Novel Design for Shifted Radiation Pattern of Rectangular Microstrip Patch Antenna Loaded with Metamaterial

Inspiring Excellence

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Submitted by

Swad Al Nahiyan(13221027)

Ahmed Raisus Salehin(13321015)

MD. Golam Mehdy Hassan Shuvho(13310006)

Sheikh Minhaj Liaqat (13321075)

Supervised by

Dr. Md. Hasanuzzaman Sagor

Assistant Professor

Department of Electrical and Electronic Engineering,

BRAC UNIVERSITY

ACCEPTANCE

The undersigned certify that he has read and recommend for acceptance, a thesis entitled "Novel Design for Shifted Radiation Pattern of Rectangular Microstrip Patch Antenna Loaded with Metamaterial" in partial fulfilment of the requirements of the degree of Bachelor of Science Electrical and Electronic Engineering.

Supervisor:

Dr. Md. Hasanuzzaman Sagor

Assistant Professor

Department of Electrical and Electronic Engineering,

BRAC UNIVERSITY

Email: hasan.sagor@bracu.ac.bd

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.

Swad Al Nahiyan

Ahmed Raisus Salehin

MD. Golam Mehdy Hassan Shuvho

Shekh Minhaj Liaqat

Dr. Md. Hasanuzzaman Sagor

Assistant Professor

Department of Electrical and Electronic Engineering,

BRAC UNIVERSITY

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ABSTRACT

Microstrip patch antenna is one of the popular types of antenna in the field of antenna manufacturing and designing. It is a narrow band wide beam antenna, which can be mounted on flat surfaces. This type of antenna has achieved huge fame in the field of antenna designing and manufacturing as it is easily printable onto a circuit board. Metamaterials are falsely organized media with unusual electromagnetic properties ranging from radio frequency and microwaves as far as possible up to optical frequencies.The study of metamaterial started very recently when Vesleago in the 1960s theoretically postulated a material with negative permiability and negative permittivity. Veselago's work came under the lime light when Pendry at Imperial College, London suggested a construction of a composite medium in the microwave region, by arranging arrays of small metallic wires and split ring resonators.This medium was able to provide negative permiability and was named metamaterial. Different aspects of this metamaterial are now elements of study and research all over the world.Among the various uses and application we are particularly concerned about the fact that metamaterials can be used to design thin sub wavelength cavity resonators.Based on this phenomenon rectangular microstrip patch antenna has already been designed. The thesis aims at designing a model of single element microstrip patch antenna loaded with metamatarial.The main target is to change the radiation pattern of microstrip patch antenna array from broadside radiation pattern to end fire radiation pattern based on the unique and influencing electromagnetic wave characteristics of metamaterial.

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ANTENNA OVERVIEW AND BASICS

1.1 Antenna Overview

An Antenna is usually a metallic device that can radiate or receive radio frequency portion of the electromagnetic spectrum. It is the most visible part in a communication system. The IEEE standard Definition of Terms for Antennas (IEEE Std 145-1983) defines antenna as "a means for radiating or receiving radio waves." Antenna can be more elaborately defined as the structure associated with the region of transition between a guided wave and free space wave or vice versa as shown in Figure 1. In the process of transmitting and receiving wave antenna converts electron to photon.

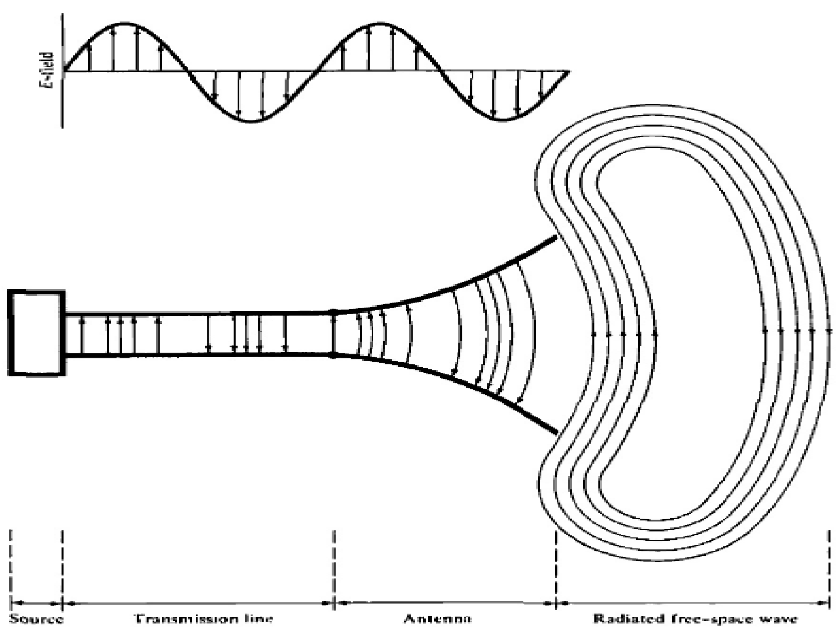


Figure 1: Antenna as a transition device

Antenna is a product of research and development in the field of electromagnetism .In 1831 British scientist Michel Faraday demonstrated that electric current can be produced by a moving magnet in the vicinity of a coil of wire. Depending on this phenomenon and a prior experiment led by Hans Christan Oersted at the University of Copenhagen where it was found that electric current in a wire could deflect a magnetic needle, Faraday implied that charges and currents interacted directly and locally with the electromagnetic field had an identity of its own, though produced by charges and currents. Finally Scottish physicist James Clerk Maxwell established the mathematical theory of electromagnetism based on the concepts of Faraday. He restated laws of Culomb,Ampare and Faraday in terms of Faradays electric and magnetic fields. Maxwell theoretically proved and developed many equations of electromagnetic waves. One of the most important deductions made by him was that the speed of propagation of wave was equal to speed of light. Maxwells's equation was not accepted by scientists immediately because of its difficult mathematical concepts and bewildering collection of mechanical analogies. Later German physicist Henrich Hertz simplified them .He based on Maxwell's equation made some experiment and was able to generate high frequency electric Oscillations. He also found that oscillations could be detected at large distances from the apparatus. Within a very short period of this discovery a young Italian engineer Guglielmo Marconi constructed the first transmitter for wireless telegraphy. Initially dipole was used for communications as for long distance the wavelengths were greater than 200 meters. Marconi established the American Marconi Wireless Telegraphy Company in 1899. Still the importance and function of transmitter and antenna was not clear to the world. On April 15, 1912 a telegrapher of American Marconi Wireless Telegraphy Company in New York City received a faint SOS signal from the steamship Titanic. He relayed the news of the sinking of Titanic to the world. This event dramatically increased the importance of antenna and new means of communication. After this event and the invention of radar during World War II research and development in radio communication and antenna configuration was conducted. Thus antenna started to become a vital element of communication.

1.2 Types of Antenna

1.2.1 Wire Antenna

Automobiles, houses, ships, airplanes, spaceships-almost everywhere wire antennas are seen. Different forms of wire antennas are there like straight wire (dipole), loop, and helix. It is not necessary for the loop antennas to be circular. Rectangular, square, ellipse, or any other shape is also applicable for loop antennas.

Dipole antenna is the simplest type of radio antenna. It consists of a conductive wire rod that is half the length of the maximum wavelength the antenna is to generate. The wire rod is divided in the central and the two segments are separated by an insulator. Both rod is joined to a coaxial cable at the end closest to the mid of the antenna. In the middle, between the two conductors of the dipole antenna radio frequency voltages are applied.

The most common type of the dipole antenna is the half wave dipole antenna. It consists of two similar conductive materials like metal rods which are balanced. The length of half wave dipole is half of the wavelength, which is the shortest resonant length that can be used for a resonant dipole. It possesses an appropriate radiation pattern too.

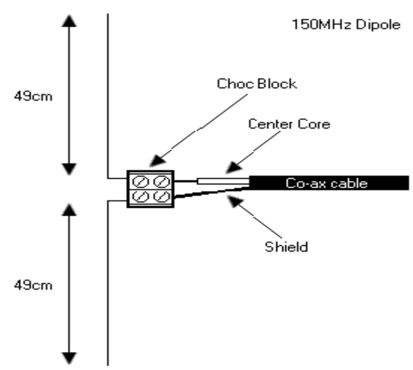


Figure 2 : Dipole Antenna

Monopole antenna is made of a straight rod-shaped conductor, and it may or may not be mounted vertically to a conductive surface or ground plane. Inverted-F antennas, for instance, contains a monopole antenna parallel to the ground plane and grounded at the mounted side. Monopole antenna is considered half of a dipole antenna. A ground system is mandatory for monopole antennas of quarter wavelength.

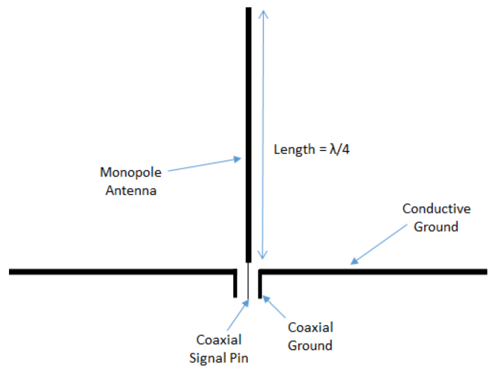


Figure 3: Monopole antenna

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 don't need antenna 'tuner' to work proficiently.

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.

1.2.2 Travelling Wave Antennas

Travelling-wave antenna mainly uses a travelling wave on a guiding structure as the main radiating mechanism. The radio-frequency current which produces the radio waves travelling through the antenna in one direction, is the unique feature of travelling wave antenna. This is different from a resonant antenna, like the monopole or dipole, where the antenna behaves as a resonator, with radio currents travelling in both directions, bouncing back and forth between the ends of the antenna. An advantage of travelling wave antennas is that since they are non-resonant they often have a wider bandwidth than resonant antennas. Helical antenna, yagi uda antenna and spiral antennas are some common kinds of travelling wave antenna.

Helical antenna or helix antenna is the simplest antenna. In this antenna, the conducting wire is wound in helical shape and linked to the ground plate using a feeder line. It contains a helix of thick copper wire or tubing wound in the shape of a screw thread used like an antenna in combination with a smooth metal plate known as a ground plate. The construction of the antenna is such that one side of the helix is connected to the centre conductor of the cable and the outer conductor is connected to the ground plate. The diameter of helix, the turn spacing and the pitch angle are the main factors on which the radiation of the antenna depends. Helical antenna provides circularly polarized waves. This type of antenna is often used in extra-terrestrial communications where satellite relays etc., are involved.

The Yagi-Uda antenna is one of the most effective RF antenna designed for directive antenna applications. For an RF antenna design that needs gain and directivity the Yagi-Uda antenna is used in a extensive diversity of applications. Mostly, for television reception, the Yagi has become very popular. But it is also used in very numerous domestic and industrial applications where an RF antenna is needed that has gain and directivity. Yagi antenna allows better levels of signal to noise ratio to be achieved which makes the gain of the Yagi antenna important. Again, the interference levels can be reduced using directivity by concentrating the transmitted power on desirable areas, or getting signals best from where it originate.

Spiral antenna is one kind of RF antenna. Usually they are extremely small antennas due to its windings. It can operate over an extensive range of frequencies. Polarization, radiation pattern and impedance of such antennas stay unaffected over a large bandwidth. Spiral antennas are fundamentally circularly polarized with low gain. For increasing the gain array of spiral antennas can be used. Often unidirectional pattern is chosen in such antennas, so to reduce back parts lossy cavities are typically located at the end.

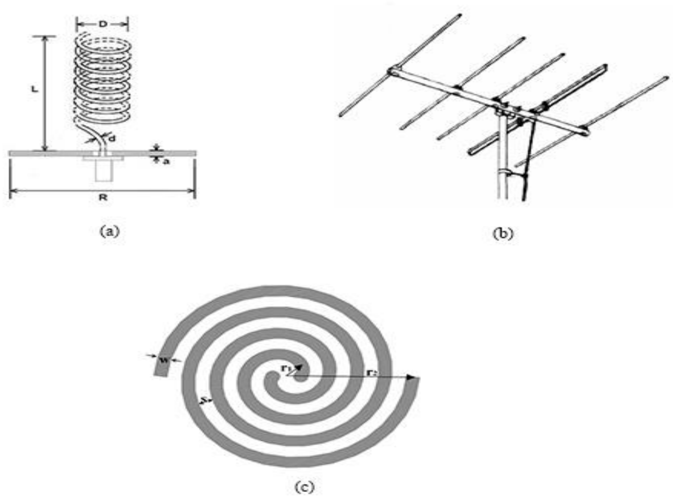


Figure 4 : Travelling Wave Antennas (a) Helical Antenna ;(b) Yagi Uda; (c)Spiral

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 to receive lower strength signals.
- The directivity of Yagi antenna allows interference levels to be reduced.

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)

1.2.3 Reflector Antennas (Corner Reflector; Parabolic Reflector)

The most broadly used high-gain antennas are reflector antennas which are necessary for long-distance radio communications. Gains of beyond 30 db can be easily accomplished for microwave and higher frequencies. Reflector antennas work on principles known long ago from geometrical optics (GO). A reflecting surface and a much smaller feed antenna at the reflector's focal point are the two components of a simple reflector antenna. Structures that are more complex involve a secondary reflector (a subreflector) at the focal point, which is illuminated by a primary feed. They are often called dual-reflector antennas. Parabolic reflector is the most common reflector. Other common reflectors are: corner, cylindrical and spherical. The parabolic reflector antenna or dish antenna has been used far more widely in recent years with advent of satellite television. However the dish antenna finds uses in many radio and wireless applications at frequencies usually above about 1GHz where very high levels of RF antenna gain are required along with narrow beamwidths. Although more difficult to manufacture than some simpler antennas, its performance means that the parabolic reflector antenna or dish antenna is widely used in a number of applications. Corner reflector antenna is a kind of directional antenna used at VHF and UHF frequencies. It contains a dipole driven element attached in front of two smooth rectangular reflecting screens linked typically at an angle of 90°. Along with having a wide bandwidth, corner reflectors have moderate gain of 10-15 dB and high front-to-back ratio of 20-30 dB. They are generally 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. It is mainly suitable in applications where a broadband directional antenna around one to 1.5 wavelengths in size is needed.

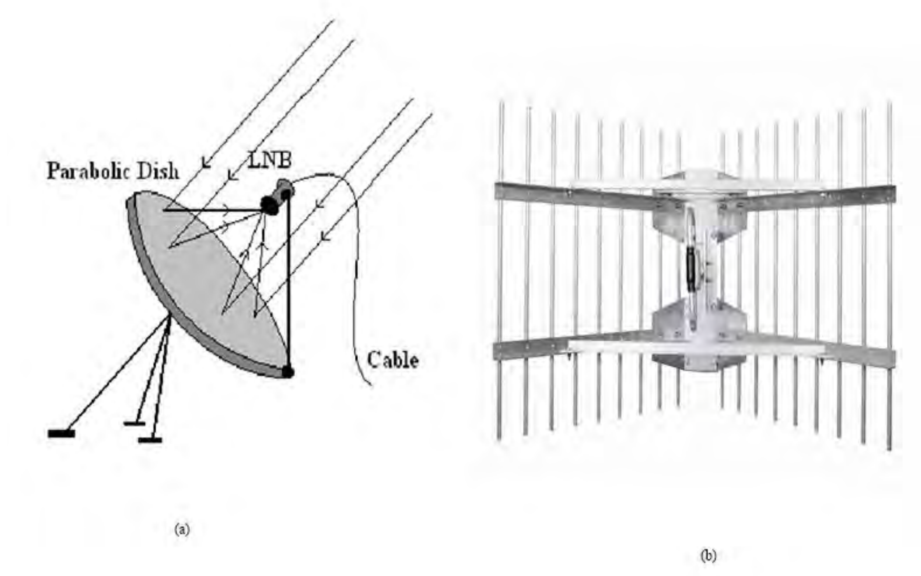


Figure 5 : Reflector Antenna. (a)Parabolic reflector; (b) Corner Reflector

Some of the major advantages of the reflector antenna are-

- Most of the construction of the antenna is non-resonant, so it can function over a extensive range of frequencies.
- Wide bandwidth.
- High gain.
- High directivity.

There are some drawbacks of reflector antennas, which are:

- Requires reflector and drive element.
- As an additional feeding system is needed, it is costly.
- Size is not as small as other antennas, although many used for satellite television reception are quite compact.

1.2.4 Microstrip Antennas (Rectangular; Circular; Planner)

Micro-strip antennas are also known as printed antennas. Basically, a micro-strip patch antenna consists of a radiating patch on one side of a dielectric substrate that has a ground plane on the other side. A thick dielectric substrate that has a low dielectric constant offers better efficiency, wider bandwidth and better radiation. Micro-strip antenna is a narrowband wide-beam antenna that is mainly used at microwave frequencies. These type of antennas are easy to fabricate and comfortable on curved surface. Also, the directivity is fairly insensitive to the substrate thickness. Micro-strip antenna patches can be of different shapes like rectangular, circular, planar etc.

The most commonly employed micro-strip antenna is a rectangular patch that looks like a reduced micro-strip transmission line. The length of the rectangular micro-strip antenna is about one-half of a free-space wavelength when air is used as the dielectric substrate. When antenna is loaded with a dielectric as its substrate, the length of the antenna decreases as the relative dielectric constant of the substrate increases. The electrical length of the antenna marginally increases as the resonant length of the antenna is slightly smaller because of the extended electric "fringing fields".

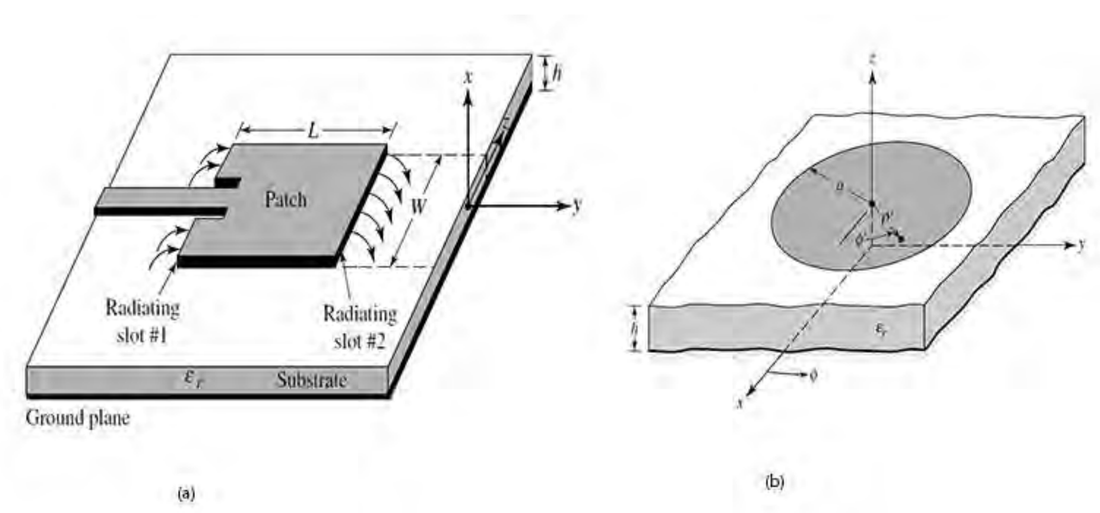


Figure 6 : Microstrip Patch Antenna. (a)Rectangular;(b)Circular

Other than the rectangular patch the next most popular configuration is the circular patch or disk. It has received a lot of attention not only as a single element but also in arrays. Handling the patch, ground plane and the material between the two as a circular cavity we can find the modes supported by the circular patch antenna. For the circular patch there is only one degree of freedom to control (radius of the patch). Although this changes the absolute value of the resonant frequency, this does not change the order of the modes.

A planar array is an antenna in which, both active and parasitic elements, are in one plane. By changing the relative phase of each element a planar array can be used for directional beam control. It also provides a large aperture. When related to a radar absorber, a planar array can be used with a reflecting screen behind the active plane so that they don't reflect incoming radiation of the chosen wavelength. The transition from air (vacuum) to the metal of the screen needs to be a gradual one for the antennas to be broadband.

Advantages of micro-strip antennas are-

- Low fabrication cost, thus can be manufactured in large quantities.
- Can be integrated easily with microwave integrated circuit.
- Dual and triple frequency operations are possible.
- Support both, linear and circular polarization.
- Low cost, less size, low mass.
- High performance.

Disadvantages of micro-strip antennas-

- Narrow bandwidth associated with tolerance problem.
- Low efficiency.
- Low gain.
- Extra radiation from feeds and junction.
- Surface waves.
- Low power handling capacity.

1.2.5 Aperture Antennas (Slot Antenna; Horn Antenna; Telescope)

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. Transmission efficiency, Axial ratio, Far-field radiation patterns, Input impedance bandwidth. Structures can further be optimized according to specified performance criteria, using the extensive optimization tools in FEKO.

Slot Antenna is an example of Aperture antenna. A rectangular slot is made on the conducting sheet. These slot antennas can be formed by simply making a cut on the surface, where they are mounted on. The frequency range used for the application of Slot antenna is 300 MHz to 30 GHz. It works in UHF and SHF frequency ranges. The slot antenna is popular because they can be cut out of whatever surface they are to be mounted on, and have radiation patterns that are roughly omnidirectional (similar to a linear wire antenna, as we'll see). The polarization of the slot antenna is linear. The slot size, shape and what is behind it (the cavity) offer design variables that can be used to tune performance.

Rectangular horn antenna is one of the simplest and commonly used antennas. The main characteristic of the rectangular horn antenna is its gain, which can range up to 25 dB in some cases, with 10-20 dB being typical. Horn antenna can be considered as a particularly designed waveguide extension. The most vital parameters for operation of this antenna are: length of antenna, width of aperture. They are very popular at UHF (300 MHz-3 GHz) and higher frequencies (upto 140 GHz). Also, these antennas have a wide impedance bandwidth, suggesting that the input impedance is slowly changing over a wide frequency range. The bandwidth for typical horn antennas can be on the order of 20:1 (for instance, operating from 1 GHz-20 GHz), while 10:1 bandwidth is also common. The gain of horn antennas often increases (and the beam-width decreases) as the frequency of operation is increased. This is because the size of the horn aperture is always measured in wavelengths; at higher frequencies the horn antenna is "electrically larger"; this is because a higher frequency has a smaller wavelength.

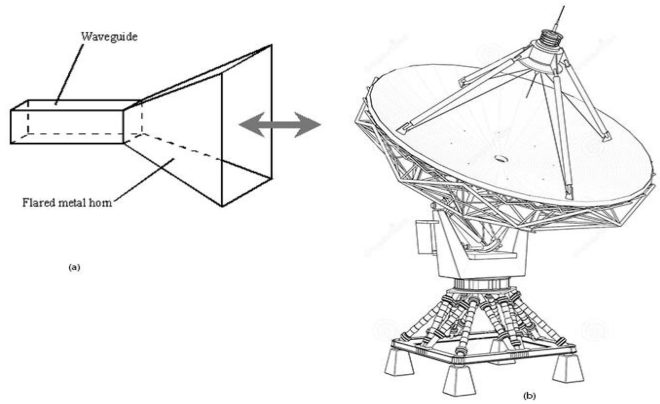


Figure 7 : Aperture Antenna. (a)Horn antenna ;(b) Telescope

Telescopes, which aren't really antennas, are connected to a receiver or transmitter and collect or transmit radiated electromagnetic waves. However, telescopes don't process electromagnetic waves after receiving them. A radio telescope is a particular antenna and radio receiver used to collect radio waves from astronomical radio sources. Just like the antennas working in tracking and communicating with satellites and space probes, radio telescopes are also large parabolic ("dish") antennas. They may be used as single element, or linked together electronically in an array. Radio telescopes can be used both in the daytime and at night. The radio waves coming from the astronomical radio sources are extremely weak because of the huge distance, thus radio telescopes need very big antennas to accumulate enough radio energy to learn them, and very delicate receiving tools. Radio stations are specially located far from places with huge population to avoid electromagnetic interference (EMI) from radio, television, radar, motor vehicles, and other manmade electronic devices.

The following are the advantages of Aperture antenna –

- Provide greater radiation than two-wire transmission line
- Radiation is Omni-directional
- It can be easily fabricated and masked within metallic substances (slot antenna)

- It can provide concealed communications with a small transmitter (slot antenna)
- Forms small minor lobes (horn antenna)
- Good impedance matching (horn antenna)
- Little loss and greater directivity (horn antenna)
- Beam width is narrower (horn antenna)
- Can avoid standing waves (horn antenna)

The following are the disadvantages of Aperture antenna −

- VSWR increases
- Poor radiation
- Higher cross-polarization levels (slot antenna)
- Poor radiation proficiency (slot antenna)
- Designing of flare angle affects the directivity (horn antenna)
- Flare angle and length of the flare should not be very small (horn antenna)

1.3 Antenna Parameters

1.3.1 Radiation Pattern

In Antenna engineering field, the term Radiation pattern indicates the variation of field intensity of an antenna which is a function of direction from the antenna. For an Antenna, one of the very basic parameter required is the radiation pattern which determines the spatial distribution of radiated energy.

An antenna radiation pattern is represented graphically which includes the radiation properties and it is a function of space coordinates. Far field region is chosen to determine radiation pattern as the variation of power with angle does not change significantly in this region. By using a spherical coordinate system, where the antenna is kept in the origin, the radiation properties of the antenna depend only on the angles Φ and θ along a path or a surface of constant radius.

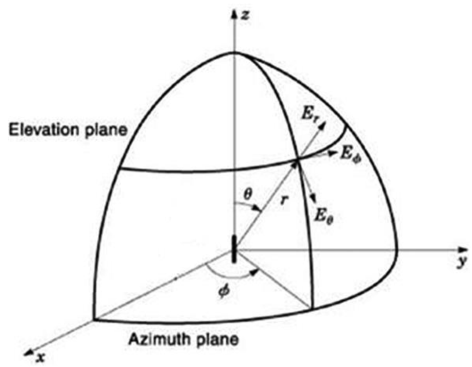


Figure 8 : Spherical coordinate system for antenna analysis purposes. A very short dipole is shown with its no-zero field component directions.

There are two common types of radiation pattern- power pattern and field pattern. Power pattern is the trace of the radiated or received power at a constant radius and it is the measure of normalized power vs. spherical coordinate position. Field pattern is the measure of variation for normalized |E| or |H| vs. spherical coordinate position along a constant radius. Depending on the complexity of radiation pattern of a specific antenna, we can retrieve necessary information by using few two dimensional radiation patterns instead of three dimensional radiation patterns. In most of the applications, a number of plots of the radiation pattern as a function of θ for some specific values off Φ and a few plots as a function of Φ for some specific values of θ give us the required information.

Different parts of radiation pattern are referred as lobes. A radiation lobe is a portion of the radiation pattern bounded by the regions of the relatively weak radiation intensity. Radiation lobes can be sub classified into major, minor, side and back lobes. A major lobe is the radiation lobe containing the direction of maximum radiation. Any lobe except a major lobe is called minor lobe. A side lobe is any lobe in any direction other than the intended lobe. And a back lobe is a radiation lobe approximately 180° with respect to the beam of an antenna.

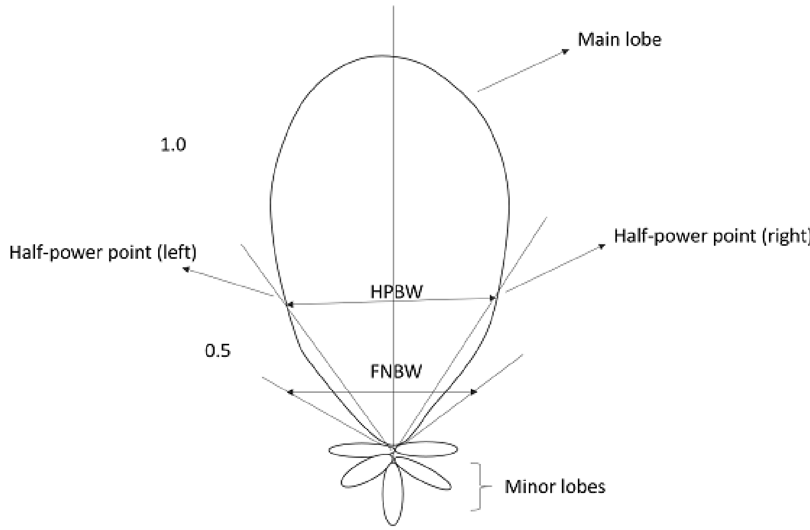


Figure 9 : Radiation lobes and beamwidths of an antenna pattern

Half power beam width and first null beam width are also two terms related to radiation pattern. The half power beam width is the angular separation between the half power points on the antenna radiation pattern; here the gain is one half the maximum values. The first null beamwidth is the angular separation between null power points of the antenna.

1.3.2 Antenna Gain

Antenna gain is the measure of transmitted power in the direction of pick radiation from an isotropic source. The transmitting antenna tells us how much we are capable of converting the input power into radio waves towards a specific direction whereas the receiving antenna gives us the information about electrical power converted from radio waves by the receiver antenna.

Antenna gain is also defined as product of directivity and efficiency.

$$G=\eta_{rad} . D$$

here G=Gain of the Antenna

η_{rad} =Radiation efficiency , D=Directivity

Gain is always less than or equal to directivity. The term gain is more frequently used than directivity for any antennas technical specification. Gain is measured in decibels (a logarithmic scale) where G is the gain factor.

$$G_{dBi} = 10. \log_{10}(G)$$

It is different from antenna transmission power which is measured in watts and related to the input power of the antenna. Antenna gain produces amplification that focuses on the actual strength of a transmitted or received signal.

The gain of an antenna is proportional to its electrical size. At higher operating frequencies we can obtain more gain for a specific antenna size and this is very important for establishing microwave communication link.

In some cases gain is measured as a function of angle. For this case we plot the radiation pattern where the units are calculated antenna gain. For a real antenna gain can reach up to 50 dB although it is very rare. Theoretically gain cannot be below 0 dB but it is possible to have a very low gain as different losses are present and due to low efficiency.

1.3.3 Directivity

The term Directivity is defined as the ability of an antenna to radiate energy in a predetermined direction. Directivity is the maximum directive gain of an antenna and it is the ratio of the maximum radiation intensity to the average radiation intensity.

$$D = \frac{Umax}{Uav} = \frac{4\pi\ Umax}{Pr}$$

Here, $Umax$ = maximum radiation intensity

Uav = average radiation intensity

Pr = total power radiated

in terms of electric field,

$$D = \frac{4\pi\ |Emax|^2}{\int_0^{2\pi}\int_0^{\pi} |E(\theta,\varphi)|^2\ sin\theta\, d\theta\ d\varphi} \quad \text{(dimensionless)}$$

Directivity can also be expressed in terms of beam area.

$$D = \frac{4\pi}{\Omega A};$$ Ω_A Beam area

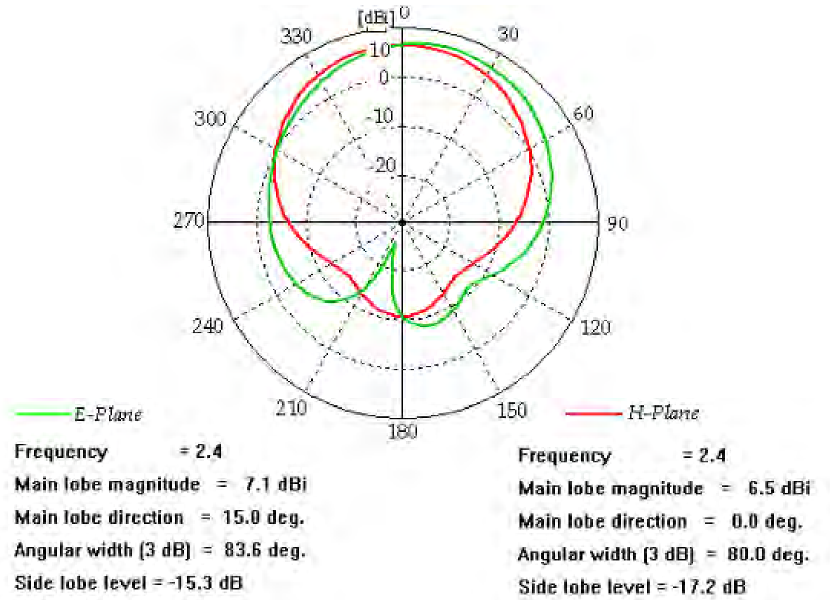


Figure 10: Directivity of a single patch antenna

For small beam area, directivity will be larger. When an antenna radiates equally in all direction its directionality becomes 0 and its directivity would be 1.An increase in directivity refers to the fact that the antenna is more directional or more focused. Directivity for a cell phone is kept in low range as it needs to receive signals from multiple directions. For other communication purpose like satellite telephones, satellite TV, satellite internet directivity is quite high.

This is a list of different antennas and their directivity:

Table 1: Different Antennas with Directivity

Antenna Type	Typical Directivity	Typical Directivity(dB)
Short Dip[ole Antenna	1.5	1.76
Half-Wave Dipole Antenna	1.64	2.15
Patch(Microstrip)Antenna	3.2-6.3	5-8
Horn Antenna	10-100	10-20
Dish Antenna	10-10,000	10-40

1.3.4 S parameter

S parameter describes the input-output relationship of an N-port network to signals incident to any of the ports in an electrical system. S Parameters are complex numbers that show reflection/transmission characteristics in frequency domain. The magnitude and the phase of the incident signal get changed by the network. The convention followed to describe S parameter is- power transferred from port M to N is represented by S_{NM}. For example, if we have two ports, there will be 4 S parameters (S_{11}, S_{12}, S_{21}, S_{22}). S_{12} represents the power transferred from 2 to 1 and S_{21} represents the power transferred from 1 to 2. S_{11} & S_{22} are reflection coefficient. S_{11} represents the power radio 1 is delivering to antenna 1. S_{22} represents the power radio 2 is delivering to antenna 2.

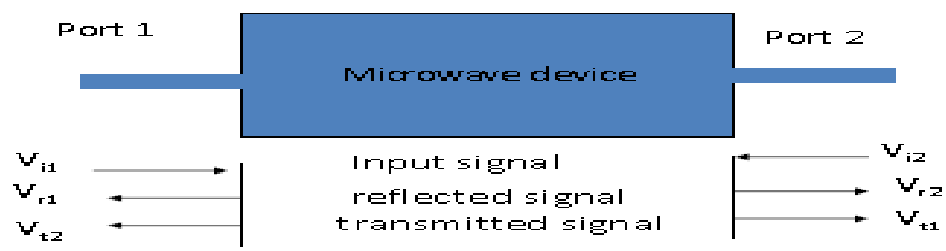


Figure 11 : S parameter system diagram for two port network

Types of S-parameters

- Small Signal S-parameter: Among all the types of S-parameter this is most widely used. Signals for which gain compression, non-linear effects do not take place are known as small signal. Small signal is only considered for passive network.
- Large signal S-parameter: Large signal S-parameters are more complicated. For large signal the S-matrix will vary depending upon the input signal strength.
- Pulsed S-parameters: They are measured on power devices so that an accurate representation is captured before the device heats up.
- Mixed-mode S-parameters: It refers to a special case of analyzing balanced circuits.

S11 is the most commonly used parameter in regards of antenna. It mainly represents how much power is reflected by the antenna. It is also known as the reflection coefficient. The unit of reflection coefficient is expressed by dB. If S11=0dB, that means all the power is reflected from the antenna, so no power is radiated. If S11 of an antenna is -10 dB and 3dB power is delivered to the antenna that means -7dB power is reflected back. For a practical antenna to operate S11 must be less than -10dB.

1.3.5 Antenna Efficiency

Antenna efficiency is one of the very important parameters of antenna. It is the ratio of the power delivered to the antenna to the power radiated from the antenna. A high efficiency antenna radiates most of the power delivered as input, while a low efficiency antenna absorbs most of the power as losses. The antenna efficiency can be expressed as a ratio of radiated power to the input power

$$\varepsilon_R = \frac{P_{radiated}}{P_{input}}$$

The efficiency of an antenna is always the same whether it is used as a transmitter or receiver. As the efficiency is number between 0 to 1, it is most often represented in terms of percentage. For example an antenna with efficiency of 0.5 means it has 50% efficiency. Antenna efficiency is also quoted in decibels (dB). An efficiency of 0.1 is 10% or -10dB, an efficiency of 0.5 is 50% or -3dB. Practically an antenna never has an efficiency of 100% or 0dB. The loss of antenna efficiency is due to finite conductivity of the component of antenna, dielectric losses and impedance mismatch.

1.3.6 Bandwidth

Bandwidth is the difference between the high and low frequencies of a signal. In other word bandwidth is the range of frequencies over which a particular antenna can radiate and receive energy properly. For example if a signal transmits between 60 and 70 MHz then it has a bandwidth of 10 MHz.

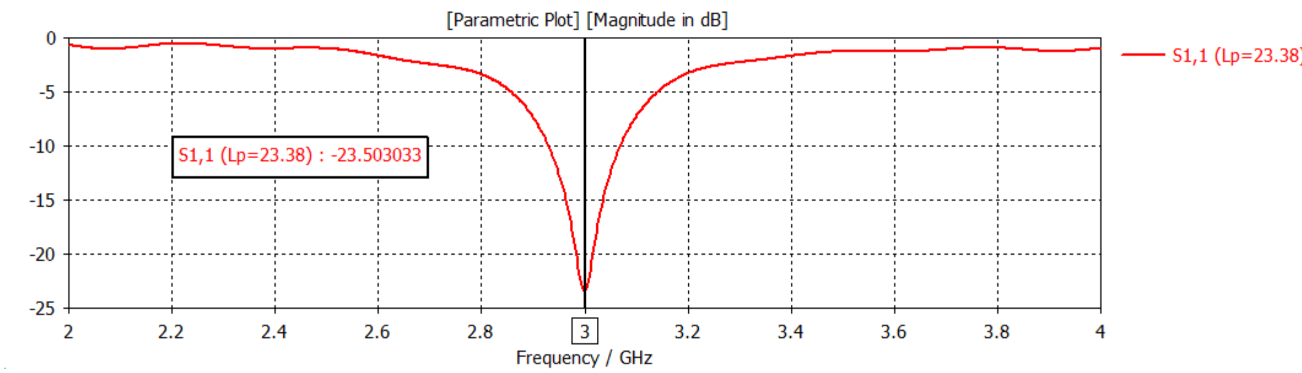


Figure 12 : Bandwidth calculation from S-parameter

Bandwidth can be described through many parameters. For example figure 12 shows the s parameter of a rectangular microstrip patch antenna. For this antenna the resonance occurs at 3 GHz, but the reflection coefficient is below -10dB from nearly 2.85GHz to 3.075. So the bandwidth of this antenna will be 0.225 GHz or 225 MHz.

1.3.7 Input Impedance

Input impedance: The input impedance of an antenna refers to the ration of voltage to current at the input terminal of the antenna. Input impedance of an antenna is normally denoted by Z_{in}.It can be expressed by the following equation

$$Z_{in} = R_A + jX_A$$

Where

R_A= Antenna resistance at input terminal

X_A= Antenna reactance at input terminal

The real part of the antenna therefore represents the power of the antenna that is radiated or absorbed by the antenna while the imaginary part of the impedance is the power stored in the near field as reactive power. For further simplicity let's consider an antenna with input impedance 50Ω. If the antenna is supplied with a signal source of 1 voltage then the current flow will have an amplitude of 1/50 =0.02 amp. As the impedance is real number the voltage and current through the antenna will be in phase. If the input impedance is something like $50 + j50$. Then the magnitude of the impedence will be $\sqrt{50^2 + 50^2} = 70.71$.This time ast the impedence is complex so there will be a phase difference and its value will be $\tan\left(\frac{50}{50}\right) = 45°$.This means the votage will lead the current by 45°.Input impedance is very important for antenna manufacturing. Antenna is connected to the source through a transmission line. Any transmission line has characteristic impedance. Characteristic impedance is the ratio of voltage and current at any point of a transmission line.

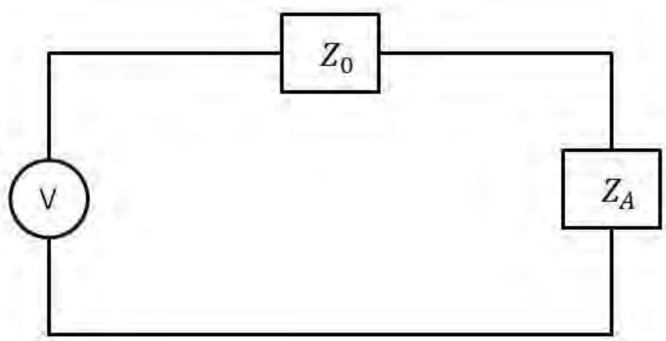


Figure 13 : Equivalent circuit diagram of an antenna

Characteristic impedance plays an important role for antenna as well. Suppose an antenna with an input impedance Z_A is connected to the sourse V through a transmission line of characteristic impedance Z_0 as shown in figure 13. The power that will be delivered to the antenna will be

$$P = V^2 \times \frac{Z_A}{Z_A + Z_0}$$

If Z_A is much smaller or much larger than $Z_0$the maximum power will not be delivered. The maximum power will only be equal when $Z_A = Z_0$. So while deigning antenna it is mandatory to design it in such a way that the input impedance matches the characteristics of transmission line. Normally characteristic impedance of any transmission line is 50Ω or 75Ω . So antenna is designed in such a way that its input impedance is the same.

1.4 Basic Ideas of EM Wave

A clear understanding of electromagnetic wave propagation is needed to analyze and design antenna. In this section general ideas about waves and basic parameters and equations related to wave propagation will be discussed.

A wave is a function of both time and space. The basic equation of wave is derived from the Maxwell's equation of Faraday's Law and Ampere's law. In a linear, source free homogeneous region these two equations are

$$\Delta \times \overline{\mathrm{E}} = -\mathrm{j}\omega\mu\overline{\mathrm{H}}$$

$$\Delta \times \overline{H} = j\omega\varepsilon\overline{E}$$

These two equations can be used to solve for either $\bar{E}$ or $\bar{H}$.thus taking the curl of equation 1 and using 2 we get

$$\Delta \times \Delta \times \bar{E} = -j\omega\mu\Delta \times \bar{H} = \omega^2\mu\varepsilon\bar{E}$$

This is an equation for $\bar{E}$.Using vector identities we get the following equation

$$\Delta^2\bar{E} + \omega^2\mu\varepsilon\bar{E} = 0$$

$$\Delta^2\bar{H} + \omega^2\mu\varepsilon\bar{H} = 0$$

This is called the wave equation or Helmholtz equation. $\omega^2\mu\epsilon$ is considered as a constant and defined as k^2.Therefore $k = \omega\sqrt{\mu\varepsilon}$. k is called the wavenumber or propagation constant of the media. If we consider an electric field with only $\vec{x}$ component and uniform in the x and y directions.Then the above equation can be derived to

$$\frac{\partial^2 E_x}{\partial z^2} = k^2 + E_x = 0$$

The solutions of this equation in the exponential form are

$$E_x(z) = E^+e^{-jkz} + E^-e^{jkz}$$

The result can be written as following in the time domain:

$$\varepsilon_x(z,t) = E^+\cos(\omega t - kz) + E^-\cos(\omega t + kz)$$

Here $E^{+}$and E^{-} are real constant. The first part of the equation represents wave travelling in the $+z$ direction and the second part represent wave travelling in the – z direction. These equations have been derived for lossless medium. But for lossy medium the wavenumber changes. It then becomes complex wavenumber or complex propagation constant. It is symbolized by γ. The equation for complex propagation constant is

$$\gamma = \alpha + j\beta = j\omega\sqrt{\mu\epsilon}\sqrt{(1 - \frac{j\sigma}{\omega\varepsilon})}$$

Here α is called attenuation constant. It is the real part of the propagation constant. Its unit is Nepers/meter and it causes the wave signal to decrease. It represents the loss. If loss is removed then α is 0 so $\gamma = 0 + j\beta$. Then $\gamma = \beta = k =$ propagation constant.

There are some other commonly used terms related to waves and wave propagation. One of them is wave velocity denoted by v_p. In free space $v_p = \frac{\omega}{k} = \frac{1}{\sqrt{\mu_0\varepsilon_0}} = 3 \times 10^8 m/sec$ which is the speed of light.Wave impedance is the ratio of the transverse electric and magnetic field. It is denoted by η.For plane wave $\eta = \frac{\omega\mu}{k} = \sqrt{\frac{\mu}{\varepsilon}}$.These terms and equations will be used frequently in later part of this thesis.

Chapter 2
RECTANGULAR MICROSTRIP PATCH ANTENNA

2.1 Basic Construction

Microstrip patch antenna are low profile antennas .They are comfortable to planner and non planner surface, simple and inexpensive to manufacture using modern printed technology. Among various types of patch antennas rectangular patch antenna is one of the most popular configurations. Microstrip patch antenna has patent in 1955 through its idea can be traced back to 1953 .It received considerable attention in the 1970s.

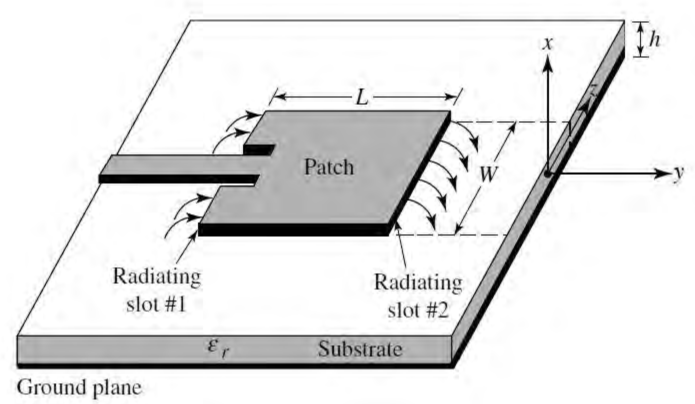


Figure 14 : Rectangular Microstrip Patch Antenna

Rectangular Microstrip Antenna shown in figure 14 consists of very thin metallic strip ($0.003\lambda_0 \le h \le \lambda$_0) above the ground plane. The strip is called patch .The patch and the ground plane are separated by a dielectric sheet called the substrate. The element of the substrate is a crucial matter for designing a rectangular patch antenna. The dielectric constant of the substrate is usually in the range of $2.2 \le \epsilon_r \le 12$.Thick substrate with low dielectric constant provides better efficiency and large bandwidth, but at the same time it requires larger element size. Thin substrate with higher dielectric reduces the size of the antenna but it affects the gain and bandwidth.

Microstrip patch antennas can be fed in different ways. Microstrip line, coaxial probe, aperture coupling and proximity coupling are most popular.

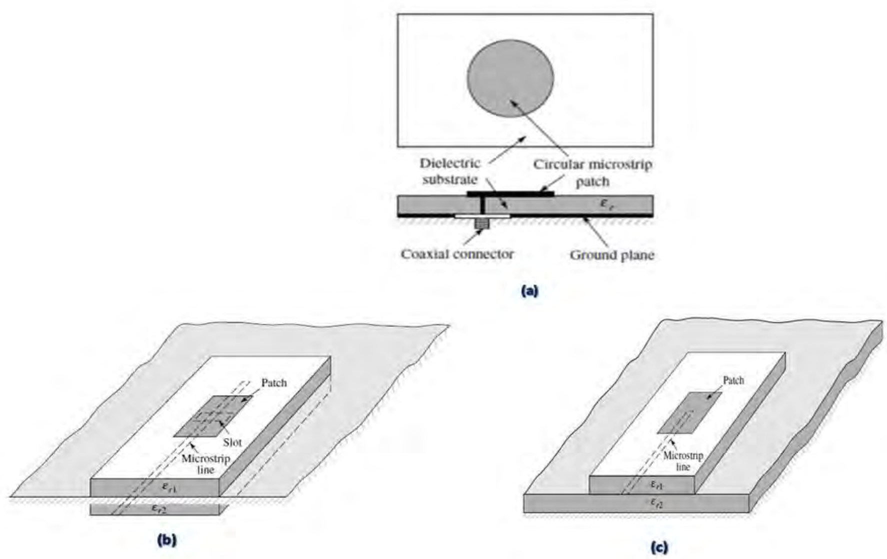


Figure 15: Feeding Methods. (a)Coaxial probe; (b) Aperture coupling ;(c) Proximity coupling

Microstrip line feed is usually a conducting strip with much smaller width compared to the patch. It is easy to fabricate and can be controlled by changing the inset position. Coaxial line feed is where the inner conductor of the coax is attached to the radiation patch and the outer conductor to the ground plane. Co axial probe feed is also easy to fabricate and match. The aperture coupling feeding method is much more complex and at the same time advanced feeding method. It consists of two substrates separated by 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. This feeding method provides a narrow bandwidth and provides solution to some problems of microstrip line feed and coaxial feed. For the purpose of our thesis co axial feeding method has been used and it provided us with satisfactory results.

2.2 Operation Principal

Operation principal of rectangular microstrip patch antenna can be easily analyzed using transmission line theory and cavity model. Transmission line theory is the easiest of all. Physical insight can be achieved from this theory. Cavity model on the other hand considers a microstrip patch antenna as an array of two radiating narrow aperture (slots.)These two theories are very important for the analysis and configuration of rectangular patch antenna. Both the theories are explained in details in next section.

2.2.1 Transmission Line Model

Transmission line method is the easiest and simplest of all. It also provides a good physical insight. Using this model different parameters of a microstrip patch antenna can be calculated.This method will mainly be used to calculate the length and width of the patch while designing. Besically the Transmission line model considers a microstrip patch antenna as two slots seperated by a transmission line of low impedence Z_c and of length L.

While analysing a rectangular microstrip patch antenna using Transmission Line Model fringing effect plays a vital role. As the dimension of the patch are finite along the length qnd width, electric fields at the edge of the patch undergo fringing as shown in figure The fringing effect depends on substarte's hight and patch dimention .It is actually a function of the length of the patch L to the hight h and dielectric constant ε_r of the substrate. Though fringing effect is reduced because for rectangular microstrip patch antenna $\frac{L}{h} \gg 1$, still it can not be avoided as it influnces the resonant frequency of the antenna.

According to this method if the dielectric constant of the substrate (ε_r), resonant frequency (f_r) and the height (h) of the substrate is predefined, the width of the patch can be calculated using the following equation:

$$W = \frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{\varepsilon_r+1}} = \frac{v_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}}$$

here, v_0 is the free space velocity of light.

Because of the fringing effect the patch looks wider electrically compared to its physical dimensions.As demonstrated in figure the dimension of the patch along the length extends on each side. Let the extended distance is ΔL. So the efficient length L_{eff}=$L + 2\Delta L$.where L is the actual length of the patch. For practical designing the extended length ΔL is calculated by approximate relation difined by the following equation

$$\frac{\Delta L}{h} = 0.412\frac{\left(\epsilon_{reff} + 0.3\right)\left(\frac{W}{h} + 0.264\right)}{\left(\epsilon_{reff} - 0258\right)\left(\frac{W}{h} + 0.8\right)}$$

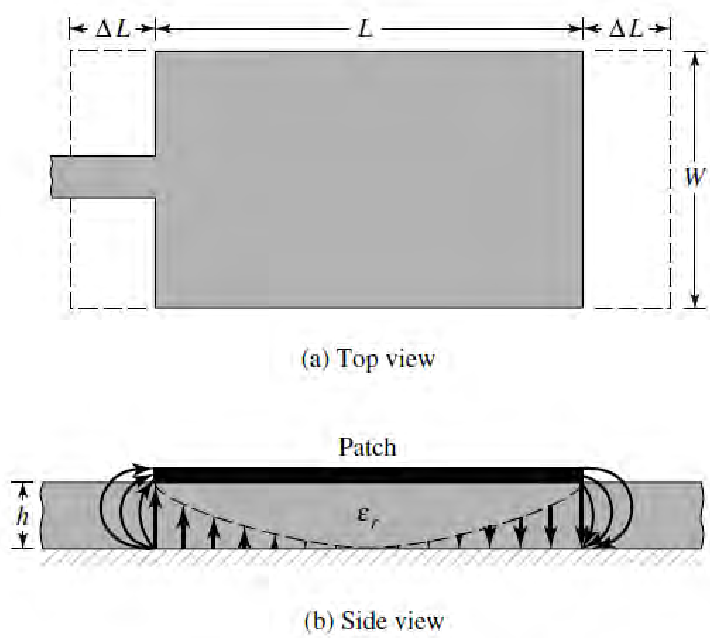


Figure 16: Physical and efficient length of rectangular microstrip patch

In the last equation ε_{reff} is another parameter that has been introduced.It is called the dielctric constant. The effective dielectric constant is defined as the dielectric constant of the uniform dielectric material surrounding the patch.Normally the dielectric constant of the substrate beneath the patch and above the patch is not same. But for the ease of calculation a uniform material is considerd around the patch with a single dielectric constant. This dielectric constant is refered as effective dilectric constant. It has a value of $1 < \varepsilon_{reff} < \varepsilon_r$. For a high dielctric substrate where $\varepsilon_r \gg 1$the value of ε_{reff} is closer to value of actual dielectric constant.ε_{reff} can be calculated using following equation

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left[1 + 12\,\frac{h}{w}\right]^{(1/2)}$$

Effective dielectric constant remains constant for low frequencies but for higher frequency it starts to increase and for much higher frequency it settles down. The relation of effective dielectric constant versus frequency is shown in the figure.

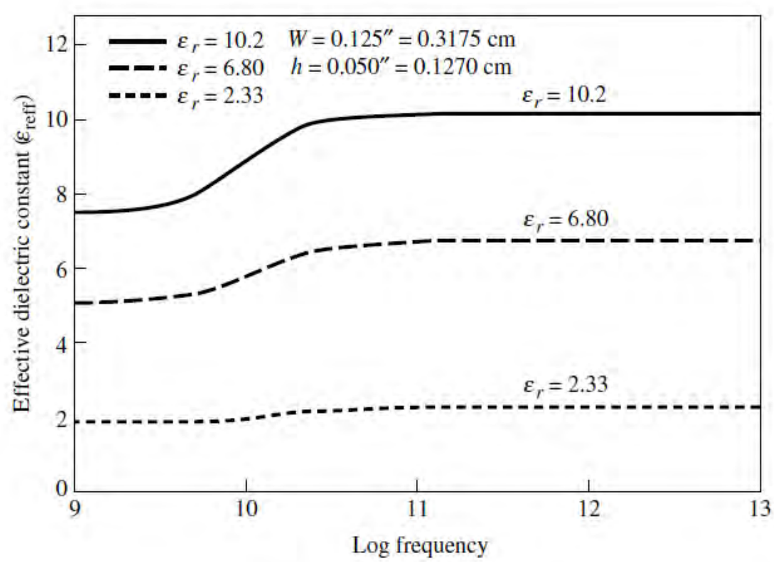


Figure 17 : Effective dielectric constant versus frequency for typical substrates.

2.2.2 Cavity Model for Rectangular Microstrip Patch Antenna

Cavity model is a very useful model for calculating input impedence and radiation pattern for antennas, specially patch antennas. Cavity means an empty space within a solid object. The electric fields and magnetic fields within the substrate of a patch antenna can be calculated accurately if it is considered as cavity bounded by electric conductors and magnetic walls. This is an accepted and effective approach. Before diving deep into the cavity model, waveguides and modes of propagation of electromagnetic wave is discussed below.

A. Waveguides: Waveguides are basically a media for transporting electromagnetic wave from one place to another. They are able to handle large amount of power and also acts as high pass filter. They are capable of transporting power precisely to where it's needed.

B. Modes of Propagation: Electromagnetic waves or signal is transferred from one place to another via a waveguide. Depending on the direction of the electric and magnetic fields and the direction of the products of these two types of fields, wave propagation can be three types. They are TEM (Transverse Electric Magnetic), TM(Transverse Magnetic); TE(Transverse Electric). The equations of these types of wave propagation have been derived from the Maxwell's equations of wave propagation.

If a time harmonic field has a $e^{j\omega t}$dependance and wave propagation along z axis. The electric and magnetic fields can then be written as

$$\bar{E}(x, y, z) = [\,\bar{e}(x, y) + ze_z(x, y)]e^{j\beta z}$$

$$H^{-}(x, y, z) = [\,\bar{h}(x, y) + zh_z(x, y)]e^{j\beta z}$$

Here $\bar{e}(x, y)$ and $\bar{h}(x, y)$ represent the transverse electric and magnetic field components while e_z and h_z are longitudinal electric and magnetic field.

Electromagnetic waves while travelling through free space have electric field and magnetic field directly perpendicular to each other. So longitudinal field components e_z and h_z are zero. This mode is called TEM mode.

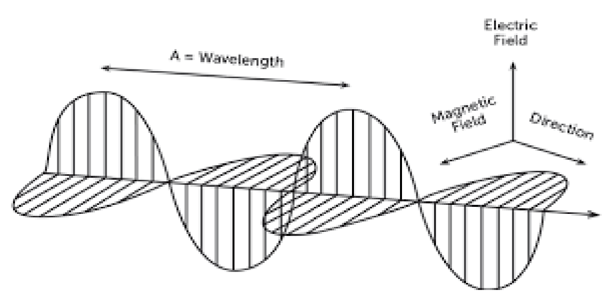


Figure 18 : EM wave traveling through space

When a wave travels through a waveguide it is reflected from the wall of its waveguide .As the waveguide is entirely enclosed, components of electric and magnetic fields travel to the direction of propagation ,in this case either $e_z = 0$ or $h_z = 0$. If $e_z = 0$ & $h_z \neq 0$ then it is called TE mode and if $e_z \neq 0$ & $h_z = 0$ then it is called TM mode.

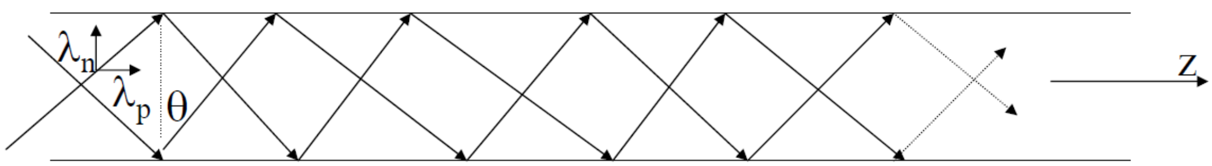


Figure 19: Wave travelling through a waveguide in z direction

Now let us shed some insight into the cavity model for rectangular microstrip patch antenna. When energy is supplied to the microstrip patch a charge distribution is established on the upper and lower side of the patch. There is also a charge distribution above the surface of the ground plane. The opposite charges located on the bottom of the patch and above the ground plane acts according t the attractive mechanism thus maintain the charge concentration on the bottom of the patch. Another mechanism called the repulsive mechanism push some charges from the bottom of the patch around its edges and forces them to move to the upper side surface. Current density $J_b$at the bottom of the patch and $J_t$on the top surface is created because of the charge movment.As in microstrip patch antennas the hight to width ratio is very small $J_b$dominates and most of the current flow remain under the patch. This current flow creates a corresponding magnetic field according to the Maxwell's theory .As the current is limited on the top surface no

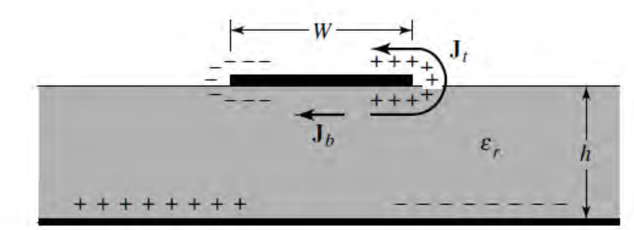


Figure 20 : Charge distribution and current density creation on microstrip patch

magnetic field will be created at the edges. This allows modeling the rectangular patch antenna as a four sided perfectly conducting magnetic wall. This will not disturb the electric field and magnetic field beneath the patch. The waves generated between the patch and the ground plane is reflected considerably within the walls .Furthermore the as the height to width ratio is very small the field variations of the electric and magnetic field along the height can be considered constant. Also the fringing effect is very low because of the small height. These entire phenomenons compel the rectangular microstrip patch antenna to support TM mode configuration. The mathematical proof of the cavity model and parameters used for it considering juxtaposed LHM and RHM substrate will be mentioned in the later section.

2.3 Radiation Pattern

The cavity model shows that the microstrip patch antenna can be reasonably modeled by a dielectric loaded cavity with two perfectly conducting electric walls on the top and bottom and four perfectly conducting magnetic walls on the side. Radiation takes place through these four sidewalls. As mentioned in the previous section the current density in the top of the patch can be considered zero because of the small height to width ratio and also the corresponding current density due to the magnetic field at the edges is zero, the only nonzero current density is the equivalent magnetic current density along the side periphery of the cavity. So it can be said that the electric field works in the space between the patch and the ground surrounded by the four side walls. The electric field is sketched in Figure .

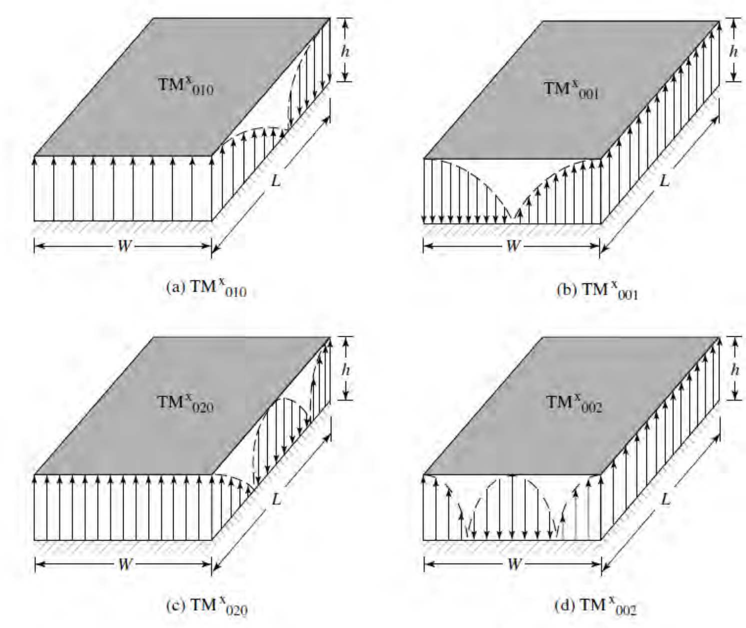


Figure 21: Field configuration for different modes in rectangular microstrip patch

The electric field in the figure shows there is a phase reversal along the length. Because of this phase reversal and the direction of the magnetic field on this side the radiated fields cancel out each other. So in a rectangular microstrip patch antenna only two sidewalls (slots separated by the length) are responsible for radiation.

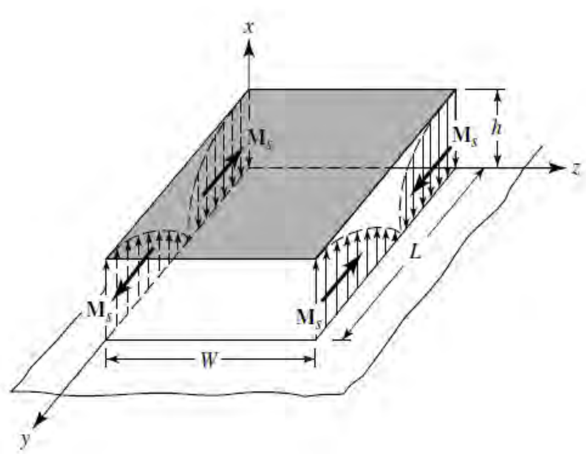


Figure 22 : Current densities and Magnetic field densities on non radiating slots

The electric fields in the two radiating sides are of same magnitude but opposite direction. The magnetic fields on the other hand are of same magnitude and direction on the two sides. The components of the field add in phase perpendicular to the ground plane and normal to the patch somewhere near the middle of the patch. Thus a broad side radiation pattern is created as shown in figure 24.

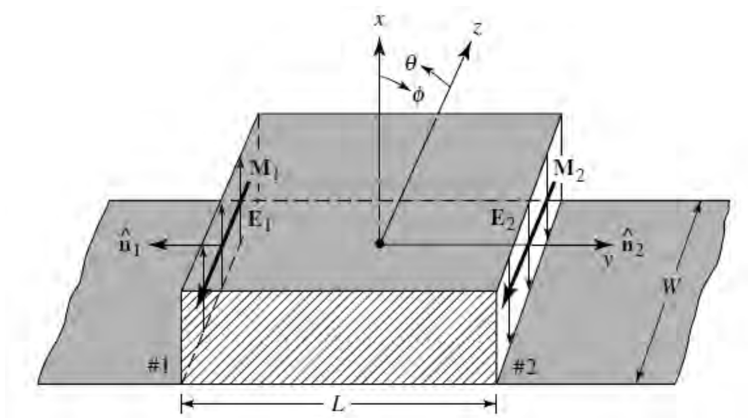


Figure 23: Current densities and Magnetic field densities on radiating slots

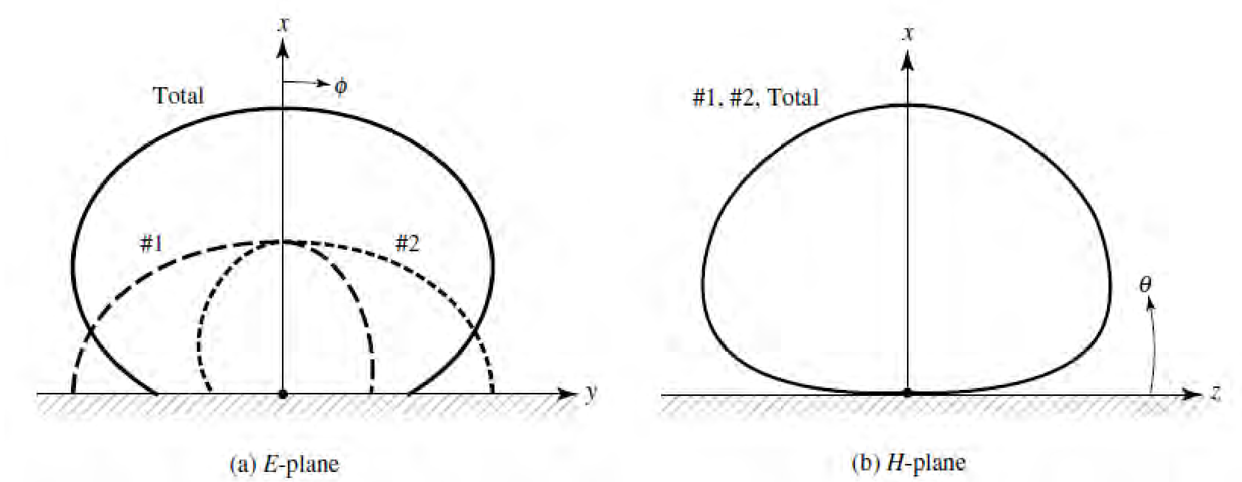


Figure 24: E and H field pattern each slot and the two slot together.

Chapter 3
Metamaterial

3.1 History of Metamaterial

Metamaterials are falsely organized media with unusual electromagnetic properties ranging from radio frequency and microwaves as far as possible up to optical frequencies. Their surprising properties are not dictated by their constituent materials but rather by man-made structures that are littler than the electromagnetic wavelength included.

As the art of materials has progressed, photonic materials have been produced which utilize the photon of light as the essential bearer of data. This has prompted photonic crystals and the start of the new thousand years, the verification of guideline for working metamaterials with a negative file of refraction in the microwave range at 10.5 Gigahertz. This was trailed by the main proof of guideline for metamaterial cloaking, additionally in the microwave range around six years later. However, a cloak that can hide protests over the whole electromagnetic range is still decades away. Numerous material science and building issues should be tackled.

All things considered, negative refractive materials have prompted the advancement of metamaterial antennas which are more productive than their customary partners. Additionally, metamaterial antennas are currently industrially accessible. Then, subwavelength centering with the super lens is likewise a piece of present-day metamaterials look into.

If we look for the history of metamaterials we can find various starting point depending on the interest. It is possible to give numerous examples of metamaterials from the 19th Century. For example the work of Bose on the rotation of the plane of polarization by artificial twisted structures in 1898 or artificial dielectrics for microwave antenna lenses by Kock in 1945. On 2000 D.R. Smith and his team had found the evidence of both electric permittivity and magnetic permeability negative in number at a specific microwave range of frequencies in a lab experiment of University of California at San Diego and that is how the modern metamaterials was born.

The important contributions of metamaterials was proposed by Vector Veselago back in 1968 and at first he said that it is possible to find the materials with negative permittivity and negative permeability. He found that a left-handed (LHM) set of vectors had been formed for the electric and magnetic field as well as the wave vector rather than the right-handed set of vector. In his experiment, it is also proved that the poynting vector of an electromagnetic wave is anti-parallel to the wave vector in left-handed materials. That is why light propagates in the opposite direction to the energy flux. This kind of phenomena have given not only some of the unusual characteristics of metamaterials but also negative-index refraction, the reversal of Cherenkov radiation, the reversal of the Doppler shift and the reversal of Snell's Law.

3.2 Effective Media

Those are called as effective media when the unit cells and the periods are smaller than the wavelength. One of the major properties of effective media is that the incident radiation sees the structure as a homogeneous medium with viable properties. The property of the effective media is usually different from the prperties of the constitute elements.

Metamaterial substrates have specific abilities to control and manipulate electromagnetic fields. The propagation of electromagnetic waves can be characterized depending on the magnitudes of μ and ε. Based on if the μ and ε are positive or negative different materials can be clarified into different types.

3.2.1. Double Positive (DPS) Material

The material which has both permittivity and permeability more prominent than zero (ε >0, μ >0) is called as double positive (DPS) medium. Most happening media (e.g. dielectrics) fall under this section.

3.2.2. Epsilon Negative (ENG) Material

The material which has permittivity less than zero and permeability greater than zero (ε <0, μ >0) is called as epsilon negative (ENG or SNG) material. Many plasma exhibit this kind of phenomena in particular frequency region.

3.2.3. Mu Negative (MNG) Material

The material which has permittivity more than zero and permeability less than zero (ε >0, μ <0) is called as Mu negative (MNG or SNG)material. Some of the gyro tropic materials exhibits this kind of phenomena in particular frequency regions.

3.2.4. Double Negative (DNG) Material

The material which has both permittivity and permeability less than zero (ε <0, μ <0) is called as Double negative (DNG) material.This kind of material is hard to find. It can be found only in artificially.

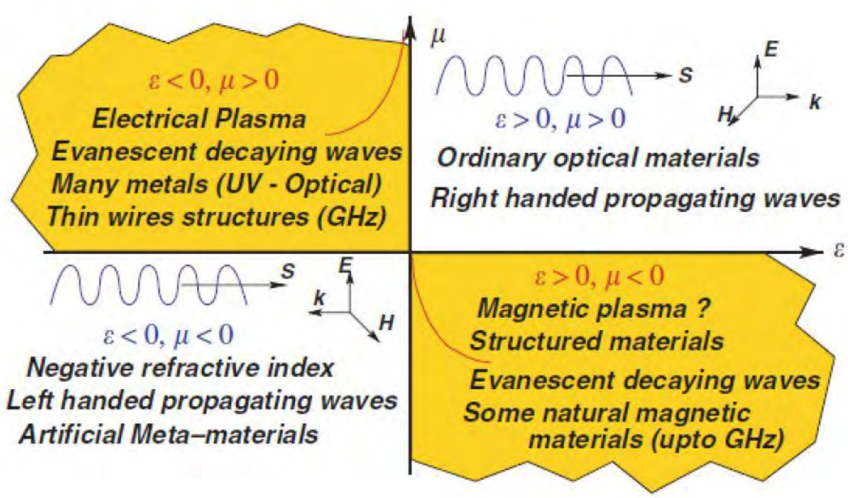


Figure 25: A schematics showing the classification of materials based on dielectric and magnetic properties.

All these kind of materials and their properties can be found from the study of the equation describing the propagation of electromagnetic waves in media as follows:

$$\text{Refraction index } \eta = \varepsilon\mu$$

and propagation constant, $k = \frac{\omega^2}{c^2}\eta^2$

From this two equation it can be found that propagation of wave is possible if both μ and ε are positive or both are negative. Still SNG(Single Negative Material)are very useful in designing artificial materials and some times more efficient than DNG or DPS

3.3 Dispersive Model of Metamaterial

3.3.1 Lorentz Model

Though a material can be described by some constant value of permittivity amd permeability, in reality all material are frequency dependent. Moreover it is not possible to directly implement and simulate negative permiability and permittivity. So it is important to use a model that can analysis the frequency response of metamaterial.The models used to describe the frequency response focus on the electron motion in the presence of nucleus and the change of basic dipole moment of the system due to the change of electric field.The most well known metamaterial model is the Lorentz model. The Lorentz model is derived by a description of electron motion in terms of a driven, damped harmonic oscillator. Also the charges are considered to be allowed to move in same direction of the electric field.The following equation represent the model:

$$\frac{d^2}{dt^2}(P_i)+\Gamma_L \frac{d}{dt}(P_i)+\omega_0^2 P_i = \varepsilon_0 \omega_p^2 E_i$$

Here $\frac{d^2}{dt^2}(P_i)$ represents the acceleration of the charges. $\Gamma_L \frac{d}{dt}(P_i)$ represents the damping mechanism of the system with damping coefficient Γ, and $\omega_0^2 P_i$ is the restoring forces where $\omega_0^2 = \frac{s}{m}$ .where s is spring constant of the harmonic oscillator and m is the mass of charge. From this equation the polarization electric field $P_i(\omega)$ can be found.

$$P_i(\omega) = \frac{\varepsilon_0 \omega_p^2 E_i(\omega)}{-\omega^2 + j\Gamma_L \omega + \omega_0^2}$$

The polarization of electric field is related to electric susceptibility by the given equation.

$$X_{(eLorentz)}(\omega) = \frac{P_i(\omega)}{\varepsilon_0 E_i(\omega)} = \frac{\omega_p^2}{-\omega^2 + j\Gamma_L \omega + \omega_0^2}$$

Now the permittivity can be obtained as

$$\varepsilon_{Lorentz}(\omega) = \varepsilon_0 (1 + X_{eLorentz}(\omega))$$

It can be written as

$$\varepsilon = 1 + X_h ost + \frac{\omega_p^2}{\omega_0^2 + \omega^2 + j\Gamma_L \omega}$$

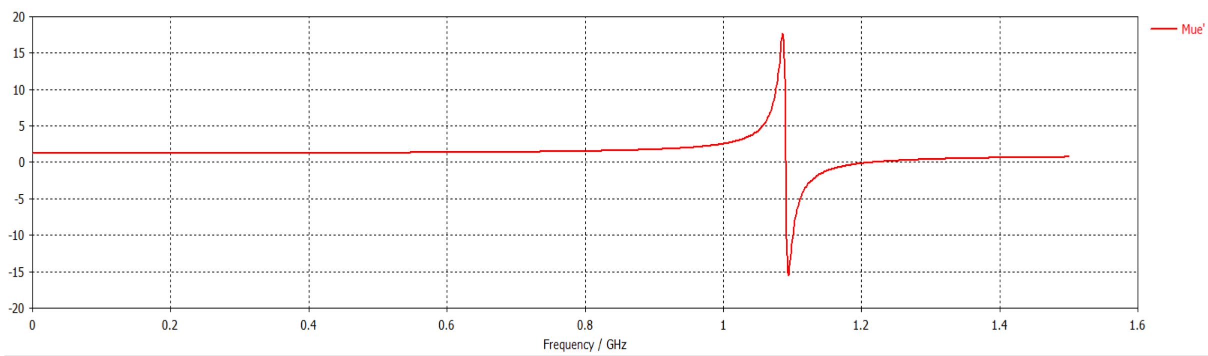


Figure 26 : Single resonance described by Lorentz's model

At microscopic level any resonance machanism can be characterized by this Lorentz model. So any number of resonance that take place can be expressed using a simple summation. The equation is as follows

$$X_{(eLorentz)}(\omega) = \sum_{i=1}^{N} \frac{\omega_p^2}{-\omega^2 + j\Gamma_L \omega + \omega_{0,i}^2}$$

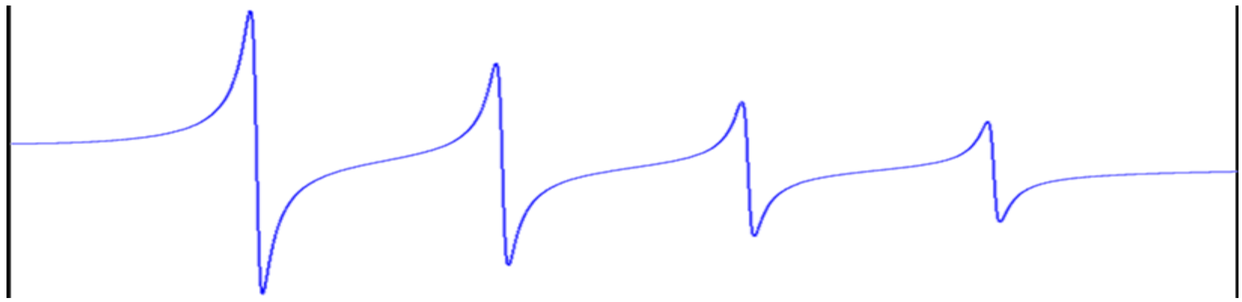


Figure 27 : Multiple resonances described by Lorentz's Model

If we are only interested in obtaining $\varepsilon_r(\omega)$ within the span of a certain frquency then at that particular span the high frequency contributes to a certain DC ofset that can be written as $\varepsilon_r(\infty)$. So at very high frequency the equation becomes

$$\varepsilon_r(\infty) = 1 + X_{host}$$

And at low frequency the equation can be written as

$$\varepsilon_r(0) = \varepsilon_r(\infty) + \frac{\omega_p^2}{\omega_0^2}$$

therefore,

$$\varepsilon_r(0) - \varepsilon_r(\infty) = \frac{\omega_p^2}{\omega_0^2}$$

hence,

$$\varepsilon_r = \varepsilon_r(\infty) + \frac{\frac{\omega_p^2}{\omega_0^2}\omega_0^2}{\omega_0^2 - \omega^2 - j\Gamma_L\omega}$$

So the final equation will be,

$$\varepsilon_r = \varepsilon_r(\infty) + \frac{[\varepsilon_r(0) - \varepsilon_r(\infty)]\omega_0^2}{\omega_0^2 - \omega^2 + j\Gamma_L\omega}$$

This equation will be used for modeling metamaterials in CST while designing antenna.Here ω_0 = resonant frequency, Γ_L =damping frequency, $\varepsilon_r(\infty)$ =epsilon infinite, $\varepsilon_r(0)$ =epsilon static

3.3.2 Drude Model

Another frequency response model is Drude model which is a well known special case of the Lorentz model. In this model the restoring force in harmonic oscillator is negligibleThe Drudes model can be defined as

$$\frac{d^2}{dt^2}(P_i)+\Gamma_L\frac{d}{dt}(P_i)=\varepsilon_0\omega_{pd}^2E_i$$

$$X_{(eDrude)}(\omega)=\frac{P_i(\omega)}{\varepsilon_0E_i(\omega)}=\frac{\omega_{pd}^2}{-\omega^2+j\Gamma_L\omega}$$

Similarly the permittivity based on the Drude model is

$$\varepsilon_{Drude}(\omega)=\varepsilon_0(1+X_{eDrude}(\omega))$$

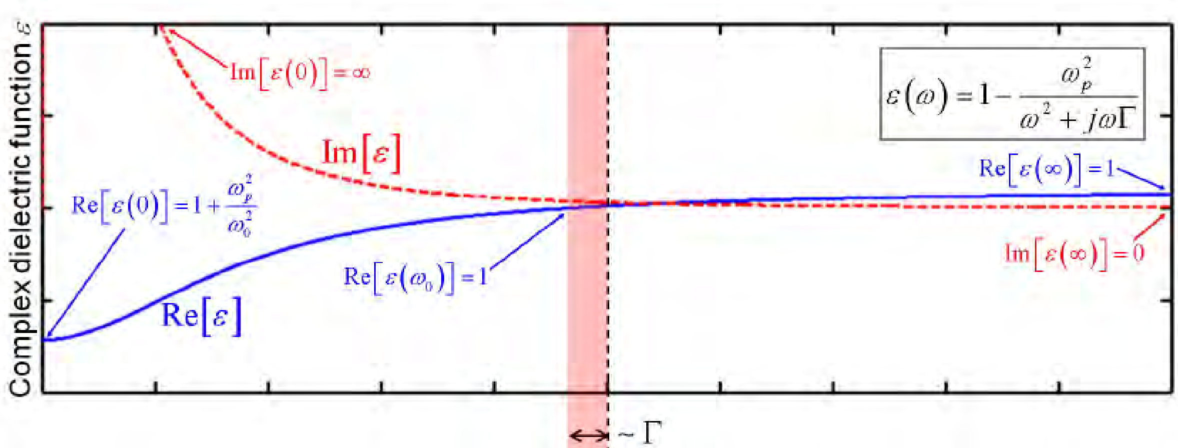


Figure 28 : Graphical representation of Drude's Model

3.3.3 Debay Model

If the acceleration term is much smaller than the other term the following equation will represent the Debye model:

$$\Gamma_L \frac{d}{dt}(P_i) + \omega_0^2 P_i = \varepsilon_0 \omega_{pdeb}^2 E_i$$

From the above equation it can be clearly seen that there have a single pole located at

$$S = -\omega_p^2 + j0$$

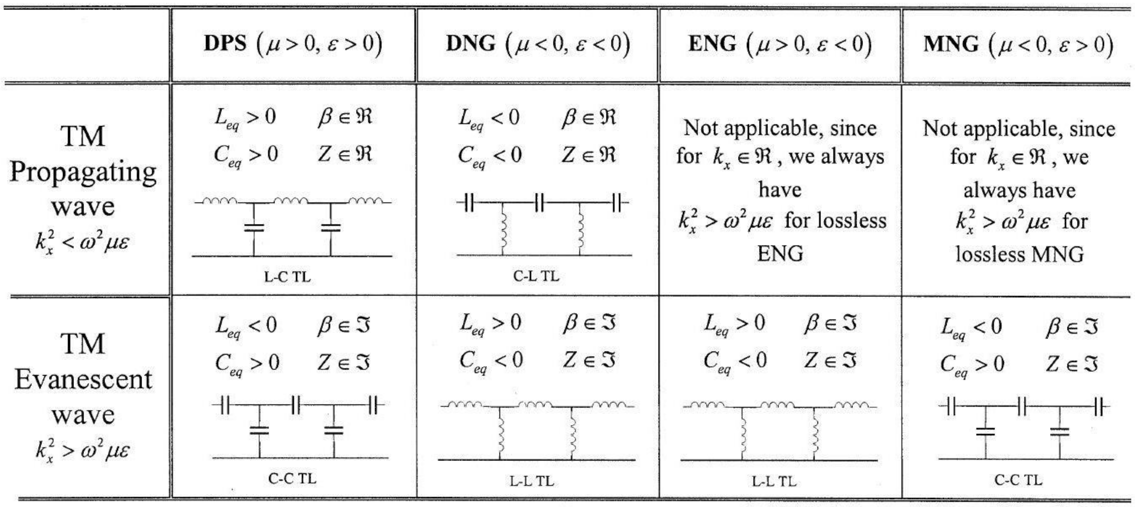
Here the the phase angle will be in between zero degree to -90 degree in the limit as absolute ω tends to ∞. As there will not have any phase angel over 90 degree the real part of the permittivity will always be positive.

Therefore the electric susceptibility will remain as:

$$X_e Debye(\omega) = \frac{\omega^2{}_{pdeb}}{j\Gamma_L \omega + \omega_0^2}$$

3.4 Wave Propagation in LHM and juxtaposed LHM & RHM

In the paper "Pairing an epsilon-negative slab with a mu-negative slab: Resonance, tunneling and transparency" Engheta et al [3]. analyzed transverse magnetic wave interaction with a pair of slabs assuming one of the slabs have negative value for the real part of permittivity while the real part of permiability is positive(ENG). The other slab is directly the opposite. They claimed that though wave interaction with each slab by itself has normal features but when paired and juxtaposed with each other under certain conditions it may show unusual features like resonance, complete tunneling, zero reflection and transparency. They analyzed the field distributions both outside and inside of this slab pairs, reflection and transmission properties. They found a satisfactory flow of Poyntig vector. They also derived transmission line models with appropriate distributed series and shunt reactive elements.



	DPS $(\mu>0,\ \varepsilon>0)$	DNG $(\mu<0,\ \varepsilon<0)$	ENG $(\mu>0,\ \varepsilon<0)$	MNG $(\mu<0,\ \varepsilon>0)$
TM Propagating wave $k_x^2<\omega^2\mu\varepsilon$	$L_{eq}>0$ $\beta\in\Re$ $C_{eq}>0$ $Z\in\Re$ L-C TL	$L_{eq}<0$ $\beta\in\Re$ $C_{eq}<0$ $Z\in\Re$ C-L TL	Not applicable, since for $k_x\in\Re$, we always have $k_x^2>\omega^2\mu\varepsilon$ for lossless ENG	Not applicable, since for $k_x\in\Re$, we always have $k_x^2>\omega^2\mu\varepsilon$ for lossless MNG
TM Evanescent wave $k_x^2>\omega^2\mu\varepsilon$	$L_{eq}<0$ $\beta\in\Im$ $C_{eq}>0$ $Z\in\Im$ C-C TL	$L_{eq}>0$ $\beta\in\Im$ $C_{eq}<0$ $Z\in\Im$ L-L TL	$L_{eq}>0$ $\beta\in\Im$ $C_{eq}<0$ $Z\in\Im$ L-L TL	$L_{eq}<0$ $\beta\in\Im$ $C_{eq}>0$ $Z\in\Im$ C-C TL

Figure 29 : Equivalent circuit diagram for propagating and evanescent TM wave in DPS,DNG,ENG,MNG

Alu et al. presented the results of their theoretical analysis for guided modes in parallel plate waveguides filled with pairs of parallel layers made of any two of the following materials:(1)ENG (2) MNG (3)DPS (4) DNG in [5]. They considered a parallel plate waveguide, made of two infinitely extent perfectly electric conducting plates separated by the distance $d = d_1 + d_2$ as shown in the figure .

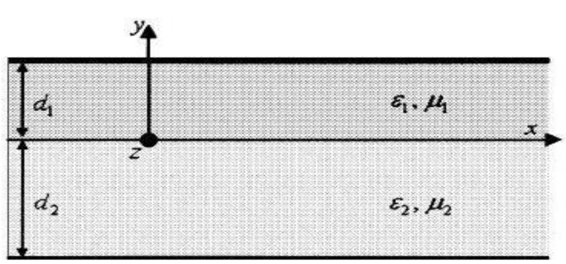


Figure 30 : Geometry of parallel plate waveguide filled with pair of layers made of any two of ENG,MNG,DNG and DPS material

This waveguide is filled with a pair of parallel layers made of any two of ENG,MNG,DPS,DNG materials. Furthermore a monochromatic time harmonic variation $e^{j\omega t}$ is assumed .The constitutive parameters of the slabs are ε_1, μ_1, ε_2, μ_2.These are assumed real but their sign depend on the type material used.From different calculations and assumption, they summarized their findings as mentioned below.

1) ENG-ENG waveguides: for any β , their dispersion relations are equivalent to: a) (TE case), a DPS-DPS waveguide with $\beta^2 > (k_i)^2 (i = 1,2)$ and, thus, no propagating mode is available and b) (TM case), a DNG-DNG waveguide with and $\beta^2 > (k_i)^2 (i = 1,2)$, again, no propagating mode may exist.

2) MNG-MNG waveguides: for similar reasons, no propagating mode may exist in such waveguides.

3) ENG-MNG waveguides: for any β , their dispersion relations are similar to the DPS-DNG waveguides with $\beta^2 > (k_i)^2 (i = 1,2)$ for both polarizations. As shown in Sections III and IV, these waveguides may be designed to be monomodal, regardless of their total thickness.

4) DPS-ENG waveguides: when $\beta^2 < (k_{DPS})^2$, their dispersion diagrams are equivalent to: a) (TE case), a DPS-DPS waveguide with $(k_1)^2 < \beta^2 < (k_2)^2$ and b) (TM case), a DPS-DNG waveguide with $(k_1)^2 < \beta^2 < (k_2)^2$.

When $\beta^2 > (k_{DPS})^2$, they become equivalent to: a) (TE case), an ENG-MNG waveguide and b) (TM case), an MNG-MNG waveguide, both not supporting any propagating mode.

5) DPS-MNG, DNG-ENG, DNG-MNG waveguides: corresponding results can be obtained by using duality. In particular, we note that the presence of a no-cutoff TM mode in a standard DPS-DPS waveguide implies $(k_1)^2 < \beta^2 < (k_2)^2$, and this waveguide may then be regarded as a DPS-MNG waveguide, which allows no-cutoff solutions, following(17), for any $\beta^2 < (k_{DPS})^2$

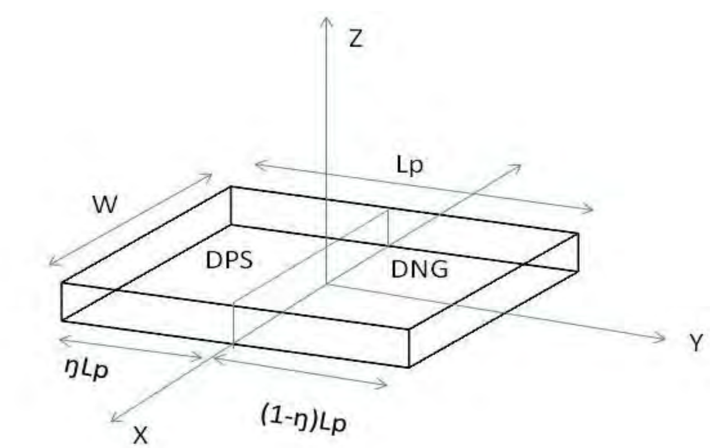
From this they concluded that depending on the way of pairing these materials and the choise of materials parameters one may obtain novel features that is different from conventional DPS-DPS waveguide.

3.5 Metamaterial as an Element of Microstrip Patch Antenna

Due to the development of microstrip patch antennas and their massive use, miniaturization of these types of integrated antennas is an emerging sector for research and development. Many potential techniques have been proposed over the years to reduce the size and dimension of microstrip antennas. In the primary stage size reduction techniques usually involved reactive loading of patch antenna with suitable designed slots, shorting parts and lumped elements. Unfortunately these techniques did not provide drastic reduction of antenna dimension. Using high dielectric materials as substrate was another solution provided by different researchers. This technique though reduced the size but destroyed the antenna's bandwidth, efficiency and shape of radiation pattern significantly. Failures in using the above mentioned technique lead the researchers to think of using artificially engineered materials and metamaterials. So far using artificially engineered materials have provided significant results for size reduction. Nader Engheta et al. [21] introduced the idea of thin subwavelength cavity resonators using metamaterials. Based on this idea miniaturization of antenna was achieved later. In the work of [21] it was revealed that a slab of DNG material can act as a phase compensator. So a DNG slab if combined with another conventional dielectric slab can produce a 1-D cavity resonator in principal.The dispersion relation of this type of resonators does not depend on the sum of the thickness of the component materials but instead it depends on the ratio of these thickness. So arbitrarily any small size antenna can be designed as long as a certain ratio is maintained. This is the main reason why metamaterial has been introduced in the field of microstrip patch antenna.

3.6 Proof of Cavity Model for Rectangular Microstrip Patch Antenna Loaded with Metamaterial

The cavity model is very crucial for designing a rectangular microstrip patch antenna .Based on this cavity model dispersive equation has been derived which has been used in most of the works related to designing rectangular microstrip patch antenna. Based on [27],[32],[33],[34],[36] the proof of cavity model for rectangular patch antenna loaded with metamaterial is provided in this section .



Region 1(DPS)

$$E_{x1} = -\frac{j\beta_1}{k_{c1}^2}\frac{\delta E_z}{\delta x}$$

$$E_{y1} = -\frac{j\beta_1}{k_{c1}^2}\frac{\delta E_z}{\delta y}$$

$$H_{x1} = \frac{j\omega\varepsilon_1}{k_{c1}^2}\frac{\delta E_z}{\delta y}$$

$$H_{y1} = -\frac{j\omega\varepsilon_1}{k_{c1}^2}\frac{\delta E_z}{\delta x}$$

Region 2(DNG)

$$E_{x2} = -\frac{j\beta_2}{k_{c2}^2}\frac{\delta E_z}{\delta x}$$

$$E_{y2} = -\frac{j\beta_2}{k_{c2}^2}\frac{\delta E_z}{\delta y}$$

$$H_{x2} = -\frac{j\omega\varepsilon_2}{k_{c2}^2}\frac{\delta E_z}{\delta y}$$

$$H_{y2} = \frac{j\omega\varepsilon_2}{k_{c2}^2}\frac{\delta E_z}{\delta x}$$

For DPS region boundary conditions are

$$E_{x1}, E_{y1}(z = 0, -\frac{W}{2} < x < \frac{W}{2}, \eta Lp < y < o) = E_{x1}, E_{y1}(z = h, -\frac{W}{2} < x < \frac{W}{2}, \eta Lp < y < o) = 0$$

$$H_{x1}(y = 0, -\frac{W}{2} < x < \frac{W}{2}, 0 < z < h) = H_{x1}(y = \eta Lp, -\frac{W}{2} < x < \frac{W}{2}, 0 < z < h) = 0$$

$$H_{y1}(x = -\frac{W}{2}, \eta Lp < y < o, 0 < z < h) = H_{y1}(x = \frac{W}{2}, \eta Lp < y < o, 0 < z < h) = 0$$

Let $E_{z1} = [A_1 cos(k_{x1}x) + B_1 sin(k_{x1}x)][A_2 cos(k_{y1}y) + B_2 sin(k_{y1}y)]$

If $E_{x1} = 0, B_1 = 0 \quad then \quad k_{x1} = \frac{n\pi}{\frac{W}{2}}$

If $E_{y1} = 0, B_2 = 0 \quad then \quad k_{y1} = \frac{m\pi}{\eta Lp}$

$$then, \quad E_{z1} = A_{mn} cos(k_{x1}x) cos(k_{y1}\eta Lp)$$

$$Similarly, \quad E_{z2} = A_{mn} cos(k_{x2}x) cos(k_{y2}(1-\eta)Lp)$$

For DPS region $$H_{x1} = \frac{j\omega\varepsilon_1}{k_{c1}^2}\frac{\delta E_z}{\delta y}$$

$$= \frac{j\omega\varepsilon_1}{k_{c1}^2}\frac{\delta}{\delta y}[A_{mn} cos(k_{x1}x) cos(k_{y1}\eta Lp)]$$

$$= \frac{j\omega\varepsilon_1}{k_{c1}^2}\frac{\delta}{\delta y}[E_0 cos(k_{x1}x)cos(k_{y1}\eta Lp)]$$

$$= \frac{j\omega\varepsilon_1}{k_{c1}^2}k_{y1}[E_0 cos(k_{x1}x)sin(k_{y1}\eta Lp)]$$

In cut off region $k_{c1}^2 = \omega^2\mu_1\varepsilon_1$

$$H_{x1} = -\frac{j\omega\varepsilon_1}{\omega^2\mu_1\varepsilon_1}k_{y1}[E_0 cos(k_{x1}x)sin(k_{y1}\eta Lp)]$$

$$H_{x1} = \frac{1}{j\omega\mu_1}k_{y1}[E_0 cos(k_{x1}x)sin(k_{y1}\eta Lp)]$$

now $$k_1^2 = k_{x1}^2 + k_{y1}^2 + k_{z1}^2$$

For TM_{010} mode $k_{x1} = 0, \quad k_{z1} = 0$

So $$k_1^2 = k_{y1}^2$$

$$k_1 = k_y$$

$$H_{x1} = \frac{1}{j\omega\mu_1}k_1[E_0 sin(k_1\eta Lp)]$$

And , $E_{z1} = E_o cos(k_1\eta Lp)$

Similarly, $$H_{x2} = -\frac{1}{j\omega\mu_1}k_2[E_0 sin(k_2(1-\eta)Lp)]$$

And, $E_{z2} = E_o cos(k_2(1-\eta)Lp)$

Now, $$\frac{H_{x1}}{E_{z1}} = \frac{H_{x2}}{E_{z2}}$$

$$\therefore \frac{k_1}{j\omega\mu_1}tan(k_1\eta Lp) = -\frac{k_2}{j\omega\mu_2}tan(k_2(1-\eta)Lp)$$

$$\frac{k_1}{\mu_1} tan(k_1 \eta Lp) = -\frac{k_2}{\mu_2} tan(k_2 (1-\eta) Lp)$$

$$\frac{\omega\sqrt{\mu_1 \varepsilon 1}}{\mu_1} tan(k_1 \eta Lp) = -\frac{\omega\sqrt{\mu_2 \varepsilon_2}}{\mu_2} tan(k_2 (1-\eta) Lp)$$

$$\frac{k_1}{\omega\mu_1} tan[k_1 \eta Lp] = -\frac{\omega\varepsilon_2}{k_2} tan[k_2 (1-\eta) Lp]$$

This equation is for DNG medium.similarly same equation can be derived for MNG and ENG in different forms. The equation mentioned above is very useful for designing patch antennas.It is the key equation for size reduction as it relates all the parameters like length,permitivity, permiability,propagation constant cut off frequency and filling ratio together.

Chapter 4
PREVIOUS WORKS ON METAMATERIAL BASED MICROSTRIP PATCH ANTENNA

4.1 Primary Construction of Metamaterial Based Patch Antenna

Alu er al. in [24] provided details and analytic report on load matching and radiation properties of sub wavelength resonant patch antennas filled with DNG/DPS/SNG material blocks. They provided some good reasons why day by day engineers and scientists are getting more attracted to metamaterials as a building component of sub wavelength cavities and patch antennas. Though microstrip patch antennas are very thin in their cross section compared to the operating wavelength($0.05\lambda - 0.01\lambda$), their transverse dimensions can not be made arbitrarily short.This is because a rectangular patch antenna resonates at a given frequency when its linear transverse dimension is of the order of half wavelength. If artificial materials like metamaterials are used, some features of antenna like impedance matching, gain bandwidth efficiency, front to back ratio can be improved, which will lead to further size reduction.Among many applications of metamaterial they are able to overcome the diffraction limit in various configuration. Further more the phase compensation properties of DNG metamaterials can synthesize sub-wavelength cavity resonators with resonant properties essentially independent on their effective physical size. What actually happens in two slab microstrip antennas is that the induced resonance happens fundamentally at the interface between metarials with oppositely signed constitutive parameters allowing to squeeze the resonant dimensions of these devices just around this complementary interface. These results do not depend on the total electric size ,rather on specific filling ratios between the materials.As a patch antenna resonance is closely related with the cavity resonance of the volume between the patch and ground plane it is possible to prove with the cavity model that not the physical dimensions but only depending on the filling ratios of the substrate underneath the patch resonant frequency can be achieved. The proof of this cavity model has beeen provided in section 6 of this report. In [24]Alu et al. provided a design of rectangular microstrip patch antenna.They considered the dimension of the antenna $L \times W$ and filled with two isotropic and homogeneous materials with permittivity and permiability of $\varepsilon_1(\omega)$, $\mu_1(\omega)$ and $\varepsilon_2(\omega), \mu_2(\omega)$.

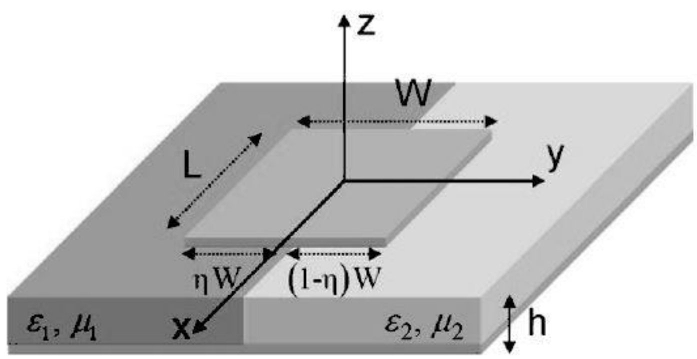


Figure 31: Rectangular Microstrip Patch Antenna of dimension $L \times W$ designed by Alu et al.

The resonant frequency of the equivalent cavity model for TM_{0m0} mode has been obtained by applying all boundary condition correspond to the solution of the following dispersion equation:

$$\frac{k_1}{\omega\mu_1} tan[k_1 \eta W] = -\frac{\omega\varepsilon_2}{k_2} tan[k_2(1+\eta)W]$$

From the above equation it can be derived that

$$\frac{\eta}{1-\eta} \approx \frac{\varepsilon_2}{\varepsilon_1}$$

This expression is independent of W and ω which proves that the patch may resonate at any arbitrarily low frequency for any arbitrarily small width of patch , provided the above equation is satisfied. The design provided by Alu et al. successfully achieved the goal of size reduction but it did not have a proper radiation pattern. In order to squize the size of the antenna, highy permitivity had to be employed. High permitivity always causes a low directivity.Furthurmore when the two radiating slots got closer the surface waves ware strongly excited ,this reduced the gain of the antenna. As a result there was no broadside radiation for conventional TM_{010} mode for this proposed design. Inspite of no broadside radiation this design opened the path of size reduction of rectangular patch antenna and many more patch antennas were designed without considering the radiation pattern.

4.2 Mode modification of Metamaterial Based Rectangular Patch Antenna

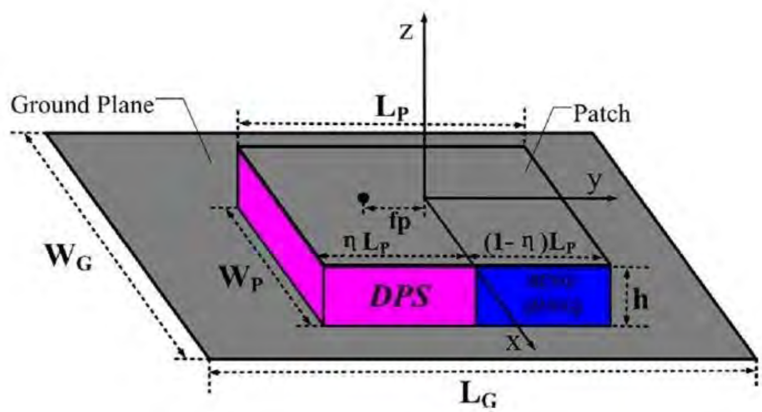


Figure 32: Geometry of a patch antenna partially loaded with MNG or DNG metamaterial. Detailed dimensions andconstitutive parameters are: W_G=120 mm, L_G= 150 mm, W_P= 50 mm, L_P= 72.8 mm, h= 5 mm, ε_1=4.9 ε_0, μ_1= μ_0.Case (a) ε_2= ε_0, μ_2= -0.1 μ_0, ε= 0.42, f_p = 15.4 mm for the case of MNG loading. Case (b) ε_2= -2ε_0, μ_2= -2.5 μ_0, ε=0.8, f_p = 25 mm for the case of DNG loading.

The design of sub wavelength compact resonant patch antenna loaded with metamaterial provided by Alu et al. in [24] is one of the primary designs of this particular type. This design did not provide satisfactory radiation pattern. Xiong et al. provided a design that supported dual Band operation in [25]. Normally rectangular patch antenna has a broad side radiation pattern for normal TM_{010} mode but in order to have a dual band multiresonators are required which increases the lateral size or thickness. TM_{020} and higher modes can be a solution to these problem but TM_{020} mode have a conical radiation pattern with maximum radiation along a certain elevation angle above the ground plane but null radiation pattern at the broadside. Based on the previous works regarding metamaterial patch antenna Xiong et al. suggested a new design in [25] .In this design along with DPS material, MNG metamaterial is used . They were able to prove that this particular design have broad side radiation pattern for TM_{020} .The geometry and radiation pattern of the proposed antenna is mentioned in figure 32 & 33.

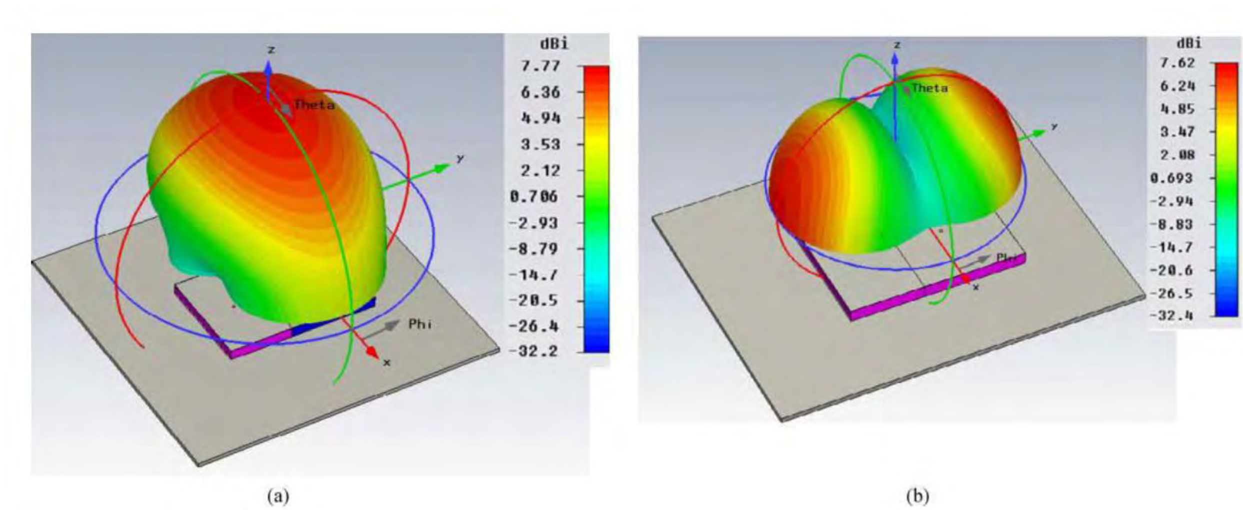


Figure 33 : The three-dimensional radiation pattern of TM_{020} mode (a) when the patch is partially loaded with a MNG metamaterial block and (b) when the regular patch is filled with a DPS block only.

4.3 Better Radiation Pattern and Mode Modification of Metamaterial based Rectangular Patch Antenna

Though in the beginning it was considered that rectangular patch antennas loaded with metamaterial can only be good resonators but may not be good radiators. But the antenna proposed by Xiong et al. in [25] was able to prove that rectangular patch antennas can also be radiator.But this idea of TM_{020} mode modification is not applicable for patch antennas smaller than $72.8mm \times 50mm$ .The solution of this problem has been provided by Mahady Rahman Chowdhury et al. in [9]They came up with "General Idea" of radiation pattern modification to solve broadside null radiation pattern problem and mode modification.They showed that above fundamental TM_{010} mode but below TM_{020} which they defined as $TM_{0\delta 0}$ mode $(1 < \delta < 2)$, successful mode modification is possible using ENG & MNG metamaterial.

The further extended the equation for DNG,MNG and ENG in the following form.

$$\sqrt{\frac{\varepsilon_1}{\mu_1}} tan(k_1 \eta Lp) = \sqrt{\frac{\varepsilon_2}{\mu_2}} tanh(k_2(1-\eta)Lp) \quad (DNG)$$

$$\sqrt{\frac{\varepsilon_1}{\mu_1}} tan(k_1 \eta Lp) = -\sqrt{\frac{\varepsilon_2}{|\mu_2|}} tanh(k_2(1-\eta)Lp) \quad (MNG)$$

$$\sqrt{\frac{\varepsilon_1}{\mu_1}} tan(k_1 \eta Lp) = \sqrt{\frac{\varepsilon_2}{\mu_2}} tanh(k_2(1-\eta)Lp) \quad (ENG)$$

In order for resonance to occur and follow the above conditions $(k_1 \eta L_p)$ has to be in the following range:

$$0° < k_1 \eta L_p < 90° \quad \text{and} \quad 180° < k_1 \eta L_p < 270° \qquad \text{(ENG)}$$

$$90° < k_1 \eta L_p < 180° \quad \text{and} \quad 270° < k_1 \eta L_p < 360° \qquad \text{(MNG)}$$

$$0° < k_1 \eta L_p < 90° \quad \text{and} \quad 180° < k_1 \eta L_p < 270° \qquad \text{(DNG)}$$

For the usual broad side radiation pattern the necessary condition is that the electric fringing field must have opposite signs with almost equal magnitude at the two radiating edges of the patch. So for better radiation pattern

$$\frac{E_{z2}(aty = (1-\eta)L_p)}{E_{z1}(aty = \eta L_p} = -1$$

In spite this condition at the resonance if the magnitude ratio of electric field is minimum 70% at the two radiating edges with 180 degree phase shift , patch antenna may show satisfactory radiation characteristics. Thus the condition used by Mahady Rahman Chowdhury et al. in [7]is

$$-1 < \frac{E_{z2}}{E_{z1}} < -0.7$$

Based on this condition the range of $k_1\eta L_p$ olso changed .The new range was:

$$180° < k_1\eta L_p < 225° \quad \text{(ENG)}$$

$$135° < k_1\eta L_p < 180° \quad \text{(MNG)}$$

$$180° < k_1\eta L_p < 270° \quad \text{(DNG)}$$

Mahady et al. expressed this idea graphically as :

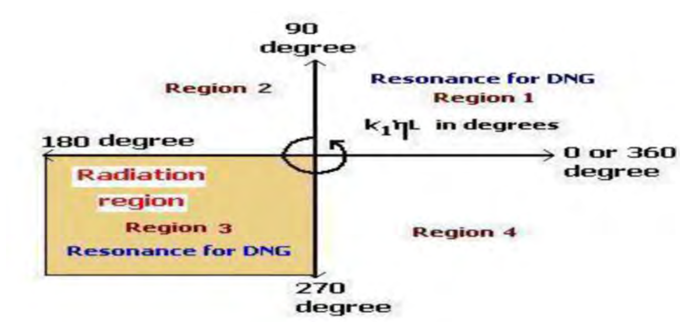


Figure 34 : Proposed better radiation region

This "General Idea" provided in [27] has given the opportunity to chose between possible range of variation of material parameters for different kinds of metamaterials in rectangular patch antenna.Satisfactory radiation pattern has also been achieved. Mahady Rahman et al. also provided a novel design algorithm [28] for rectangular patch antenna loaded with DNG/SNG materials. This algorithm provides the opportunity to design any rectangular patch antenna loaded with metamaterial according to our desired size and operating frequency. Proposed Algorithm for designing rectangular patch antenna loaded with SNG metamaterial is mentioned below:

For MNG Metamaterial Loading

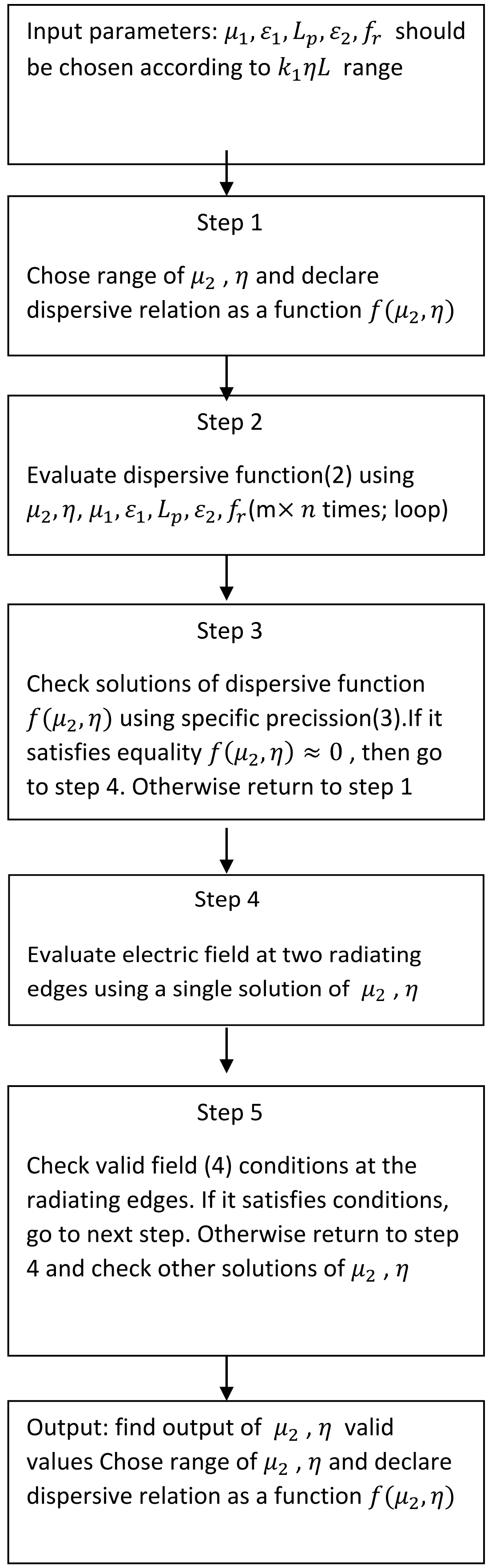
1. $k_1\eta L$ range for MNG metamaterial loading : $135° < k_1\eta L_p < 180°$
2. Dispersive function, $f(\mu_2, \eta)$: $\sqrt{\frac{\varepsilon_1}{\mu_1}} tan(k_1\eta Lp) + \sqrt{\frac{\varepsilon_2}{|\mu_2|}} tanh(k_2(1-\eta)Lp) =$ precision
3. Precision range for dispersive equation : Solution of function within 0.0000001 to -0.000001
4. Electric field at radiating edges: $E_{z_1} = E_0 \cosh(|k_2|(1-\eta)L_p)$ & $E_{z_2} = E_0 \cos(k_1\eta L_p)$
5. Edge electric fields ratio(r) must be -1<r<-0.7. Where $r = E_{z_2}/E_{z_1}$.

For ENG Metamaterial Loading

1. $k_1\eta L$ range for MNG metamaterial loading : $180° < k_1\eta L_p < 225°$
2. Dispersive function, $f(\varepsilon_2, \eta)$: $\sqrt{\frac{\varepsilon_1}{\mu_1}} tan(k_1\eta Lp) - \sqrt{|\frac{\varepsilon_2}{\mu_2}|} tanh(k_2(1-\eta)Lp) =$ precision

Step 3, 4 and 5 is same as MNG metamaterial loading.

The flowchart of the algorithm is provied below


Input parameters: $\mu_1, \varepsilon_1, L_p, \varepsilon_2, f_r$ should be chosen according to $k_1 \eta L$ range
Step 1
Chose range of μ_2 , η and declare dispersive relation as a function $f(\mu_2, \eta)$
Step 2
Evaluate dispersive function(2) using $\mu_2, \eta, \mu_1, \varepsilon_1, L_p, \varepsilon_2, f_r$(m$\times$ n times; loop)
Step 3
Check solutions of dispersive function $f(\mu_2, \eta)$ using specific precission(3).If it satisfies equality $f(\mu_2, \eta) \approx 0$, then go to step 4. Otherwise return to step 1
Step 4
Evaluate electric field at two radiating edges using a single solution of μ_2 , η
Step 5
Check valid field (4) conditions at the radiating edges. If it satisfies conditions, go to next step. Otherwise return to step 4 and check other solutions of μ_2 , η
Output: find output of μ_2 , η valid values Chose range of μ_2 , η and declare dispersive relation as a function $f(\mu_2, \eta)$

Chapter 5
NOVEL DESIGN AND ANALYSIS

Metamaterial based dual band patch antenna has provided an alternative to large bandwidth planner antennas. Primarily Alu et al. designed a rectangular patch antenna with DPS & ENG juxtaposed substrate layer, which gave a null broadside radiation pattern for TM_{010} [24]. This design was therefore not well accepted as normal rectangular microstrip patch antenna provides broadside radiation pattern. Despite this null broadside radiation pattern several antenna designs had been proposed without considering radiation performance. Until the work of Jian Xiong et al. came to light it was considered that this type of metamaterial based microstrip patch antennas can only be good resonators but may not be good radiators. Jian Xiong et al. proved that normal broadside radiation pattern is possible for conventional TM_{020} mode. Still the design provided by them had some problems.TM_{020} mode modification was not possible for dimensions smaller than 72.8 mm×50mm. So miniaturization of antenna was not possible with this type of design. This problem was solved by Mahdy et al. in [27]. They proposed a 'general idea' of radiation pattern modification. This 'general idea' solved the broad side null radiation pattern. They also provided an algorithm [28] to provide possible range of variation of the material parameters for different kinds of metamaterial in rectangular patch antenna. They introduced $TM_{0\delta0}$ mode using ENG ($1 < \delta < 2$) and MNG ($0 < \delta < 1$). This mode is not affected by antenna size. So their design was able to give proper radiation for small patch size as well. Up to this point size reduction and achieving natural broadside radiation pattern was the main target. In this novel contribution radiation pattern modification has been proposed in order to reduce the dimension of rectangular microstrip patch antenna array. In order to change the radiation pattern and minimize antenna array size we had to consider small increase in the dimension of single rectangular antenna slot.

We have proposed two types of design in order to achieve our target. In this thesis we are only concentrating on mode modification and shifting radiation pattern. Size reduction of antenna array will be analyzed in future.

5.1 Type 1 Design

In [27] Mahdy et al. presented design of rectangular microstrip patch antenna loaded with MNG material of dimension 25mm×15mm.Using their proposed algorithm they proposed multiple designs of the same dimension but different frequencies. Their frequency ranged from 2GHz to 2.5 GHz. All this designs had broadside radiation pattern with main lobe deviation of maximum 4 degree. They also proposed a design that had a dimension of $50mm \times 40mm$ with a theoretically chosen resonant frequency of 1.48GHz and practical resonant frequency of 1.224GHz. This was the lowest possible frequency used by them. Furthermore these designs supported $TM_{0\delta 0}$ mode which is quite same as the conventional TM_{010} and TM_{020} mode.

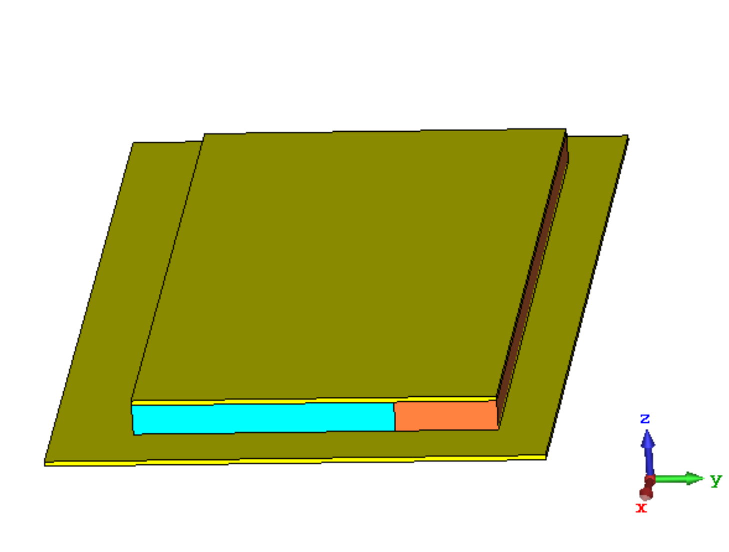


Figure 35 : Rectangular microstrip patch antenna loaded with metamaterial

In these types of modes the radiating slot (L) is larger than the non radiating slots (W). The electric field has a phase shift in the non radiating slots and no phase shift in the radiating slots. Normally the condition for these two modes is $L > W > H$ [32]. In our design we are considering $TM_{00\delta}$ mode .It is a hybrid mode with $0 < \delta < 1$ or $1 < \delta < 2$. The relation of the size of radiating slots and non radiating slot is $W > L > h$. The main reason we are considering this design is that in this case there is also a phase shift for electric field in the radiating slots(Figure 21). This phase shift affects the normal radiation pattern. We are using MNG material for this type of designs. MNG material is used because MNG materials support low frequency much better than ENG materials. It is easy to vary different properties of the antenna for low frequency using MNG than ENG. At first we chose a frequency of 0.7 GHz and length of 35mm. In order to let the $TM_{00\delta}$ mode work we chose the width of the antenna 62mm .Then with the help of the algorithm provided in [28] we calculated other values required for the antenna. The parameters of the proposed Type 1 Design 1 are provided in table [2].

The dimension of this antenna is $35mm \times 62mm$ which is larger than the size of the proposed design in [71]. The reason of not choosing much smaller size is that with the reduction of size the resonant frequency has to be increased otherwise it does not satisfy the equation for cavity resonance. Also if the size decreases the value of permittivity and permeability increases, theoretically this affects the gain. Considering all the factors the antenna has been designed using CST. The first resonance occurred at 0.61422 GHz which can be called the resonance for $TM_{00\delta}$. The other resonance occurred at 0.72376GHz. It is the resonance for TM_{001} mode. Because of the shifting effect we do not get resonance exactly at 0.7GHz. The S-parameter of the design is shown in figure: 36. The 3D and 1D radiation pattern for directivity at 0.61422 GHz is also shown in figure: 37.

This radiation pattern is completely different from the normal broad side radiation pattern. It has two lobes directly opposite each other along the x axis and a null along the z axis. This design satisfies our primary target of moving the radiation pattern approximately 90 degree from the normal broad side radiation pattern. It is also a successful demonstration of using TM_{001} mode in rectangular microstrip patch antenna loaded with metmaterial. The reason behind this unusual radiation pattern is probably the phase shift of electric field in the radiating slot. It is clearly seen from the electric field pattern for 0.612422 GHz that there is phase shift, whereas for other frequencies especially when the radiation pattern is normal broadside there is no phase shift in the electric field(Figure 38).

Table 2 : Parameters for Type 1 Design 1

Parameters	Value	Parameters	Value	Parameters for calculating (μ_s)	Value
Length(L)	35mm	Permittivity for DPS(ε_1)	53	ω	4398229715
Width(W)	62mm	Permeability for DPS(μ_1)	1	ω_o	3455751919
Chosen resonance frequency(fr)	0.7GHz	Permittivity for MNG(ε_2)	27	δ	50MHz
Ratio between DPS & MNG(η)	0.7182	Permeability for MNG(μ_2)	-0.4747	Calculated (μ_s)	1.91
Hight(h)	3mm				

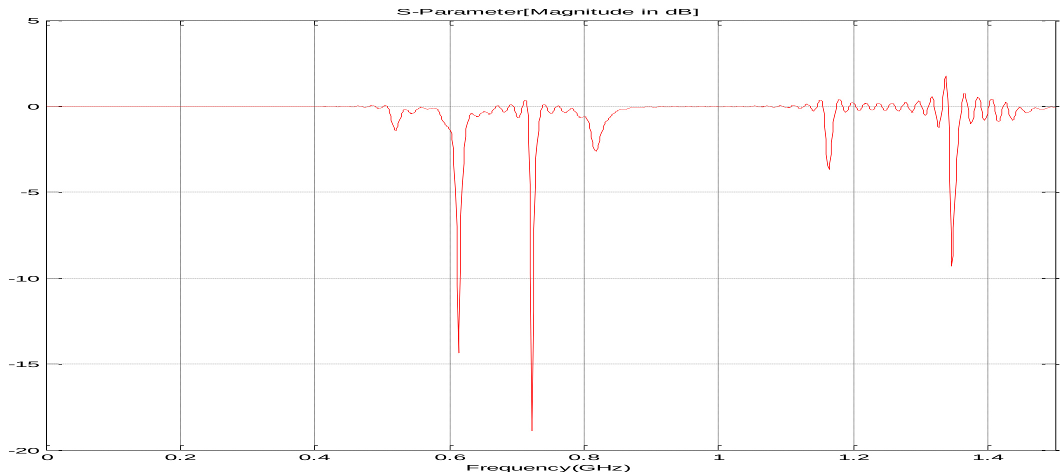


Figure 36 : S-parameter for Type 1 Design 1

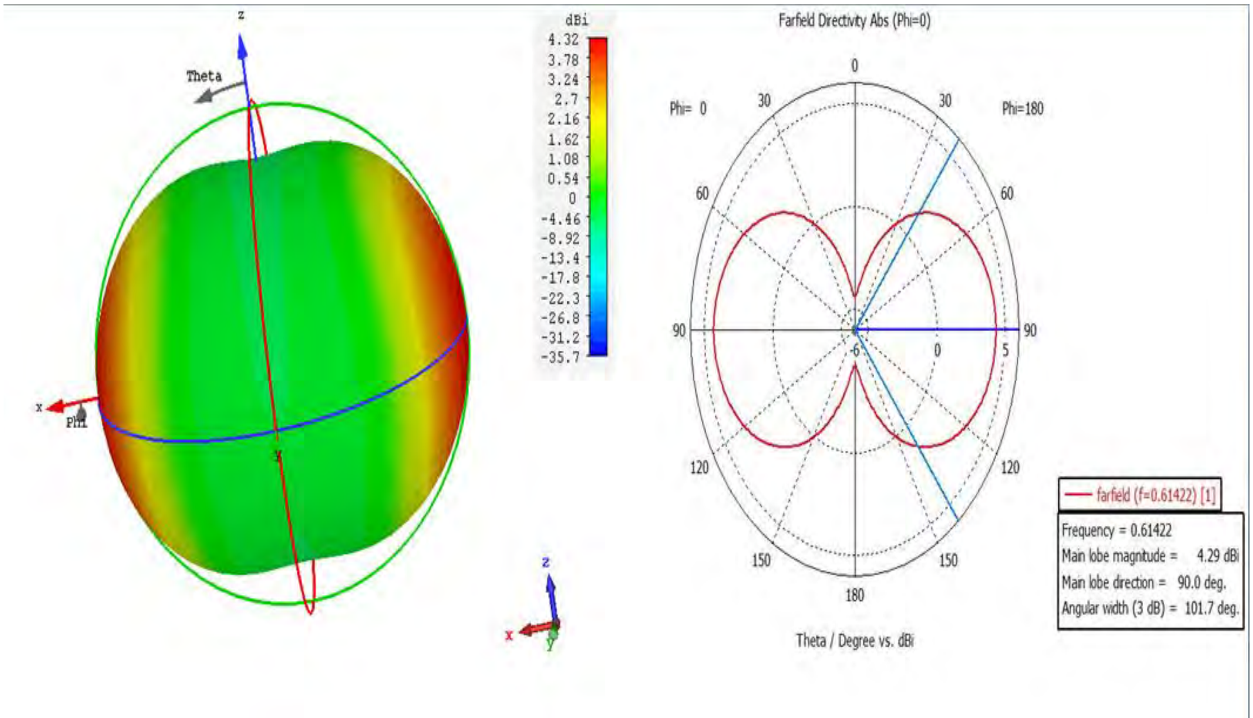


Figure 37 : 3D and 1D radiation pattern for directivity at 0.61422 GHz for Type 1 Design 1

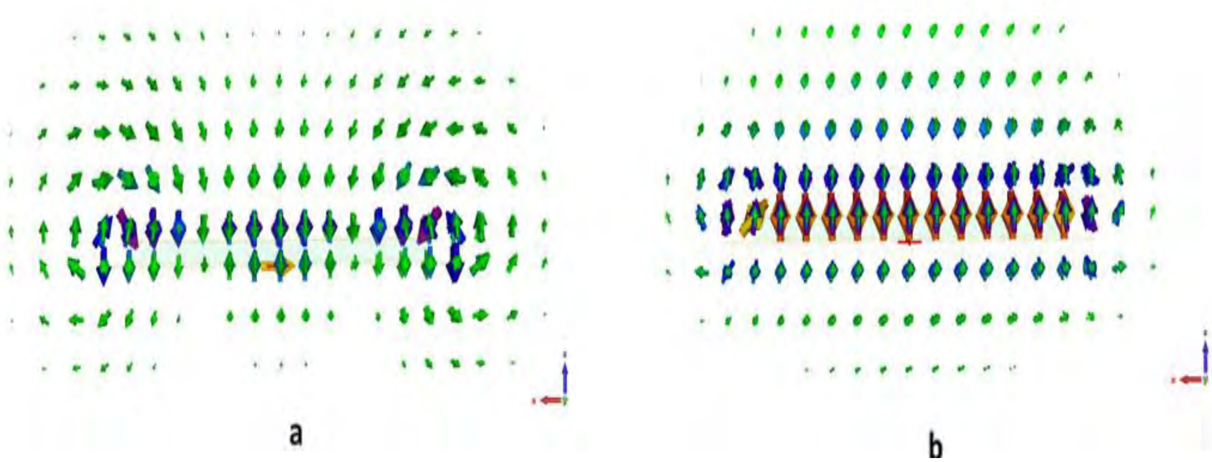


Figure 38: Electric field pattern for (a)0.61422GHz (b) 0.72376GHz

The following is another design designed maintaining the same principal as the previous one. The chosen resonant frequency for this design is 0.9 GHz. The novel radiation pattern with two lobes is achieved at 0.79945 GHz. The parameters are mentioned in table 3.Figure37 shows the s parameter and Figure 38 shows the 3D and 1D radiation pattern.

Table 3 : Parameters for Type 1 Design 2

Parameters	Value	Parameters	Value	Parameters for calculating (μ_s)	Value
Length(L)	33mm	Permittivity for DPS(ε_1)	29	ω	5654866776
Width(W)	62mm	Permeability for DPS(μ_1)	1	ω_o	4838052687
Chosen resonance frequency(fr)	0.9GHz	Permittivity for MNG(ε_2)	29	δ	50MHz
Ratio between DPS & MNG(η)	0.7273	Permeability for MNG(μ_2)	-0.3131	Calculated (μ_s)	1.366
Hight(h)	3mm				

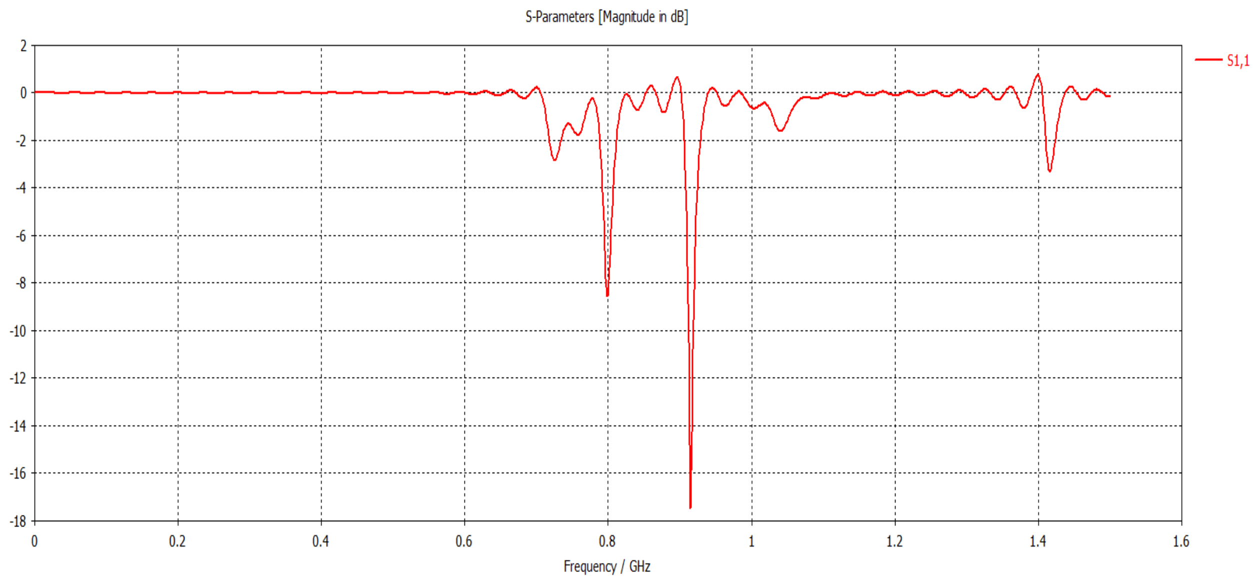


Figure 39 : S-parameter for Type 1 Design 2

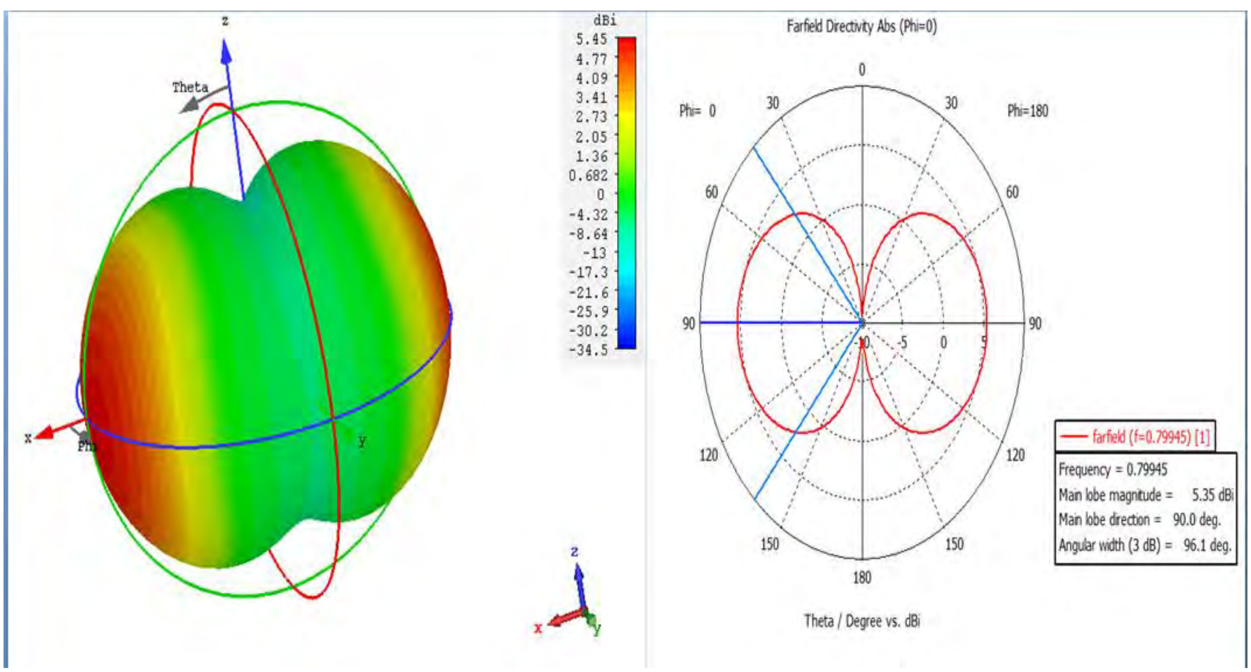


Figure 40 : 3D and 1D radiation pattern for directivity at 0.79945 GHz for Type 1 Design 2

Though this Type 1 design satisfies the primary target of shifting the conventional broadside radiation pattern, it has some negative sides as well. First of all this design cannot provide any acceptable gain, as a result this type of antenna is practically unusable. Furthermore as there is two lobes directly opposite each other the average power is divided between the two lobes, this reduce the antenna efficiency. So, in spite of having a very good reflection coefficient and directivity this design is not very useful. But this design technique provides some important information. For example prior to this design the width of rectangular patch antenna was not considered as an important factor. The width has always been considered smaller than the length. But change in the width brought some significant change to the radiation pattern. It was the key factor for shifting the radiation pattern. Also this design provided ideas about conventional TM_{001} and TM_{002} . These ideas will be used for the type 2 design which will solve many of the problems of type 1 design.

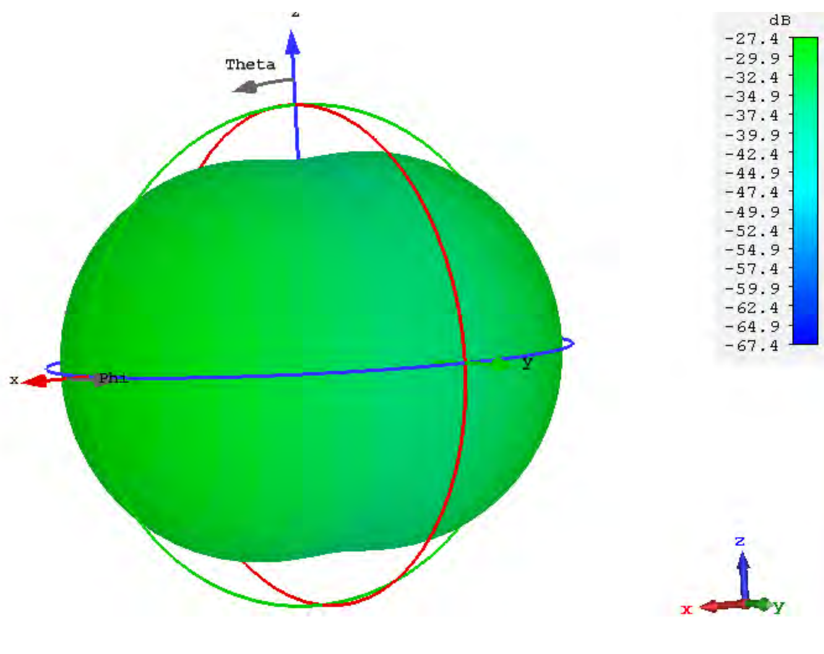


Figure 41 : Unacceptable gain for Type 1 Design

5.2 Type 2 Designs

The main problem for type 1 design was that it had no acceptable gain for any of the resonance frequencies. The main reason behind this problem was the low frequency. Normally for high frequency the directivity and gain of any antenna is almost the same. So if an antenna has an acceptable directivity it can be automatically considered that it has acceptable gain. But for low frequencies the gain decreases drastically even if there is acceptable directivity. The solution for this problem is obviously to use higher frequency. But it is quite difficult to design antenna with higher frequencies using MNG metamaterial. So in the type 2 design ENG metamaterial has been used. The concept of larger width than length has also been used in the type 2 design. In the primary steps it had been very difficult to get the desired radiation pattern for desired frequency. So lots of design has been simulated. Some of the results provided satisfactory results. The antennas with satisfactory results were designed using lot of assumptions.

For the type 2 design we tried to consider the lowest possible dimension. So we considered the length of our novel design 15 mm. At first we considered a rectangular patch antenna of length 15mm and $\varepsilon = 24.4$ and $\mu = 1$. As we are considering TM_{001} and TM_{002} mode the width has been considered larger than the length (25mm).After simulation the first two resonant frequencies for the reflection coefficient have been found at 2.1505 GHz and 4.1394 GHz. 2.1505 GHz can be considered as TM_{001} mode and 4.1394 GHz can be considered as TM_{002} mode. Now for the DPS and ENG juxtaposed design we considered the same dimension. The value of permittivity and permeability for DPS is same as the single DPS substrate antenna ($\varepsilon_1 = 24.4$ and $\mu_1 = 1$). The rest of the parameters are calculated using the algorithm [28].The parameters are mentioned in the table 4. We chose a resonance frequency 3.25 GHz which is between the two modes. After simulation the maximum resonance was found at 4.0907GHz. The radiation pattern at this frequency is quite interesting. It has a directivity of 3.4 dBi and a gain of 3.36 dB. The main lobe covers an area from 0 degree to 90 degree with a maximum gain at 28.0 degree. The S-parameter for antenna with only DPS is shown in figure 40 whereas S-parameter for juxtaposed DPS and ENG is shown in figure 41. Figure 42 shows the 3D and 1D radiation pattern for the maximum frequency.

Table 4 : Parameters for Type 2 Design 1

Parameters	Value	Parameters	Value	Parameters for calculating (μ_s)	Value
Length(L)	15mm	Permittivity for DPS(ε_1)	24.4	ω	20420352240
Width(W)	31mm	Permeability for DPS(μ_1)	1	ω_o	19163715190
Chosen resonance frequency(fr)	3.25GHz	Permittivity for ENG(ε_2)	-0.722	δ	50MHz
Ratio between DPS & MNG(η)	0.8182	Permeability for ENG(μ_2)	9.6	Calculated (ε_r)	1.233
Hight(h)	3mm				

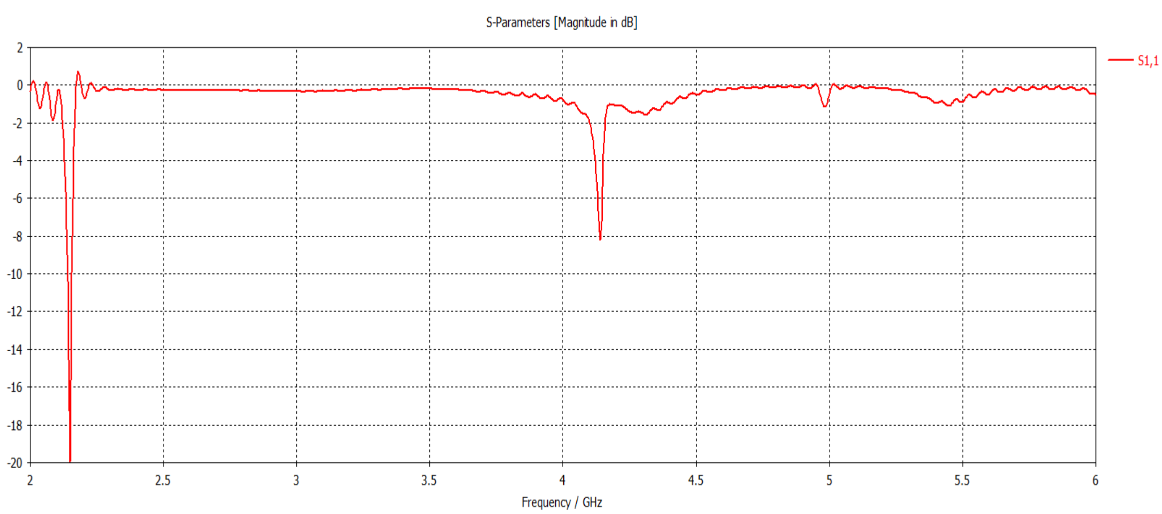


Figure 42 : S-parameter for Type 2 Design 1(with only DPS substrate)

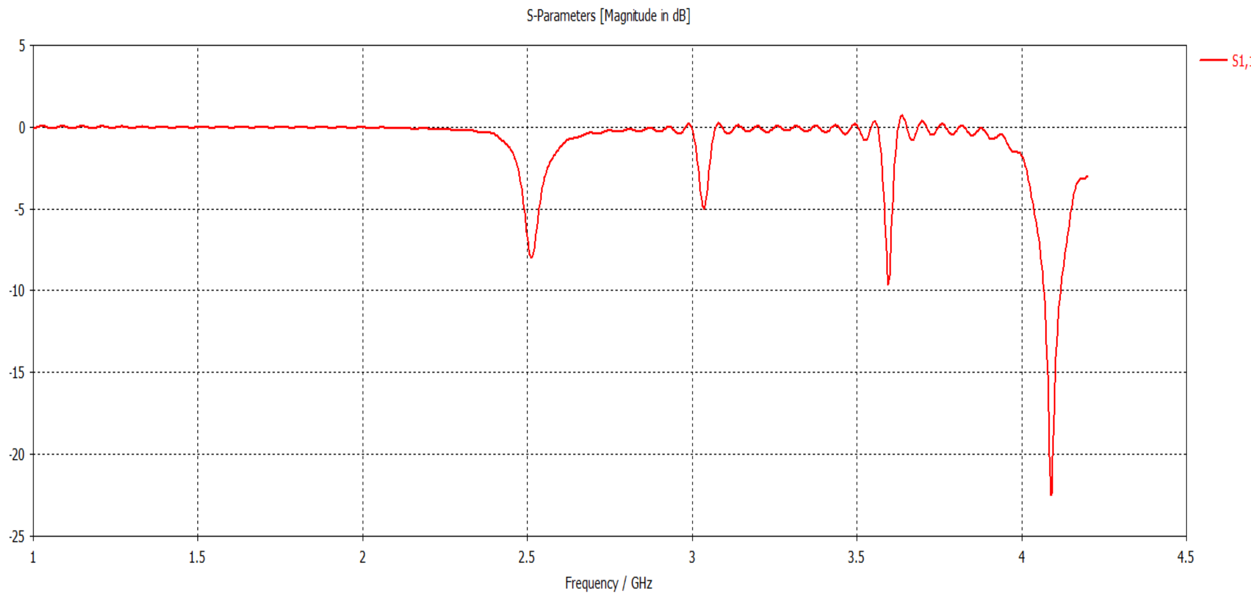


Figure 43 : S-parameter for Type 2 Design 1(with DPS & ENG juxtaposed substrate)

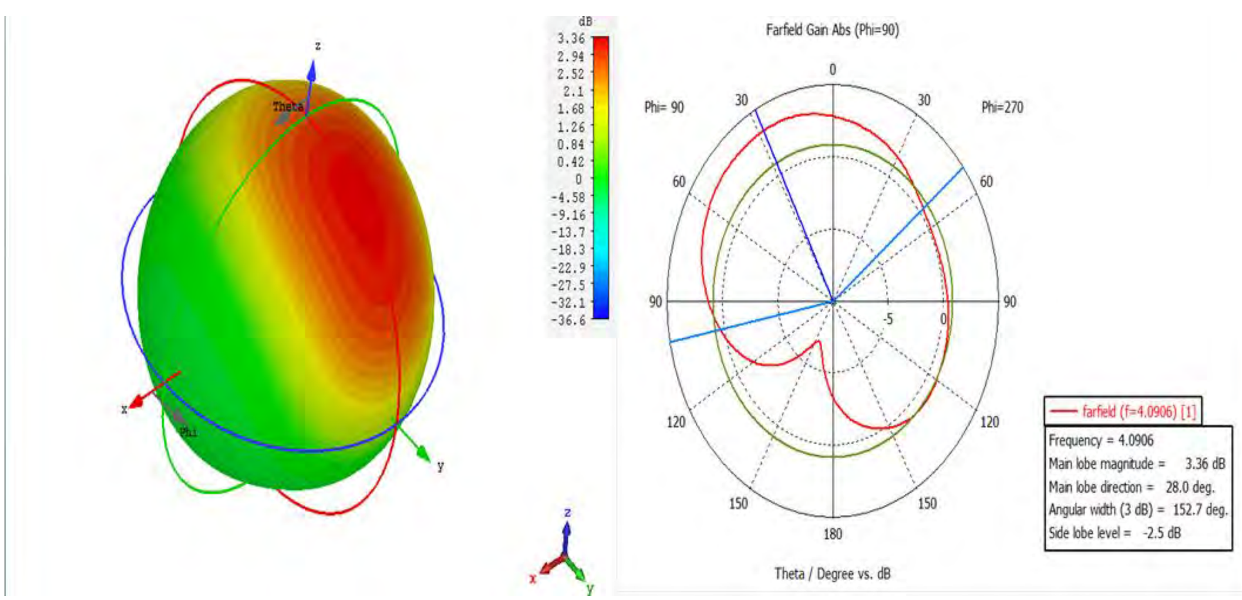


Figure 44 :3D and 1D radiation pattern for directivity at 4.0906GHz for type 2 design 1

Similarly we designed another antenna. This time the length of the antenna has been chosen to be 25 mm while the width is 31mm. Using $\varepsilon = 26.1$ and $\mu = 1$ an antenna with only DPS substrate was designed at first. The resonance frequency for TM_{001} and TM_{002} has been found at 2.4414 and 3.3952. This time for the DPS and ENG juxtaposed design we considered the resonance frequency at 3.8 GHz which is above the TM_{002} mode .Other parameters were calculated using the algorithm as done for previous design. After simulation the maximum resonance was found at 3.0859 GHz. For this design there were resonance for multiple other frequencies as well but none of the radiation pattern for those frequencies showed acceptable results. At 3.0859GHz the radiation pattern showed similar results as the previous design. We considered this frequency as $TM_{oo\delta}$ mode where $1 < \delta < 2$. The value of gain and directivity was 2.78. It had the maximum gain at 66 degree and almost covered an area from 0 degree to 90 degree.

Table 5 : Parameters for Type 2 Design 2

Parameters	Value	Parameters	Value	Parameters for calculating (μ_s)	
Length(L)	25mm	Permittivity for DPS(ε_1)	26.1	ω	23876104170
Width(W)	31mm	Permeability for DPS(μ_1)	1	ω_o	22619467110
Chosen resonance frequency(fr)	3.8GHz	Permittivity for MNG(ε_2)	-0.833	δ	50MHz
Ratio between DPS & MNG(η)	0.5273	Permeability for MNG(μ_2)	2.3	Calculated (μ_s)	1.21
Hight(h)	3mm				

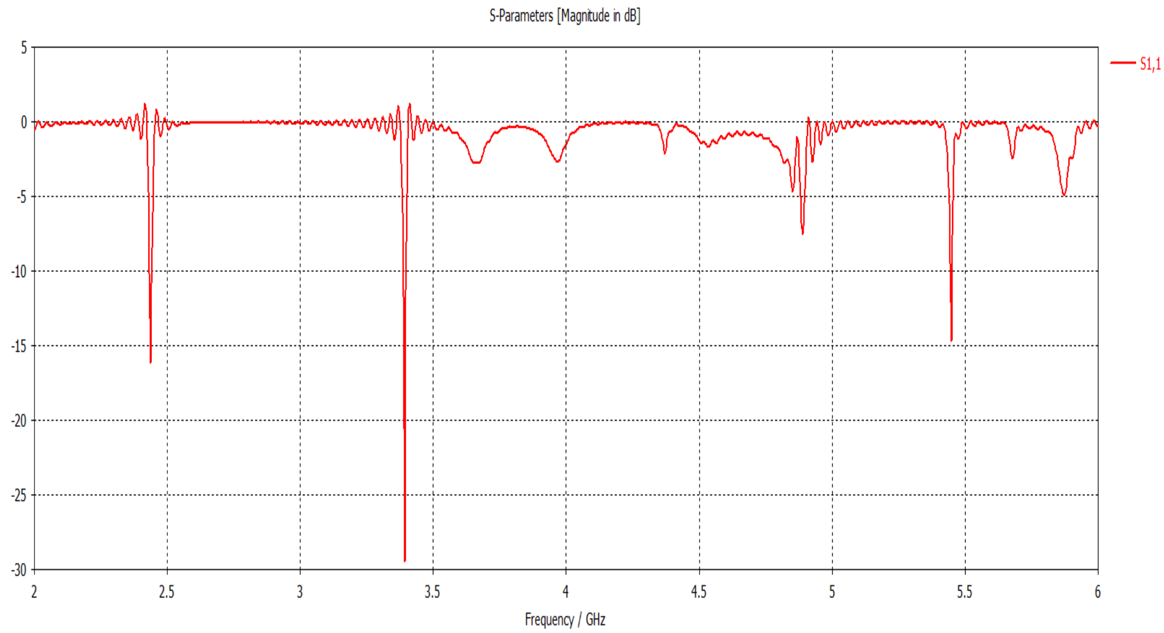


Figure 45 : S-parameter for Type 2 Design 2(with only DPS substrate)

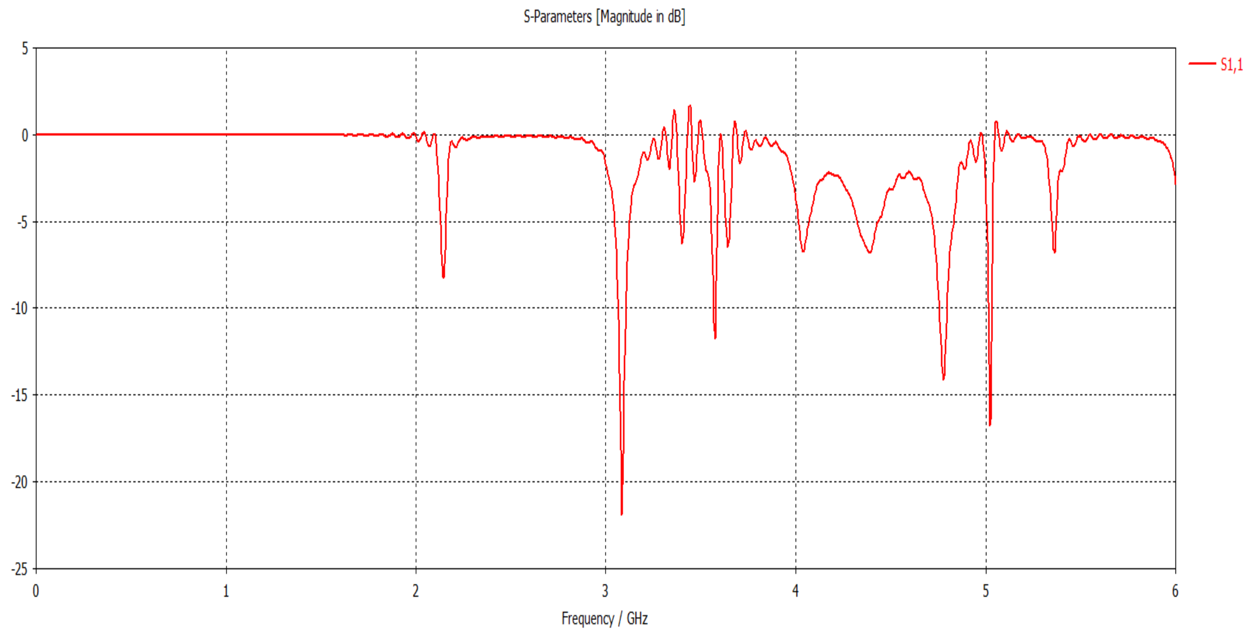


Figure 46 : S-parameter for Type 2 Design 2(with DPS & ENG juxtaposed substrate)

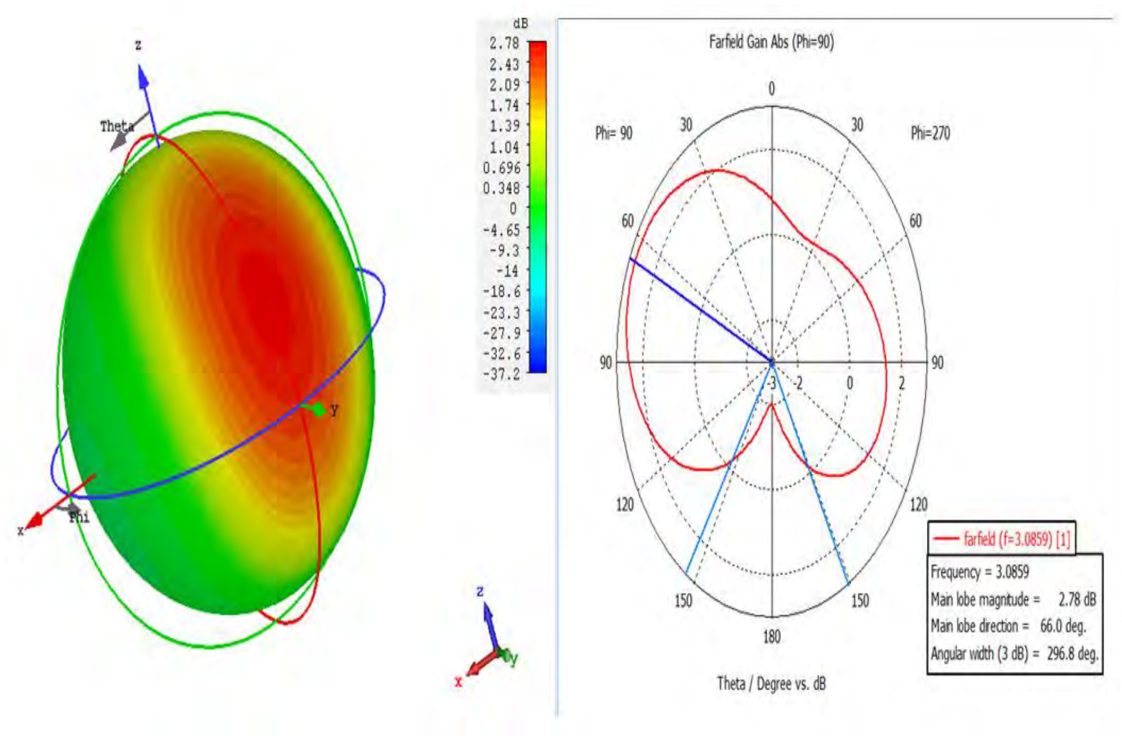


Figure 47 : 3D and 1D radiation pattern for directivity at 3.0859GHz for Type 2 Design 2

Chapter 6
RESULTS AND CONSTRUCTIVE DISCUSSION

6.1 Results and Constructive Discussion

From different works of Nader Engheta, Andrea Alu, Filiberto Bilotti and many others [6-14 & 17-24] it has been found that mematerial can play an important role in reducing size of rectangular microstrip patch antenna because of its unusual physical properties. Based on this phenomenon some designs of rectangular microstrip patch antennas have already been provided. In our novel contribution we analyzed the characteristics and design mechanism of rectangular microstrip patch antenna. We also studied different aspects of metamaterial. Finally we proposed two types of design based on our thesis. Our novel designs have shifted radiation pattern. They also have unique physical parameters. Furthermore analyzing the operating modes of normal rectangular microstrip patch antenna and previously provided designs containing metamaterial we came up with a new mode configuration for metamaterial based patch antennas. In this section we will thoroughly explain our results of thesis and discuss their consequences. Firstly we will focus on the mode modification factor of our novel design then we will discuss about the shifted radiation pattern followed by size reduction factor and directivity and gain factor. Finally we will explain overall efficiency and pros and cons of our proposed design.

A. **Mode modification:** Any waveguide thus an antenna operates in certain mode. Rectangular microstrip patch antenna is one kind of rectangular waveguide so it operates in TM mode. We have briefly discussed about different modes in section 3.2.2. Normally a rectangular microstrip patch antenna operates in TM_{010} mode. Because TM_{010} mode offers the lowest order resonant frequency. Mode of any rectangular microstrip patch antenna depends on the size of length and width ant the permittivity and permeability of the substrate material. The basic condition for TM_{010} mode is $L > W > h$. If this condition is fulfilled then the resonant frequency will be $(f_r)_{010} = \frac{1}{2L\sqrt{\mu\varepsilon}}$. For this mode the electric field in the two radiating slots appear directly opposite to each other. The primary design of metamaterial based rectangular microstrip patch antenna provided by Alu et al. [24] did not define any mode for their proposed design. But based on the dimension of the antenna it can be claimed that it operated in TM_{010} mode. Later Xiong et al. focused on the mode factor and provided a design in [25]. This design supported TM_{020} mode. This is a mode that provides the second lowest resonant frequency. The electric field and magnetic field configuration of this mode is almost same as TM_{010} but it has an extra phase shift in the non radiating slot. In a very recent work by Mahdy et al. [27] a modified $TM_{0\delta 0}$ mode was introduced.

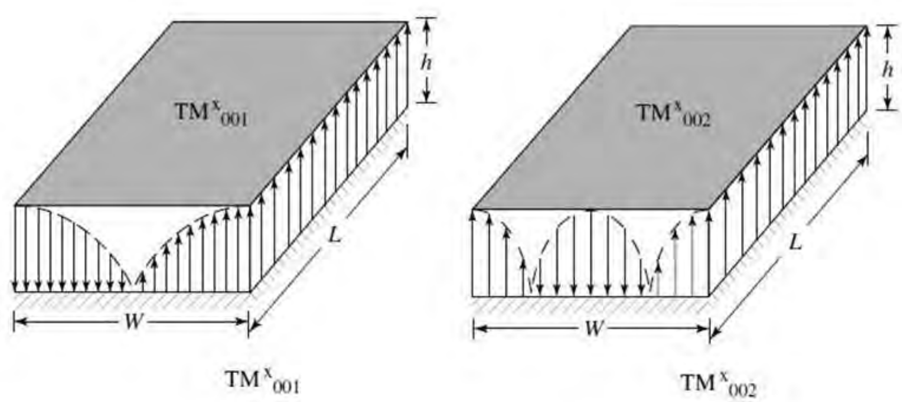


Figure 48 : Electric field configuration for TM_{001} and TM_{002}

As mentioned in section 11 of our thesis we have introduced another mode of operation. We have defined this mode as $TM_{0\delta 0}$ mode. This is a modified mode for TM_{001} and TM_{002} mode where $0 < \delta < 1$ *or* $1 < \delta < 0$. For the first time we have tried to use this configuration for metamaterial based patch antenna. Even this mode is not common for normal patch antenna. Before our novel contribution this mode was not used because it could not provide normal broadside radiation pattern. The main reason behind the absence of normal broadside radiation pattern is that in this type of mode configuration there is a phase shift in electric field in the radiating slots. As our primary target was to shift the radiation pattern we tried use this mode in our design. The condition for TM_{001} *and* TM_{002} is W>L>h . In our proposed design we considered the width size bigger than the length. After simulation of our designs we found that for type 1 design (MNG & DPS juxtaposed substrate) there is indeed a phase shift in electric field in the radiating slot(Figure 38) for a certain frequency and only in that frequency we achieve a shifted radiation pattern. So our proposed Type 1 design is a successful demonstration of $TM_{00\delta}(0 < \delta < 1)$ mode. We are not clarifying this mode as perfect TM_{001} mode because the use of second material (MNG) and shifting property of frequency due to the dependence of multiple variables the resonant frequency is not the same as the calculated resonant frequency. Furthermore, resonant frequency for $TM_{001}$is calculated using the formula $(f_r)_{001} = \frac{1}{2W\sqrt{\mu\varepsilon}}$, while using juxtaposed metamaterial the μ and ε have some modified value that cannot be calculated. As the resultant frequency is smaller than the frequency for TM_{001} mode we define it as $TM_{00\delta}(0 < \delta < 1)$.

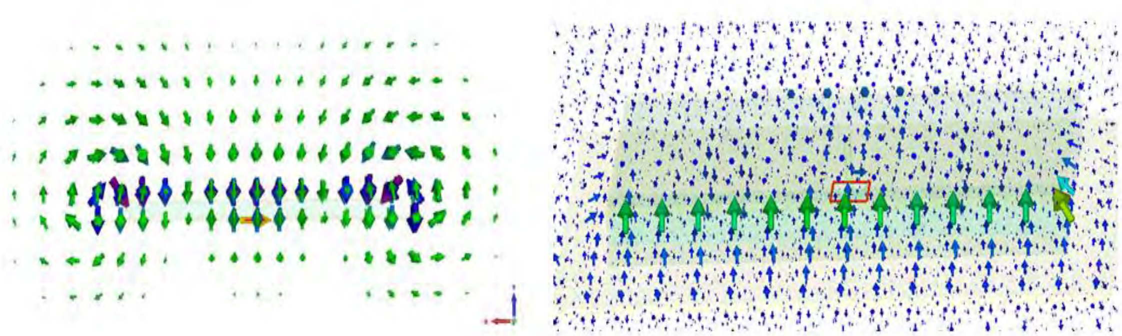


Figure 49 : Electric field configuration in radiating slot for Type 1 and Type 2 design

Type 2 design parameters were also selected based on the of TM_{002} mode but after simulation it has been found that there is no phase shift in electric field in the radiating slots rather the magnitude of electric field in one of the radiating slot is larger than the other. So Type 2 design is not a successful demonstration of modified TM_{002} *or* TM_{001} mode .The electric field in this case might have experienced some other properties that changed the phase pattern and this phenomenon requires further research.

B. **Shifted Radiation Pattern:** It has already been mentioned that shifting the radiation pattern of rectangular microstrip patch antenna is the main target of our thesis. We have successfully achieved our target. In fact we have been able to achieve two types of radiation pattern that is different from the normal broadside radiation pattern. The design of first metamaterial based patch antenna provided by Alu et al. [24] did not have a usual broadside radiation pattern. They claimed their radiation pattern unusual but did not provide any reason for change. Furthermore it was an unexpected radiation pattern so it was simply overlooked. But in our novel contribution we have intentionally achieved shifted radiation pattern. Type 1 design provided radiation pattern in the end fire direction with two sided lobes. To explain further if the perpendicular direction situated on the plane of the patch is considered 0 degree then our type 1 design had two separate lobes at 90 degree and -90 degree. 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 $TM_{00\delta}$ mode. The reason behind this two sided lobe radiation pattern is mainly the electric field configuration in the radiating slot. This phenomenon is already discussed in the previous section. An interesting fact about this radiation pattern is that the tow lobes are created across the non radiating slot.

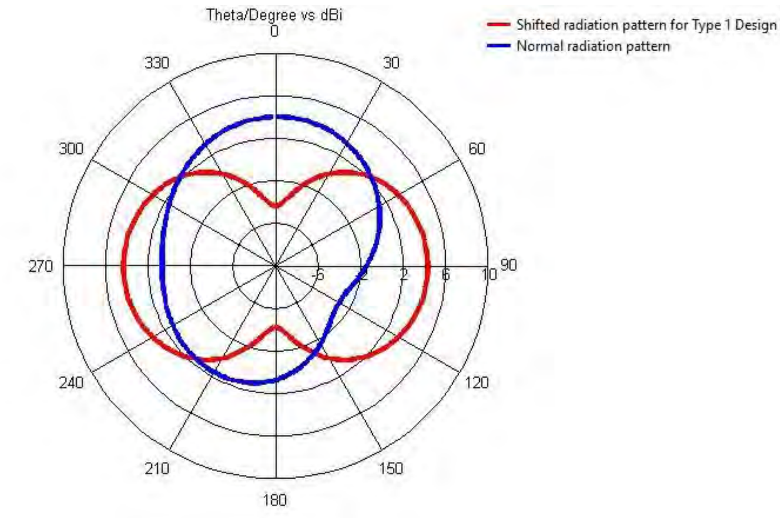


Figure 50 : Radiation Pattern comparison for Type 1 Design

Type 2 design also has a shifted radiation pattern but unlike the type 1 design it has a single lobe in one side. The single lobe is shifted towards one of the radiating slot. Normally it shifted to the side of the mematerial and away from the coaxial port. Practically single lobed radiation pattern is a much better radiation pattern so Type 2 design is better option than type 1 design in terms of radiation pattern. The reason behind this one sided radiation pattern is not clear. Though this design is quite same as type 1 design in terms of width to length ratio but resonance frequency does not react the same way it did for type 1 design. Moreover it is much complex procedure to achieve resonance at a certain frequency. Unlike type 1 design, type 2 design is multiple band configurations. From experimented results it has been confirmed that the one side shifted lobed radiation pattern occurs for the resonance frequency that have the minimum reflection coefficient. And based on the electric field pattern for different resonance frequencies it can be confirmed that this unique radiation pattern is achieved when the electric field in one of the radiating slot is much higher than the other in magnitude.

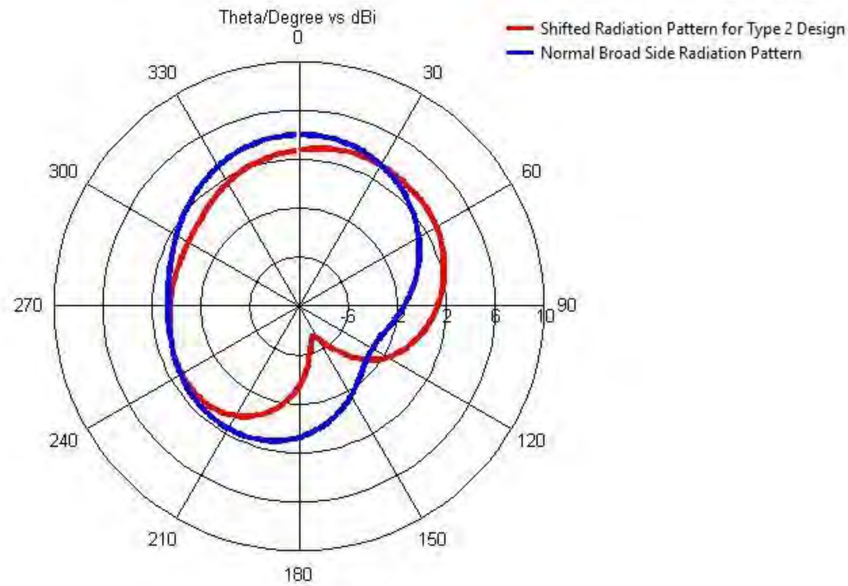


Figure 51 : Radiation Pattern comparison for Type 2 Design

C. **Size reduction factor:** Miniaturization is the main reason metamaterial is introduced in the field of rectangular patch antenna design. Alu et al. [24] reduced the size of antenna at a great instinct. It was the first successful miniaturization of rectangular patch antenna. Later Xiong et al. [25] tried to develop the idea of using metamaterial in microstrip antenna. They introduced TM_{020} mode with better radiation pattern but could not reduce the dimension. In fact their proposed design did not work below the dimension of $72.8mm \times 50mm$. In [27] Mahdy et al. built up a design algorithm and proposed a design that reduced the size of antenna furthermore. Their smallest dimension of rectangular patch antenna using MNG was $25mm \times 18mm$ and $30mm \times 22mm$ using ENG. Our proposed novel design is not a success in terms of size reduction. The smallest dimension for Type 1 design (MNG) is $33mm \times 62mm$. This dimension is larger than the dimension of antenna design provided by Mahdy et al. in [27]. One of the resign for a larger dimension is the pre condition for $TM_{001} and\ TM_{002}$ mode which is $W > L > h$. So the width had to be larger than the length. The dispersive equation provided by Engheta et al. in[21] suggests that proper dispersion of wave does not depend on the total length of the juxtaposed layer but depends on the ratio of thickness or length, this equation therefore suggests that the total length of the antenna can be of any small length as long as the filling ratio of DPS and metamaterial maintains the equation. But in practical very small length does not provide satisfactory results. Moreover the range of $k_1 \eta L_p$ has to be maintained. For MNG material this range is $135° < k_1 \eta L_p < 180°$. As $k_1 = 2\pi f \sqrt{\mu_1 \varepsilon_1}$, in order to maintain the range frequency had to be considered small. But if the frequency is considered small then in order to satisfy the dispersive equation Lp cannot be very small. Taking all this matter into consideration and after lots of trial and error it was satisfactory result was found for the smallest dimension of $33mm \times 62mm$. Type 2 design on the other hand has smaller dimension than type 1 design. The smallest possible dimension for type 2 design is $15mm \times 31mm$ .It is nearly half the size of type 1 design. As ENG is used in type 2 design the condition for $k_1 \eta L_p$ is $180° < k_1 \eta L_p < 225°$. This allows choosing a higher frequency thus a smaller length. So it can be said that both type 1 and type 2 designs did not allow sufficient size reduction. But using the shifted radiation pattern these deigns can be used to reduce antenna array size.

D. **Directivity and Gain factor:** Directivity and Gain are two important parameters of antenna. In order for practical use of any antenna it must have both positive directivity and gain. Our proposed type 1 design though has positive directivity but does not have positive gain. It is a huge flow for the type 1 design. But luckily type 2 design has both positive directivity and gain. While using juxtaposed DPS and metamaterial if very small length and low frequency is used the gain of an antenna becomes unstable. This is a much resent finding. Most of the previous works mentioned in our thesis did not take Gain and directivity factor separately because in normal case the directivity and gain of any antenna is almost same. So they considered positive directivity as success. The main reason behind introducing type 2 design is the absence of positive gain in type 1 design. As type 2 design supports high frequencies it has nearly same directive and gain value as normal antennas.

To summarize, Type 1 design uses MNG as metamaterial and is designed for low frequency (UHF and L Band) with a larger dimension. This type of design has 2 side lobed radition pattern along the non radiating slots.Type 2 design on the other hand uses ENG as the metamaterial. It can be used to design antenna for high frequencies(S and C band) and has smaller dimension than type 1 design .This design provides radiation pattern that has one lobe shifted on one side of the two radiating slots. The negative side of type 1 design is it does not have acceptable gain and the average power divides because of the two sided lobe. Whereas type 2 design has both acceptable gain and directivity and maximum power in a single direction. So Type 2 design can be considered as much more acceptable design. But type 2 design is much more difficult and unpredictable. Because type 2 design does not follow any rules that can be followed without question. It has a lot of exceptions. For example most of the time the radiation pattern has a large side lobe which divides the power. The one lobe shifted radiation pattern designs shown in the previous section are not the usual case. Furthermore this design is not handy to design antenna for a particular frequency, but it can definitely be used if there is flexibility in the frequency range.

Chapter 7
FUTURE WORK AND CONCLUSION

7.1 Future Work

In this thesis we were able to use modified modes of rectangular patch antenna and shift the radiation pattern. The future work will involve size reduction of antenna array. The proposed designs were not able to provide size reduction technique. In fact with the proposed design it was not possible to design antenna with the existing smallest dimension. But it can turn an antenna array into a much smaller size. Normally rectangular microstrip patch antenna has a broad side radiation pattern. So when creating an array with the normal rectangular patch design the array the single antenna slots are kept vertically side by side so the size of the array is larger than the multiple of the surface area of a single antenna. But with antennas configured based on our proposed design if the antennas are kept horizontally in the array it will consume much smaller area. This area will be slightly larger than the combined thickness of single antennas. But the radiation pattern will remain at the same direction which is above the plane. This idea is explained graphically in figure 52. Variation of radiation pattern can also be a huge scope for research. If a pattern can be discovered for the change of radiation pattern of rectangular patch antenna then it will provide much wider scope for rectangular patch antenna use.

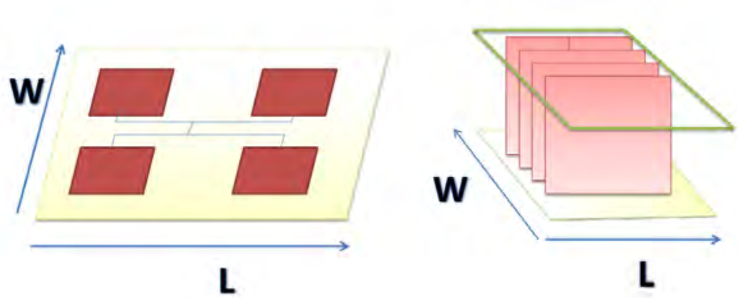


Figure 52 : Miniaturization of rectangular patch antenna array

7.2 Conclusion

In this contribution we have analyzed and studied the characteristics of rectangular microstrip patch antenna. We then studied the use of metamaterial as a substrate component for patch antenna. After analyzing the previous works related to microstrip antenna manufacturing using metamaterial we set our primary target to changing the normal broadside radiation pattern. Our main goal was to use the design with novel radiation pattern in miniaturizing rectangular patch antenna array. While trying to shift the normal broadside radiation pattern we found that it is quite impossible to shift the radiation pattern while antenna is working in conventional mode like TM_{010} and TM_{020} or any hybrid mode like $TM_{0\delta 0}(0 < \delta < 2)$. So we introduced a new $TM_{00\delta}$ mode . This mode is similar to the conventional TM_{001} and TM_{002} modes. Designing antenna in this new mode we achieved significant success. We were able to shift the radiation pattern. We provided two types of design. Using MNG metamaterial we proposed Type 1 design for low frequency and using ENG metamaterial we proposed Type 2 design for High frequency. We tried to establish a guideline for designing antenna with shifted radiation pattern. Our type one design is a successful demonstration of $TM_{00\delta}$ mode. It has tow side lobed radiation pattern.But it does not have positive gain. Type 2 design on the other hand provides positive gain but it cannot be designed for particular frequency. Our proposed antenna is very simple in terms of physical structure.It is simply some solid blocks of material engineered to function as an anmtenna. This is the main reason behind the increasing demand of rectangular patch antenna. There are some techniques available such as introducing air gap inside the substrate, cutting the edges of patch or different feeding methods etc. These techniques can increase the gain and directivity or improve the s-parameter. But we have not considered these techniques in our thesis. We have tried to provide all the required features within the simplest design possible. These gain increasing techniques might help to overcome some of the negative sides of our proposed design, especially the absence of positive gain in type 1 design. Using metamaterial to fabricate rectangular microstrip patch antenna was a revolutionary idea. In our contribution we have tried to give the metamaterial based antenna design a new dimension. Our contribution is not a criticism of the previous works but merely a clarification. We wish to carry on our work from here and onwards.

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