ENHANCEMENT OF BANDWIDTH OF RECTANGULAR PATCH ANTENNA USING TWO SQUARE SLOTS TECHNIQUES

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ABSTRACT

The research in wireless communication has spurred the development of extra ordinary range of antennas, each with its own advantage and limitations. There are many applications where space is at premium, and where there is an urgent need for an antenna with the flexibility to efficiently combine the capabilities of multiple antennas. In fact rapidly developing market in personal communication systems (PCS), mobile satellite communications, direct broadband television (DBS) wireless local area networks (WLANs) suggest that demand for Microstrip antennas and array will increase even further. Conventional Microstrip patch antennas has some drawbacks of low efficiency, narrow bandwidth (3-6%) of the central frequency, its bandwidth is limited to a few percent which is not enough for most of the wireless communication systems nowadays. In this paper one of the efficient methods used for the enhancement of patch antenna bandwidth is the loading of rectangular microstrip patch antenna with two square slots across its side surface. This type of Microstrip patch antenna meets the requirement of operation for wireless applications. The proposed configuration is simulated and analyzed using GENESYS software package. The VSWR, input impedance, and S11 performance are used for the analysis of the different configurations. The simulated results for square slots antenna structure give bandwidth of 311 MHZ. Feed point on the patch that gives a good match of 50 ohm. The results of the fabricated microstrip antenna give the bandwidth of 286 MHz.

KEYWORDS

Rectangular microstrips patch antenna, Bandwidth enhancement, square, slot, Genesys.

I. INTRODUCTION

A MICROSTRIP ANTENNA (MSA) in its simplest form consists of a radiating patch on one side of a dielectric substrate and a ground plane on the other side. The top view and side views of a rectangular *MSA* (RMSA) are shown in Figure-1and 2.
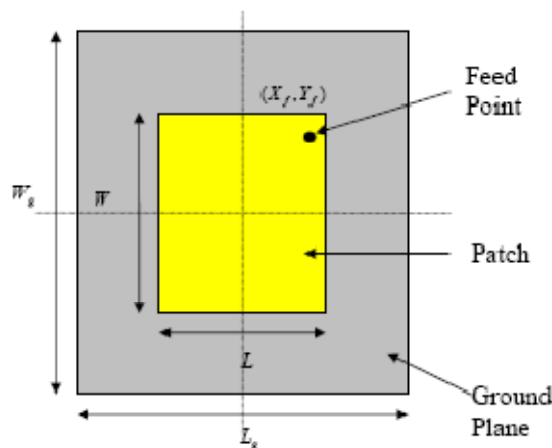
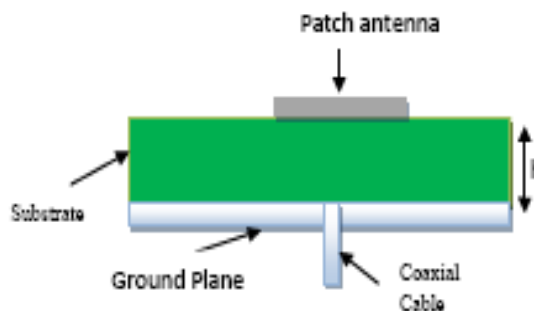**Figure-1:** The top view of a rectangular *MSA* (RMSA).   **Figure-2:** side view of patch antenna

However, other shapes, such as the square, circular, triangular, semicircular, sectoral, and annular ring shapes   are also used. Microstrip antennas are popular for their attractive features such as low profile, low weight, low cost, ease of fabrication and integration with RF devices. The major disadvantages of Microstrip antennas are lower gain and very narrow bandwidth [1, 2, 3]. Microstrip patch antenna consists of a dielectric substrate, with a ground plane on the other side. Due to its advantages such as low weight , low profile planar configuration, low fabrication costs and capability to integrate with microwave integrated circuits technology, the microstrip patch antenna is very well suited for applications such as wireless communications system, cellular phones, pagers, Radar systems and satellite communications systems [4,5,6]. Several designs have been investigated and reported to decrease the size of the antenna [7, 14] and to improve the bandwidth of the antenna [8, 9, 15]. Handset antenna has been reported with wide bandwidth [10]. Half U-slot patch antenna with shorting wall reported in [11] with 28% impedance bandwidth.

In this paper, broadband patch antenna with two square slots across its side surface is proposed. This type of Microstrip patch antenna meets the requirement of operation for wireless applications. The proposed configuration is simulated and analyzed using GENESYS software package [30]. The VSWR, input impedance, and S11 performance are used for the analysis of the different configurations. The paper is divided as: section 2 presents the brief literature survey about microstrip antenna and bandwidth enhancement techniques are explained in section 3. The structure and dimensions of the proposed antenna is presented in section 4 followed by the result of the simulated antenna in section 5. Finally, section 6 provides the conclusion. Results are based on an antenna simulation software package GENESYS.

II.   BRIEF LITERATURE SURVEY

The microstrip antenna concept dates back about 26 years to work in the U.S.A. by Deschamps [12] and in France by Gutton and Baissinot [13]. Shortly thereafter, Lewin investigated radiation from stripline discontinuities. Additional studies were undertaken in the late 1960's by Kaloi, who studied basic rectangular and square configurations. However, other than the original Deschamps report, work was not reported in the literature until the early 1970's, when a conducting strip radiator separated from a ground plane by a dielectric substrate was described by Byron. This half wavelength wide and several wavelength long strip was fed by coaxial connections at periodic intervals along both radiating edges, and was used as an array for Project Camel. Shortly thereafter, a microstrip element was patented by Munson [14] and data on basic rectangular and circular microstrip patches were published by Howell. Weinschel developed several microstrip geometries for use with cylindrical S band arrays on rockets. Sanford showed that the microstrip element could be used in conformal array designs for L band communication from KC-135 aircraft to the ATS-6 satellite. Additional work on basic microstrip patch elements was reported in 1975 by Garvin et al, Howell, Weinschel and Janes and Wilson. The early work by Munson on the development of microstrip antennas for use as low profile

flush mounted antennas on rockets and missiles showed that this was a practical concept for use in many antenna system problems and thereby gave birth to the new antenna industry.

There are some other technique for enhancement of bandwidth of antennas is the multiple layers which consisting of two or more metallic patches supported by one or more dielectric layers. There are two techniques for multi-band MPA using multiple layers. Firstly the dichroic technique with frequency band separation of 10:1 [17]. Secondly the stacking technique which uses two or three substrates providing two or more metallic patches within the same aperture area with frequency bandwidth of 5.6% for the stacked circular disc [18] or up to 13% with four rectangular patches [19] or up to 33% with strip-slot-foam-inverted patch antenna [20]. Size, weight, feed fabrication, and high coupling between stacked patches are the main disadvantages of the stacked antennas [21].Joshi and Lohokare [22] highlighted Microstrip Patch Antenna Loaded with Magnetoinductive Waveguide. Chen and Zhang [23] described Bandwidth enhancement of a microstrip-linefed printed wide-slot antenna with a fractal shaped slot. A novel monopole antenna with a self-similar slot for wideband applications [25] is designd by Song and Zhang. In[24] Kim and Junghas explained about Bandwidth enhancement of CPW fed tapered slot antenna with multi-transformation characteristics. Kalteh [26] has enhancd bandwidth for A Microstrip-fed UWB Circular slot antenna. In [27][28] [29] bandwidth enhancement is presented for UWB applications.

III.   TECHNIQUES OF BANDWIDTH ENHANCEMENT FOR MSA

MSA in its regular shape cannot yield multi-octave BW because of its resonant nature. Some modification of the MSA configuration is required to obtain an octave BW. If a rectangular patch without the substrate and ground plane is fed at the edge by a coaxial feed with a perpendicular ground plane, then the patch will have an effective dielectric constant equal to 1 with large *h*. Both of these factors yield broad BW. This modified configuration can be thought of as a planar rectangular monopole antenna. Other configurations such as triangular, hexagonal, circular, and elliptical monopoles also yield broad BW [12, 15]. An elliptical monopole with an ellipticity of 1.1 yields BW of 1:11 for $VSWR \leq 2$. The most serious limitation of the MSA is its narrow BW.

3.1 Definition of BW

The BW could be defined in terms of its VSWR or input impedance variation with frequency or in terms of radiation parameters. For the circularly polarized antenna, BW is defined in terms of the *axial ratio* (AR).Therefore, before describing the various methods for increasing the BW, the various definitions of the BW are described.

The VSWR or impedance BW of the MSA is defined as the frequency range over which it is matched with that of the feed line within specified limits. The BW of the MSA is inversely proportional to its quality factor *Q* and is given by

$$BW = \frac{VSWR-1}{Q\sqrt{VSWR}} \tag{1}$$

The BW is usually specified as frequency range over which VSWR is less than 2 (which corresponds to a return loss of 9.5 dB or 11% reflected power). Sometimes for stringent applications, the VSWR requirement is specified to be less than 1.5 (which corresponds to a return loss of 14 dB or 4% reflected power). Conversion of BW from one VSWR level to another can be accomplished by

$$\frac{BW1}{BW2} = \frac{(VSWR_1-1)\sqrt{VSWR_2}}{\sqrt{VSWR_1}(VSWR_2-1)} \tag{2}$$

where BW1 and BW2 correspond to VSWR1 and VSWR2, respectively.

The expressions for approximately calculating the percentage BW of the RMSA in terms of patch dimensions and substrate parameters is given by

$$\%BW = \frac{Ah}{\lambda_0\sqrt{\varepsilon_r}}\sqrt{\frac{W}{L}} \tag{3}$$

Where

A=180 for $\frac{h}{\lambda_0\sqrt{\varepsilon_r}} \leq 0.045$,   A = 200 for $0.045 \leq \frac{h}{\lambda_0\sqrt{\varepsilon_r}} \leq 0.075$,   A = 220 for $\frac{h}{\lambda_0\sqrt{\varepsilon_r}} \geq 0.075$

And *W* and *L* are the width and length of the RMSA. With an increase in *W*, BW increases.

Another simplified relation for quick calculation of BW (in megahertz) for VSWR = 2 of the MSA operating at frequency f in gigahertz, with h expressed in centimeters, is given by- $BW \cong 50hf^2$

The BW can also be defined in terms of the antenna's radiation parameters. It is defined as the frequency range over which radiation parameters such as the gain, half-power beam width (HPBW), and side lobe levels are within the specified minimum and maximum limits. This definition is more complete as it also takes care of the input impedance mismatch, which also contributes to change in the gain.

The above definitions for BW are mainly for a linearly polarized MSA. For a circularly polarized MSA, the BW is generally limited by its AR. This BW is the frequency range over which AR is less than a maximum limit (e.g., 3 or 6 dB).

The main techniques used to increase the BW are presented briefly in the following sections.

3.2 Modified Shape Patches

The regular MSA configurations, such as rectangular and circular patches have been modified to rectangular ring and circular ring, to enhance the BW. The larger BW is because of a reduction in the quality factor Q of the patch resonator, which is due to less energy stored beneath the patch and higher radiation. When a U-shaped slot is cut inside the rectangular patch, it gives a BW of approximately 40% for VSWR. Similar results are obtained when a U-slot is cut inside a circular or a triangular MSA.

3.4 Planar Multi-resonator Configurations

The planar stagger–tuned coupled multiple resonators yield wide BW in the same way as in the case of multistage tuned circuits. Several configurations are available yielding BW of 5–25%.

Various parasitic patches like narrow strips, shorted quarter-wavelength rectangular patches, and rectangular resonator patches have been gap-coupled to the central-fed rectangular patch .These planar multi-resonator configurations yield broad BW but have the following disadvantages:

 IV.   They are of large size, which makes them unsuitable as an array element.
 V.   There is variation in the radiation pattern over the impedance BW.

3.5 Multilayer Configurations

In the multilayer configuration, two or more patches on different layers of the dielectric substrate are stacked on each other. Based on the coupling mechanism, these configurations are categorized as electromagnetically coupled or aperture-coupled MSA.

Various direct-coupled multi-resonators are:
(a) RMSAs direct-coupled along radiating edges,
(b) RMSAs direct-coupled along non-radiating edges,
(c) Direct-coupled RMSAs.

3.6 Electromagnetically Coupled MSAs

In the electromagnetically coupled MSA, one or more patches at the different dielectric layers are electromagnetically coupled to the feed line located at the bottom dielectric layer.

Alternatively, one of the patches is fed by a coaxial probe and the other patch is electromagnetically coupled. Either the bottom or top patch is fed with a coaxial probe. The patches can be fabricated on different substrates, and accordingly the patch dimensions are to be optimized so that the resonance frequencies of the patches are close to each other to yield broad BW.

3.7 Stacked Multi-resonator MSAs

The planar and stacked multi-resonator techniques are combined to further increase the BW and gain. A probe-fed single rectangular or circular patch located on the bottom layer has been used to excite multiple rectangular or circular patches on the top layer, respectively. Besides increasing the BW, these configurations also provide an increase in gain as well.

3.8 Effect of Feeding Techniques on bandwidth

Microstrip antennas are fed by a variety of methods that are broadly classified into two main categories-Contacting and Non-contacting.

In the contacting method, the RF power is fed directly to the radiating patch using a connecting element such as a microstrip line. In the non-contacting method, electromagnetic field coupling is done to transfer power between the micro strip line and the radiating patch.

The four most popular feed techniques used are:-The microstrip line, Coaxial probe (both contacting schemes), Aperture coupling, Proximity coupling (both non-contacting schemes).

The following table indicates effect of Feeding Techniques on bandwidth which shows that proximity coupled feed gives highest bandwidth.[16]

Table 1: Effect of Feeding Techniques on bandwidth**.**

Characteristics	Microstrip Line Feed	Coaxial Feed	Aperture Coupled Feed	Proximity Coupled Feed
Bandwidth	2-5%	2-5%	2-5%	13%

IV.   PROPOSED DESIGN METHODOLOGY TO ENHANCE BANDWIDTH

Microstrip patch antennas are the most common form of printed antennas. They are popular for their low profile geometry, light weight and low cost. These antennas have many advantages when compared to conventional antennas and hence have been used in a wide variety of applications ranging from mobile communication to satellite, aircraft and other applications.

Similarly, the different structures shapes of slots in MSA have attracted much attention in the recent years in the microwave community for its unique properties. These structures are periodic in nature that forbids the propagation of all electromagnetic surface waves within a particular frequency band – called the bandgap – thus permitting additional control of the behavior of electromagnetic waves other than conventional guiding and/or filtering structures. Various compact structures have been proposed and studied on antenna systems. Radiation efficiency and directivity of antennas have been improved using such structures.

4.1 Problem to be solved: Low Bandwidth of Patch Antenna

In spite of the many advantages that patch antennas have in comparison to conventional antennas, they suffer from certain disadvantages. The major drawback of such antennas is the narrow bandwidth. In this paper, the narrow bandwidth problem of a patch antenna is tackled and solved. A reference antenna is taken and efforts are made to improve its bandwidth by etching the feed line connecting the patch using two square slots type patterns across side surface of rectangular microstrip patch antenna. This is shown in fig.

4.2 Choice of Substrate

Choosing a substrate is as crucial as the design itself. The substrate itself is part of the antenna and contributes significantly to its radiative properties. Many different factors are considered in choosing a substrate such as dielectric constant, thickness, stiffness as well as loss tangent. The dielectric constant should be as low as possible to encourage fringing and hence radiation. A thicker substrate should also be chosen since it increases the impedance bandwidth. However, using a thick substrate would incur a loss in accuracy since most microstrip antenna models use a thin substrate approximation in the analysis. Substrates which are lossy at higher frequencies should not be used for obvious reasons. The choice of a stiff or soft board basically depends on the application at hand. In this paper air is selected as the dielectric material having dielectric constant as 1.

4.3 Input Impedance Matching

Impedance matching is critical in microstrip antennas since the bandwidth of the antenna depends upon it. Besides this, a poor match results in lower efficiency also. Line fed rectangular patches may be fed from the radiating or the non-radiating edge.

To find an impedance match along the non-radiating edge we may use the Transmission Line Model. The input impedance along the non-radiating edge is lowest at the centre since two equally high impedances at the two ends are transformed into a low value at the centre and connected in parallel. Matching along the edge is also symmetrical about the mid-point of the length.

4.3 Use of simulation software

In this work Genesys simulation software [30] is used for design, analysis and testing the results.

Some of the Key Features of Genesys are:
Genesys Core environment is a full-featured design environment with schematic, linear simulation, optimization, statistical, layout, and data display capabilities. Additional capabilities can then be extended to include RF system architecture, circuit synthesis, nonlinear circuit and 3D planer electromagnetic simulation.
Genesys Synthesis creates high-performance circuits, accelerates routine design tasks from hours to minutes, and enables fast make-or-buy decisions on common components. Synthesis modules for filters, matching networks, oscillators, mixers, transmission lines, equalizers, PLL and signal control can be added to the Genesys Core or other Genesys bundles.
Genesys Simulation offers additional RF/Microwave analysis capabilities for system architecture & frequency planning, nonlinear circuits in the time- and frequency-domain, and planar 3D electromagnetic (EM) characteristics. The powerful data display and processing includes MATLAB-compatible equations and engineering math language.

V.   DESIGN AND ANALYSIS

5.1 Analysis model of 1 x 1 array antenna structure

The antenna is designed to operate band frequency range of 2.1GHz to 2.4GHz the feed patch is 0.5mm thick copper plate suspended in air with probe feed mechanism, and ground plane is also 0.5mm thick copper plate. The design layout is selected in GENESYS software and kept grid spacing as 0.5mm, box width (X) as 100-400 cells and box height (Y) as 100-400 cells. Then the sizes of the finite ground metal as 70mm x 70mm.The fed patch dimensions are 52mm x 62mm. The coaxial feed probe is placed at x=20.5mm and y=17mm from left bottom corner.
The following section deals with the antenna simulation and experimental result. Parametric study in fed patch dimensions, variation in fed patch and effect of probe feed location and its dimensions are deal in detail. All the structures are simulated using GENESYS software and all dimensions specified in mm.
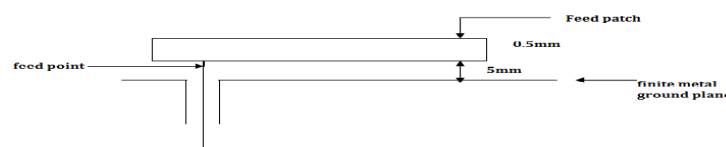

Figure-3: Front view of the antenna structure

The various parametric study is done like effect of variation of fed height, effect of feed probe location and its diameter, variation in fed patch length as well as variation in fed patch width.

5.1.1 Different Parametric Study of 1 x 1 array antenna structure
i) Effect of variation in feed patch height:
The coaxial probe feed passing through air dielectric exhibits inductive shifts in impedance curve and capacitive curve. The inductive and capacitive reactance curve never passes through zero. The variations in the feed patch height changes the electrical thickness of the air dielectric below it. The decrease in feed patch height to 3mm shifts the impedance curve and resonated frequency is shifted. The resonate frequency can be restored back by changing the length of feed patch. The cross polarization is reduced and efficiency is improved. The increased in the fed patch height to 6mm shift the impedance curve clockwise on the smith chart with increase in impedance and resonant condition is altered. It can be again restored by changing the feed patch height. The fed patch with the height 5mm gives the best result because it gives the impedance matching. Maximum number of lobes near the matching point i.e origin of the smith chart lead to give broad bandwidth. The fed height of 5mm
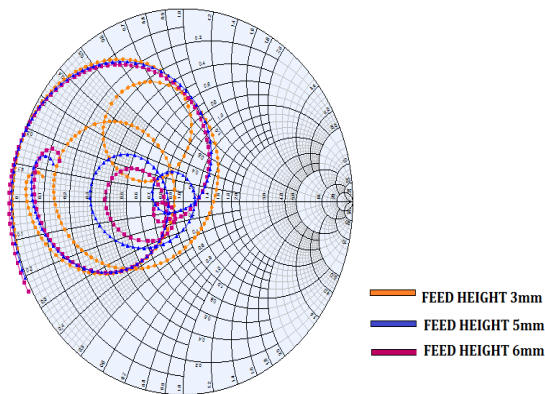
gives maximum lobs near matching point.

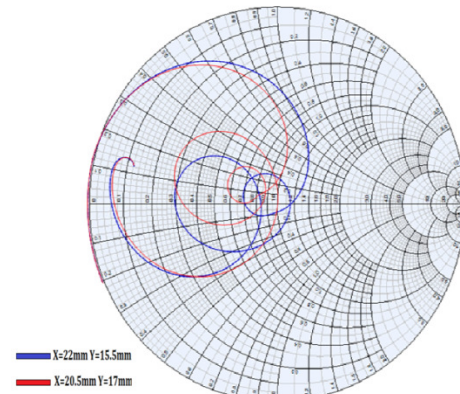**Figure-4:** Impedance Variations v/s different feed patch height.   **Figure-5:** variation in feed probe

ii) Effect of feed probe location:

The coaxial probe feed it effect the antenna characteristics it can be seen that by changing the position of the feed probe we can achieve the impedance matching for the antenna. Variation of the probe location along the X and Y axis varies the lobes of the on the smith chart which is shown below.

Here it has been observed that the feed position of probe at X as 22mm and Y as 15.5mm is not gives perfect impedance matching. The position of feed position of probe at X as 20.5mm and Y as 17mm we get perfect impedance matching as it passes through the origin of the smith chart i.e matching point.

iii) Effect of variation in feed patch length:

For a patch antenna, the length is determining factor in deciding resonant condition in fundamental operating mode. The rectangular patch resonates in its fundamental TM10 mode, where there is no variation along the width and field is constant while there is half wavelength variation along the length. The sinusoidal variation cancels in broadside direction and the radiation is only accomplished by the field along the width. The resonant frequency is detuned when the length of the feed patch is varied. When the feed patch length is 60mm, the bandwidth we get is 18MHz is observed.

When we increase the length of the feed patch to 62mm we got the bandwidth as 114MHz for return loss -9.54dB. These differences of bandwidth are shown below graph.

iv) Effect of variation feed patch width:

For rectangular fed patch to resonate at 2.4 GHz, air dielectric. The theoretical calculated width is 62mm. It is seen that for the width of the 50 mm, the return loss is less   than the width of 52mm and approximately same bandwidth is obtained. It does not affect the resonant frequency of the antenna.

The graph shows the variation of width by trial and error method it is concluded that,the theoretical width and practical width both are different.
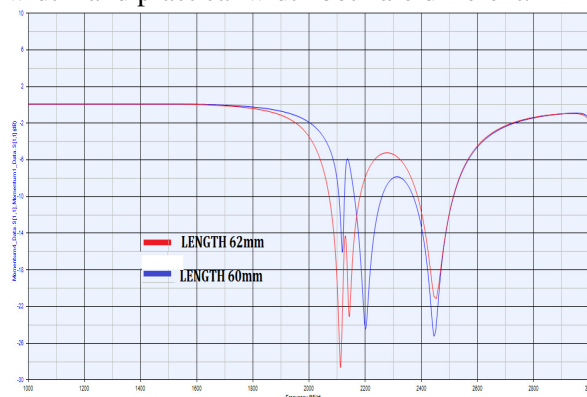

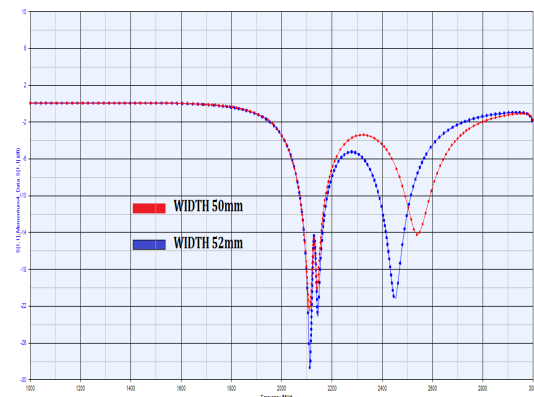**Figure-6 :** Return loss v/s frequency for change in feed patch length.   **Figure-7:** Comparison plots of return loss for different widths of feed patch

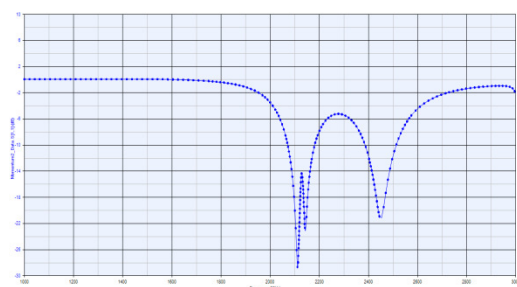## 5.1.2 Final simulated results of 1 x 1 reference antenna
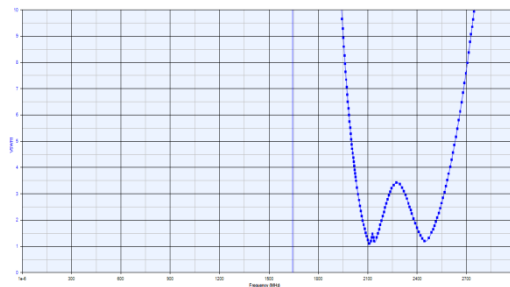
Figure-8: Return Loss

Figure-9: VSWR

For reference antenna   bandwidth obtained is as **109MHz.**

5.2 Modified structure of Microstrip Antenna:
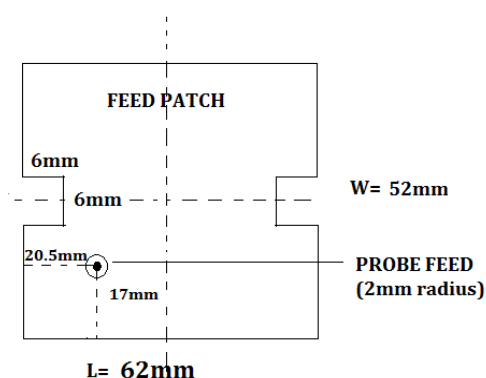The following are the various structural changes done in the modified MSAs
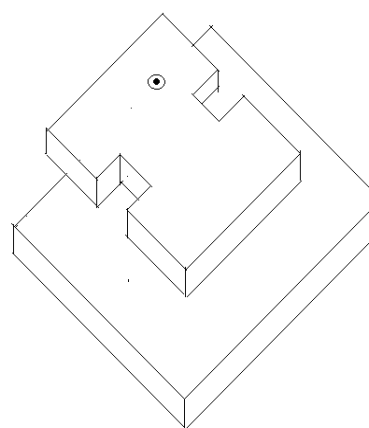

Figure-10: Feed patch

Figur-11: View of final structure

5.2.1 Parametric study for the modified Microstrip Antenna:
i) Effect of feed probe position: By changing the position of the feed probe location we can see the variations in the impedance on smith chart. It also varies the return loss of the antenna which affect the bandwidth of the antenna.

ii) Effect of notch size:
The notch or shape which cuts in the patch affects the antenna parameter. Here we cut the square at both the radiating edge of the feed patch. The graph below shows the variation in return loss as well as variation in the impedance of the antenna. Here we consider two type of square shape of 6mm x 6mm and 12mm x 12 mm. It is find that bandwidth is more in the structure having the notch of the 6mm x 6mm rather than the 12mm x 12mm and it also shows that the impedance matching is perfect for the notch of 6mm x 6mm rather than 12mm x 12mm.
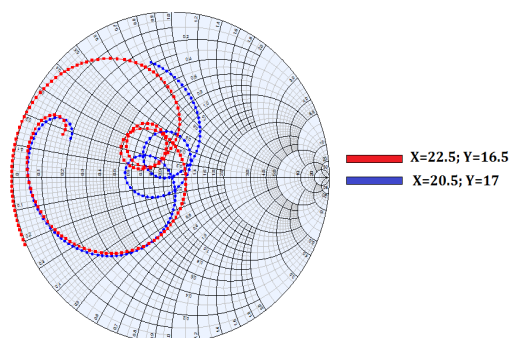

Figure-12: Impedance variation v/s different feed patch location.
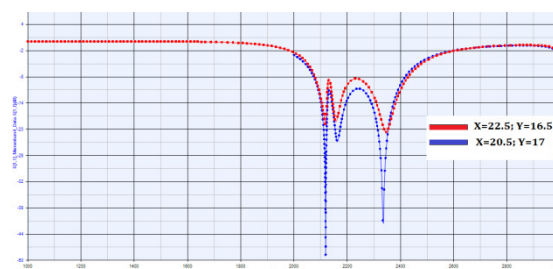

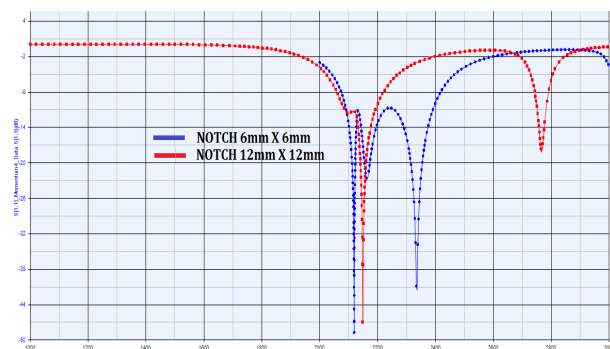**Figure-13:** return loss variation v/s different feed location
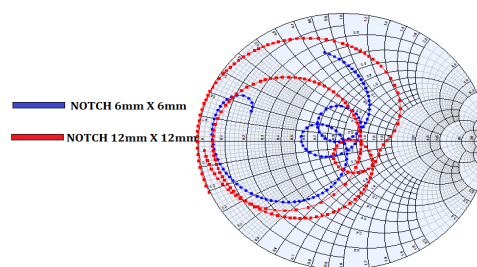
Figure-14 : Return Loss v/s different notch size

Figure-15 : Impedance variation V/s different notch size
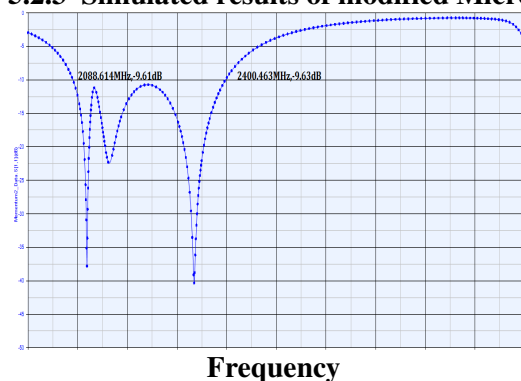
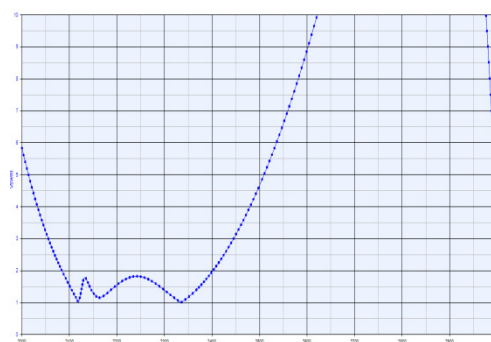### 5.2.3 Simulated results of modified Microstrip Antenna:

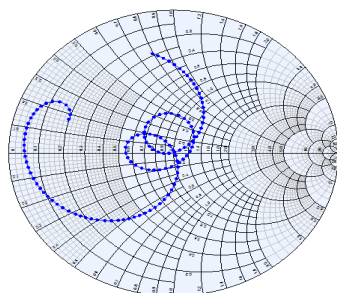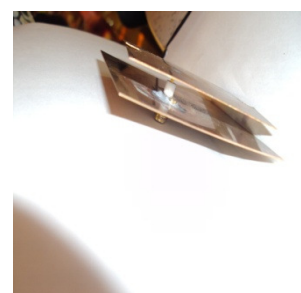**Figure-16:** Return Loss

Figure-17: VSWR

Figure-18: Impedance at resonance Frequency

Figure-19: Antenna Hardware

Bandwidth obtained after simulation= 311.845Mhz
In this antenna lower and upper conducting layers' material is copper metal of thickness 0.5mm. The size of ground metal is 70mm x 70mm and the size of feed patch is 62mm x 52mm. The coaxial feed is used for that purpose SMA connector of diameter 2mm is used. This connector is connected at (20.5mm,17mm) from the left bottom corner of the feed patch.

5.3 Results of fabricated Modified Patch Antenna

The proposed antenna is fabricated for the designed dimensions and its results are tested by using spectrum analyzer. The fig shows the results for return loss, impedance. and it is seen that the results of simulated antenna structure and fabricated structure are almost similar .

Figure-20: Measurement Of Return Loss   **Figure-21:** Impedance Measurement Impedance

 Measurement is done for Return Loss (-37.28dB at 2.205 GHz) and Impedance Measurement (50Ω at 2.205GHz).Bandwidth obtained on spectrum analyses at -9.54dB: BW= (2.383-2.102) GHz = 286MHz

5.4 Comparison of Simulated and Fabricated Results

The table 2 shows the comparative results for return loss, impedance. VSWR and bandwidth and it is seen that the results of simulated antenna structure and fabricated structure are almost similar. The impedance bandwidth of the designed antenna is 109 MHZ .Whereas the impedance bandwidth of the antenna with two square slots across side surface of rectangular patch antenna is 311.84 MHZ. That means, the bandwidth enhancement is approximately (202 MHZ) higher than that of original case (patch without slot, Bandwidth 109 MHZ). The return loss of simulated antenna is -27 db whereas that of fabricated antenna is -37.28 db. The impedance at resonance for both simulated and fabricated antenna is found same i.e. 50 ohms.

Table 2: performance comparison of Simulated and Fabricated Result of micro-strip patch antenna

Type of Structure used	Result Of Simulated Antenna structure By Genesys Software			
	Return Loss(Db)	Impedance At Resonance	VSWR	Bandwidth
Reference Antenna	-27dB	50	1.05	109MHz
Modified Antenna	-40dB	50	1.00	311.845MHz
Results of Fabricated Antenna structure				
Fabricated Modified Antenna	-37.28	50		286MHz

VI.   CONCLUSION

In this paper the rectangular patch Antenna with (50) ohm coaxial feed has been designed. A small broadband antenna has been introduced and bandwidth is enhanced by inserting two square slots on side surface of rectangular patch antenna The impedance bandwidth of the designed antenna is 109 MHZ .Whereas the impedance bandwidth of the antenna with two square slots across side surface of rectangular patch antenna is 311.84 MHZ. That means, the bandwidth enhancement is approximately (202 MHZ) higher than that of original case (patch without slot, Bandwidth 109 MHZ). The improved antenna characteristic is satisfactory for most of the wireless system.

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