DESIGN, SIMULATION AND FABRICATION OF DYNAMIC PATCH ANTENNA

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CERTIFICATE

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ABSTRACT

A conventional patch antenna that can alter its radiation pattern without any passive element is impractical to implement. Also a conventional microstrip antenna has a steady and constant resonant frequency which cannot be altered. The main objective of this paper is to present an idea of an antenna array structure which can vary its radiation pattern using switching technology.

This antenna structure consists of array of four patches (Dynamic Patch Antenna Array-DPAA) placed at an optimized distance with respect to wavelength radiating at 2.437 GHz which is the center frequency of 6th Wi-Fi channel. With such configuration, the main beam radiated by the array can be steered due to the effect of mutual coupling between the driven elements and the parasitic elements (directors). The active feed network will consist of a 1:4 equal power divider (Wilkinson's Power Divider). The antenna radiation characteristics are simulated using Agilent's Advanced Design System (ADS) software. The results confirm that the main beam can be pointed in the following directions depending on the energizing combination of patches: 0°, 4°, 25°, 335°(-25°), 356°(-4°).

The future scope is to make the beam achieve high directivity and narrow beam width thereby achieving beam steering control using RF switches which will be autonomously controlled by software coding.

ACKNOWLEDGEMENTS

After the completion of this work, words are not enough to express our feelings about all those who helped us to reach our goal; feeling above all this is our indebtedness to the Almighty for providing us this moment in life.

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Chapter 1

INTRODUCTION

The beginning of the 21^{st} century has seen peak rise of the technological inventions. Decade by decade the technology is getting updated and the devices are getting more and more compact and flexible. The need of the day is to design more compact devices which have small size, light weight and high efficiency.

Currently personal communication service (PCS) are now getting deeply integrated into society. The PCS world covers everything from cellular phones that incorporate digital cameras and web browsing to Wireless Local Area Networks (WLAN). Since they can all be linked together, their applications are no longer limited. It is now both possible and affordable to surf the web from your laptop and smartphone simultaneously without any wire connectivity.

A WLAN is a flexible data communication network used as an extension to, or an alternative for, a wired LAN in a building. Primarily they are used in industrial sectors where employees are on the move, in temporary locations or where cabling may hinder the installation of wired LAN. Increasingly more and more wireless LANs are being setup in home and or home office situations as the technology is becoming more affordable. With progress and expansion comes the need for faster technology and higher transfer rates. The ongoing wireless LAN standardization and Research & Development activities worldwide, which target transfer rates higher than100 Mbps, justify the fact that WLAN technology will play a key role in wireless data transmission.

Due to increased usage of WLAN equipments in residential and office areas, these systems are required to be low profile, aesthetically pleasing and low cost as well as highly effective and efficient. Microstrip patch antennas are well suited for wireless LAN application systems due to their versatility, conformability, low cost and low sensitivity to manufacturing tolerances.

Conventionally patch antennas have showed a narrowband response, a constant radiation characteristics and invariable resonant frequency.

1.1 LITERATURE SURVEY

1.1.1 WLAN

A wireless local area network (WLAN) links two or more devices using some wireless distribution method, and usually providing a connection through an access point to the wider internet. This gives users the mobility to move around within a local coverage area and still be connected to the network. Most modern WLANs are based on IEEE 802.11 standards, marketed under the Wi-Fi brand name. Wi-Fi is a WLAN (Wireless Local Area Network) technology. It provides short-range wireless high-speed data connections between mobile data devices (such as laptops, PDAs or phones) and nearby Wi-Fi access points (special hardware connected to a wired network). The most common variant of Wi-Fi is 802.11g, which is capable of providing speeds of up to 54Mbps and is backwards compatible with 802.11b (providing up to 11Mbps). There is currently a new standard in the works called 802.11n (offering twice the speeds of 802.11b) and there are already retail networking devices that support its draft specifications.

The IEEE 802.11g protocol has 14 channels. Each channel has 22 MHz bandwidth and 5 MHz separation between channel center frequencies. Each channel overlaps with between four and eight adjacent channels, leaving the possibility of only three simultaneous operating, non-overlapping channels. This means that an apartment complex with a high density of wireless networks will encounter difficulties in establishing connections without interference.

Fig. 1.1 shows the center frequencies of the 802.11g channels and channels which overlap with neighbouring channels. Channels 1, 6, and 11, in fig. 1.1, are the only three channels which can be operated simultaneously while not overlapping.

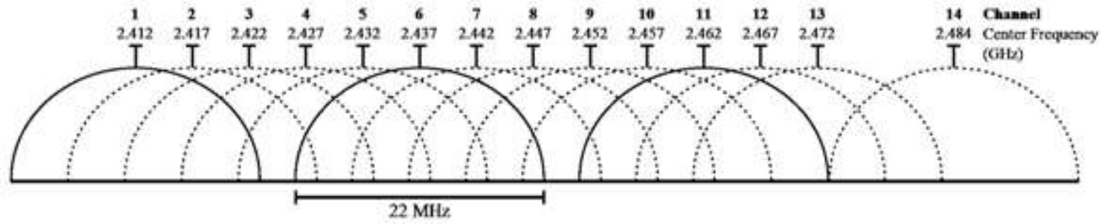


Fig. 1.1: 802.11g channel distribution

In addition to 802.11g channel saturation, many devices such as microwave ovens and Bluetooth adaptors cause additional interference in the 2.4 GHz range. Current wireless adapters sold for desktop computers use omnidirectional dipole antennas that are very susceptible to interference. A directional antenna will alleviate many of these problems, as relatively low-power side lobes can minimize signals received from unintentional sources and diminish interference sent to other networks. The increased main beam gain also allows improved signal reception. The Dynamic antenna can prove to be very useful in such situations where adjusting the aperture of antenna according to available signal strength is important.

1.1.2 CONCEPT OF DYNAMIC ANTENNA

An antenna that physically moves to alter its structure is impractical to implement. Instead, a basic skeletal structure is electrically manipulated to provide a very large, but finite, number of possible configurations.

Dynamic antenna does not involve any alteration in its physical dimension, but it is switch controlled. It is a cognitive, adaptive, and self-reconfiguring antenna which responds to changing signal conditions. It makes use of Generic algorithm which is a program embedded in a microprocessor [1]. It can give feedback signal to the controller circuit so that the controller can automatically adjust the switch configuration in order to change the features of the antenna without changing it physical dimensions. The block diagram of dynamic antenna system is shown in fig. 1.2.

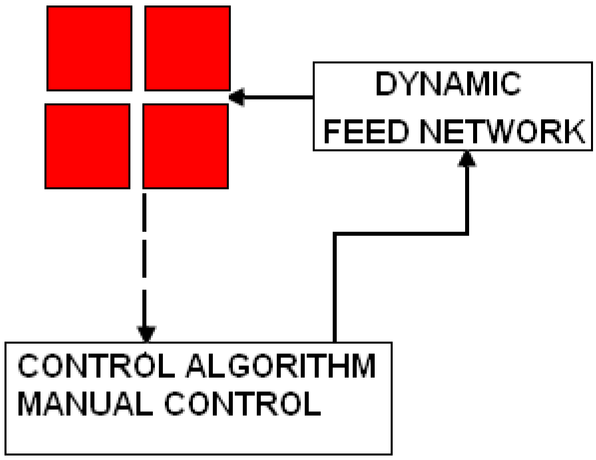


Fig. 1.2: Dynamic Antenna General Block Diagram

The switches are used to control the mutual coupling between the patches. The switches are more probably RF switches formed using PIN diodes or FET/MOSFET's so that they should be capable of conducting in saturation region. The next part is the most important part of dynamic antenna i.e. switch control/dynamic feed network. The switches are controlled using generic algorithm which takes help of the feedback signals. But for the purpose of demonstration, manual switch control is also practiced. The features of dynamic patch antenna are adaptive pattern shaping, adaptive frequency tuning and self healing capabilities.

1.2 PROJECT OBJECTIVE

The conventional patch antenna has various advantages, but it also has some significant disadvantages which a point of concern. Microstrip patch antenna has low directivity. Also a single patch antenna without any active or passive element has steady radiation characteristics which cannot be altered. The microstrip patch antenna can be designed for moreover two or three resonating frequencies which cannot be altered.

All the above problems can be solved using the concept of reconfigurable antenna array [2].The directivity of patch antenna can be increased using antenna array. The alteration of radiation pattern can be achieved by using different switching configurations which will excite antenna array in combinations or with different phases.

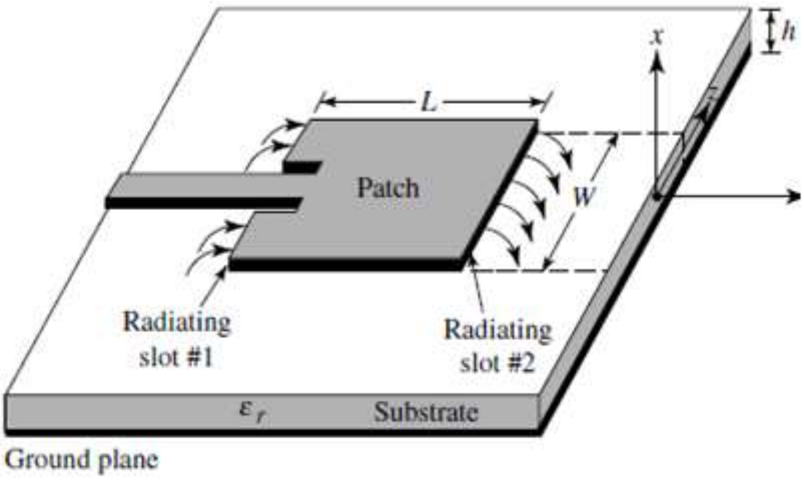
The objective of our project is to design an antenna array with a switching feed network which will alter the radiation characteristics of an array. The antenna array will be designed for WLAN channel no. 6 having center frequency of 2.437 GHz. The results i.e. return loss (S11), resonant frequency (F_r) and bandwidth will be observed and optimized in order to get satisfactory results. The proposed antenna array will be simulated using Agilent’s Advanced Design System(ADS) and results will be verified on Vector Network Analyzer (VNA).

Chapter 2

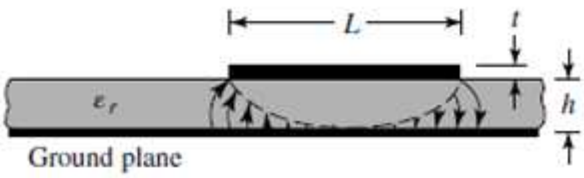
MICROSTRIP PATCH ANTENNA

2.1. INTRODUCTION TO MICROSTRIP PATCH ANTENNA

There are many applications like aircraft, spacecraft, satellite, missile applications, mobile radio and wireless communications where antenna size, weight, cost, performance and ease of installation plays very important role. These requirements are best satisfied by microstrip antennas. These antennas mostly consists of a rectangular or square metal patch on a thin layer of dielectric (called as substrate) on a ground plane as shown in fig. 2.1(a) and fig 2.1(b) . These antennas are also called as patch antennas.



(a) Microstrip Antenna



(b) Side View

Fig. 2.1: Microstrip Antenna Isometric and Side View

The simplest configuration of a microstrip antenna is shown in Fig. 2.1. It consists of a very thin (t) metallic strip (patch) placed on a small fraction of a wavelength (h) above a ground plane. The length of the patch is L and the width is W.

Typical values of these parameters are:

$t << \lambda_0$;

$h << \lambda_0$ usually $0.003\lambda_0 \leq h \leq 0.05\lambda_0$;

$\frac{\lambda 0}{3} < 1 < \frac{\lambda 0}{2}$;

$2.2 \leq \varepsilon_r \leq 12$

where λ_0 is the free space wavelength.

The microstrip patch is designed so that its pattern maximum is perpendicular to patch (broadside radiator). This is done by properly choosing the configuration of excitation beneath the patch. Being a metal ground plane, such antennas are commonly referred to as patch antennas. The radiating elements and feed lines are produced by the process of photo-etching on the dielectric substrate, similar to printed circuit boards. As the resulting printed circuit board is very thin (about 1 mm thick), these antennas are also known as paper thin antennas.

The radiating patch may take different shapes like square, rectangular, thin strip (dipole), circular, elliptical, triangular or any other shape. These are shown in Fig. 2.2.The choice depends on the required type of the radiated field viz. linear, circular or elliptical polarization.

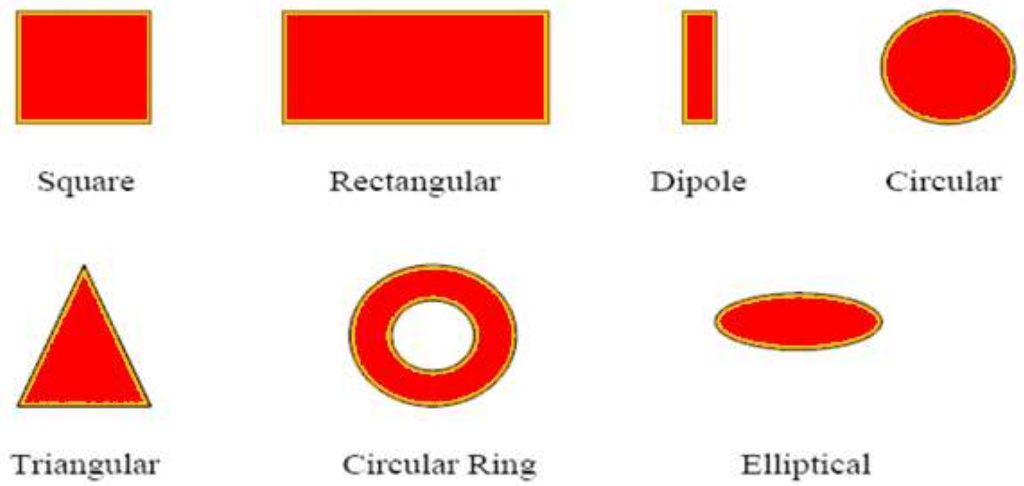


Fig. 2.2: Various shapes of the patch elements

Square, rectangular, dipole (strip) and circular are the most commonly used shapes because of ease of analysis and fabrication and their attractive radiation characteristics. Microstrip dipoles are very attractive because of their large bandwidth; occupy less space which makes them attractive for arrays.

When the signal is applied to microstrip antenna through feed line the antenna radiates. The radiation is due to suitably shaped discontinuities that are designed to radiate. These discontinuities involve:

i) a step change in width
ii) an open end of the patch
iii) a microstrip bend

These discontinuities alter the electric and magnetic field distributions resulting in storage of energy and sometimes radiations at the discontinuity. But when the strip width remains constant or relative dielectric constant of the line remain constant, no radiation occurs. As shown in Fig. 2.1 the signal applied of feed line travels along it and at the patch input the strip width changes suddenly. This step change in width at the input to the patch results in spreading out of the electric field. The fringing field stores energy. But the patch is much wider than a typical microstrip feed line, this causes fringing field to radiate. The signal from feed line when enters into patch and travels along it, due to width along the patch remain constant, this patch portion do not radiate. When the signal reaches the other edge of the patch where the patch ends, that discontinuity results in radiation. Similarly the bending of the microstrip line also results in radiation.

2.1.1 ADVANTAGES OF MICROSTRIP PATCH ANTENNA

1) The structure is planar in configuration and enjoys all the advantages of printed circuit technology.
2) The feed lines and matching networks are fabricated simultaneously with the antenna structure.

3) The solid state components can also be added directly on the microstrip antenna board and hence such antennas are compatible with modular designs.
4) These antennas meet the prime requirements i.e. small size, low weight and hence easy to manufacture on mass scale with low manufacturing cost.
5) Also these can be applied directly to metallic surface on an aircraft or missile and do not disturb the aerodynamic flow and thus have better aerodynamic properties. Accordingly these antennas are replacing old and bulky antennas on aerospace vehicles i.e. on satellite, missile, rocket or aircraft, etc.
6) The other advantages of microstrip antennas are that linear and circular polarizations are possible with simple change in feed position and dual frequency antennas can be made possible.

2.1.2 DISADVANTAGES OF MICROSTRIP PATCH ANTENNA

1) Narrow bandwidth (a few percent)
2) Practical limitations on maximum gain
3) Radiate into a half plane.
4) Poor endfire radiation performance
5) Low power handling capability
6) Possibility of excitation of surface waves

2.1.3 APPLICATIONS OF MICROSTRIP PATCH ANTENNA

1. In aircraft, spacecraft, satellite and in missile applications where small size, lightweight, cost-efficiency, performance, ease of installation, etc. are required.
2. In many government and commercial applications like mobile radio and wireless communications

2.2. FEEDING TECHNIQUES

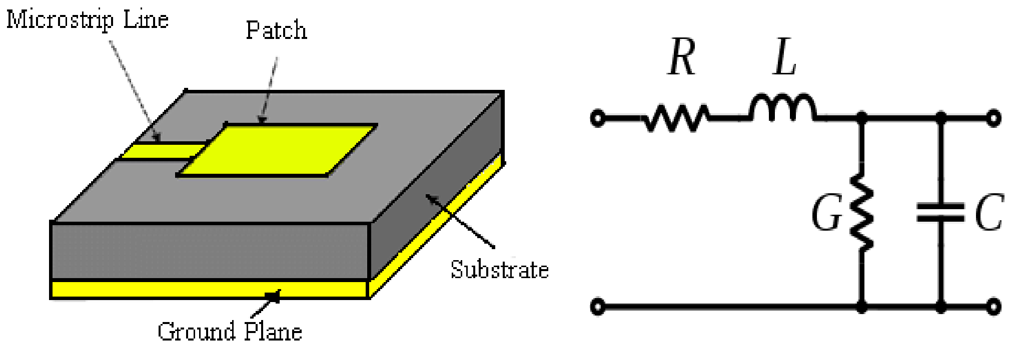
There are many feeding methods to feed the microstrip antennas [3]. These methods are classified into two main types as follows depending upon whether the feed line is directly in contact with the microstrip patch or not.

2.2.1 DIRECT CONTACTING FEEDS:

Here the feed line is in direct contact with the patch. Two most popular methods are discussed below:

2.2.1.1 Microstrip line feed

In this method a microstrip line is used to feed the patch. The microstrip feed line is also a conducting strip of much smaller width as compared to the patch. As in any system, for maximum power transfer the feed line impedance should be matched with the patch impedance. The matching is done by notching the patch to provide an inset feed point and controlling the inset position. The method is shown in Fig. 2.3 along with its equivalent model.



(a) Microstrip line feed (b) Equivalent circuit

Fig. 2.3: Microstrip Line Feed Patch Antenna

The advantages and disadvantages of this method are listed below.

Advantages:

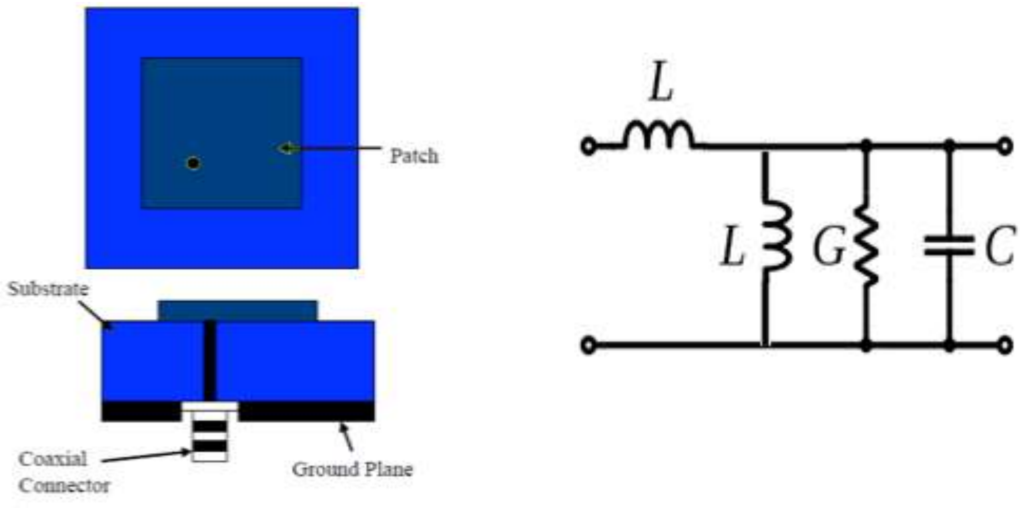
1) Easy to fabricate.
2) Simple to match by controlling the inset position.
3) Simple to model.

Disadvantages:

1) As the substrate thickness increases, surface waves and spurious feed radiation increases, which limits the bandwidth.
2) Possess inherent asymmetries which generate higher order modes which produce cross-polarized radiation.

2.2.1.2 Coaxial Probe Feed

When the signal from the transmitter is available via coaxial line we go for this method. In this method the inner conductor of the coaxial line is attached to the radiation patch while the outer conductor is attached to the ground plane as shown in Fig. 2.4. This method is also widely used.



(a) Coaxial probe feed (b) Equivalent circuit

Fig. 2.4: Coaxial Probe Fed Patch Antenna

Advantages:

1) Easy to fabricate and match.
2) Low spurious radiations

Disadvantages:

1) More difficult to model for thickness of substrate ($h > 0.02 \lambda_0$)
2) It has narrow bandwidth.

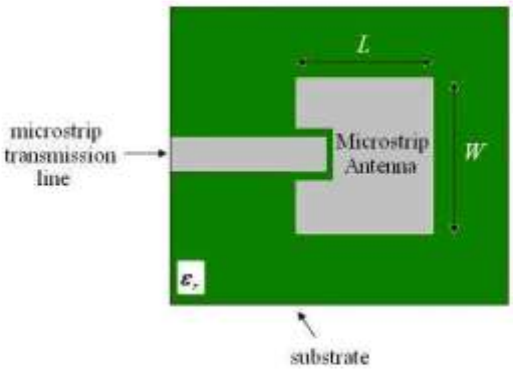
3) Possess inherent asymmetries which generate higher order modes which produce cross-polarized radiation.

2.2.2 NON CONTACTING FEEDS:

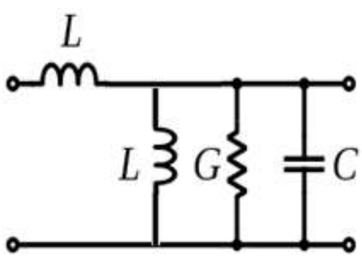
Both the microstrip feed line and the coaxial feed possesses inherent asymmetries which generate higher order modes which produce cross-polarized radiation. To overcome some of these problems, the non-contacting type of feed is used. Two most popular methods are:

2.2.2.1 Proximity-coupled feed:

Here a two layer substrate is used with patch on upper substrate and feeding microstrip line on the lower substrate terminating in an open stub below the patch. The two are capacitively coupled as shown in Fig. 2.5. The patch exists on a relatively thick substrate to improve bandwidth while feed line sees a thinner substrate to reduce spurious radiation of coupling. Bandwidth of about 13% are realised using this method. This feeding method is shown in Fig. 2.5.



(a) Proximity-coupled feed



(b) Equivalent circuit

Fig. 2.5: Proximity Coupled Fed Patch Antenna

Advantages:

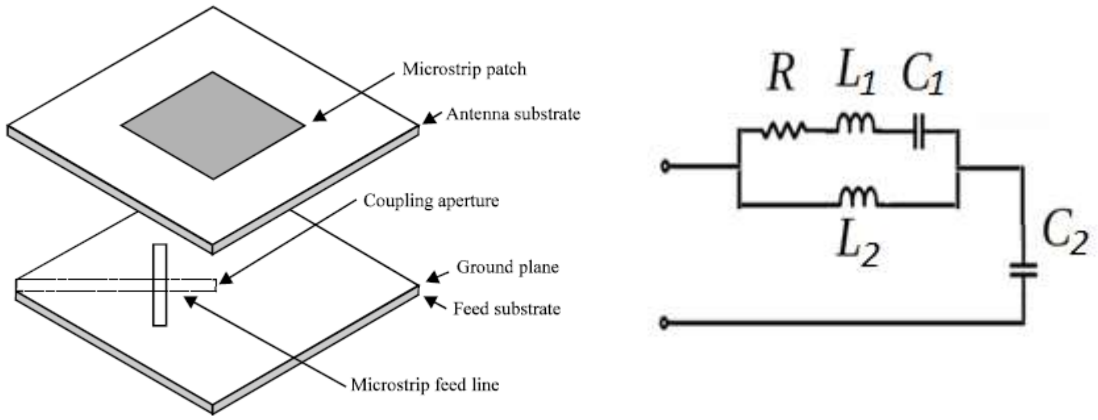
1) Largest bandwidth (high as 13 %).
2) Easy to model.
3) Low spurious radiation

Disadvantages:

1) Fabrication is difficult.

2.2.2.2 Aperture-coupled feed:

The aperture coupling consists of two substrates separated by ground plane. At the bottom side of lower substrate there is microstrip feed line whose energy is coupled to the patch through a slot on the ground plane separating the two substrates. This arrangement allows independent optimization of the feed mechanism and the radiating element. A high dielectric material is used for the bottom substrate and thick low dielectric constant material for the top substrate. The ground plane between the substrates also isolates the feed from the radiating element and minimizes interference of spurious radiation for pattern formation and polarization purity. The layout is as shown in fig. 2.6.



(a) Aperture-coupled feed (b) Equivalent circuit

Fig. 2.6: Aperture Coupled Fed Patch Antenna

Advantages:

1) Easier to model.
2) Moderate spurious radiations.

Disadvantages:

1) Most difficult of all to fabricate.
2) Narrow bandwidth.

2.3. METHOD OF ANALYSIS

The Microstrip antenna generally has a two-dimensional radiating patch on a thin dielectric substrate and therefore may be categorized as a two-dimensional planar component for analysis purposes. The analysis methods for Microstrip antennas can be broadly divided into two groups. In the first group, the methods are based on equivalent magnetic current distribution around the patch edges (similar to slot antennas).Following are the popular analytical techniques:

1) The transmission line model
2) The cavity model

In the second group, the methods are based on the electric current distribution on the patch conductor and the ground plane (similar to dipole antennas, used in conjunction with full-wave simulation/numerical analysis methods). Some of the numerical methods for analyzing Microstrip antennas are listed as follows:

1) The Method of Moments (MoM)
2) The Finite-Element Method (FEM)

Following section briefly describes these methods.

2.3.1 TRANSMISSION LINE MODEL

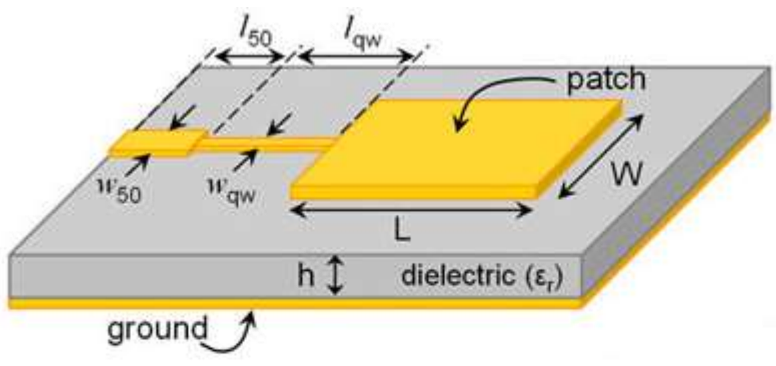


Fig. 2.7: Patch Antenna

For patch antenna in fig. 2.7, the equivalent circuit is as shown in Fig. 2.8. At the edges of the patch, capacitors are shown which represents the capacitance between the patch metal plate and the ground plate. The fringing at the edges which radiates is a loss represented by a conductance in shunt with the edge capacitance. The patch is shown as a transmission line in Fig. 2.8.

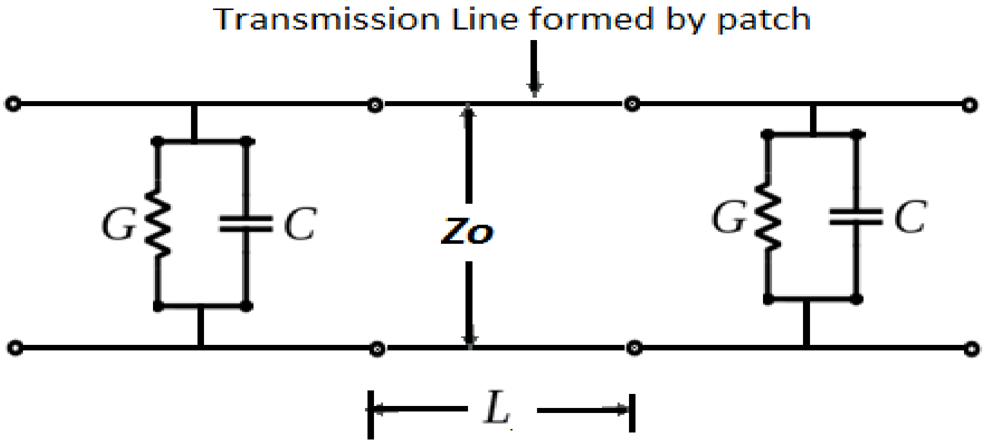


Fig. 2.8: Equivalent Circuit of Patch Antenna

Consider a patch is of length λ/2 long. This length is equivalent to a phase of

$$\beta l = \frac{2\pi}{\lambda} x \frac{\lambda}{2} = \pi^c$$

Thus the fringing field at the output edge of the patch is out of phase with the fringing at the input edge. Let the field at the input is pointing upward then at the output it is downwards the ground plane. When looking directly down on the patch, the fringing field point in the same directions. Refer Fig. 2.9 and Fig. 2.10.

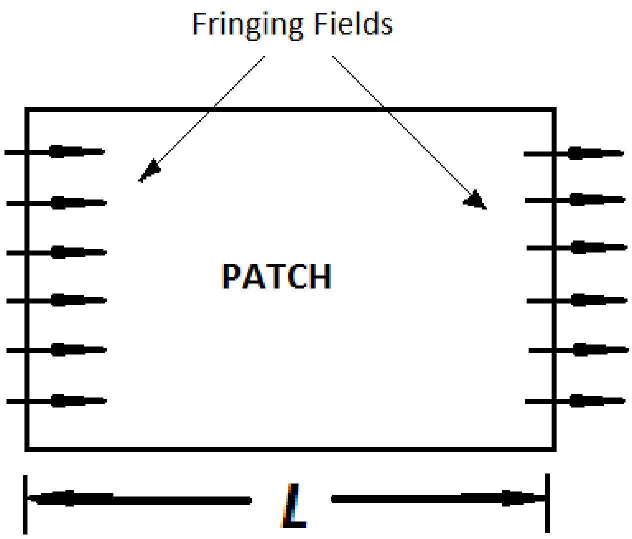


Fig. 2.9: Fringing Fields in Patch Antenna - 1

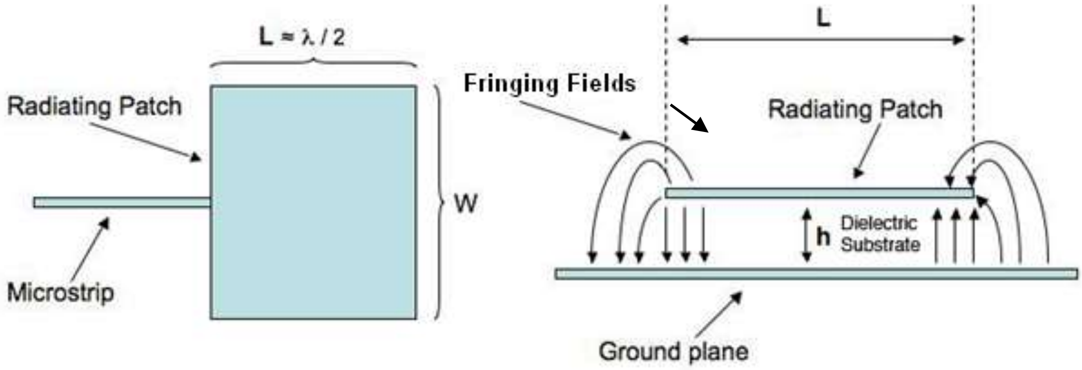


Fig. 2.10: Fringing Fields in Patch Antenna – 2

The radiation from these fields adds up to produce a far-field pattern with a maximum broadside to the patch. The microstrip antenna radiates a relatively broad beam broadside to the plane of the substrate with poor endfire radiation.

The following are some important results required for determining the dimensions i.e. Length (L), Width (W), Effective dielectric (ε_{eff}), Effective length due to fringing effects (ΔL) of the patch. Using formula [4],

I. Computation of width of the patch:

$$W = \frac{1}{2Fr\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{\varepsilon_r + 1}}$$

II. Effective dielectric constant:

$$\varepsilon_{eff=} \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\frac{1}{\sqrt{1 + 12\frac{h}{w}}}$$

III. Effective length due to fringing effects:

$$\Delta L = 0.412h\frac{(\varepsilon_r + 0.3)(\frac{W}{h} + 0.264)}{(\varepsilon_{eff} - 0.268)(\frac{W}{h} + 0.8)}$$

IV. Computation of length of the patch:

$$L = \frac{1}{2F_r\sqrt{\varepsilon_{eff}\mu_0\varepsilon_0}} - 2\Delta L$$

Where,

W = Width of the antenna

Fr = Resonant frequency

μ_0 = Permeability of free space

ε_0 = Permittivity of free space

ε_r = Dielectric constant of substrate material

h= Height of substrate material

L = Length of the patch

2.3.2 CAVITY MODEL

In the cavity model shown in fig. 2.11, the region between the patch and the ground plane is treated as a cavity that is surrounded by magnetic walls around the periphery and by electric walls from the top and bottom sides.

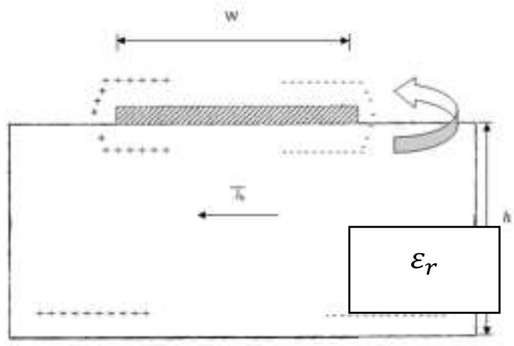


Fig. 2.11: Cavity Model of Patch Antenna

Since thin substrates are used, the field inside the cavity is uniform along the thickness of the substrate. The fields underneath the patch for regular shapes such as rectangular, circular, triangular, and sector shapes can be expressed as a summation of the various resonant modes of the two-dimensional resonator. The fringing fields around the periphery are taken care of by extending the patch boundary outward so that the effective dimensions are larger than the physical dimensions of the patch. The effect of the radiation from the antenna and the conductor loss are accounted for by adding these losses to the loss tangent of the dielectric substrate. The far field and radiated power are computed from the equivalent magnetic current around the periphery. An alternate way of incorporating the radiation effect in the cavity model is by introducing an impedance boundary condition at the walls of the cavity. The fringing fields and the radiated power are not included inside the cavity but are localized at the edges of the cavity. However, the solution for the far field, with admittance walls is difficult to evaluate.

2.3.3 METHOD OF MOMENTS

In the MoM, the surface currents are used to model the microstrip patch, and volume polarization currents in the dielectric slab are used to model the fields in the dielectric slab. An integral equation is formulated for the unknown currents on the microstrip patches and the feed lines and their images in the ground plane. The integral equations are transformed into algebraic equations that can be easily solved using a computer. This method takes into account the fringing fields outside the physical boundary of the two-dimensional patch, thus providing a more exact solution.

2.3.4 FINITE ELEMENT METHOD

The FEM, unlike the MoM, is suitable for volumetric configurations. In this method, the region of interest is divided into any number of finite surfaces or volume elements depending upon the planar or volumetric structures to be analyzed. These discretized units, generally referred to as finite elements, can be any well-defined geometrical shapes such as triangular elements for planar configurations and tetrahedral and prismatic elements for three-dimensional configurations, which are suitable even for curved geometry. It involves the integration of certain basic functions over the entire conducting patch, which is divided into a number of subsections. The problem of solving wave equations with inhomogeneous boundary conditions is tackled by decomposing it into two boundary value problems, one with Laplace's equation with an inhomogeneous boundary and the other corresponding to an inhomogeneous wave equation with a homogeneous boundary condition.

Chapter 3

DYNAMIC PATCH ANTENNA

3.1. INTRODUCTION

An antenna which can change its parameters can be said to be as dynamic antenna. The antenna implemented here is dynamic in its radiation pattern. By switching the feed network, radiation pattern and steering angle can be changed. Dynamic patch antenna does not involve any alteration in its physical dimension, but it is switch controlled. It is an adaptive antenna which will respond to changing signal conditions with the help of external sensing device.

The switches are used to control the mutual coupling between the patches. [5] The switches are RF switches implemented using PIN diode OR FET/MOSFETs so that they conduct in the saturation region. The structure of the antenna can be changed by using such integrated switches for e.g. PIN diode switches as mentioned in the clause above. The next part is the most important part of Dynamic Antenna i.e. Switch Control mechanism. The switches are controlled using generic algorithm which takes help of the feedback signals. But for the purpose of initial demonstration, it is restricted to manual switching and without including the front end model which is concerned with the signal sensing and scanning. The features of dynamic antenna are adaptive pattern shaping, adaptive frequency tuning and self-healing capabilities

3.2. APPLICATIONS OF DYNAMIC PATCH ANTENNA

Recently dynamic patch antennas have gained tremendous research interest for many different applications, for example, cellular radio system, radar system, satellite communication, airplane, and unmanned airborne vehicle (UAV) radar, smart weapon protection. In mobile and satellite communications, dynamic patch antennas are useful to support a large number of standards (e.g., UMTS, Bluetooth, Wi-Fi, WiMAX, DSRC) to mitigate strong interference signal and to cope with the changing environmental condition. On the other hand, in radar applications, reconfigurability at antenna level is often needed for multifunctional operation. This feature is achieved by implementing dynamic antenna array systems that can be quickly adapted according to the mission. A single dynamic antenna array can replace a number of single-function antennas. Thereby overall size, cost, and complexity of a system can be reduced while improving performance such as radar cross-section (RCS).

Dynamic patch antennas also have their applications in areas such as surveillance. They possess the properties to modify the relevant circuital characteristics and/or radiation properties in real time. The implementation of several functionalities on the same antenna requires topological reconfigurability to achieve radiation pattern agility. This is made possible by using dynamic antenna array.

All the clauses stated above can be elaborated by stating some of the relevant applications.

3.2.1 MISSILE GUIDANCE SYSTEMS AND AIRCRAFTS

In case of guided weapons such as missiles, the missiles are guided to strike their target using radar waves. The base station radar illuminates the path to the target by its waves on which the missile rides. The missile receives the radar signals with the help of a patch antenna. But in case of moving targets the target position keeps on changing due to which the base station radar keeps on steering its illumination on an account of target sensing. The dynamic antenna array is the most ideal in this case as it can steer its beam depending on the changes in incoming illumination. Similar application is possible in aircrafts for the purpose of airborne communication as shown in fig. 3.1.

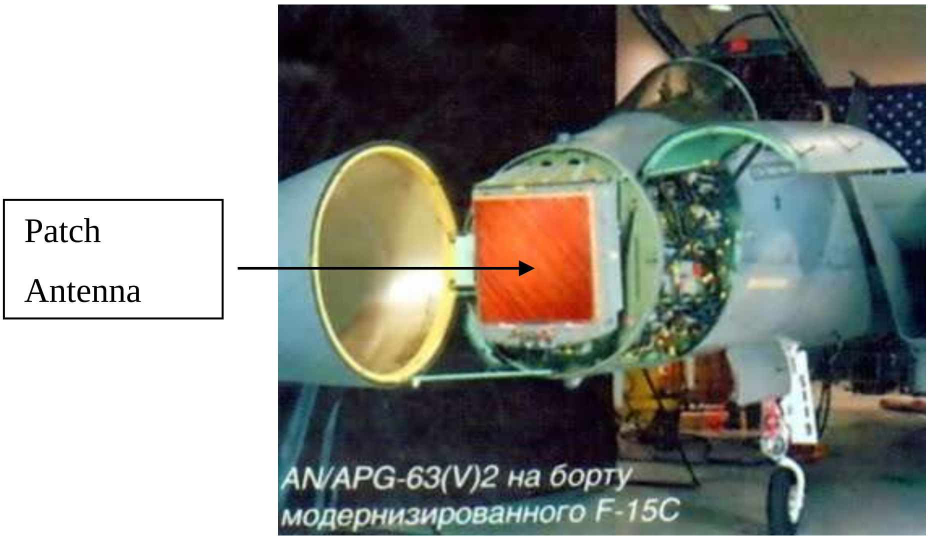


Fig. 3.1: Patch antenna array fixed in missiles

3.2.2 MOBILE BASE STATION RADARS & MOBILE SCUD LAUNCHERS

At the military mobile base stations the radar continuously scans for incoming threats such as enemy aircrafts. For this the radar system is equipped with a mechanically steerable antenna which rotates about its axis to illuminate all the area around. But this decreases the stealth of the station which can make it vulnerable to attacks. Using dynamic antenna array the use of rotating antenna can be eliminated thereby increasing the stealth along with scanning in all directions as shown in fig. 3.2 and fig. 3.3.

Fig. 3.2: Radar System using Antenna patch array

Fig. 3.3: SCUD Launcher

3.2.3 COGNITIVE RADIO

The basic principle of cognitive radio is utilizing the unused frequency bands known as white spaces in the frequency spectrum when a particular band gets crowded. This requires frequency reconfigurability and agility which can be provided by dynamic patch antenna array. For frequency reconfigurability the electrical lengths of the elements are varied abiding the concept of open and shot circuiting of the distributed components at high frequency.

With the increase in demand of bandwidth, enormous amount of efforts have been the aid to the development of antennas that can function on more than one band. Due to this design of reconfigurable antennas has received a lot of attention in recent years. Refer fig. 3.4 for cognitive radio antenna.

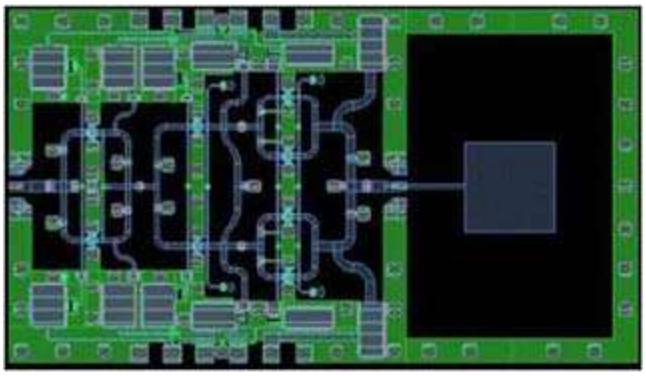


Fig. 3.4: Cognitive Antenna Array

3.2.4 WIRELESS SENSING NETWORKS

Wireless Sensor Networks (WSNs) have emerged as a leading technology with many promising applications. Although challenges encountered in WSNs range from limited power, computation, and memory capability to mislocalization of sensor nodes and events, unpredictable wireless channel propagation conditions, superfluous amount of data created in the network, most researchers focused on networking aspects such as routing protocols, energy minimization, and localization in WSNs. During the past two decades, smart antenna systems have been studied extensively with particular applications to traditional cellular communication systems (2G and 3G systems), and they were proven to provide crucial benefits in these systems such as effective suppression of co-channel interference, capacity increase, and extended coverage. Using similar techniques, recent research efforts concentrated on the application of dynamic antenna arrays to overcome the disadvantages of WSNs.

3.3 ANTENNA COUPLING

Mutual coupling is an electromagnetic phenomenon which exists in many antenna arrays. In most of the usual cases it is detrimental to the antenna operation [6], although there are some examples in which its presence can be beneficial. The effect of mutual coupling on array antennas stretches over many different areas from the conventional use of antennas to their modern employment in such exotic areas as multiple-input multiple-output (MIMO) systems, diversity systems, medical imaging, sonar and radar systems. One of the applications is demonstrated by Dynamic patch antenna array.

The electromagnetic interaction between the antenna elements in an antenna array is called mutual coupling. By its nature, mutual coupling exhibits differently in transmitting and receiving antenna arrays [7] and therefore has to be treated differently. The effect of mutual coupling is serious if the element spacing is small. It will affect the antenna array mainly in the following ways:

1) Change the array radiation pattern.

2) Change the array manifold (the received element voltages).

3) Change the matching characteristic of the antenna elements (change the input impedances)

We will consider the change of array radiation pattern in an array. Mutual coupling between array elements affects both the embedded element radiation patterns and the element input impedances. The radiation from one driven element induces currents on other nearby elements and scatters into the far field, which causes the embedded element pattern to differ from the isolated element pattern. The driven element also induces a nonzero voltage at the terminals of other elements. As a consequence, some of the power accepted by the input port of one element is fed as a reverse wave back into the feeding transmission lines connected to other element ports instead of radiating to the far field. These two effects, perturbation of the element patterns and element feed port coupling, are closely related, since the induced currents on the non-driven elements produce both the perturbation to the radiation pattern and the induced voltage at the element terminals.

By optimizing the distance between the patches the coupling between the patches is changed and optimized value of distance is obtained in the simulations.

3.5. ANTENNA ARRAY WITH DIRECTORS

Director is a parasitic element which is used in antenna arrays to increase the directivity or gain of the antenna [1]. In dynamic patch antenna directors are used with each patch to obtain beam steering. As shown in fig. 3.5 an additional phase delay due to the finite distance between the elements which further delays the phase of the currents in both the directors and reflector(s).

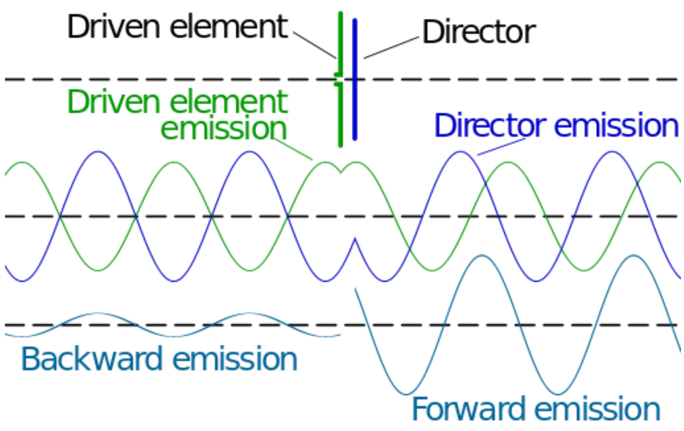


Fig. 3.5: Driven Element with Director

A director is slightly shorter than a half-wavelength; it serves to increase the radiation in a given direction. But by optimization the director length for Dynamic patch antenna is found out to be equal to the length of antenna.

3.5. WILKINSON POWER DIVIDER (WPD)

The Wilkinson Power Divider is a specific class of power divider circuit that can achieve isolation between the output ports while maintaining a matched condition on all ports. It can be used to divide the power in either equal or unequal parts depending upon the requirement [8]. The Wilkinson design can also be used as a power combiner because it is made up of passive components and hence reciprocal. The Wilkinson divider can meet the ideal three-port network conditions (if it is matched at all ports) being lossless, reciprocal, matched.

3.5.1 SCATTERING MATRIX

The scattering parameters for the common case of a 2-way equal-split Wilkinson power divider at the design frequency is given by

$$[S] = \frac{-j}{\sqrt{2}} \begin{bmatrix} 0 & 1 & 1 \\ 1 & 0 & 0 \\ 1 & 0 & 0 \end{bmatrix}$$

Inspection of the S matrix reveals that the network is reciprocal ($S_{ij} = S_{ji}$), that the terminals are matched ($S_{11}, S_{22}, S_{33} = 0$), that the output terminals are isolated ($S_{23} = S_{32}$), and that equal power division is achieved ($S_{21} = S_{31}$). The non-unitary matrix results from the fact that the network is lossy. An ideal Wilkinson divider would yield,

$$S_{21} = S_{31} = -3dB = 10\log_{10}(1/2)$$

Network theorem governs that a divider cannot satisfy all three conditions (being matched, reciprocal and loss-less) at the same time. Wilkinson divider satisfies the first two (matched and reciprocal), and cannot satisfy the last one (being loss-less). Hence, there is some loss occurring in the network. No loss occurs when the signals at ports 2 and 3 are in phase and have equal magnitude. Some modification can be done to achieve unequal power division at the output ports. By cascading, the input power might be divided to any ‘n’ number of outputs.

3.5.2 1:4 WILKINSON POWER DIVIDER

Dynamic patch antenna consists of four patches. In order to give feed to the four patches 1:4 WPD is designed which will give 6dB down output compared to the input to the WPD. Four outputs from the Wilkinson Power Divider have equal outputs which will excite the patches.

3.6. DESIGN PROCEDURE

3.6.1 ANTENNA ARRAY DESIGN

Using formulae specified in section 2.3.1, we can calculate the dimensions of the microstrip patch antenna.

The calculated values of dimensions of the single patch antenna are as follows:

Length of single Patch antenna (L) = 28.96 mm

Width of single Patch antenna (W) = 37.43 mm

The antenna will be excited through coaxial feed using SMA connector. The feed location was found out by trial and error method the starting location being (Xf, Yf) = (W/2, L/3). The feed point is optimized for the least value of S11.

After optimization, the dimensions of the single patch antenna are as follows:

Optimized length = 28.52 mm

Optimized width = 37.43 mm

Feed Point Location = (20, 7.1) mm

As the conventional patch antenna has low directivity, hence we used directors in order to increase its gain and directivity and achieve some beam steering. The directors usually have length less than the antenna length in 1stmode. But after simulations, the director was chosen as a square of side length equal to length of antenna. The center to center distance between patch antenna and director was optimized for S11, resonant frequency and directivity.

After optimization, the dimensions of the single patch antenna with director are as follows:

Optimized length of patch = 28.68 mm

Optimized width of patch = 37.43 mm

Optimized length of director = 28.68 mm

Optimized width of director = 28.68 mm

Feed Point Location = (20, 6.1) mm

Center to center distance between patch antenna and director = 0.625λ

= 38.055 mm

Single microstrip antenna with director is optimized. The dynamic antenna array consists of 4 such antenna director elements placed in a 2x2 array. The spacing between two antenna elements is very important as that will decide the amount of coupling. The coupling between antennas decides the input impedance and radiation pattern of the antenna system. Hence the distance between two individual antennas was optimized and the observations were made.

Two antenna elements with their directors were placed adjacent to each other first along horizontal axis and then along vertical axis. The observations are as shown in table no. 3.1 and table no. 3.2.

Table no. 3.1: Results of two patch antennas with different Horizontal spacing between them

Distance between Patches	Feed to Antenna	Directivity(dB)	Gain(dB)	Theta(°)
λ* 60.88 mm	1st antenna	7.718	3.621	-23
	2nd antenna	7.699	3.618	23
	Both antenna	8.273	4.855	0
3λ/2 91.33 mm	1st antenna	7.706	3.709	-18
	2nd antenna	7.69	3.709	17
	Both antenna	9.32	5.442	0
2λ 121.77 mm	1st antenna	7.505	3.513	-19
	2nd antenna	7.485	3.509	19
	Both antenna	9.486	5.486	0

Table no. 3.2: Results of two patch antennas with different Vertical spacing between them

Distance between Patches	Feed to Antenna	Directivity(dB)	Gain(dB)	Theta(°)
λ/2 30.44 mm	1st antenna	6.232	1.235	-28
	2nd antenna	6.371	1.477	-27
	Both antenna	8.58	4.808	-27
λ 60.88 mm	1st antenna	8.098	4.123	-17
	2nd antenna	7.978	3.969	-18
	Both antenna	10.303	6.73	-17
3λ/2* 91.33 mm	1st antenna	8.559	4.49	-18
	2nd antenna	8.348	4.287	-18
	Both antenna	11.621	7.263	-18
2λ 121.77 mm	1st antenna	7.207	3.235	-21
	2nd antenna	7.259	3.277	-21
	Both antenna	10.847	6.527	-21

The distances marked with asterisk (*) sign were selected as for those distances, the gain, directivity and the angle theta were having significant values.

The final layout of dynamic patch antenna array was designed considering following specifications:

Optimized length of patch = 28.68 mm
Optimized width of patch = 37.43 mm
Optimized length of director = 28.68 mm
Optimized width of director = 28.68 mm
Feed Point Location = (20, 6.1) mm
Center to center distance between patch antenna and director = 0.625λ
= 38.055 mm

Center to center horizontal distance between two patch antennas = λ
= 60.88 mm
Center to center vertical distance between two patch antennas = 3λ/2
= 91.33 mm

3.6.2 WILKINSON POWER DIVIDER DESIGN

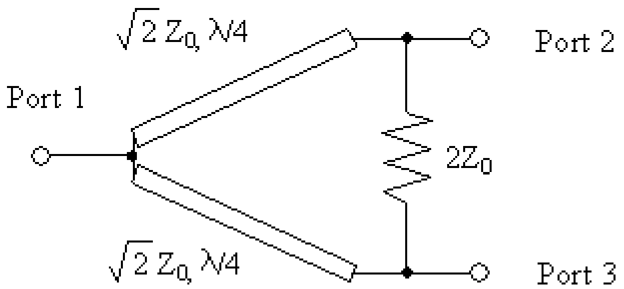


Fig. 3.6: 1:2 Wilkinson Power Divider

The dynamic antenna consists of array of four antennas. Hence 1:4 Wilkinson power divider was designed in order to excite 4 antennas using 1:2 WPD as shown in fig. 3.6. The input and output port microstrip line was designed with

Z_O = 50 Ω as the SMA connector with Z_O = 50 Ω was selected for connecting WPD output to antenna. The characteristic impedance of quarter wave transformer was calculated to be 70.71 Ω [8]. The dimension for microstrip transmission line for given value of characteristic impedance was calculated using Advanced Design System's inbuilt function.

The specifications of 1:4 WPD are as follows:

Width of 50 Ω transmission line = 3.06 mm
Width of 70.71 Ω transmission line = 1.62 mm
Isolation resistance = 2 Z_O = 100 Ω
No. of 1:2 WPD = 3
Length of each transmission line section can be adjusted according to design and various hardware requirements.

Chapter 4–ADS Simulation Software

4.1. BASIC TUTORIAL

4.1.1. ADVANCED DESIGN SYSTEM (ADS) INTRODUCTION

Advanced Design System (ADS) [9] is an electronic design automation software system produced by Agilent EEs of EDA, a unit of Agilent Technologies. It provides an integrated design environment to designers of RF electronic products such as mobile phones, pagers, wireless networks, satellite communications, radar systems, and high-speed data links.

Agilent ADS supports every step of the design process schematic capture, layout, frequency-domain and time-domain circuit simulation, and electromagnetic field simulation allowing the engineer to fully characterize and optimize an RF design without changing tools.

Agilent EEs of has donated copies of the ADS software to the electrical engineering departments at many universities, and a large percentage of new graduates are experienced in its use. As a result, the system has found wide acceptance in industry.

4.1.2. KEY BENEFITS OF ADS

1) Complete, integrated set of fast, accurate and easy-to-use system, circuit & EM simulators enable first-pass design success in a complete desktop flow.
2) Application-specific Design Guides encapsulate years of expertise in an easy-to-use interface
3) ADS is supported exclusively or months earlier than others by leading industry and foundry partner

4.1.3 ADS DESIGN PROCEDURE

1) Start ADS and create a new project by selecting "File → New Project" item. You can call this project Tutorial. Start a new layout by clicking on the "New Layout Window" button (). A new layout drawing window appears as shown in fig. 4.1.

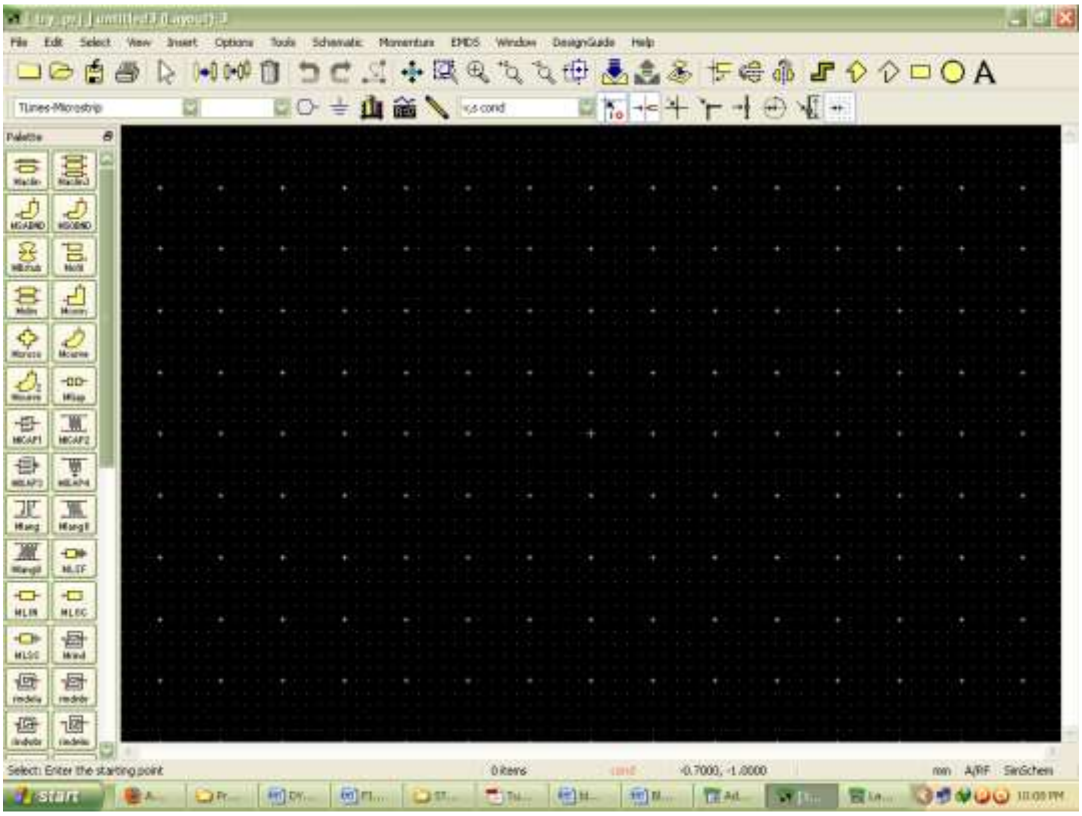


Fig. 4.1: Momentum Layout Window

2) Select "Momentum→Substrate→Create/Modify" item. The "Create/Modify Substrate" window pops up. This window is shown in Fig. 4.2. In this window, you can define the substrate parameters and metal layers and properties all in one place. Under the "Substrate Layers" tab, you can define the layers of dielectric. In this case, we have a microstrip patch antenna that is fabricated on a 1.6 mm thick FR4 substrate. Therefore, we have only one dielectric layer that has an infinitely large ground plane on one side and free space on the other side; the default dielectric layer is Alumina. You can change the name to FR4 and change the thickness to 1.6 mm. Momentum allows for entering the dielectric parameters in three different formats. You can use the Real and Imaginary parts of the dielectric constant ($\mathcal{E}_r = \mathcal{E}' - j\mathcal{E}''$), the real part of the

dielectric constant in conjunction with its loss tangent ($\tan(\delta) = \mathcal{E}''/\mathcal{E}'$), or the real part of the dielectric constant in conjunction with the conductivity of the material. In this case, we will use the “Real, Loss Tangent” option. You should keep in mind that in many circumstances, all three options are three different methods of representing the complex dielectric constant of the material. In this case, we will use the “Real, Loss Tangent” option. You should keep in mind that in many circumstances, all three options are three different methods of representing the complex dielectric constant of the material. In the most general case, the complex dielectric constant of a material can be represented as $\mathcal{E}_r = \mathcal{E}' - j\mathcal{E}'' - j\sigma/\omega$.

3) In the same window, you can enter the magnetic properties of the material. In this case, the material that is used is nonmagnetic. Therefore, you should just make sure that the Real part of the magnetic permeability is 1 and the imaginary part is 0. At this stage, your window should look like the one presented in fig. 4.2.

Fig. 4.2: Create/Modify Substrate Window

4) You can also select the other layers and check their properties. The other two layers are GND and FreeSpace and you can see that the GND is a perfect electric conductor (PEC) and FreeSpace is an open layer of free space.

5) While the Create/Modify window is still open, move to the “Layout Layers” tab. In this window you can change the properties of metallic layers and assign different metal layers to the appropriate surfaces. This is shown in Fig.4.3. On the right hand side of the menu, you can choose the metal layers and change their properties. In this case, we are going to use only one conductor layer “cond” and for the time being, we will consider it to be a perfect electric conductor (PEC). You can change these settings later on. On the left hand side of the menu, you will see the three substrate layers GND, FR4, and FreeSpace. Notice that there is layer represented with a horizontal bar “___” between FR4 and FreeSpace layers. You can select this layer by clicking on it. After selecting this layer, click on the “Strip” button and the layer will be assigned as a strip conductor. This means that everything drawn on this layer is considered a metallic strip. If we had chosen the “slot” option, the layer would have been assigned as a slot layer. This means that everything drawn on this layer would have been considered as an aperture in an infinite ground plane; this option is useful in simulating slot antennas or aperture coupled microstrip antennas. After assigning the appropriate metallic layers, click OK and the definition is complete.

6) In this tutorial, we use millimeters as the length units. Make sure that the default unit is millimeters. You can do this by selecting “Options→Preferences” and the Preferences Menu for the appropriate layout pops up. Select the “Units/Scale” tab and make sure that the units for Frequency and Length are GHz and mm respectively.
Move to “Layout Units” tab and make sure that the layout units are also in mm.

7) Select “Options→Grid Spacing→<0.05-1-100>”. This determines the major and minor grid points on the layout screen. In this design, we would like to

have accuracies in length up to 0.05 mm and that is why we choose the lowest grid spacing to 0.05 mm.

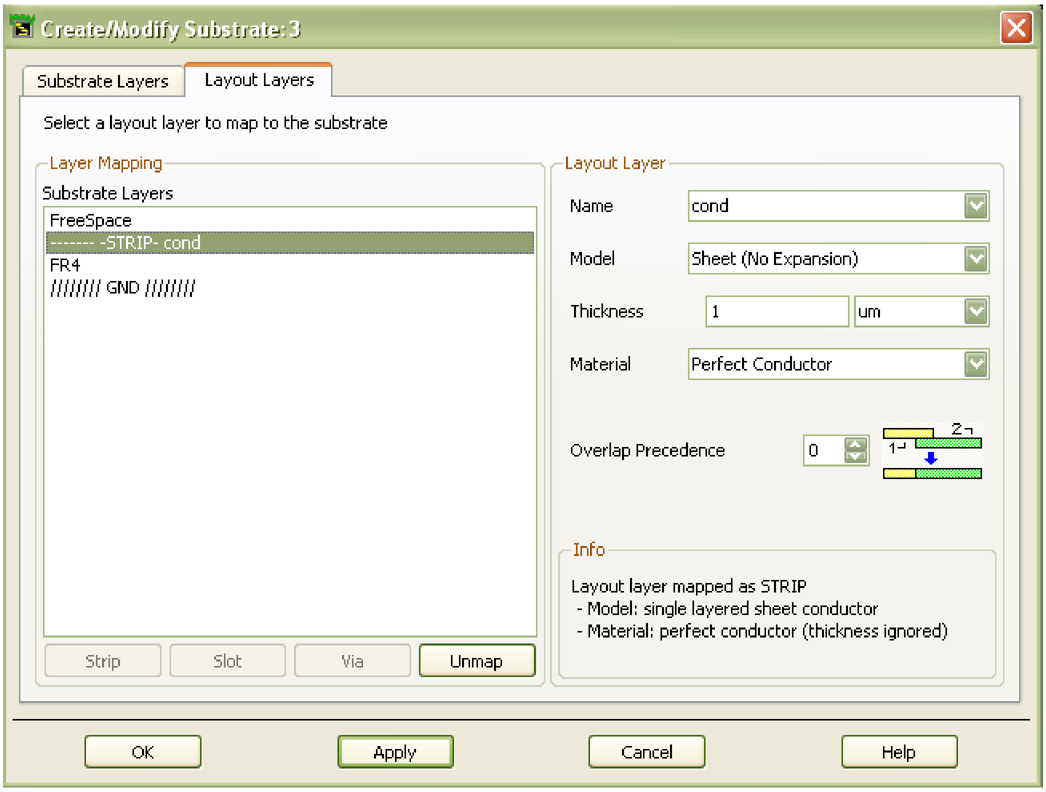
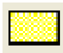


Fig. 4.3: Create/Modify Substrate – Layout Layers Window

8) Now we can start drawing the patch antenna and its feeding structure. Let us start by drawing a rectangle. Select the "Insert Rectangle" button () and the shape of the mouse cursor changes. As you move the mouse cursor on the layout screen, the values of the *x* and *y* coordinates are displayed on the screen. Draw a rectangle and define origin, length and width of patch. We will enter Width = 37.43 mm, Height = 28.25 mm as shown in fig. 4.4.

9) Now that drawing the structure is complete, we should specify simulation parameters. We will start by setting up excitations. Select "Insert→Port" item. By doing this, we enter the port definition mode. Move the cursor to (*x*=20 mm, *y*=7 mm) and click. Port 1 will be placed at the specified co-ordinate.

10) Select "Momentum→Mesh→Setup" and the "Mesh Setup Controls" window pops up. In this window, you can enter the parameters of the mesh such as the highest frequency of operation and the number of cells per

wavelength, and the edge cell parameters. In the “Global” tab choose 3 GHz as the mesh frequency, 30 as the number of cells/wavelength, and make sure that the Edge Mesh check box is NOT checked. Click OK to finish setting up mesh parameters.

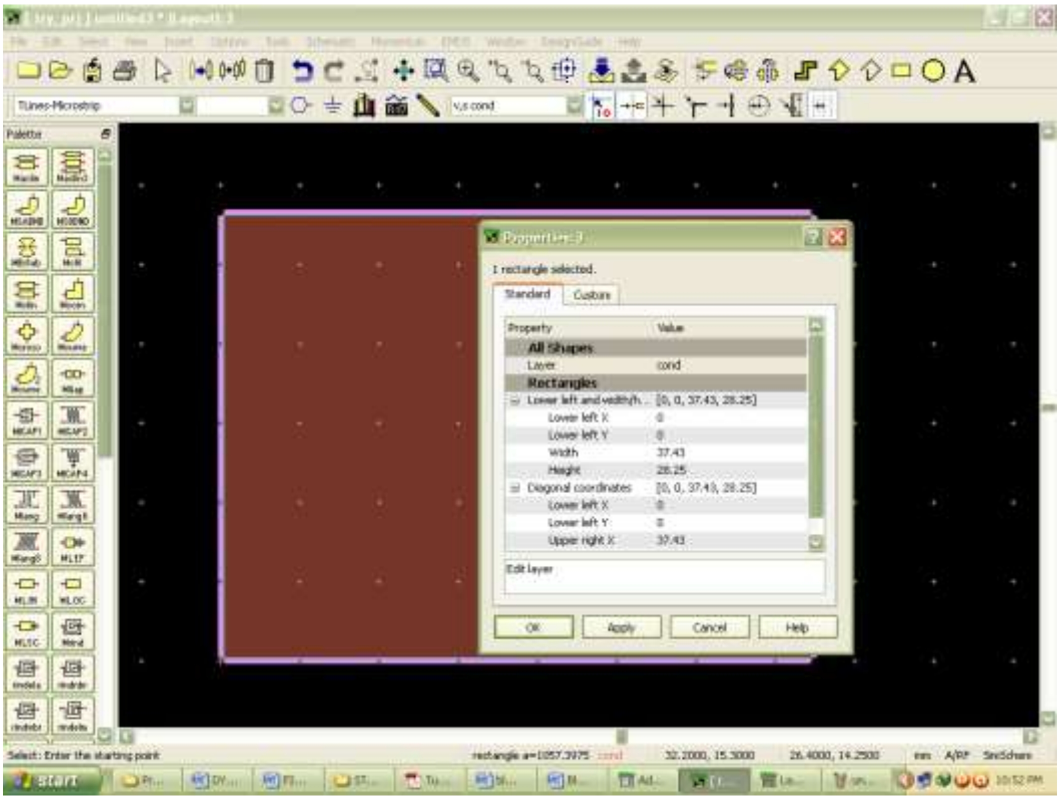


Fig. 4.4: Layout Patch Dimension Window

11) Select “Momentum→Mesh→Preview”. The “Preview Mesh” window appears. Click OK and the mesh will be calculated and displayed.

12) Select the “Momentum→Simulation→S-parameters”. The simulation control menu pops up; in the “Edit/Define Frequency Plan” field, choose “Adaptive” from the “Sweep Type” menu. Enter 1 and 3 GHz in the Start and Stop frequency points and enter 201 as the “Sample Point Limits”. Click on “Add to Frequency Plan List” to add the sweep to the “Frequency Plans” list; make sure that the “Open data display when simulation completes” check box is checked. Click on Simulate to start simulating the structure. The display window will open and display s11 graphs as shown in fig. 4.5.

13) Click on “Momentum→ Post Processing→ Radiation Pattern”. Select Frequency and 2D plot and click Compute. The 2D radiation pattern window will open up as shown in fig. 4.6.

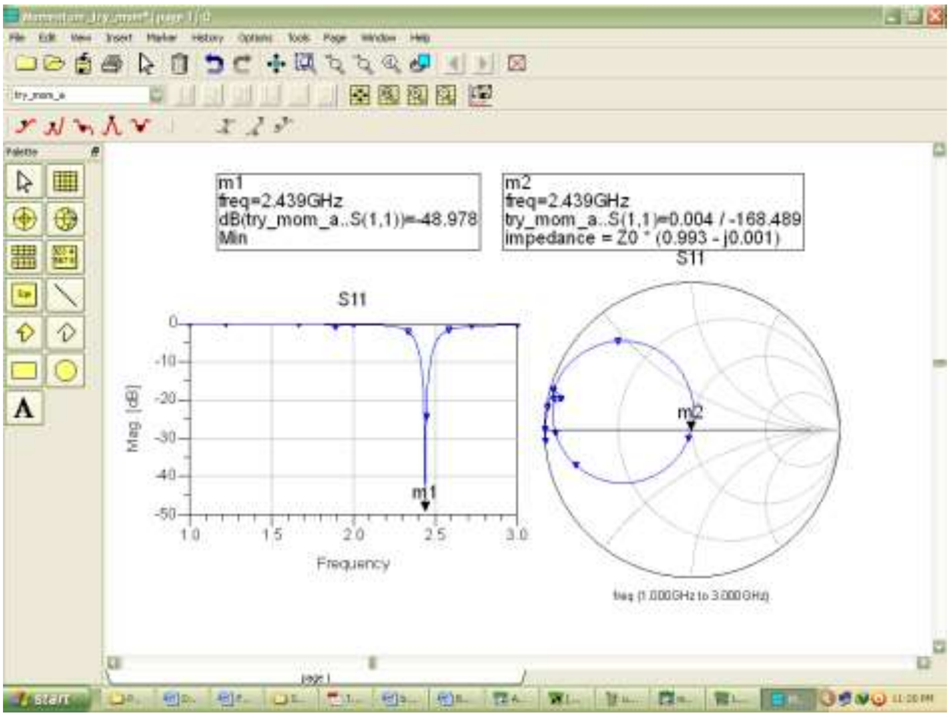


Fig. 4.5: Data Display Window

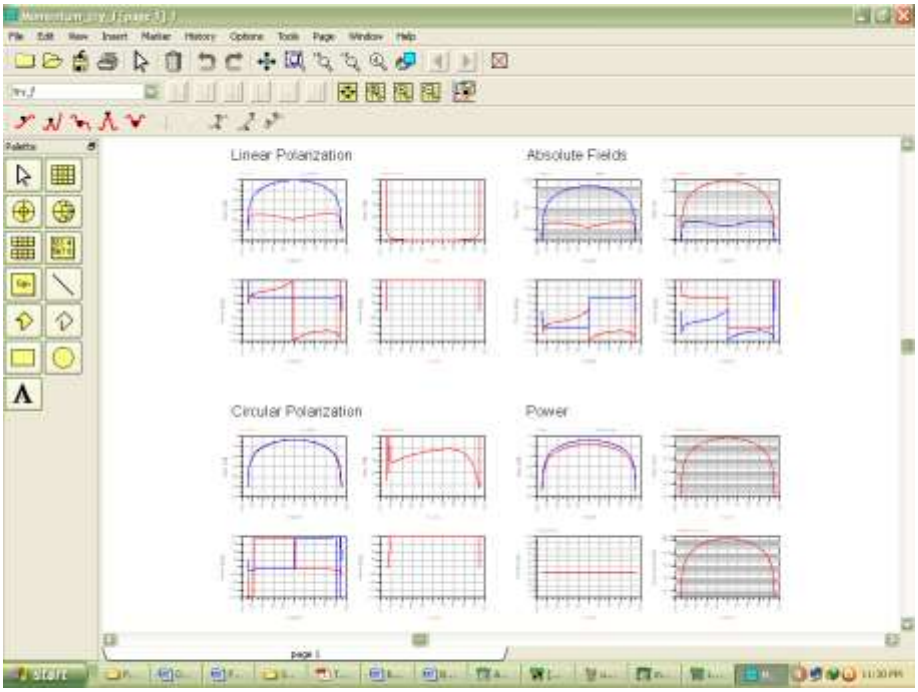


Fig. 4.6: 2D Radiation Pattern Window

14) To view radiation pattern in 3D, Click on “Momentum→ Post Processing→ Radiation Pattern”. Select Frequency and 3D plot and click Compute. The 3D radiation pattern window will be invoked.

15) To see far field antenna parameters, Select “Far Field Antenna parameters” item and a window pops up in which the radiation parameters of the antenna such as its gain, efficiency, and directivity are listed in different fields.

4.2. LAYOUT OF SINGLE PATCH

Before designing the desired dynamic patch antenna, the first step we will consider is the specifications of the single microstrip patch antenna. After performing some research and optimization, the various parameters are listed in the table below:

Parameter	Calculated Value	Optimized Value
Width	37.43 mm	-
Length	28.96 mm	28.52 mm
Feed Point Location	(18.715, 13.99) mm	(20, 7.1) mm

Table no. 4.1: Single Patch Dimensions

Using the procedure mentioned in 4.1.3, we can design and simulate single microstrip patch antenna. While simulating the antenna structure, we will consider the optimized value of the antenna dimensions.

The optimized layout of patch antenna is as shown in fig. 4.7.

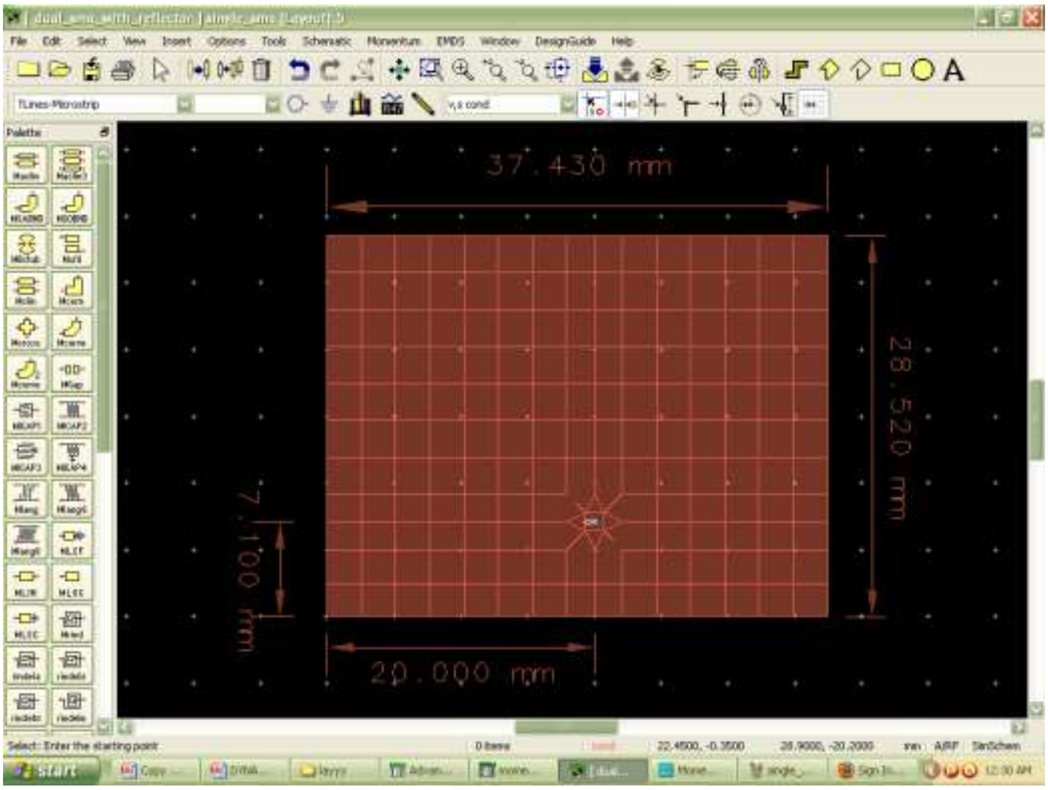


Fig. 4.7: Single Microstrip Patch Antenna Layout

4.3. LAYOUT OF SINGLE PATCH WITH DIRECTOR

In the next step, we will consider the simulation of single microstrip antenna with director placed at an optimum distance. The following table includes all the dimensions and the spacing information of patch antenna with director.

Table no. 4.2: Dimensions of Single Antenna with Director

Parameter	Value
Width of Antenna	37.43 mm
Length of Antenna	28.68 mm
Width of Director	28.68 mm
Length of Director	28.68 mm
Feed Point Location	(20, 6.1) mm
Distance between Antenna and Director	0.625λ = 38.055 mm

The optimized layout of patch antenna is as shown in fig. 4.8.

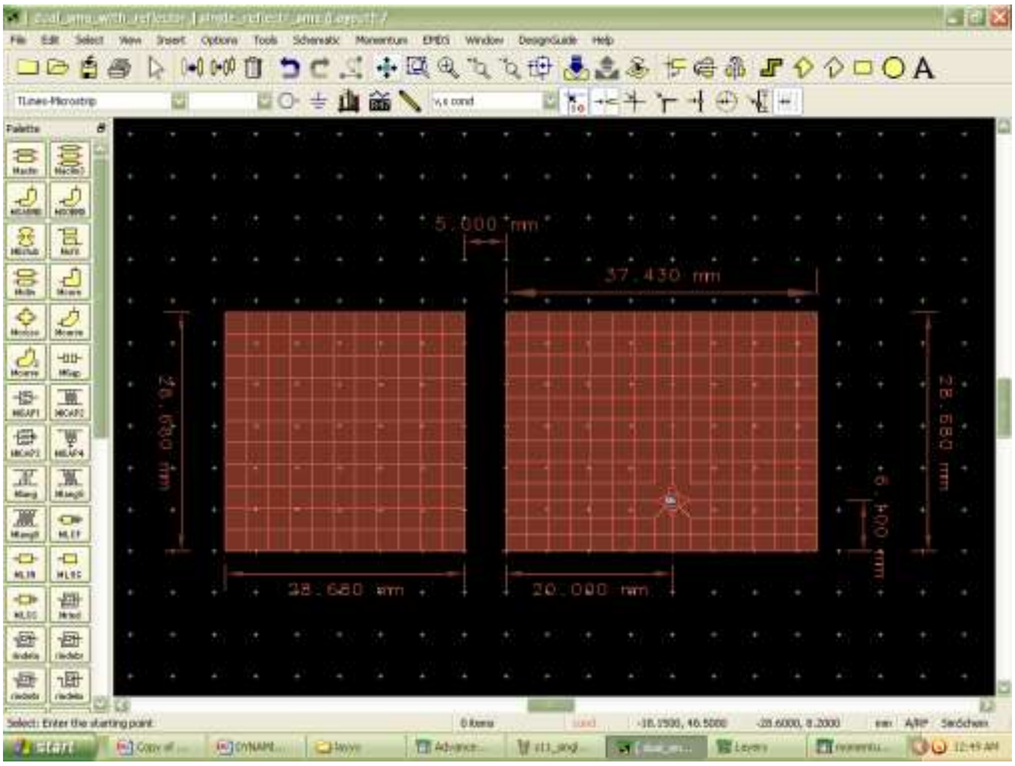


Fig. 4.8: Single Microstrip Patch Antenna with Director Layout

4.4. LAYOUT OF FOUR PATCHES WITH DIRECTORS

Before we start with the actual design of dynamic antenna array, we need to know the spacing between antenna array elements. The antenna dimensions and spacing information is given by table no. 4.3. The distance between two patches is chosen according to the results of the simulation of two patch antennas with directors. The antennas were excited in combination and the distance was varied starting from λ/2, λ, 3λ/2 and so on. The optimum distance was selected which resulted into satisfactory value of gain and directivity.

After calculating all the required optimized dimensions, we will have to design 4 antenna elements and four passive elements i.e. directors. The design procedure will remain same as that used for above two cases 4.2 and 4.3. There will be four excitation ports in order to excite the dynamic antenna array in 16 combinations (2^4=16).For simulation purpose only, we will not use any switching technique; instead we will give excitation ports to array in 16 combinations and observe the results.

Table no. 4.3: Dimensions of Dynamic Antenna Array Elements
(* indicates refer table no. 3.1 and table no. 3.2)

Parameter	Value
Width of Antenna	37.43 mm
Length of Antenna	28.68 mm
Width of Director	28.68 mm
Length of Director	28.68 mm
Feed Point Location	(20, 6.1) mm
Distance between Two Antennas along Horizontal Axis*	λ = 60.88 mm
Distance between Two Antennas along Vertical Axis*	$3\lambda/2$ = 91.33 mm

The above table includes all the parameters of the dynamic antenna array. The distance between two antennas along horizontal and vertical axis is shown in the table. The horizontal and vertical separations are optimized and observations are shown in table no. 3.1 and table no. 3.2 respectively. The distances are optimized for gain, directivity, S11 and resonant frequency. Fig. 4.9 shows the designed layout of dynamic patch antenna with all the specifications mentioned in the above table.

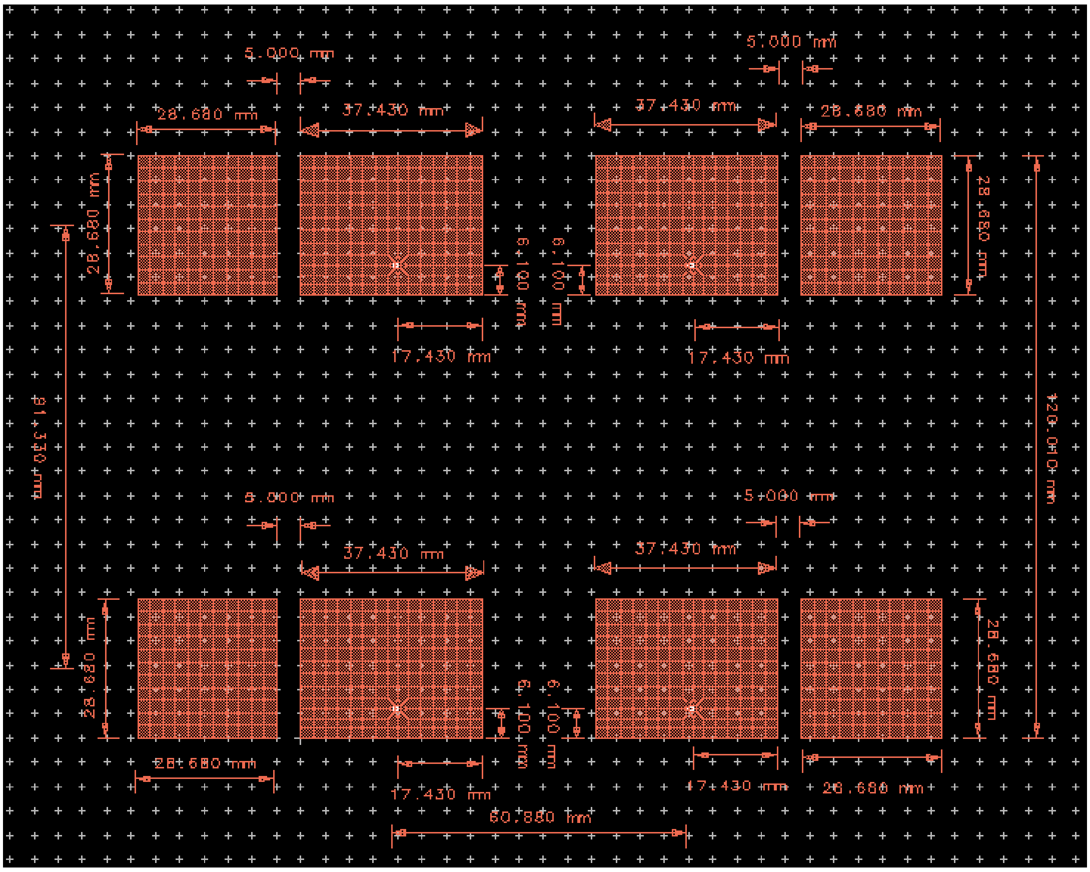


Fig. 4.9: Dynamic Patch Antenna Layout

4.5. LAYOUT OF WILKINSON POWER DIVIDER

The Wilkinson power divider is a lossless power divider. As we need to divide power to 4 patches, 1:4 Wilkinson power divider is designed [10]. Various specifications related to 1:4 Wilkinson power divider are given in table no. 4.4.

Table no. 4.4: Wilkinson Power Divider Specifications

Parameter	Value
Input Port Impedance (Z_o)	50 Ω
Output Port Impedance (Z_o)	50 Ω
Quarter Wave Impedance (Z_1)	70.71 Ω
Width of 50 Ω Transmission Line	3.06 mm
Width of 70.71 Ω Transmission Line	1.62 mm
Isolation Resistance ($2Z_o$)	100 Ω

As it is quite tedious to design curved transmission line in layout of ADS, we designed 1:4 Wilkinson Power Divider in schematic first and then we updated it in layout. The layout of Wilkinson power divider is shown in fig. 4.10.

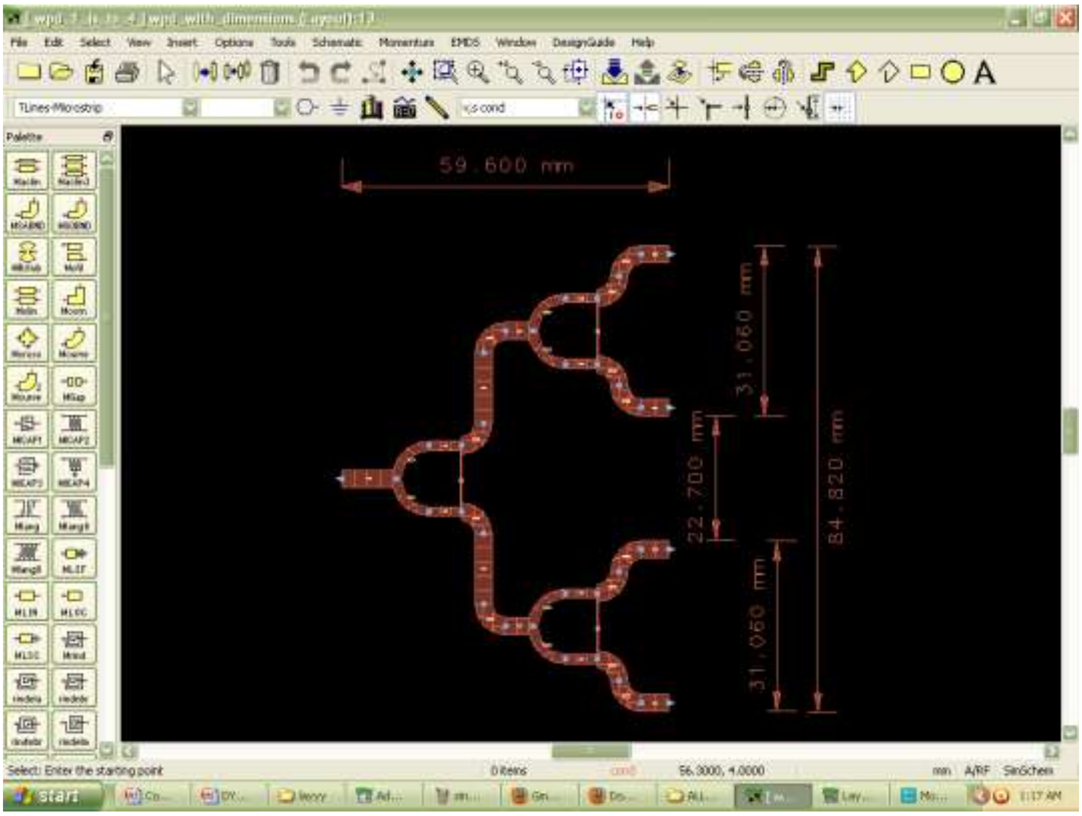


Fig. 4.10: 1:4 Wilkinson Power Divider Layout

The layout of both dynamic antenna and feed network are designed in ADS and various results are observed and verified.

Chapter 5

IMPLEMENTATION OF DYNAMIC PATCH ANTENNA

5.1 INTRODUCTION

After design and simulation of dynamic antenna array, next step is to fabricate dynamic antenna. The specifications of dynamic patch antenna are given in table no. 5.1.

Table no. 5.1: Specifications of Dynamic Patch Antenna

Resonant Frequency	2.437 GHz
Substrate	Flame Retardant – 4 Glass Epoxy
Dielectric Permittivity	4.4
Loss Tangent	0.02
Substrate Height	1.6 mm
Length of Patch	28.68 mm
Width of Patch	37.43 mm
Length of Director	28.68 mm
Width of Director	28.68 mm
Center to Center Distance between Patch Antenna and Director	38.055 mm
Center to Center Distance between 2 Patch Antenna along Horizontal Axis	λ = 60.88 mm
Center to Center Distance between 2 Patch Antenna along Vertical Axis	$3\lambda/2$ = 91.33 mm
Length of Ground metal	150 mm
Width of Ground metal	200 mm

5.2 FABRICATION PROCESS

The details of the fabrication process while developing the project includes,

1) Selection of substrate (FR - 4)
2) Selection of Connector (SMA)
3) Fabrication

5.2.1 FLAME RETARDANT (FR – 4) SUBSTRATE

A dielectric substrate is a main constitute of the microstrip structure whether is it a microstrip line circuit or an antenna. For MSA application a thicker substrate with low dielectric constant is preferred to enhance the fringing field and hence the radiation. Another important substrate parameter is its loss tangent (*tan d*). The tan d indicates the dielectric loss, which increases with frequency. For the higher efficiency of antenna, the substrate with low tan d should be used; this is costlier than the substrate with high *tan δ*. Therefore, judicious selection of the substrate is required with consideration with application and frequency of application.

To sum up, the choice of the substrate is the first important step in successful design of MSA. The FR – 4 substrate shown in fig. 5.1 is selected for fabrication of dynamic antenna as it is readily available, cost effective and also PCB circuitry can be fabricated on same substrate as it is commonly used. Permittivity of the FR - 4 is 4.4 and *tan δ* is 0.02 which is quite high. Hence significant losses are present.

Fig. 5.1: FR-4 Substrate

5.2.2 COAXIAL CABLE CONNECTOR (SMA)

A number of different connectors are used with the coaxial cable. The most commonly used connectors are BNC connecters, TNC connectors, type N connectors, UHF connectors and subminiature version A (SMA) series connectors.

SMA connectors are semi precision, high-frequency subminiature connectors. The inner diameter of the outer conductor is only 3mm. A typical cable plug has an inside diameter of 0.14 inch (3.6 mm) and a length of 0.43 inch (10.9mm). Large-diameter rigid and semi rigid cables use special connectors. The male and female SMA – connector is shown in fig. 5.2.

a. SMA Male Connector

b. SMA Female Connector

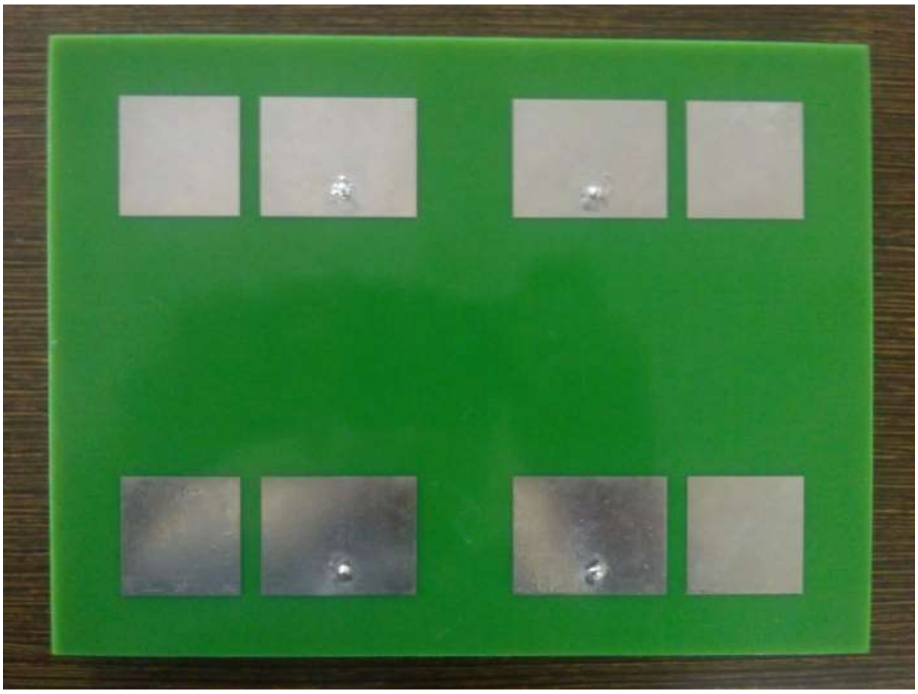
Fig. 5.2: SMA Connector

Table no. 5.2: Specifications of an SMA connector

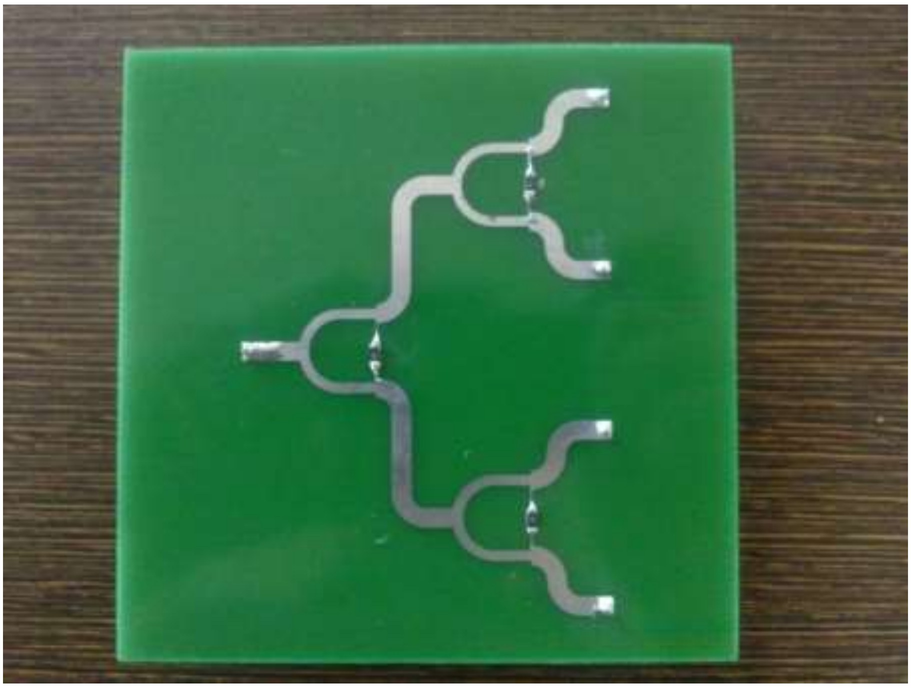
Impedance	50 ohm
Frequency range	Semi–rigid cable for 0.141" or .085" copper jacket: 0–18 GHz Flexible cable: 0–12.4 GHz
Voltage rating	RG–58, 141, 142, 223: 500V_{peak} RG–174, 188, 316: 375V_{peak}
Dielectric withstanding voltage	0.141" & RG–58 cable group: 1000V_{RMS} 0.085" & RG–316 cable group: 750V_{RMS}
Contact resistance	Center: 2.0 milliohms Body: 2.0 milliohms Braid to body: 0.5 milliohms
Insulation resistance	5000 Mega-ohms

5.2.3 FABRICATION

The antenna fabrication took place at Yashna Circuits Pvt. Ltd., Vileparle (E), Mumbai- 400057. The fabricated antenna is as shown in fig. 5.3.



a. Antenna Array with Director



b. 1:4 Wilkinson Power Divider

Fig. 5.3: Fabricated Dynamic Antenna Array

Chapter 6

RESULTS AND ANALYSIS

As the dynamic patch antenna is designed, simulated and fabricated; the results of the antenna need to be observed and verified in order to comment on the performance of the dynamic antenna.

6.1 RESULTS FOR SINGLE PATCH ANTENNA

The designed layout of single patch antenna is shown in fig. 4.7. The results for single microstrip patch antenna are shown in fig. 6.1 and fig. 6.2:

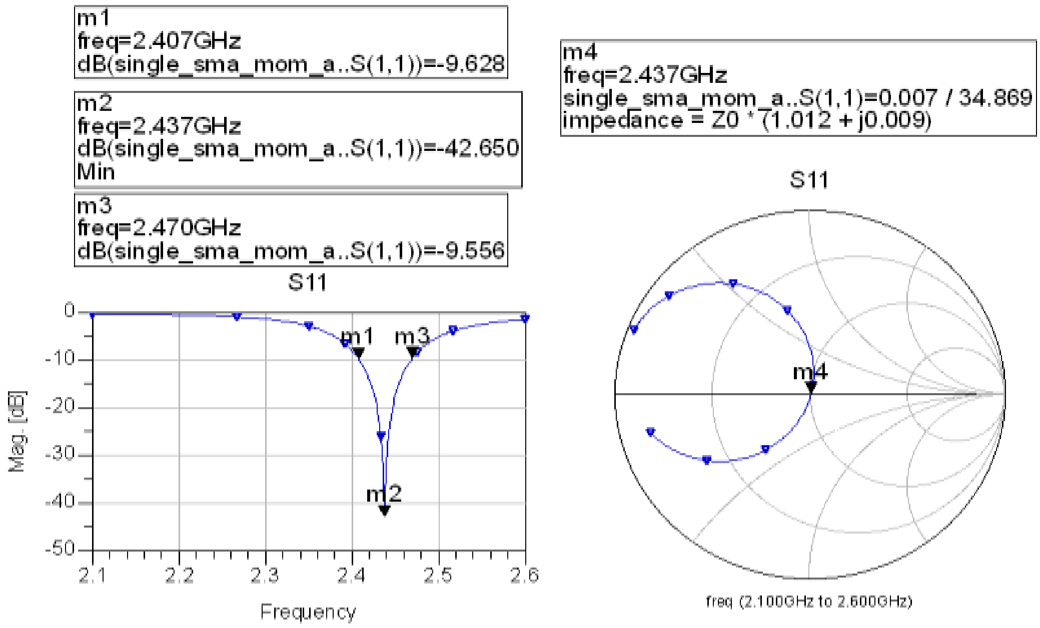
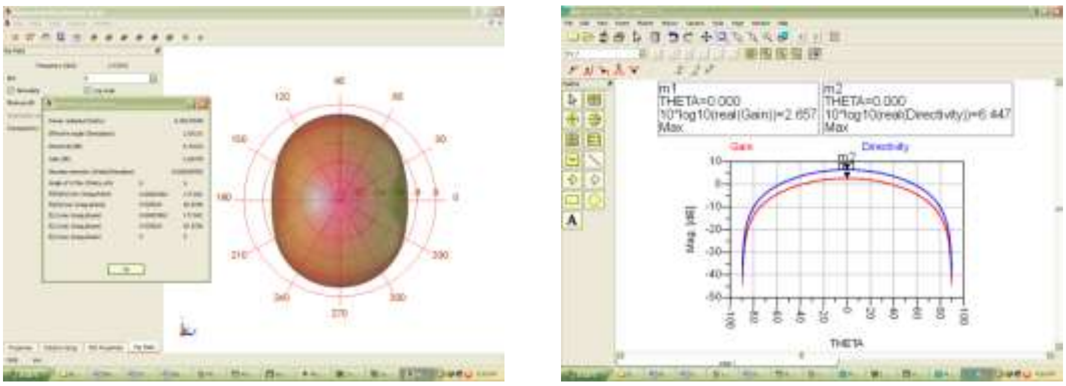


Fig. 6.1: Momentum Results for Single Patch Antenna



a. 3D Radiation Pattern b.Directivity and Gain Graph

Fig. 6.2: Radiation Characteristics of Single Patch Antenna

6.2 RESULTS FOR SINGLE PATCH ANTENNA WITH DIRECTOR

The designed layout of single patch antenna with director is shown in fig. 4.8. The results are shown in fig. 6.3 and fig. 6.4.:

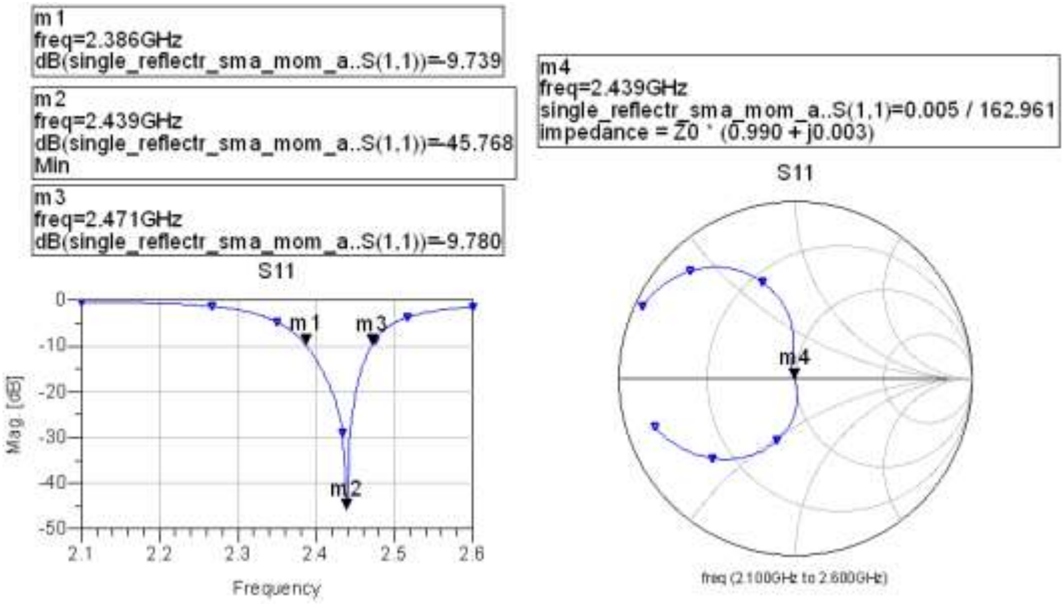
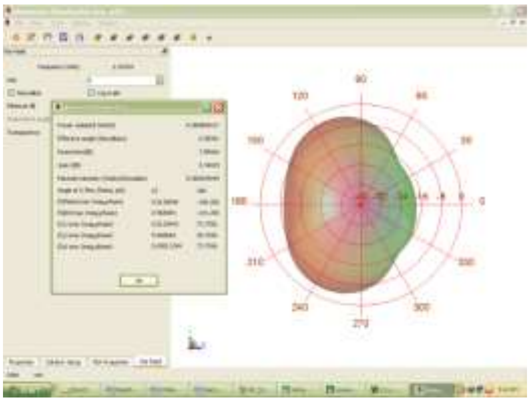
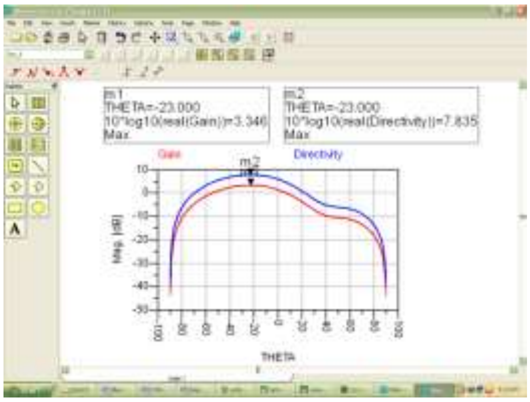


Fig. 6.3: Momentum Results for Single Patch Antenna



a. 3D Radiation Pattern



b.Directivity and Gain Graph

Fig. 6.4: Radiation Characteristics of Single Patch Antenna with Director

Here, we can clearly see that adding a passive element have a change in radiation pattern of the antenna system. Also there is increase in gain and directivity of the antenna. The beam is now having maximum at -23° which shows that passive elements like directors can be used to achieve beam steering characteristics. Also, if we refer fig.6.1 and fig. 6.3, we can clearly observe that in latter case, there is increase in bandwidth. If such system is used in an array, various different combinations of radiation characteristics are possible.

6.3 RESULTS FOR WILKINSON POWER DESIGN

The graph of transmission coefficient for all the output ports of Wilkinson power divider is given in fig. 6.5.

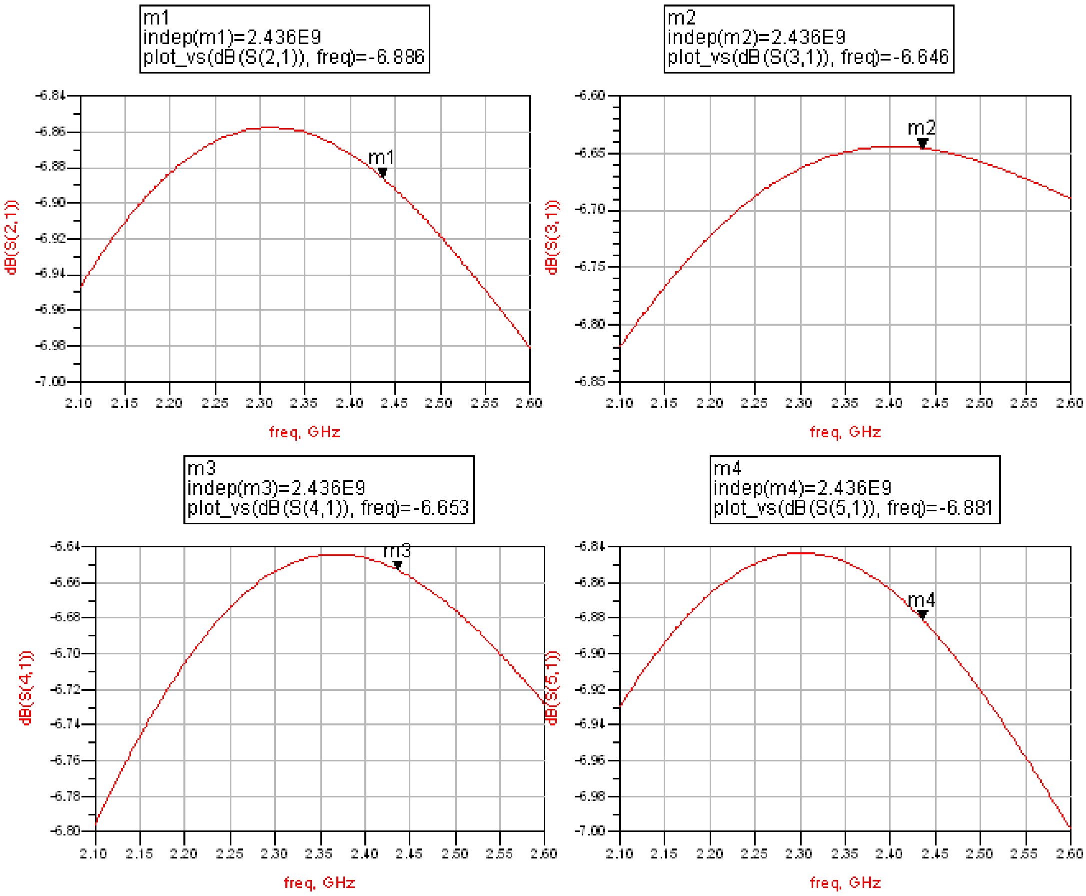


Fig. 6.5: Transmission Coefficient of 4 output ports of Wilkinson Power Divider

As 1:4 power divider will divide power at input port into equal power at output ports, the transmission coefficient should be equal to -6 dB at each output port. But as, FR-4 substrate is used having loss tangent of 0.02, due to losses we are getting average output power of -6.76 dB. But the powers at each output port are almost equal and hence we can use this network as an equal power divider.

6.4 RESULTS FOR DYNAMIC PATCH ANTENNA

As dynamic antenna consists of 4 patches, therefore in all $2^4 = 16$ combinations of excitation are possible. Every combination has different gain, directivity and beam steering property. The microstrip patches in the designed array are numbered as given in fig.6.6.

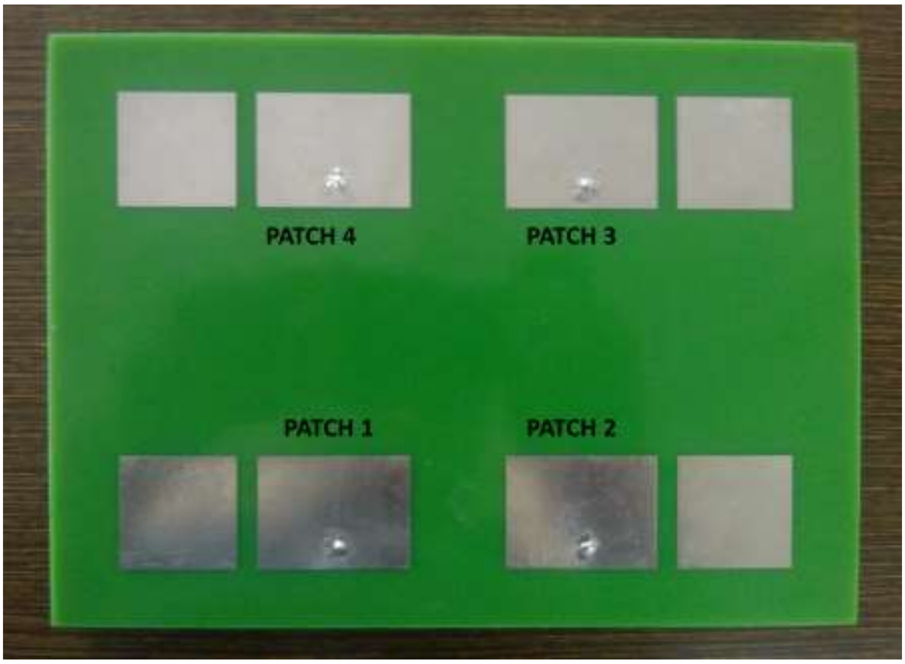


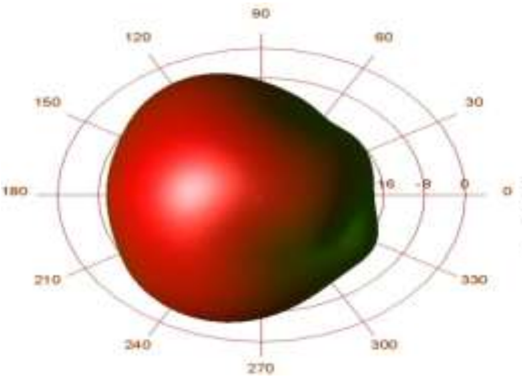
Fig 6.6: Dynamic Antenna Array with Microstrip Patches Numbered

Table no. 6.1 given below includes radiation characteristics of all the combinations. The left bottom patch is numbered as patch 1 and then all the subsequent patches are numbered in anticlockwise manner. All the four patches are identical in dimensions. The location of feed point for all the patch antennas is also same.

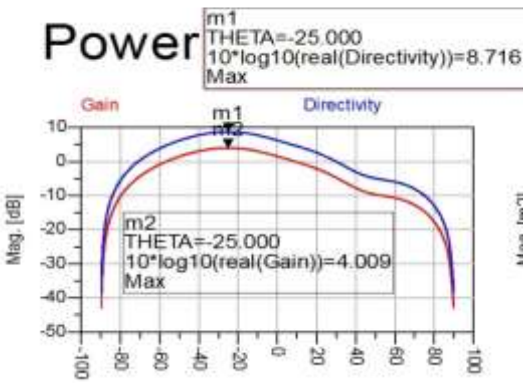
Table no. 6.1: Radiation Characteristics of Dynamic Patch Antenna

Patches Excited	Directivity	Gain	Theta
1	8.716	4.009	-25
2	8.706	4.019	25
3	8.589	3.909	24
4	8.678	3.973	-25
1,2	8.801	4.983	0
2,3	11.937	6.987	25
3,4	8.503	4.676	0
4,1	11.958	6.982	-25
1,3	9.283	4.371	0
2,4	9.269	4.352	0
1,2,3	10.98	6.594	4
2,3,4	10.878	6.48	4
3,4,1	10.881	6.48	-4
4,1,2	10.984	6.584	-4
1,2,3,4	12.093	7.817	0

The 3D radiation pattern and graph of directivity and gain for all the combinations are given in figures below:

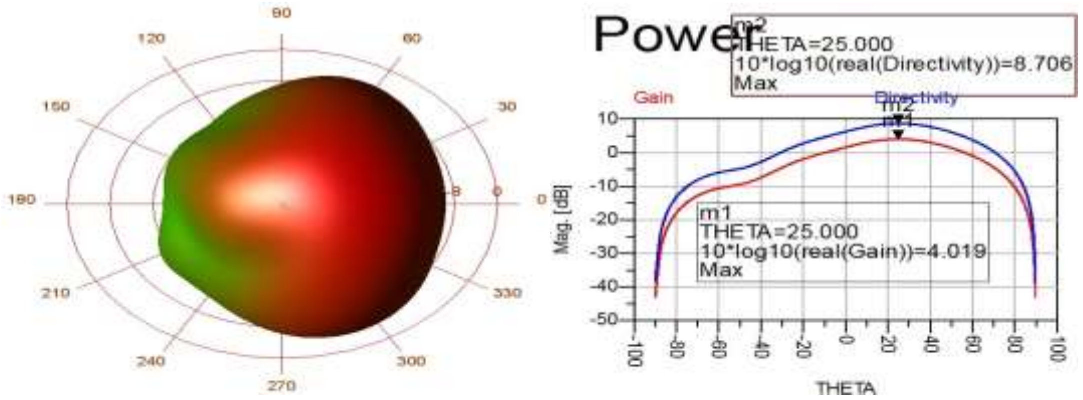


a. Radiation Pattern



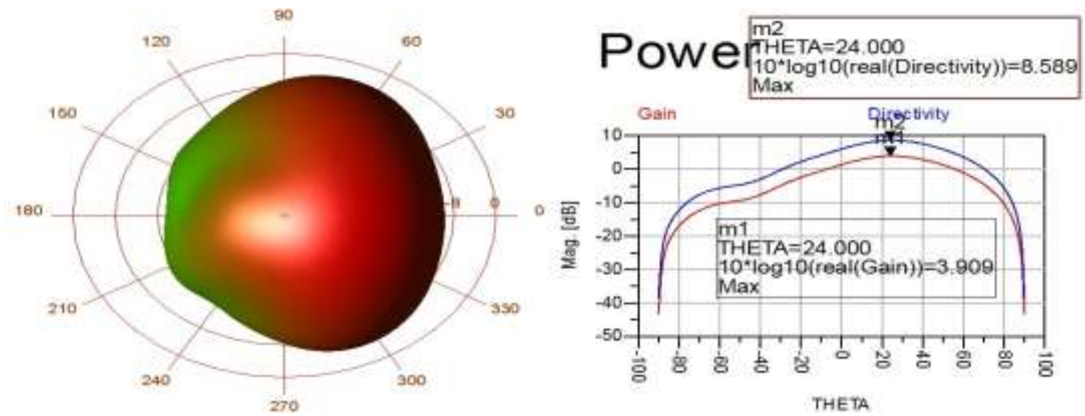
b. Graph of Directivity/Gain

Fig. 6.7: Patch 1 Excited



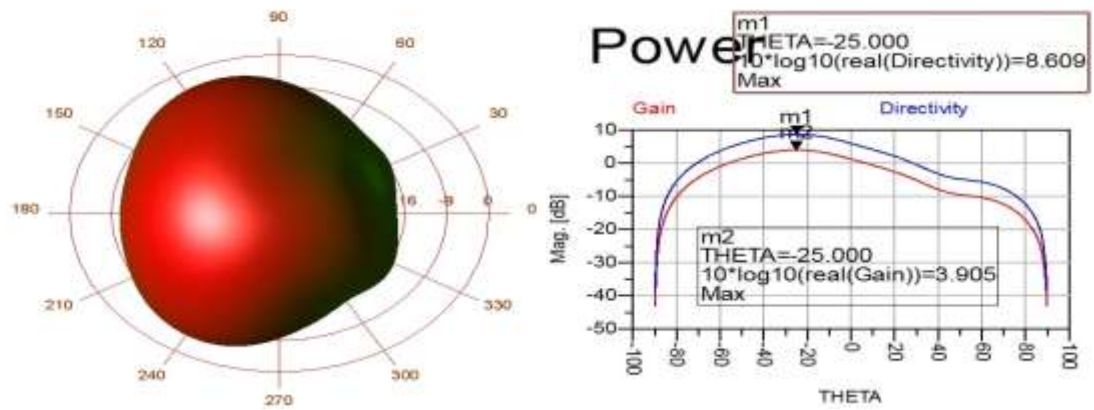
a. Radiation Pattern b. Graph of Directivity/Gain

Fig. 6.8: Patch 2 Excited



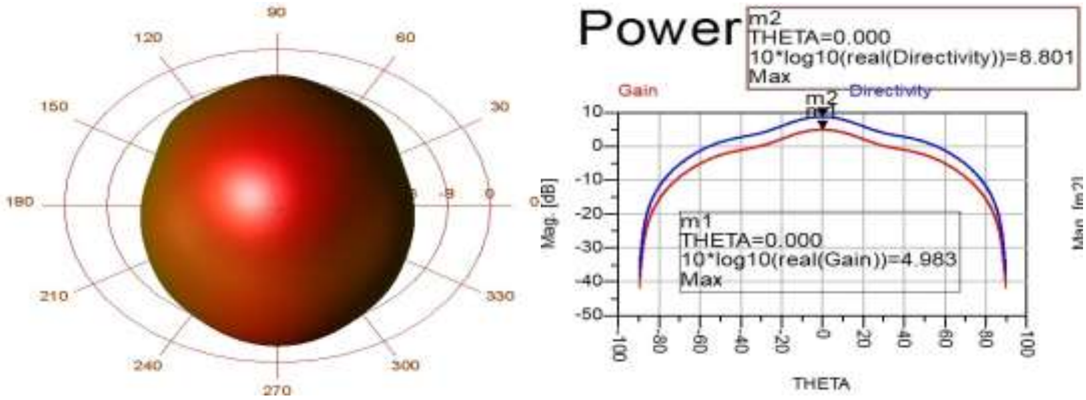
a. Radiation Pattern b. Graph of Directivity/Gain

Fig. 6.9: Patch 3 Excited



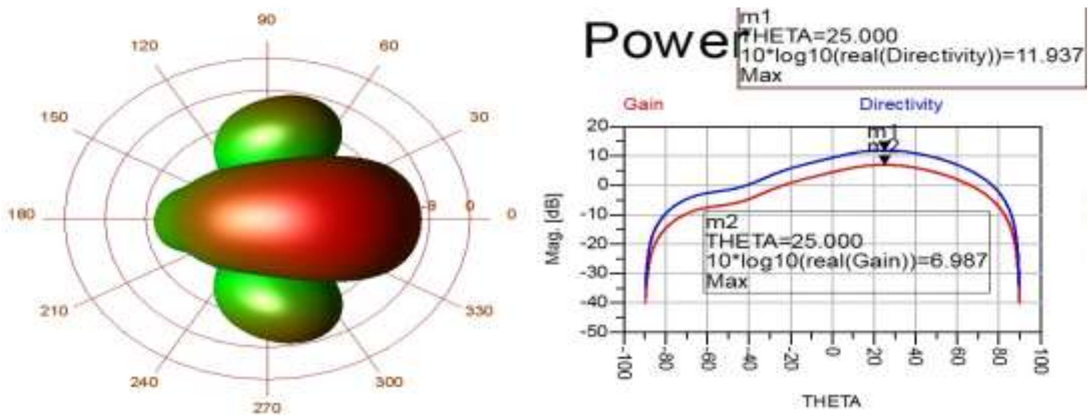
a. Radiation Pattern b. Graph of Directivity/Gain

Fig. 6.10: Patch 4 Excited



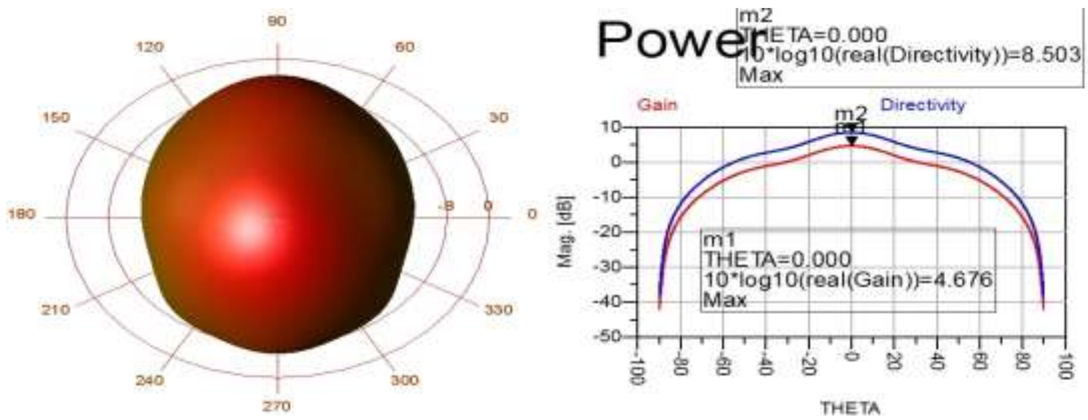
a. Radiation Pattern b. Graph of Directivity/Gain

Fig. 6.11: Patch 1, 2 Excited



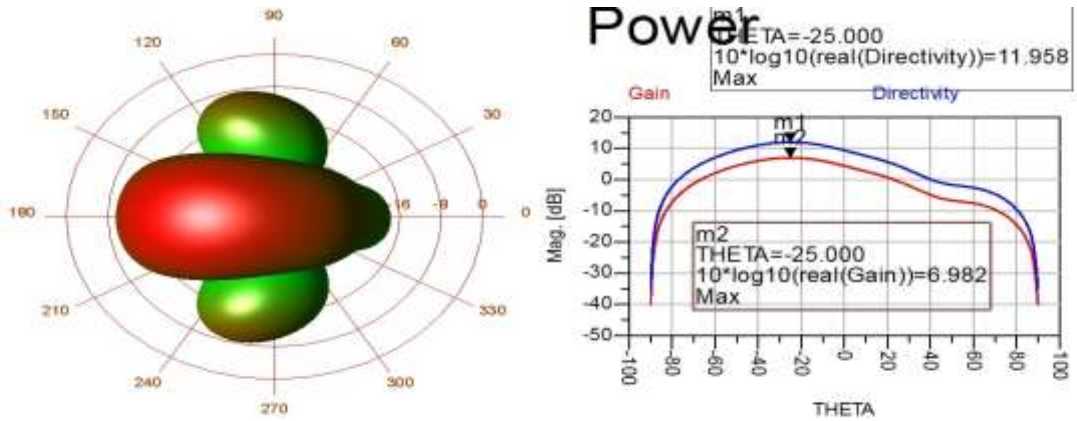
a. Radiation Pattern b. Graph of Directivity/Gain

Fig. 6.12: Patch 2, 3 Excited



a. Radiation Pattern b. Graph of Directivity/Gain

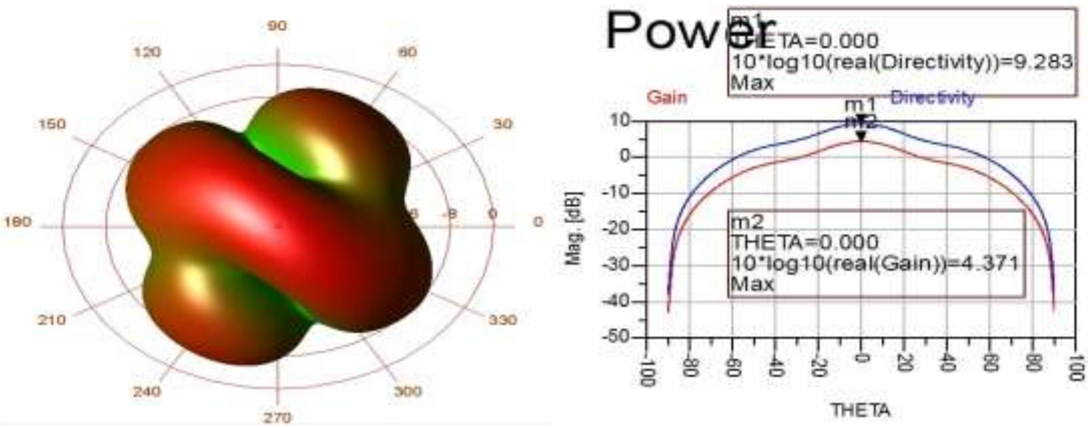
Fig. 6.13: Patch 3, 4 Excited



a. Radiation Pattern

b. Graph of Directivity/Gain

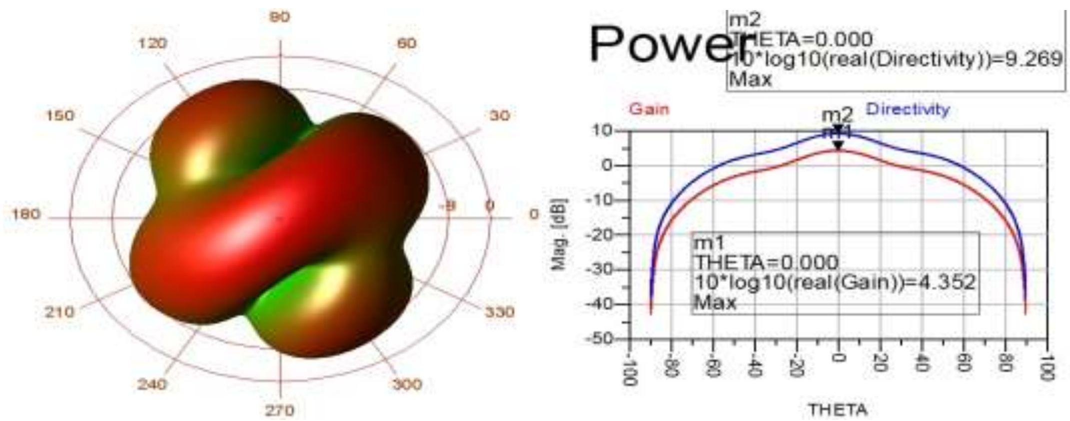
Fig. 6.14: Patch 4, 1 Excited



a. Radiation Pattern

b. Graph of Directivity/Gain

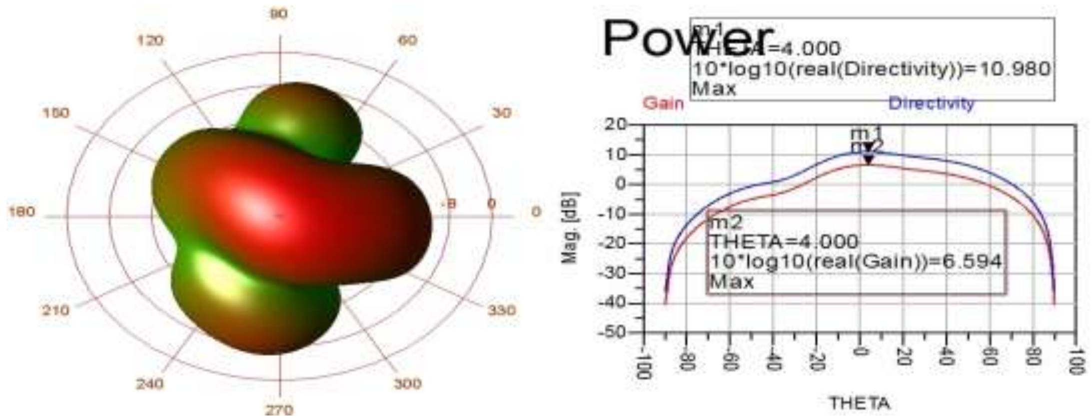
Fig. 6.15: Patch 1, 3 Excited



a. Radiation Pattern

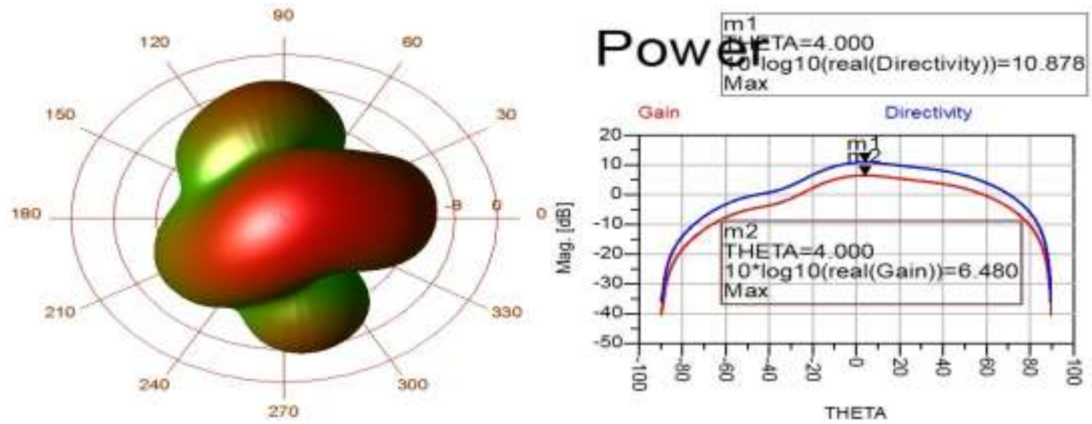
b. Graph of Directivity/Gain

Fig. 6.16: Patch 2, 4 Excited



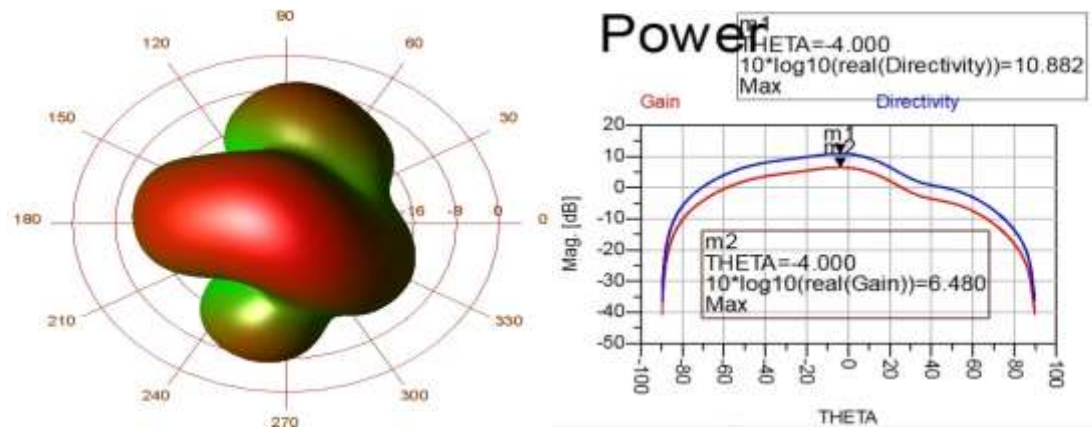
a. Radiation Pattern b. Graph of Directivity/Gain

Fig. 6.17: Patch 1, 2, 3 Excited



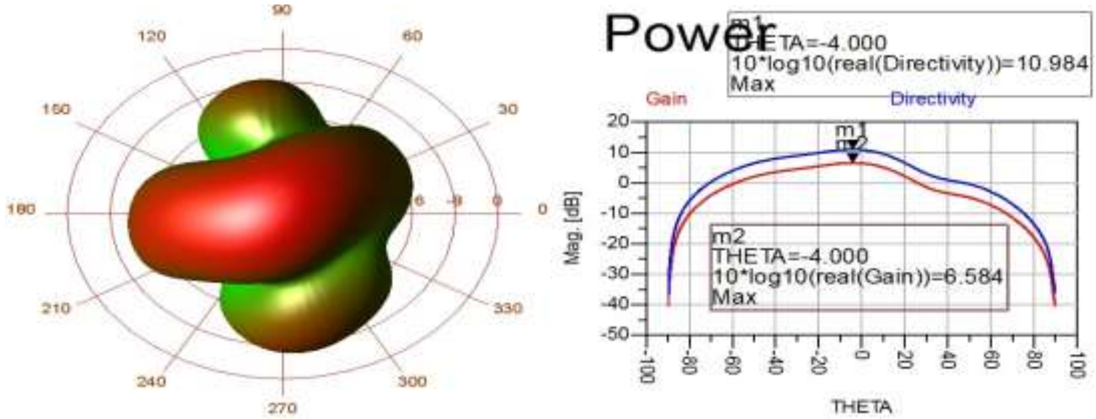
a. Radiation Pattern b. Graph of Directivity/Gain

Fig. 6.18: Patch 2, 3, 4 Excited



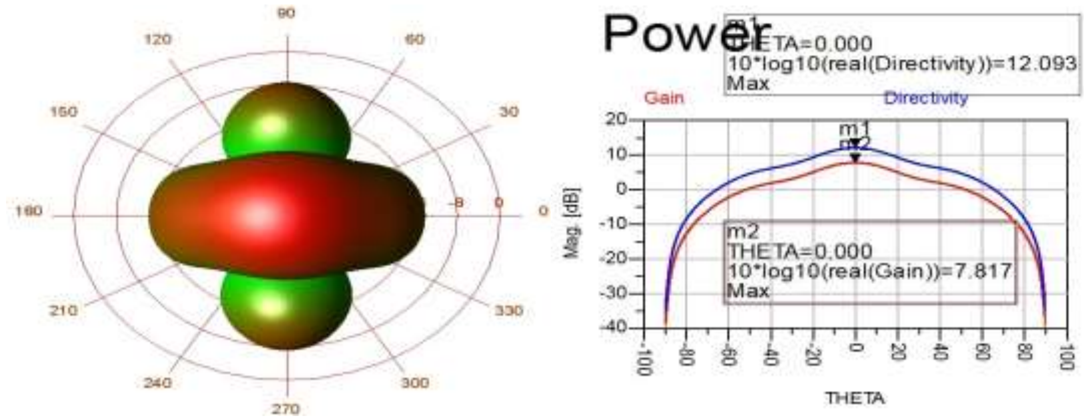
a. Radiation Pattern b. Graph of Directivity/Gain

Fig. 6.19: Patch 1, 3, 4 Excited



a. Radiation Pattern b. Graph of Directivity/Gain

Fig. 6.20: Patch 1, 2, 4 Excited



a. Radiation Pattern b. Graph of Directivity/Gain

Fig. 6.21: Patch 1, 2, 3, 4 Excited

The above figures (fig. 6.7 – fig. 6.21) give the 3D radiation pattern and graph of directivity/gain of all the combinations. It is observed that by changing the configuration, there is change in radiation pattern, gain and directivity. The maximum gain and directivity is obtained when all the patches are excited like that of any conventional array. But slight amount of beam steering is achieved only if we observe some significant combinations. Table no. 6.1 shows that beam can be steered to 0°, 4°, 25°, 335° (-25°), 356° (-4°) i.e. beam can be steered upto 25° on both sides.

The main objective of this thesis is to alter the radiation pattern of an antenna array exciting different combination of array elements. As of now, the switching process is carried out manually by connecting only required patch antennas to power divider's output ports. The remaining ports in case if not connected to any patch antenna, will be terminated with 50 Ω to avoid any reflection and thus losses.

The hardware testing was done on Vector Network Analyzer as shown in fig. 6.22 and fig. 6.23

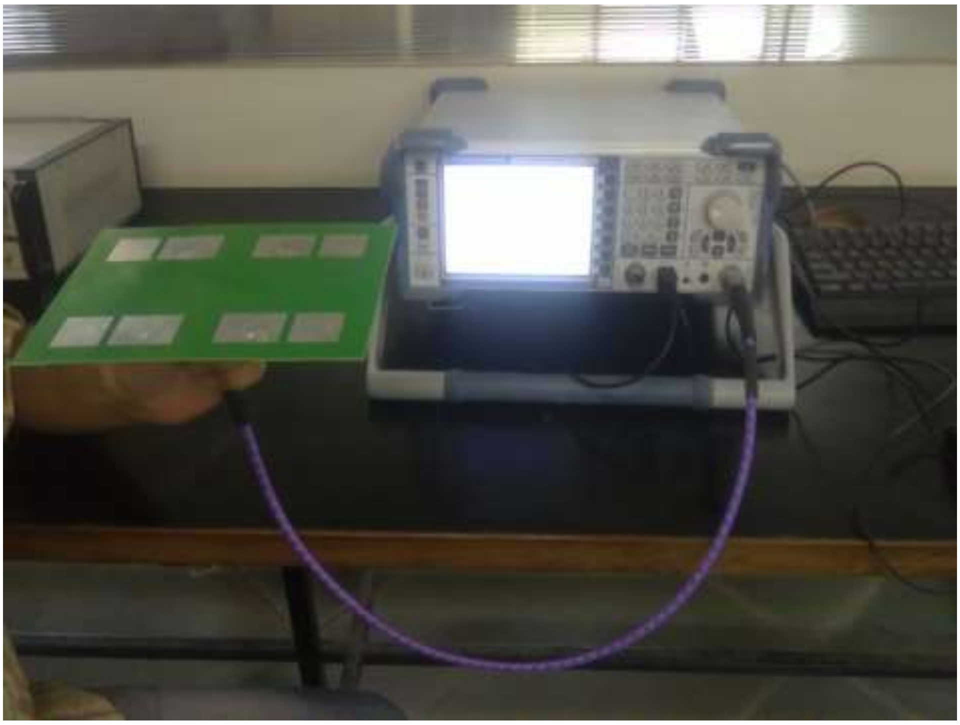


Fig. 6.22: Testing of Dynamic Antenna

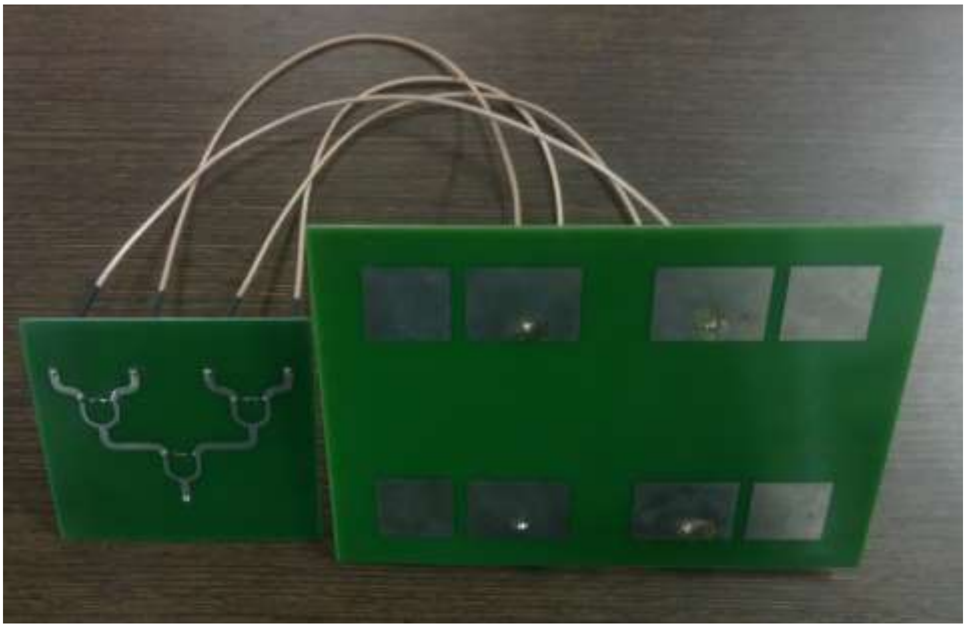


Fig. 6.23: Dynamic Antenna with Feed Network

The graph of return loss versus frequency is shown in fig. 6.24 for combination where all the patch antennas are excited.

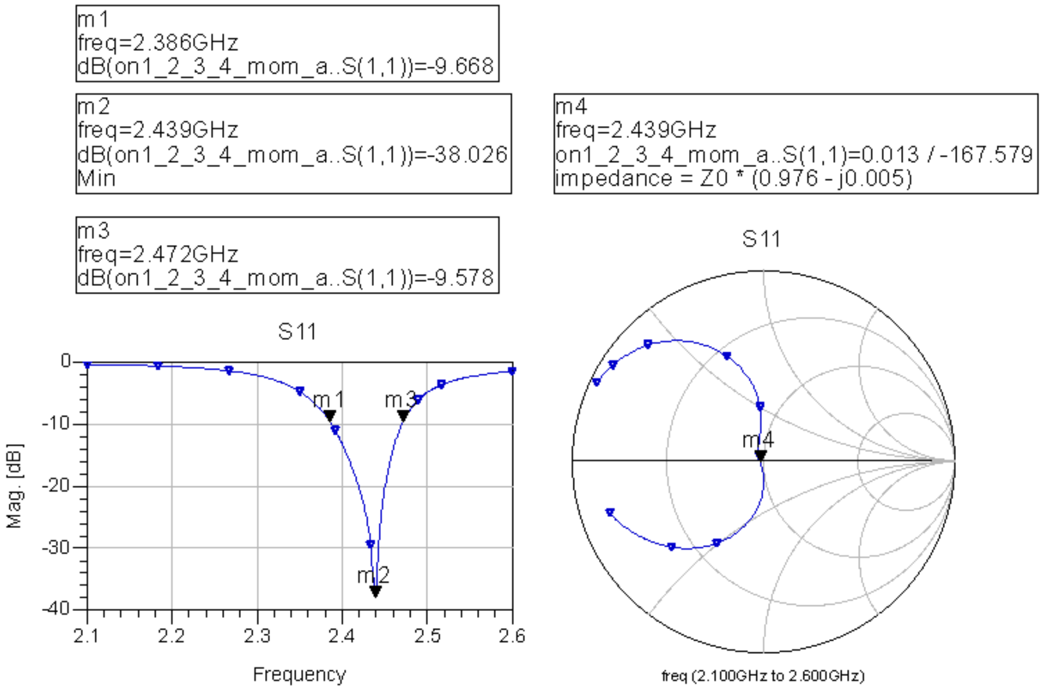


Fig. 6.24: Graph of S11 when all patches are excited.

The graph of return loss versus frequency as observed on VNA is shown in fig. 6.25 for combination where all the patch antennas are excited.

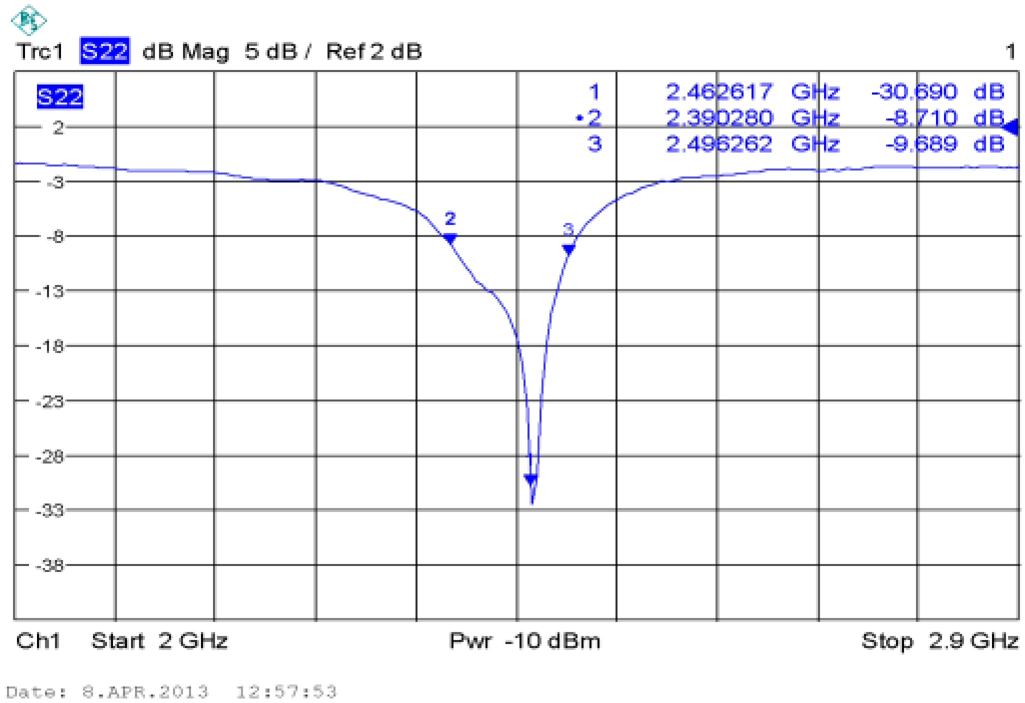


Fig. 6.25: Graph of S11 when all patches are excited as observed on VNA

The graph of VSWR versus frequency as observed on VNA is shown in fig. 6.26 for combination where all the patch antennas are excited.

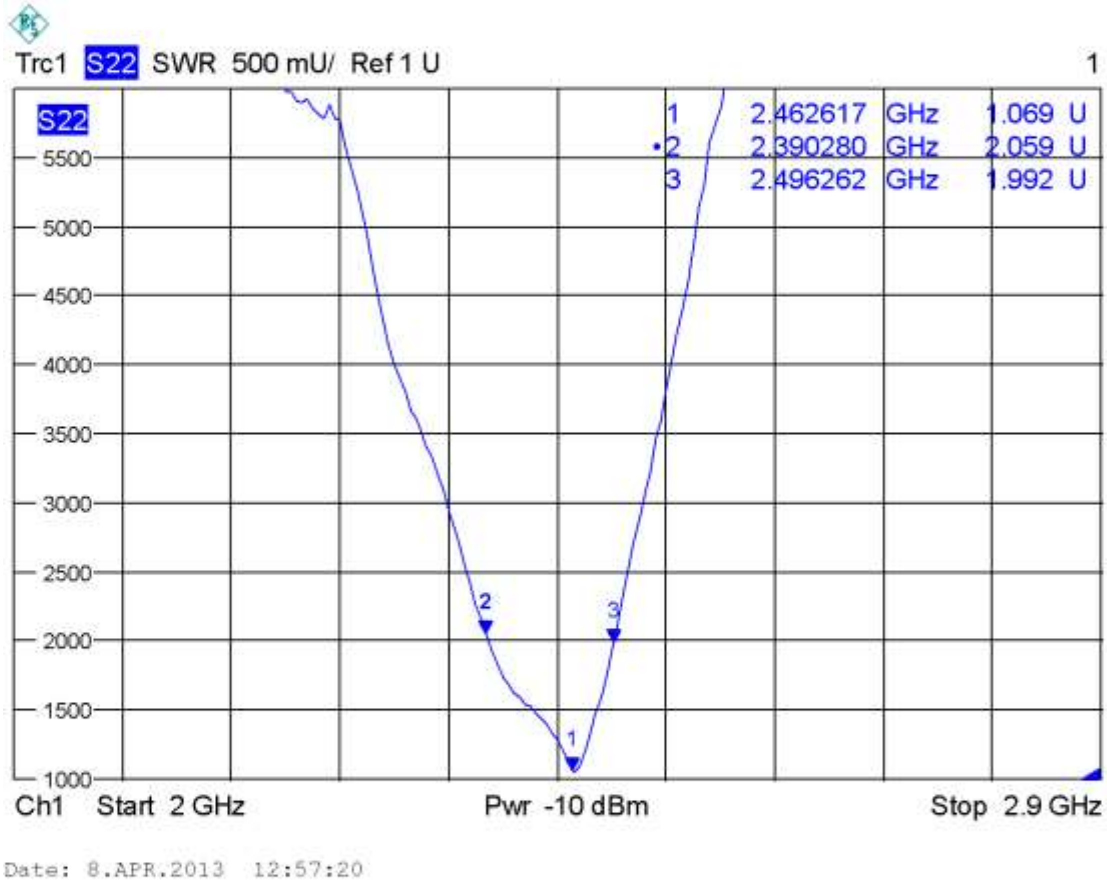


Fig. 6.26: Graph of VSWR when all patches are excited as observed on VNA

Chapter 7

SUMMARY, CONCLUSION AND FUTURE SCOPE

The Dynamic patch antenna array is designed and results are obtained. From the above results and observations, we can conclude that the radiation pattern of a patch antenna can be changed using switching mechanism. Further research, optimization and other advancements can be performed on Dynamic Patch Antenna Array. The beam can be steered significantly in various directions using phase shifted feeds.

The results show that various radiation patterns can be obtained using different switching configurations. Simulated data is demonstrated with the concepts of reconfigurable planar array antenna producing steering beam pattern characteristics. The reconfigurable radiation beam antenna presented in this paper can be steered in directions of 0^0, 25^0, 335^0, 4^0, 356^0, at resonant frequency, with excellent transmission matching for all configuration modes. By using substrate of low dielectric permittivity and less loss tangent e.g. Rogers RT Duroid, the gain and directivity of the antenna array can be significantly increased and beamsteering can be achieved successfully.

The following study or research can be done on dynamic antenna:

1) In future, we can reduce the beamwidth of antenna radiation pattern in order to get sharper beam. This will increase the efficiency of the antenna.
2) The gain and directivity of the array can be increased using substrates having low dielectric constant and less loss tangent. For example, Rogers RT Duroid substrate can be used for better performance as its dielectric constant is 2.2 and *tan δ* is 0.0009.
3) Using passive elements and sidelobes reduction techniques, the pattern sidelobes can be reduced and beam can become more directive. Also the bandwidth improvement methods can help to increase the overall bandwidth of the antenna array.
4) The beam steering control can be achieved and beam steering antenna can be used as a scanning antenna in more sophisticated technology such as Cognitive Radio.

5) RF switches using PIN diode can be implemented instead of using manual physical switching. The RF switches can be controlled using a microcontroller in which an autonomous software code called as generic algorithm will first scan the environment for any signal. It will then automatically reconfigure itself by switching in one of the combinations for better reception of the signal.
6) The efficiency and sensitivity of the antenna array can be improved by increasing number of array elements. A 'n' patch array can provide (2^n – 1) combinations. For example, 4 patches in an array can provide you with 15 combinations and 9 patches will provide 511 combinations.
7) Not only radiation pattern, but also resonant frequency of array can be changed keeping radiation pattern as it is. This is again possible by using different switching configurations.
8) The generic algorithm is designed in such a way that in case one or more of the patch antennas fail to operate due to some reason, the algorithm can note the non-functional patches and provides the similar pattern with the remaining functional patches, as if none of the patches have failed. This is called as the self healing ability of an antenna array.

A lot further research and testing is yet to be done on the Dynamic Patch Antenna Array to make it a powerful tool in the communication sector. Hope the information provided helps in the development and advancement research that are currently being performed all over the world.

Chapter 8

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