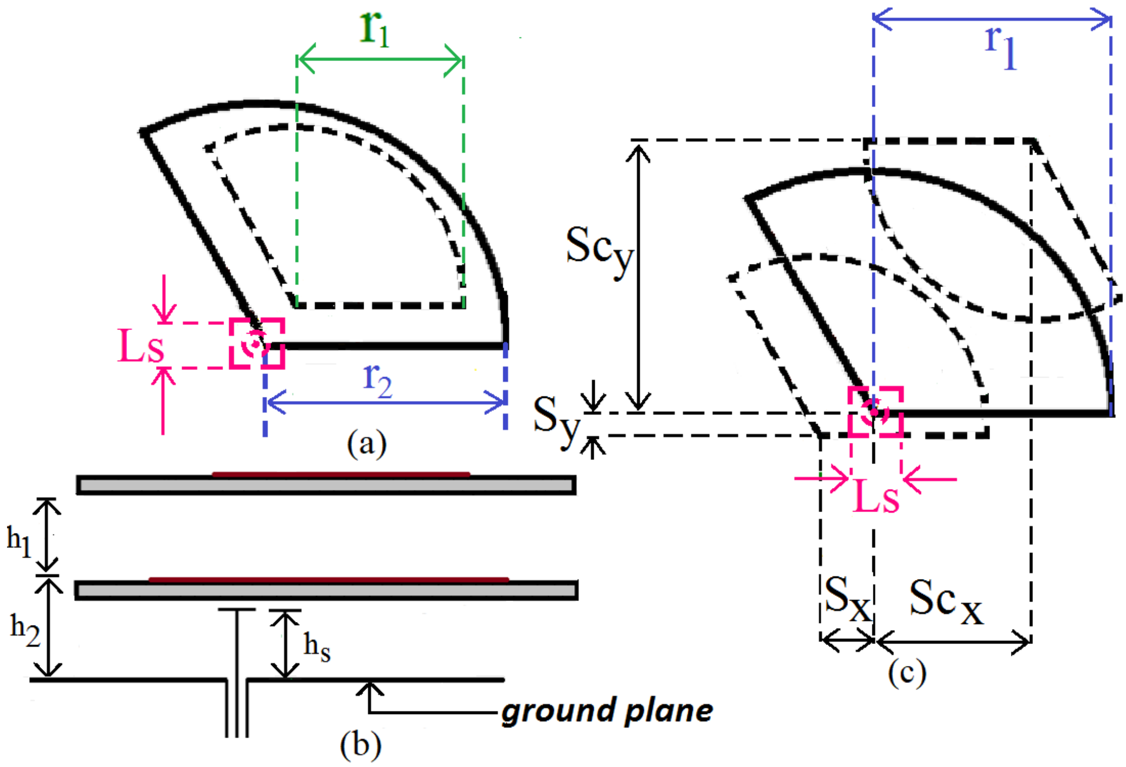
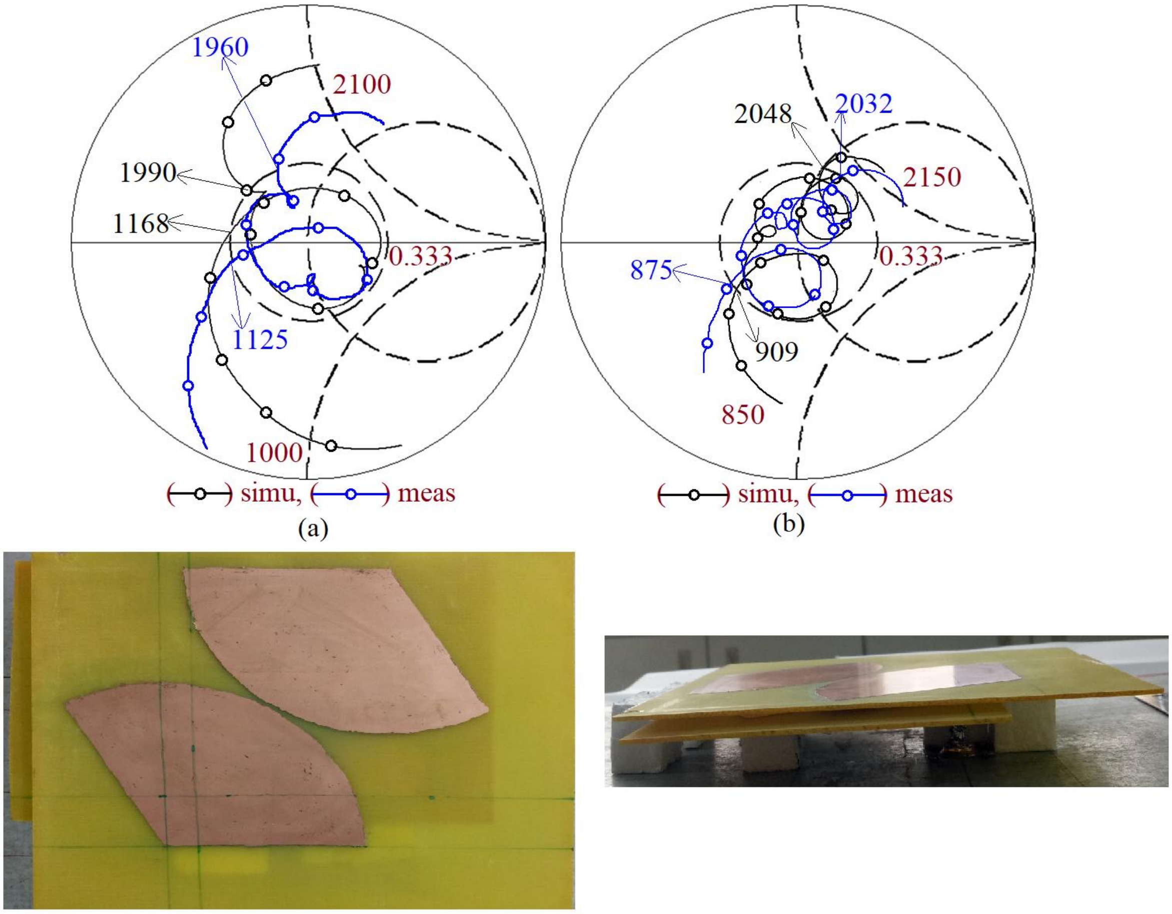


Figure 4.2.1 (a) Top view of stack 120° sectoral patch using single patch and its (b) side view and (c)Top view of stack 120° sectoral patch using two parasitic patches.

Fig.4.2.1(c) shows 120^0 sectoralmicrostrip antenna having 2 stack patches. This antenna can be seen in the fig. Here the height of the fed patch from the ground is $h_{2.}$ Radius of the sectoral patch is given by $r_{1.}$ The radius of patch r_1 is greater than that of r_2. The separation between the two vertices of 120^0 sector is Sx and the distance between the two vertices in y axis is given by Sy. The separation between patch 2 and feed patch is given by $Sc_y$and $Sc_{x.}$ the height of the stack patch from the feed patch is given by h_1 radius of the feed point is given by Ls=1.6mm. fig.4.2.2(a)(b) shows the smith chart with the response from stack patch having two 120^0sectoral patches. The loop lies completely inside the VSWR=2 circle and the bandwidth obtained is 908 MHz and gain obtained is 8 dBifig.4.2.2 (a-b) shows the fabricated prototype of stacked 120^0 sectoral MSA.



(c)

Figure 4.2.2 (a) (b) Input impedance plots for single 120^{0}sectoral stack patch and two 120^{0}sectoral stack patches (c) photograph of fabricated antenna.

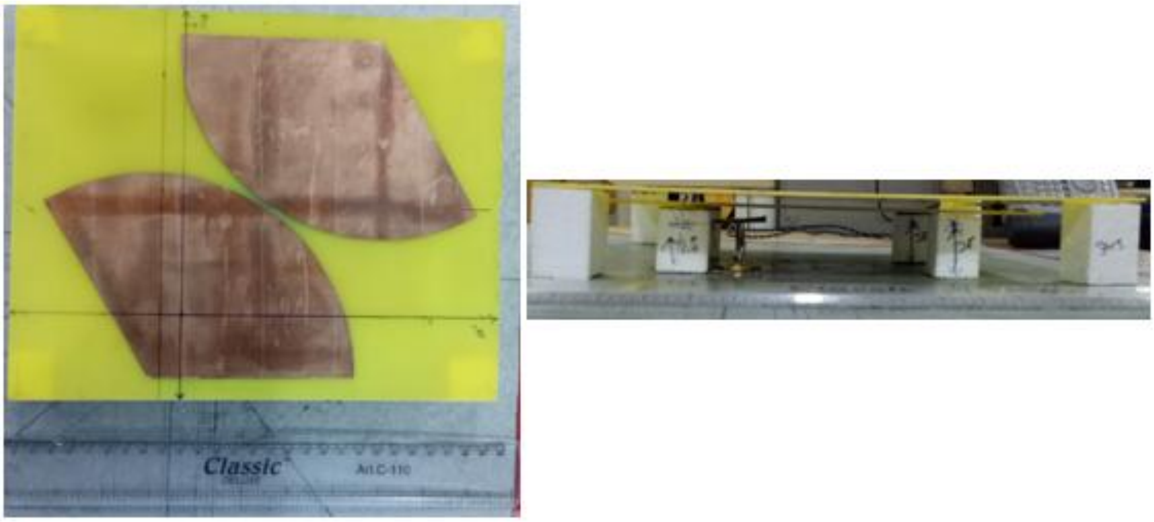


Figure 4.2.3 photograph of fabricated antenna at 1000 MHz

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Chapter 5

Multiple Slots Cut RMSA

The antenna design of rectangular patch that is embedded with four slots on one of its edge is shown in Fig. 5.1(a, b) [17]. The reported return loss plot is also given in Fig. 5.1(c) [17].

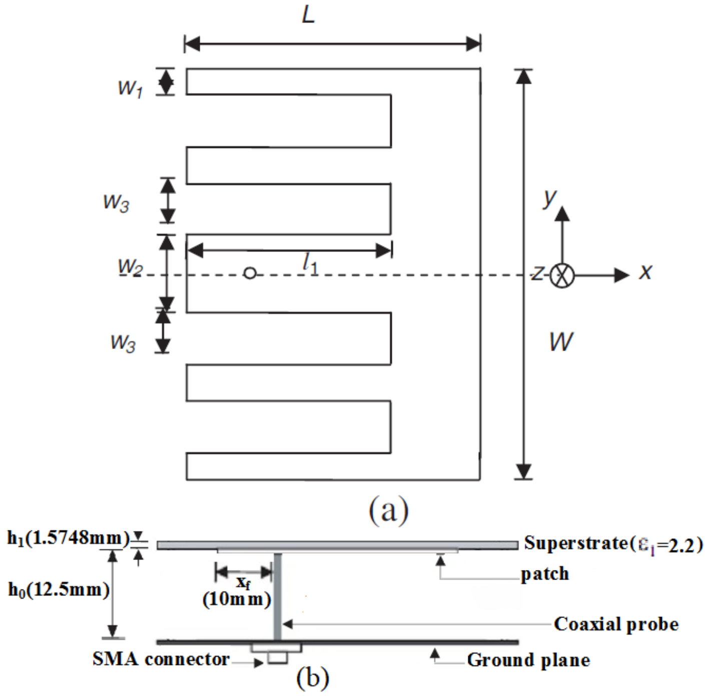


Figure 5.1 (a, b) Top and side views of multiple slots cut RMSA

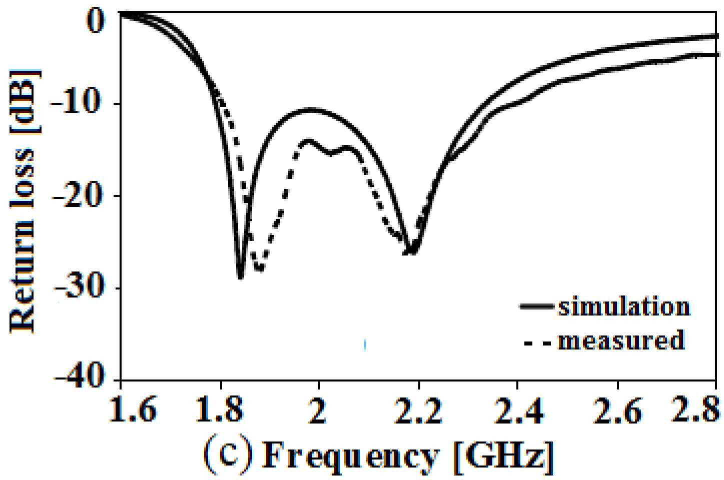


Figure 5.1 and its (c) return loss plots [17]

The antenna is fabricated on two layer suspended design ($0.089\lambda_0$). It is fabricated on inverted substrate having dielectric constant 2.2 and thickness 1.574 mm [17]. Due to inverted design, substrate layer provides superstrate effect that helps in gain enhancement [17]. For the dimensions mentioned in [17], antenna gives VSWR BW from 1810 to 2390 MHz (580 MHz, 27.62%). It shows gain of above 8 dBi across VSWR BW [17]. In E-shape patch, two rectangular slots are embedded on one of the radiating edge of RMSA. In reported work, comparison between BW obtained in multiple slot cut antenna and E-shape patch is not explained. Also it does not discuss modal explanation for wide band response. To bring out the antenna functioning and also its comparison with E-shape patch, its analysis is discussed in following section.

5.1 Analysis Of Multiple Rectangular Slots Loaded RMSA

The four slots cut antenna is simulated using IE3D for optimum patch dimensions as given in [17] and its smith chart and resonance curve plot is shown in Fig. 5.1.1(a, b). The current distributions at first three observed resonant modes is also shown in Fig. 5.1.1(c - e).

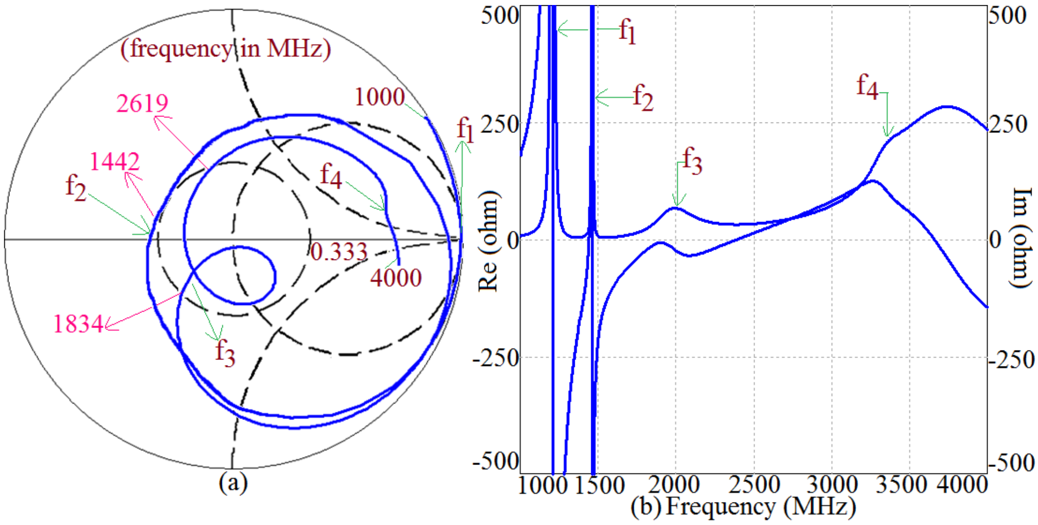


Figure 5.1.1 (a) Smith chart, (b) resonance plots

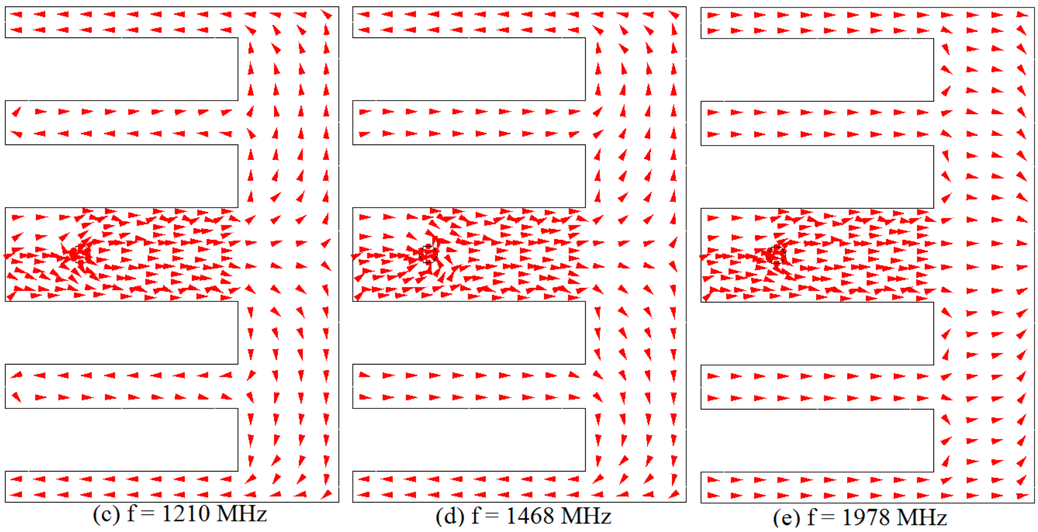


Figure 5.1.1 (c – e) current distributions plots at three modes for the design of multiple slots cut RMSA

Using IE3D simulations, on infinite ground plane, VSWR BW is from 1834 to 2619 MHz (785 MHz, 35.3%). Here infinite ground plane was only considered to reduce computation time. On finite square ground plane of side length 20 cm, reported design yields BW from 1870 to 2586 MHz (716 MHz, 32.13%). In that frequency range three peaks in resonance plot are observed. At f_1, currents exhibit two half wavelength variations along patch width which is perturbed by slot lengths. At next peak, i.e. f_2, more than two half wavelength variations in currents is noted. At third peak, f_3, currents are varying along patch length. To understand these modes, rectangular patch with varying slot lengths are studied.

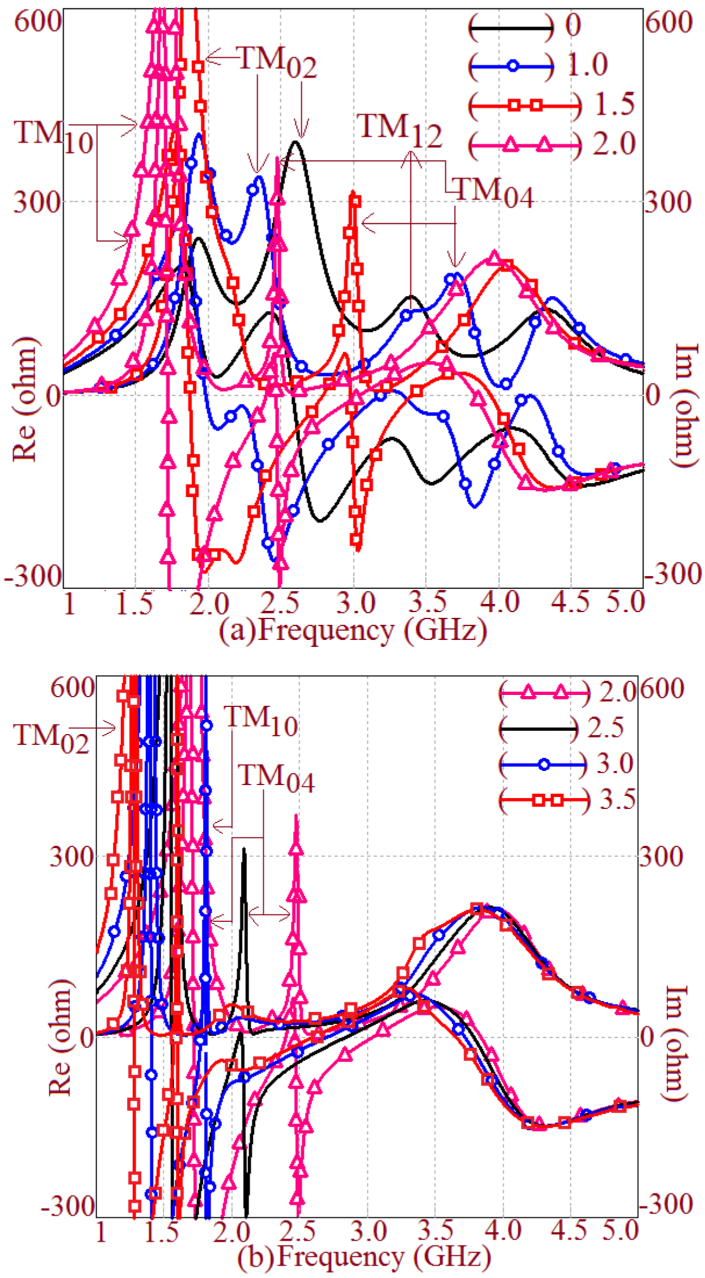


Figure 5.1.2 (a, b) Resonance curve plots showing impedance variations at respective modal frequencies for multiple slots cut RMSA

Further in the paper infinite ground plane is used in simulations. Use of the same will only affect BW's but modal behaviour of patch will remain same. The rectangular patch is simulated for increasing slot lengths 'l_1' from 0 to 3.5 cm and impedance curve explaining variations in real and imaginary part, are provided in Fig 5.1.2(a, b). The current distributions across different peaks/modes for two different slot lengths are shown in Fig. 5.1.3(a – e).

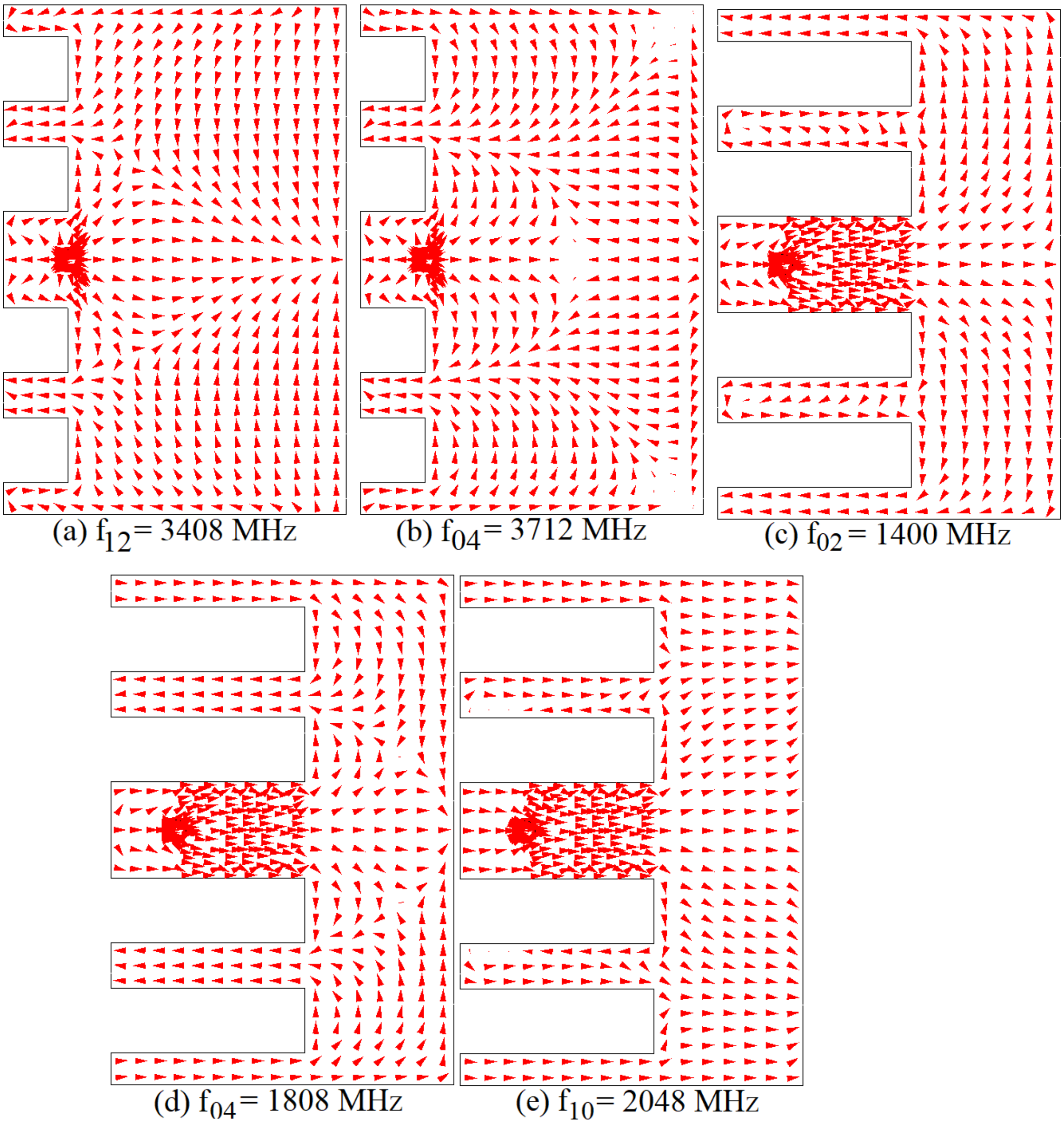


Figure 5.1.3 Surface current distributions for multiple slots cut RMSA at observed resonant peaks for slot length (l_1) of (a, b) 1.0 and (c – e) 3.0 cm

For RMSA without slot (i.e. l_1 = 0), for feed location as shown in Fig. 5.1.2 (a) peaks due to TM_{10}, TM_{02}, TM_{12} are observed. The frequencies of those modes whose currents are orthogonal to slot length will reduce in their values. Maximum reduction in frequency will be noticed in those modes for which variations are predominantly along the patch width. Thus with increasing length TM_{02} mode frequency reduces and TM_{10} mode frequency remains constant. As frequencies are overlapping in their values for varying lengths, they are not easily distinguishable in the resonance plots. For slot length of 1.0 cm, two peaks near 3500 MHz are observed. They are due to TM_{12} and TM_{04} modes. Although TM_{04} mode frequency is higher but as two pairs of slots is placed on width of patch, they have offered maximum reduction in its frequency and hence it has appeared nearer to TM_{12} mode. Since here two modal frequencies are nearer, reflections of respective current distributions are observed at two modes. Further for slot length of 3.0 cm, frequencies of TM_{02} and TM_{04} mode reduces below TM_{10} mode, which is due to maximum perturbation in lengths have been offered to respective modal currents as shown in Fig.5.1.3 (a-e). Here at modified TM_{02} and TM_{04} mode frequencies, two and four half wavelength variations in currents are observed across slot cut patch width. As observed from current plots maximum contributions of currents are along the patch length. The smith charts for slot lengths increasing from 3 to 4 cm, are shown in Fig.5.1.4. Here with increase in lengths as TM_{02} and TM_{04} frequencies reduces, loop formed due to their optimum spacing with reference to TM_{10} mode is placed inside VSWR = 2 circle resulting in wide band response. This has been realized for slot length of 3.7 cm as reported in [17].

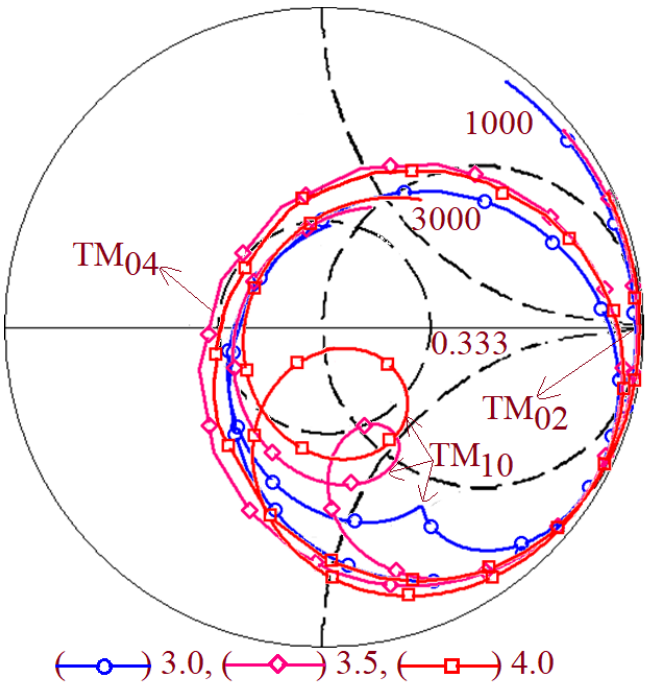


Figure 5.1.4 Smith charts for increasing slot length for multiple slots cut RMSA

Thus it can be inferred from above study that wider BW in multiple slots cut RMSA is due to spacing of TM_{04} mode frequency with reference to TM_{10} mode as against spacing of TM_{02} mode frequency with respect to TM_{10} mode as that observed in for E-shape patch. Further for comparison purpose E-shape patch variation from equivalent RMSA has been optimized for wideband response. It yields simulated BW of 858 MHz (38.5%) on infinite ground plane and BW of 816 MHz (36.9%) on the finite square ground plane of side length 20 cm. Thus as compared with infinite ground plane and finite ground plane, simulated BW of multiple slots RMSA is smaller than given by E-shape patch. Further for comparison purpose simulated broadside gain plots for two variations for same equivalent RMSA dimensions as reported in [17] are given in Fig. 5.1.5(a). As can be seen, E-shape MSA offers better gain characteristics. Lastly slot cut RMSA design using four rectangular slots cut on the radiating edge of patch in 1000 MHz is optimized for wider BW as shown in Fig. 5.1.5(b, c). Here MSA is optimized on suspended FR4 substrate. The simulated and measured smith charts for this design is shown in Fig 5.1.6(a).

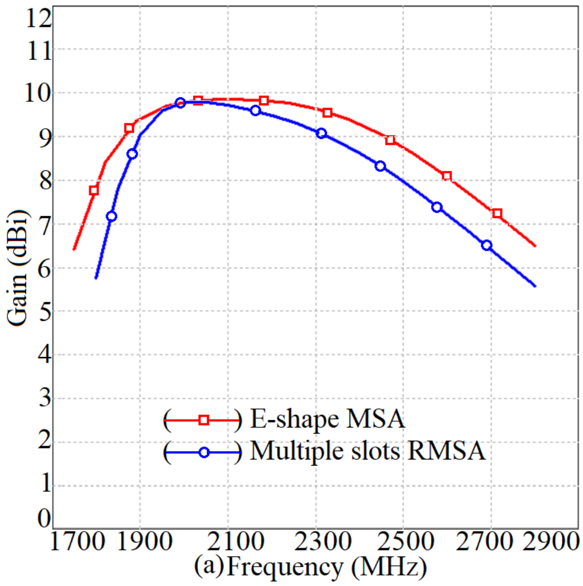


Figure 5.1.5 (a) Gain variation over BW for multiple slots cut RMSA

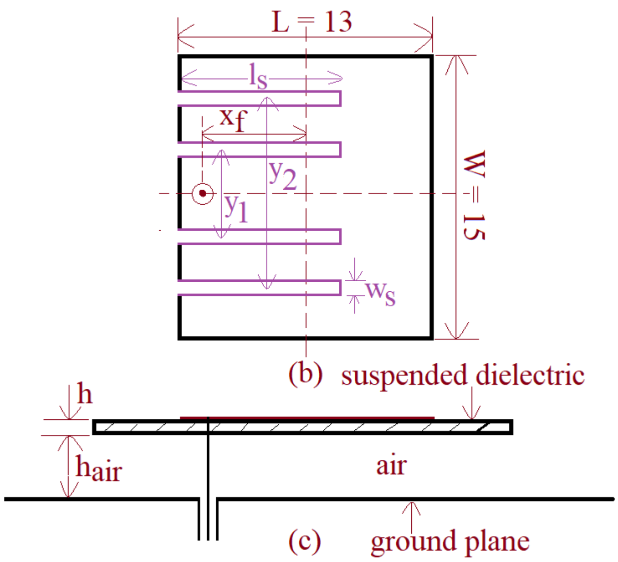
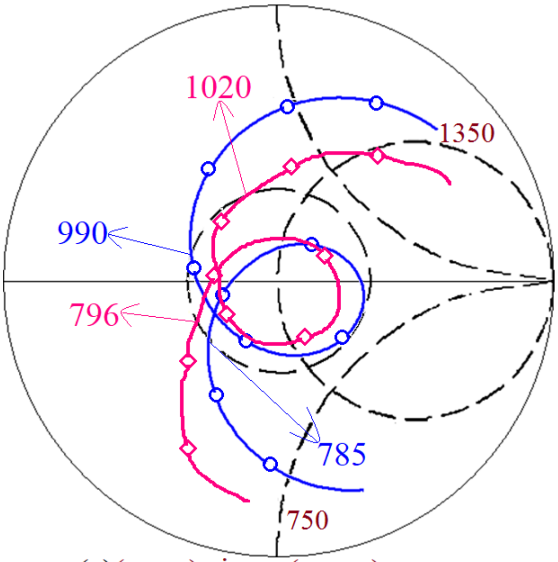
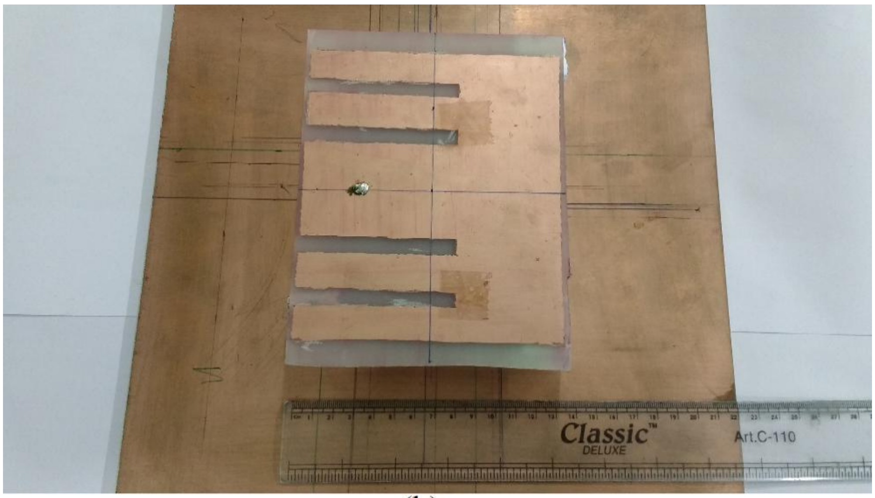


Figure 5.1.5(b, c) multiple slots cut RMSA in 1000 MHz range

The simulated BW is 205 MHz (23.1%), whereas the measured BW is 224 MHz (24.7%). The picture of fabricated antenna is shown in Fig. 5.1.6 (b). This design shows similar pattern and gain characteristics to that given by reported MSA in 2000 MHz frequency range. However this MSA is optimizes on thinner substrate ($0.068\lambda_0$) as compared with reported MSA and also is compact in size (patch aspect ratio 1.15).





(b)

Figure 5.1.6 (a) Input impedance plots and (b) photograph of fabricated antenna for multiple slots cut RMSA in 1000 MHz range

5.2 Desktop Shaped Antenna for A Wideband Response

A comparative study of rectangular base desktop shaped broadbandpatch antenna (Antenna1) and triangular base desktop shaped broadband patch antenna (Antenna2).Apart from base dimensions all parameters of both antennas are constant. The broadband characteristics are achieved by introducing two parasitic ground planes and notches are etched on the radiating patch. Both antennas are simulated, fabricated and tested for obtaining the desired performance. The designed Antenna1 shows bandwidth of 39.97% (4.95GHz to 7.42 GHz) whereas an improved bandwidth of 49.0% (4.53GHz to 7.47 GHz) is achieved through Antenna2. The reason for the broadband response with various modes which occur where not discussed in the paper. Hence, we have made a detailed studied and found that coupling between TM_{20}, $TM_{21}$and TM_{03} results in broadband response further we have redesigned it 1500MHz.

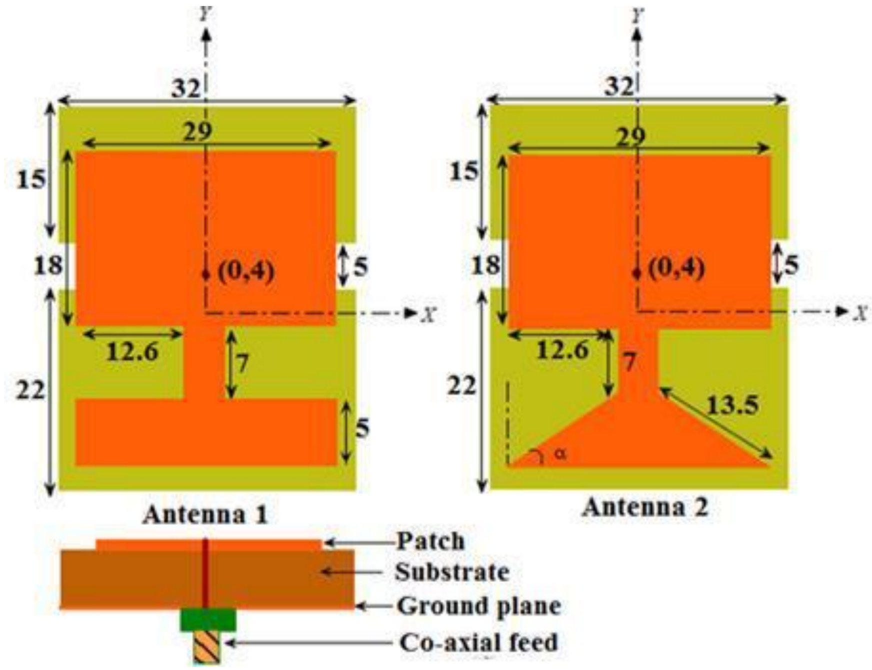


Figure 5.2.1 Geometrical configurations of the proposed antennas top view and side view[14]

Further the desktop shape antenna is redesigned at 1500MHz frequency and it is shown in the figure 5.2.4The feed patch has the dimensions of length and width as 29mm and 30mm, the length of the slot on the feed patch is slightly increased and the response that we observed can be seen in the figure5.2.2. Initially when there was no slot we get 4 modes namely TM_{02} TM_{20} TM_{21} TM_{03} But as the length of the slot is increased from 0 to 6mm we can observe that TM_{02} is decreased. And an additional resonant mode i.e. TM_{03} at frequency 7.9GHz is introduced. It shows that as the length is increased from 0 to 6mm we get an additional resonant mode having three current variations along width of the patch. The current distributions can also be seen in figure.5.2.3Further on increasing the length of the patch from 6mm to 12.6mm this additional resonant mode goes to a higher frequency and cannot be observed on the frequency range from 4GHz to 8GHz. Figure.5.2.2 (a-d).

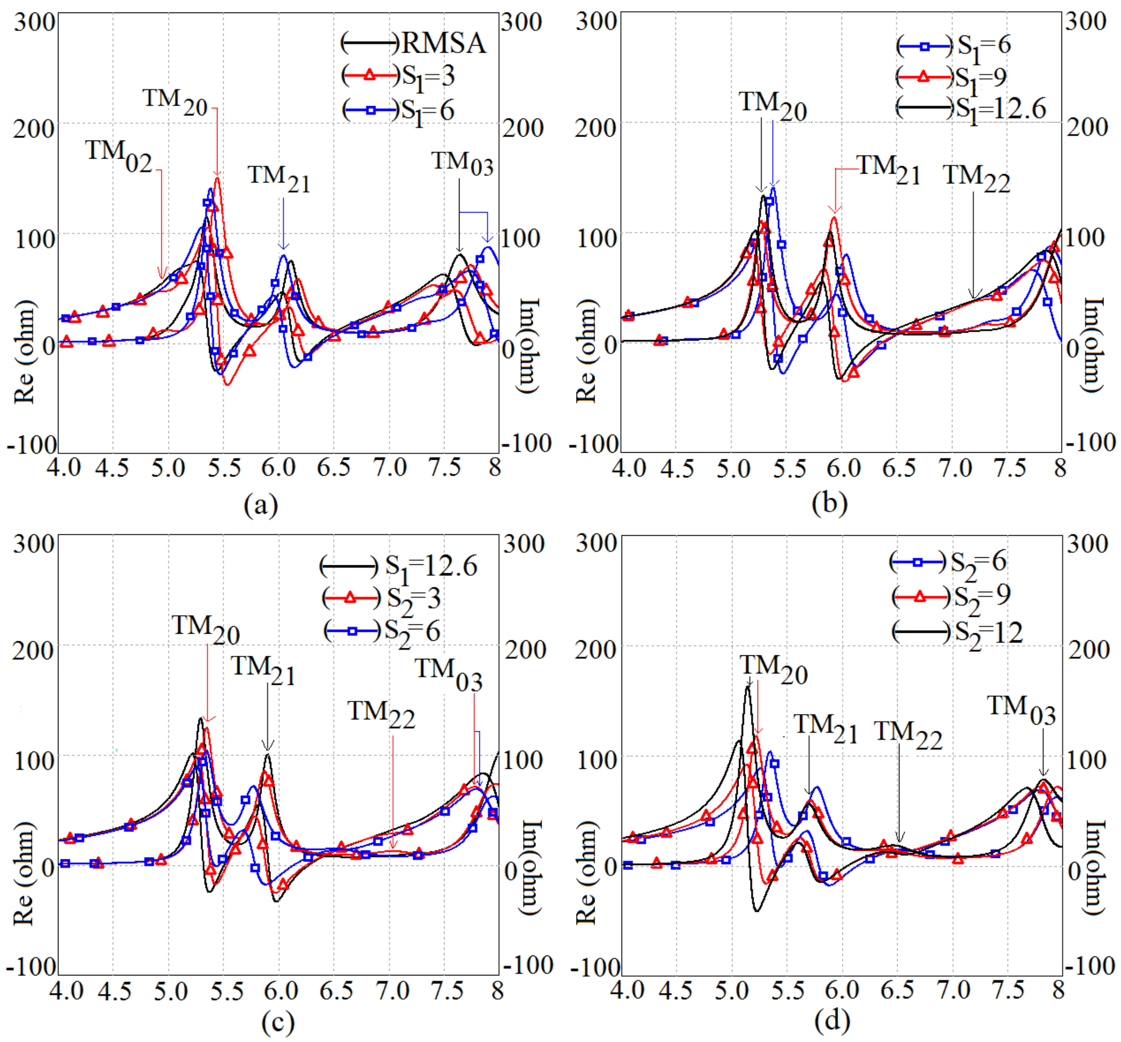
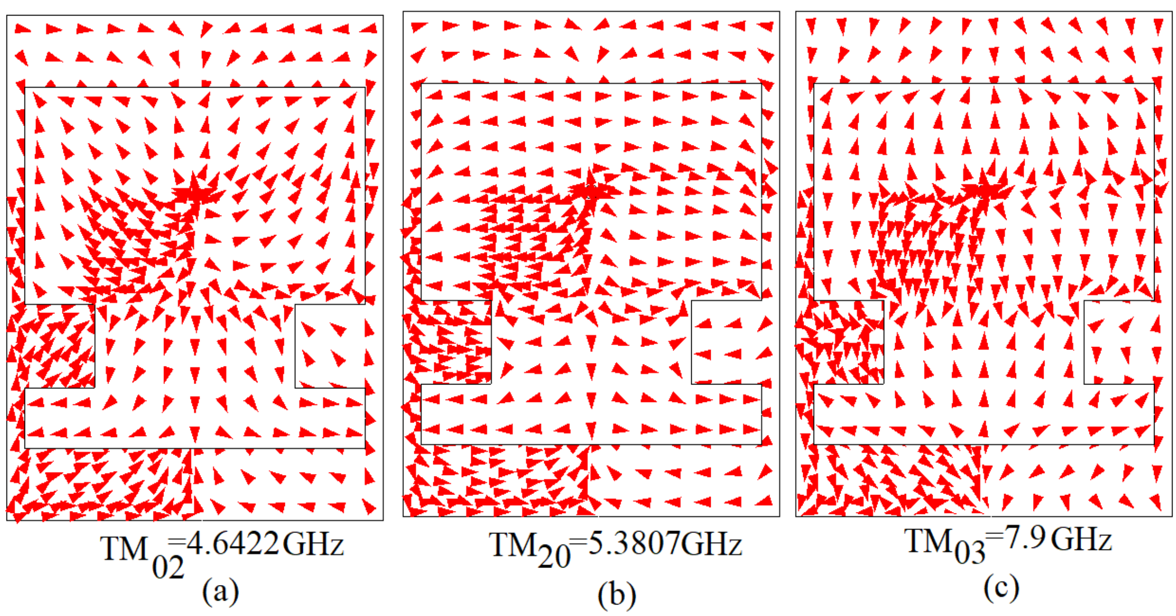


Figure 5.2.2(a-d) Resonance curve plots showing impedance variations at respective modal frequencies for desktop shape antenna.



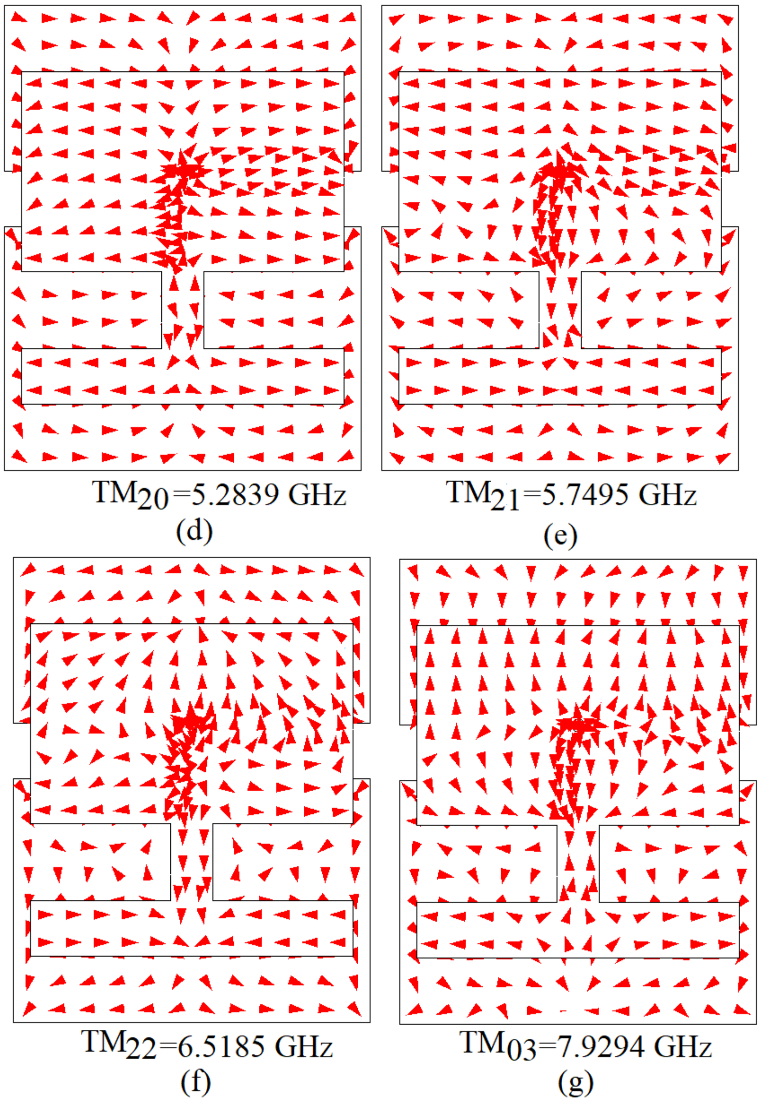


Figure 5.2.3 Surface current distributions for desktop shape antenna at observed resonant peaks for slot length of (a, c) 6.0 and (d – g) 12.6 mm

We also have redesigned it at a lower frequency to get a optimum result. Redesigning is seen in figure 5.2.4(a),(b) here by keeping the length of the slot S_1 and S_2 we get a wideband response. Feed is given at y_f. Ground plane is of h_1 at height ha we have the feed patch which is fed by using a proximity feed of strip length Ls. Width of the slot is S_3 length and width of patch is L_1 W_1 and length and width of ground plane is L_2 W_2.

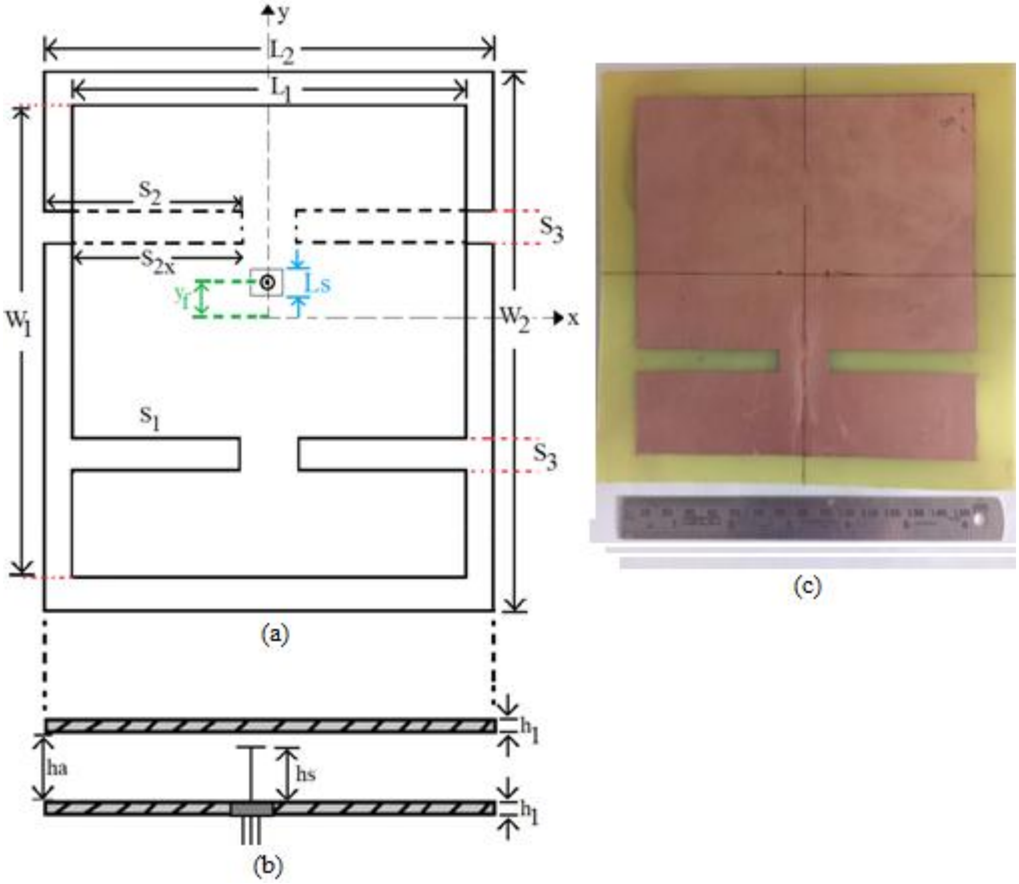


Figure 5.2.4(a), (b) Desktop shape antenna at 1500 MHz and (c) its fabricated prototype

This structure is a defected ground structure; it also has slots on the ground plane. Initially, the slot on the ground plane is 0mm and further it is increased to 15 mmas the length of the slot is increased on the ground plane TM_{03} mode's frequency is reduced and it appears at frequency 7.8GHz the current distribution having 3 current variations along width of the patch is seen in the figure. Further when the length of the slot is S_2 we get TM_{20} TM_{21} TM_{22} TM_{03} this all modes combine to give a wide band response of around 900 MHz.Hence, we have analysed the desktop shape antenna and we have studied various modes and the effect of the slots on the ground and patch.

Chapter 6

Conclusion and Scope of Future Work

Proximity fed design of 120^0 S-MSA derived from equivalent CMSA was proposed which gives a broadside radiation pattern. Resonant length formulation for fundamental patch mode in 120^0Sectoral patch is proposed. The proposed 120^0Sectoral patch gives higher BW with better gain characteristics with slight increase in the patch area. In Broadband gap-coupled variations of 120^0 S-MSAs, Gap-coupled design along diagonal axis yields optimum result. Compared to single patch gap-coupled antenna yields 10% increase in antenna BW with moderate improvement in the peak gain. Although with respect to CMSA proposed design requires more patch area, but without slots it gives 20% additional BW. The multi-resonator gap-coupling technique of BW and gain enhancement is further used. Various gap-coupled configurations of 120^0Sectoral patches coupled along diagonal axes were studied. In the configuration of 120^0 S-MSAs gap-coupled with their larger dimension towards the fed MSA obtains maximum BW. It yields bore-sight pattern showing peak gain. This VSWR BW is more than the BW obtained from regular shape MSAs and their gap-coupled and slot cut variations. The enhancement in BW of rectangular patch using four wide rectangular slots on the edge of patch was reported. detailed study that clearly brings out that wide band response is result of coupling between higher order TM_{04} mode of the patch to that with fundamental TM_{10} mode and optimum spacing between them yields wider BW. Further in comparison, multiple slots cut antenna has smaller BW as compared with the E-shape MSA. Also E-shape MSA provides better gain characteristics compared with the multiple slots cut antenna.

Design of four slots cut antenna is proposed in 1000 MHz frequency band on thinner substrate with smaller patch aspect ratio. Further stack variations of 120^0sectoralmicrstrip antenna is also studied. When we use a single 120^0 stack patch we get radiation in the broadside direction. A detailed study was also made for 120^0 stack by using two stack patches the bandwidth and gain obtained here was slightly more than that by using a single patch. further a detailed study of desktop shape antenna was made by dong the modal analysis we have observed that the broadside radiation pattern is obtained because of coupling between TM_{20} TM_{21} TM_{22} and TM_{03} mode of frequency. We have also redesigned it at 1500MHz of frequency which gives a optimum result.

Further study can also be done by changing the angle of the sectoralmicrostrip antenna and studying its gap coupled configuration along with its stack configurations.

Chapter 7

List of Publications

[1] Amit A. Deshmukh, PritishKamble, Akshay Doshi, DishaIssrani and K. P. Ray, “Proximity Fed Broadband 1200 Sectoral Microstrip Antenna”, Proceedings of ICACC – 2017, 22nd -24th August 2017, Kochi, India (Volume 115, 2017, pp. 101–107,https://doi.org/10.1016/j.procs.2017.09.082,http://www.sciencedirect.com/science/article/pii/S1877050917318896)

[2] Amit A. Deshmukh, Poonam A. Kadam, Akshay Doshi and PritishKamble, “Sectoral Patch Antenna Embedded with Arc Shape Slots and Slits For Circular Polarized Response” Accepted for publication in ICCICT 2018, 2nd – 3rd February 2018, Mumbai, India (IEEE digital library)

[3] Amit A. Deshmukh, Akshay Doshi, PritishKamble, DishaIssrani and K. P. Ray, “Modified Triangular Shape Microstrip Antenna For Circular Polarization”, Proceedings of ICACC – 2017, 22nd – 24th August 2017, Kochi, India (Volume 115, 2017, pp. 101–107,https://doi.org/10.1016/j.procs.2017.09.082,http://www.sciencedirect.com/science/article/pii/S1877050917318896)

[4] Amit A. Deshmukh, PritishKamble, Venkata A. P. C., Akshay Doshi and K. P. Ray, “Gap-Coupled Variations of 1200 Sectoral Shape Microstrip Antennas For Wideband Response”, Proceedings of AEMC 2017, 19th - 22nd December 2017, Aurangabad, India (IEEE digital library)

[5] Amit A. Deshmukh, Aarti G. Ambekar, Venkata A. P. C., Akshay Doshi and K. P. Ray, “Modified U-slot Cut Rectangular Patch Antenna For Wideband Response”, Proceedings of AEMC 2017, 19th - 22nd December 2017, Aurangabad, India (IEEE digital library)

[6] Amit A. Deshmukh, PritishKamble, Akshay Doshi and Venkata A. P. C., “Multi-Resonator Variations of 120^0Sectoral Microstrip Antennas For Wider Bandwidth”, Proceedings of ICWiCOM 2017, 19th & 20th January 2018, Mumbai, India (Lecture Notes on Data Engineering and Communications Technologies – eBook ISBN978-981-10-8339-6, DOI 10.1007/978-981-10-8339-6)

[7] Amit A. Deshmukh, AnujaOdhekar, Akshay Doshi and PritishKamble, “Modified Circular Shape Microstrip Antenna for Circularly Polarized Response”, Proceedings of ICWiCOM 2017, 19th & 20th January 2018, Mumbai, India (Lecture Notes on Data Engineering and Communications Technologies – eBook ISBN978-981-10-8339-6, DOI 10.1007/978-981-10-8339-6)

[8] Amit A. Deshmukh, Poonam A. Kadam, PritishKamble and Akshay Doshi, “Multiple Rectangular Slots Cut Rectangular Microstrip Antenna For Wide Band Response” Accepted for publication in ICCICT 2018, 2nd – 3rd February 2018, Mumbai, India (IEEE digital library)

[9] Amit A. Deshmukh, Poonam A. Kadam, Akshay Doshi and PritishKamble, “Design and Analysis of Multiband Defected ground plane MSA” Accepted for publication in ICCICT 2018, 2nd – 3rd February 2018, Mumbai, India (IEEE digital library)

Chapter 8

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12. A.A. Deshmukh and K.P. Ray, “Analysis of broadband Ψ-shapedmicrostrip antennas”, IEEE Mag Antennas Propag 55 (2013), 107–123
13. Amit A. Deshmukh, KshitijLele, Ami Desai, Saleha Shaikh, Sudesh Agrawal and K. P. Ray,“Broadband Designs of Shorted Slot cut 60^0SectoralMicrostrip Antennas” presented at 2015 IEEE international conference on research in computational intelligence and communication networks.

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