Millimetre wave Antenna for Tracking Applications in 60GHz Band

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIRMENTS FOR THE DEGREE OF BACHELOR OF SCIENCE IN ELECTRICAL & ELECTRONIC ENGINEERING

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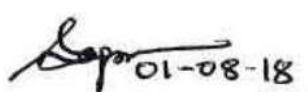

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DECLARATION

We, undersigned, hereby declare that this thesis contains no material which has been accepted for the award of any other degree or diploma at any university or equivalent institution except where due reference is made in the text of the thesis.

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ABSTRACT

In this thesis, the design, fabrication, and characterization of a 2 x 8 corporate feed antenna array operating at the 60 GHz band for applications of directional purposes like automated vehicle. To design our desired antenna, we are using Microstrip Patches with feed line and we are working on CST. We are creating an array by square patches with one feed line. To design array we considered about array spacing, impedance matching, length and width of feed line with most importance. We have implemented 2 x 8 element array. We had proceeded step by step by designing and analysing of single patch, 4 element array and 8 element array. Then we implement our proposed design and got the desired result. In all those designs we use Roger5880 substrate. We used square patches in our design and we feed them with quarter wave transformer. All the transmission line bands are 90 degree bands in our design. The array pattern is symmetry of our proposed design. We match our whole design with 50-ohm feedline where input impedance is 86.1-ohm. The main purpose of this thesis is to reduce the complexity of making antenna array of higher number of element. We got our desired result at 59.76 GHz which is in unlicensed band (57-64 GHz) and has a maximum realized directivity is 14.3 dB. The bandwidth is roughly 4.2 GHz, with 61.9 GHz the high end and 57.7 GHz the low end of the frequency band. The antenna design will be fabricated later.

ACKNOWLEDGEMENT

We would like to express our sincere appreciation and gratitude to our advisor Dr. Md. Hasanuzzaman Sagor for his continuous support and guidance. He was very helpful and always inspired us. Without guidance and instruction, we could never complete our work.

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1 Antenna Overview and Basics

1.1 Antenna Overview

An Antenna is normally a metallic gadget that can transmit or get radio recurrence bit of the electromagnetic range. It is the most visible part in a communication system. The IEEE standard Definition of Terms for Antennas (IEEE Std 145-1983) characterizes reception apparatus as “a means for radiating or receiving radio waves”. Antenna can be all the more extravagantly characterized as the structure related with the region of transmission between a guided wave and free space wave or the other way around as appeared in Figure 1-1. During the time spent transmitting and getting wave reception apparatus changes over electron to photon. [2]

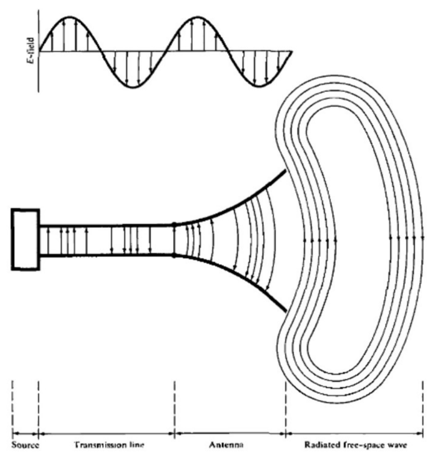


Figure 1-1: Antenna as a transmission device [1]

Antenna is an item of inquire about and improvement in the field of electromagnetism. In 1831 British researcher, Michel Faraday illustrated that electric current can be delivered by a moving magnet in the region of a coil of wire. Depending on this wonder and an earlier explore driven by Hans Christan Oersted at the College of Copenhagen where it was found that electric current in a wire could divert an attractive needle, Faraday suggested that charges and streams connecting specifically and locally with the electromagnetic field had a character of its claim, in spite of the fact that delivered by charges and streams. Finally, Scottish physicist James Receptionist Maxwell built up the numerical hypothesis of electromagnetism based on the concepts of Faraday. He repeated laws of Coulomb, Ampere and Faraday in terms of Faradays electric and attractive fields. Maxwell hypothetically demonstrated and created numerous conditions of electromagnetic waves. One of the most critical derivations made by him was that the speed of engendering of wave was rise to speed of light. Maxwell's condition was not acknowledged by researchers promptly since of its troublesome scientific concepts and befuddling collection of mechanical analogies. Afterward-German physicist Henrich Hertz rearranged them. He based on Maxwell's condition made a few try and was able to create tall recurrence electric Motions. He moreover found that motions could be recognized at huge separations from the device. Inside an exceptionally brief period of this revelation, a youthful Italian build Guglielmo Marconi developed the design of a transmitter for remote telecommunication. At first dipole was utilized for communications as for long separate the wavelengths were more noteworthy than 200 meters. On April 15, 1912 a telegrapher of American Marconi Wireless Telegraphy Company in New York City gotten a black out SOS flag from the steamship Titanic. He transferred the news of the sinking of Titanic to the world. This occasion significantly expanded the significance of antenna and modern means of communication. After this occasion and the development of radar amid World War II inquire about and advancement in radio communication and antenna arrangement was conducted. In this way antenna begun to ended up an imperative component of communication. [1]

1.2 Types of Antenna

1.2.1 Wire Antenna

Cars, houses, ships, planes, spaceships wherever wire antennas are seen. Diverse types of wire antennas are there like straight wire (dipole), circle, and helix. It is not essential for the circle reception apparatuses to be round. Rectangular, square, circle, or some other shape is likewise pertinent for circle antennas. [1]

Dipole antenna is the least difficult kind of radio reception apparatus. It comprises of a conductive wire pole that is a large portion of the length of the most extreme wavelength the antenna is to create. The wire bar is isolated in the focal and a protector isolates the two sections. Both bar is joined to a coaxial link toward the end nearest to the mid of the antenna. In the centre, between the two conductors of the dipole reception apparatus radio recurrence voltages are connected. [1]

The most widely recognized sort of the dipole antenna is the half wave dipole reception apparatus. It comprises of two comparative conductive materials like metal poles which are adjusted. The length of half wave dipole is half of the wavelength, which is the most brief thunderous length that can be utilized for a full dipole. It has a fitting radiation design as well.

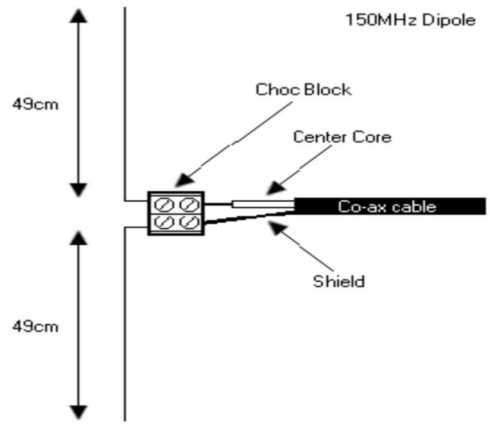


Figure 1-2: Dipole Antenna [1]

The advantages of dipole antenna are-

- It obtains balanced signals.
- The double pole design allows receiving signals of different frequencies.
- Loss is less as lot of the radiating signal is transmitted closer to the horizon.
- We do not need antenna 'tuner' to work proficiently. [2]

The disadvantages are-

- The outdoor antennas are large and wide.
- This type of antenna is not used for space communication.
- The installation of outdoor antenna is difficult. [2]

Monopole antenna is made of a straight bar formed conveyor, and it could possibly be mounted vertically to a conductive surface or ground plane. Rearranged F antennas, for example, contains a monopole reception apparatus parallel to the ground plane and grounded at the mounted side. Monopole antenna is viewed as half of a dipole reception apparatus. A ground framework is compulsory for monopole reception apparatuses of quarter wavelength.

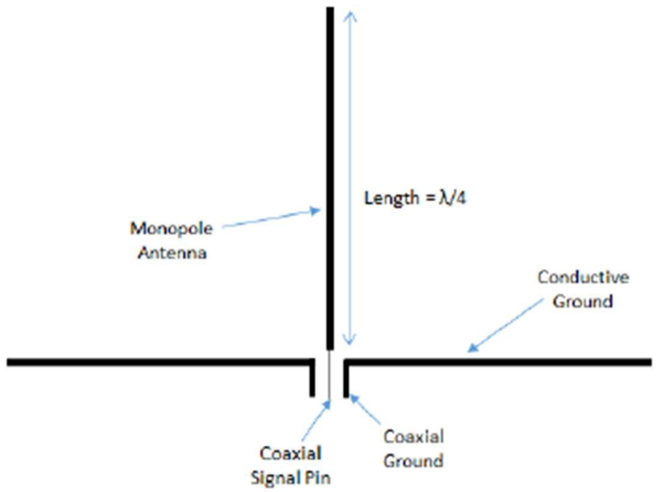


Figure 1-3: Monopole antenna [1]

1.2.2 Travelling Wave Antennas

Travelling wave reception apparatus chiefly utilizes a travelling wave on a managing structure as the fundamental transmitting component. The radio-recurrence current which delivers the radio waves going through the reception apparatus one way, is the one of a kind element of travelling wave antenna. This is not the same as a thunderous reception apparatus, similar to the monopole or dipole, where the antenna carries on as a resonator, with radio streams going in the two headings, ricocheting forward and backward between the finishes of the reception apparatus. Favourable position of travelling wave antennas is that since they are non-thunderous they frequently have a more extensive transfer speed than resounding antennas. Helical antenna, yagi uda antenna and winding reception apparatuses are some basic sorts of travelling wave reception apparatus. [5]

Helical antenna or helix reception apparatus is the most straightforward antenna. In this antenna, the directing wire is twisted fit as a fiddle and connected to the ground plate utilizing a feeder line. It contains a helix of thick copper wire or tubing twisted in the state of a screw string utilized like an antenna in mix with a smooth metal plate known as a ground plate. The development of the antenna is with the end goal that one side of the helix is associated with the middle channel of the link and the external conveyor is associated with the ground plate. The measurement of helix, the turn dispersing and the pitch edge are the principle factors on which the radiation of the reception apparatus depends. Helical reception apparatus gives circularly spellbound waves. This sort of reception apparatus is regularly utilized as a part of additional earthly correspondences where satellite transfers and so on. [2]

The Yagi-Uda reception apparatus is a standout amongst the best RF antenna intended for order antenna applications. For a RF antenna outline that necessities pick up and directivity the Yagi-Uda reception apparatus is utilized as a part of a broad assorted variety of uses. For the most part, for TV gathering, the Yagi has turned out to be extremely well known. Yet, it is additionally utilized as a part of extremely various residential and mechanical applications where a RF antenna is required that has pick up and directivity. Yagi reception apparatus enables better levels of signal to noise ratio to be achieved which makes the pickup of the Yagi antenna essential. Once more, the obstruction levels can be diminished utilizing directivity by focusing the transmitted power on attractive zones, or getting signals best from where it begins. [5]

Spiral antenna is one sort of RF antenna. Normally they are amazingly little antennas because of its windings. It can work over a broad scope of frequencies. Polarization, radiation example and impedance of such reception apparatuses remain unaffected over an extensive data transmission. Winding reception apparatuses are on a very basic level circularly enraptured with low pick up. For expanding, the pickup cluster of winding antennas can be utilized. Regularly unidirectional example is picked in such reception apparatuses, so to diminish back parts lossy pits are normally situated toward the end. [1]

Advantages of travelling wave antennas are-

- Simple and easy to construct
- More cheap
- Larger bandwidth
- Input impedance is high
- Highest directivity
- Can achieve circular polarization
- Can be used at HF & VHF bands also

- Antenna gain allows receiving lower strength signals.
- The directivity of Yagi antenna allows interference levels to be reduced. [2]

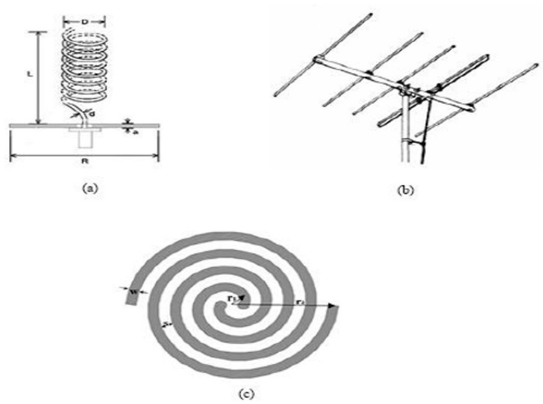


Figure 1-4: Travelling Wave Antennas (a) Helical Antenna; (b) Yagi Uda; (c) Spiral [1]

Disadvantages of travelling wave guide are-

- Offers strong Minor Lobes
- Antenna needs more space as it is large in size (Helical)
- Efficiency falls as number of turns increases (Helical)
- For high gain levels the antenna becomes very long (Yagi Uda)
- For a single antenna, gain is limited to around 20dB (Yagi Uda) [2]

1.2.3 <u>Long wire antenna:</u>

Another special type and a great example for slow wave travelling antenna is long wire antenna. Long wire antenna is an antenna, which is a straight conductor with a length from one to many wavelengths. Long wire antenna is thought to be the first travelling wave antenna. [1]

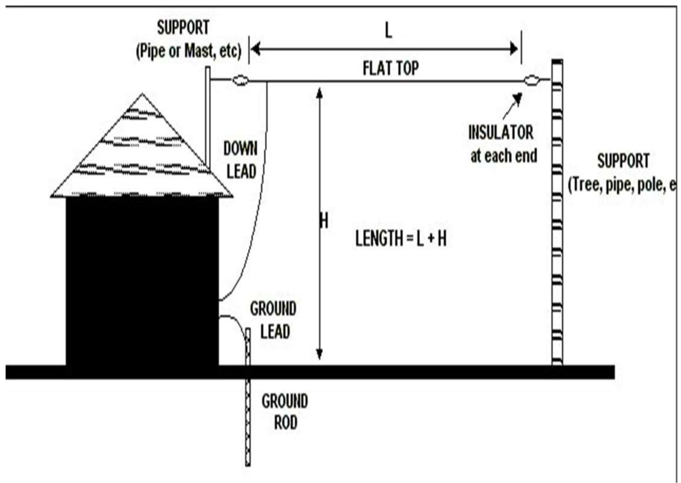


Figure 1-5: Long wire antenna [1]

To calculate the current distribution of the forward traveling wave of long wire can be represented in terms of attenuation coefficient we can use formula given below

$$\mathbf{I}_f = \hat{\mathbf{a}}_z I_z(z')e^{-\gamma(z')z'} = \hat{\mathbf{a}}_z I_0 e^{-[\alpha(z')+jk_z(z')]z'}$$ [2]

When I(z')=I0 is constant then the far field radiatin can be written as:

$$E_r \simeq E_\phi = H_r = H_\theta = 0$$
$$E_\theta \simeq j\eta \frac{klI_0e^{-jkr}}{4\pi r} e^{-j(kl/2)(K-\cos\theta)} \sin\theta \frac{\sin[(kl/2)(\cos\theta - K)]}{(kl/2)(\cos\theta - K)}$$
$$H_\phi \simeq \frac{E_\theta}{\eta}$$
[2]

1.2.4 Reflector Antenna:

An antenna reflector is a device that reflects electromagnetic waves. Antenna reflectors can exist as a standalone device for redirecting radio frequency (RF) energy, or can be integrated as part of an antenna assembly. Reflector antennas are typically used when very high gain (e.g. satellite transmission or reception) or a very narrow main beam (e.g. secure communication) is required. Gain is improved and the main beam narrowed with increase in the reflector size. Large reflectors are however difficult to simulate as they become very large in terms of wavelengths. [6]

FEKO is well suited to the simulation of reflector antennas and provides the following relevant techniques:

Multilevel Fast Multi-Pole Method (MLFMM): This is an efficient version of the MoM, suited to multi-wavelength structures. This full-wave method yields very accurate results. [5]

Physical Optics (PO): The PO high frequency approximation can be used to approximate current flow on the reflector. This technique is generally computationally inexpensive. It is most suited when the feed can be considered decoupled from the reflector. Large element PO (LE-PO) is particularly efficient for reflector antenna modelling. Continuous current flow can be modelled from standard MoM regions to PO regions. [5]

Ray launching Geometrical Optics (GO): This is another high frequency approximation method. The GO is even less expensive than the PO. It can take multiple reflections into account at little cost. It is based on shooting and bouncing rays. [5]

Uniform Theory of Diffraction (UTD): Computational cost is independent of reflector size, but only flat plates can be considered. [5]

To keep computational costs down further, domain decomposition can be used. The feed antenna is simulated in isolation and the result is then used to replace it with an equivalent source (e.g. radiation pattern or spherical mode point source) when simulating the reflector.

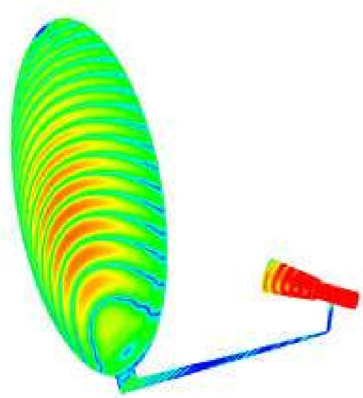


Figure 1-6: Reflector antenna current distribution

1.2.4.1 <u>Plane reflector:</u>

Amongst the type of reflector antennas, the simplest type of them all is called plane reflectors. It is used to direct energy to in a desired direction shown is Figure 1-8.

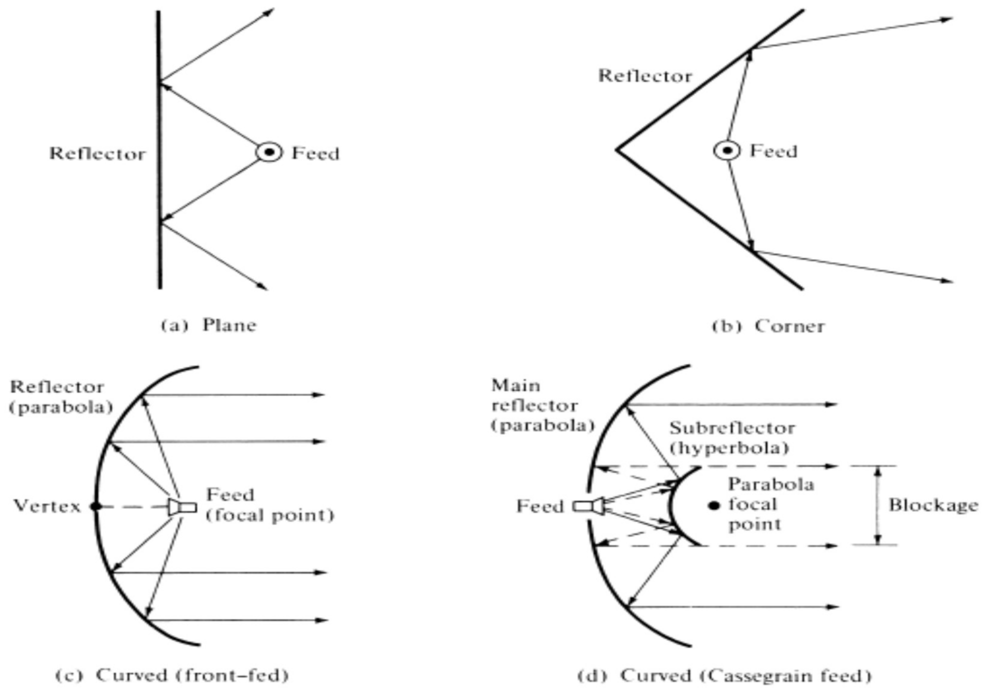


Figure 1-1-7: Plane reflector antenna [1]

In the above figure, it is clearly shown that the polarization of the radiating source and its position relative to the reflecting surface can be used to control the patterns, impedance and directivity of the overall system. [6]

1.2.4.2 <u>Corner Reflector:</u>

Another type of reflector antenna is called corner reflector antenna. A corner reflector antenna is a type of directional antenna used at VHF and UHF frequencies. John D. Kraus invented it in 1938. It consists of a dipole driven element mounted in front of two flat rectangular reflecting screens joined at an angle, usually 90°.Corner reflectors have moderate gain of 10-15 dB, high front-to-back ratio of 20-30 dB, and wide bandwidth. They are widely used for UHF television receiving antennas, point-to-point communication links and data links for wireless WANs, and amateur radio antennas on the 144, 420, and 1296 MHz bands. They radiate linearly polarized radio waves and can be mounted for either horizontal or vertical polarization. [6]

In most practical applications the included angle formed by the plates is usually 90 degrees' o maintain the efficiency of the system the spacing between vertex and he feed element must increase where the reflector angle decreases. If the reflector has infinite sides, then the gain increases as the angle decreases. [6]

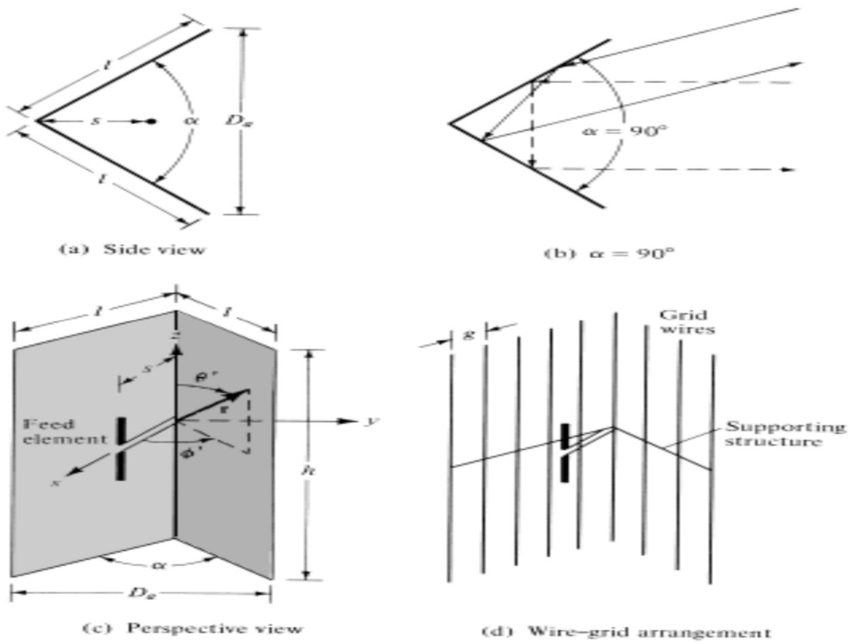


Figure 1-8: Corner Reflector [1]

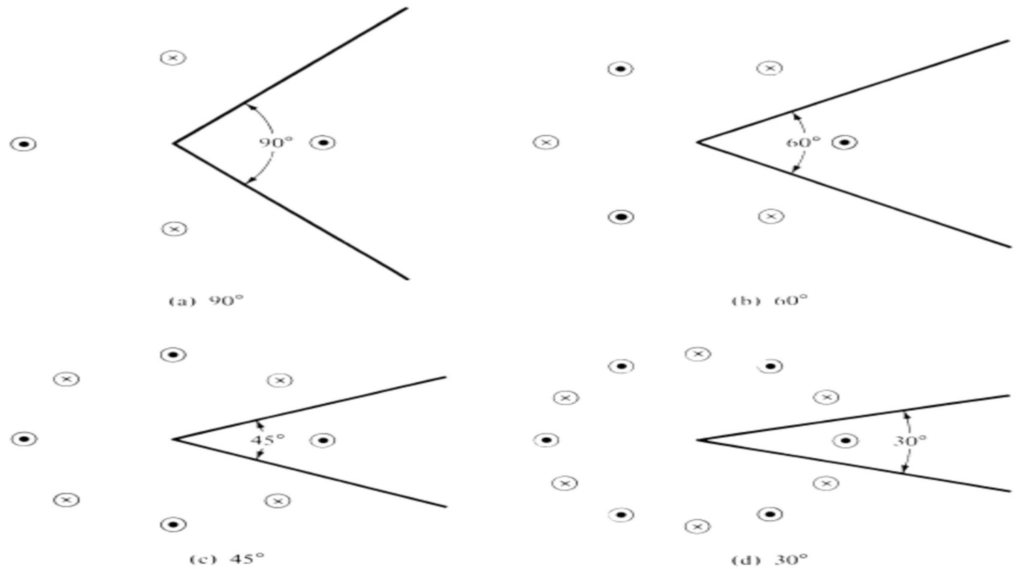


Figure 1-9: Corner reflectors and their images with perpendicularly Polarized feeds [1]

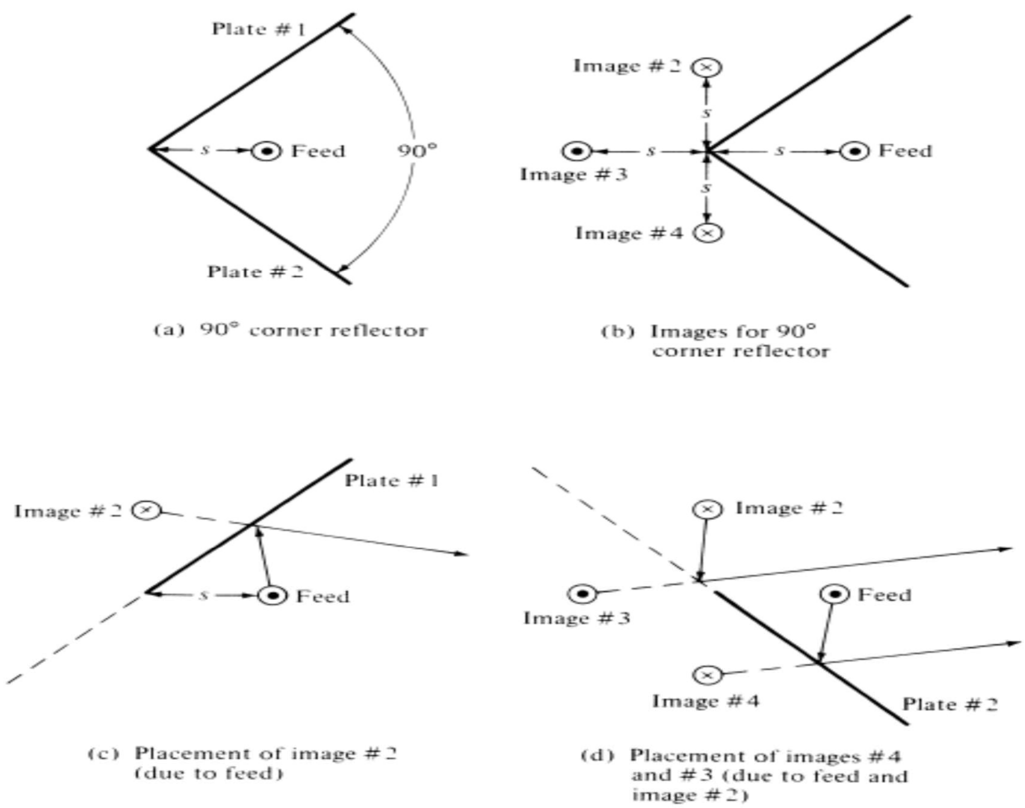


Figure 1-10: 90 degrees' corner reflector [1]

In figure 1-9, 1-10 & 1-11; there is shown the geometrical placements as well as the electrical polarity of a 90-degree Corner reflector

1.2.5 Microstrip Antennas:

The most used type of antenna in the current world is microstrip antenna. A microstrip patch antenna (MPA) consists of a conducting patch of any planar or non-planar geometry on one side of a dielectric substrate with a ground plane on other side. It is a popular printed resonant antenna for narrow-band microwave wireless links that require semi hemispherical coverage. Due to its planar configuration and ease of integration with microstrip technology, the microstrip patch antenna has been heavily studied and is often used as elements for an array. A large number of microstrip patch antennas have been studied to date. An exhaustive list of the geometries along with their salient features is available [1]. The rectangular and circular patches are the basic and most commonly used microstrip antennas. These patches are used for the simplest and the most demanding applications. Rectangular geometries are separable in nature and their analysis is also simple. The circular patch antenna has the advantage of their radiation pattern being symmetric. Microstrip antennas received considerable attention starting in the 1970s, although the idea of a microstrip antenna can be traced to 1953 [1] and a patent in 1955 [2]. Microstrip antennas, as shown in Figure 1-12(a), consist of a very thin ($t<\lambda_0$, where λ_0 is the free-space wavelength) metallic strip (patch) placed a small fraction of a wavelength ($h<<\lambda_0$, usually $0.003\lambda_0 \leq h \leq 0.05\lambda_0$) above a ground plane. The microstrip patch is designed so its pattern maximum is normal to the patch (broadside radiator). This is accomplished by properly choosing the mode (field configuration) of excitation beneath the patch. End-fire radiation can also be accomplished by judicious mode selection. For a rectangular patch, the length L of the element is usually $\lambda_0/3 < L < \lambda_0/2$. The strip (patch) and the ground plane are separated by a dielectric sheet (referred to as the substrate), as shown in Figure 1-12(a). [1]

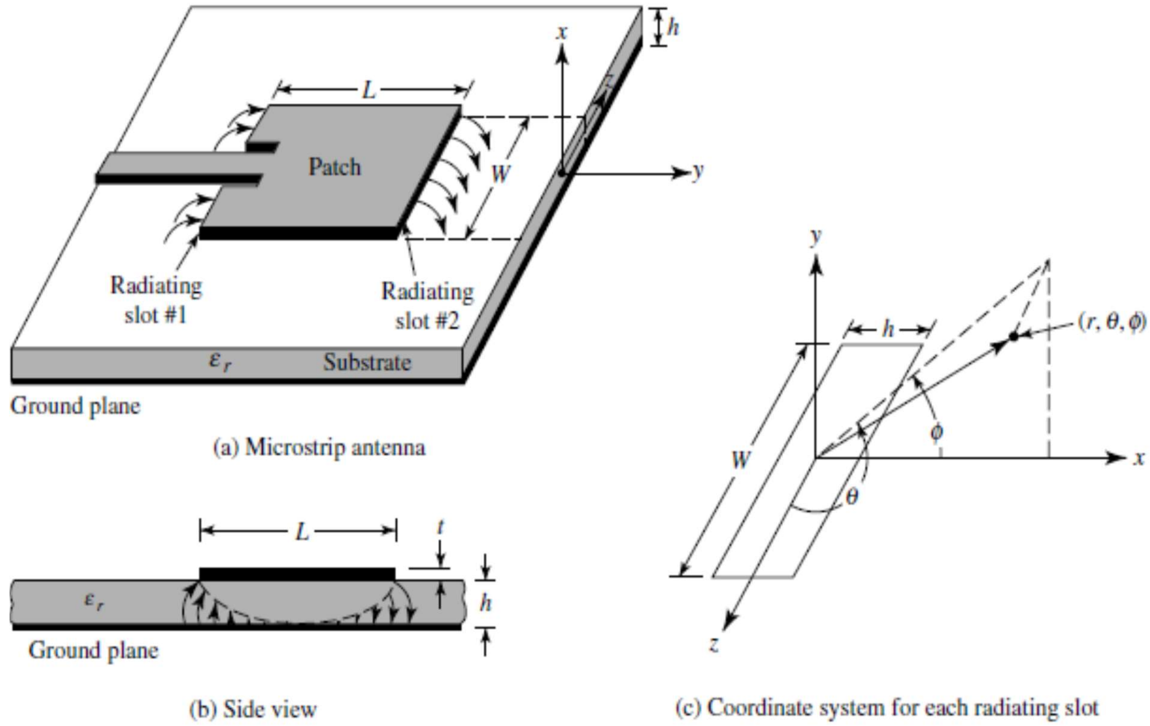


Figure 1-11: Microstrip antenna and co-ordinate system[1]

1.2.5.1 <u>Feeding method:</u>

There are many configurations that can be used to feed micro strip antennas. The four most popular are the microstrip line, coaxial probe, aperture coupling, and proximity coupling The microstrip feed line is also a conducting strip, usually of much smaller width compared to the patch. The microstrip-line feed is easy to fabricate, simple to match by controlling the inset position and rather simple to model. However, as the substrate thickness increases, surface waves and spurious feed radiation increase, which for practical designs limit the bandwidth (typically 2–5%). Coaxial-line feeds, where the inner conductor of the coax is attached to the radiation patch while the outer conductor is connected to the ground plane, are also widely used. The coaxial probe feed is also easy to fabricate and match, and it has low spurious radiation. However, it also has narrow bandwidth and it is more difficult to model, especially for thick substrates ($h > 0.02\lambda_0$). Both the microstrip feed line and the probe possess inherent asymmetries which generate higher order modes which produce cross-polarized radiation. To overcome some of these problems, no contacting aperture-coupling feeds, as shown in Figures 1-13have been introduced.

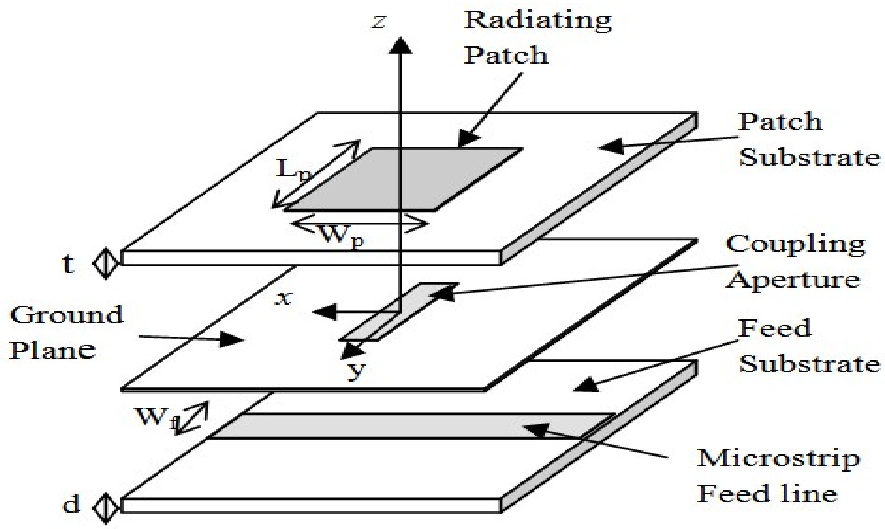


Figure 1-12: aperture-coupling feeds[1]

The aperture coupling is the most difficult of all four to fabricate and it also has narrow bandwidth. However, it is somewhat easier to model and has moderate spurious radiation. The aperture coupling consists of two substrates separated by a ground plane. On the bottom side of the lower substrate there is a microstrip feed line whose energy is coupled to the patch through a slot on the ground plane separating the two substrates. [2]

1.2.5.2 <u>Feeding techniques:</u>

A feed line is used to excite to radiate by direct or indirect contact. There are many different techniques of feeding and four most popular techniques are coaxial probe feed, microstrip line, aperture coupling and proximity coupling [2]. Coaxial probe feeding is feeding method in which that the inner conductor of the coaxial is attached to the radiation patch of the antenna while the outer conductor is connected to the ground plane. Advantages of coaxial feeding is easy of fabrication, easy to match, low spurious radiation and its disadvantages is narrow bandwidth and difficult to model specially for thick substrate. [2]

Microstrip line feed is one of the easier methods to fabricate as it is a just conducting strip connecting to the patch and therefore can be consider as extension of patch. It is simple to model and easy to match by controlling the inset position. However, the disadvantage of this method is that as substrate thickness increases, surface wave and spurious feed radiation increases which limit the

Amongst all of the types the rectangular by far the most widely used configuration.

Substrate	Dielectric Constant (ε_r)	Loss tangent (tanδ)	Cost
Alumina	9.8	0.001	Very High
Glass Epoxy	4.4	0.02	Low
Duroid / Arlon	2.2	0.0009	Very High
Foam	1.05	0.0001	Low/ Medium
Air	1	0	NA

Figure 1-13: Substrate for microstrip patch antennas[1]

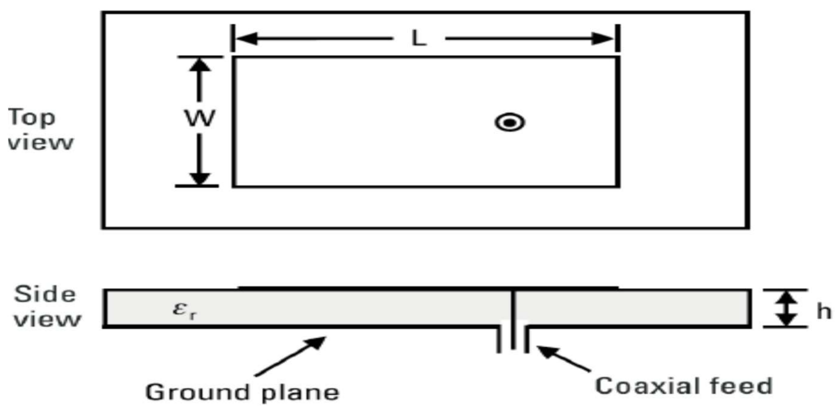


Figure 1-14: Co-axial feed [1]

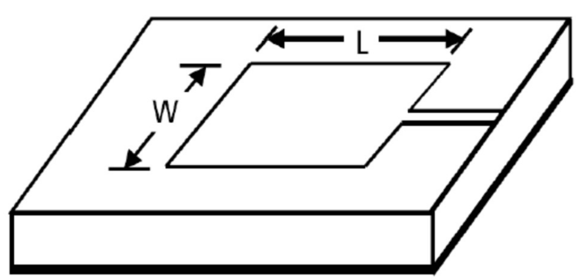


Figure 1-15: Line

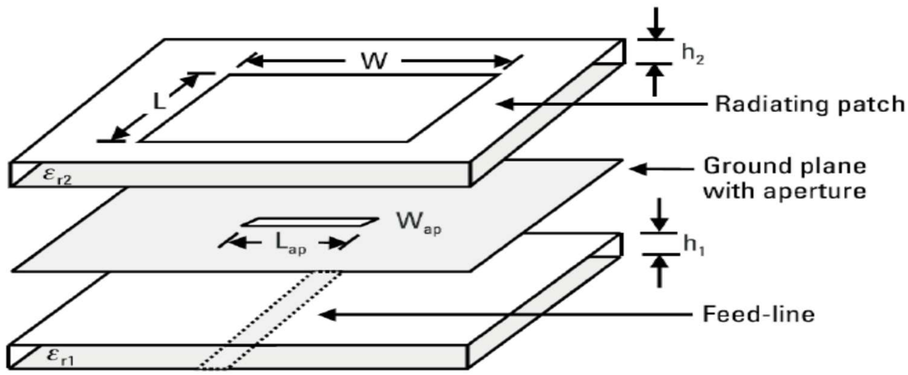


Figure 1-16: Aperture coupled feed [1]

To calculate the dielectric constant, the formula will be:

$$\underline{W/h > 1}$$

$$\epsilon_{\text{reff}} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-1/2}$$ [1]

Dielectric constants are considered to be a static value.

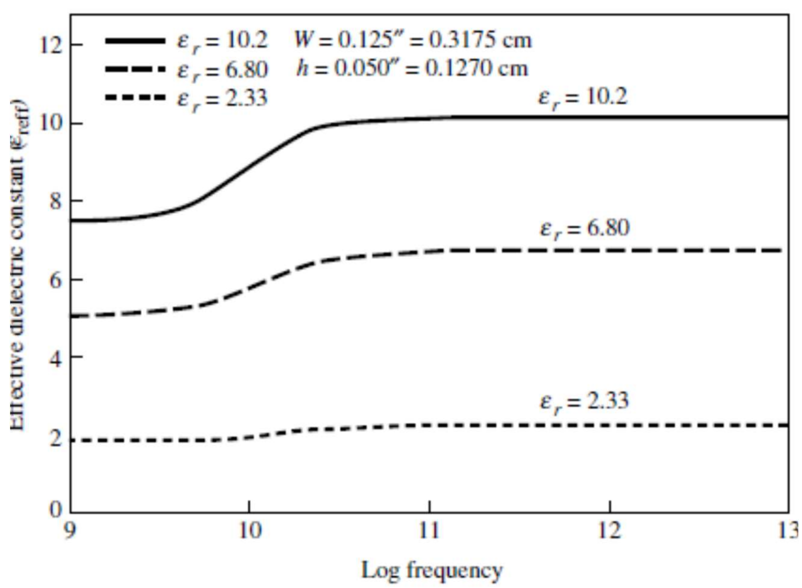


Figure 1-17: Effective dielectric constants vs. frequency for typical substrates constants vs. frequency for typical substrates [1]

1.2.5.3 Applications of microstrip antenna:

The Microstrip patch antennas are well known for their performance and their robust design, fabrication and their extent usage. The advantages of this Microstrip patch antenna are to overcome their de-merits such as easy to design, light weight etc., the applications are in the various fields such as in the medical applications, satellites and of course even in the military systems just like in the rockets, aircrafts missiles etc. the usage of the Microstrip antennas are spreading widely in all the fields and areas and now they are booming in the commercial aspects due to their low cost of the substrate material and the fabrication. It is also expected that due to the increasing usage of the patch antennas in the wide range this could take over the usage of the conventional antennas for the maximum applications. Microstrip patch antenna has several applications. [5]. Some of these applications are discussed as below:

1.2.5.3.1 Mobile and satellite communication application:

Mobile communication requires small, low-cost, low profile antennas. Microstrip patch antenna meets all requirements and various types of microstrip antennas have been designed for use in mobile communication systems. In case of satellite communication circularly polarized radiation patterns are required and can be realized using either square or circular patch with one or two feed points. [1]

1.2.5.3.2 Global Positioning System applications:

Nowadays microstrip patch antennas with substrate having high permittivity sintered material are used for global positioning system. These antennas are circularly polarized, very compact and quite expensive due to it positioning. It is expected that millions of GPS receivers will be used by the general population for land vehicles, aircraft and maritime vessels to find their position accurately. [2]

1.2.5.3.3 Radio Frequency Identification (RFID):

RFID uses in different areas like mobile communication, logistics, manufacturing, transportation and health care [2]. RFID system generally uses frequencies between 30 Hz and 5.8 GHz depending on its applications. Basically RFID system is a tag or transponder and a transceiver or reader. [1]

1.2.5.3.4 **<u>Worldwide Interoperability for Microwave Access (WiMAX):</u>**

The IEEE 802.16 standard is known as WiMAX. It can reach up to 30-mile radius theoretically and data rate 70 Mbps. MPA generates three resonant modes at 2.7, 3.3 and 5.3 GHz and can, therefore, be used in WiMAX compliant communication equipment. [1]

1.2.5.3.5 **<u>Radar Application:</u>**

Radar can be used for detecting moving targets such as people and vehicles. It demands a low profile, light weight antenna subsystem, the microstrip antennas are an ideal choice. The fabrication technology based on photolithography enables the bulk production of microstrip antenna with repeatable performance at a lower cost in a lesser time frame as compared to the conventional antennas. [2]

1.2.5.3.6 **<u>Antenna Application:</u>**

Antenna is a rectifying antenna, a special type of antenna that is used to directly convert microwave energy into DC power. Antenna is a combination of four subsystems i.e. Antenna, ore rectification filter, rectifier, post rectification filter. In Antenna application, it is necessary to design antennas with very high directive characteristics to meet the demands of long-distance links. Since the aim is to use the Antenna to transfer DC power through wireless links for a long distance, this can only be accomplished by increasing the electrical size of the antenna. [5]

1.2.5.3.7 **<u>Telemedicine Application:</u>**

In telemedicine application antenna is operating at 2.45 GHz. Wearable microstrip antenna is suitable for Wireless Body Area Network (WBAN). The proposed antenna achieved a higher gain and front to back ratio compared to the other antennas, in addition to the semi directional radiation pattern which is preferred over the Omni-directional pattern to overcome unnecessary radiation to the user's body and satisfies the requirement for on-body and off-body applications. An antenna having gain of 6.7 dB and an F/B ratio of 11.7 dB and resonates at 2.45GHz is suitable for telemedicine applications. [5]

1.2.5.3.8 Medicinal applications of patch:

It is found that in the treatment of malignant tumours the microwave energy is said to be the most effective way of inducing hyperthermia. The design of the particular radiator which is to be used for this purpose should possess light weight, easy in handling and to be rugged. Only the patch radiator fulfils these requirements. The initial designs for the Microstrip radiator for inducing hyperthermia was based on the printed dipoles and annular rings which were designed on S-band. And later on the design was based on the circular microstrip disk at L-band. There is a simple operation that goes on with the instrument; two coupled Microstrip lines are separated with a flexible separation which is used to measure the temperature inside the human body. A flexible patch applicator can be seen in the figure below which operates at 430 MHz [5]

1.2.6 Millimetre wave Antenna:

Millimetre wave (also millimetre band) is the band of spectrum between 30 gigahertz (GHz) and 300 GHz. Researchers are testing 5G wireless broadband technology on millimetre wave spectrum. Millimetre wave, which is also known as extremely high frequency (EHF) or very high frequency (VHF) by the International Telecommunications Union (ITU), can be used for high-speed wireless broadband communications. Millimetre wave is an undeveloped band of spectrum that can be used in a broad range of products and services like high speed, point-to-point wireless local area networks (WLANs) and broadband access. In telecommunications, millimetre wave is used for a variety of services on mobile and wireless networks, as it allows for higher data rates up to 10 Gbps. [5]

Millimetre waves have short wavelengths that range from 10 millimetres to 1 millimetre; they have high atmospheric attenuation and are absorbed by gases in the atmosphere, which reduces the range and strength of the waves. Rain and humidity can impact performance and reduce signal strength, a condition known rain fade. Due to its short range of about a kilometre, millimetre wave travels by line of sight, so its high-frequency wavelengths can be blocked by physical objects like buildings and trees. [5]

1.2.7 Aperture Antenna:

Aperture antennas are typically constructed with dielectric and metal walls, often with ridges. Feed pins or waveguide ports are used as excitations. FEKO can accurately model and simulate such antennas. Surface currents are solved and these are used to compute secondary parameters that are of interest, e.g.

1. Transmission efficiency
2. Axial ratio
3. Far-field radiation patterns
4. Input impedance bandwidth [1]

1.3 Antenna parameters:

The basic parameters f antennas are given as such

1. Radiation pattern hence Field pattern: $E\theta(\theta,\varphi)$, $E\varphi(\theta,\varphi)$, $H\theta(\theta,\varphi)$, $H\varphi(\theta,\varphi)$, and Power pattern $S(\theta,\varphi)$,
2. Directivity
3. Gain
4. Effective aperture
5. beam area
6. Antenna polarization [1]

1.3.1 Radiation Pattern:

An antenna radiation pattern or antenna pattern is defined as a mathematical function or a graphical representation of the radiation properties of the antenna as a function of space coordinates

• Defined for the far-field.

• As a function of directional coordinates.

• There can be field patterns (magnitude of the electric or magnetic field) or power patterns (square of the magnitude of the electric or magnetic field).

• Often normalized with respect to their maximum value.

• The power pattern is usually plotted on a logarithmic scale or more commonly in decibels (dB)

Radiation patterns are conveniently represented in spherical coordinates. Pattern: $E(\theta,\phi)$

$$dA = r^2 \sin\theta \, d\theta \, d\phi. \qquad \text{Azimuth: } \phi \text{ Elevation: } \pi/2-\theta.$$ [1]

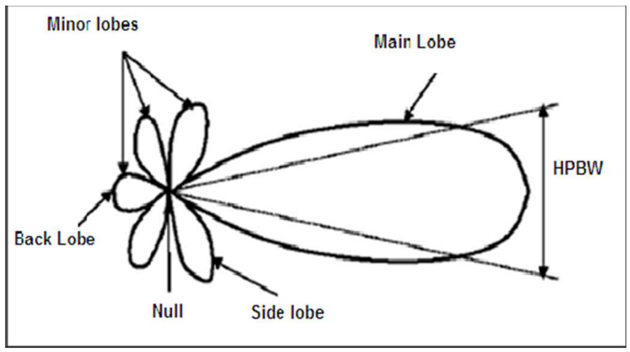


Figure 1-18: Directional radiation pattern [2]

All three patterns in figure 1-19 yield the same angular separation between the two halfpower points, 38.64±, on their respective patterns, referred to as HPBW.

Components in the Amplitude Pattern:

There would be, in general, three electric-field components (E_r,E_μ,E_A) at

Each observation point on the surface of a sphere of constant radius.

In the far field, the radial $E_{r\ component}$ for all antennas is zero or vanishingly small

Some antennas, depending on their geometry and also observation distance, may have only one, two, or all three components.

In general, the magnitude of the total electric field would be

$$|E| = \sqrt{|E_r|^2 + |E_\theta|^2 + |E_\phi|^2}. \quad [1]$$

1.3.1.1 Different types of radiation patterns:

Isotropic Radiator: A hypothetical lossless antenna having equal radiation in all directions.

Omnidirectional Radiator: An antenna having an essentially no directional pattern in a given plane (e.g., in azimuth) and a directional pattern in any orthogonal plane.

Directional Radiator: An antenna having the property of radiating or receiving more effectively in some directions than in others. Usually the maximum directivity is significantly greater than that of a half-wave dipole. [5]

1.4 Beam Width:

The beam width of an antenna is a very important figure of merit and often is used as a trade-off between it and the side lobe level; that is, as the beam width decreases, the side lobe increases and vice versa.

The beam width of the antenna is also used to describe the resolution capabilities of the antenna to distinguish between two adjacent radiating sources or radar targets.

Half-Power Beam Width (HPBW): In a plane containing the direction of the maximum of a beam, the angle between the two directions in which the radiation intensity is one-half value of the beam.

First-Null Beam width (FNBW): Angular separation between the first nulls of the pattern.

1.5 Directivity:

Directivity is the ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all directions.

The average radiation intensity: total power radiated by the antenna divided by 4*pi*

Stated more simply, the directivity of a no isotropic source is equal to the ratio of its radiation intensity in a given direction over that of an isotropic source.

For directivity:

$$D = D(\theta,\phi) = \frac{U(\theta,\phi)}{U_0} = \frac{4\pi U(\theta,\phi)}{P_{\text{rad}}}.$$ [2]

If direction is not specified, then the relation between radiation intensity and directivity implies as:

$$D_{\text{max}} = D_0 = \frac{U}{U_0} = \frac{U|_{\text{max}}}{U_0} = \frac{U_{\text{max}}}{U_0} = \frac{4\pi U_{\text{max}}}{P_{\text{rad}}}.$$ [2]

Where,

- D = directivity (dimensionless)
- D_0 = maximum directivity (dimensionless)
- $U = U(\theta,\phi)$ = radiation intensity (W/sr)
- U_{max} = maximum radiation intensity (W/sr)
- U_0 = radiation intensity of isotropic source (W/sr)
- P_{rad} = total radiated power (W)

1.6 Antenna Gain:

Gain the ratio of the intensity, in a given direction, to the radiation intensity that would be obtained if the power accepted by the antenna were radiated isotopically.

For calculating the gain of the antenna:

$$\text{Gain} = 4\pi\frac{\text{radiation intensity}}{\text{total input accepted power}} = 4\pi\frac{U(\theta,\phi)}{P_{\text{in}}} \text{ (dimensionless).}$$ [1]

We can introduce an absolute gain Gabs that takes into account the reflection or mismatch losses (due to the connection of the antenna element to the transmission line)

$$G_{\text{abs}} = e_r G(\theta,\phi) = (1-|\Gamma|^2)G(\theta,\phi) = e_r e_{cd} D(\theta,\phi) = e_o D(\theta,\phi$$ [1]

1.7 Antenna Efficiency:

The total antenna efficiency e0 is used to take into account losses at the input terminals and within the structure of the antenna.

$$\boxed{e_0 = e_r e_c e_d}.$$

$$\begin{aligned} e_o &= \text{total efficiency,} \\ e_r &= \text{reflection(mismatch) eff.,} \\ &= (1 - |\Gamma|^2), \\ e_c &= \text{conduction efficiency,} \\ e_d &= \text{dielectric efficiency,} \\ \Gamma &= \frac{Z_{\text{in}} - Z_0}{Z_{\text{in}} + Z_0}, \\ \text{VSWR} &= \frac{1 + |\Gamma|}{1 - |\Gamma|}. \end{aligned}$$

[1]

¡ = voltage reflection coefficient at the input terminals of the antenna Z_{in} =antenna input impedance, Z_0 = characteristic impedance of the transmission line. VSWR = voltage standing wave ratio.

1.8 S Parameters:

The scattering matrix is a mathematical construct that quantifies how RF energy propagates through a multi-port network. The S-matrix is what allows us to accurately describe the properties of incredibly complicated networks as simple "black boxes". For an RF signal incident on one port, some fraction of that signal gets reflected back out of the incident port, some of it enters into the incident port and then exits at (or scatters to) some or all of the other ports (perhaps being amplified or attenuated). What's left of that incident power disappears as heat or even electromagnetic radiation. The S-matrix for an N-port contains N2 coefficients (S-parameters), each one representing a possible input-output path.

S-parameters are complex numbers, having real and imaginary parts or magnitude and phase parts, because both the magnitude and phase of the incident signal are changed by the network. Quite often we refer to the magnitude of the signal only, as it is frequently of most interest. Who cares how the signal phase is changed by an amplifier or attenuator? You mostly care about how much gain (or loss) you get. S-parameters are defined for a given frequency and system impedance, and vary as a function of frequency for any non-ideal network.

S-parameters are usually displayed in a matrix format, with the number of rows and columns equal to the number of ports. For the S-parameter Sij the j subscript stands for the port that is excited (the input port), and the "i" subscript is for the output port. Thus S11 refers to the ratio of the amplitude of the signal that reflects from port one to the amplitude of the signal incident on port one. Parameters along the diagonal of the S-matrix are referred to as reflection coefficients because they only refer to what happens at a single port, while off-diagonal S-parameters are referred to as transmission coefficients, because they refer to what happens at one port when it is excited by a signal incident at another port. Here are the S-matrices for one, two and three-port networks.

S-parameters describe the response of an N-port network to signal(s) incident to any or all of the ports. The first number in the subscript refers to the responding port, while the second number refers to the incident port. Thus S21 means the response at port 2 due to a signal at port 1. The most common "N-port" networks in microwaves are one-port and two-port networks. Three-port network S-parameters are easy to model with software such as Agilent ADS, but three-port S-parameter measurements are extremely difficult to perform with accuracy. Measured multi-port S-parameters are typically available from vendors for amplifiers and other devices but, as always, make sure you check your answers for reasonableness.

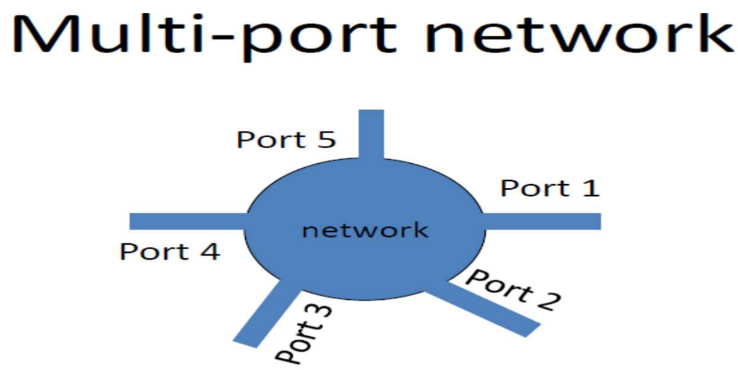
S-parameters

$$S_{11} = \frac{V_{r1}}{V_{i1}}\bigg|_{V_{r2}=0} \qquad S_{12} = \frac{V_{t2}}{V_{i2}}\bigg|_{V_{r2}=0}$$

$V_{r2}=0$ means port 2 is matched

$$S_{21} = \frac{V_{t1}}{V_{i1}}\bigg|_{V_{r1}=0} \qquad S_{22} = \frac{V_{r2}}{V_{i2}}\bigg|_{V_{r1}=0}$$

$V_{r1}=0$ means port 1 is matched



$$\begin{bmatrix} b_1 \\ b_2 \\ b_3 \\ b_4 \\ b_5 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} & S_{15} \\ S_{21} & S_{22} & S_{23} & S_{24} & S_{25} \\ S_{31} & S_{32} & S_{33} & S_{34} & S_{35} \\ S_{41} & S_{42} & S_{43} & S_{44} & S_{45} \\ S_{51} & S_{52} & S_{53} & S_{54} & S_{55} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \\ a_5 \end{bmatrix}$$

Figure 1-19: S-parameter for different port networks [1]

1.9 Input Impedance:

Input impedance is the impedance presented by an antenna at its terminal or the ratio of the voltage to current at a pair of terminals or the ratio of the appropriate components of the electric to magnetic fields at a point [1]

The input impedance of an antenna per se is not usually reported directly in the brochure; rather the antenna's nominal impedance and its VSWR are given. The nominal impedance is the impedance for which the antenna is (ideally) designed and the VSWR can be "seen" as the antenna's deviation from this value. [2]

The VSWR (voltage standing wave ratio) is a parameter that is derived from the antenna's input impedance and the reported nominal impedance. One can view the VSWR as "how far" the antennas input impedance is from the nominal impedance. If the VSWR at a particular frequency is given as 1:1, then you can deduce that the antenna input impedance is equal to the nominal impedance. The higher the VSWR the further the antenna input impedance is from the nominal impedance. [5]

The input impedance of an antenna is generally a function of frequency. Thus the antenna will be matched to the interconnecting transmission line and other associated equipment only within a bandwidth. In addition, the input impedance of the antenna depends on many factors including its geometry, its method of excitation, and its proximity to surrounding objects. Because of their complex geometries, only a limited number of practical antennas have been investigated analytically. For many others, the input impedance has been determined experimentally. [5]

1.10 Bandwidth:

The bandwidth of an antenna refers to the range of frequencies over which the antenna can operate correctly. The antenna's bandwidth is the number of Hz for which the antenna will exhibit an SWR less than 2:1. The bandwidth can also be described in terms of percentage of thecenter frequency of the bandwhere FH is the highest frequency in the band, [1]

$$BW = 100 \times \frac{F_H - F_L}{F_C}$$

[2]

FL is the lowest frequency in the band, and FC is the centre frequency in the band in this way, bandwidth is constant relative to frequency. If bandwidth was expressed in absolute units of frequency, it would be different depending upon the centre frequency. Different types of antennas have different bandwidth limitations.

2 Basic Construction

2.1 Basic of Construction:

The main purpose of antennas is to either transmit or to receive signals in the form of electromagnetic waves. Along with the miniaturization of current electronics devices the demand for compact antenna increases now a days Microstrip antenna can easily accomplish those demands due to its compact size and convenience of fabrication. Fundamentally, microstrip antennas are designed with thin metal strip on dielectric material with ground plane inserted on other side.

Before designing microstrip antennas sudden limitations and problems of this type of design has to be considered. For instance, narrow bandwidth and high power losses makes poor quality factors Q. One way of improving this is by increasing thickness of dielectric but it in this way a significant portion of energy spend on surface wave where electromagnetic trapped between two media and propagate along the surface. As result the efficiently goes dramatically low. Though thick dielectric with low dielectric constant can improve the performance in terms of efficacy bandwidth and radiation. Other problem is low gain and power handling capacity. This problem can be solved in several ways like arranging multiple of this identical microstrip antennas in array can boost overall gain in a single direction.

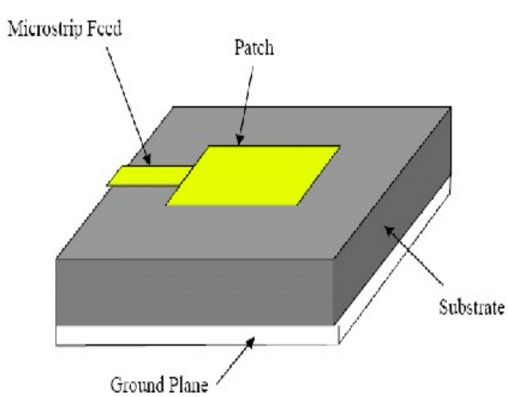


Figure 2-1: Microstrip line feeding

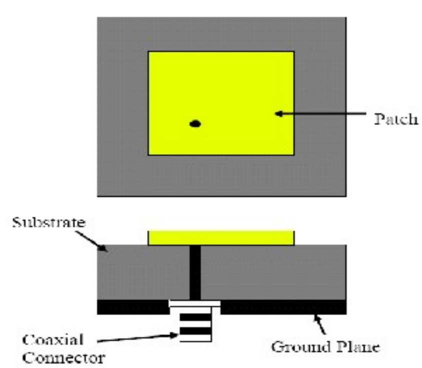


Figure 2-2: coaxial probe feeding

Besides impedance matching is important factor. Impendence should be controlled in feed line to ensure the maximum power delivery into the antenna. The main two approaches in feed line are microstrip are coaxial probe feeding and microstrip line feeding which can provide high gain. Inset line feed are used in case of microstrip line feeding to control line impedance. The alternative way to control the impedance is to vary the location of shorting also known as pin the impedance is reactive loading.

In terms of constriction copper or gold used as conductive material. The width and length of each patch depends on the wavelength on which the antenna is intended to use. If the free space wavelength isλ and the length of each patch is L, then L should be in between 33%-50% of λ[2]. On the other hand the thickness of the patch is *t* then t<<λ, approximately 0.3% to 5% of wavelength. The microstrip antenna's resonant frequency should be matched with its operating frequency for better performance. The lowest resonant frequency can be calculated by equation (1).

$$f_r = \frac{c}{2(L+2\Delta l)\sqrt{\epsilon_e}} \; ; c = 3 \times 10^8 \frac{m}{s} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (1)$$

$$\Delta l = 0.412h \frac{(\epsilon_e + 0.3)}{2(L+2\Delta l)\sqrt{\epsilon_e}} \frac{(\frac{W}{h} + 0.264)}{(\frac{W}{h} + 0.8)}$$

$$\epsilon_e = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \frac{1}{(1 + 12h/W)^{1/2}} where \frac{W}{h} \geq 1$$

Here ϵ_e is effective permittivity where ϵ_r is relative permittivity on dielectric. L and W are the length and width of each patch as shown by figure 2-3:

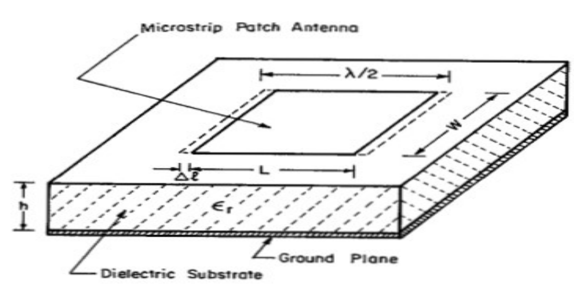


Figure 2-3: Cross-section of micro strip patch antenna

On the other hand, width of this patch is very important as smaller width can reduce efficiency on the other side larger can create higher order modes. If the wavelength of propagated wave is $\lambda_o$at free space the width should be [5].

$$W = \sqrt{\frac{\lambda_o}{2}(\frac{\epsilon_{r+1}}{2})}$$

2.2 Operation principal:

The radiation pattern of microstrip antenna is not uniform along its border. It depends on distribution and phase of electric field on the substrate. During the fabrication of microstrip dielectric constant of substrate increased slightly from effective dielectric constant so that the electric field can leave the substrate and propagates into the air. Most common type of microstrip antenna is rectangular in shape. So it has both lengths along the inset feed and width. Along the length electromagnetic field remains out of phase and produce no radiation while along the width it is different story. Here fields divide into vertical and horizontal components. Only horizontal components add up and create radiation pattern along the width borders but no radiation along the length.

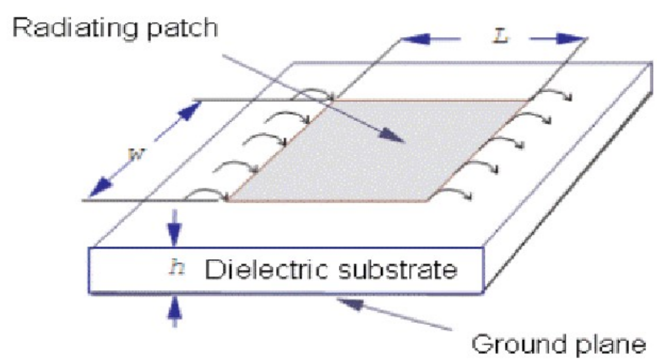


Figure 2-4: Radiating edge of microstrip patch antenna

The electric field of this kind of patch remains uniform along the width but it changes sinusoidal along the length.

2.3 Transmission line model:

Analysing this type of patch antenna is depending of assumptions on different view point. Among the several type of analysing method transmission line model, cavity model, MNM model are often used along with some numerical method like method of moments, Finite

Element Method, Finite Difference Time Domain method etc. However, the electric field on the edges can model as equivalent capacitors and radiation resistance. This method of analysing the microstip antennas called transmission line model. It is the easiest but inaccurate as does not take account of field variation in orthogonal direction. In this method antennas considered as transmission line resonator where the two edges along the width contributes in the radiation.

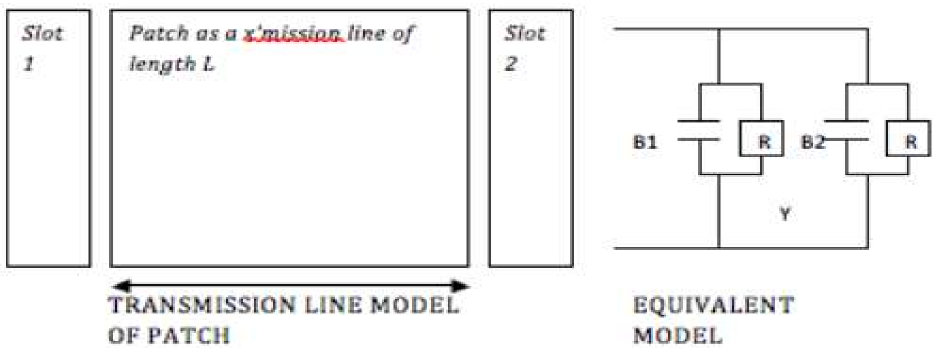


Figure 2-5: Transmission line model

2.4 <u>Feeding methods:</u>

Microstrip patch antenna can be feed with both contacting and non-contacting feeding method. Microstrip line and coaxial probe are the most popular form of contacting feeding method and aperture coupling and proximity coupling are non-contacting from of feeding. Among several feeding method this four feeding method descried here.

2.4.1 <u>Microstrip Line Feed:</u>

In this line feed method, metal interconnect directly attached to the edge of individual patch antennas where the width of this trace line is much narrower then patch itself as shown in figure 2-6. There are some advantages of this kind of feeding especially in the manufacturing end as this feed line can fabricated with PCB (Printed Circuit Board) etching. As well as impedance matching can be achieved by inserting perfectly positioned inset cut so no other extra matching element.

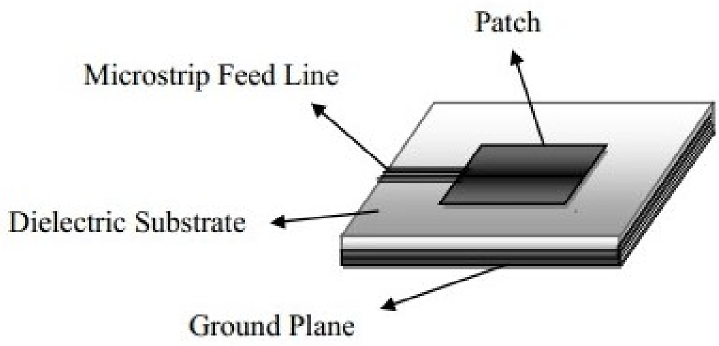


Figure 2-6: Microstrip Line Feed

However, there is some downside of this feeding method also. For instance, the thickness of dielectric barrier like circuit board can create surface wave where most of the radiation trapped in between air and patch surface. On the other side spurious feed radiation reduce the bandwidth further more [7]. Along with this cross polarization effects appears in this kind of feeding system. Overall this limitation is not a big issue when it comes to simplicity, impedance matching and efficient manufacturability.

2.4.2 Coaxial Probe:

Coaxial probe is one of the most common ways to feed microstrip antennas. Generally coaxial cable consists of a solid core and a non-contacting hollow outer shell covering the inner core. In this type of feeding solid inner core get through dielectric and connects to top radiating patch and outer shell connects directly to the ground panel as shown in figure 2-7. In coaxial probe feed inset cut is not needed and feed line can be placed any position for impedance patching. Another advantage of this coaxial probe over microstrip line is low spurious radiation effects.

Along with this advantages there also have many disadvantages like narrow bandwidth and harder to manufacture. Not only that if the substrate become thicker the inner core of coaxial probe will be longer which eventually leads to inductive impedance and results impedance mismatch. So coaxial probe feeding is not simple to manufacture and not so efficient also but it can achieve impedance matching easily.

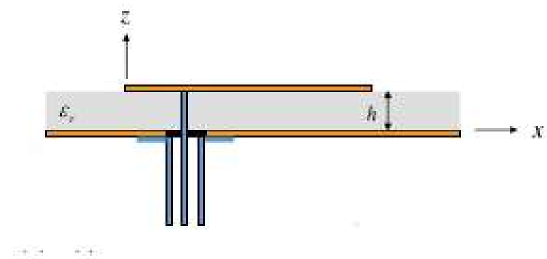


Figure 2-7: Coaxial Probe feeding

2.4.3 <u>Aperture Coupled Feed:</u>

Spurious feed radiation and matching problem was the main disadvantage of contacting feeding methods. The solution of these problems comes in non-contracting method like aperture coupled feeding method. In this approach ground panel sandwiched between two layers of dielectric material having micro strip feed line on one side and microstrip patch on the other as shown in figure 2-8. The thickness and dielectric constant of this individual dielectric layers chosen independently. Normally high value dielectric use between ground panel and microstrip feed line and low value but thick layer of dielectric used between ground and patch antenna. Aperture coupling normally takes place at the centre of the patch which leads to lower cross-polarization as the configuration is more or less symmetric. So the advantages are less spurious radiation. Not only that this configuration provides 21% [7] more bandwidth compares to others.

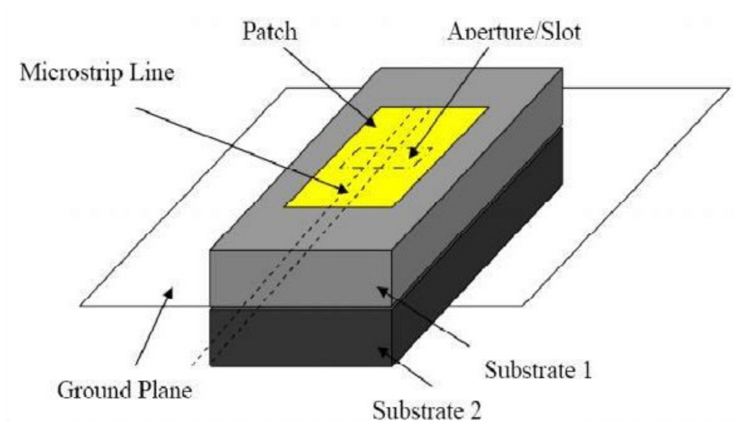


Figure 2-8: Aperture Coupled Feed

However, the main disadvantage of this type of configuration is complicated process of fabrication due to multilayer approach.

2.4.4 Proximity Coupled Feed:

This method is quite similar to aperture coupling but different layer alignment. Here feed line inserted between two layers of dielectric materials and one side ground panel other is patch antenna. This arrangement is also known as electromagnetic coupling scheme. The superiority of this design comes in reducing spurious feed radiation and increasing bandwidth about 13%.

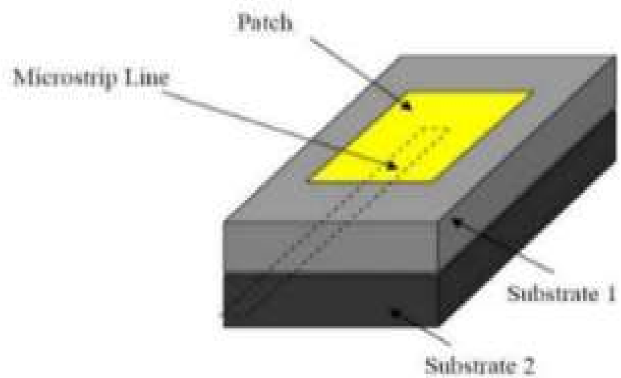


Figure 2-9: Proximity Coupled Feed

Unfortunately, this type of arrangement also faces same problem like aperture coupled feed, which is fabricating multilayer dielectric with different dielectric constant.

2.5 Microstrip Array Feeding Method:

Microstrip antennas usually aligned in arrays to overcome its main disadvantages of low gain but feeding those patches in array configuration is also challenging due to losses and high cross polar radiation by the feed line network. Researchers are currently working on this. The major concern of designing feed lines in arrays is complexity and size. Most common types of design in passive antenna array are corporate feed network and inline series feed network.

2.5.1 Corporate Feed Network:

Corporate feed network gives design flexibility on two dimensional array configurations. To obtain sudden magnitude and phase distribution of output current feed line designed based on transmission line theory or the equivalent waveguide model. In this feeding system electromagnetic feed line connects to the patch on the same substrate where feed lines spread like brunches of tree with one patch end of each brunch.

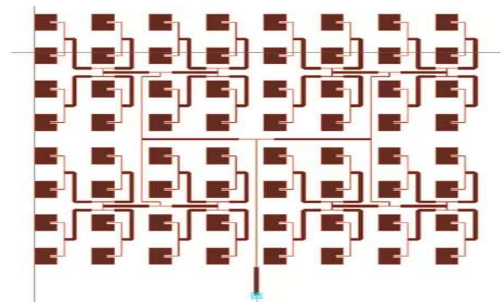


Figure 2-10: Corporate Feed Network

The main disadvantage is large number of feed line which makes low efficacy especially at high frequency but it can be overcome with waveguide feed network with compensating size and weight. Besides, multilayer approach can increase efficiency with shorter feed network length per wavelength. The aperture distribution of corporate feed network can be controlled easily.

2.5.2 <u>Inline Series Feed Network:</u>

In this series feed system multiple microstrip attached serially with single feed line which gives this kind of design an edge on parallel corporate feed network in terms of compactness. On the other hand, series feed network encounters less line radiation loss by feeder network.

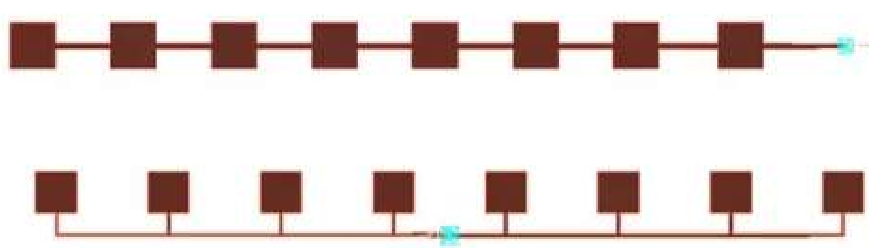


Figure 2-11: Inline Series Feed Network center feed and side feeding

However, the main limitation of this configuration is narrow bandwidth and phase difference due to not uniformly distributed length if feed lines.

2.6 Array with Single-Feed:

Most simple way of feeding microstrip patch array is using microstrip lines on the same surface. In this technique impedance controls with inserting inset in perfect position. Most conventional way of feeding each patch is using single line though it can be feed with two feed line known as double line feeding.

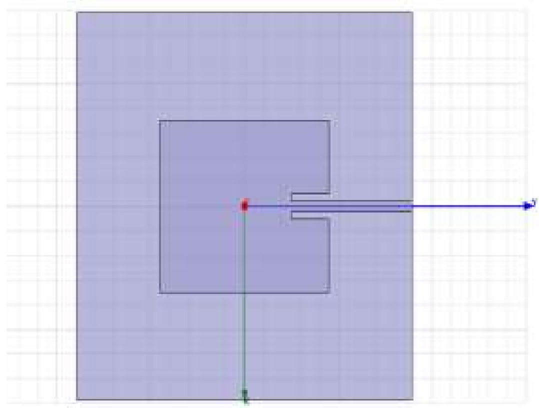


Figure 2-12: Single inset fed microstrip antenna.

Single line feeding is flexible where double line feeding can produce better gain and efficiency. For example, a 35mm X 45mm patch can produce 19.5dB with single line compare to 32dB with double line feeding.

2.7 Feed line impedance:

Feed line impedance is very important parameter of microstrip antenna as unmatched impedance causes unavailability to transfer maximum power to the patch. The simpler way to calculate this is to neglecting the effect of higher order modes. If input resistance is R_{in} then.

$$R_{in} = 90 \frac{\epsilon_r}{pc_1} \epsilon_r \mu_r \left(\frac{L}{W}\right)^2 sin^2(\frac{\pi x_f}{L})$$

The impedance of edge of each patch stays between 100Ω to 400Ω and the radiation impedance approximated as [10]

$$Z_a \approx 90 \frac{{\epsilon_r}^2}{\epsilon_r - 1} (\frac{L}{W})^2$$

2.8 Micro strip square patch theory:

Micro strip square patch antenna has three parameters which mainly directly or indirectly with the concept of substrate and its die-electric constant, height of the substrate and resonance frequency.

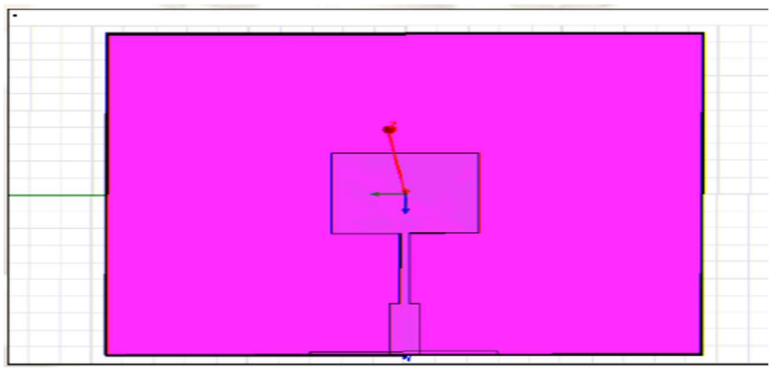


Figure 2-13: Microstrip square patch antenna

3 Antenna Array

3.1 Introduction and basic concept of antenna array:

A set of multiple connected antenna element into an antenna array. In many times single element array fail to get the desired radiation pattern requirement of a particular application like satellite communication or telecommunication. An antenna array is congregation of radiation elements for a single element radiation pattern is comparatively wide, there each element dispenses low values of directivity. In radio waves, the radiation by each single antenna and superpose with the combinational can enhance the power radiation in particular direction and removes the other direction radiation pattern. An antenna array always has the ability to get the higher gain that is narrower beams of radio waves. From more than single antenna combination, antenna's signal is combining in order to reach best performance over that of a single antenna which maximum of interference plus noise ratio. An antenna array also manages to reduce the power wastage of unwanted radiation pattern and better performance is obtained overall.

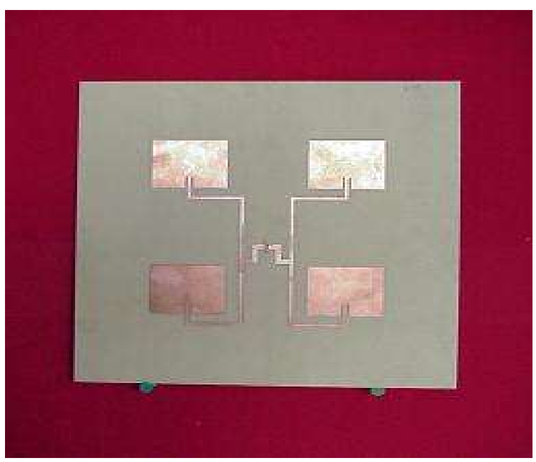


Figure 3-1: Four element microstrip antenna array

For the desirable gain and radiation pattern requirement in many applications, single element array can't perform wisely. For this reason, several antennas element in an array used to solve the problem. An antenna array combination of intent 'N' spatially separated antennas. In an antenna array, the sum of antennas will be as limited as or as large as several thousand. There is drawback of normal in cost, size and complexity.

In figure3-1 the general form of antenna array which indicate the origin and coordinate system with **'N'** element position indication.

$$\mathbf{d}_n = [x_n \;\; y_n \;\; z_n]$$

Position of the phase array represent by the down coordinate system figure 3-2

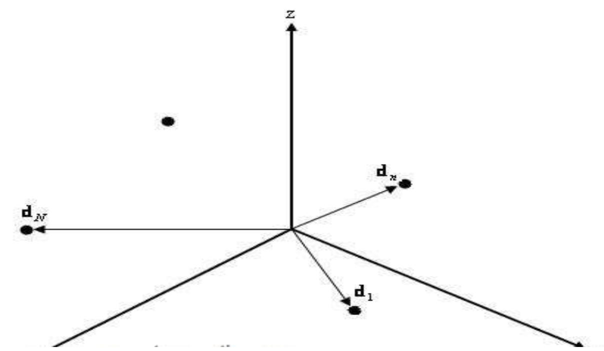


Figure 3-2: Geometry of an arbitrary N element antenna array.

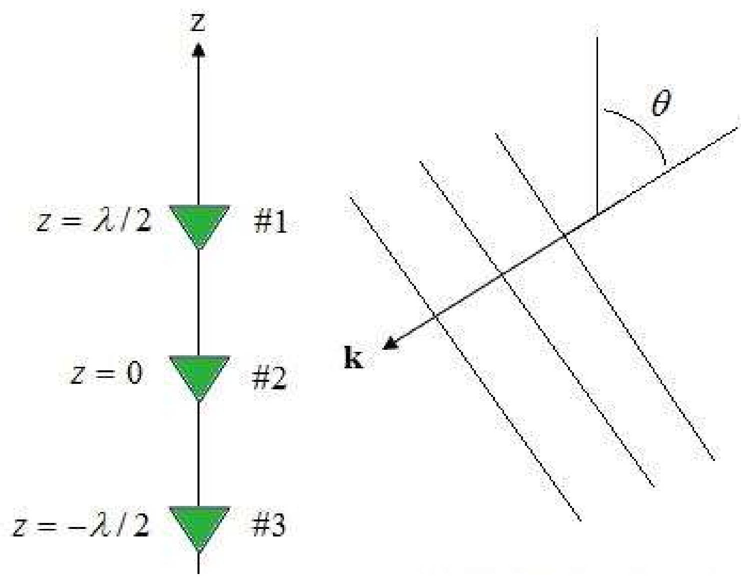
Weight of the antenna W and summing of signals from the antenna which is denoted by X will be the form of antenna array Y

$$Y = \sum_{n=1}^{N} w_n X_n$$

3.2 <u>Benefit of antenna array:</u>

For understanding the benefit of antenna array here with the example 3 element array antenna in z axis allocated an angle Θ where at z=0 the wavelength will be one half.

There for the effect the varied electric field which change the arrays wavelength and impact the antenna Array with the direction. In antenna array this changing of electric field is the reason of antenna's location. With the change of electric field location and direction factor can impact the antenna array design which helps to make a stable



Propagation in any direction array graph in a certain range of frequency

$$
\begin{aligned}
E(x,y,z) &= e^{-j(k_x x + k_y y + k_z z)} \\
&= e^{-j|\mathbf{k}|(\sin\theta\cos\phi\, x + \sin\theta\sin\phi\, y + \cos\theta\, z)} \\
&= e^{-j\mathbf{k}\cdot\mathbf{r}}
\end{aligned}
$$

Single antenna element can’t handle more power. So antenna array will have wider gain than single one. Benefits of antenna array especially the phase’s array in broadcasting, beam forming, naval usage, radio frequency identification, fire radar aircraft etc.

3.3 Types of antenna array:

An antenna array which have a radiation pattern always arranged in a line, circle, plane to divergent radiation pattern. There are different types of antenna array

1. Liner array (an antenna element exhibit in a straight line)

2. Circular array (antenna element exhibit around a circular ring)

3. Planar array (antenna element in which both active and parasitic are in one plane)

4. Conformal array (antenna in which designed to conform or follow some prescribed shape)

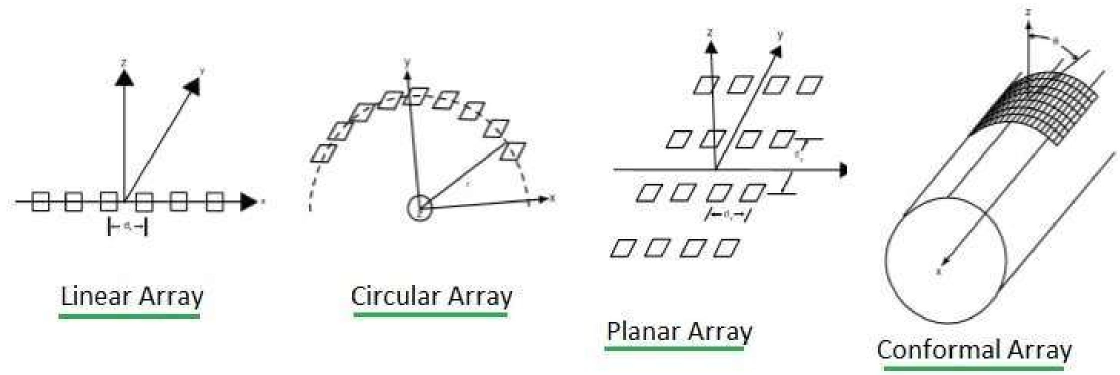


Figure 3-3: Different types of antenna array

There are also different kinds of antenna array like:

- Broadside: right angles radiation to main axis of antenna
- End-fire: along the main axis maximum radiation
- Phased: connected to the source all the element
- Parasitic: re-radiate power comes from other element and they are not connected with the source.

The basic types of arrays are −

- Collinear array
- Broad side array
- End fire array
- Parasitic array
- Yagi-Uda array
- Log-peroidic array
- Turnstile array
- Super-turnstile array

3.3.1 **Planar array:**

A planar array is an antenna array in which both active and parasitic are in one plane. By changing the relative phase of each single element, it can be implemented in a large aperture and used for directional beam control. In the field of radar absorber, a planar array works as a reflecting screen. Planar array affords easy symmetrical pattern towards any point in space with lower side lobes and the ability to scan the main beam.

From the geometry figure 3-4, we get the **M** element in the X axis with the equation

$$\mathrm{AF}_{\mathrm{x1}} = \sum_{m=1}^{M} \mathrm{I}_{\mathrm{Ml}} e^{j(m-l)(kdsin\alpha cos\emptyset+\beta x)}$$

It is clarified that all element are equally spaced with an interval of **dx** and a progressive shift **βx** where the coordinate $X = (M-1)d_x$, y=0 andsin $\alpha\ cos\emptyset = cos'\Upsilon_x$.

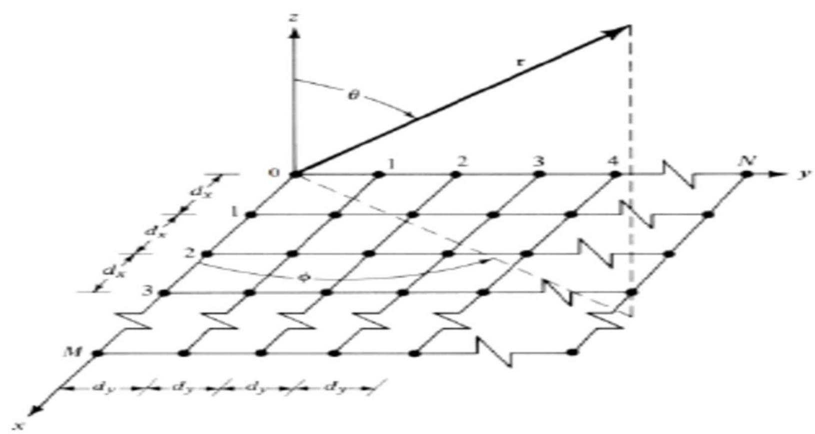


Figure 3-4: Planar array geometry equal array spacing

3.4 Array factor:

Array factor is the factor in every single directivity function of an individual antenna always multiplied to desire the overall directivity of an entire array. Identical multiple antenna works together in an antenna. Considering a set of same radiation pattern directional in same with it. Assume I is the position of located by the accurate position

$$\mathbf{r}_i = (x_i, y_i, z_i)$$

All the signals from the element and from the array complex weight summed together we get the phased array output **Y**. Based on the angle the output of the antenna array varied a lot in incident plane wave. The output **Y** is the combinational of **(Θ, Φ)** arrival angle of wave which interconnect to the array. In summary if the array transmitting and change the radiation pattern that will also be same in shape to the receiver antenna where for the reason of reciprocity the output can be different

$$Y = R(\theta,\phi)w_1 e^{-j\mathbf{k}\cdot\mathbf{r}_1} + R(\theta,\phi)w_2 e^{-j\mathbf{k}\cdot\mathbf{r}_2} + \cdots + R(\theta,\phi)w_N e^{-j\mathbf{k}\cdot\mathbf{r}_N}$$

Where k is the wave factor. And the array factor can be simplified by the below equation of the output

$$Y = R(\theta,\phi)\sum_{i=1}^{N} w_i e^{-j\mathbf{k}\cdot\mathbf{r}_i}$$

$$= R(\theta,\phi)AF$$

$$\boxed{AF = \sum_{i=1}^{N} w_i e^{-j\mathbf{k}\cdot\mathbf{r}_i}}$$

AF is the array factor. It is the combination of position and weight of the antenna array. With the change of weight antenna array can be change. With the entire steering factor, array factor represent the way is

$$AF = \mathbf{w}^T \mathbf{v}(\mathbf{k})$$

3.5 <u>Dielectric thickness:</u>

Dielectric thickness of an antenna performance characteristic and result for return loss, VSWR, impedance- gain, bandwidth and directivity. In the design of micro strip patch antenna which is similar to a rectangular patch antenna that represent the radiation pattern of square shape on one side of the dielectric subtract in the overall geometric of rectangular patch antenna having dielectric micro strip antenna connected with some electric structure of a device which has the ability to protect the dielectric cover.

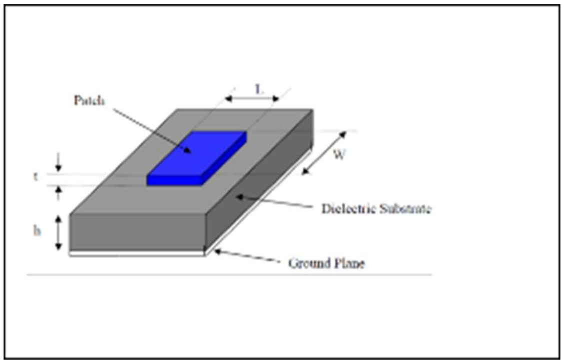


Figure 3-5: Microstrip patch antenna has a ground plane on the one side of a dielectric substrate which other side has a radiating patch.

For different dielectric cover, the dielectric thickness will be change. For Micros trip patch antenna dielectric cover vary from different thickness mm value having step of .1 with the variation.

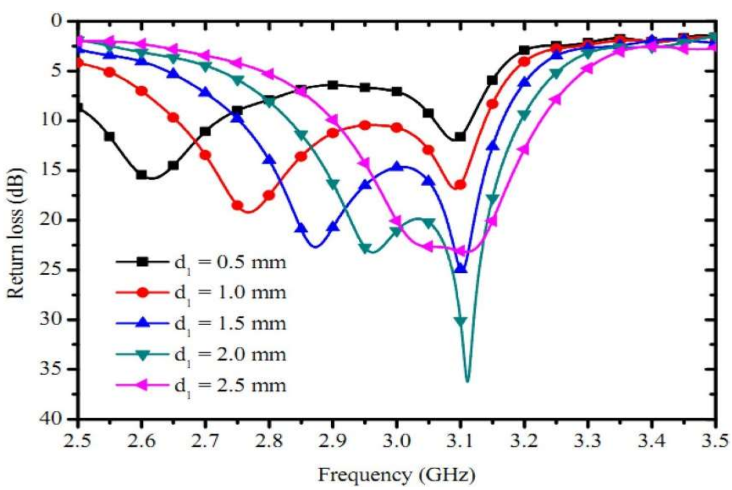


Figure 3-6: Variation of return loss with frequency for different slot thickness (d1).

There figure we can see for different slot of thickness we are getting different return loss for micros trip antenna. With the return loss changing there also change of impedance with the varying of dielectric thickness.

3.6 Geometry optimization in antenna:

The performance of an array depends on many factors. In all factor the set of element of weighting vector and geometry of the array plays an important role. Overall estimate of wave factor plays an important role to create an array’s output which is the most impactful function of geometry. For N element array and space between of an individual array successfully somehow enhance the size of array and for this reason beam width minimize in lobes section, as a result it become the reason of change in the geometry optimization of overall array. In effect of excess of size of the set of an array refers the change of granting lobes which minimize the direction in the highest radiation.

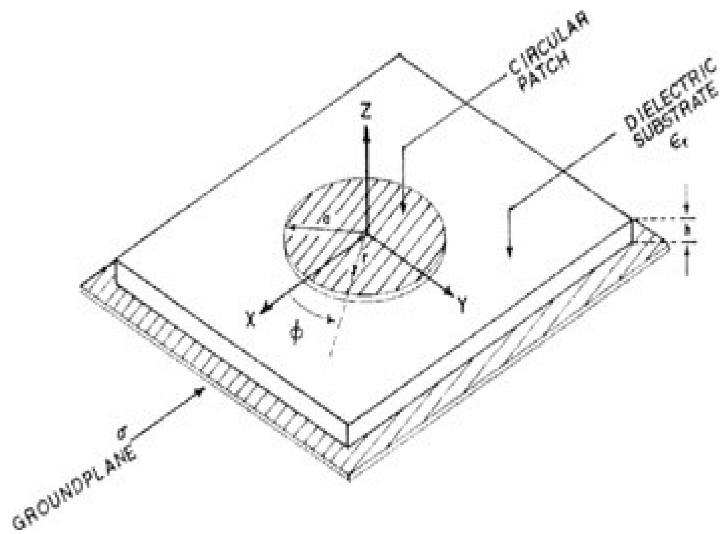


Figure 3-7: Geometric optimization in Antenna

3.7 Array Spacing

Array can be designed to radiate in either Broadside (radiation orientation is perpendicular to array-the Z axis) or end fire (radiation orientation is the same as the direction of array orientation). We considered broadside arrays for our design and this allows easy transformation to 2-dimensional planar arrays with the elements in the X-Y plane and the radiation in the Z direction.

The array factor relies upon the quantity of elements, the elements spacing, amplitude and phase of the applied signal to each element. The quantity of elements and the element spacing determine the surface area of the general radiating structure. The surface zone is called aperture. A larger aperture brings about a higher gain. The aperture efficiency measures how efficient the aperture is utilized.

Increasing with the number of elements the array directivity also increases. At the same time the number of side lobes and levels of side lobes next to the main lobes also increase with the number of elements. This problem can be solved by array specification. Any larger element spacing results in a higher directivity. In general the element spacing is kept smaller than $\lambda/2$

(λ is the Wave length) to avoid the occurrence of grating lobes. The grating lobes are another unwanted peak value in the radiation patters of the array.

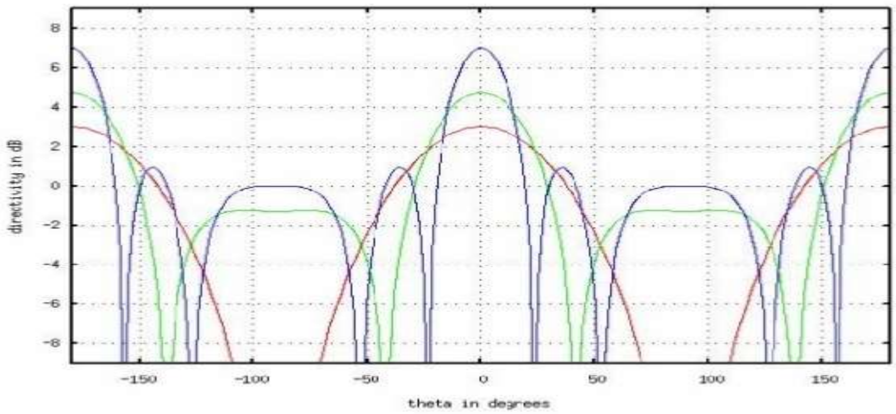


Figure 3-8: Directivity of a 5 element array with 0.2(red), 0.3(green) and 0.5(blue) time's λ element spacing.

Increasing the element spacing towards λ occurs increased directivity as well as grating lobes effect with a maximum amplitude equal to the main lobe magnitude at an element spacing λ as shown in figure 3-9

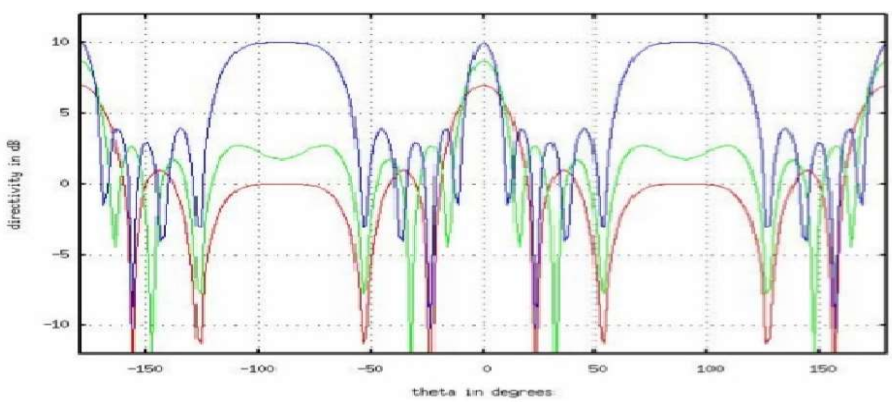


Figure 3-9: Directivity of a 5 element array with 0.5(red), 0.75(green) and 1(blue) time's λ element spacing.

An element spacing more than λ becomes impractical and results in multiple unwanted grating lobes as shown in figure 3-10.

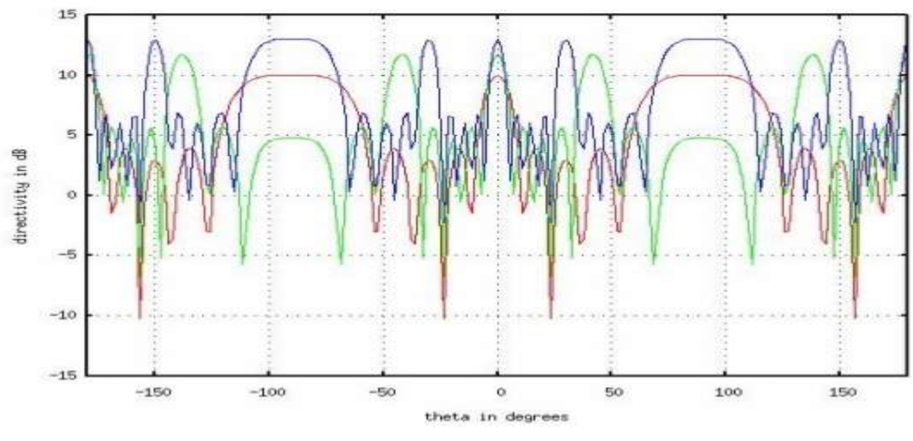


Figure 3-10: Directivity of a 5 elements array with 1(red), 1.5(green) and 2(blue) time's λ element spacing.

4 Literature Review:

We have gone through a lot of papers and books to gain a details knowledge about antenna. We started our learning with theory part. To learn all the theories, rules and formulas for our thesis we started our research study with the book named Antenna Theory by Balanis [1] and then moved to many other books [2, 3, 4, 5, 6, 54 and 55] which are listed in reference part. We gained our basic ideas about microstrip antenna arrays from these books and then we moved to observe various papers. We reviewed a lot of papers to research that what kinds of works are done by microstrip patch and microstrip arrays for millimetre wave at the same time. We learned about Multi-Band Microstrip Array for Millimetre-wave Radar System [23], where a 4x4 patch antenna array implemented at 77 GHz and the purpose is for automobile anti-collision system. Another microstrip array of 4x2 patches in 60 GHz band we studied [24] where they got a good S-parameter and it was implemented on Ultra-Flexible Micro machined Polydimethylsiloxane. For the purpose of directivity, we have gone through those papers which are based on directional array [25, 26].

Feeding method is an important issue for designing antenna. To feed our design in a sufficient way we learned about feeding techniques [27, 28, 39 and 41]. Moreover, we have to consider about the high gain and efficiency when we design a directional array. For this we learned about these [20, 32] to make our design efficient and to get high gain. Another issue which cannot leave without considering is side-lobe which causes destruction to have a directive result. We learned the theory and experiments done before to keep the side-lobe level low [49, 56].

Now the most important fact is impedance matching which is not easy to be done perfectly. There are many difference processes to match overall impedance for an antenna array. So we have studied [2, 4, 54, 9, 44, 46, 47 and 52] to get a brief knowledge for this part and tried to have a good impedance matching for our design. As we designed an array so here many different stages contain where we needed to match the impedance for different transmission line. Mostly when two different transmission line of different impedance are connected, that time we considered to apply appropriate matching techniques. Overall we matched our 86.1-ohm patch to main feed line of 50 ohms. For this purpose, we have used quarter wave length transformer and considered about equal power division.

At this stage we are going to describe about the designs which we are followed to design our main array of 16 elements. We implemented our design based on a basic design of "Corporate Fed Microstrip Array" which has been described in "Microstrip and Printed Antenna Design by Randy Bancroft" [2]. Here an array of four patches has been demonstrated and for this design four similar square patches has been taken and the impedance is same for all four patches. Here the patches are fed by a corporate feed network. Here to match the impedance for individual patches current and impedance ratio ($\frac{{I_1}^2}{{I_2}^2}=\frac{Z_2}{Z_1}$) has been used. By using this ratio, they considered to supply different current for individual patches. By using this formula impedance of transmission line easily calculated as the input resistance is know from the width of patch. To match the line impedance with patch impedance/input impedance here quarter wave transformer used. The impedance at junction of two transmission line of two different impedances is remained the parallel of those two impedance. After that, these junctions are connected by another quarter wave transformer to match with another transmission line. They calculated the line impedances for a single side and the other side implemented by these results as array need to be symmetric. Here the main feed line of 50 ohm matched with 100-ohm transmission line by the basis of equal power division. For this design different power can be delivered to different patches easily by changing the ratio of current and impedance. Though we designed our array based on this we did not follow this way of power division. We kept the entire ratio same and delivered same power to all the patches and the corresponding transmission lines also remained same for our design. Another paper [9] we also followed to design our array where 100-ohm radiator is matched by 50-ohm feed line. Here they used the structure of matching 50 ohm to 100 ohms by quarter wave transformer repeated time to the entire corporate system.

This is not the very first time we have designed a 16 element array. A lot of arrays for 16 elements have been designed already and these all are different from each other. These are different in design, different in feeding system and many other basic parameters. We have reviewed some papers which are based on 16 elements array and here we are giving a short description about some different arrays of 16 elements.

First on is "Design of a High Gain 16 Element Array of Microstrip Patch Antennas for Millimetre wave applications" [20]. Here four individual square designed by four patches and those four squares are connected by another square form of transmission line. This array designed for 28.5 GHz millimetre wave application and fed by Co-axial feeding method. Here they got there result for reflection co-efficient -21.7 dB at 28.5 GHz and -26 dB at 33 GHz which is quite good. This design and simulated result is applicable for 5G cellular mobile communication applications.

The second one is “60-GHz Patch Antennas and Arrays on LTCC with Embedded-Cavity Substrates” [21]. Here a 4x4 planar array implemented for 60 GHz and it works for 57-64 GHz frequency band. They used quarter wave matched T-junctions and Wilkinson power dividers. Another major fact is here they used cavity model and compared there result also. They measured their maximum gain 18.2 dBi with cavity model and 15.7 dBi without cavity model. These outcomes are both good but this summarized that with cavity model we got a higher gain.

The third one is “Design of 60 GHz mm-wave Patch Antenna Arrays” [51], where a single patch and two arrays of 4x1 and 4x4 patches implemented for 60 GHz and compared all the results. They observed maximum gain 7.65 dBi for single patch. For arrays maximum gain 12.5, 18 dBi for 4x1 and 4x4 respectively. Here they used series and parallel fed at the same time. Though there gain for 16 elements array is good but from their far-field it can be noticed that this result is not a good directive one as their side lobe level is high.

Another important one we have reviewed where a 2x8 element microstrip planar array designed for 60 GHz band [55], which is looks very similar to us. But the difference is there antenna structure consists of two layers, where each array element is a Conductor-Backed Coplanar Waveguide (CB-CPW) loop-fed patch antenna. There transmission line is designed on microfabrication-compatible quartz substrate and the patches on a Rogers RO3003 substrate. They also used Air bridges to suppress the parasitic coupled slot line mode of the CP line divisions. Compared with this we have tried to implement a 2x16 element microstrip patch array by using Roger 5880, where microstrip feed system used to feed the corporate. Moreover, we used only one substrate to reduce the complexity.

We also reviewed many other papers for 16 elements which are implanted in different purpose and their designing method and results are different also. We designed a different 16 elements array from already implemented array designs and tried to implement it in an easier way. Our simulated result also obtained as better to our desired. But, we can work on it to taste in other ways for much better result than our simulated result and we can bring change to our design and other parameters to get results for any other applications too.

5 Design

5.1 Single patch microstrip design:

We didn't make our proposed 16 element array at the first time. We started from a single patch element and calibrated result for this. The purpose of this is to show how the results changes with increasing the number of patches.

At first we designed a single square patch with W=L=3.5 mm. We calculated R_{in} = 86.1 Ω which is similar to the patches of array. This patch is fed by 50 Ω feed line. To match this impedance with the input impedance of patch we used quarter wave ($\lambda/4$) transmission line. Here the value of $\lambda/4$ is 0.93 mm and the impedance for this line calculated is 65.61 Ω. For this impedance we got the width of this transmission line is 0.505 mm. The calibrated result for this are shown in result part.

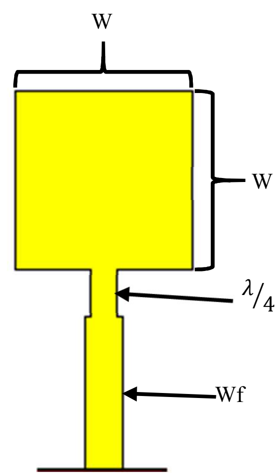


Figure 5-1: Single patch microstrip antenna

5.2 4 Element array design:

After single patch we constructed an array of 4 patches. The patch size remains same. To feed every single patch we used quarter wave transformer as shown in figure (4-2). The length for this calculated 0.95 mm. The impedance of transmission line which are connected to these quarter wave lines is Z=140.5 Ω and the width for this calculated 0.094 mm. The impedance at the junction of these two transmission lines are calculated by paralleling the value of Z and we got it Zp=70.25 Ω. The width for this parallel junction is 0.4507 mm. This junction is connected with main feed of Wf=50Ω by another quarter wave transformer. For this line the impedance is 59.3 Ω and the respective width 0.596.

Here we considered about the spacing between elements. We kept the spacing lower than $\lambda/_2$ (1.9mm) to avoid more side lobes. The spacing between every couple of patches is 1.806 mm. The calibrated details results are given in result part.

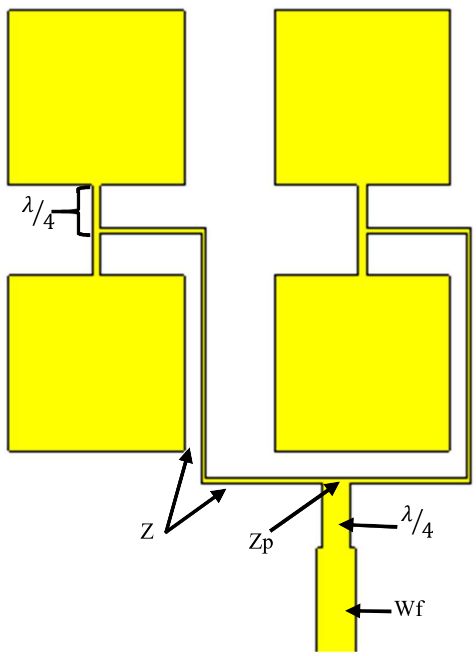


Figure 5-2: 4 Element microstrip array

5.3 8 Element array design:

In this stage we increased the array size. We designed a new array of 8 patches where the spacing remains same as before (array of 4 patches). The feeding method to every single patch also similar as before. Just the changes come in transmission lines with impedances. Here Z1=140.5 Ω impedance for the transmission line which matched to input impedance through quarter wave transformer. The impedance at junction of these transmission line is denoted by zp1 and it is calculated 70.25 Ω and the width for this junction is 0.4507 mm. This junction is connected to another transmission line of Z2=100 Ω through another quarter wave transformer. The impedance for this transformer is 70.71 Ω and the width for this 0.4455 mm. The impedance of second junction for Z2=100 Ω transmission line is denoted by Zp2, where

Zp2=50 Ω and the width for this 0.78 mm. This junction is directly fed by main feed line of 50 Ω. The calibrated details results for this 2x4 array explained in the result part.

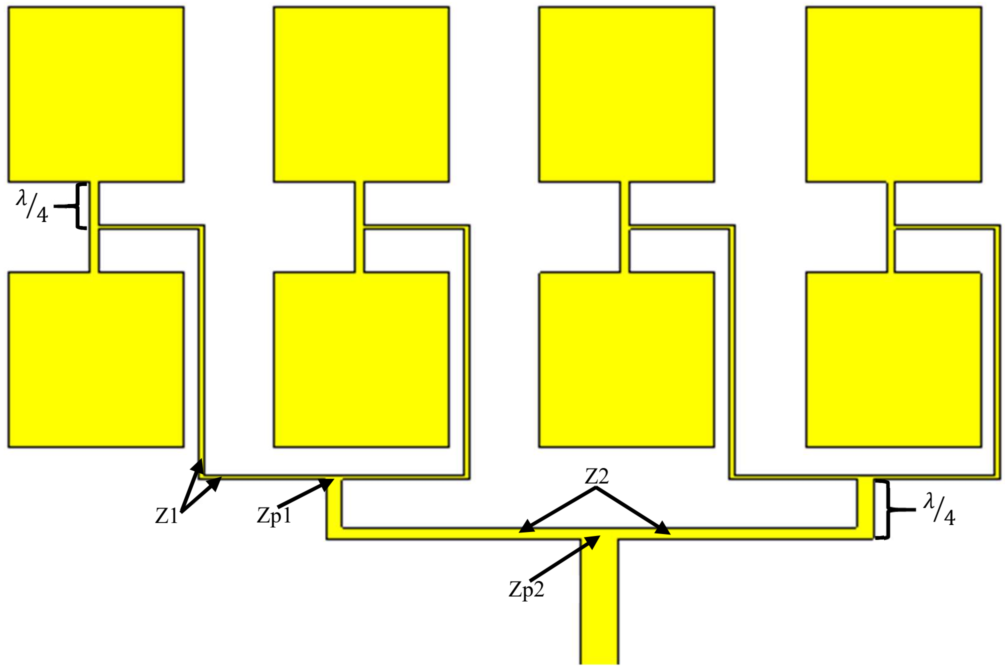


Figure 5-3: 8 Element array

5.4 Corporate Fed Microstrip Array (2x8):

The array feed techniques that are most well-known are corporate feeding and series feeding. Series feeding has various troubles associated with its implementation. The beam direction is sensitive to frequency.

To represent an elementary corporate feed network, we feed an array of sixteen-path element, as showed in Figure 5-1. Every identical square patch antennas has an input resistance R_{in}at resonance [R_{in}= $R_e/2$ = 1/ ($2G_e$)]. This element resistance at each patch matched to connecting transmission line impedance, which is utilized to give a desired power split. This is done with quarter-wave transformer technique.

To implement this design, we feed the array with a 50-Ω microstrip feed line into a couple of 100 Ω lines. This will split the power in an equivalent way to both lines of impedance,Z_3. These transmission lines are used to match with transmission lines of impedance, Z_2 and this is done by $\lambda/_4$ transformer lines of impedance, Z_b. Then these transmission lines are matched to next transmission lines of impedance, Z_1 and this also done by $\lambda/_4$ transformer lines of impedance, Z_a. The transmission lines of impedance Z_1 are matched to load line of impedance, Z_q which are designed as input line of square patches.

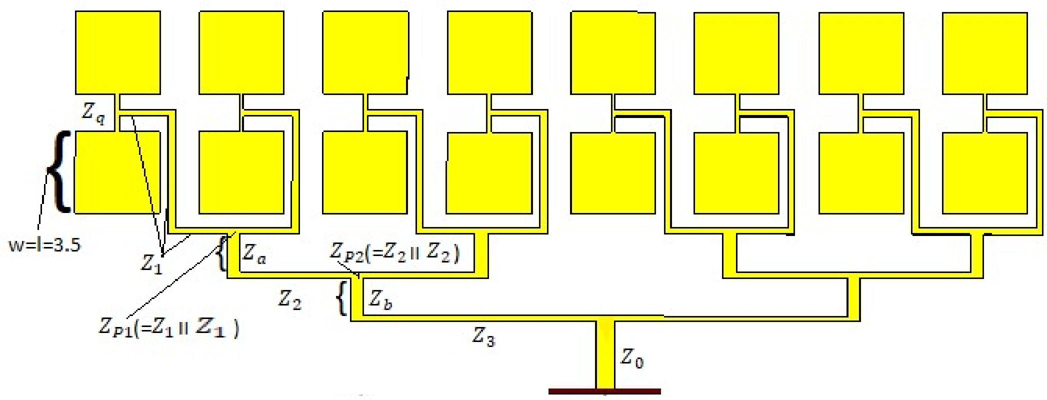


Figure 5-4: Design of proposed 16 element antenna array showing Impedance

We fixed the same impedance for all patch to provide same current as well as same power. Therefore, the ratio of current and impedance is same and it is one here. To change the ratio of transmission line impedance we can choose the desired ratio of the current. By changing this ratio, we can provide different power to each of the patch, as we want.

For our thesis project we choose an operating frequency of 60 GHz. Square patch with length of 3.5 mm on a 0.25 mm thick substrate with dielectric constant$\mathcal{E}_r$ = 2.2 has an element edge resistance of R_{in} = 86.1Ω.

For etching microstrip circuit, we had to care about line widths smaller than 152 µm (0.006 inches). For this substrate we calculated this value and tried to keep the impedance below than that value. We consideredZ_q = 110 Ω for the quarter wave transmission line which made for matching with patch impedance (86.1Ω) to transmission line of 140.5 Ω.

We know the element resistance of the patch antenna at resonance (R_{in}) and we used the quarter-wave transformer for each patch to be the maximum impedance of 110 Ωfrom this we calculated the value ofZ_1:

$$\frac{Z_q^2}{R_{in}} = Z_1 = \frac{110^2}{86.1} = 140.5\Omega$$

The impedances at the power split points:

$Z_{P1} = Z_1 || Z_1$ = 70.25 Ω

For our design we considered Z $_2$= 100 Ω. So the parallel node of Z $_2$:

$$Z_{P2} = Z_2 || Z_2 = 50\ \Omega$$

The quarter-wave ($\lambda/4$) transformers are computed as

$$Z_a = \sqrt{(70.25 * 100)} = 83.82\Omega \text{ and } Z_b = \sqrt{(50 * 100)} = 70.71\Omega.$$

For our design, we have chosen a symmetric array distribution so the values of the impedances for the two sides have been evaluated. The losses in a corporate fed array will increase as substrate height increases and dielectric constant decreases. The loss additionally increases as the fed line impedances decreases. As the measurements of an array increase, the length of the corporate feed network broadens further and further. The microstrip line losses increment and reduction the acknowledged gain of the array and furthermore add to the antenna noise figure. One can achieve a state of reducing return. As the quantity of array elements (and in this manner the effective aperture) are expanded, the losses from the feed network end up bigger and bigger. The expansion in gain created by a bigger gap can be adjusted by the losses in the feed lines or surpassed.

5.5 <u>Corporate Fed Microstrip Array Spacing:</u>

Another important part of our design is the spacing between the patches. We had to do the spacing more efficiently because the radiation pattern depends on that spacing. If the spacing is not applied properly then the radiation pattern varies a lot. As we mentioned earlier that we are working with 60 GHz band, thus our spacing measurement is 1.611mm. We took our spacing less than λ/2 (1.8) because in general the element spacing is kept smaller than $\lambda/2$ (λ is the Wavelength) to avoid the occurrence of grating lobes. The grating lobes are another unwanted peak value in the radiation patterns of the array. So, we maintained this spacing for every couple of patches.

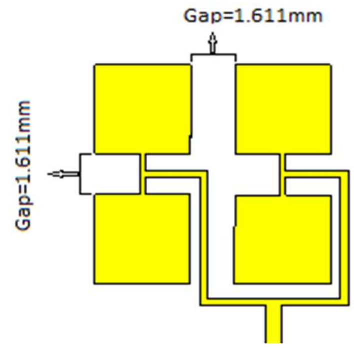


Figure 5-5: Microstrip Array Spacing with wg=1.611mm

5.6 <u>Patch and transmission line design:</u>

Patch element are the part from where the power of an antenna radiates. Designing of a patch is very critical. In our proposed design, we used square patch element. We designed 16 patches here. Where the length and the width are equal and the value of 3.5mm, which is in the direction of y-axis and x-axis respectively. Another main element of an antenna is its substrate. The substrate is the element between the patch and the ground. In our proposed design, we used a substrate named Roger5880. Which dielectric constant Ɛ=2.2. We used the height of the substrate is 0.25mm. Which is a constant height for the Roger5880 substrate. The thickness of the copper patch, transmission lines and the ground is .035mm. In figure 4-3, we showed not only the length, width and height of our patch but also the height of the substrate.

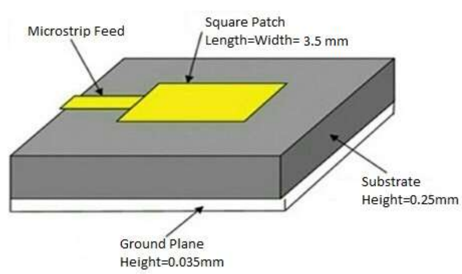


Figure 5-6: Square patch with w=l=3.5mm and with a height (ht) of .035mm

We also used an impedance transformer which length is λ/4. It has an impedance of 110**Ω**. In figure 4-4, we showed the length of this impedance transformer.

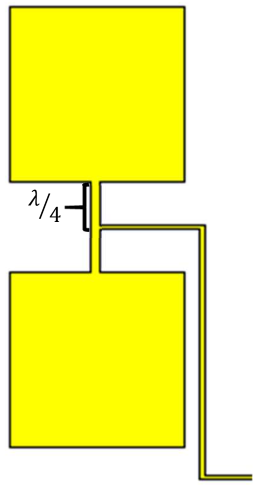


Figure 5-7: Load line with a length of λ/4.

We used different impedance in different transmission lines. So that, the width of the transmission lines is different from each other. We also use λ/4 transformers in w_{2f} and w_{4f} feedlines. In the figure 4-5, we showed all the width and impedance transformers. All the calculated width for different impedances are shown in table below:

Table 1: parameter list of proposed design

Parameter	Measurement(mm)		Parameter	Measurement(mm)
W1f	0.225		W	3.5
W2f	0.4455		L	3.5
W3f	0.225		Hs	0.25
W4f	0.325		Ht	0.035
W5f	0.094		Wg	1.611
W6f	0.094		W31f	0.78
W7f	0.094		W51f	0.4507
W8f	0.18		Wf	0.77

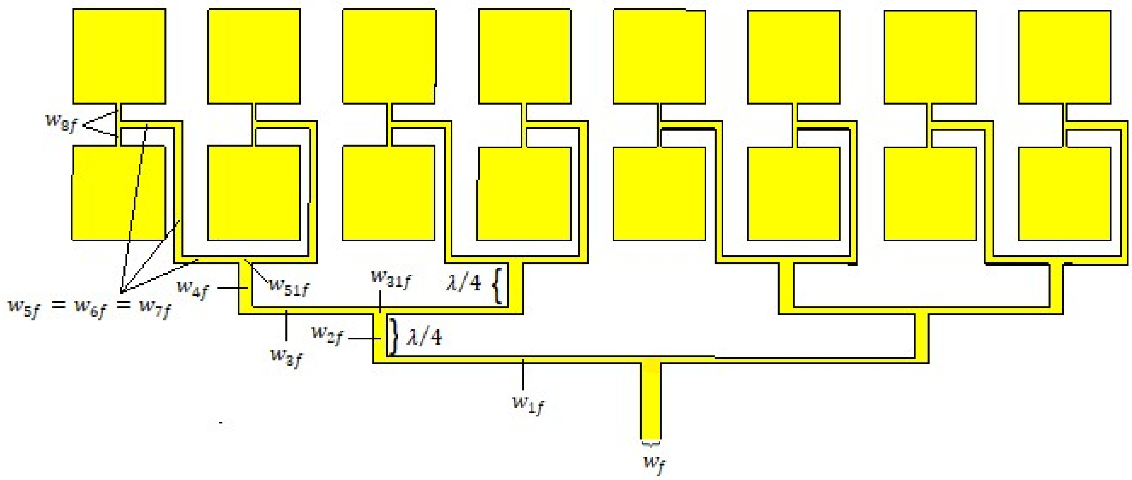


Figure 5-8: Proposed 16 element antenna array with the entire transmission line width and impedance transformer's length

6 Result

From different works of it has been found that millimetre wave microstrip array has important role for making the directional antennas. Based on this phenomenon a design of corporate fed microstrip array antenna has already been provided. In our work, we analysed the characteristics and design mechanism of corporate fed microstrip array antenna. Finally, we proposed a design based on our thesis. Our thesis design has directional radiation pattern. The design has unique physical parameters. Furthermore, analysing the operating modes of normal corporate fed microstrip array antenna and previously provided designs we came up with a new mode configuration for corporate fed microstrip array antenna. In this section, we will thoroughly explain our results of thesis and discuss their consequences. Firstly, we will focus on the S-parameter of our antenna design then we will discuss about the directional radiation pattern. Finally, we will explain overall efficiency, pros, and cons of our proposed design.

6.1 S-parameter:

S-parameters describe the input-output relationship between ports (or terminals) in an electrical system. For instance, if we have 2 ports (intelligently called Port 1 and Port 2), then S12 represents the power transferred from Port 2 to Port 1. S21 represents the power transferred from Port 1 to Port 2. In general, SNM represents the power transferred from Port M to Port N in a multi-port network.

A port can be loosely defined as any place where we can deliver voltage and current. So, if we have a communication system with two radios (radio 1 and radio 2), then the radio terminals (which deliver power to the two antennas) would be the two ports. S11 then would be the reflected power radio 1 is trying to deliver to antenna 1. S22 would be the reflected power radio 2 is attempting to deliver to antenna 2. In addition, S12 is the power from radio 2 that is delivered through antenna 1 to radio 1. In general, S-parameters are a function of frequency.

In practice, the most commonly quoted parameter in regards to antennas is S11. S11 represents how much power is reflected from the antenna, and hence is known as the reflection coefficient (sometimes written as gamma: Γ or return loss. If S11=0 dB, then all the power is reflected from the antenna and nothing is radiated. If S11=-10 dB, this implies that if 3 dB of power is delivered to the antenna, -7 dB is the reflected power.

The remainder of the power was "accepted by" or delivered to the antenna. This accepted power is either radiated or absorbed as losses within the antenna. Since antennas are typically designed to be low loss, ideally the majority of the power delivered to the antenna is radiated.

6.1.1 S-parameter of single patch microstrip:

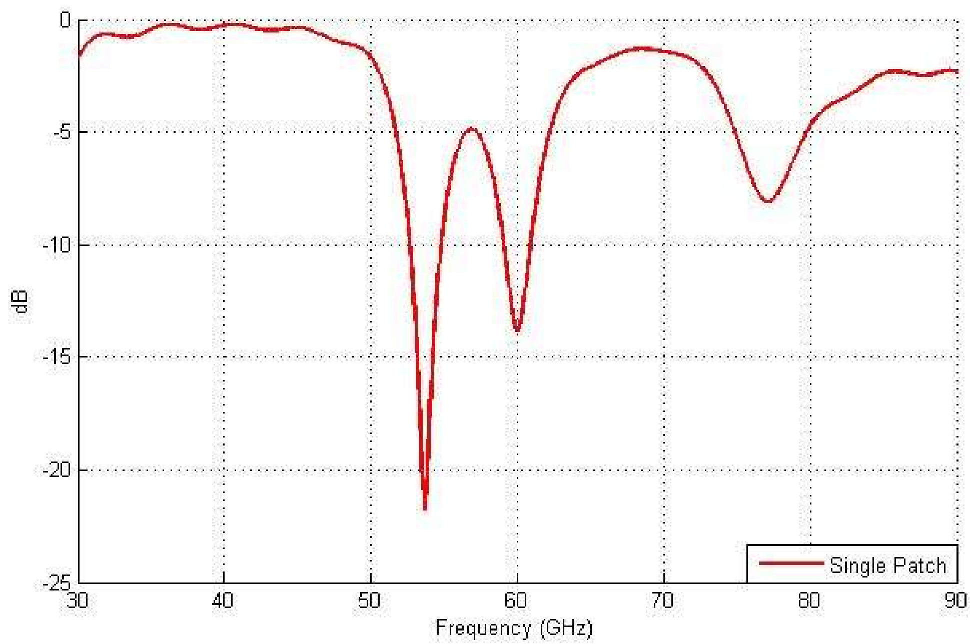


Figure 6-1: S-parameter of single patch microstrip

The above would typically be measured using a Vector Network Analyser (VNA), which can plot S11. The above figure implies that the antenna radiates at both 54.12 GHz and 60 GHz, where S11=-21dB and 13.78dB respectively. Further, at other frequencies the antenna will radiate virtually nothing, as S11 is higher than -10 dB. As our desired frequency is 60 GHz we measured the bandwidth from the above figure. If the bandwidth were defined as the frequency range where S11 is to be less than -6 dB, then the bandwidth would be roughly 4.2 GHz, with 61.9 GHz the high end and 57.7 GHz the low end of the frequency band.

6.1.2 S-parameter of 4 element array:

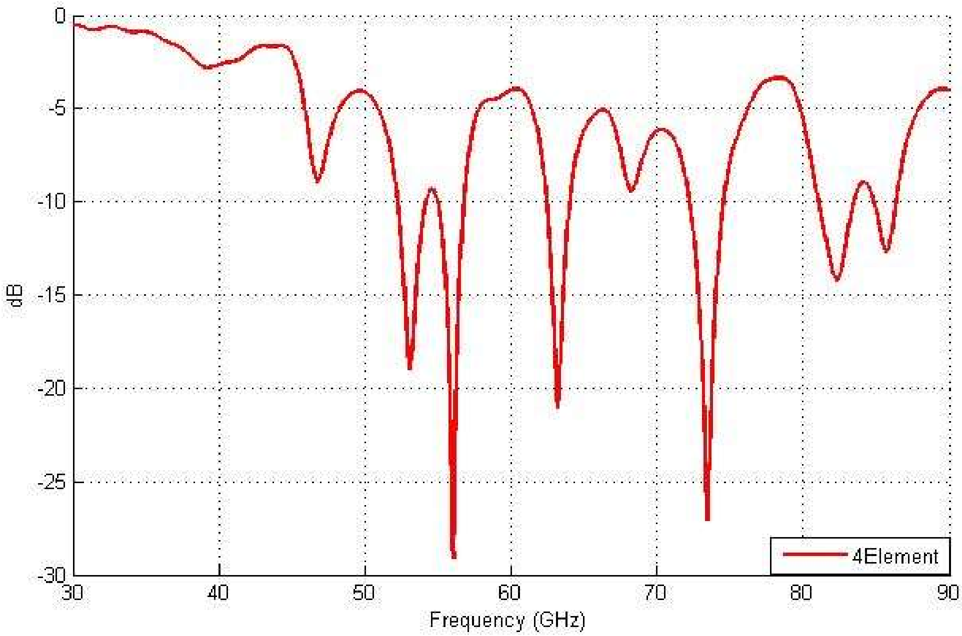


Figure 6-2:S-parameter of 4 element array

From VNA we obtained the plot of S11. The above figure implies that the antenna radiates in many different frequencies. But at 56.04 GHz the antenna radiates best. So we took this frequency as our desired frequency as it is near 60 GHz. At this frequency S11=-29dB. Further, we consider that at other frequencies the antenna will radiate virtually nothing. As our desired frequency is 60 GHz we measured the bandwidth from the above figure. If the bandwidth were defined as the frequency range where S11 is to be less than -9.5 dB, then the bandwidth would be roughly 1.3 GHz, with 56.1 GHz the high end and 54.8 GHz the low end of the frequency band.

6.1.3 S-parameter for 8 element array:

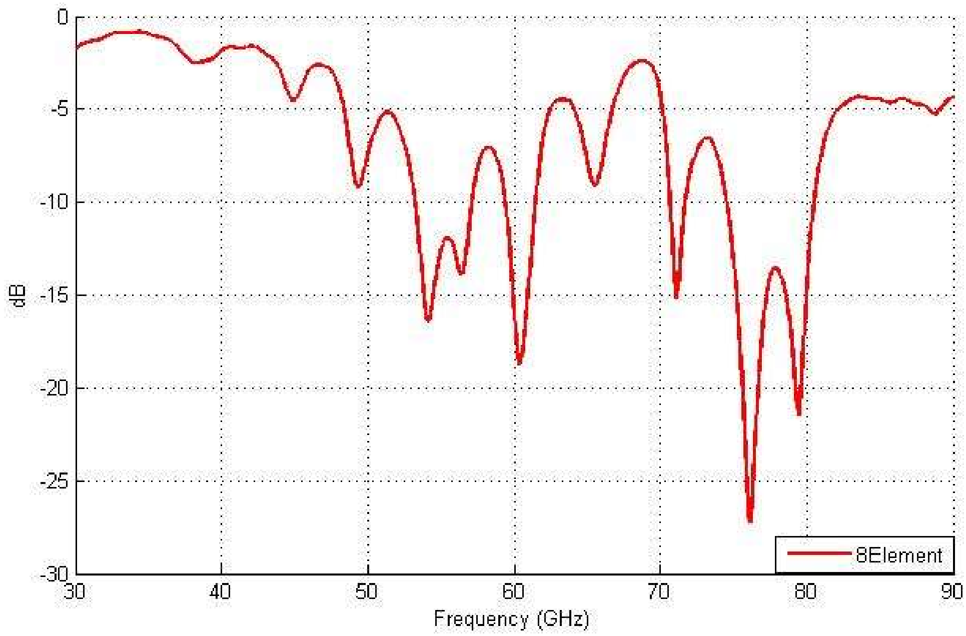


Figure 6-3:S-parameter for 8 element array

From VNA we obtained the plot of S11. The above figure implies that the antenna radiates in many different frequencies. But at 60.52 GHz the antenna radiates one of the best and it is nearer from our desired frequency 60 GHz. So we took this frequency as our desired frequency. At this frequency S11=-18dB. Further, we consider that at other frequencies the antenna will radiate virtually nothing. As now our desired frequency is 60.52 GHz we measured the bandwidth from the above figure. If the bandwidth were defined as the frequency range where S11 is to be less than -7 dB, then the bandwidth would be roughly 3.8 GHz, with 61.8 GHz the high end and 58 GHz the low end of the frequency band.

6.1.4 S-parameter of our proposed 16 element array design:

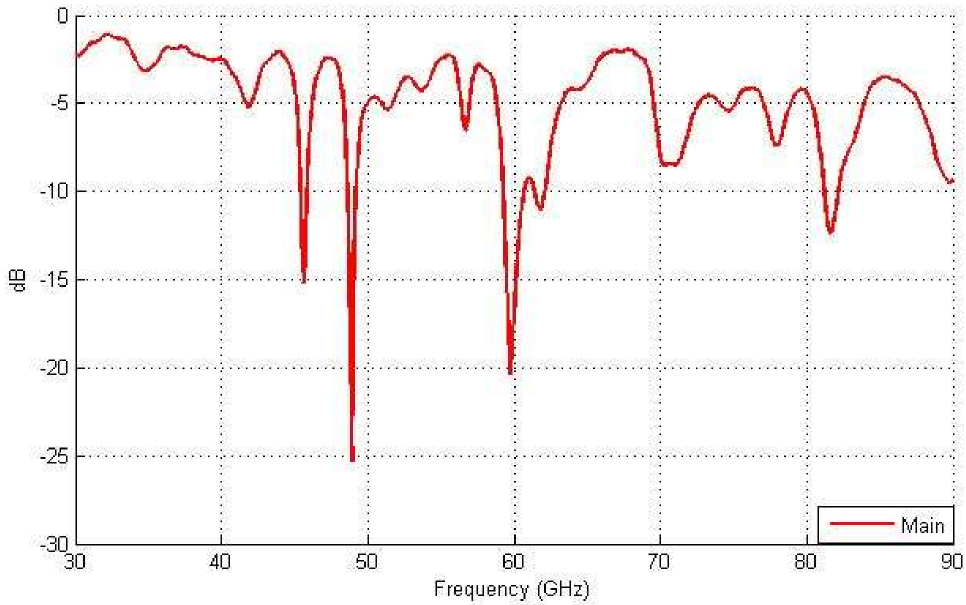


Figure 6-4: S-parameter of our proposed 16 element array design

The above would typically be measured using a Vector Network Analyser (VNA), which can plot S11. The above figure implies that the antenna radiates best at 59.76 GHz, where S11=-20.665 dB. Further, at other frequencies the antenna will radiate virtually nothing, as S11 is higher than -10 dB. The antenna bandwidth can also be determined from the above figure. If the bandwidth were defined as the frequency range where S11 is to be less than -9 dB, then the bandwidth would be roughly 1.8 GHz, with 61 GHz the high end and 59.2 GHz the low end of the frequency band.

6.2 Radiation Pattern:

A radiation pattern defines the variation of the power radiated by an antenna as a function of the direction away from the antenna. This power variation as a function of the arrival angle is observed in the antenna's far field. It has already been mentioned that making the radiation pattern directional of corporate fed microstrip array antenna is the main target of our thesis. We have successfully achieved our target with the 16 element array antenna.

6.2.1 Radiation pattern for single patch microstrip antenna:

For this single patch design, we did not get our desired directional radiation pattern. The magnitude of main lobe is too low and the magnitude of the side lobes are close to the main lobe. And if we consider the patch plane is 0 degree then our main lobe came at 110 degrees.

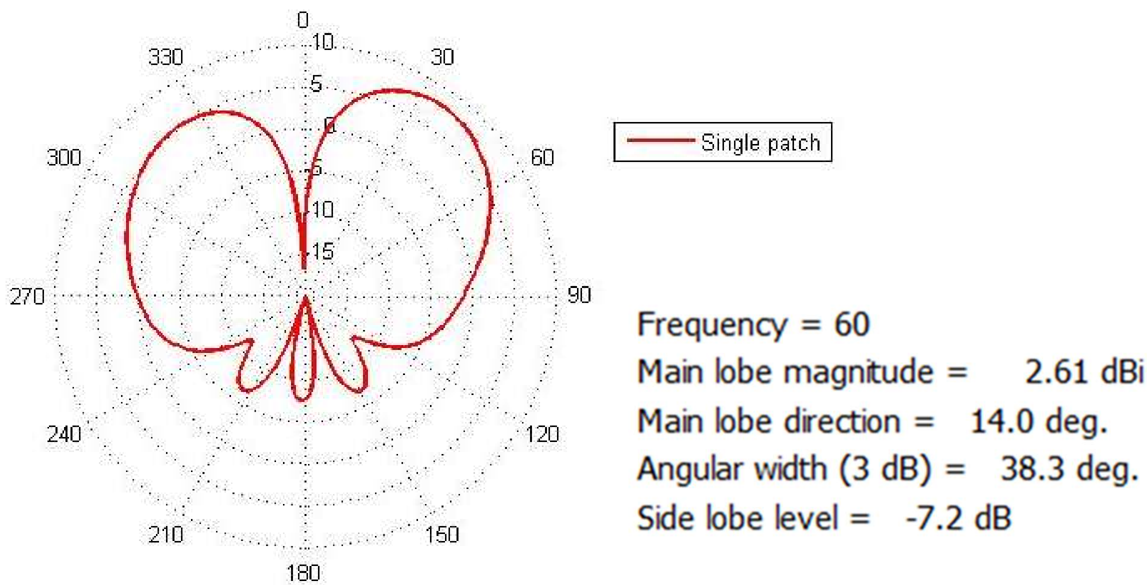


Figure 6-5:1D plot of farfield

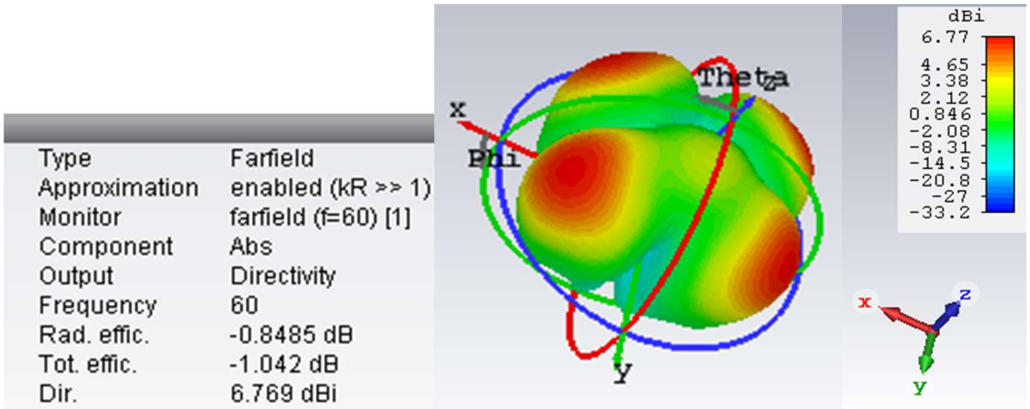


Figure 6-6:3D plot of Fairfield

6.2.2 <u>Radiation pattern for 4 element array design:</u>

For this 4 element array design, we did not get our desired directional radiation pattern. The magnitude of main lobe is too low and the magnitude of the side lobes are close to the main lobe. And if we consider the patch plane is 0 degree then our main lobe came at 160 degrees.

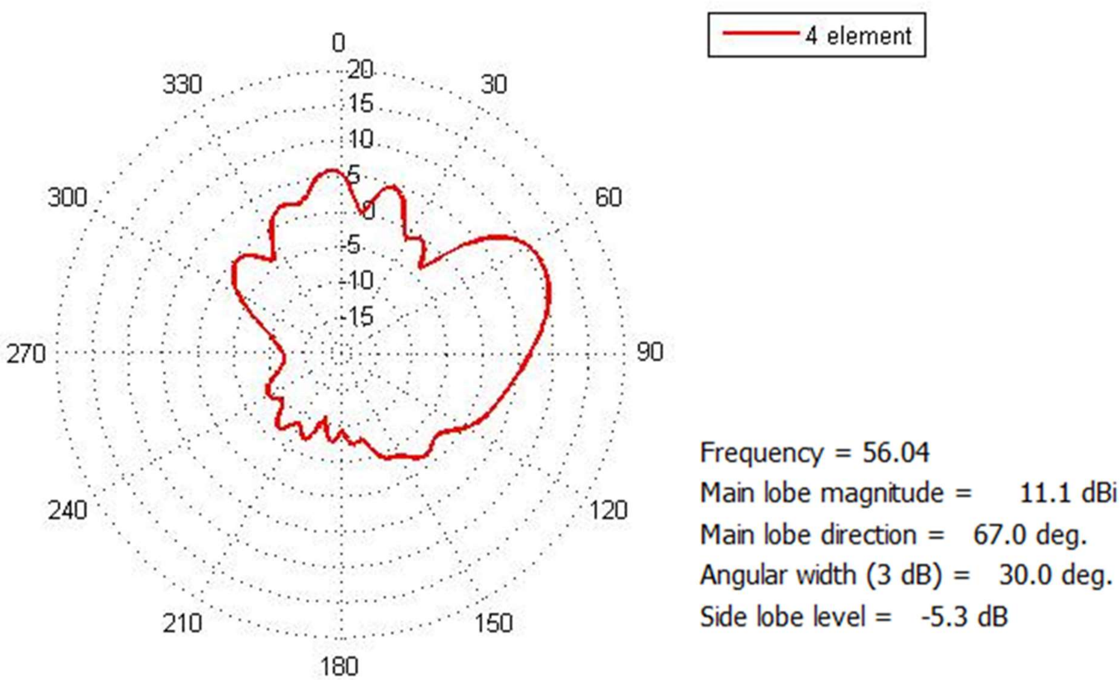


Figure 6-7:1D plot of farfield

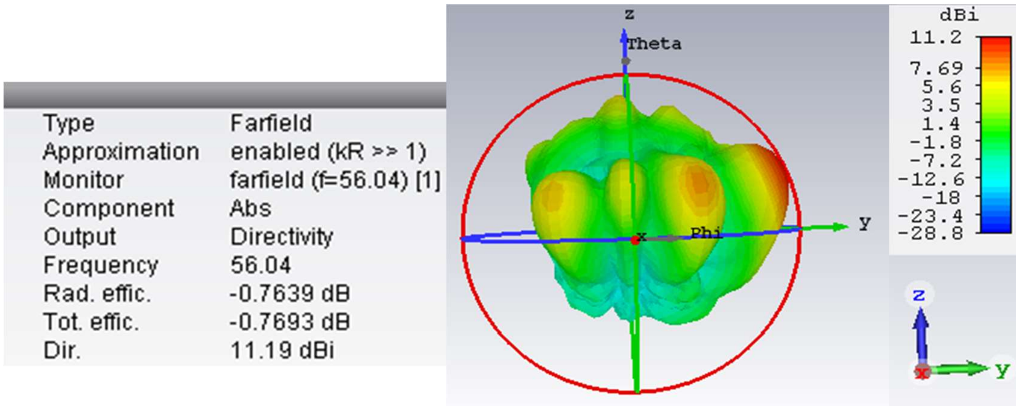


Figure 6-8:3D plot of farfield

6.2.3 <u>Radiation pattern for 8 element array design:</u>

For this 4 element array design, we did not get our desired directional radiation pattern. The magnitude of main lobe is too low and the magnitude of the side lobes are close to the main lobe. And if we consider the patch plane is 0 degree then our main lobe came at 90 degrees but it is hard to define which one is main lobe because the other lobes' magnitudes are closer to the main lobe magnitude.

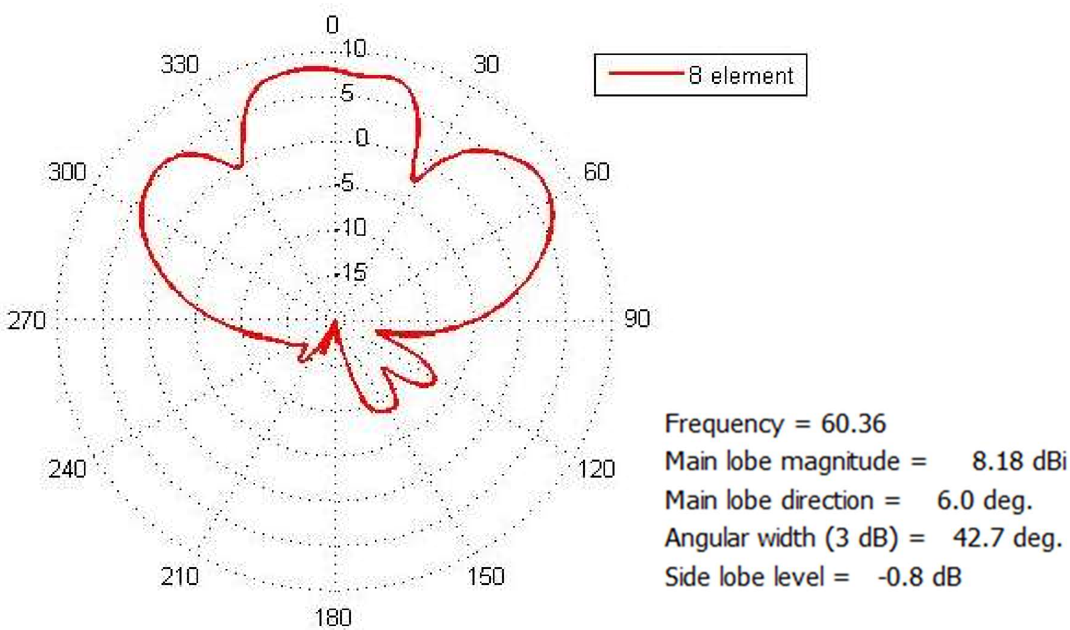


Figure 6-9:1D plot of farfield

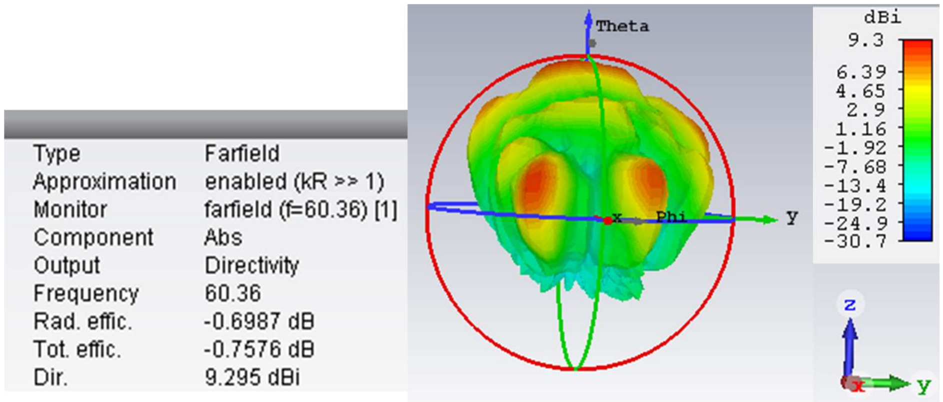


Figure 6-10:3D plot of farfield

6.2.4 <u>Radiation pattern for our proposed 16 element array design</u>

In our thesis, we have achieved directional radiation pattern. By our proposed design provided radiation pattern with one directional lobe. To explain further if the horizontal direction situated on the plane of the patch is considered 0 degree then our design had a lobe at 90 degrees. In order to achieve this type of radiation patterns some assumptions and precious calculations have been made. This two sided lobe radiation pattern is not achieved for all frequencies. It is only available for the resonant frequency of millimetre wave.

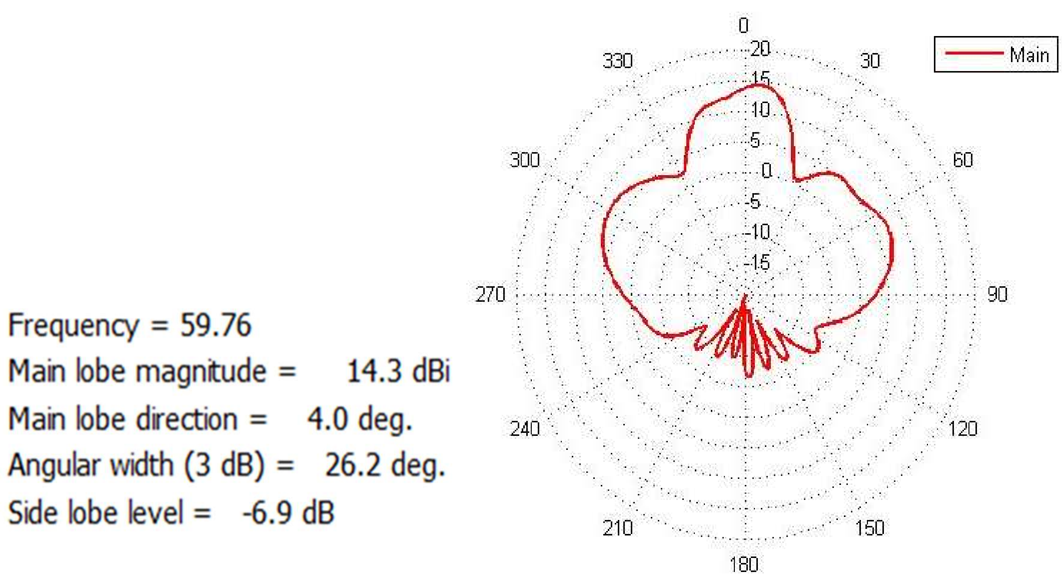


Figure 6-11:1D plot of farfield

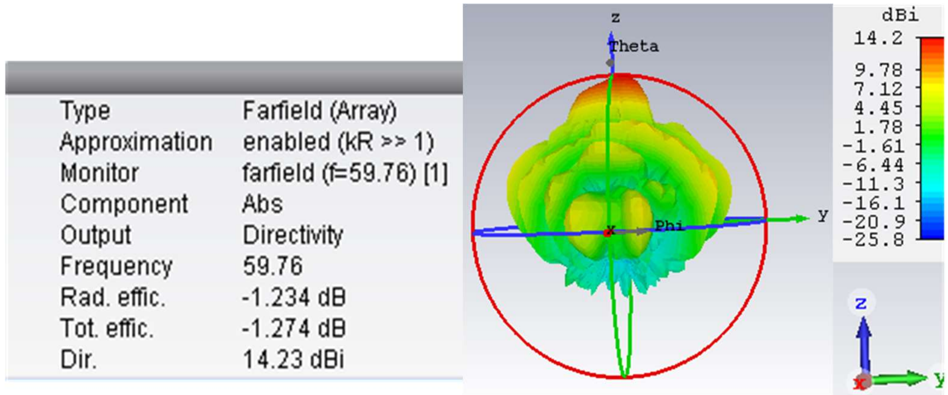


Figure 6-12:3D plot of Farfield

6.3 E- Field and H- Field:

Electromagnetic waves are made up of Electric Fields (often called the E-field) and magnetic fields.

Technically, the E-field at a point in space is a measure of how strong the force would be on a unit point charge (a small sphere with an electric charge of 1 Coulomb on it).

The E-field is a vector quantity - this means at every point in space it has a magnitude and a direction. For instance, let us say an E-field exists in space given by:

$$\mathbf{E} = A\cos(\omega t - kz)\hat{\mathbf{y}}$$

This is the E-field of a plane wave travelling in the +z-direction, and the E-field is linearly polarized and 'points' in the y-direction (k is the wavenumber). The amplitude of the wave is A Volts/meter.

At time t=0 and z=0, the E-field is A Volts/meter in the +y-direction. This means that a unit point charge (1 Coulomb) at this location would experience a force of A Newton's in the +y-direction.

The electric field also relates to voltage - a stronger E-field incident upon an antenna will induce a larger voltage difference across the antenna's terminals. However, except for low frequencies, the relationship between E-fields and Voltage is not simple (the voltage is a potential which is subject to different definitions). At d.c., when the fields are static (no variation with time), the E-field and voltage V are related to each other by:

$$\mathbf{E} = -\nabla V$$

$$V = -\oint \mathbf{E} \cdot \mathbf{dl}$$

The electric field associated with a point charge with a positive charge point away from it at every location; the fields associated with a point charge with a negative charge point towards it.

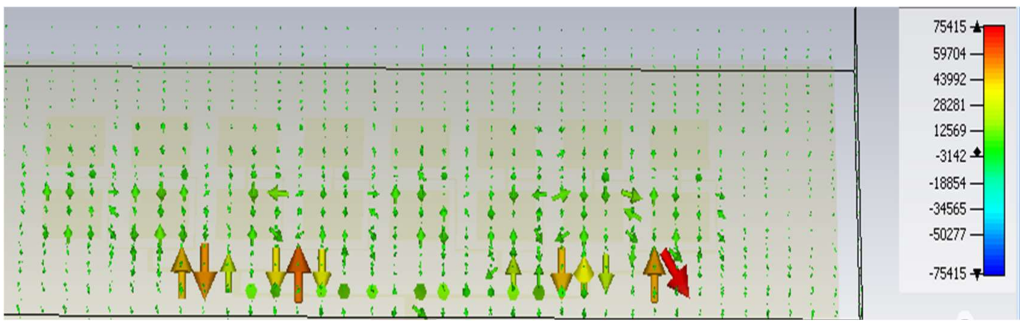


Figure 6-13: E-Field for our proposed antenna

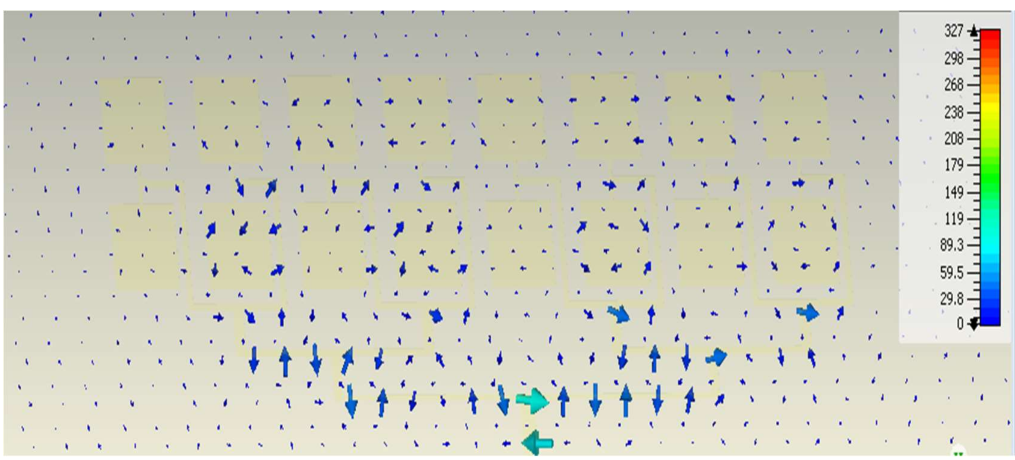


Figure 6-14: H-Field for our proposed antenna

Figure 6-4 and Figure 6-5 shows the E-field and H Field distribution of the whole antenna structure simulated by CST. It is seen that the radiation pattern is strongly excited by the proposed antenna design and the majority of the E-field has been confined.

7 Comparison

By our proposed design, we got our expected result. We have made several designs but the results were not good enough as our expected one. Here we give comparisons with some of our tested design to our main design.

7.1 Design-2 Comparison:

At first we applied different formula for our main design and calibrated the results. Here the patch size remains same as 3.5mm. There are no major changes in the design for this. For different formula we measured different impedances at different stages and this differs the width also. All the measured parameters are given below (table).

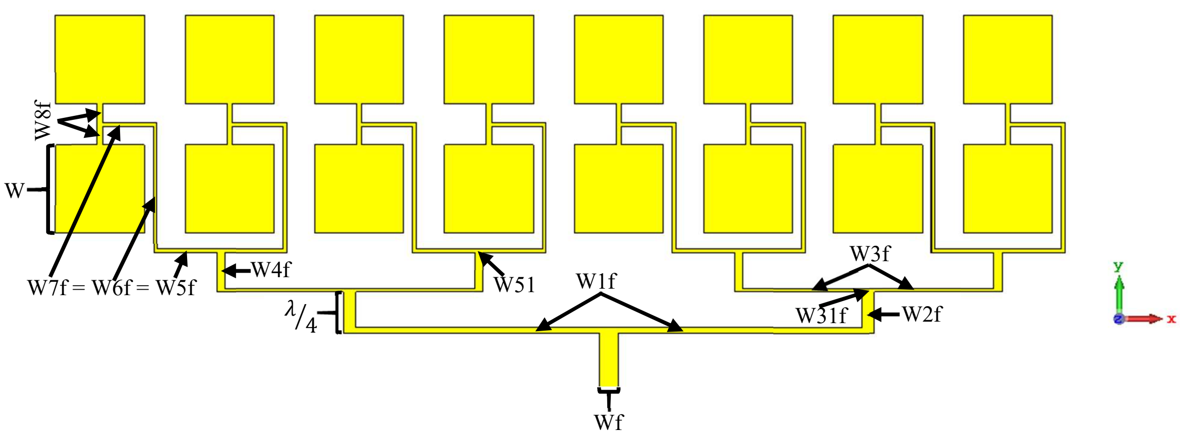


Figure 7-1: Comparative design 2

Table 2:parameter list of comparative design 2

Parameter	Measurement(mm)		Parameter	Measurement(mm)
W1f	0.225		W	3.5
W2f	0.492		L	3.5
W3f	0.145		W31f	0.59
W4f	0.317		W51f	0.59
W5f	0.145		Wg	1.611

W6f	0.145		W8f	0.18
W7f	0.145			

7.1.1 S-Parameter comparison:

The curve of our proposed design's S-parameter shows a very good power radiation. It reflects almost 96% power. We compared it with another work, whichradiates at frequency 59.76GHz also and its magnitude is approximately -14 dB. However, our result shows a better magnitude than this. We have the magnitude of -20 dB and it radiates at 59.76GHz.

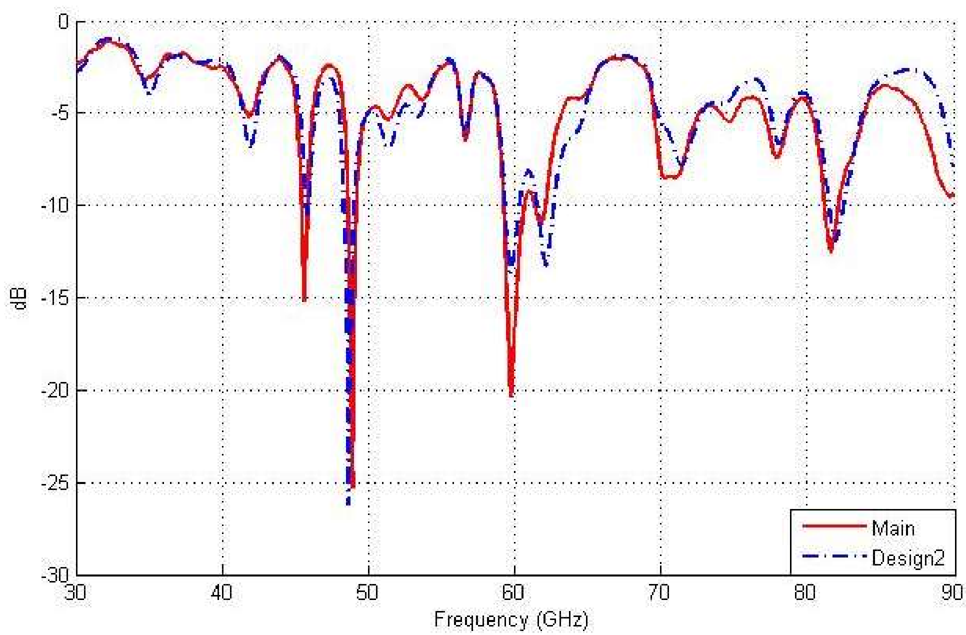
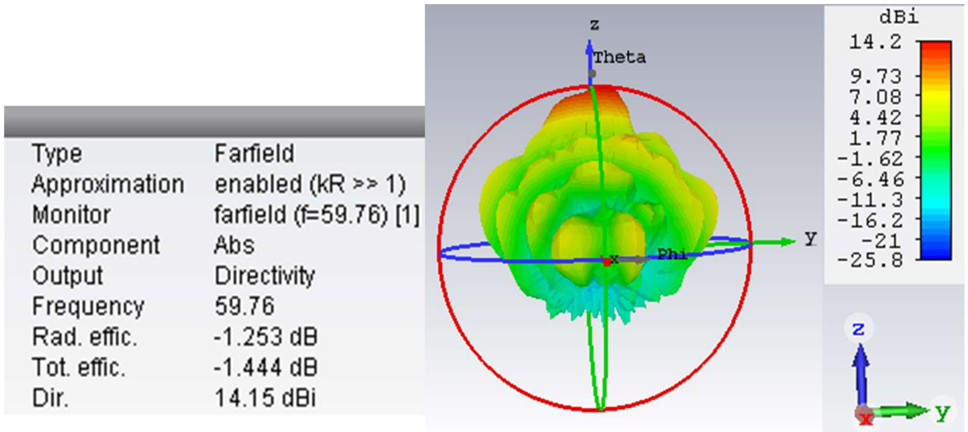


Figure 7-2: S-Parameter comparison between our proposed design with Comparative design 1

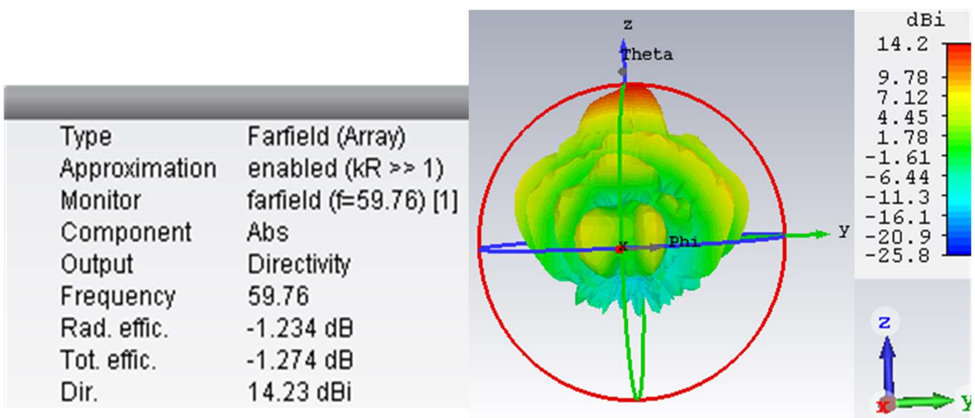
7.1.2 Radiation Pattern comparison:

The radiation pattern of our proposed design is far better than the work we are comparing with. From the figure below, we can see that the radiation pattern (3D& 2D) is closer to each other. Both are directive about at the same region and the main lobes are also looks similar. But the first one's main lobe magnitude is 14.2 dBi, where the second one's (main result) main lobe magnitude is 14.3 dBi. So, our main design gives slight better lobe.

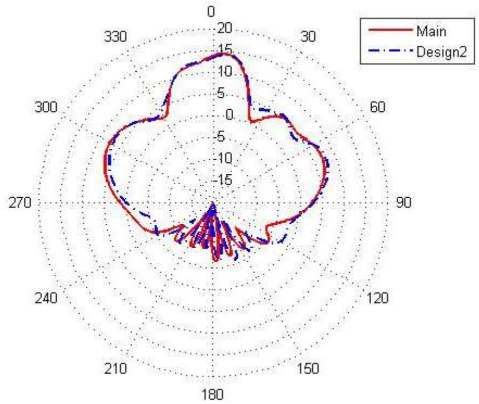
On the other hand, our proposed design's radiation pattern is much better than this design. Our final design's total efficiency & directivity also more than that one.



(a)



(b)



For main design

Frequency = 59.76
Main lobe magnitude = 14.2 dBi
Main lobe direction = 6.0 deg.
Angular width (3 dB) = 27.9 deg.
Side lobe level = -6.3 dB

For design 2

Frequency = 59.76
Main lobe magnitude = 14.3 dBi
Main lobe direction = 4.0 deg.
Angular width (3 dB) = 26.2 deg.
Side lobe level = -6.9 dB

Figure 7-3: Radiation pattern comparison between our proposed design with comparative design 2 where (a) and (b) are the 3D view of respectively design 3 and our proposed design

7.2 <u>Design-3 comparison:</u>

In this stage we mirrored our main design. The main change is the patches of left side are turned to the patches of right side. Besides this change we made some minor changes in impedance to bring change in transmission line. All the parameters remain same but measurement for these parameters changed. We calibrated this changed design to clarify for good outcome. The changed design (fig6-4) and measurements are also given here (table)

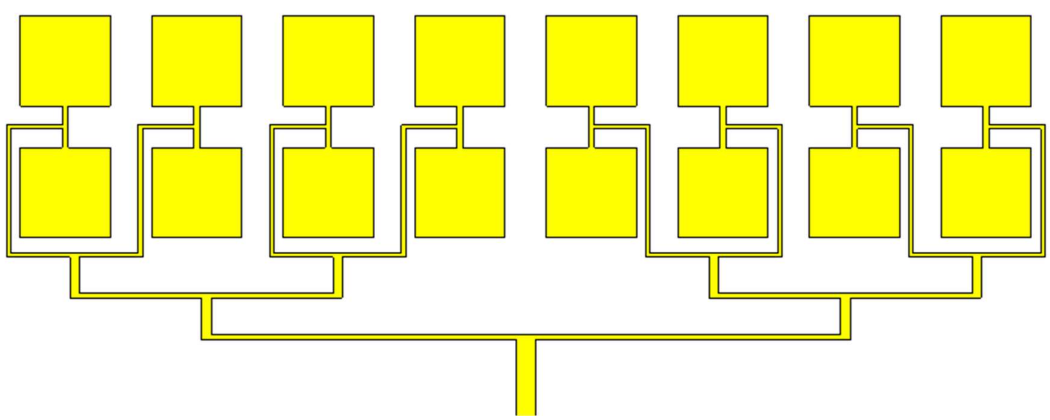


Figure 7-4: Comparative design 3

Table 3: parameter list of comparative design 3

Parameter	Measurement(mm)		Parameter	Measurement(mm)
W1f	0.225		W31f	0.62
W2f	0.39		W51f	0.62
W3f	0.1585		Wg	1.611
W4f	0.339		W7f	0.1585
W5f	0.1585		W8f	0.225
W6f	0.1585		W	3.5

7.2.1 S-Parameter comparison:

Here the curve of our proposed design's S-parameter isn't shows a very good. The S-parameter for this tested result is steeper than our main result and it has the magnitude of more than -20 dB at about 61.38 GHz. Where, our main result has the magnitude of -20 dB and it radiates at 59.76GHz.

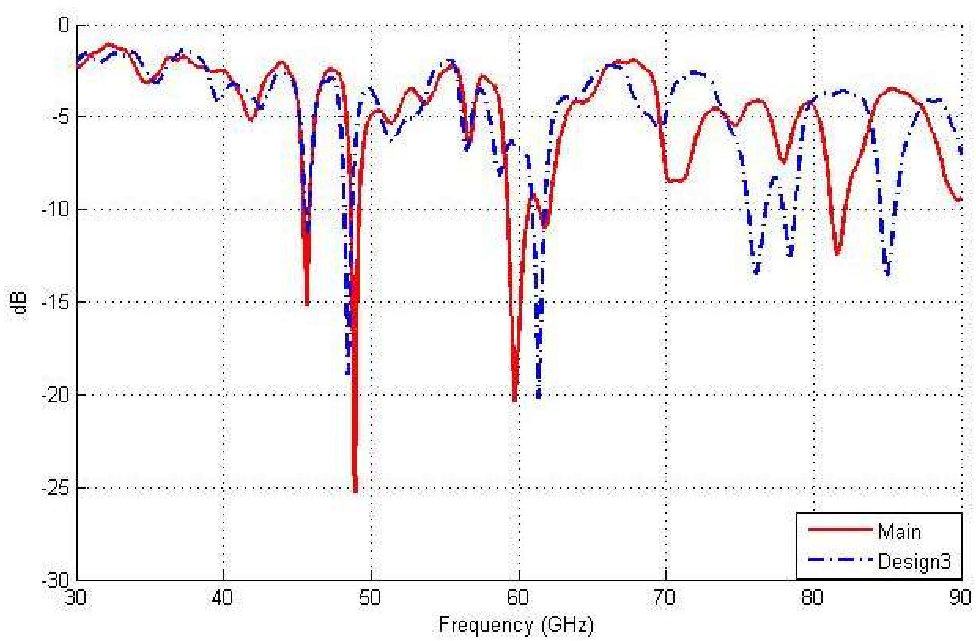


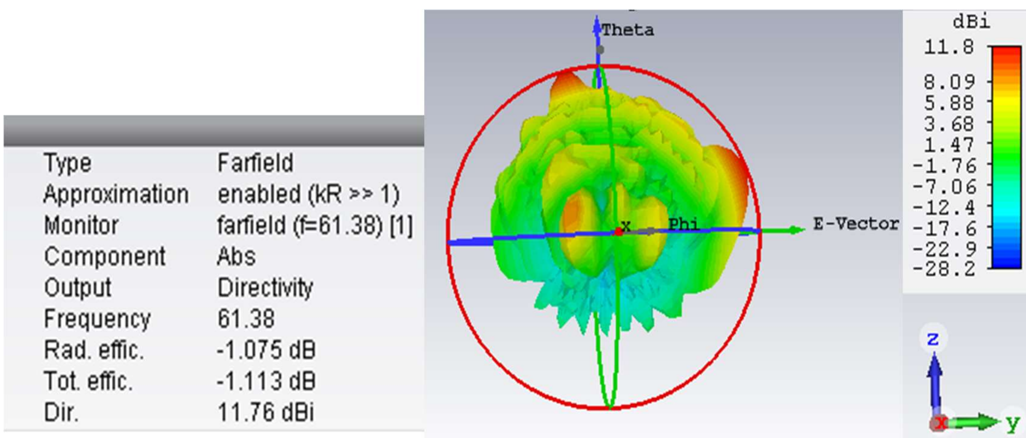
Figure 7-5: S-Parameter comparison between our proposed design with Comparative design 3

Now come to the reason why we didn't choose this design as our main, though we got better S-parameter for this. The reason is when we calibrated the Far-field for this result we got a worst result and the radiation pattern is not good enough to meet our desired result, which is shown in the part of Radiation pattern comparison.

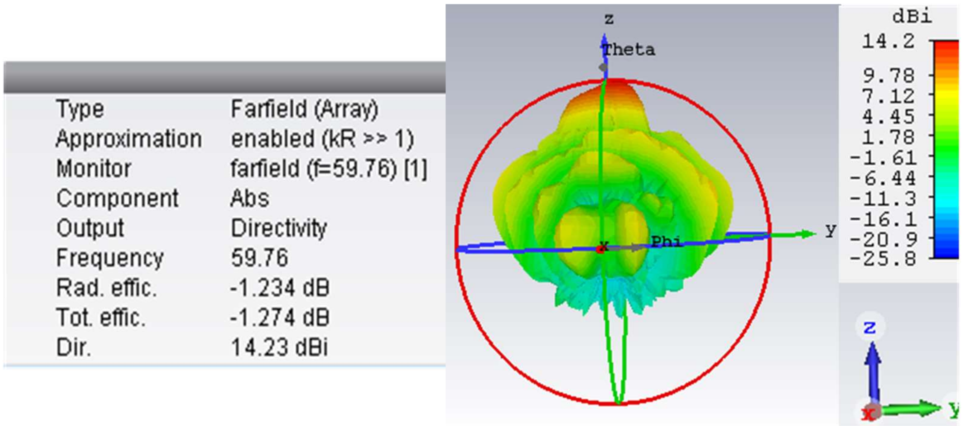
7.2.2 <u>Radiation Pattern comparison:</u>

The radiation pattern of our proposed design is far better than the work we are comparing with. From the figure below, we can see that the radiation pattern (3D & 2D) is how different to each other. From the far-field we can see that the tested one's far-field is not a directional. It radiates in more than one direction. Which don't even come to our desired result and in comparison it has no doubt that we calibrated a better result than this one.

On the other hand, comparing other parts such as total efficiency, directivity, main lobe's magnitude and considering the side lobes level we got a better result which match to our desired result.



(a)



(b)

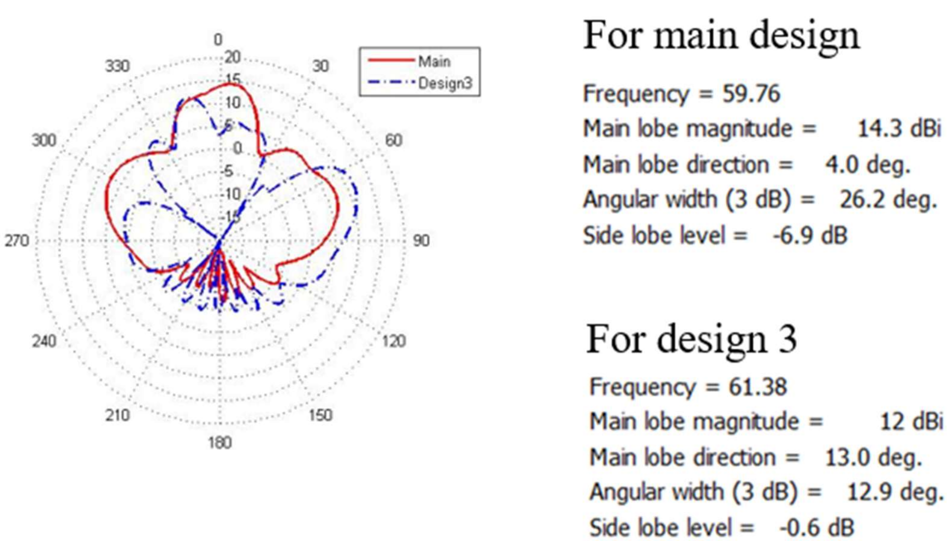


Figure 7-6: Radiation pattern comparison between our proposed design with comparative design 3 where (a) and (b) are the 3D view of respectively design 3 and our proposed design

7.3 <u>Design-04 comparison:</u>

This time we changed the main design and completely created a new structure. This design is based on 4x4 strip array where the number of patches remain same but configured a new one with 16 elements from our main design.

Here (Fig:6-7) we used quarter wave length (λ/4) transformer to feed every patches and to match impedances in change of transmission line from one impedance to another. λ/4 transformer used at the positions of Wq, Wa and Wb. All the patches are square and width of 3.5 mm. As we made it like symmetric so, all the parameters calculated for one side is matched with other side. All the width for different positions calculated with the impedances. As a result, the width changes at different points. The parameters we measured are given in table above (table). All the parameters are pointed out at the figure below (fig6-7).

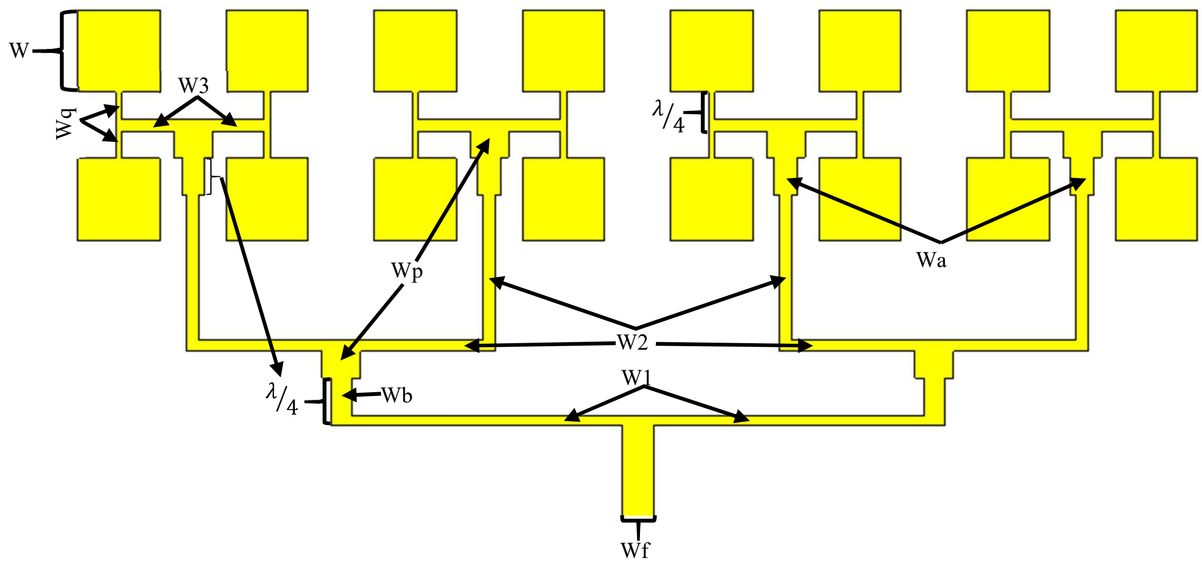


Figure 7-7: Comparative design 4

Table 4: parameter list of comparative design 4

Parameter	Measurement(mm)		Parameter	Measurement(mm)
Wa	0.5524		Wp	0.9338
Wb	0.496		Wq	0.162
W2f	0.2935		Wg	1.6065
W3f	0.2935		W1f	0.225
W	3.5			

7.3.1 S-Parameter comparison:

For this changed design we experienced a bad outcome. The S-parameter we got for this is much unorganized. We got two peaks below -10 dB from 50 GHz to 70 GHz.

Moreover, there we didn't find any good peak with better magnitude around our working frequency (60 GHz). In the figure below the clear image has given to show the difference between the graphs of our main design and this new design. So this ends up without any good findings.

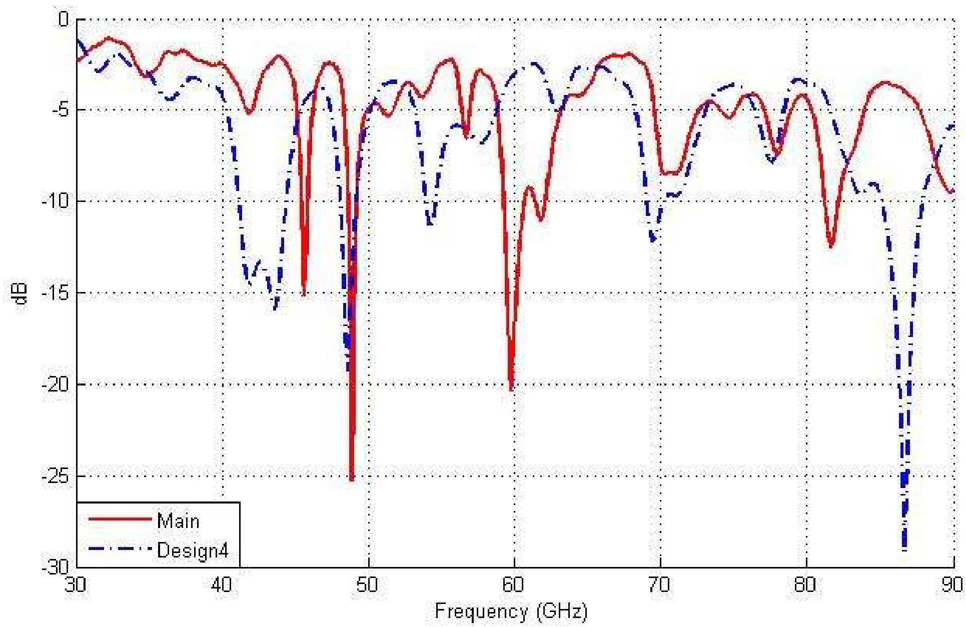
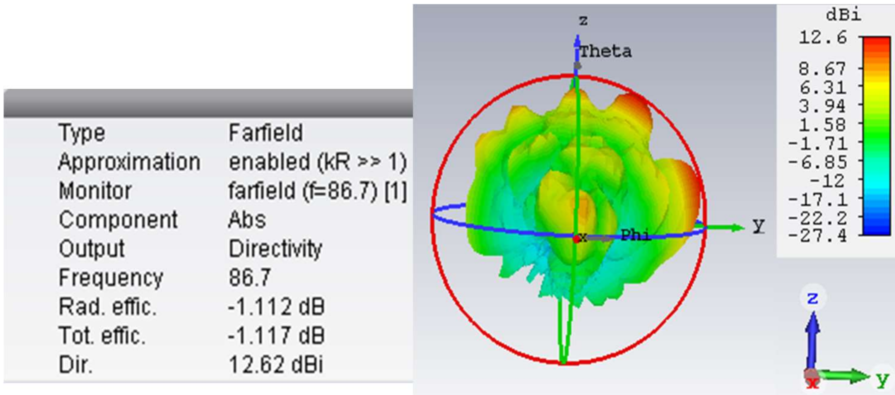


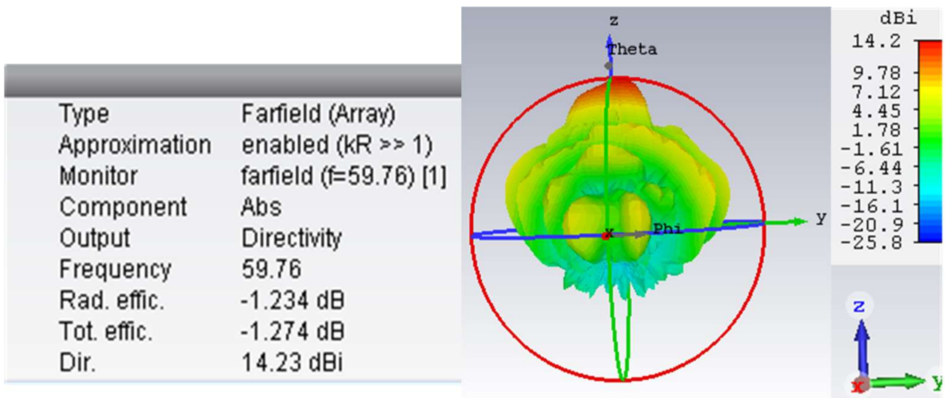
Figure 7-8: S-Parameter comparison between our proposed design with Comparative design 4

7.3.2 Radiation Pattern comparison:

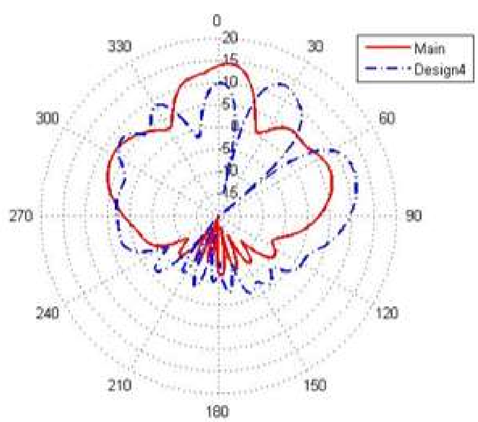
We calibrated far-field for this at 86.7 GHz to test if any better outcome might be seen. But not happened that. From the image of far-field given below in 3D and polar form we can see that the far-field is not even closer to our final result. Here we observed many lobes in different direction which don't match to our expectation. Moreover, from the consideration of other parameters as like Directivity, Total efficiency, Side lobe and Main lobe magnitude we didn't get anything better. These all are much less than our finalised one and this indicates us that we calibrated a better result for our proposed design.



(a)



(b)



For main design

Frequency = 59.76
Main lobe magnitude = 14.3 dBi
Main lobe direction = 4.0 deg.
Angular width (3 dB) = 26.2 deg.
Side lobe level = -6.9 dB

For design 4

Frequency = 86.7
Main lobe magnitude = 12.8 dBi
Main lobe direction = 27.0 deg.
Angular width (3 dB) = 19.1 deg.
Side lobe level = -0.6 dB

Figure 7-9: Radiation pattern comparison between our proposed design with comparative design 4 where (a) and (b) are the 3D view of respectively design 3 and our proposed design

7.4 <u>Design-5 comparison:</u>

This is another test work where we kept the patch size 2mm and considered the impedance 115 Ω at quarter wave feed for every single patch where this value was 110 Ω before. Also some small changes brought to this design as for the parallel junctions. Before the parallel junctions were positioned at the middle of corresponding upper transmission lines. Here we bring the parallel junctions just to the down part of corresponding transmission lines and this was connected with quarter wave transformer as like before for impedance matching purpose. We also used different formula to measure the parameters for this test design. The changed design (fig:6-13) and measurements (table) are given below:

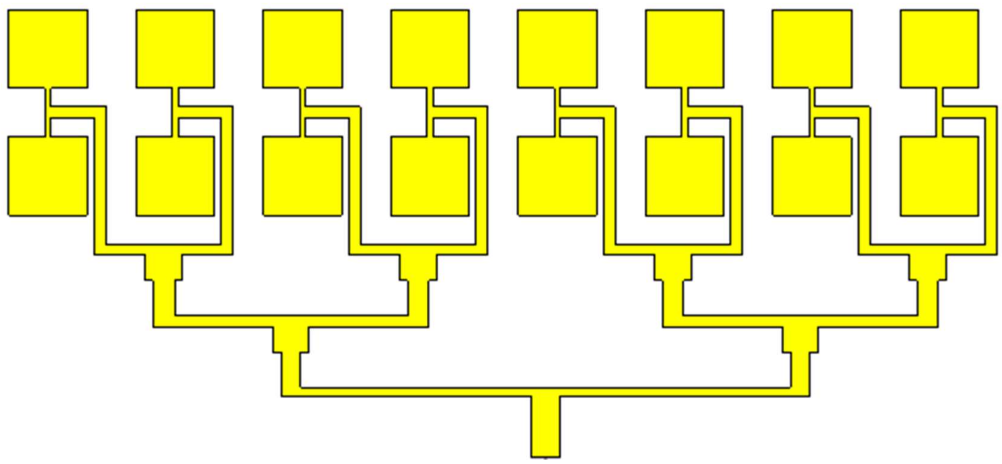


Figure 7-10:Comparative design 4

<u>Table 5: parameter list of comparative design 5</u>

Parameter	Measurement(mm)		Parameter	Measurement(mm)
W1f	0.225		W31f	0.9338
W2f	0.496		W51f	0.9338
W3f	0.2935		Wg	1.25
W4f	0.5524		W7f	0.2935
W5f	0.2935		W8f	0.162

W6f	0.2935		W	2

7.4.1 <u>S-Parameter comparison:</u>

For this tested design the S-parameter we got is not bad. We got two peaks: one at 55.74 GHz and another at around 60.7 GHz. The first one has magnitude about -23 dB
The second one about -20 dB. We calibrated for these two frequencies to check might we get any better result. But unfortunately we didn't get anything better. For 60.7 GHz we experienced a much unorganized result. That's why we didn't take it in consideration. Here we discussed about the result for 55.74 GHz. At this frequency, though S-parameter gives us a good hope but the other results depending on this S-parameter break that hope and we couldn't take it as a good one. Comparing with main result we also kept it as a demo test.

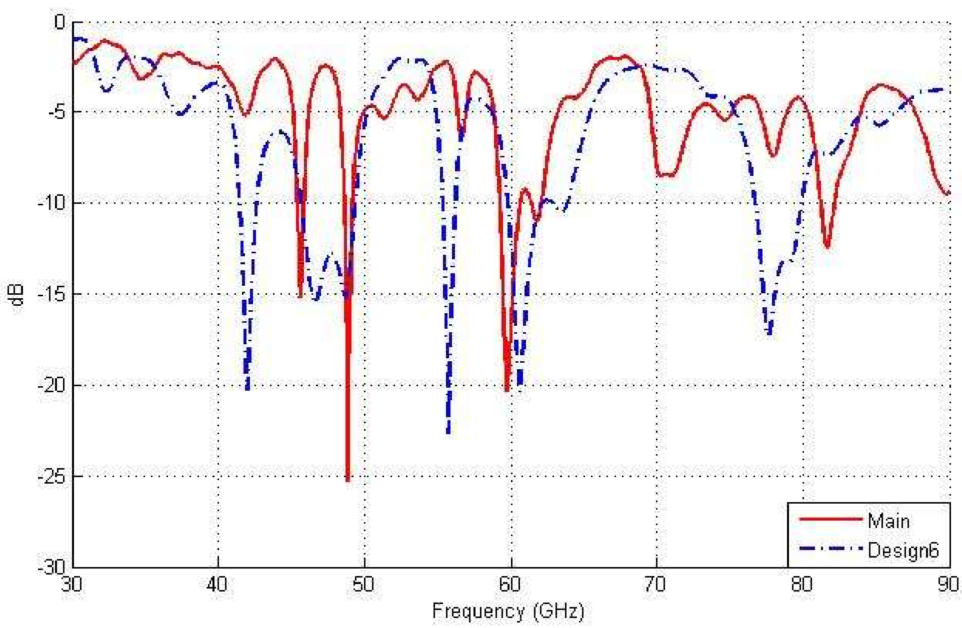
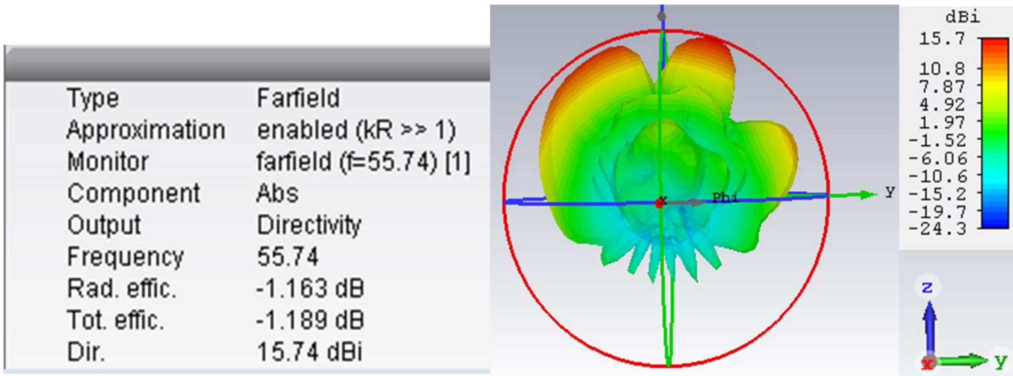


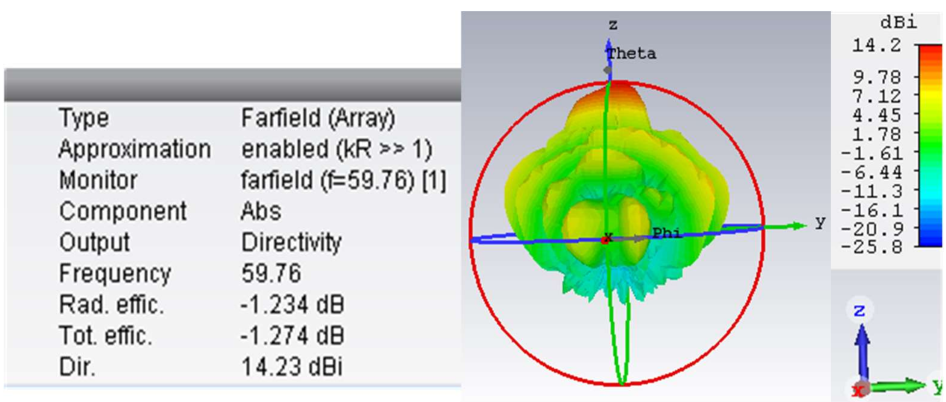
Figure 7-11: S-Parameter comparison between our proposed design with Comparative design 5

7.4.2 <u>Radiation Pattern comparison:</u>

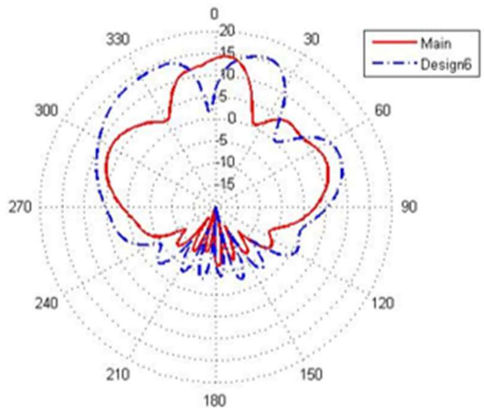
In this test design we got something difference. Compared to our main result we observed higher magnitude at main lobe and it is 15.8 dBi where our main result gives 14.3 dBi. Moreover, we observed very low level at side-lobes and higher magnitude in main lobe. Total efficiency also higher than our main result. When we observing these better sides for this result at the same time this result gives us some error which made this result imperfect. The error is at main lobe. This result gives more than one directive lobe which is fully unwanted. These unwanted high directive lobes made this result as well as the design inconsiderable. So, comparing with our proposed design we got a better directive result than this one.



(a)



(b)



For main design

Frequency = 59.76
Main lobe magnitude = 14.3 dBi
Main lobe direction = 4.0 deg.
Angular width (3 dB) = 26.2 deg.
Side lobe level = -6.9 dB

For design 6

Frequency = 55.74
Main lobe magnitude = 15.8 dBi
Main lobe direction = 19.0 deg.
Angular width (3 dB) = 21.7 deg.
Side lobe level = -1.4 dB

Figure 7-12: Radiation pattern comparison between our proposed design with comparative design 5 where (a) and (b) are the 3D view of respectively design 3 and our proposed design

8 Future Work and Conclusion

8.1 Future work

The future work on our project includes mostly making our antenna more power efficient, size efficient, cost efficient as well as increasing the performance of the antenna for users.

We have designed16-element microstrip patch antenna array. For using 16 elements and for using complex impedance matching we found out that we can prepare this antenna much more power efficient than its present condition. In future, we are willing to design the antenna with Co-Axial Feeding method instead of Corporate Feeding. Advantage of doing that will be able to design even array of 32 elements and still will drain less power making a very power efficient as well as much powerful.

To achieve our desired result and expected radiation graph we used 16 elements to make the antenna, which essentially made the size of the antenna a bit bigger than expected. However, if we can achieve the same results utilizing Co-axial Fed then the size of the antenna will be much less than its present design.

One of our prime aims with our project is to make it very much cost efficient to customers so that it can be used in various platforms.

There is never a limit of upgrading. Even though we achieved our currently desired result there will always be more stages for development. Our goal is to make our antenna as good as possible making it better in every way possible. In the result of far field, we got some unwanted side-lobs. Our very next step for future work is to get the far field without side-lobs and make the designed antenna directional.

8.2 Conclusion:

To sum up our project that we put a lot of effort in is making a directional millimetre wave microstrip patch antenna array consists of 16 elements. The purpose of the antenna is to radiate in a particular direction at 57GHz to 66 GHz keeping the return loss less than -10 dB. The 16 element patch array presented here are suitable for short-range. The simulation results including VSWR and radiation patterns validated the design method of series feed network for conformal antenna array.

At the end, with refer to all comparison we can conclude that our proposed design gives much better directive result at 59.76 GHz. Moreover, the BW is 4.2 GHz and the resulting frequency is very closer to our working frequency.

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