Design and Analysis of Two Element MIMO Antenna for
5G Applications

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Certificate of Approval

This is to certify that the thesis entitled "Design and Analysis of Two-Element MIMO Antenna for 5G Applications" submitted by Antardip Majumder to Indian Institute of Information Technology, Guwahati, is a record of bona fide research work under my supervision and I consider it worthy of consideration for the award of the degree of Master of Technology in Electronics and Communication Engineering at Indian Institute of Information Technology Guwahati.

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Chapter-1:

Introduction

1.5G Technology:

5G is the 5th generation mobile network. It is a new global wireless standard after 1G,2G,3G and 4G networks. 5G enables a new kind network that is designed to connect virtually everyone and everything together including machines, objects, and devices.

5G wireless technology is meant to deliver higher multi-Gbps peak data speeds, ultra-low latency, more reliability, massive network capacity, increased availability, and a more uniform user experience to more users. Higher performance and improved efficiency empower new user experiences and connects new industries.

Performance:

i)Speed:

5G speeds will range from around 50mbps to 1000mbps depending on the RF Channel and base station load. Faster speed requires use of the mm-Wave bands, reaching 4Gbps with carrier aggregation and MIMO , assuming a perfect channel and no other base station load .

Sub-6 GHz 5G by far the most common, can deliver between 10 and 1,000 Mbps; it will have a much further reach than mm-Wave bands. In the sub-6 bands, C-Band (n77/n78) was deployed by various U.S. operators in 2022. C-Band had been planned to be deployed by Verizon and AT&T in early January 2022 but was delayed due to safety concerns raised by the Federal Aviation Administration.

Low bands (such as n5) offer a greater range, thereby a greater coverage area for a given cell, but their speeds are lower than the mid and high bands.

ii)Latency:

In 5G, the ideal "air latency" is of the order of 8 to 12 milliseconds i.e., excluding delays due to HARQ retransmissions, handovers, etc. Retransmission latency and backhaul latency to the server must be added to the "air latency" for correct comparisons. Verizon reported the latency on its 5G early deployment is 30 ms. Edge Servers close to the towers can probably reduce latency to between 10 and 15 milliseconds.

Latency is much higher during handovers; ranging from 50 to 500 milliseconds depending on the type of handover. Reducing handover interruption time is an ongoing area of research and development; options include modifying the handover margin (offset) and the time-to-trigger (TTT).

iii) Error Rate:

5G uses adaptive modulation and coding scheme (MCS) to keep the bit error rate (BLER) extremely low. Whenever the error rate crosses a (very low) threshold the transmitter will switch to a lower MCS, which will be less error-prone. This way speed is sacrificed to ensure an almost zero error rate.

iv)Range:

The range of 5G depends on many factors: transmit power, frequency, and interference. For example, mm-Wave (e.g.: band n258) will have a lower range than mid-band (e.g.: band n78) which will have a lower range than low-band (e.g.: band n5).

Standards:

Initially, the term was associated with the International Telecommunication Union's IMT-2020 standard, which required a theoretical peak download speed of 20 gigabits per second and 10 gigabits per second upload speed, along with other requirements. Then, the industry standards group 3GPP chose the 5G NR (New Radio) standard together with LTE as their proposal for submission to the IMT-2020 standard.

5G NR can include lower frequencies (FR1), below 6 GHz, and higher frequencies (FR2), above 24 GHz. However, the speed and latency in early FR1 deployments, using 5G NR software on 4G hardware (non-standalone), are only slightly better than new 4G systems, estimated at 15 to 50% better.

The standard documents for 5G are organized by 3GPP.

The 5G system architecture is defined in TS 23.501. The packet protocol for mobility management (establishing connection and moving between base stations) and session management (connecting to networks and network slices) is described in TS 24.501. Specifications of key data structures are found in TS 23.003.

Deployment:

Beyond mobile operator networks, 5G is also expected to be used for private networks with applications in industrial IoT, enterprise networking, and critical communications, in what being described as NR-U (5G NR in Unlicensed Spectrum).

Initial 5G NR launches depended on pairing with existing LTE (4G) infrastructure in non-standalone (NSA) mode (5G NR radio with 4G core), before maturation of the standalone (SA) mode with the 5G core network.

As of April 2019, the Global Mobile Suppliers Association had identified 224 operators in 88 countries that have demonstrated, are testing or trialing, or have been licensed to conduct field trials of 5G technologies, are deploying 5G networks or have announced service launches. The equivalent numbers in November 2018 were 192 operators in 81 countries. The first country to adopt 5G on a large scale was South Korea, in April 2019. Swedish telecoms giant Ericsson predicted that 5G internet will cover up to 65% of the world's population by the end of 2025. Also, it plans to invest 1 billion reals ($238.30 million) in Brazil to add a new assembly line dedicated to fifth-generation technology (5G) for its Latin American operations. When South Korea launched its 5G network, all carriers used Samsung, Ericsson, and Nokia base stations and equipment, except for LG U Plus, who also used Huawei equipment. Samsung was the largest supplier for 5G base stations in South Korea at launch, having shipped 53,000 base stations at the time, out of 86,000 base stations installed across the country at the time.

The first fairly substantial deployments were in April 2019. In South Korea, SK Telecom claimed 38,000 base stations, KT Corporation 30,000 and LG U Plus 18,000; of which 85% are in six major cities. They are using 3.5 GHz (sub-6) spectrum in non-standalone (NSA) mode and tested speeds were from 193 to 430 Mbit/s down. 260,000 signed up in the first month and 4.7 million by the end of 2019.

Spectrum:

Large quantities of new radio spectrum (5G NR frequency bands) have been allocated to 5G. For example, in July 2016, the U.S. Federal Communications Commission (FCC) freed up vast amounts of bandwidth in underused high-band spectrum for 5G. The Spectrum Frontiers Proposal (SFP) doubled the amount of millimeter-wave unlicensed spectrum to 14 GHz and created four times the amount of flexible, mobile-use spectrum the FCC had licensed to date. In March 2018, European Union lawmakers agreed to open up the 3.6 and 26 GHz bands by 2020.

As of March 2019, there are reportedly 52 countries, territories, special administrative regions, disputed territories and dependencies that are formally considering introducing certain spectrum bands for terrestrial 5G services, are holding consultations regarding suitable spectrum allocations for 5G, have reserved spectrum for 5G, have announced plans to auction frequencies or have already allocated spectrum for 5G use.

Technology:

i)New Frequency Technology:

The air interface defined by 3GPP for 5G is known as New Radio (NR), and the specification is subdivided into two frequency bands, FR1 (below 6 GHz) and FR2 (24–54 GHz).

ii)Frequency Range:

Otherwise known as sub-6, the maximum channel bandwidth defined for FR1 is 100 MHz, due to the scarcity of continuous spectrum in this crowded frequency range. The band most widely being used for 5G in this range is 3.3–4.2 GHz. The Korean carriers use the n78 band at 3.5 GHz.

Some parties used the term "mid-band" frequency to refer to higher part of this frequency range that was not used in previous generations of mobile communication.

iii)Frequency range 2 (24–71 GHz):

The minimum channel bandwidth defined for FR2 is 50 MHz and the maximum is 400 MHz, with two-channel aggregation supported in

3GPP Release 15. The higher the frequency, the greater the ability to support high data-transfer speeds. Signals in this frequency range with wavelengths between 4 and 12 mm are called millimeter waves.

Cell Types		Deployment environment	Max number of users	Output Power(W)	Max. distance from base station
5G NR FR2	Femto Cell	Homes, business	Home:4-8 Business: 16-32	Indoors:0.01-0.1 Outdoors: 0.2-1	Tens of meters
	Pico Cell	Public areas like shopping malls, airports, train stations, skyscrapers	64 to 128	Indoors:0.1 to 0.25 Outdoors: 1-5	Tens of meters
	Micro Cell	Urban areas to fill coverage gaps	128 to 256	Outdoors: 5-10	Few hundreds of meters
	Metro Cell	Urban areas to provide additional capacity	More than 250	Outdoors:10-20	Hundreds of meters
Wi-Fi (for comparison)		Homes, Business	Fewer than 50	Indoors: 0.02-0.1 Outdoor: 0.2-1	Few tens of meter

2.MIMO:

Multiple Input Multiple Output is an efficient transmission technology used in modern wireless communication. As the name implies, MIMO uses multiple antennas for transmission and reception. Combination of multiple transmission sources enhances higher data rate and system efficiency. Smart devices with wireless standard 802.11n support MIMO technology.

In conventional signal transmission, one antenna sends signal and another antenna pick up the signal at the receiving end. In a basis MIMO system more than one transmitting antennas and single or multiple receiving antennas used for signal transmission simultaneously.

- **<u>Applications of MIMO</u>:**

A.MIMO in LTE, LTE Advanced

MIMO technology can be used in LTE and LTE advanced radio networks for improving network efficiency. With the introduction of MIMO technology, signal disturbances due to multipath have been significantly reduced. MIMO technology make use of multipath phenomenon to maximize transmission by receiving bounced signals from obstructions.

Multipath is a phenomenon in wave propagation. Transmitted signals reflected from buildings, vehicles, trees and other terrain. These reflected signals with slight delay will cause confusion at receiver side and information couldn't be decoded correctly.

In order to increase signal quality and gain, multiple antennas are placed in different directions without interfering the radiation pattern of each antenna. In order to implement MIMO technology, much complex signal processing is required at transmitting and receiver side.

B. MIMO in Wireless LAN:

One of the common uses of MIMO technology today is wireless LAN. Wireless routers with multiples antenna become common nowadays. Data rate can be doubled or multiplied many times with effective use of MIMO technology in wireless routers and mobile devices. In order to have an efficient system, both transmitting and receiving devices must be compatible.

C.5G and Internet of Things:

5G and Internet of Things requires massive data rate. MIMO technology with Beamforming is one of the significant transmission terminologies for super charged 5G networks and IoT. Transmission tower will be equipped with multiple antennas. It will locate a particular user at a specific location and will transmit to that user using multiple antennas simultaneously.

Change in user location can be tracked and user will be handled by the antennas located at the specific direction of user. It enables network operators to offers an uninterrupted service effectively.

MIMO can be used in Internet of Things, smart home, smart cities and connected car applications.

Advantages of MIMO:

i)Higher data rate-with use of multiple Tx and Rx combinations.

ii) Time diversity – a data packet can be transmitted at different time slots.

iii) Frequency diversity – different frequency channels can be used for transmission.

iv) Reduced signal distortion due to multipath phenomenon.

v) Higher accuracy.

Disadvantages of MIMO:

i)System requires higher level of signal processing at transmitter and receiver end.

ii) Implementation is costly.

3.PRINTED ANTENNA:

A microstrip patch antenna is a low-profile antenna that widely used in the microwave frequency region because of its numerous advantages over and other non-planer types antenna surfaces. Some advantages are (i) simple design (ii)comfortability in expensive manufacturing to planar using modern printed circuit technology(iii)mechanical robustness (iv) versatility in terms of resonant frequency, polarization and impedance.

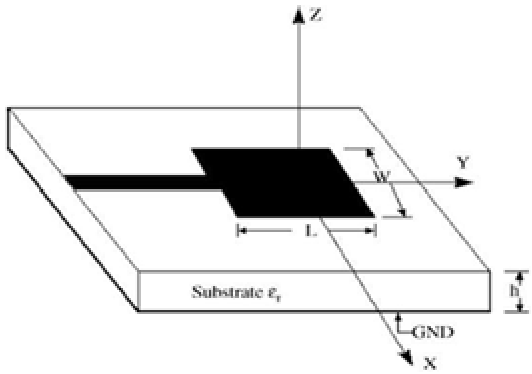


Fig 1.1(a): Geometry of Rectangular Patch Antenna

In order to simplify analysis and performance prediction, the patch is generally square, rectangular, circular, triangular and elliptical or some other common shape as shown in Fig 1.1(b). For a rectangular patch, the length L of the patch is usually $0.3333\lambda < L < 0.5\lambda$, where λ is the free-space wavelength. The patch is selected to be very thin such that $t \ll \lambda$ (where t is the patch thickness). The height h of the dielectric substrate is usually $0.003\ \lambda \leq h \leq 0.05\ \lambda$. For Micro Strip Antenna (MSA) applications in the microwave frequency band, generally h is taken greater than or equal to 1/16th of an inch (0.159 cm). The dielectric constant of the substrate is typically in the range $2.2 \leq r \leq 12$.

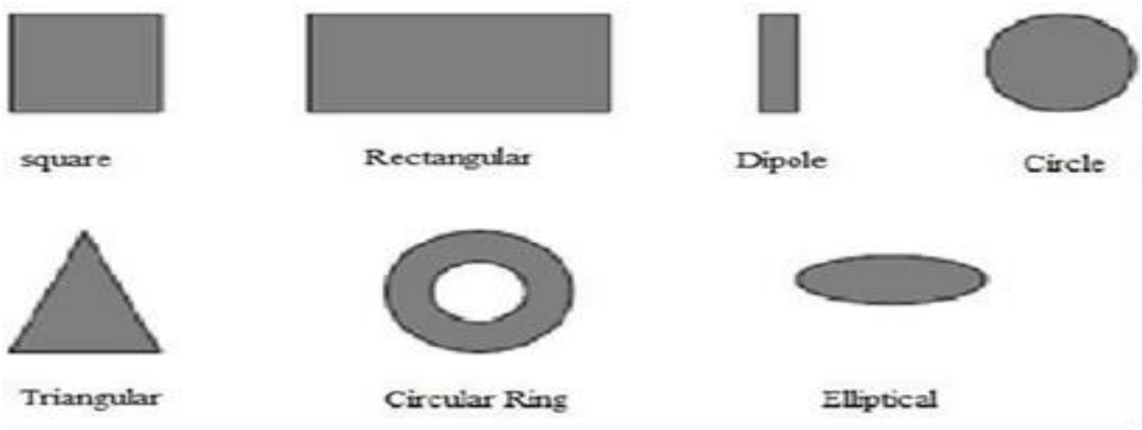


Fig 1.1(b): Different types of Patch Antennas

4.Feeding Technique:

There are different types of feeding methods. They are

A.Inset Feed:

In this type of antenna yields a high input impedance, we would like to modify the feed. Since the current is low at the ends of a half-wave patch and increases in magnitude toward the centre, the input impedance (Z=V/I) could be reduced if the patch was fed closer to the centre. One method of doing this is by using an inset feed (a distance R from the end) as shown in Figure 2(a).

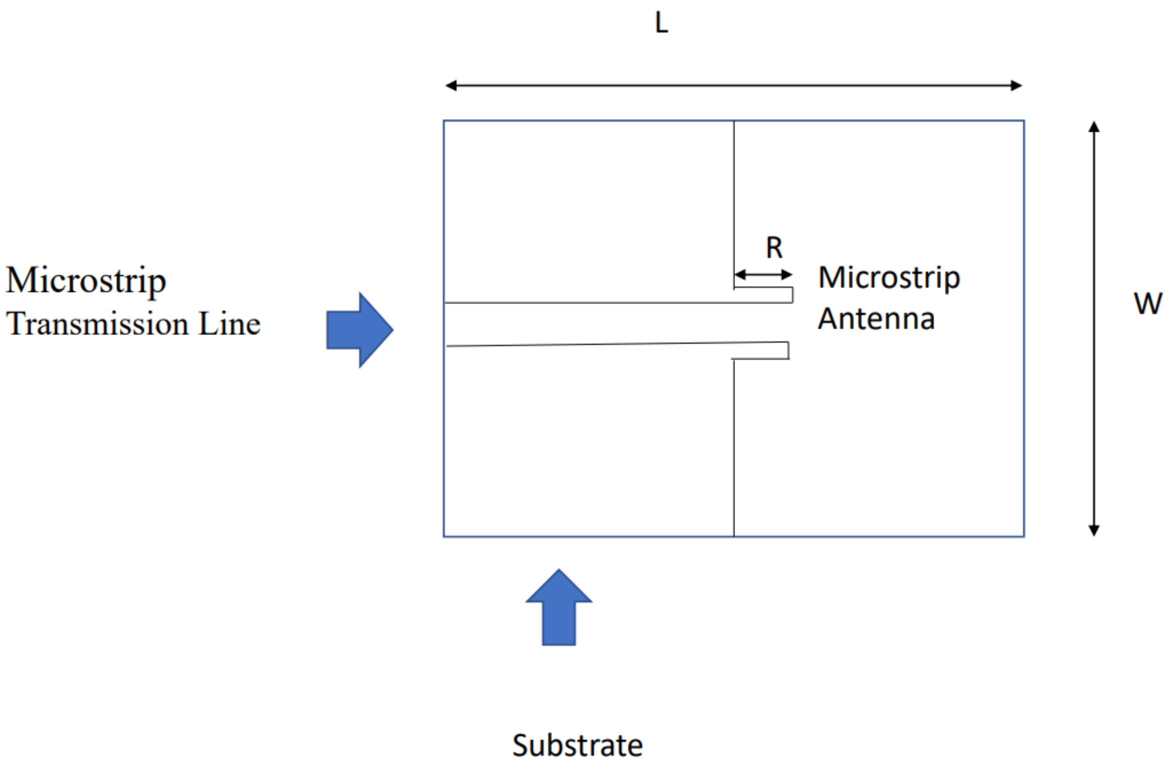


Fig.1.1(c) Inset Feed

Since the current has a sinusoidal distribution, moving in a distance R from the end will increase the current by cos(pi*R/L) - this is just noting that the wavelength is 2*L, and so the phase difference is 2*pi*R/(2*L) = pi*R/L.

The voltage also decreases in magnitude by the same amount that the current increases. Hence, using Z=V/I, the input impedance scales as:

$$\text{Zin(R)} = \cos\left(\frac{\pi R}{L}\right)^2 Zin(0)$$

In the above equation, Zin (0) is the input impedance if the patch was fed at the end. Hence, by feeding the patch antenna as shown, the input impedance can be decreased. As an example, if R=L/4, then cos(pi*R/L) = cos(pi/4), so that [cos(pi/4)]^2 = 1/2. Hence, a (1/8)-wavelength inset would decrease the input impedance by 50%. This method can be used to tune the input impedance to the desired value.

<u>B.Fed with a quarter wavelength Transmission Line:</u>

The microstrip antenna can also be matched to a transmission line of characteristic impedance Z0 by using a quarter-wavelength transmission line of characteristic impedance Z1 as shown in Figure 2(b).

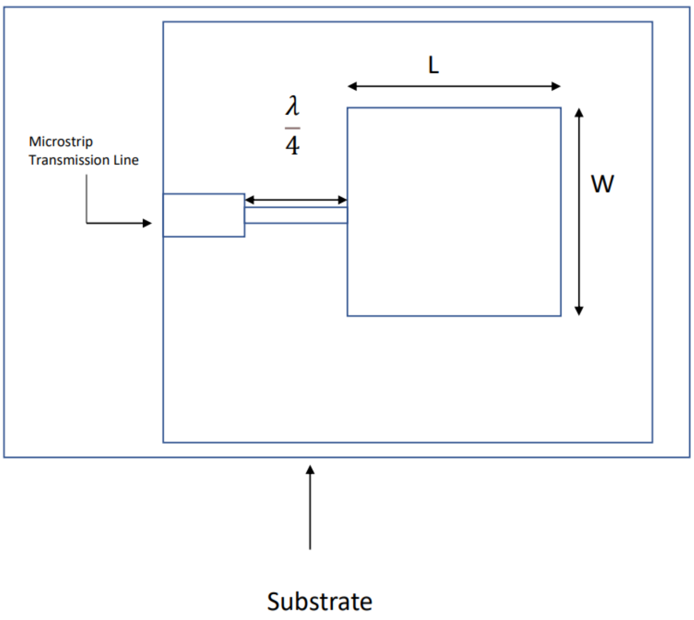


Fig.2(b): Patch Antenna with quarter wavelength transmission line

The goal is to match the input impedance (Zin) to the transmission line (Z0). If the impedance of the antenna is ZA, then the input impedance viewed from the beginning of the quarter-wavelength line becomes

Zin = Z0 = $Z1^2$/ Za

This input impedance Zin can be altered by selection of the Z1, so that Zin=Z0 and the antenna is impedance matched. The parameter Z1 can be altered by changing the width of the quarter-wavelength strip. The wider the strip is, the lower the characteristic impedance (Z0) is for that section of line.

C.Coaxial Feed :

Microstrip antennas can also be fed from underneath via a probe as shown in Figure 3. The outer conductor of the coaxial cable is connected to the ground plane, and the centre conductor is extended up to the patch antenna.

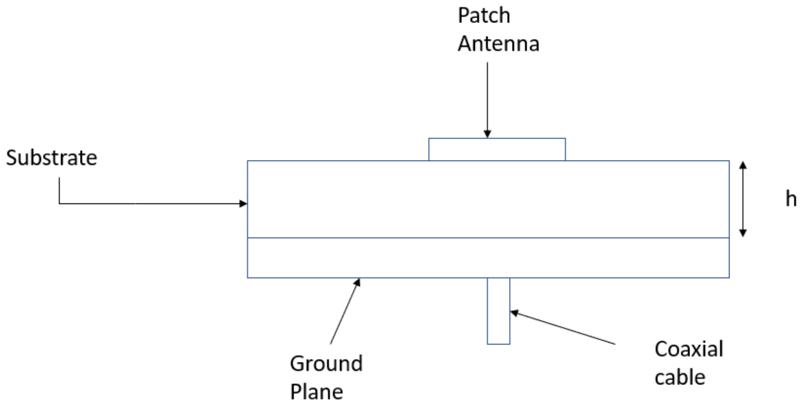


Fig3: Coaxial Feed Cable Patch Antenna

The position of the feed can be altered as before (in the same way as the inset feed, above) to control the input impedance.

The coaxial feed introduces an inductance into the feed that may need to be taken into account if the height *h* gets large (an appreciable fraction of a wavelength). In addition, the probe will also radiate, which can lead to radiation in undesirable directions.

D.Aperture Feed:

Another method of feeding microstrip antennas is the aperture feed. In this technique, the feed circuitry (transmission line) is shielded from the antenna by a conducting plane with a hole (aperture) to transmit energy to the antenna, as shown in Figure 4.

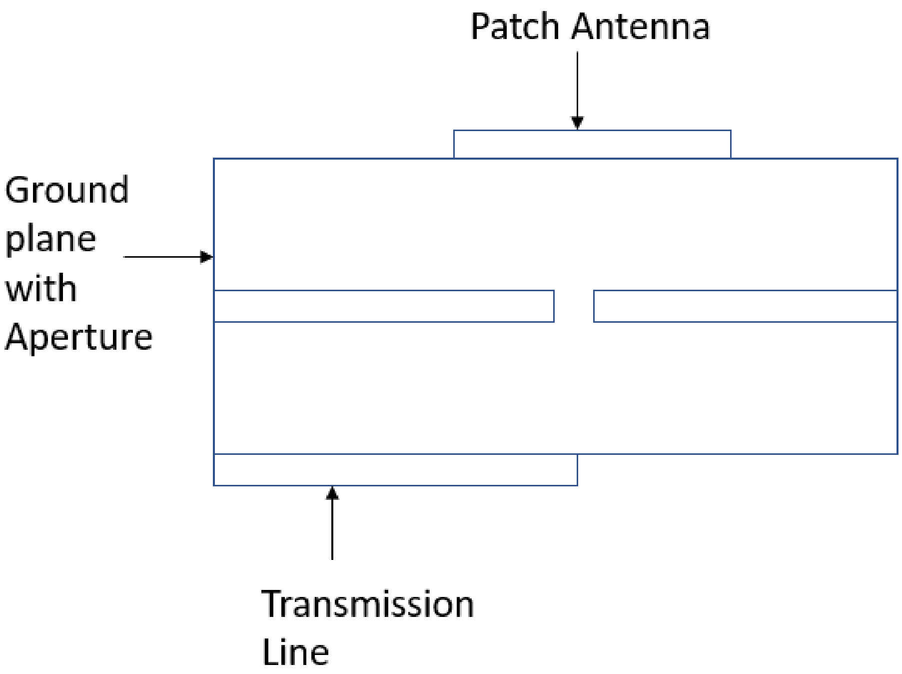


Fig.4: Aperture coupled feed Antenna

The upper substrate can be made with a lower permittivity to produce loosely bound fringing fields, yielding better radiation. The lower substrate can be independently made with a high value of permittivity for tightly coupled fields that don't produce spurious radiation. The disadvantage of this method is increased difficulty in fabrication.

5. 5G Antenna:

In recent years , lots of 5G Antennas are designed on the different performance enhancement techniques.

Classification Based on Input and Output Ports:

1.SISO: It means Single Input Single Output. SISO Antenna which is either a single or multi-element antenna is implemented for 5G Applications. The SISO antenna is easy to design and implement. Also, it can be easily integrated into 5G communication devices. To achieve a high gain, the size of a single element antenna is large. At above 6 GHz frequency bands, the signals suffer from higher propagation losses and quality of service degrades. So, to achieve a uniform and good performance, it is required to replace a single element antenna by a multi-element antenna. A multi-element antenna is mainly used to enhance the gain of an antenna at the cost of increased size and design complexity.

2.MIMO:

The wireless communication is prone to interference, multipath fading, and radiation losses. Also, it becomes severe at higher frequencies. To overcome these issues, the utilization of multiple input multiple output (MIMO) antennas becomes very important as it enhances the transmission range without increasing the signal power. Thus, MIMO design can be used in 5G to achieve low latency, maximum throughput, and large efficiency. In MIMO more signals can be launched intelligently by using multiple antennas and thus enhancing channel capacity significantly.

The method used to reduce the number of an antenna in MIMO is to use multiband antennas that provide coverage of different wireless applications [13]. Further, the MIMO antennas can be classified depending upon their frequency band as wideband and multiband antennas. The wideband and multiband antennas can be further classified into multi-element with a metal rim and multi-element without metal rim antennas.

Classification Based on Antenna Types:

a)Monopole Antenna:

It consists of a straight microstrip line of λ/4 length where λ is the wavelength of the resonant operating frequency of an antenna. As found in the literature, several modifications were proposed which change the basic structure into new shapes like conical, spiral and others as per the applications and requirements.

b)Dipole Antenna:

It consists of two straight microstrip lines each of λ/4 length and feeding is provided in between two microstrip lines So, the total length of dipole antenna is λ/2.

c) Magneto-Electric (ME) Dipole Antenna:

It consists of a planar electric dipole and vertically shorted planar magnetic dipole. The feeding is provided to the magnetic dipole from the bottom side of the substrate.

d) Loop Antenna:

It consists of a circular, rectangular, square or any other shape of a ring. The radius of the loop antenna is smaller than wavelength.

e) Antipodal Vivaldi Antenna (AVA):

It consists of two conductors on both sides of the substrate and they are mirror images of each other. The upper conductor acts as a radiator whereas bottom conductor acts as a ground.

f) Fractal Antenna:

It consists of a repetition of the same structure multiple times. It is designed by using an iterative mathematical rule. The fractal antenna can be of different shapes like rectangle, circle, star, triangle, and leaf.

g) Inverted F Antenna (IFA):

It consists of a microstrip line with one bend and feeding is given to the straight part of the microstrip line. The feed point is near to the bent part and hence the overall look of an antenna is of inverted F type.

h)Planar Inverted F Antenna(PIFA):

It consists of the patch antenna and ground plane which are connected by using shorting pin and feeding is provided from the bottom side of the substrate. As it resonates at quarter wavelength, it requires less space.

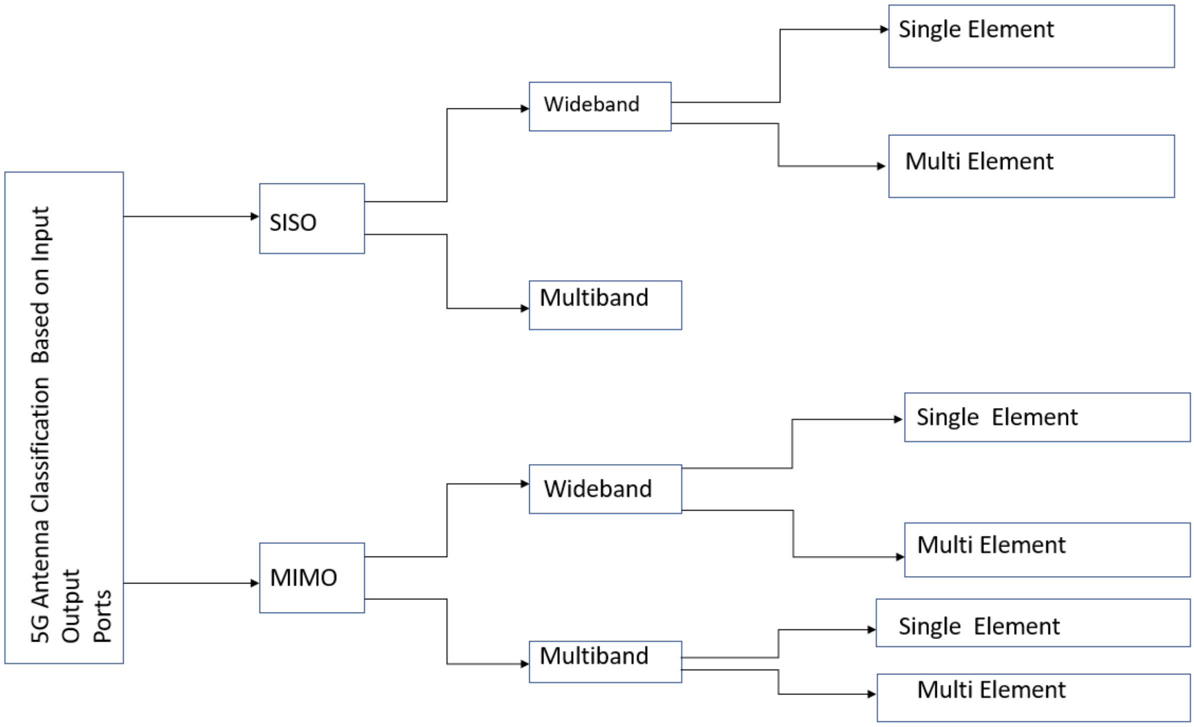


Fig.5(a): 5G Antenna classification based on input output ports.

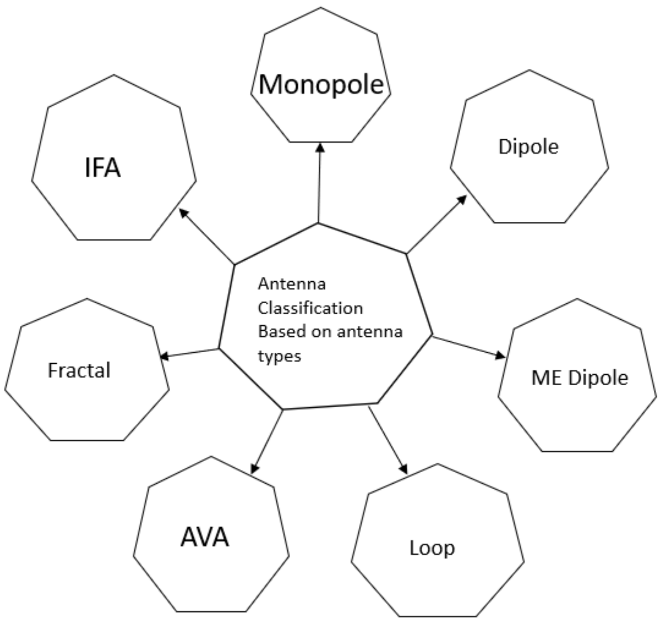


Fig.5(b): 5G Antenna classification based on antenna types

<u>6.5G BAND:</u>

Table1:Frequency bands of 5G for below 6 GHz (frequency range 1 (FR1))

Frequency Range (MHz)	Frequency Band
470-698	n71
698-960	n5, n8, n12 , n14, n15, n20 , n25, n28, n29 , n81-n83, n89, n91- n94
1427-1518	n50, n51, n71-n74, n91-n94
1710-2025	n1-n3, n34, n39, n65, n66, n70, n84, n86, n95
2110-2200	n65, n66
2300-2400	n30, n40
2500-2690	n7, n38, n41, n90
3300-3400	n77, n78
3400-3600	n48, n77, n78
3600-3700	n48, n77, n78
3700-4200	n77
4400-4990	n80

Frequency Range (MHz)	Frequency Band
24250 - 29500	n257, n258, n261
37000 - 43500	n260
45500 - 47000	--
47000 - 71000	--

Table2: Frequency bands of 5G for above 6 GHz.

• Motivation and Problem Definition:

In last few years, economic and social development is greatly influenced by the advancements in the field of mobile communication. As a result, 5G technology has emerged as a pedestal of the future 2020 generation. 5G technology is an emerging technology with evolutionary and revolutionary services. It is the next generation of technology to provide ultrahigh data rates, very low latency, more capacity, and good quality of service. It is worth mentioning that 5G technology will unleash new opportunities to leapfrog traditional barriers to development.

As 5G technology supports IoT also, The associate editor coordinating the review of this manuscript and approving it for publication was Giorgio Montiscit. it gives leverage of a major societal transformation in the fields of education, industry, healthcare, and other social sectors. 5G technology is expected to unlock an extensive IoT ecosystem wherein many devices will be connected and by maintaining a trade-off between latency, cost, and speed a network can suffice the communication needs.

The main motivation of this project work is to address such challenging areas. s. A very careful literature survey was conducted and it was also found that very limited work has been done on MIMO Antenna for 5G Applications. So, this is a relatively unexplored research area.

• Problem Definition:

The aim of the project is to design and analysis of 2-Element MIMO Antenna for 5G Applications. So in brief, following are the objectives:

• First aim is to design the 2 -Element MIMO Antenna.

• Second aim is to make this antenna to work under 5G frequency range.

• Final aim is to design and analysis of 2-Element MIMO Antenna. The designing of antenna geometries, parametric studies and finally the performance analysis of each geometry will be done by using Microwave CST tool.

Chapter-2:

1.Selection of Antenna:

A. Circular Patch Antenna Geometry:

One sided copper coated Fire-Resistant (FR-4) substrate (€ = 4.3 @ 1-9 GHz) is chosen for designing antennas in this work because it is cost effective. The dimension of antenna is represented by $S_L \times S_W \times h$. A coplanar transmission line is designed to excite the antenna and it consists of a central conducting micro strip (*1.5* mm×$L_f$mm). The two symmetrical grounds around the strip have dimension of $G_L \times G_W$ with coplanar gap of 0.035mm between ground and central conducting strip to provide 50Ω impedance match.

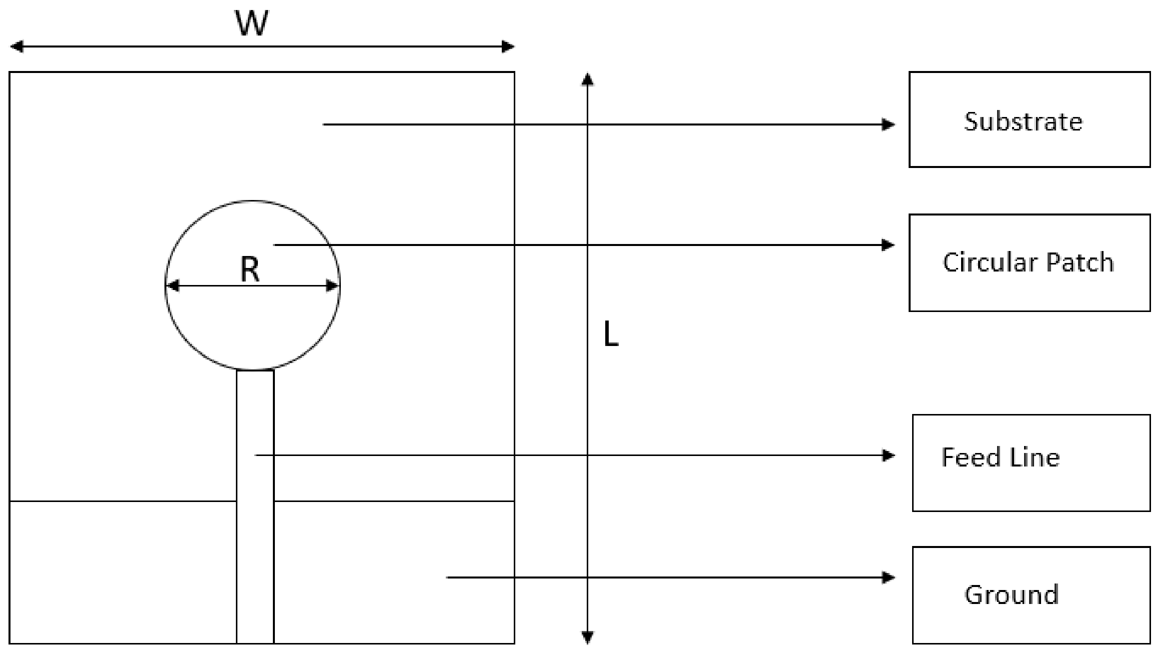


Fig. 6. Antenna Geometry: SL =60mm, SW = 60mm, h=1.5mm ,

To start with, the above schematics (Fig.6), the dimension of the patch antenna has been designed by using the following equations : Assume the operating frequency f, h, ε_r are known.

Operating wavelength, $\lambda = \frac{c}{f}$

Where, C= velocity of light (3×11^{11}mm)

f = Resonant frequency

ε_r = Dielectric constant of substrate

L_{eff} = Effective length, and it is given by

$$L_{eff} = \frac{c}{2f\sqrt{\varepsilon_r}}$$

The effective radius of the circular patch due to fringing effects is given by the following equation

$$a_e = a\ [1 + \frac{2h}{\pi a\varepsilon}\left\{\ln\left(\frac{a}{2h}\right) + 1.41\varepsilon + 1.77 + \frac{h}{a}(0.268\epsilon + 1.65)\right\}]^{\frac{1}{2}}$$

Where, ε_{reff} = Effective dielectric constant, and the equation for it is given below

$$\varepsilon_{eff} = \frac{C(a,h,\varepsilon,\epsilon)}{C(a,h,\varepsilon)}$$

And $\quad h = \frac{0.0606\lambda}{\sqrt{\varepsilon_r}}$

Feed line length is calculated using the below equation,

Feed length (L_f) $L_f = \frac{\lambda g}{4}$

Where λ_g is guided wavelength and it is given by, $\lambda_g = \frac{\lambda}{\sqrt{\varepsilon\ \mathrm{eff}}}$

and finally, efficiency of the antenna is calculated by,

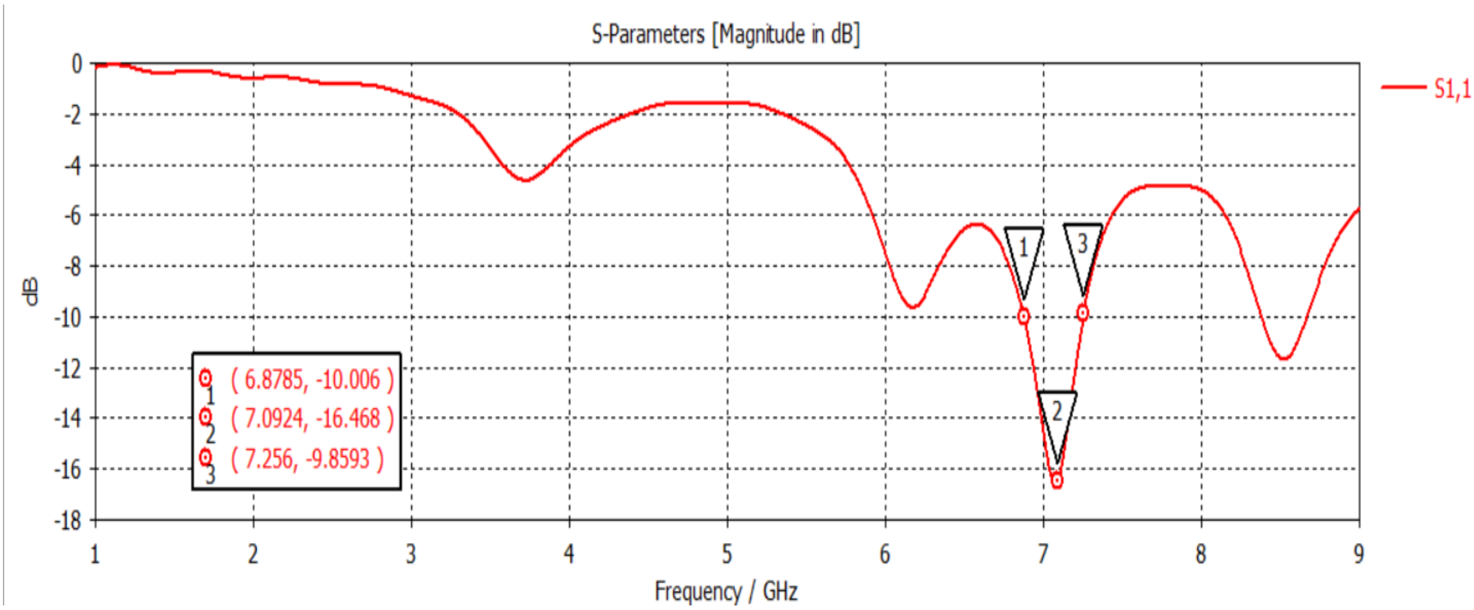
$$\eta = \frac{gain}{directivity} \times 100\%$$

Where, η = efficiency Radiation box

The simulated S11 characteristic of simple rectangle monopole is presented in Fig 4.1.2. for specific values of feed gap Fl = 0.1mm (i. e. distance between patch and ground). From S11 characteristic, it is evident that impedance matching is very poor as S11>-10 dB. The feed gap is always very important optimization parameter for such shapes and should always be considered for impedance matching. As the feed gap increases to 2 mm, the impedance matching improves and the antenna now operate over 2.4 GHz to 8.4 GHz as shown in Fig 4.1.2. So it offers 117.6 % (S11 < -10 dB) impedance bandwidth. Also, some S11 minima are seen at characteristic near 2.7 GHz, 5 GHz, 7 GHz and 8.2 GHz (shallow) respectively.

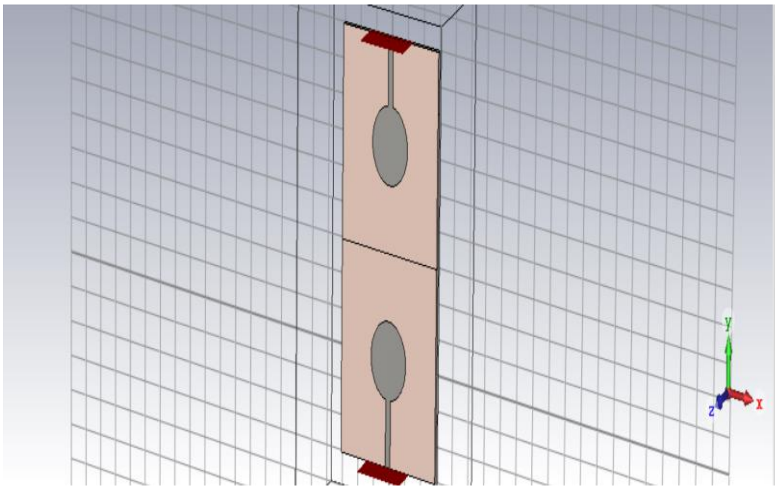
Fig 7. Simulated S11 Characteristic for Single Element Circular Patch Antenna

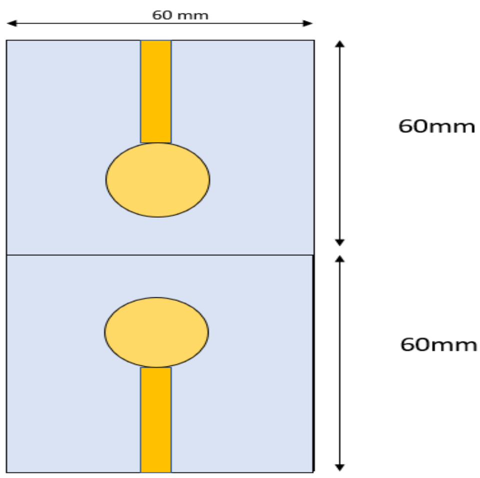
B.<u>Double Element Circular Patch Antenna</u>:



Main objective is to get 5G bands. Here Circular Patch Antenna is giving the 5G bands. Now next task is to operate the double element MIMO Antenna to work under 5G bands. So, for this purpose Doble Element Circular Patch Antenna is designed. Here two circular patch is placed up and down vertically. Geometry of the circular patch is same as Single Element Circular Patch Antenna. The size of the ground plane is kept same as 120 mm x 60 mm.

Fig.8.<u>Double Element Circular Circular Patch Antenna</u>





From S11 characteristic, it is shown that antenna is now working as dual band where first band is narrow and it varies from 2.058GHz to 2.91GHz. The second band is wide and it varies from 4.27GHz to 7.058GHz. From this structure it is concluded that multiband can be formed using Double Element Circular Patch Antenna.

From S22 characteristic, it is shown that antenna is now working as dual band where first band is narrow and it varies from 2.058GHz to 2.38GHz. The second band is wide and it varies from 3.77GHz to 4.279GHz.

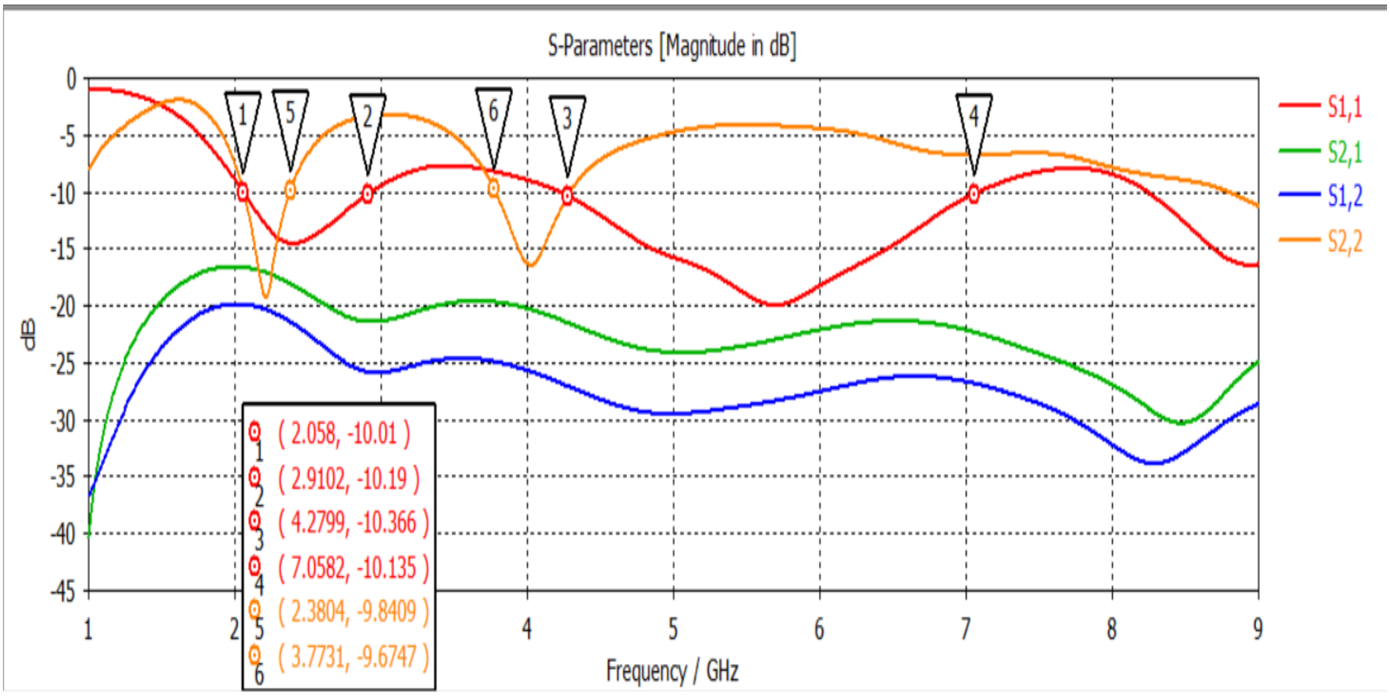


Fig 9. Simulated S11, S22 Characteristic for double element circular patch antenna.

C.<u>Double Element Circular Patch Antenna:(side by side)</u>

Here two circular patch is placed side by side. Geometry of the circular patch is same as Single Element Circular Patch Antenna. The size of the ground plane is kept same as 120 mm x 60 mm.

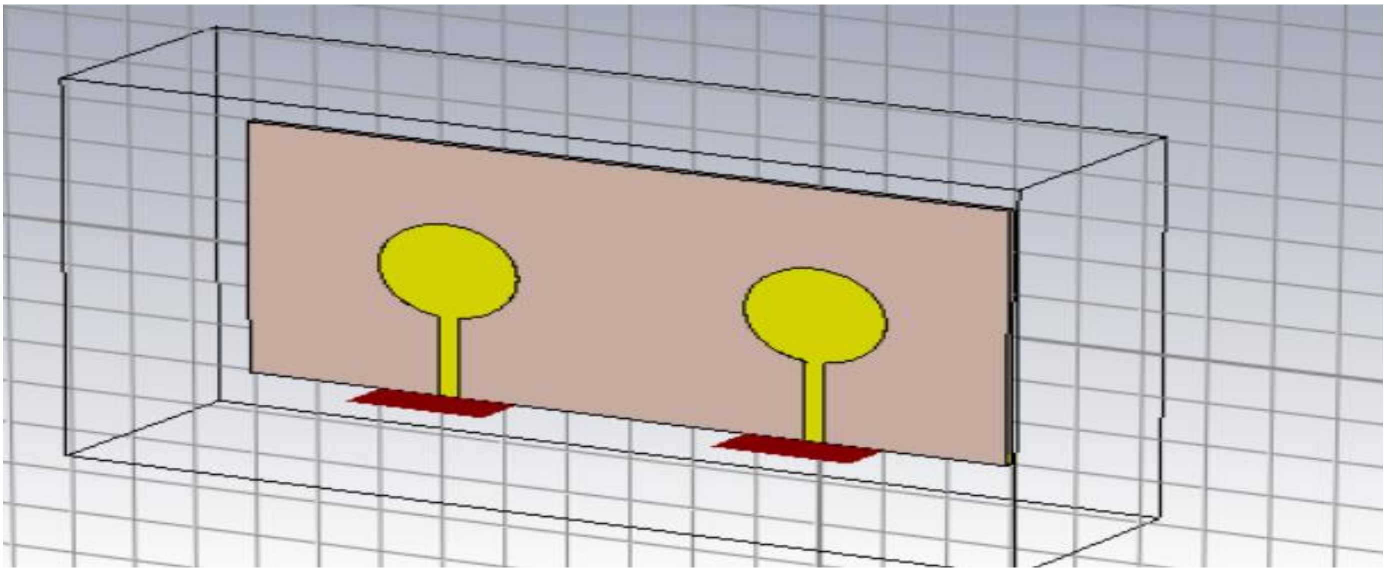


Fig.10:Double Element Circular Patch Antenna (side by side)

From S11 characteristic, it is shown that antenna is now working as single band antenna where it varies from 1.9GHz to 3.1GHz.

From S21 characteristic, it is shown that antenna is now working as single band antenna and it varies from 4.82GHz to 6.91GHz.

From S12 characteristic, it is shown that antenna is now working as single band antenna and it varies from 4.79GHz to 6.89GHz.

From S22 characteristic, it is shown that antenna is now working as dual band where first band is narrow and it varies from 1.89GHz to 3.03GHz. The second band is wide and it varies from 4.07GHz to 6.98GHz. From this structure it is concluded that multiband can be formed using Double Element Circular Patch Antenna.

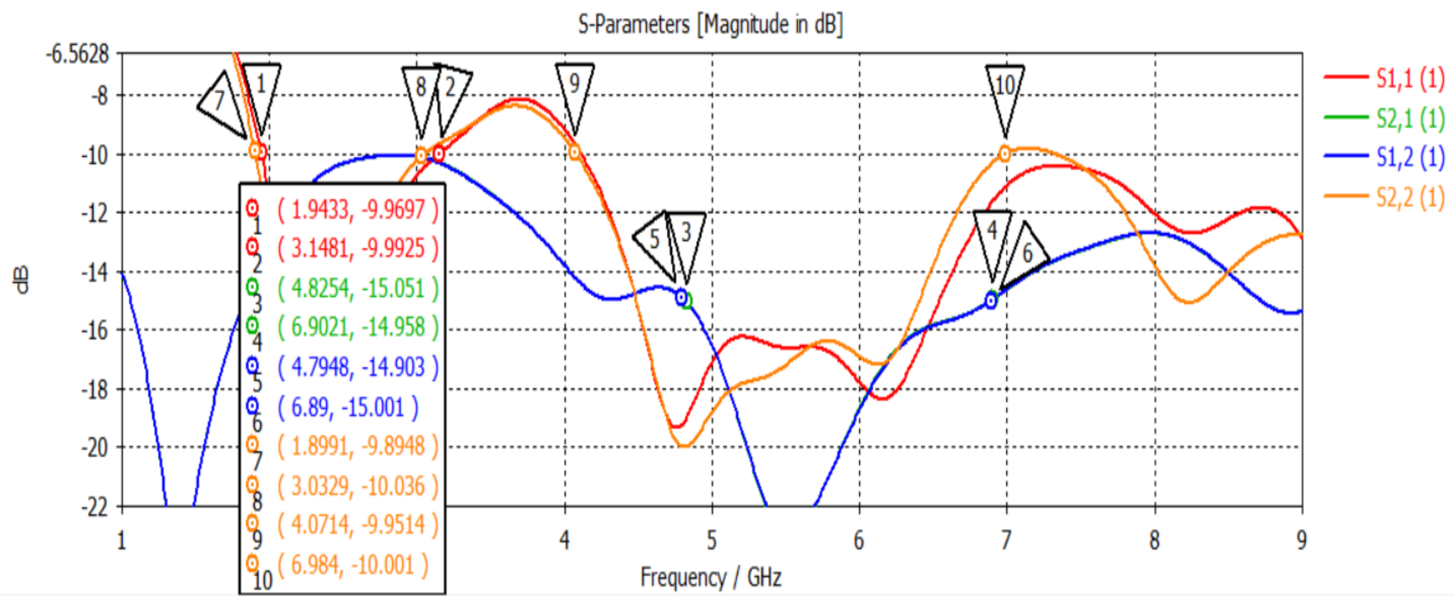


Fig.11:S Parameter analysis for Double Element Circular Patch Antenna (side by side).

Here all these structures dimensions are more than the practical value. So if we want to fabricate these structures, we face some kinds of problem in measurement. The measured values will not match with the simulated values. This will complicate the research work. To avoid this kind of problem, a new structure is designed.

D.2-Element MIMO Antenna with metal plate :

Here two circular patch is placed up and down vertically. Geometry of the circular patch is same as Single Element Circular Patch Antenna. The size of the ground plane is kept same as 40 mm x 40 mm. This structure gives the required 5G bands and operating for 5G applications.

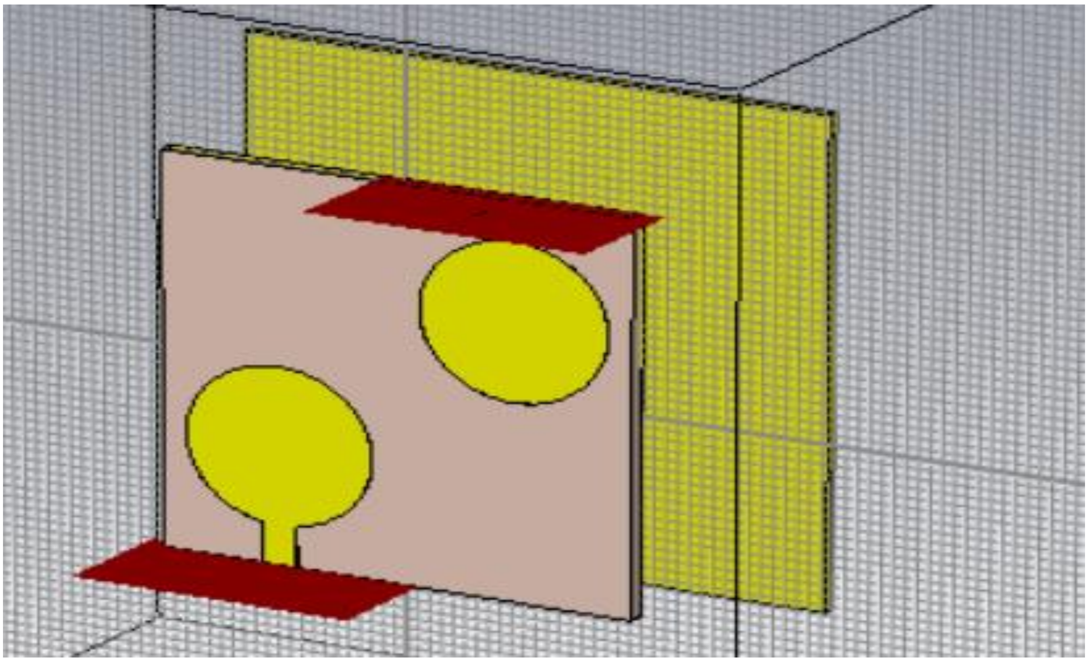


Fig12:2-Element MIMO Antenna with metal palte

From S11 characteristic, it is shown that antenna is now working as single band antenna where it varies from 4.038GHz to 5.05GHz.

From S21 characteristic, it is shown that antenna is now working as single band antenna and it varies from 3.9GHz to 5.9GHz.

From S12 characteristic, it is shown that antenna is now working as single band antenna and it varies from 3.9GHz to 5.9GHz.

From S22 characteristic, it is shown that antenna is now working as dual band where first band is narrow and it varies from 4.038GHz to 5.05GHz.

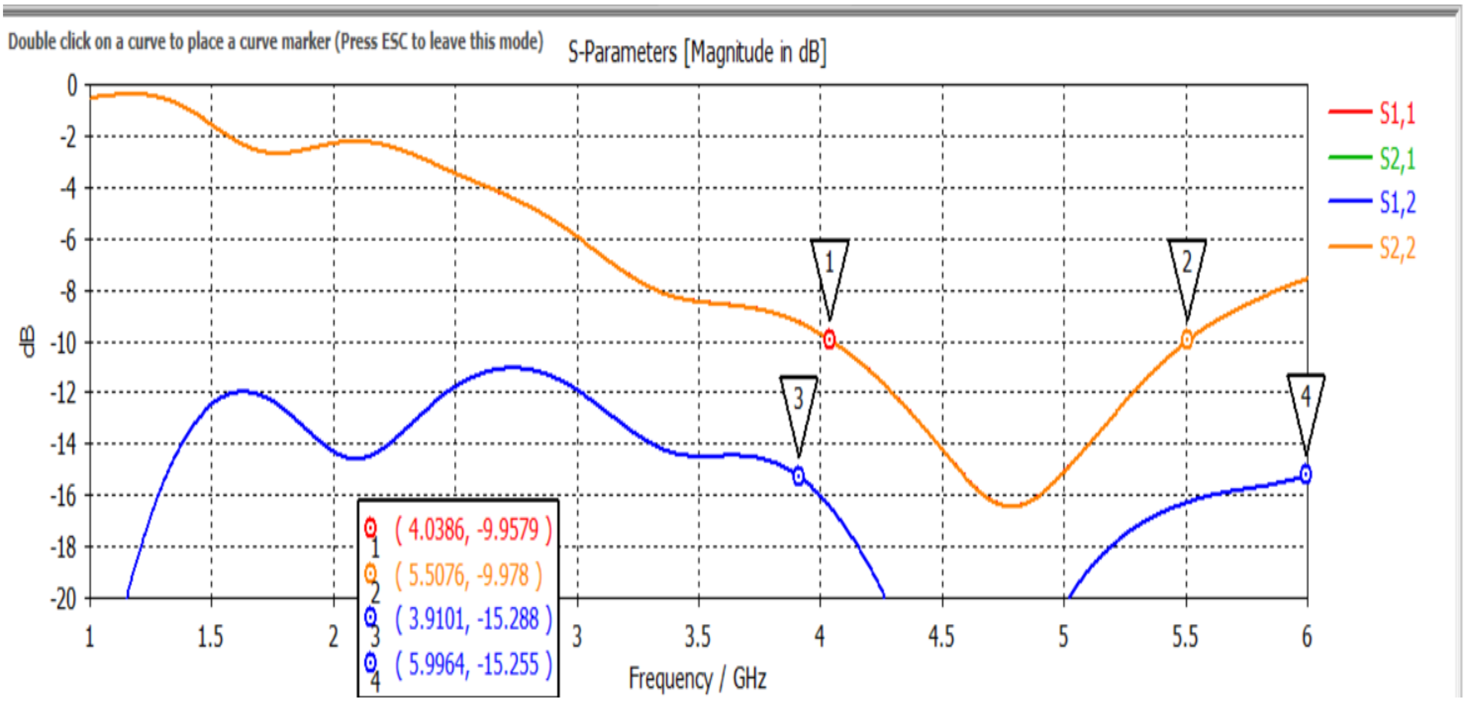


Fig.13:S-parameter of 2-Eleemnt MIMO Antenna with metal plate

Here this updated structure is not giving exactly what is expected. So another 2-Element MIMO structure is developed with externally metal plate is not given under the ground plane.

E.2-Element MIMO Antenna:(without metal plate)

Here two circular patch is placed up and down vertically. Geometry of the circular patch is same as Single Element Circular Patch Antenna. The size of the ground plane is kept same as 40 mm x 40 mm. This structure gives the required 5G bands and operating for 5G applications.

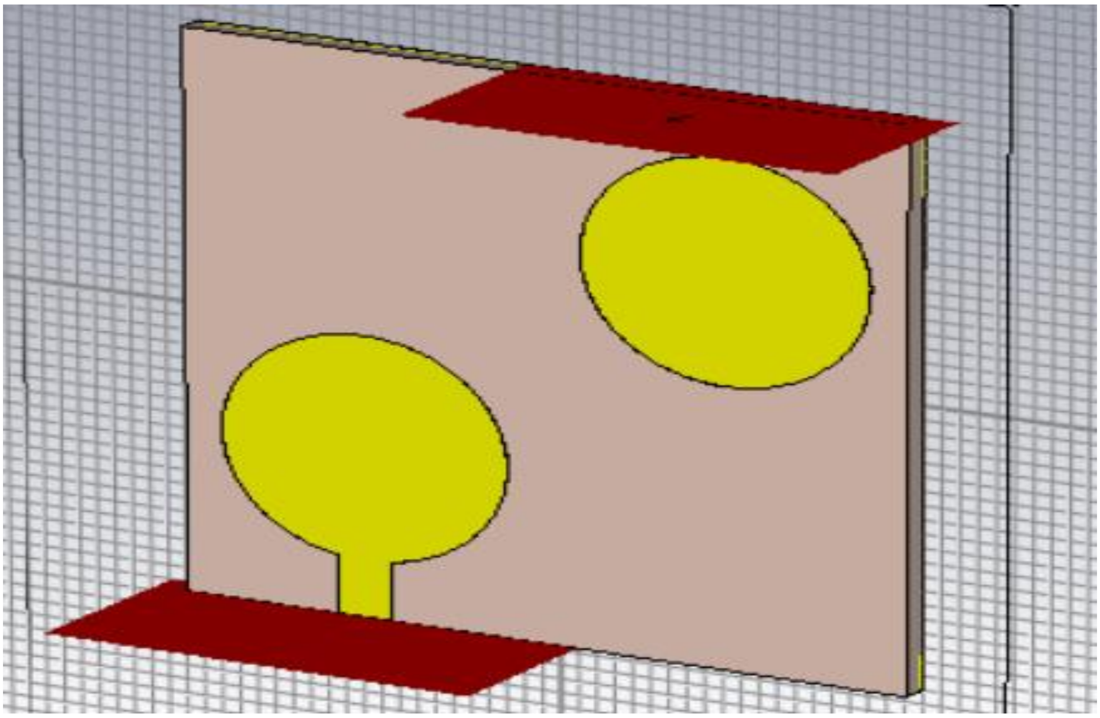


Fig.14:2-Element MIMO Antenna

From S11 characteristic, it is shown that antenna is now working as single band antenna where it varies from 4.26GHz to 5.61GHz.

From S21 characteristic, it is shown that antenna is now working as single band antenna and it varies from 3.11GHz to 4.6GHz.

From S12 characteristic, it is shown that antenna is now working as single band antenna and it varies from 3.11GHz to 4.6GHz.

From S22 characteristic, it is shown that antenna is now working as dsingle band where first band is narrow and it varies from 4.26GHz to 5.61GHz.

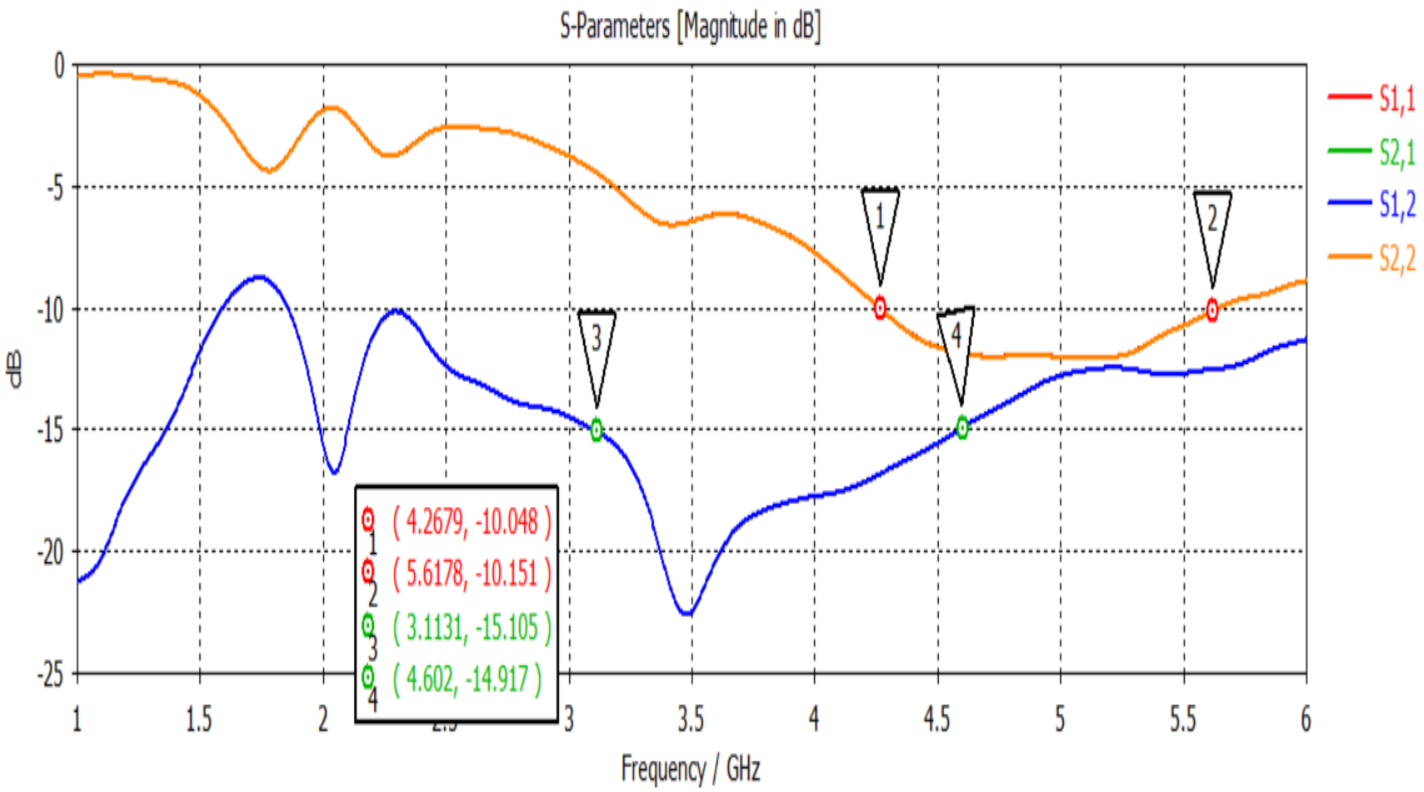


Fig.15:S-Parameter of 2-Element MIMO Antenna

- Envelope Correlation Coefficient:

Envelope Correlation Coefficient tells us how independent two antennas' radiation patterns are. So if one antenna was completely horizontally polarized, and the other was completely vertically polarized, the two antennas would have a correlation of zero. Similarly, if one antenna only radiated energy towards the sky, and the other only radiated energy towards the ground, these antennas would also have an ECC of 0. Hence, Envelope Correlation Coefficient takes into account the antennas' radiation pattern shape, polarization, and even the relative phase of the fields between the two antennas.

To get the mathematical formula for ECC, let's define the radiation pattern mathematically as a vector function in spherical coordinates. We'll call the radiation pattern $\overline{F_1(\theta,\phi)}$ (the line on the top means it is a vector function), and we can write the radiation pattern as:

$$F_1(\theta,\emptyset) = F_{1\theta}(\theta,\emptyset).a_{\theta} + F_{1\emptyset}(\theta,\emptyset).a_{\emptyset}$$

(θ,ϕ) represents the spherical angles (elevation, azimuth), $\overline{a_\theta}$ represents a unit vector in the theta direction, and $\overline{a_\phi}$ represents a unit vector in the phi direction. Equation shown in above is a mathematical representation for a vector-valued function defined over the sphere. The vector notation represents the polarization of the Electric Field. Note also that $F_{1\theta}(\theta,\phi)$ and $F_{1\phi}(\theta,\phi)$ are complex functions; the angle of the complex value represents the relative phase of the radiation pattern at each point.

The envelope correlation coefficient is written mathematically in Equation:

$$\rho = \frac{|\iint \bar{F}.\overline{F^*}\, d\Omega|^2}{\iint |\bar{F}|^2 d\Omega . \iint |F|^2\, d\Omega}$$

What's a good value for ECC? It turns out 0.5 is ok, higher than 0.5 is considered bad, and 0.3 or less is considered pretty good for MIMO applications.

It turns out that for highly efficient antennas (let's say >90% or > -1dB), the ECC can be completely determined from the antenna isolation (so you can just measure s12 and determine the ECC without measuring the antennas' radiation patterns. Why is this? Without going through the math, the reason is that if antennas produce the same (or highly correlated) radiation pattern, then they will also have tight coupling (or low isolation). This is because antennas have the same properties for transmit and receive (due to reciprocity), so if antenna 1 is transmitting a radiation pattern, antenna 2 will "see" this pattern and receive energy proportional to how correlated the antennas' radiation patterns are. It's a simple argument, but it turns out to be true. Hence, you can save a lot of time and focus on improving isolation in order to improve ECC. The formula for ECC in terms of isolation (s12) is given below:

$$\rho = \frac{|s_{11} * s_{12} + s_{21} * s_{22}|^2}{(1 - |S_{11}|^2 - |S_{21}|^2)(1 - |S_{22}|^2 - |S_{12}|^2)}$$

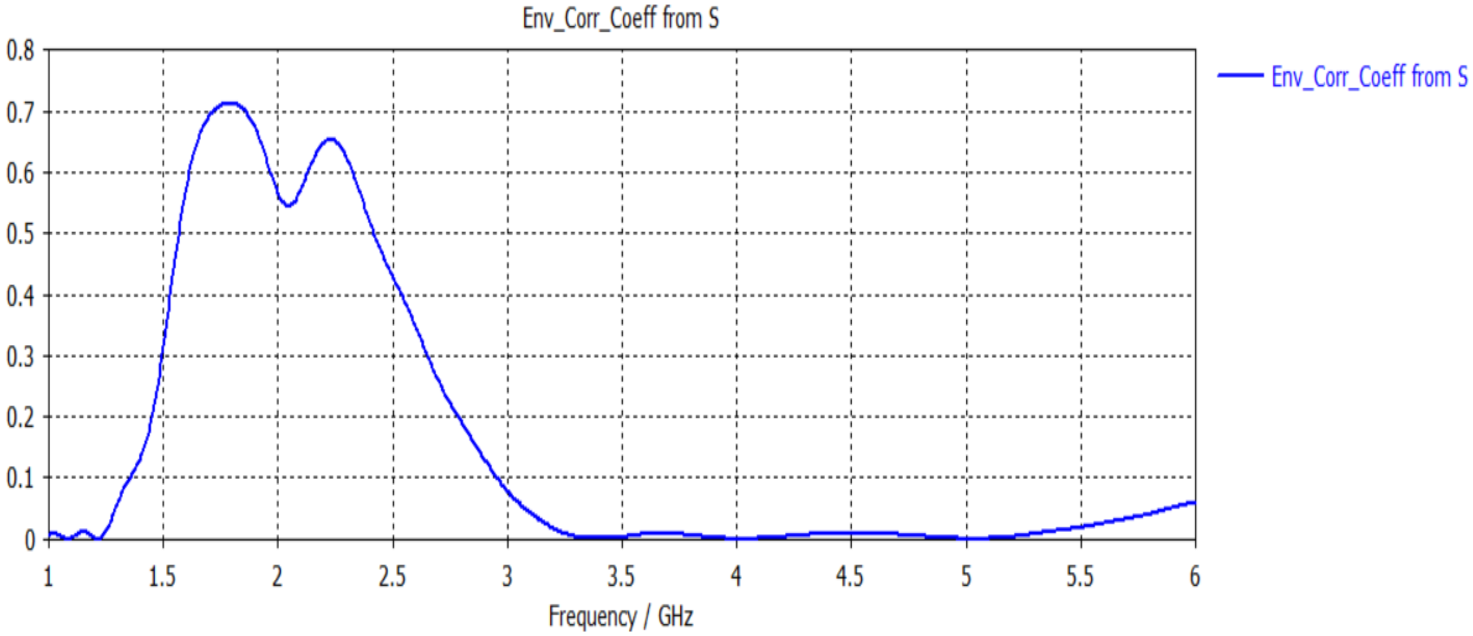


Fig.16: ECC from S-Plane

This is the ECC (Envelope Correlation Coefficient) from S-Plane. It's value lies below 0.1 dB in the operating frequency range (4.4Ghz to 5.5GHz).

- Diversity Gain:

Diversity gain is the increase in signal-to-interference ratio due to some diversity scheme, or how much the transmission power can be reduced when a diversity scheme is introduced, without a performance loss. Diversity gain is usually expressed in decibels, and sometimes as a power ratio. An example is soft handoff gain. For selection combining N signals are received, and the strongest signal is selected. When the N signals are independent and Rayleigh_distributed, the expected diversity gain has been shown to be , expressed as a power ratio.

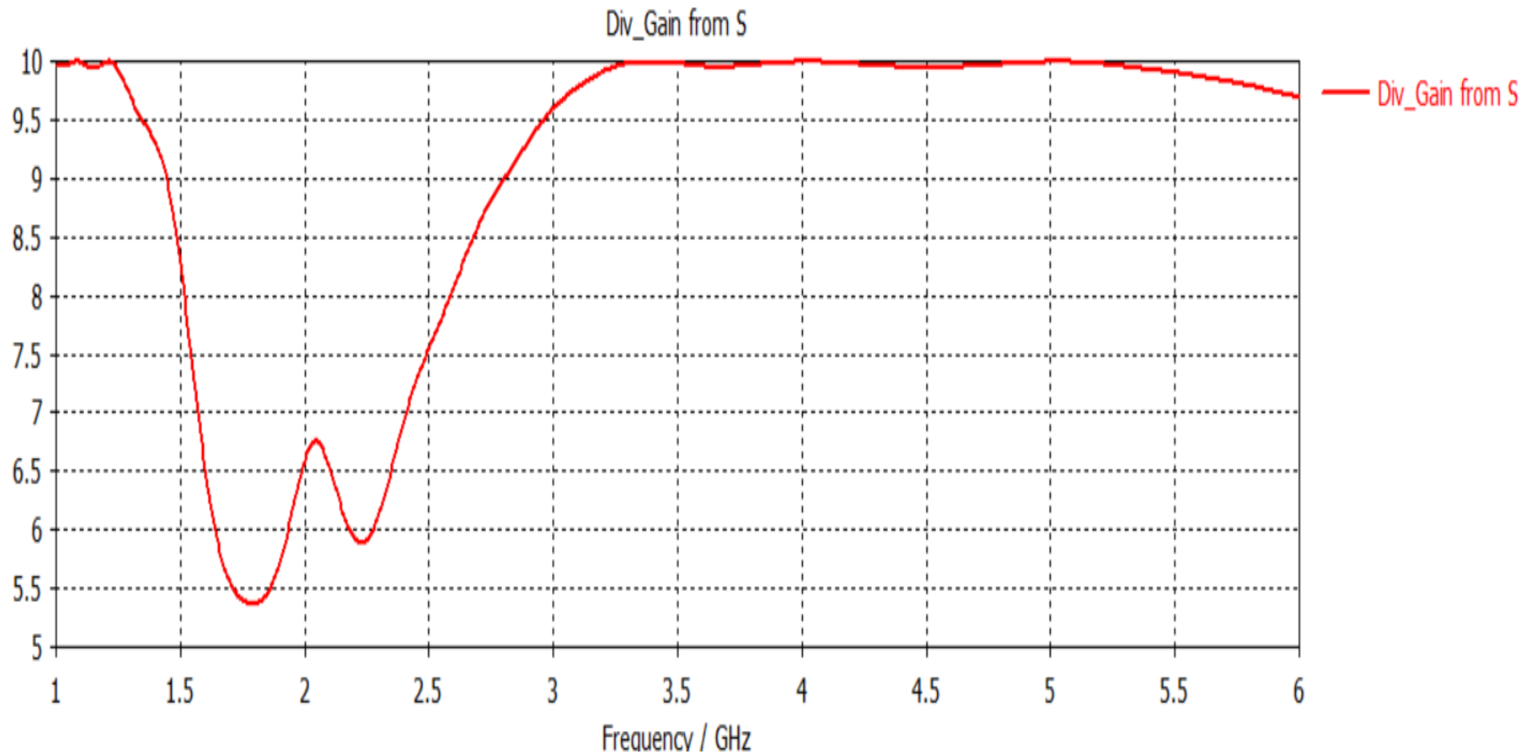


Fig.17: Diversity Gain from S-Plane

This plot shows that the diversity gain is lying under the 10GHz line between the desired frequency range (4.3GHz to 5.5GHz).So this result perfect to measure and good for this structure.

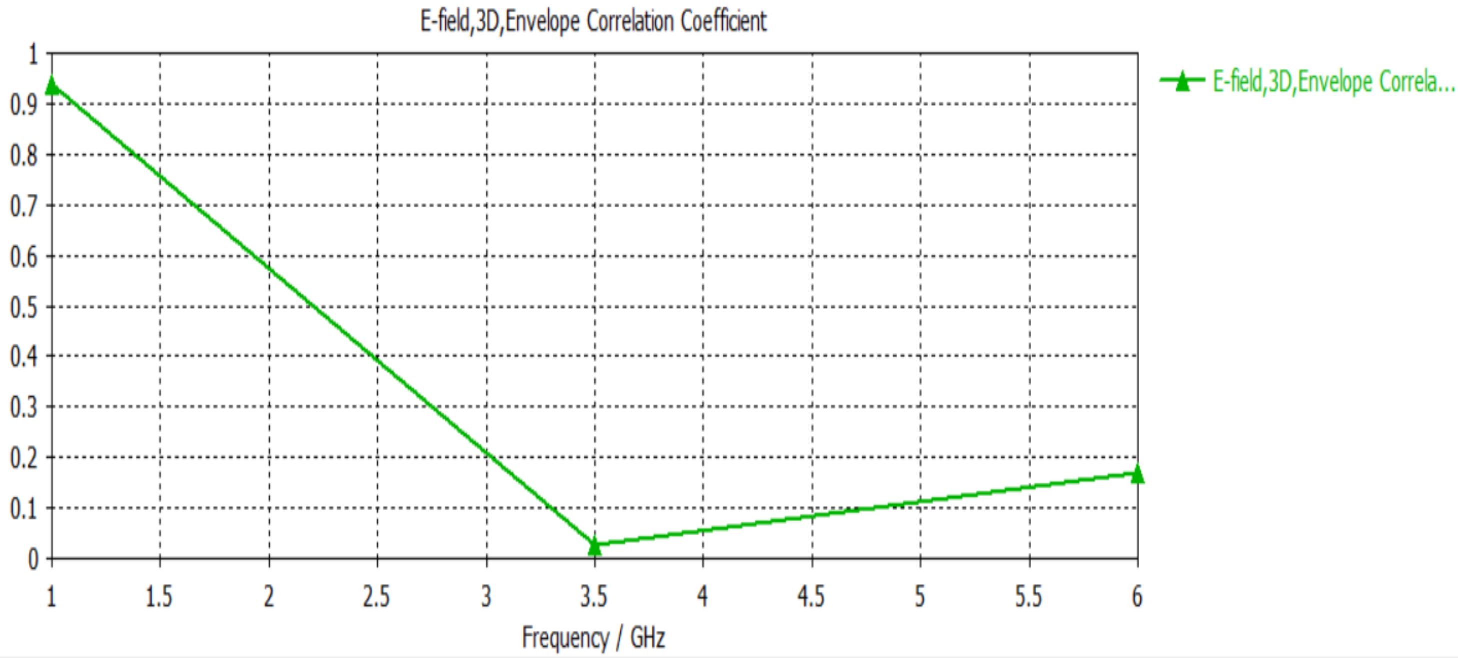
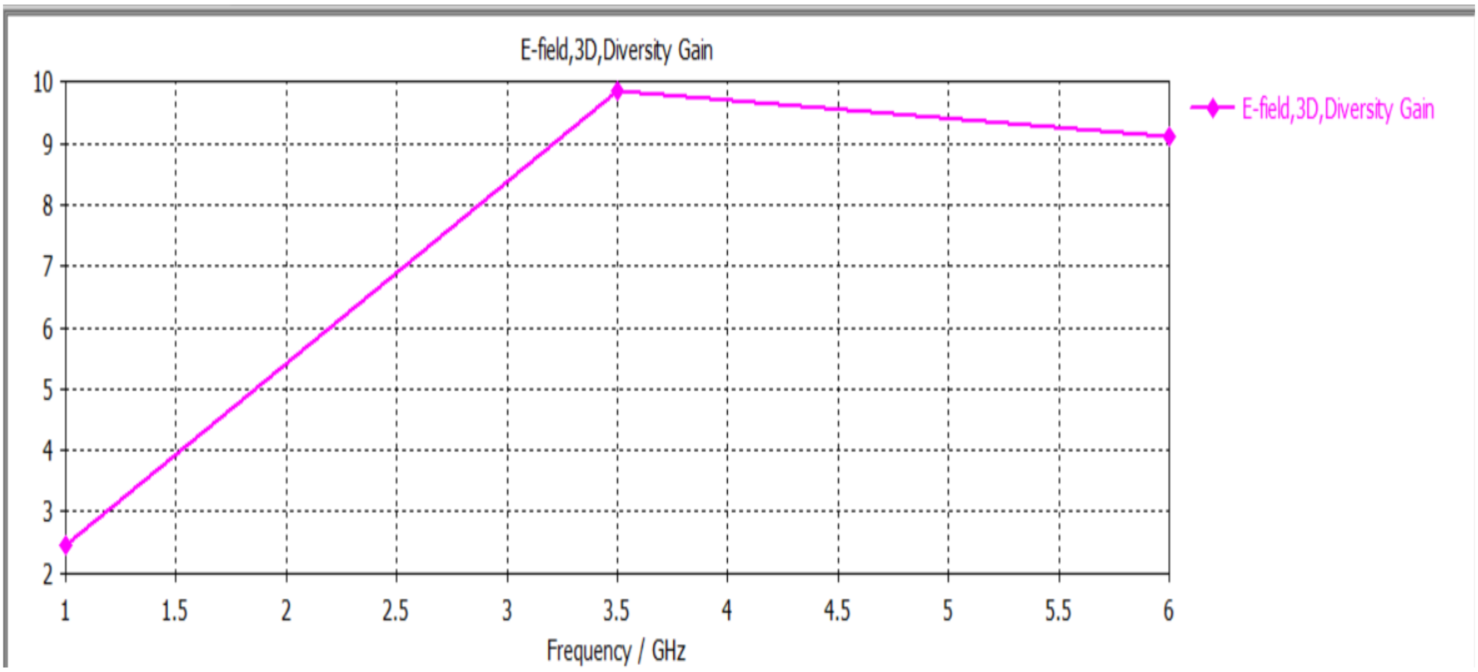


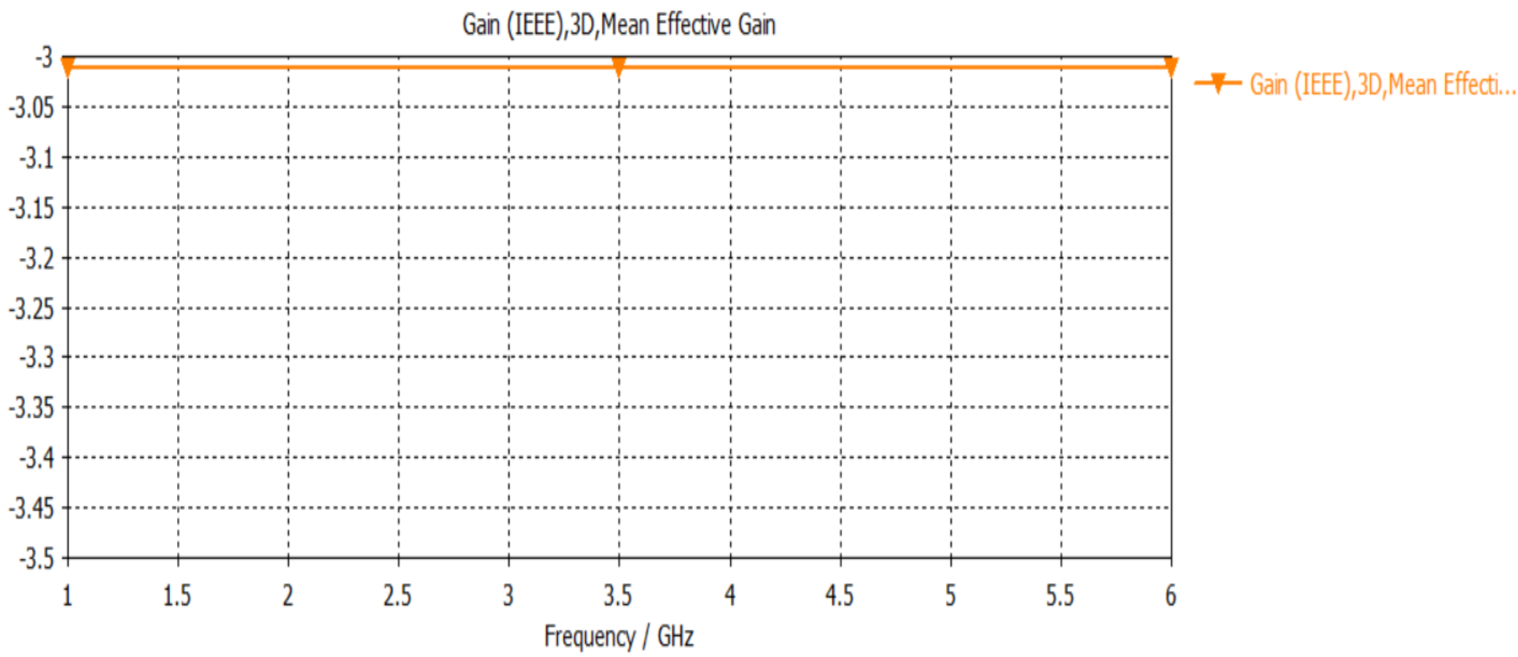
Fig.18:ECC from field Parameter



<u>Fig.19: Diversity Gain from field Parameter</u>

- <u>Mean Effective Gain:</u>

Mean effective gain (MEG) is considered as one of the important parameter for diversity performance in MIMO system. It is defined as the average power received by the diversity antenna relative to the power received by an isotropic antenna.



<u>Fig.20:Mean Effective Gain</u>

Chapter-3:

- **Fabrication:**

The materials required for the fabrication of the antenna are as given below :-

(i)Ferric Chloride ($FeCl3$)

(ii) FR-4 Substrate Single Layer Printed Circuit Board (PCB)

(iii) Iron

(iv) Gloves

(v) Thinner

(vi) Cutter

(vii) Photo Paper

(viii) Laser Printer

The steps involved in fabricating the design practically are as follows:-

1.The proposed antenna is designed and simulated using Microwave CST Tool.

2.Then, the antenna structure is converted into Auto Computer Aided Design (AutoCAD) .dxf file.

3.Now, the CAD file is prepared for printing purpose using Dip Trace PCB Designing.

4.The designs are printed on a photo paper.

5. For the proposed structure, the dimension of the substrate required is 4cm x 4cm. According to the required dimension, the PCB Sheet is cut into a 4cm x 4cm piece as shown in Fig.21.

6. The photo paper is then pasted on the PCB sheet piece and ironed for 10-15 minutes till the image gets stuck to the PCB sheet. It is done to keep the copper part of the PCB that forms the antenna structure.

7. Now, to prepare the solution for etching process, one tea-spoon of FeCl3 is put into a plastic container with water. The structure is put in the solution and kept for 3-4hrs. It shows the structure dipped in Ferric Chloride (FeCl3) solution. After completion of the etching process, the structure appears as shown in Fig.22.

8. Now, the structure is cleaned with thinner. For this purpose ISO Propyl Alcohol is used.

9.Then port is connected. The prototype has been developed by "Thermal Toner Transfer Method". The commercial SMA probe has been used as feed.

Fig.21: Measuring the PCB to 4cm × 4cm and cutting according to them.

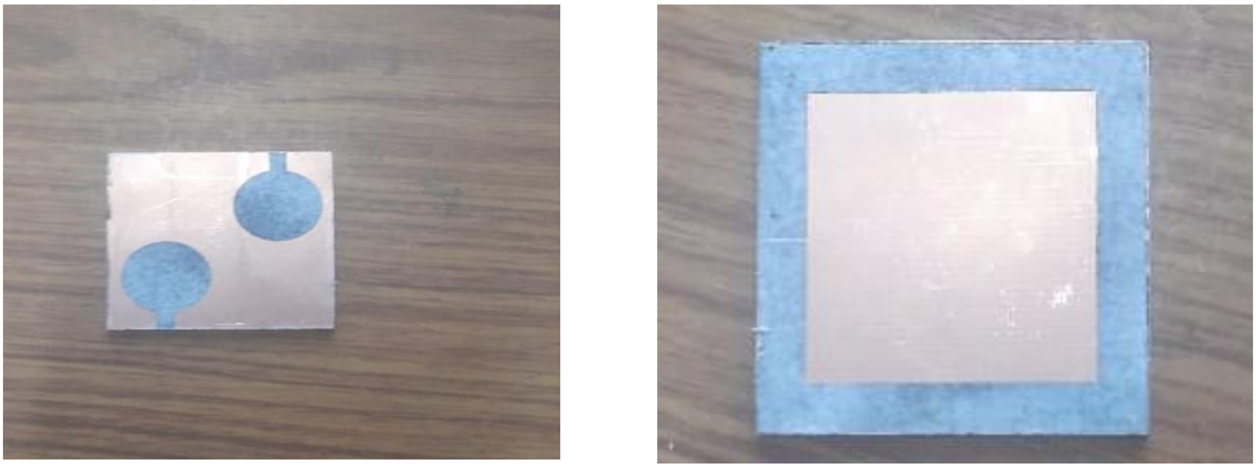
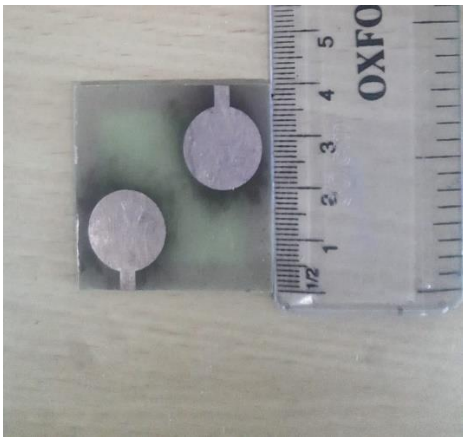


Fig.22: Top view and Bottom view of the antenna after the etching process



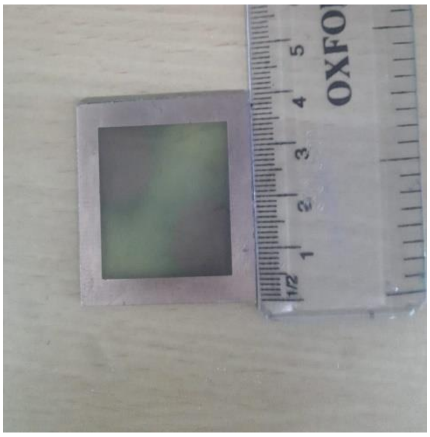


Fig.23: After washing the Top and Bottom of the antenna after etching process.

Fig.24:After installing port, Top and Bottom view of the antenna.

- ## **<u>Comparison of Fabricated and Measured Results</u>:**

The commercial SMA probe has been used as feed. The S11 characteristics of the prototype has been measured using an in-house Vector Network Analyzer (VNA) (make: Anritsu, model number: MS2028C VNA Master) for different switching conditions (Fig.25)

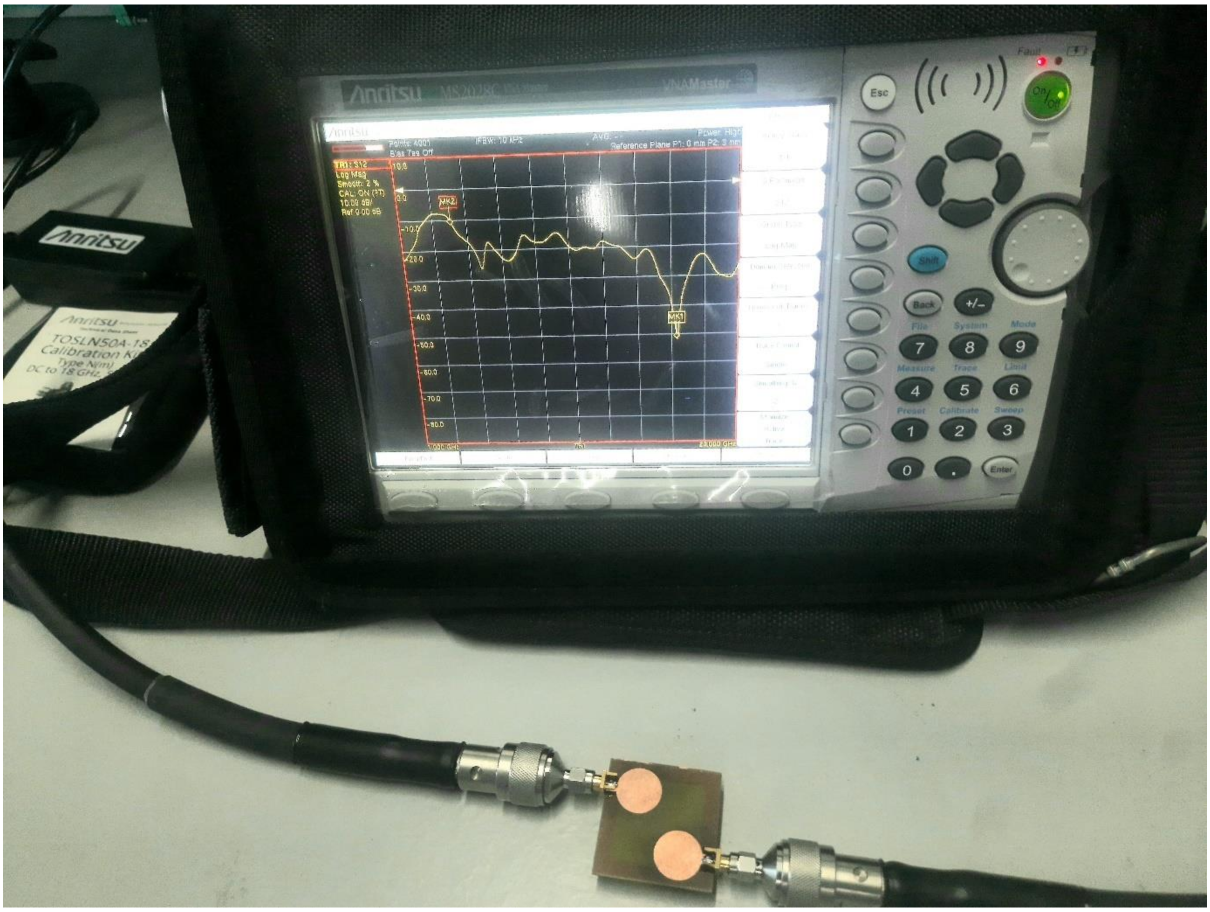


Fig 25. In-house measurement setup hand-held VNA for measuring S-parameters.

A comparative study between the measured and simulated S11,S12,S21,S22 characteristics of the fabricated antenna of the proposed geometry is presented in shown in Fig 26.,Fig.27,Fig.28,Fig.29. These characteristics provide close agreement but slightly shifted between the simulated and the measured results due to inductive effect. However, there are small discrepancies at some frequencies due to the imperfection of connectors, commercial probe, and so forth.

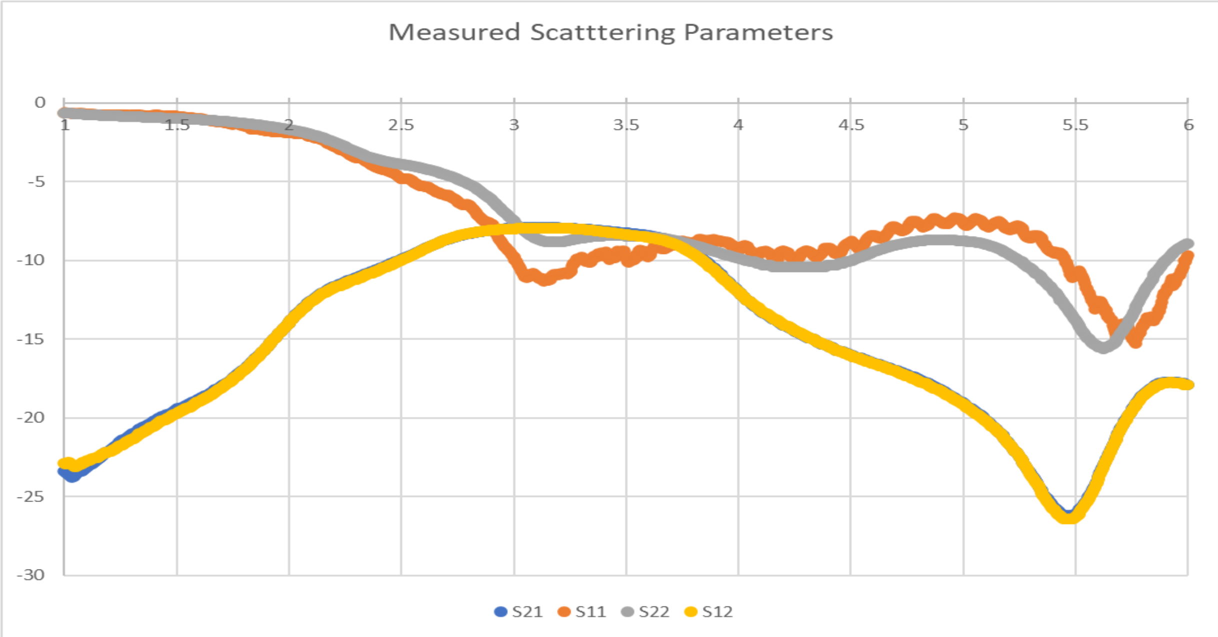


Fig.26: Measured S-Parameter Characteristics

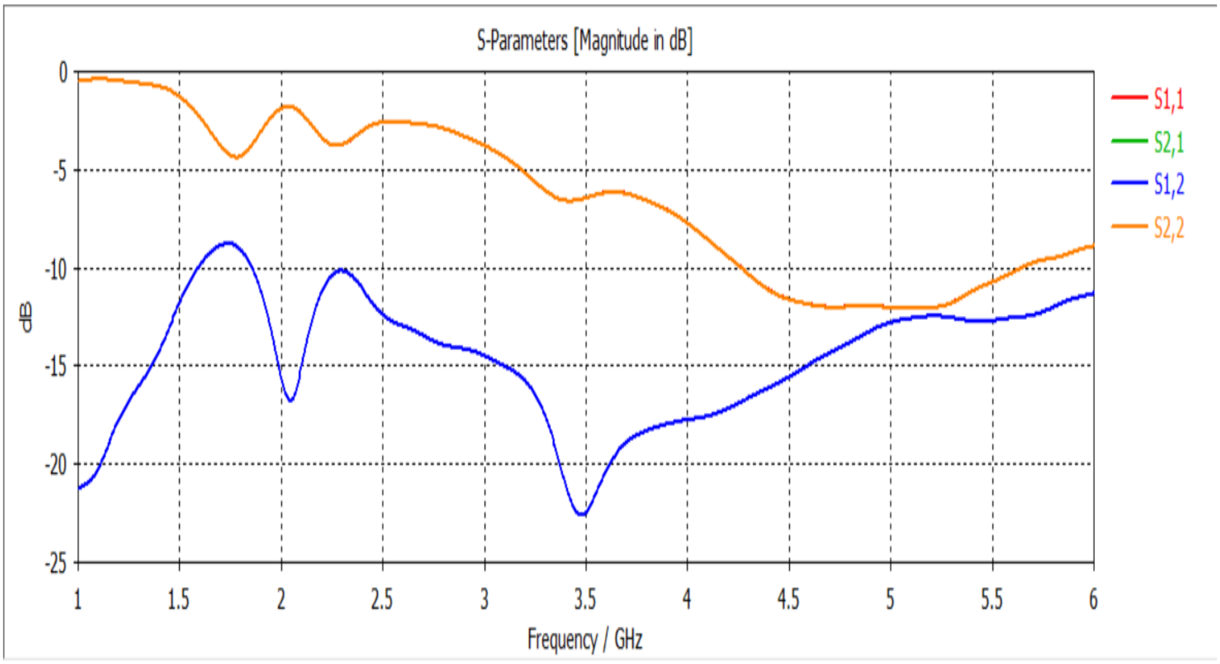


Fig.27: Simulated S-Parameter Characteristics

• Conclusion and Future Work:

The present study reveals the fact that by introducing 2-Element Circular Patch antenna, the performance of the antenna improves in terms of gain. The main objective is to design the antenna which will work under the 5G bands. Here designing this 2-Element MIMO Antenna gives the desired result. It follows the 5G bands n77, n78, n80. The frequency range lies between 4.26GHz to 5.62GHz.

However, the isolation can be obtained more by placing a thin metal plate between these two circular patch antennas. Then parametric optimization can be done by changing the values of the radius of the circular patch, the height and the length of the ground plane. It may cover more 5G bands. For this purpose new design and simulation is required. Further fabrication can be done for rest of the three cases and results can be studied in future.

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