Design & Simulation of 5G Multiband Antenna with Phase Shift Operation

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Abstract

5G will revolutionize the world more than 3G or 4G. 5G means a world where not only people but all the things are also connected. This new version of wireless technology gives us a lot of advantages which includes a boost in speed, reduce reluctance and it provides a more reliable connection for a wide range of users. In the world of mobile communication, 4th Generation (4G) technology has been a huge successful and trend. But for a large amount of data and wider bandwidth still there is a need of faster way of communication. So, we propose a dual band 5th Generation (5G) antenna of frequencies 28Giga Hertz (GHz) and 38GHz. The main patch is designed for the frequency of 28GHz and 38GHz is achieved through slots on patch. The dielectric substrate used in the proposed design is Rogers RT 5880(lossy) which has dielectric constant(ε_r) of 2:2 with loss tangent (tanδ) of 0:0009 and thickness(h) of the substrate is taken as 0:381mm. The main patch has achieved the impedance matching(S-Parameter) of -43:33dB at 28:405GHz and -28:695dB at 37:75GHz and at -10dB bandwidth of 755MHz at 28GHz and 645MHz at 38GHz. The patch has been arranged into 4array antenna using quarter-wave transform power divider with left and right phase shift.

Keywords: 5G, CST software, Impedance match, Gain, Microstrip Patch Antenna, Radiation pattern, S-Parameter, Smith chart, VSWR. Microstrip Patch Antenna (MSA), Insert feed, Slots, Array, Power divider, Quarter-wave transform, Phase shift

CONTENT

INTRODUCTION

5G is the fifth-generation mobile communication technology. 5G technology is the next generation of wireless communications. It is expected to provide Internet connections that are least 40 times faster than 4G LTE due to its wider bandwidth. 5G technology may use a variety of spectrum bands, including millimetre wave (mm Wave) radio spectrum, which can carry very large amounts of data for a short distance. 5G will use spectrum in the existing LTE frequency range (600 MHzto 6 GHz) and also in millimetre wave bands (24-86 GHz).

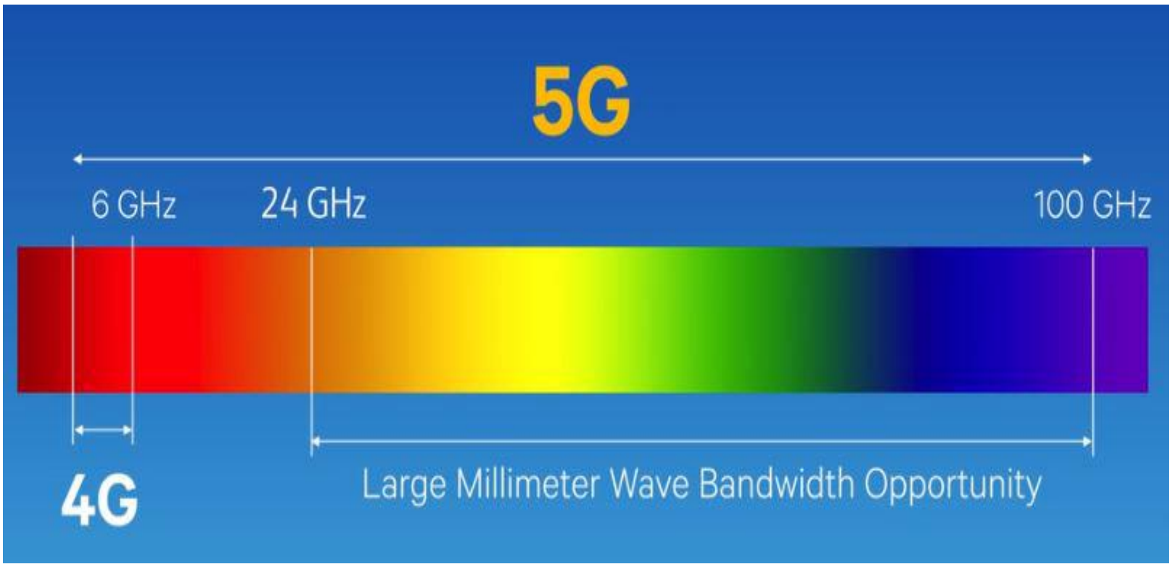

Fig 1.1: Spectrum representation of 4G and 5G

The above figure 1 shows that 5G spectrum ranges from 24GHz to 100GHz and sub-6GHz.And 4G lies from less than 6GHz. This shows that the frequency of 5G is more then 4G, which defines more speed. The above figure 2 image shows the bandwidth and frequencies of different wavelength of 2.4GHz, 5GHz, 28GHz and 39GHz.

1.1. Microstrip Patch Antenna

Microstrip patch is a kind of antenna which is made up of radiating patch of some shape on one side of dielectric substrate and ground on other side. Microstrip antennas have a ton of favourable circumstances which make mobile communication industry operatives prefer them to the preservationist antennas for mobile to satellite communication, cell, GPS, satellite, remote LAN for PCs Wi-Fi, Bluetooth innovation, RF ID gadgets, WiMAX, etc. Future needs in the field of remote portable correspondence, for example, high data transfer capacity, radio wire clusters for upgraded productivity, moveable versatile specialized gadgets and data and checking amassing gadgets, have interested the considerations of numerous scientists in the field of correspondence building to grasp the plan and examination of endless states of MSA for changed transmission capacity and other reception apparatus parameters to suit their necessities.

1.1.1. Elements of MSA:

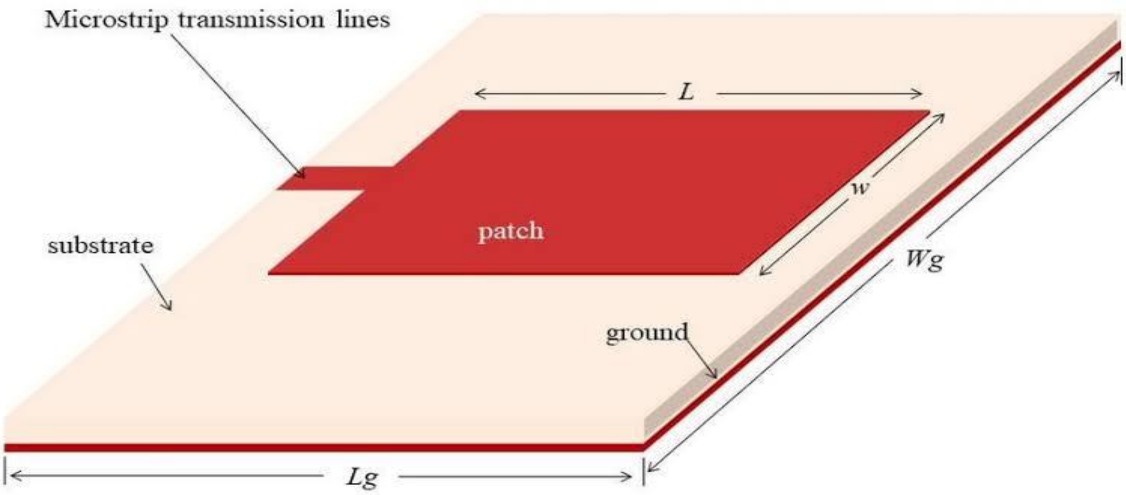

Fig1.3. Structure of Microstrip Patch Antenna

1. Metal or Radiating Patch.
2. Dielectric Substrate.
3. Ground Plane.
4. Microstrip Feed.

Fromthe above Figure 1,moderate Microstrip patch antenna involves a couple of equal leading sheets separated by dielectric medium, expressed as substrate. In this design, the upper leading sheet or "Patch" is the reason for radiation where electromagnetic vitality borders off the edges of the patch and into the substrate. The lower directing sheet goes about as a faultlessly reflecting ground plane, ricocheting vitality back through the substrate and into free space. Generously, the patch is a slight conductor that is an impressive portion of frequency in degree. The fix which has thunderous conduct is responsible to achieve sufficient data transfer capacity. [3]

LITERATURE REVIEW

2.1.1 In[1], This paper presents the design and simulation of a microstrip patch antenna operating at 28 GHz for 5G communication. The antenna operates at the Local Multipoint Distribution Service band having a center frequency at 27.91 GHz with a maximum reflection coefficient of –12.59 dB, a very wide bandwidth of 582 MHz and a high gain of 6.69 dB. The transmission line of the antenna used is an inset feed. The substrate used is Rogers RT Duroid 5880 which has a dielectric constant of 2.2 and a height of 0.254 mm. The antenna dimensions were calculated and simulated results have been displayed and analyzed using HFSS.

2.1.2 In [2]Communication systems have been driven towards the fifth generation (5G) due to the demands of compact, high-speed, and large bandwidth systems. In this research, a 28 GHz rectangular microstrip patch antenna is designed and simulated. The patch has a compact structure of 6.285 mm × 7.235 mm × 0.5 mm. The proposed antenna resonates at 27.954 GHz with a return loss of -13.48 dB, bandwidth of 847 MHz, gain of 6.63 dB and efficiency of 70.18%. An inset feed transmission line technique is used for matching the radiating patch and the 50 Ω microstrip feedline. In the design, a Roger RT Duroid 5880 substrate which has a dielectric constant of 2.2 and loss tangent of 0.0009 with a height of 0.5 mm was used. The geometry of the antenna was calculated and simulated results have been displayed and analysed using Computer Simulation Technology Microwave Studio.

2.1.4 In [3]Recently, the industry and academia there is significant activity in research and development towards the next generation micro and Pico cellular wireless Networks (5th generation). This paper presents, a structure design of microstrip patch antenna array operate at the central frequency of 28 GHz waveband is proposed. The patch antenna array consists of four elements with rectangular patch and uniform distribution. It has a compact size of 26.51 x 20.37 mm with operating frequency at 28 GHz. The inset feed technique is used for the matching between radiating patch and the 50Ω microstrip feedline. The proposed 2x2 antenna array successfully improve the antenna gain up to 8.393dB compare to existing CRLH TL CPW antenna with 2.99 dB, wideband antenna with 7.1 dB and 3.7 dB for broadband elliptical-shaped slot antenna. As a conclusion, the directivity of 10.13 db and efficiency is higher than 80% considered as a potential candidate for the 5G wireless networks and applications.

2.1.5 In [4], The mobile technology is fast-developing nowadays owing to its large impact on social life. Accordingly, there is a need to study the progress of the antenna systems as they are considered as core devices for wireless technology. The modern antenna designs allow a single element to be employed in many systems. The microstrip patch antennas are essentially considered in the advancement of the latest communication mechanisms in contrast to the conventional type because they offer the advantage of being low profile along with simple or inexpensive manufacturing procedures. In the recent four decades, extensive research has been carried out on the antenna systems. Consequently, this review paper provides a comprehensive account of the former and subsequent research achievements of the microstrip patch antennas (MPAs) at 28 GHz for fifth generation (5G) application systems. The various types of systems considered for comparison include millimeter-wave, broadbanding techniques, dual/multi-band or reconfigurable structure, size-reduction, compact, low-profile, impedance bandwidth, high gain or linear and circular polarization applications.

2.1.6 In [5], Due to rapid increase of mobile user's, demands occur for mobile communication. Mobile users need more features on their mobile phones such as high date rate, efficient communication, reduced traffic, comfort to use various applications etc. Service providers are in need to satisfy the needs of mobile users which can be done with help of 5G technology. 5G technology provides very high bandwidth, reduced latency better Quality of Service, optimum capacity, wide band of spectrum availability. 5G is operated at mm wave band in that we can provide high frequency range with large amount of bandwidth. This paper is based on the study of suitable antenna design for 5G technology for the use of mobile communication. Measurements of various parameters of an antenna design is also studied which is to check whether the microstrip patch antenna design is suitable for 5G mobile communication.

2.1.7 In[6], Triple band microstrip patch antenna is yet to design for 5G Application. The paper proposed a triple band microstrip patch antenna for 5G communication. Here, Rogers RT Duroid-5880 is used having a low relative permittivity, $\varepsilon r = 2.2$ as a substrate with thickness 0.25 mm. The proposed antenna is designed and simulated by IE3D and HFSS software. Finally, their outcome is compared by HFSS software. Simulation result shows that the proposed antenna provides reflection coefficient less than -10 dB, good gain & bandwidth at (24.4/28/38 GHz) having comparatively less antenna size and substrate thickness.

PROPOSED METHODOLOGY

Most important step in design consideration is the selection of initial parameters such as design frequency selection of substrate with required material and proper loss tangent, electrical properties such as relative dielectric constant (ε_r) and loss tangent (tan δ) of material used as substrate. Istaken is consideration to provide a proper efficiency and required bandwidth above properties of material, which effect the parameter of the antenna. The high dielectric constant results in small patch, which reduces bandwidth as well as in tighter fabrication tolerances. A high loss tangent reduces antenna efficiency with increase losses. The substrate thickness(h) is chosen as large as possible to maximum bandwidth and efficiency of antenna designed, but should avoid the surface wave excitation. The value of these are chosen as per the equation below.

$$h \leq \left(\frac{0.3\,C}{2\pi f_0 \sqrt{\varepsilon_r}}\right) \qquad 3.1$$

where:

C = is the velocity of light in cm

f_0 = is the operating frequency in GHz

ε_r = is the relative dielectric constant

3.1.Inset Feeding Technique

A feed line is a type of wire used to associate the antenna with radio. A feed line is like wise utilized to energize to transmit by indirect or direct contact. There are various diverse methods of feeding techniques as I have mentioned the above chapter. Here I will be using Inset feeding technique for designing the MIMO antenna.It is an advancement made to the microstrip line feed. An inset feed is fed closer to the patch to reduce the input impedance.

Design theory:

Selection of substrate is very important while designing of a Microstrip patch. An antenna cannot be designed without appropriate choice of substrates parameters like Width, Length, Dielectric Constant and height. There are different kinds of materials are accessible and are utilized as a substrate depending upon the prerequisite and performance. Here substrate, FR4 epoxy of thickness 1.6mm with a relative permittivity of 4.4 is utilized. The dimensions of the patch aredesigned using below given formulas. The antenna feeding is structured cautiously to give a proper or exact impedance matching. At high-signal frequencies taking care of feed line likewise assumes a significant job for radio wire execution. For good outcomes taking care of line ought to have impedance equivalent to qualities impedance of fix. For appropriate feeding of antenna Inset Feeding Method is utilized in this paper. A point inside patch where the input impedance is 50Ω, the patch antenna is feed with a microstrip line

3.2.Design of Inset Feed Rectangular MSA.

The three fundamental boundaries or parameters of MSA are:

- f_r = Resonant Frequency.
- ε_r = Substrate Dielectric Constant.
- h = Substrate thickness.

After the right choice of these three boundaries or parameters, the subsequent stage is to calculate the emanating patch estimations that is Width and Length.

The designing process can be divided into following steps:

The microstrip feed designed by calculating the values of $\left(\frac{w}{h}\right)$ ratio for the known values of characteristic impedance Z_0 and ε_r. The $\left(\frac{w}{h}\right)$ equation are.

$$\frac{w}{h} = \left(\frac{8e^{A}}{e^{2A}-2}\right) \; for \, \frac{W}{h} < 2 \quad 3.2.$$

$$\frac{w}{h} = \frac{2}{\pi}\left[B - 1 - \ln(2B-1) + \frac{\varepsilon_r - 1}{2\varepsilon_r}\right]\left\{\ln(B-1) - 0.39 - \frac{0.61}{\varepsilon_r}\right\} for \, \frac{w}{h} > 2 \qquad 3.3$$

Where, $A = \frac{Z_0}{60}\sqrt{\frac{\varepsilon_r+1}{2}} + \frac{\varepsilon_r-1}{\varepsilon_r+1}\left(0.23 + \frac{0.11}{\varepsilon_r}\right)$

$$B = \frac{377\pi}{2Z_0\sqrt{\varepsilon_r}}$$

$$\lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon_{eff}}}$$

Phase 1: Calculationor designing of Width of Patch (W).

$$\mathrm{W} = \frac{C}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \qquad 3.4$$

$$when\ \left(\frac{W}{h}\right) > \varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[\frac{1}{\sqrt{1+12\left(\frac{h}{W}\right)}}\right] \quad 3.5$$

$$when\ \left(\frac{W}{h}\right) < \varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[\frac{1}{\sqrt{1+12\left(\frac{h}{W}\right)}} + 0.4\left(1-\frac{W}{h}\right)^2\right] \quad 3.6$$

Phase 2: Calculation or designing of Effective Dielectric Constant (ε_{eff}).

$$\varepsilon_{eff} = \left(\frac{\varepsilon_r+1}{2}\right) + \left(\frac{\varepsilon_r-1}{2}\right)\left[1 + 12\left(\frac{h}{W}\right)\right]^{-1} \quad 3.7$$

Phase 3: Calculation or designing of Length Extension (ΔL).

$$\Delta L = (0.412)h\left[\frac{(\varepsilon_{eff}+0.3)(\frac{W}{h}+0.264)}{(\varepsilon_{eff}-0.258)(\frac{W}{h}+0.8)}\right] 3.8$$

Phase 4: Calculation or designing of Effective Length of patch (L_{eff}).

$$L_{eff} = \frac{C}{2fr\sqrt{\varepsilon_{eff}}} \quad 3.9$$

Phase 5: Calculation or designing of Actual Length of Patch (L).

$$L = L_{eff} - 2\Delta L \quad 3.10$$

Phase 6: Calculation or designing of Patch Width (W_g).

$$W_g = (6 \times h) + W \quad 3.11$$

Phase7: Calculation or designing of Patch Length (L_g).

$$L_g = (6 \times h) + W \quad 3.12$$

Phase 8: Calculation or designing of Inset Depth

$$y_0 = \frac{L}{\pi}\cos^{-1}\left(\sqrt{\frac{Z_{in}}{R_{in}}}\right) \quad 3.13$$

OR

$$y_0 = 10^{-4}\{0.001699\varepsilon_r^7 + 0.13761\varepsilon_r^6 - 6.1783\varepsilon_r^5 + 93.187\varepsilon_r^4 - 682.69\varepsilon_r^3 + 2561.9\varepsilon_r^2 - 4043\varepsilon_r^1 + 6697\}\frac{L}{2}$$

Where, Z_{in} = resonant input impedance and

R_{in} = resonant input resistance.

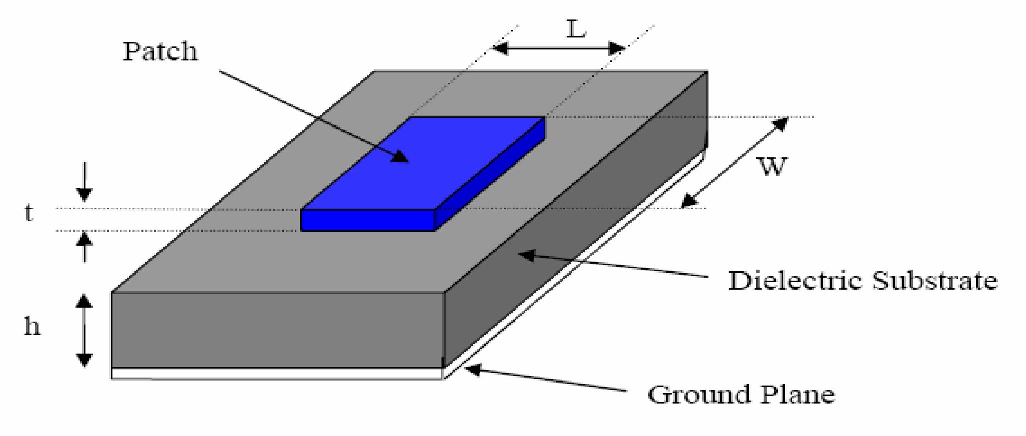

Fig 3.1: Dimensions of MSA

3.3.Inset Feed Patch Antenna

The microstrip line feed designed as per the above procedure is of 50. This can be connectedat the midpoint (M_p) along the width (W) of square patch. But the impedance offered by thepatch at M_p may not be equal to 50. Hence, microstrip line feed need not be connected at thisimpedance mismatch occurs. In such case a matching transformer must be used between M - p and50 microstrip line for better impedance matching. The following equations are used to determinethe impedance R_{in} at M_p along the width of SQMSA.

$$R_{in} \cong \frac{(120\lambda_0)^2+\left(\frac{372h}{\sqrt{\varepsilon_p L}}\right)^2 \tan^2 \beta l}{240 * L * \lambda_0 (1+\tan^2 \beta l)} \quad 3.14$$

$$where\ \beta = \frac{2\pi\sqrt{\varepsilon_e}}{\lambda_0}$$

$$l = \frac{\theta x}{180\beta}$$

The impedance of quarter wave transformer Z_t is given by $Z_t = \sqrt{R_{in} * Z_0}$. The length is determined by using equations mentioned above. The width of quarter wave transformer is determined by using equations after making the condition $\frac{w}{h} < 2\ or \frac{w}{h} > 2$.

$$y_0 = \frac{L}{\pi}\cos^{-1}\left(\sqrt{\frac{Z_{in}}{R_{in}}}\right) \quad 3.15$$

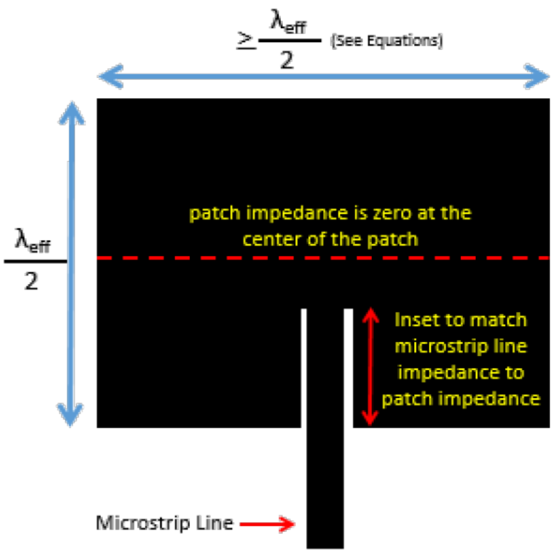

Fig 3.2: Structure of insect feed

3.4.Antenna array

In some wireless communication applications, we need to have narrow beam for large distance communication. So, it is possible by two ways.

1. Increasing the size of antenna
2. Using antenna Array

Antenna array is a antenna formed by multiple of antenna. Basically it increases gain of antenna and have narrow beam. In most cases elements of an array are identical. This is not necessary but it is convenient, simpler and more practical. If array arranged in one axis (x,y or z) then it is called single dimensional array or linear array. If array arranged in phase (xy, yz or xz) then it is said to be two dimensional array or planner array.

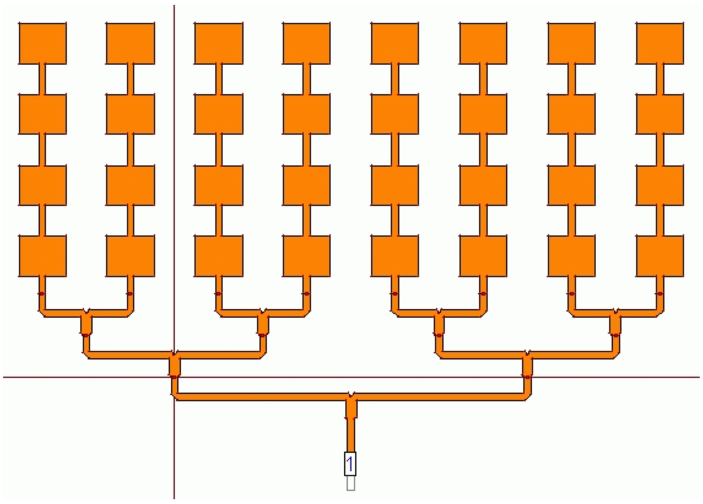

Fig 3.3: example of array antenna

Electric field by different element in array is given by

$\overrightarrow{E_1} = E_1 e^{j\psi 1},\ \overrightarrow{E_2} = E_2 e^{j\psi 2},\ \dots\dots\dots \overrightarrow{E_n} = E_n e^{j\psi n}$ 3.16

Current supplied to different elements is given by

$I_1 = I_1 e^{j\psi 1}, I_2 = I_2 e^{j\psi 2}, \dots\dots\dots\dots I_n = I_n e^{j\psi n}$ 3.17

So total electric field is

$$E = \overrightarrow{E_1} + \overrightarrow{E_2} + \cdots \dots\dots + \overrightarrow{E_n}$$

$$E = E_1 e^{j\psi 1} + E_2 e^{j\psi 2} \dots\dots\dots + E_n e^{j\psi n}$$

$$\psi = \beta d + \alpha$$

$$= \frac{2\pi}{\lambda} d + \alpha$$

Here d is spacing and α is initial phase, λ is wavelength

3.5.Power Divider

Power divider as the name suggest it divides the microwave energy into two ports with equal powerat both the terminals. Power divider is also known as power splitter or directional couplers. Itis passive device. Power combiners are used in reverse to combine the divided power. There aredifferent types of power divider like Wilkinson power divider, Quarter-wave transformer.

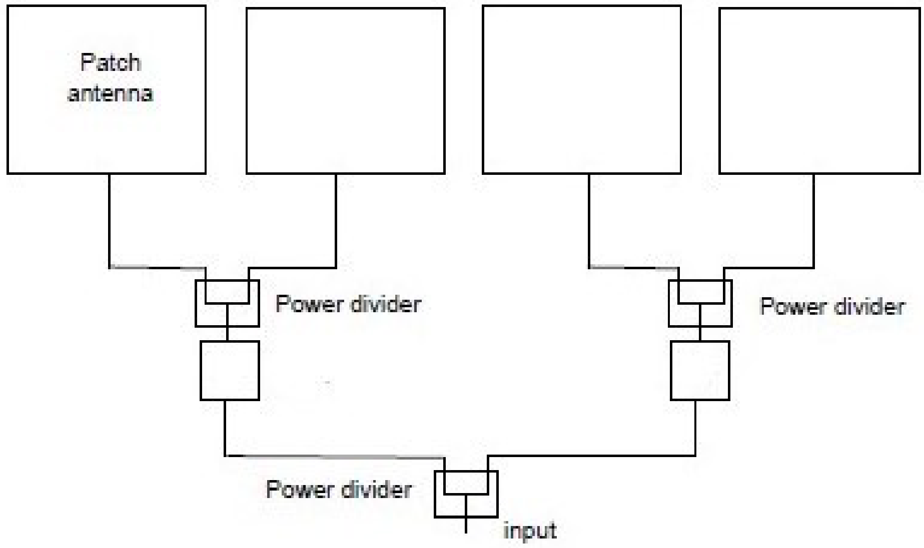

Fig 3.4: Power divider used MSA

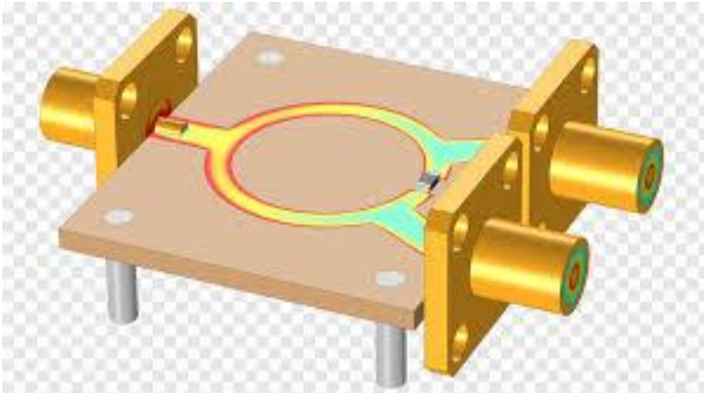

Fig 3.5: Wilkinson power divider

3.6.Quarter wave transformer

Quarter-wave transform are mostly used power divider on microstrip patch antenna. These are directly designed with patch. It is basically a transmission line whose length is quarter wavelength$\frac{\lambda}{4}$. The power from port 1 is divided equally and transmitted to port 2 and port 3. From the port 1

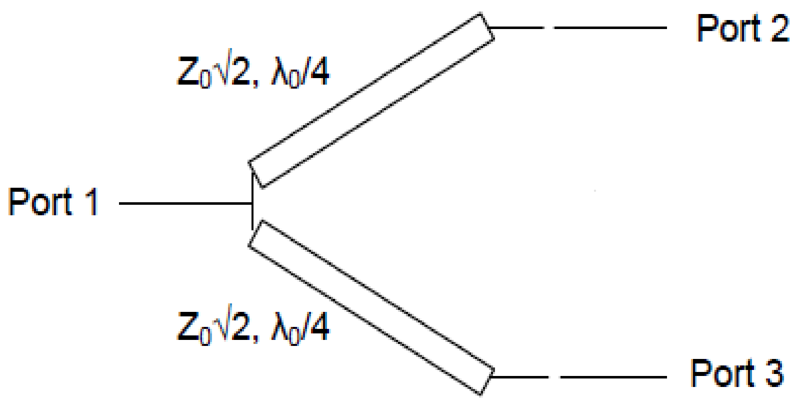

Fig 3.6: Model of quarter wave transform

50 transmission line, power to divide equally we add a quarter-wave transform of width$z_0\sqrt{2}$ andlength of$\frac{\lambda}{4}$then again while connecting to port 2 and port 3 patch use impedance matching z_0.

3.7.Phase shift array

Phase shifts in array MSA plays a very important role in differentiating each patch with different phase. They are used to shift the direction of the beam or main lobe. The main lobe is deviated from the original angle to defined phase shift in order of degree. The equations below defines the design of phase shift based on transmission line load using varactor diode.

$$Z_i = Z_0\sqrt{1+x} \quad 3.18$$

$$I_{seci} = \frac{V_i}{(\pi f_{Bragg}\sqrt{1+x})} \quad 3.19$$

$$C_{max} = xC_d \quad 3.20$$

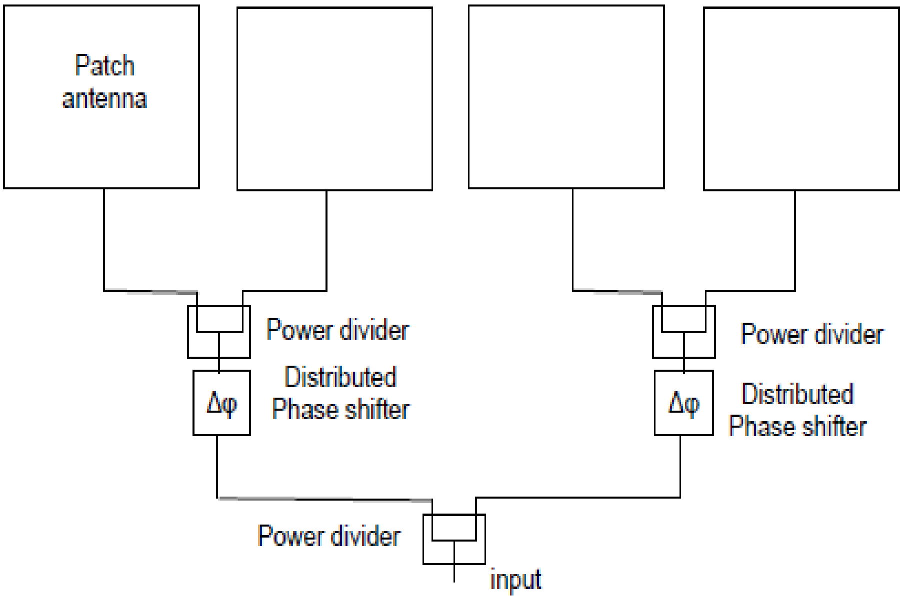

Fig 3.7: Model of phase shifter implemented on MSA

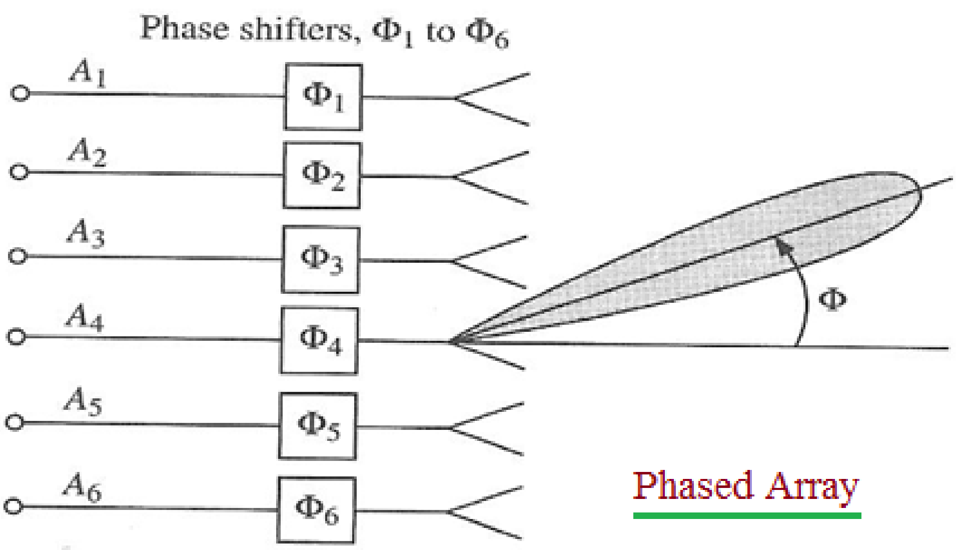

Fig 3.8: Model of phase shift

3.8.How to start with CST Microwave Studio?

Open installed CST Microwave Studio, start with a new project template, select the application area as Microwave and RF / Optical, in that Antennas. Then select the work ow as Planar (Patch,Slot etc.), then select solver type as Time domain. Then set the units, frequency range far field monitoring. The best of designing or modelling is to define parameters first in parameter list and then start defining structure of antenna you want to design. Here is the quick start guide to follow for design and simulation process in CST software

(a) Set Units: First step as you open the software and create new project, you need to set the units of all parameter you are going to define. Like Dimensions are measured in centimetre (cm), millimetre (mm), meter(m) etc. Usually dimensions are set in millimetre (mm) so that we can define even a smaller structure on patch of antenna. Then temperature are measured in Celsius(^{0}C), Kelvin(K) or Fahrenheit(^{0}F), frequency are usually set in Megahertz(MHz)or Gigahertz(GHz), time in nanosecond(ns), voltage in volt(V), current in ampere(A), resistance(Ohm), inductance in Henry(H), capacitance in Faraday(F).

(b) Define structure: This is the basic task to be followed to design a shape with required dimension. For simple shape creation you have brick, sphere, cylinder, cone, torus, but for complex you can combine using Boolean expressions, extrude, rotate, loft or bond wire.

(c) Set Frequency: Set min. and max. frequency in which you want to process your defined structure, so that the solver will process in the range given.

(d) Set Excitation: There are two types of excitations, Ports and Field sources. Ports excitation is again classified in to discrete port and waveguide port or multipin ports. And plane waves, far field source and near field source falls under field sources. Excitation is set at end face of feed line which provides power or current to patch in antenna. First select the feed line face, the waveguide port is set with some dimension.

(e) Set field monitor: Field monitor is selected for a particular frequency, to check the far field at those frequencies.

(f) Start solver: Solvers are of many types, but the mainly used solvers are Time Domain Solver and Frequency Domain Solver. Time domain solver is used to simulate antenna for some particular frequency but varying time.

(g) Analyse Results: After simulation we can see 1D, 2D and 3D results of the proposed design.1D results include Port signals, S-Parameters, Reference Impedance, Balance, Power, Energy, Materials, Port information, Efficiency, VSWR. 2D/3D results include Port modes like E-field and H-field. And Far field of selected boundaries.

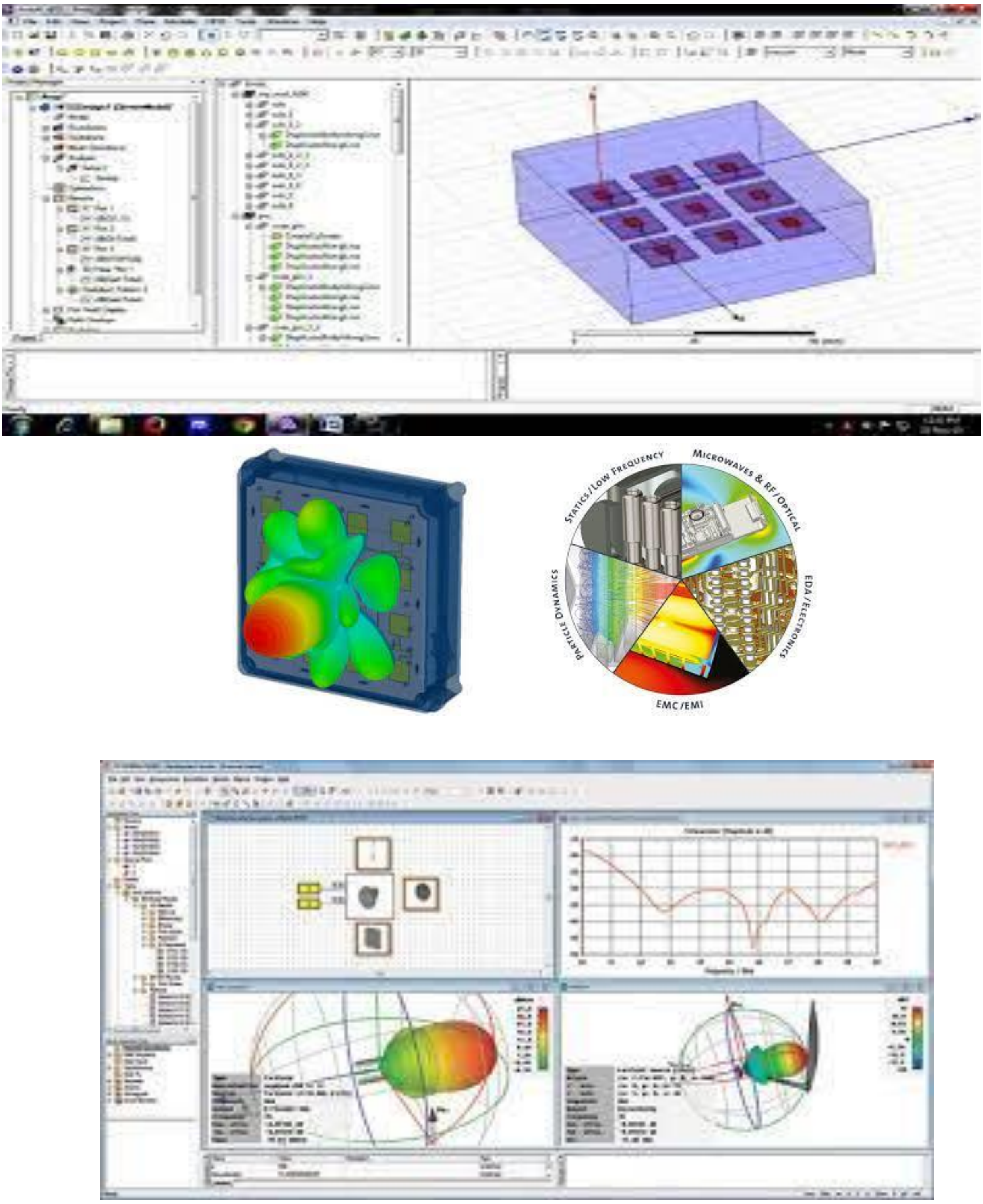

Fig 3.9: CST Studio Images

SIMULATION AND RESULTS

The antenna has been designed using CST Microwave Studio (CST MWS) software. The simulation results of the magnitude of s_{11} parameter, Bandwidth, VSWR and Gain of all proposed design arementions below respectively.

5.1. S-Parameter

S-parameter describes the response of an N-port network of signal incident to any or all of the ports.

The simulated results of theoretical calculated patch MSA of S_{11} parameter shows that goodmatching is not achieved at desired frequencies (-3:6905 dB at 29:59 GHz) as presented in figure below. The simulated results of Insert feed patch MSA of S_{11} parameter shows that matching is achievedat desired frequencies (-15:472 dB at 28:27 GHz) as presented in figure below.

The simulated results of Line-slot on patch MSA of S_{11} parameter shows that matching is achieved at both desired frequencies (-12:419 dB at 25:24 GHz and -9:7785 dB at 37:705 GHz) as presented in figure below. The simulated results of H-shaped slot on patch MSA of S_{11} parameter shows that good matching is achieved at both desired frequencies (-21:19 dB at 28 GHz and -19:523 dB at 38 GHz) as

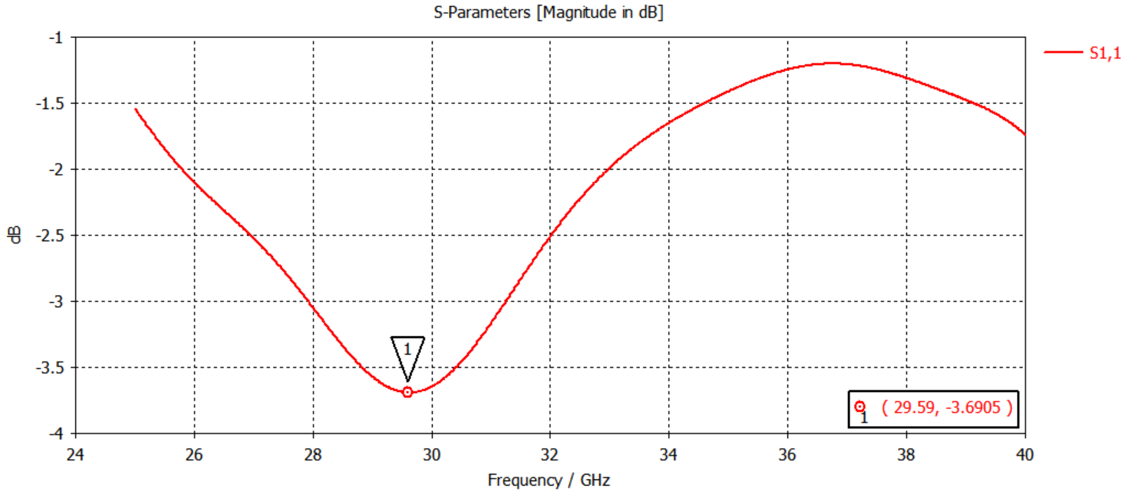

Figure 5.1: S_{11} Parameter of Figure 4.1

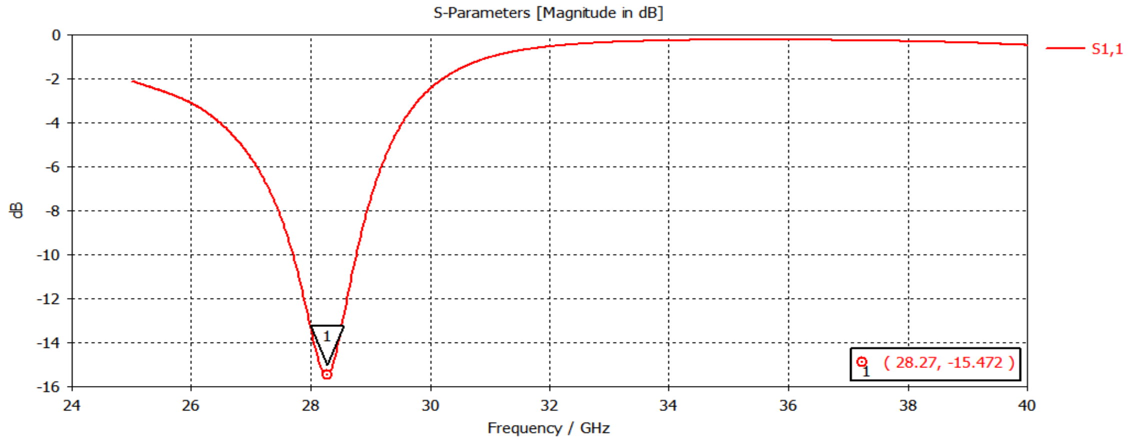

Figure 5.2: S_{11} Parameter of Figure 31

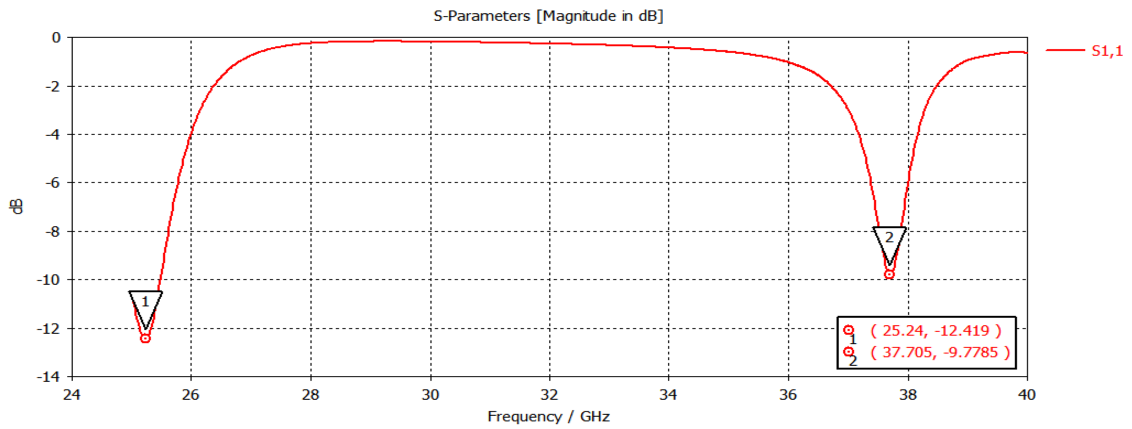

Figure 5.3: S_{11} Parameter of Figure 31

presented in figure below. The bandwidth of the antenna at -10 dB is about 615 MHz at 28 GHz and 792 MHz at 38 GHz.

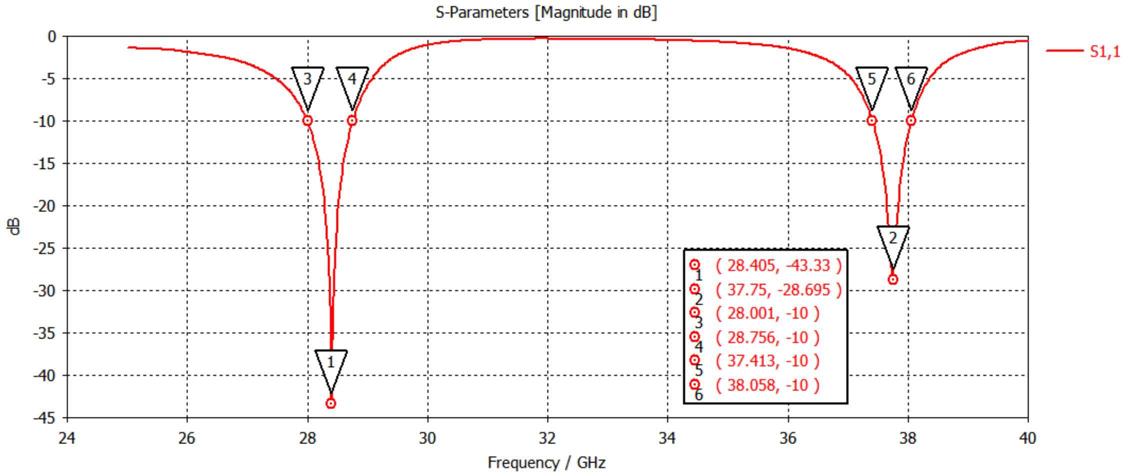

Figure 5.4: S11 Parameter of Single Element 5G MSA

The simulated results of 2 sub-Array 5G MSA of S_{11} parameter shows that matching has reducedwhen compare to previous element (-13:294 dB at 27:32 GHz and -16:45 dB at 38:54 GHz) as presented in figure below. The bandwidth of the antenna at -10 dB is about 547 MHz at 28 GHz and 811 MHz at 38 GHz.

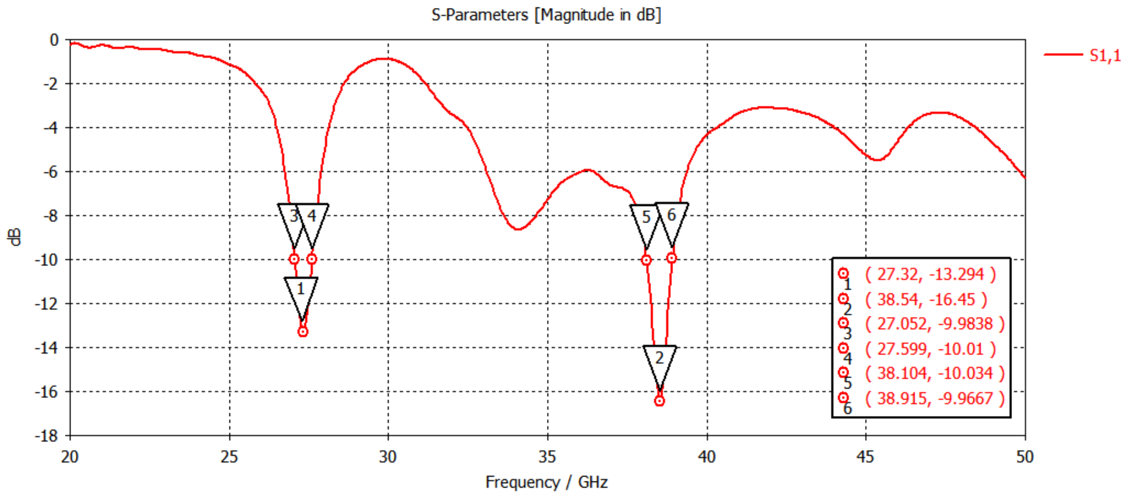

Figure 5.5: S_{11} Parameter of 2 sub-array 5G MSA

The simulated results of 4 sub-Array 5G MSA of S_{11} parameter shows that good matching isachieved at both desired frequencies (-42:369 dB at 27:43 GHz) as presented in figure below. The band width of the antenna at -10 dB is about 1109 MHz at 26 - 27 GHz.

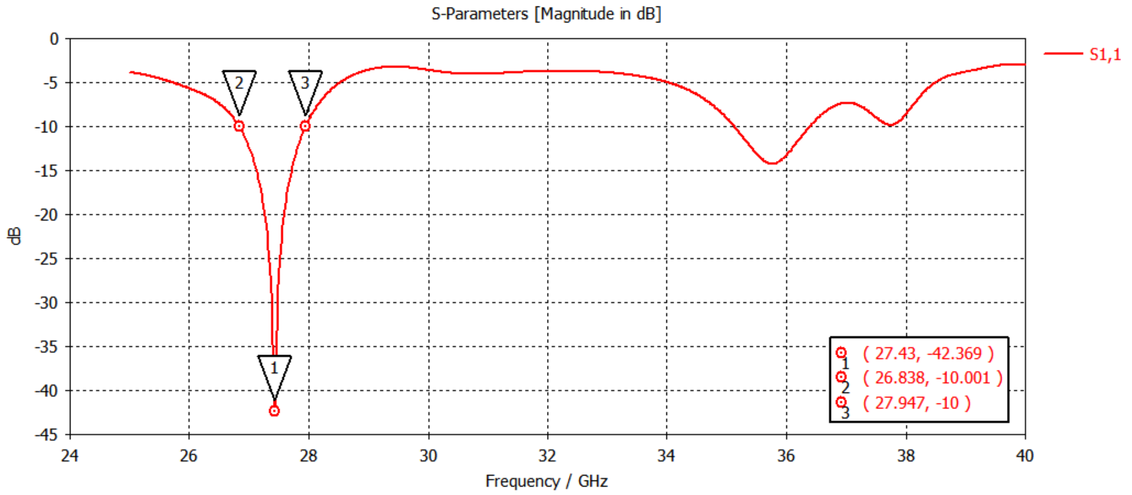

Figure 5.6: S_{11}Parameter of 4 sub-array 5G MSA

The simulated results of left phase shift 5G sub-array shows that it has got good impedance matching of -41.323dB at 28.135GHz, a wider bandwidth of 1.679GHz as shown in the figure below

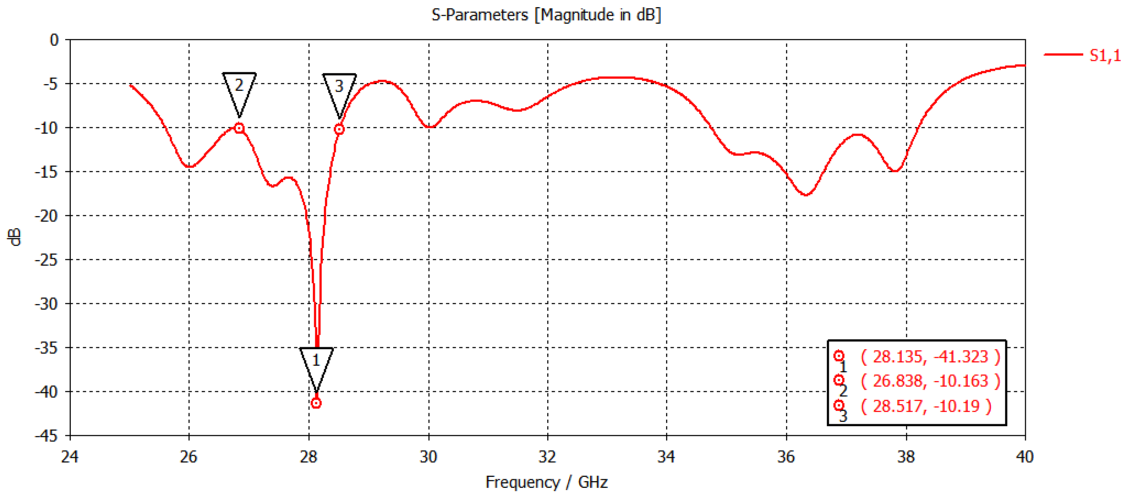

Figure 5.7: S_{11} Parameter of Left Phase Shift

Same as the above, the below fig Above right phase shift also achieved the similar results.

Below showed fig below is a S_{11}parameter of Sub-Array of I shaped array, which has achieved near to -40dB for all 3 ports S_{11}, S_{22}, S_{33} and -70dB to -80dB for different ports.

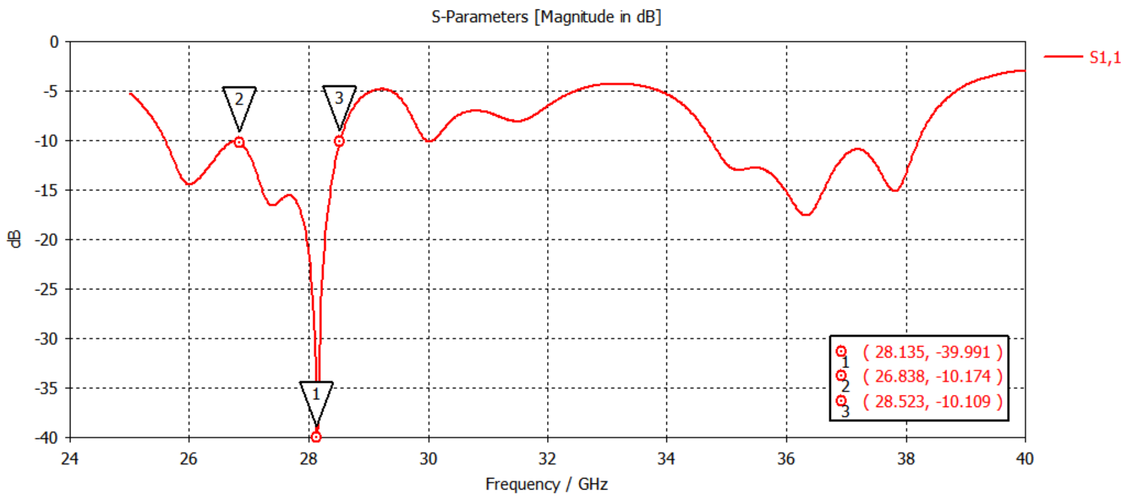

Figure 5.8: S_{11} Parameter of Right Phase Shift

CONCLUSION AND FUTURESTIC SCOPES

The proposed design has s_{11}parameter Impedance match less then -40dB, wide bandwidth of 1109MHz, gain > 13dBi for 28GHz and > 11dBi for 38GHz and perfect VSWR < 1 is achieved.

Table 6.1: Various designs of MSA and their S11 parameter Values

Design of antenna	Frequencies (GHz)	S_{11} parameter
Simple MSA	29.59	-3.6905
Insect Feed MSA	28.27	-15.472
Line slot MSA	25.24	-12.419
Line slot MSA array	37.705	-9.7785

The purposed design has meet with the industrial standards. The single element microstrip patch antenna has meet perfect impedance matching (S_{11}parameter) of -43.33dB at 28.405GHz and -28:695dB at 37.75GHz. The bandwidth availability at 28GHz is 757MHz and at 38GHz is 645MHz. The Voltage standing wave ration (VSWR) of 1.9257 is achieved at 28GHz and 1.17068 is achieved at 38GHz. The far-field gain of single element microstrip patch antenna at 28GHz is 6.75dBi and 7.37dBi at 38GHz.

Table 6.2: Results of H-Slot design on Patch

Parameter	Frequencies (GHz)	*Values*
S_{11}	28.405	-43.33db
S_{11}	37.75	-28.695db
Bandwidth	28	757 MHz
Bandwidth	38	645 MHz
VSWR	28	1.9257
VSWR	38	1.17068
Far-Field Gain	28	6.75dBi
Far-Field Gain	38	7.37dBi

Table 6.3: Left Phase Shift MSA

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