

5G MIMO ANTENNA DESIGN AND SIMULATION ON MATLAB WITH PARTICLE SWARM OPTIMISATION

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Abstract - The antenna is our electronic eyes and ears of the world. They are our links with space. With the rapid growth of the wireless communication system the future technologies need a very small and multiband antenna. Antenna plays a vital role in the field of wireless application. The reflected based antennas are commonly used because they satisfy all the requirements, but they are not practical due to their relatively big size and their 3D geometry. So the world is moving to MIMO antennas. MIMO antenna is one of the promising technologies for 5G. MIMO technology can enhance data transmission speed and gives a resistance to multiple path fading which has been widely investigated. The MIMO wireless system has demonstrated the capability to increase the communication spectral efficiency in a multipath environment. The rectangular microstrip antenna is used in wireless communication due its low profile, small size and light weight. A microstrip patch antenna consists of a radiating patch on one side of a dielectric substrate which as a ground plane on the other side.

Key Words: Multiband, Patch Antenna, MIMO (Multiple Input Multiple Output, 5G (5th generation), Microstrip, Path fading, Substrate, Dielectric.

1. INTRODUCTION

With an increase in the number of users, the frequency allocation is getting deficient due to limited channel bandwidth. Within the same frequency the number of users cannot exceed a certain specified limit. Also, the co-channel interference increases with an increase in number of users. After the evolution of high definition (HD) and quadruple high definition (QHD) video resolutions, it becomes quite difficult for the hand-held devices to send or receive large volume videos on the 3G and 4G frequency channels. It thus becomes a necessity to

have a wider bandwidth and a faster data rate for rapid transmission and reception of high quality multimedia wirelessly from one terminal to the other. To cater for this problem, 5G frequencies are under research due to their wider bandwidth. 5G offers greater bandwidth with more number of frequency channels as compared to 3G and 4G thus making it suitable for increased number of users who demand fast data rate on the go.

Besides it's impressive features 5G frequencies face a potential problem related to low penetration power due to which the signal fades and gets weaker while transmitted from transmitter to receiver using one antenna at each end. In order to enhance the range of transmitted signal, Multiple Input Multiple Output (MIMO) systems are used. MIMO antennas can be a better solution especially when dealing with compact battery powered devices. It has been observed that it is very difficult to obtain a high gain using a single antenna so multiple antennas are to be used. The array antennas being fed through the single port have same capacity as that of a single antenna. Due to this reason the frequency channel is busy most of the time thus reducing the data transfer rate.

2. PROBLEM DEFINITION

The existing challenges in antenna designing - the primary challenges arise from the specifications that are often high demanding in terms of performance expectations like gain, bandwidth, pattern characteristics (including polarisation), decreased sensitivity to environment etc. Even though the antenna itself may be small the Degrees Of Freedom may still be large especially when dealing with metamaterial composites. In view of these the focus is mainly on "Performance enhancement of small antennas using metamaterials and optimisation techniques" because such designs are certain to have a very large impact on communication antenna

designing which is believed to be a centrepiece topic of the era.

3. PROPOSED METHOD

In this research project work, “MIMO ANTENNA FOR 5G APPLICATIONS”, the main objective is to get the most suitable and optimised antenna parameters such as frequency, VSWR, return loss etc. For this various options in both Antenna Design Softwares and Antenna Optimisation Algorithms are considered. Finally, the best and most effective method in terms of cost and accuracy using Particle Swarm Optimisation (PSO) algorithm on MATLAB as it supports both.

3.1 Design Factors

- 1.) Antenna must have some degree of directivity that can be controlled
- 2.) Antenna must have some degree of cross polar discrimination
- 3.) Antenna must have differently directed spatial radiation patterns
- 4.) Cross coupling between the antennas must be minimised
- 5.) Gain must be high
- 6.) Antennas must be electrically small to minimise the interaction between them
- 7.) Antennas must have probably matched terminations

3.2 DESIGN METHODOLOGY STEPS

STEP 1: Finding the most accurate antenna design software

STEP 2: Design the antenna using selected software

STEP 3: Search for all the possible optimisation algorithms

STEP 4: Find the most accurate Antenna Optimisation Algorithm

STEP 5: Perform the optimisation and get the optimised parameters

STEP 6: Compare and crossmatch the results before and after optimisation

3.3 Matrix Laboratory (MATLAB)

MATLAB is a high performance language for technical computing. It integrates computation, visualisation and programming in a high performance and easy to use environment where problems and solutions are expressed in familiar Mathematical notations.

The MATLAB antenna toolbox helps design, visualise and analyse antennas. It has in built libraries for all the design functions.

The main Antenna toolbox functionalities are :

- 1.) Select antennas based on general antenna parameters or performance
- 2.) Select structures from the gallery
- 3.) Visualise antennas based on frequency
- 4.) Analyse antennas based on radiation pattern, VSWR, return loss and ECC.
- 5.) Export the designed antennas as variables to the MATLAB workspace
- 6.) Save and load an existing .m file and analyse the results
- 7.) Optimise the antenna parameters for various results under specific constraints

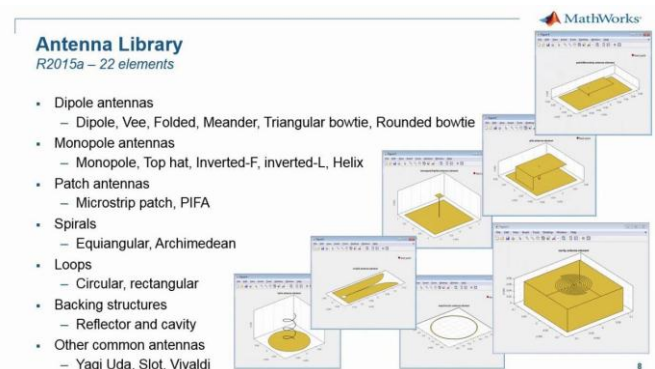


Figure 1: Antenna library of MATLAB

3.4 MATLAB Antenna Design Steps

STEP 1: Define antenna element using Antenna library

STEP 2: Show structure of antenna

STEP 3: Modify the properties of the antenna

STEP 4: Plot radiation pattern

STEP 5: Plot azimuth and elevation pattern

STEP 6: Calculate directivity

STEP 7: Calculate EH fields

STEP 8: Plot different polarisations

STEP 9: Calculate axial ratios, impedance, VSWR, return loss and reflection coefficient

STEP 10: Calculate current and charge distributions

STEP 11: Show mesh of antennas

3.5 Particle Swarm Optimisation Algorithm (PSO)

In Computational Science, PSO is a computational method that optimises a problem by iteratively trying to improve a candidate solution with regard to a

given measure of quality. It solves a problem by having a group of candidate solutions, here dubbed particles and then moving these particles around in the search space according to simple mathematical formulae over the particle's position and velocity. The simplest method works by having a population called swarm of all the candidate solutions. Swarms are formed by moving the particles until the best result is obtained and after that these positions will then come to guide the movements of the entire swarm. The process is repeated until a satisfactory solution is reached. This can be executed on MATLAB.

STEP 1: Define dimension of problem, objective function, solution space and population space

STEP 2: Initialise Population(X), Velocity($V=0$), Personal best ($p_{best} = X$)

STEP 3: For each iteration
 For each particle
 Evaluate objective function
 Update
 End

STEP 4: Find best local guide in search space
 Update velocity
 Update position
 End

STEP 5: Check for the termination criteria

The designed antenna parameters are further made accurate using the PSO algorithm. The Graphical User Interface (GUI) of MATLAB provides a highly customised simulator of a classical collective intelligence algorithm: PSO. Execute 'main.m' for running the main GUI program. The program allows the user to configure the most important parameters of the PSO.

First of all, it is necessary to set the target search function. The GUI offers twelve different benchmark functions: A paraboloid, Griewank, Rastrigin, Rosenbrock, Bukin, Log-sumcan, Ackley, Drop-wave, Holder-table and Levy. Also, if 'custom' is selected, a new window will appear in order to configure the customised function in terms of a two-dimensional MATLAB expression @ (x,y).

Once the target function is plotted, it is time to set the swarm parameters, such as the population size, the generation limit, the precision (error tolerance), and the velocity factors (percentage of the region of

interest limits): inertia weight, individual confidence factor and swarm confidence factor.

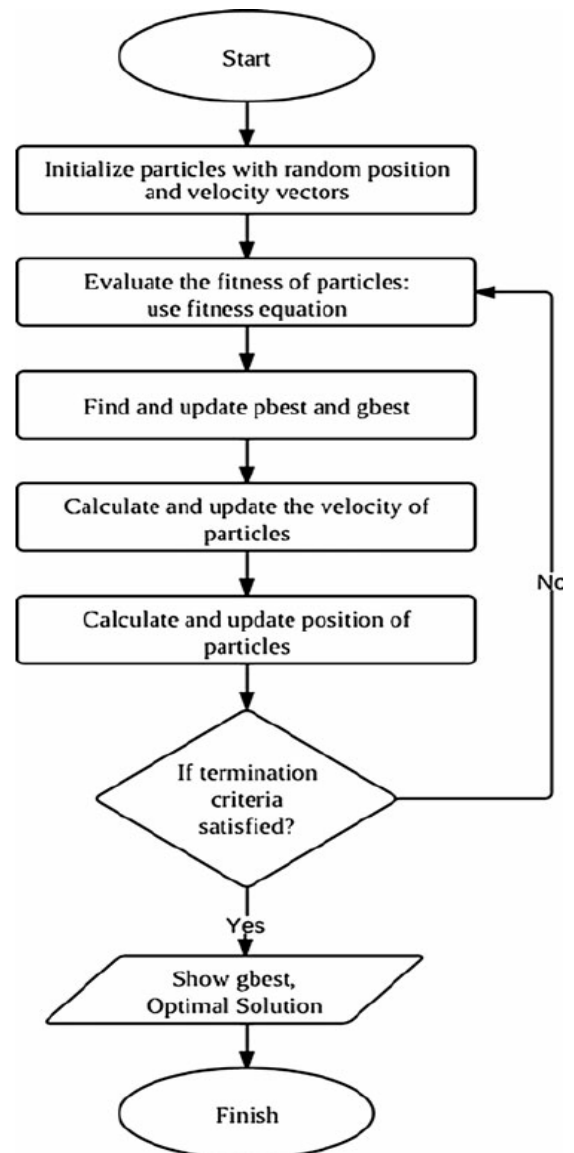


Figure 2: Flow chart of PSO.

Finally, pressing the 'run' button, the algorithm will start. Depending on the type of optimisation previously selected, the fitness is the inverse of the function evaluation (minimisation) or not (maximisation). The GUI presents 3 different graphs: 3D-function graph (upper left), contour function with swarm evolution (upper right) and fitness monitoring (bottom). Swarm particles are displayed as black dots, while the best position ever found by the swarm is displayed as a red cross-hair.

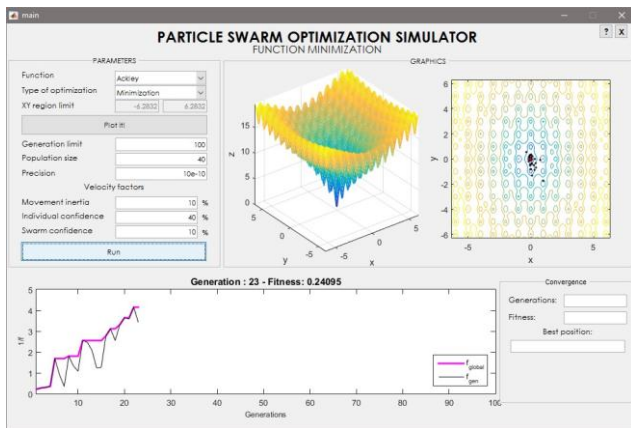


Figure 3: PSO simulator

3.6 Antenna Type And Design Equations

According to the new demand in the field of the communication system, all the components of the system needs to be small, portable in size and also which occupy less space in the board design. The new trend in the field of communication systems of Government and Private sectors are seriously working on the development of cost-effective, lightweight, small size and low profile antennas with the capable of wide range of frequency coverage with high performance.

Microstrip slot antennas have more advantages than other antennas because of its merits like, very less in weight, simple structure, cost-effective device by means of fabricating by using a printed circuit board, low profile and they can fit for planar and non-planar surfaces. The MSPA shape can be designed to have many geometrical shapes and dimensions. The few of the examples are dipole, triangle, square, rectangular, pentagon, hexagon, circle, ellipse, semi-circular ring, circular ring, cross junction, star, U-shaped, rectangular ring, trapezoid, H-shaped and L-shaped etc.

Nowadays, we can find the multi-functional wireless system in single handset. In this context, the compact, broadband, high gain and multiple frequency bands capable of microstrip antennas are required.

Thus the most suitable antenna type is a Microstrip Slot Antenna as it has the following characteristics and advantages:

- Low profile volume and light weight.

- They can be made conformal for host surfaces.
- Manufacturing process is simple
- Low fabrication cost
- Inexpensive and so readily available for mass production by using the printed circuit board technology.
- They can be made compact in size
- Multi-frequency range operation.
- Can allow the both linear and circular polarisations
- Without major alterations of MSSAs can be used for missiles, rockets and satellites.
- Well-matched to solid state devices.
- Matching networks and Feed line are made-up simultaneously.

To design the antenna we need to first calculate the parameters including those related to the size (dimensions) and radiation pattern.

Dimensions include: width and length of patch, thickness of material, extension length, effective length, width and length of substrate, feed length, width, length and height of the radiation box.

Parameters related to radiation pattern include: resonating frequency, velocity of light, dielectric constant, effective dielectric constant and guided wavelength.

Consider the following parameters :

f_0 - Resonating frequency of the antenna

C - Velocity of light

ϵ_r - Dielectric constant

W_1 - Width of patch

L_1 - Length of patch

W_2 - Width of strip

L_2 - Length of strip

h - Thickness of material

λ - Wavelength

$$\lambda = C / f_0$$

where $C = 3 * 10^8$ m/s

$$W_1 = \frac{C}{2f\sqrt{\epsilon_r + 1}}$$

$$(-\lambda_g/6, -\lambda_g/6, -\lambda_g/6)$$

Length : $\lambda_g/6 + \lambda_g/6 + W_g$

Width : $\lambda_g/6 + \lambda_g/6 + L_g$

Height : $\lambda_g/6 + \lambda_g/6 + h$

ΔL - Extension length

L_{eff} - Effective length

$$L_1 = L_{eff} - 2\Delta L$$

$$L_{eff} = C / (2f\sqrt{\epsilon_{reff}})$$

$$\Delta L = 0.412h (\epsilon_{reff} + 0.3) (\frac{w}{h} + 0.264) / (\epsilon_{reff} - 0.258) (\frac{w}{h} + 0.8)$$

ϵ_{reff} - Effective dielectric constant

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

For substrate length and width :

$$L_g = L + 6h$$

$$W_g = w + 6h$$

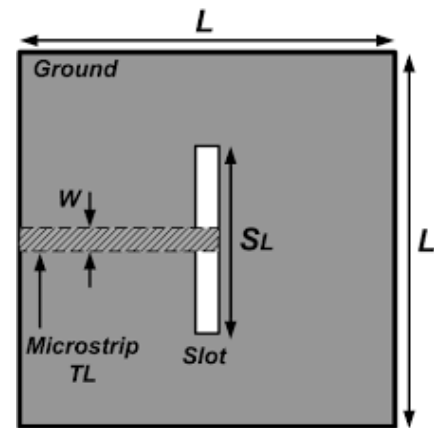


Figure 4 : Rectangular microstrip slot antenna with dimensions.

Table 1 : Parameters of the designed microstrip slot antenna

PARAMETERS	VALUES (in mm)
L_1	25
W_1	50
h	27
L_2	165
W_2	150
L_g	190
W_g	200
Gp_l	100
Gp_w	70

where, L_g - length of substrate

W_g - width of substrate

$$L_2 = L_g - L_1$$

$$W_2 = W_g - W_1$$

λ_g - Guided wavelength

$$\lambda_g = \frac{\lambda}{\sqrt{\epsilon_{reff}}}$$

Feed length - L_f

$$L_f = \lambda_g / 4$$

Gp_l - Ground plane length

Gp_w - Ground plane width

For Radiation box :

Axis position :

4. RESULTS AND ANALYSIS

Designed the required rectangular microstrip slot MIMO antenna parameters mathematically by using the design equations.

Coded the design on MATLAB as per the calculated design parameters.

Simulated the code on MATLAB.

The performance analysis of the antenna is done on MATLAB.

The resulting parameters obtained are further optimised using Particle Swarm Optimisation (PSO) algorithm.

The final results after optimisation are then cross matched with the desired theoretical values.

4.1 Stimulated Antenna

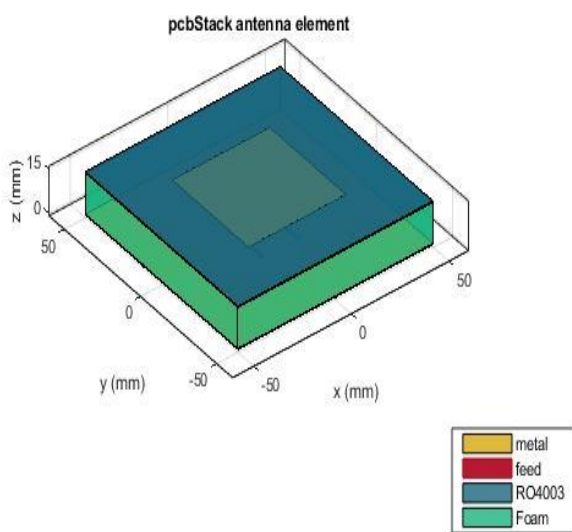


Figure 5 : Simulated antenna

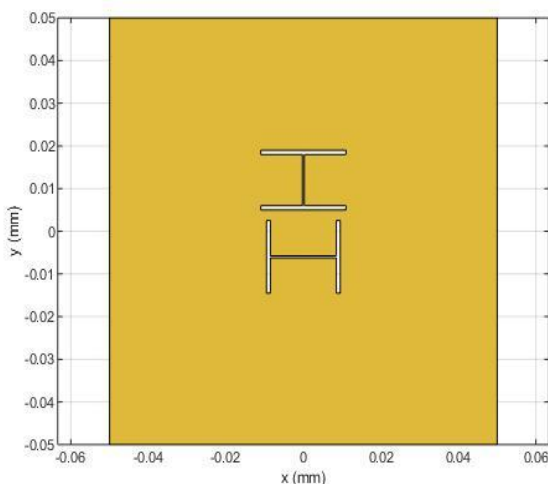


Figure 6 : Image of the designed antenna.

4.2 S Parameters

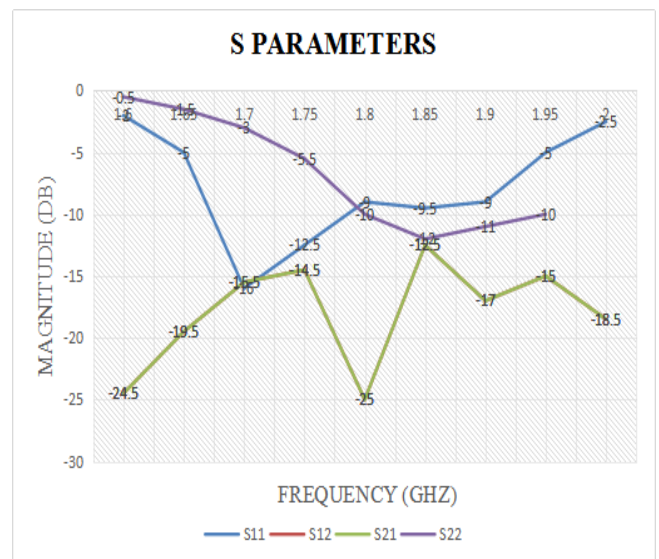


Figure 7 : S parameters of the antenna ports.

4.3 Voltage Standing Wave Ratio (VSWR)

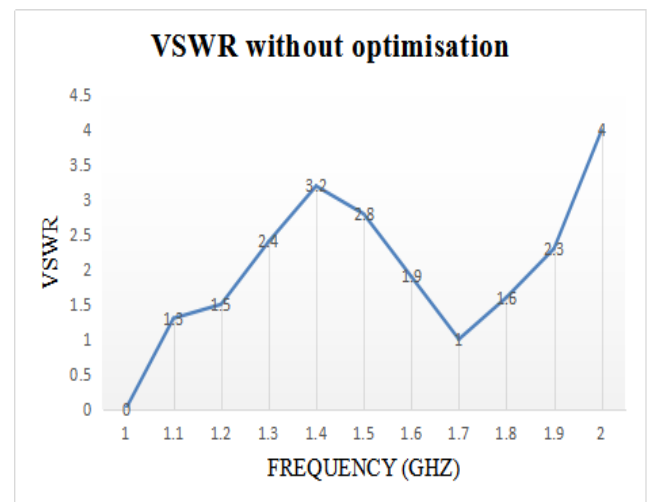


Figure 8 : VSWR before performing PSO

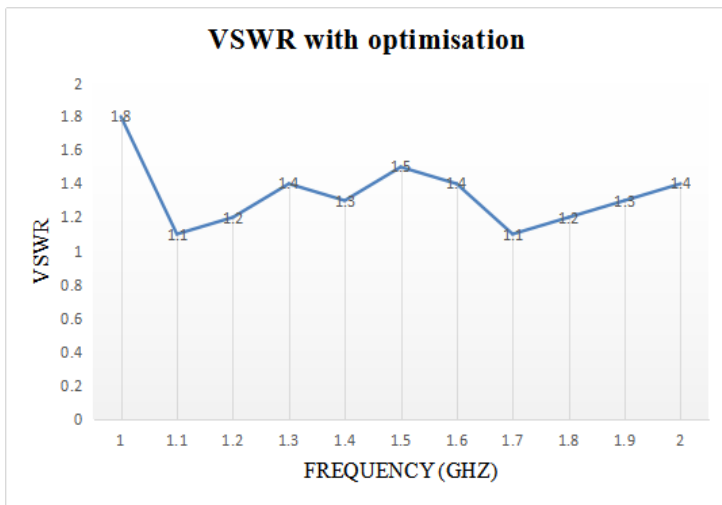


Figure 9 : VSWR after performing PSO

4.5 Return Loss

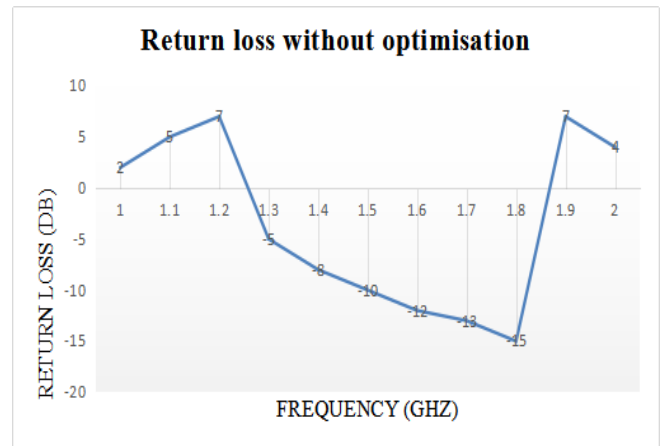


Figure 12 : Return loss before optimisation

4.4 Active Impedances

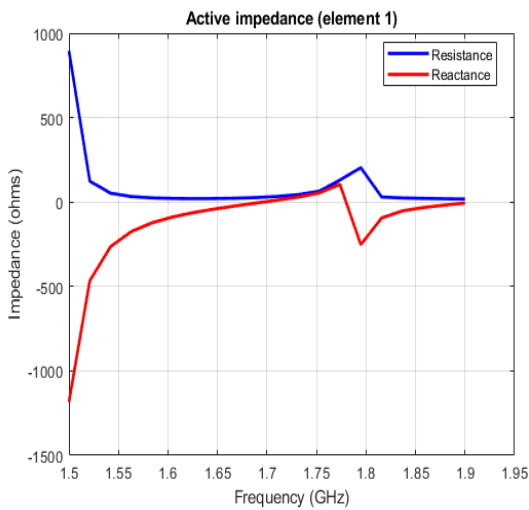


Figure 10 : Active impedance of element 1

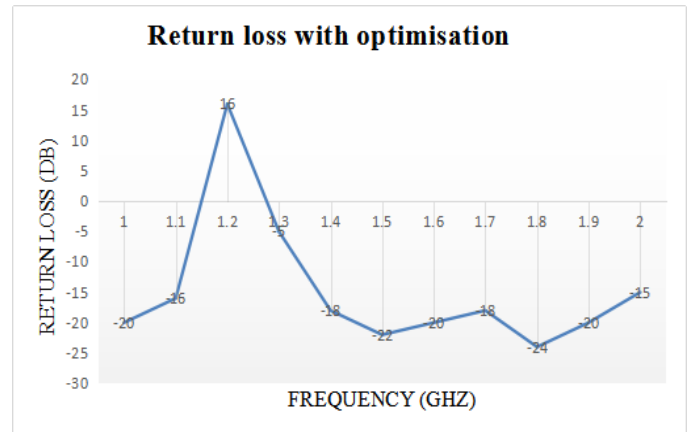


Figure 13 : Return loss after optimisation

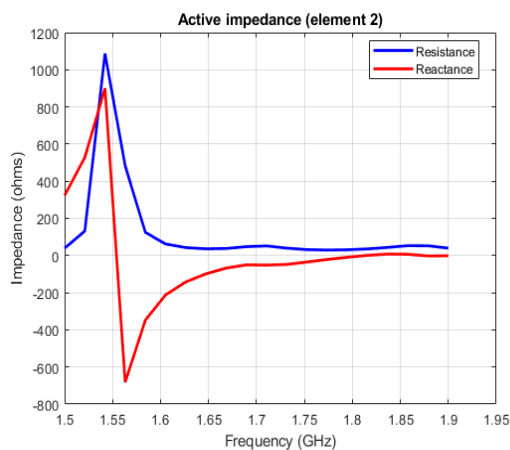


Figure 11 : Active impedance of element 2

4.6 Envelope Correlation Coefficient (ECC)

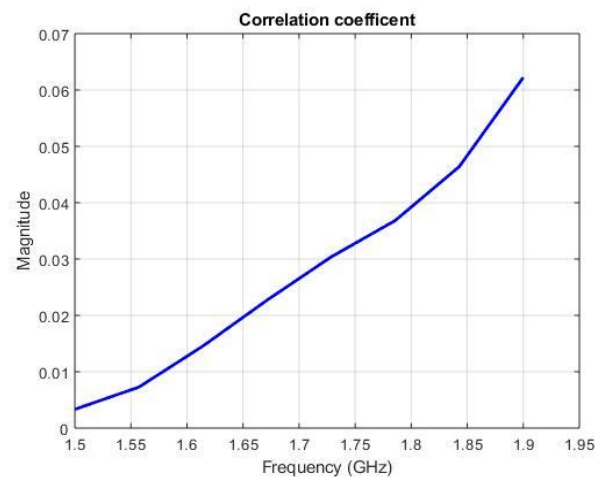


Figure 14 : Envelope Correlation Coefficient (ECC)

4.7 Radiation Pattern and Gain

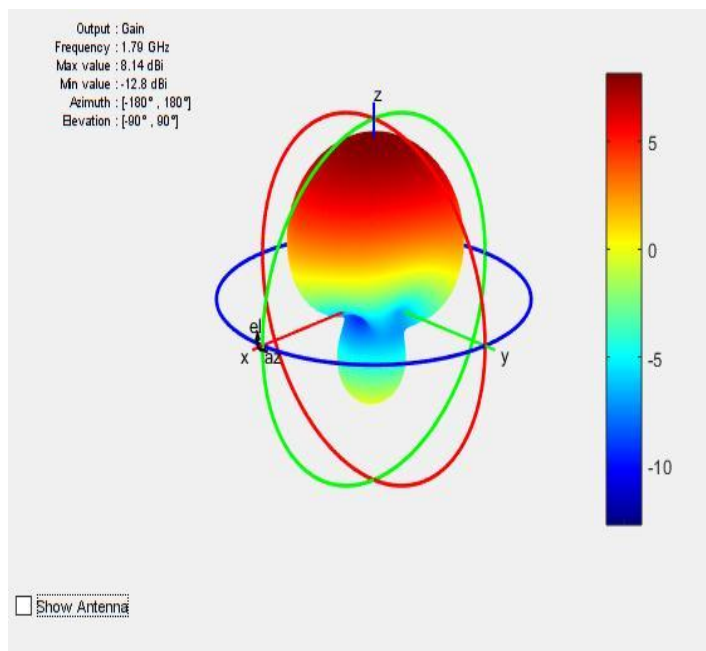


Figure 15 : Gain and radiation pattern

4.8 Efficiency

$$\text{Efficiency } \eta = \frac{Prad}{Ps} * 100 \%$$

Or

$$\text{Efficiency } \eta = \frac{\text{resultant gain}}{\text{theoretical gain}} * 100 \%$$

Theoretical expected gain = 9 dBi

Resultant maximum gain obtained = 8.14 dBi

$$\eta = \frac{8.14}{9} * 100 \% = 90 \%$$

Table 2 : Comparision of designed calculated parameters with ideal values

PARAMETER	IDEAL VALUES	OBTAINED RESULTS
S ₁₁	- 10 dB	- 9 dB
S ₁₂	- 20 dB	- 25 dB
S ₂₁	- 20 dB	- 25 dB
S ₂₂	- 10 dB	- 9 dB
VSWR	1	1.6
ECC	Less than 0.3	0.04
GAIN	9 dBi	8.14 dBi
EFFICIENCY	100 %	90 %

ANTENNA	RESONANT FREQUENCY GHz	RETURN LOSS dB	VSWR
Before optimisation	1.79	- 15	1.6
After optimisation	1.79	- 25	1.2

Table 3 : Comparing and crossmatching the results before and after performing PSO

5. CONCLUSIONS

This Research Projct Work “ MIMO Antenna for 5G Applications “ has been done with the aim of designing and simulating a 5G MIMO rectangular microstrip slot antenna. MATLAB 2018a software is used for desining, simulating and analysing the characteristics or parameters of the antenna viz return loss, VSWR, isolation, Envelope Correlation Coefficient (ECC), reflection coefficient, gain and effiency. All parameters are obtained with values close to the expected ideal values necessary for the optimum and cost efficient design. Return loss, resonant frequency and VSWR are further optimised using the Particle Swarm Optimisation Algorithm. Thus more accurate results and design is reached.

The simulated results reveal that the PSO Algorithm yielded good results in terms of return loss and VSWR than the conventional antenna. Since the

antenna operates in the S band it can be employed in various applications like airport surveillance radar for air traffic control, weather radar, surface ship radar and some communications satellites, especially those used by NASA to communicate with the Space Shuttle and the International Space Station. The MIMO antenna is implemented on an Roger R04003 dielectric and provides good properties including S-parameters, efficiency, and radiation pattern coverage. The performance of the antenna is validated by measurements of the prototype. The simulation results of the antenna are compared, cross matched and it is found that good results are achieved.

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