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Design of Phased Array Multiple Beam Microstrip Antenna with Beam Steering for 5G Applications

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Abstract

In this paper, a compact microstrip antenna for 5G applications is designed. 5G wireless systems (millimeter wave systems) are improved networks to be deployed. A novel structure for the frequency 27.72 GHz with five element array and eight port feeding is here reported. The multiport feeding is able to vary the resultant beam position in the desired direction by changing the relative phase of input beams at different ports. The reported structure produces a beam, which is more directive with HPBW of 22.3-degree, maximum gain of 14.1 dB and a minimum return loss of -58.75 dB. In this paper, four different steering positions and four multiple beams in different directions with phase changes are reported. The simulation for this novel antenna array structure is carried out on CST microwave studio and structure is fabricated on the substrate Rogers RT5880LZ having dielectric constant 1.96 and results are tested and compared with the simulated results

Keywords: *Beam steering, Beamforming, Phased Array, Microstrip Antenna, Multiple Beams, HPBW*

I. INTRODUCTION

With the development of modern wireless technologies high speed and high data rates are in demand. So, to fulfill such demands 5G technologies come into the picture. **5th generation wireless systems**, abbreviated **5G**, are improved networks to be deployed in coming future. The primary technologies used in 5G include: millimeter wave bands (26, 28, 38, and 60 GHz) that offers performance as high as 20 gigabits per second. [1]. Advanced antenna systems (AAS) is a viable option nowadays to be deployed for future 4G and 5G mobile networks. An advanced antenna system consists of an antenna array that is integrated with hardware and software that is used for transmission and reception of radio signals. This 5G array provides greater beam steer ability in terms of adapting the antenna radiation patterns to rapidly time-varying traffic along with beam forming. [2].

1.1 Motivation behind the work

The antennas designed for 5G applications are quite different compared to normal low frequency antennas. The antennas for 5G applications should be compact and very small in size, they should have a high gain and should be highly directive thus having a low HPBW. The proposed antenna is a phased array antenna in which the position of beam varies depending on the relative phase difference between the inputs applied at different ports.[3-4] This is a very necessary requirement for 5G antenna because at a very high frequency the signal suffers from a large attenuation by obstacles so there should be multiple paths for the signal to travel and the antenna should have a capability to switch between different beam positions, this is called beam steering where the main beam of the antenna is steered at different positions.[5-6].

This work is motivated to design an antenna which is working on the 28 GHz (5G band dedicated to GSM by ITU standard) band. The low loss material is kept in mind and also the design should be compact in size compared to all reported till today. Multiport element array is targeted to capture the signal from different directions. Different phase of the beam among the ports are to be optimized to find a single directive beam with gain above 10 dB. This resultant beam is able to steer in different directions. The direction to steer the resultant beam is to be optimized for desired directions by changing the phase among the applied beam phases.

1.2 Methodology

A single patch of miniature dimension (2.95 X 2.95) mm^2, with transformer coupling is optimized for the 5G band (28 GHz) frequency. Transformer coupling is here proposed due to very small size of patch, and to fulfill the objective of producing a directive beam with multiple beams of different magnitude. Dual port orthogonal transformer feeding is first optimized for this purpose. Next, number of designed dual port single element is increased by two and four element arrays. The final array structure is having five elements with eight ports. The middle patch is parasitically coupled. This middle patch is supposed to make the resultant beam directive in the center direction. The array structure is optimized for directive single beam for different phases of input signal from different ports. This change in direction of beam with change in phases of input port beam are also optimized. The resultant beam position of the phase array structure is dependent on the difference in phases at the inputs. So, controllability over the beam steering increases by increasing the number of input ports. All the performance parameters are optimized and measured result of return loss is compared with the simulated result for validation of the work.

II. SINGLE PATCH ANTENNA DESIGN AND ANALYSIS

The design of phased array antenna starts with designing a single patch antenna that is further replicated to form an array. The single patch is fed with a feed line with the impedance matching transformer. The square patch as shown in Fig.1 having dimensions W3 X L3 = 2.95 X 2.95 mm^2. The substrate is Rogers RT5880LZ having dielectric constant 1.96 and thickness of 1.27 mm. The structure is designed for a frequency of 28 GHz. The optimized dimensions for quarter wave matching transformer are W2 X L2 = 0.7 X 2.2 mm^2 with feed line dimensions W1 X L1 = 4.2 X 4.1 mm^2. The single port antenna is simulated and the S11 results are shown in Fig.2, The structure was initially resonant on 27.52 GHz with S11=-45.34 dB.

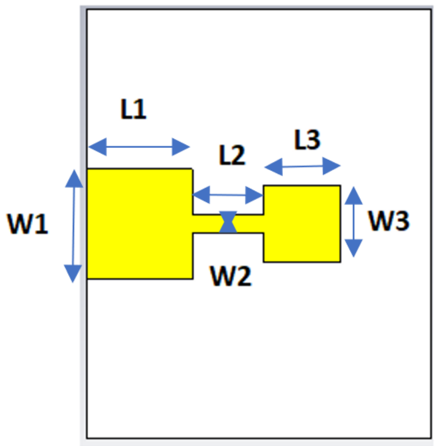

Fig.1. Single patch antenna

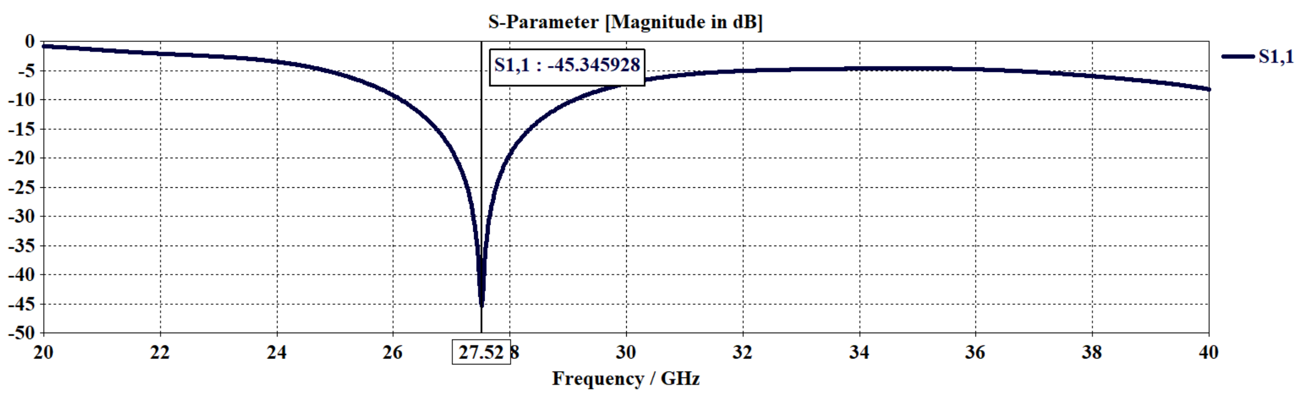

Fig.2. S11(dB) vs frequency

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III. MULTIPLE PORTS FEEDING

To achieve the objective of getting multiple beams and beam steering in multiple directions, orthogonal feeding arrangement is optimized. To change the direction of current on the patch, the designed patch is fed with two orthogonal ports, as shown in Fig.3. The mutual coupling between the two orthogonal ports should be very low. As shown in Fig.4 the simulation results of S12 and S21 are equal with the value -20.04 dB, at the frequency of 27.74 GHz. It is due to the orthogonal port and it shows that they are working independent to each other.

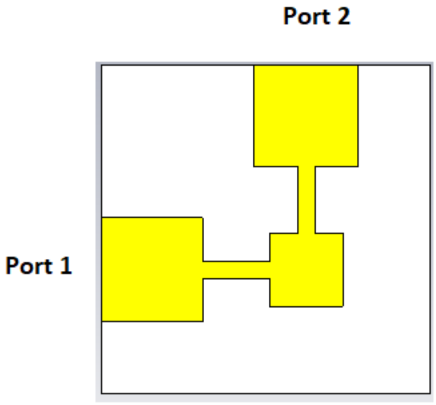

Fig.3 Multiple port feeding

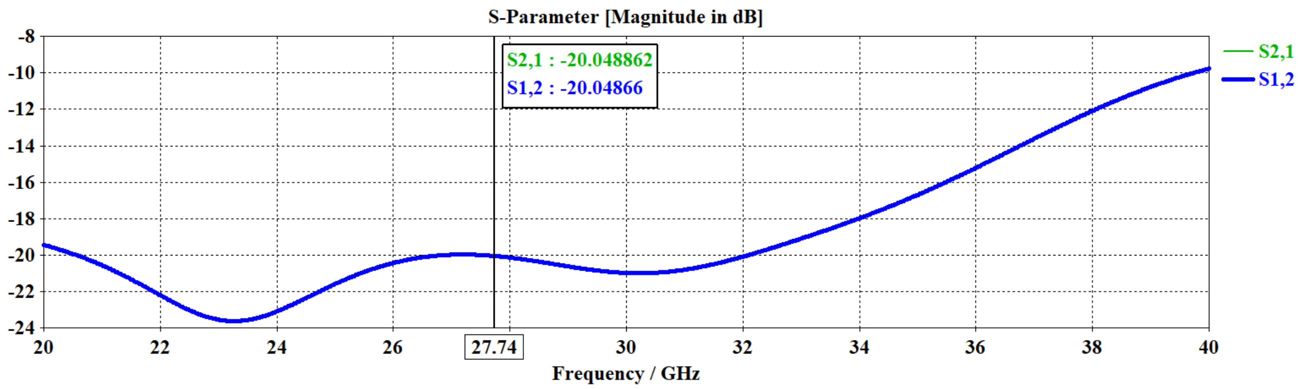

Fig.4. Graphs for S21, S12

Correlation coefficient (ρ) and diversity gain between the two ports are calculated by equations (1) and (2) [7]. The calculated values are zero and 9.99 dB from the formulae. The simulated results for correlation coefficient and diversity gain with frequency is also shown in Fig.5 which shows a very minimum value of correlation coefficient and a diversity gain of nearly 10 dB at the frequency of 27.74 GHz. It validated that the two ports are not correlated to each other.

$$\rho = \frac{\left|S11^{*}S12 + S21^{*}S22\right|^{2}}{\left(1-\left|S11\right|^{2}-\left|S21\right|^{2}\right)\left(1-\left|S22\right|^{2}-\left|S12\right|^{2}\right)} \quad (1)$$

$$DG(dB) = 10 * \sqrt{1-(0.99*\rho)^{2}} \quad (2)$$

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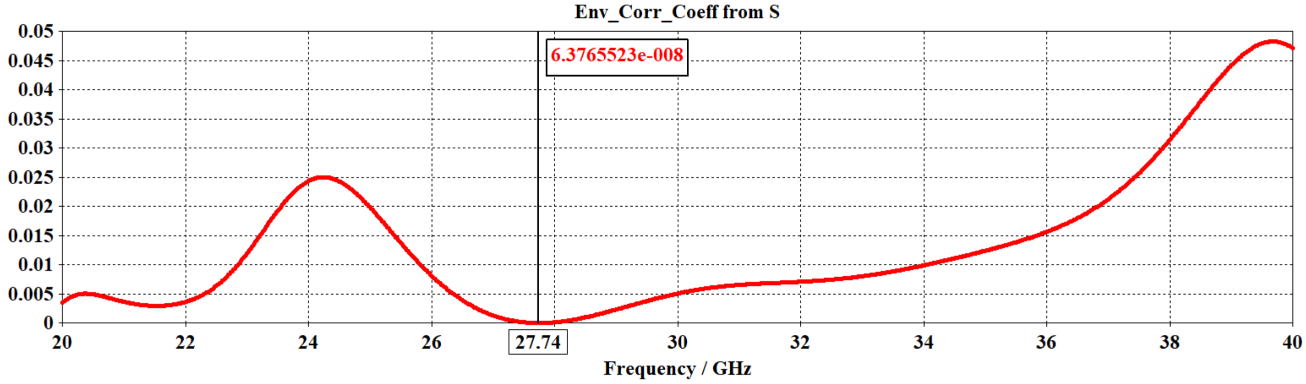
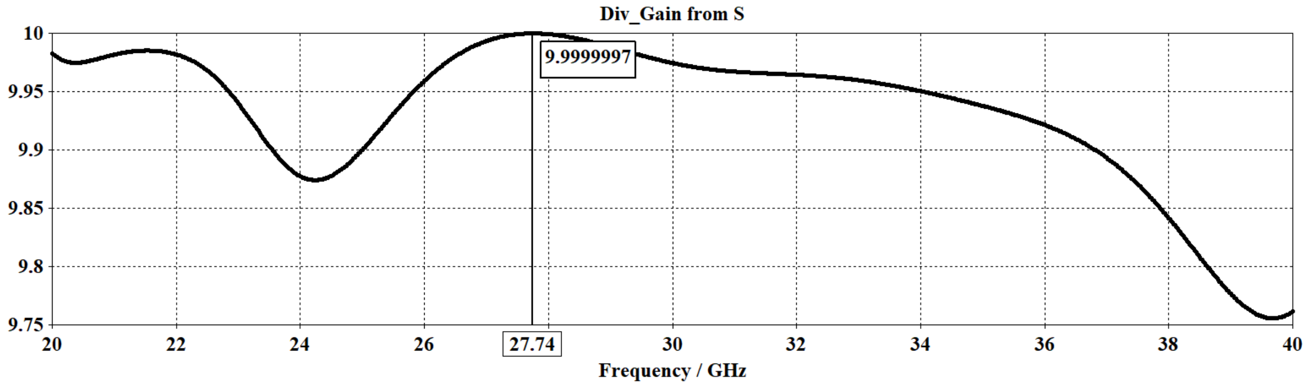


(a)



(b)

Fig.5. Graphs for (a) Correlation Coefficient (b) Diversity Gain with frequency.

IV. DESIGN OF ANTENNA AND ITS ARRAY

The extend of the work is to design an array structure that produces a highly directive beam at the center by applying multiple beams at the input ports and steering this beam in the desired direction. A single patch of compact dimension 2.95 X 2.95 mm^2 is optimized for the resonant frequency of 28 GHz. The single beam must be directive towards the center so one more transformer coupling feed with the same dimension at the orthogonal position is optimized by applying the signal of same phase of 0 degree on both ports of Fig. 6(a) and the simulation results as in Fig. 7(a). It is observed that S11=S22=-57.7 dB at a frequency of 27.74 GHz.

The single patch with orthogonal feeds is further duplicated to form two and four array structures with two transformer coupling feed ports for each single patch as shown in Fig. 6(b) and (c) respectively. The overall design is symmetric and the gap among each patch are d=6.95 mm. The return loss simulation result for the structure of fig. 6(b) is shown in fig. 7(b), it is observed that minimum value is -35.45 dB at a frequency of 27.76 GHz. The return loss simulation result for the structure of fig. 6(c) is as shown in fig. 7(c), it is observed that minimum value is -37.79 dB at a frequency of 27.76 GHz.

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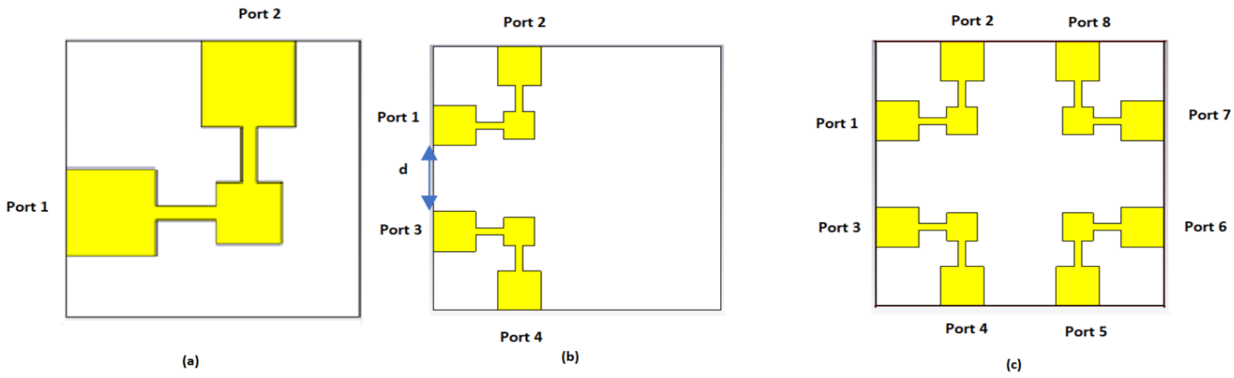
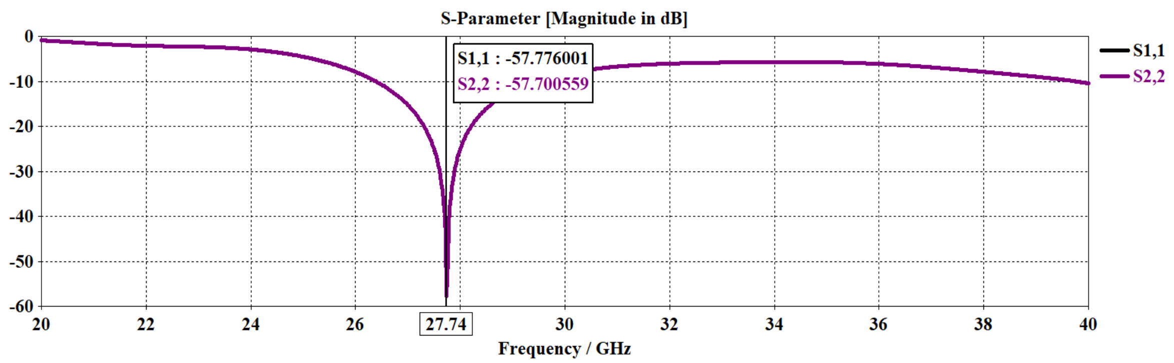
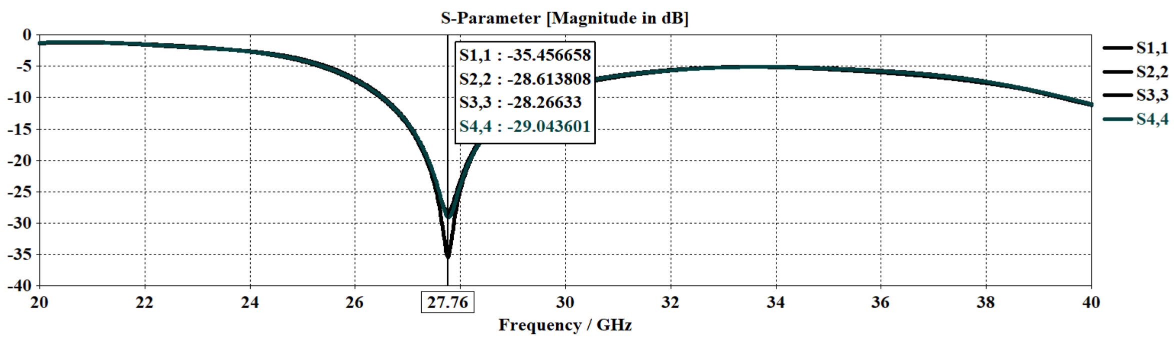


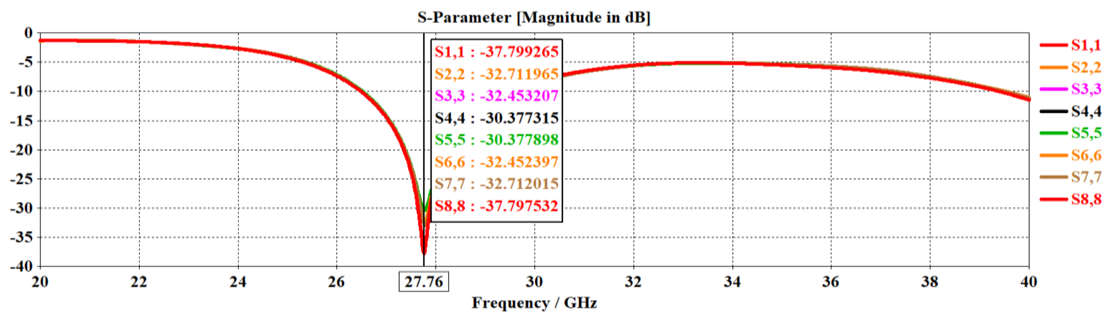
Fig.6. Transformer coupling orthogonal feeding structure on the patch (a) Single element (b) Two elements (c) Four elements



(a)



(b)



(c)

Fig.7 Simulation result of return loss for the structure (a) with single element, (b) Two elements and (c) Four elements

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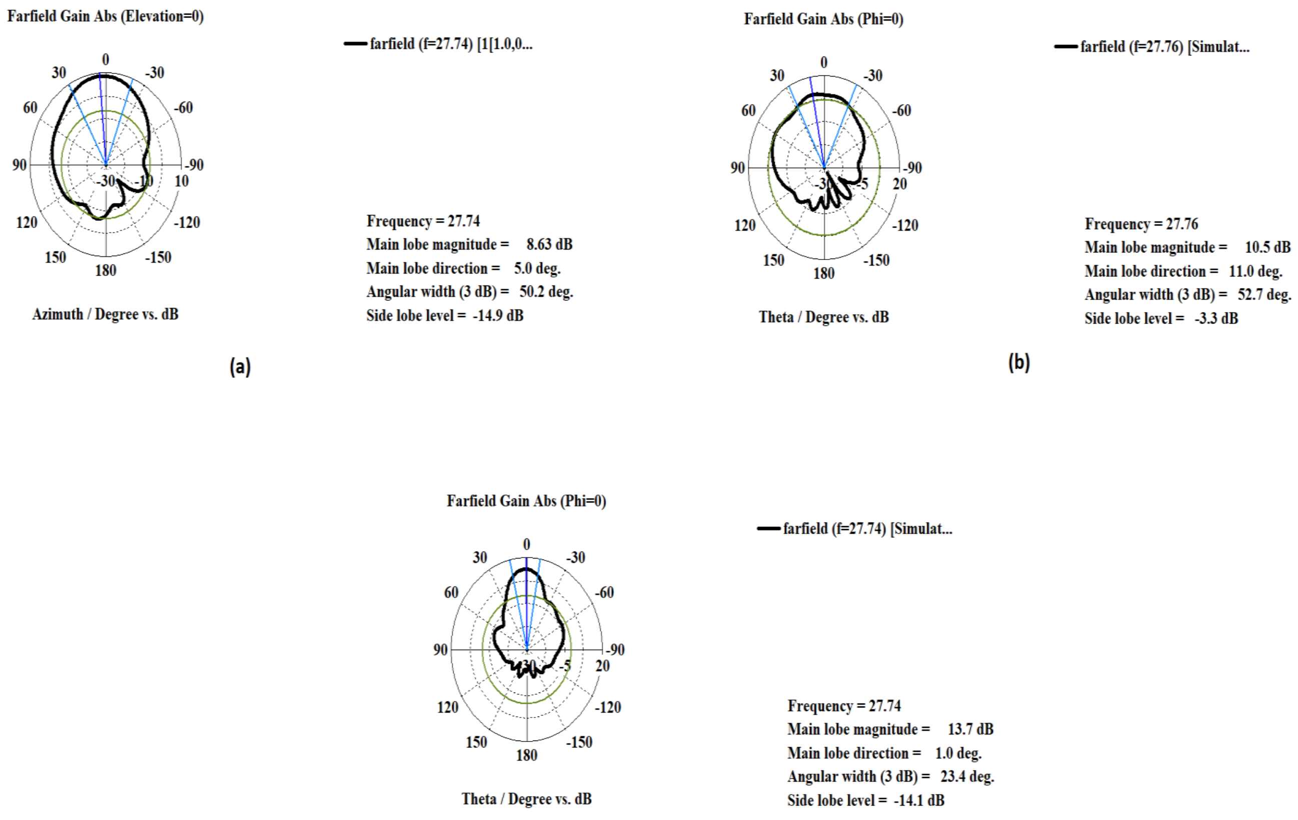
The far field radiation pattern for gain is also simulated for the single element structure; the gain is 8.63 dB when there is a phase difference of 0 degree between the ports as shown in Fig. 8(a) with HPBW of 50.2 degrees and as the number of elements increase by two patch elements and four patch elements, the gain increases to 10.5 dB and 13.7 dB when there is a phase shift of 45 degree between the ports respectively as shown in Fig 8 (b) and (c). It shows that the beam becomes more directive.



(c)

Fig.8. Polar plots for designs as in Fig. 6(a), (b) and (c)

V. FINAL ANTENNA ARRAY WITH PARASITIC PATCH AT THE CENTRE

Final configuration of the 5-element antenna array with a center patch is as shown in Fig. 9. The center patch is to receive the excitation parasitically by other four patches and able to produce the resultant directive beam of good strength. The overall dimensions of antenna are 27.7 x 27.7x 1.27 mm^3 that is very much compact compared to others reported till. The other dimensions are taken as mentioned above.

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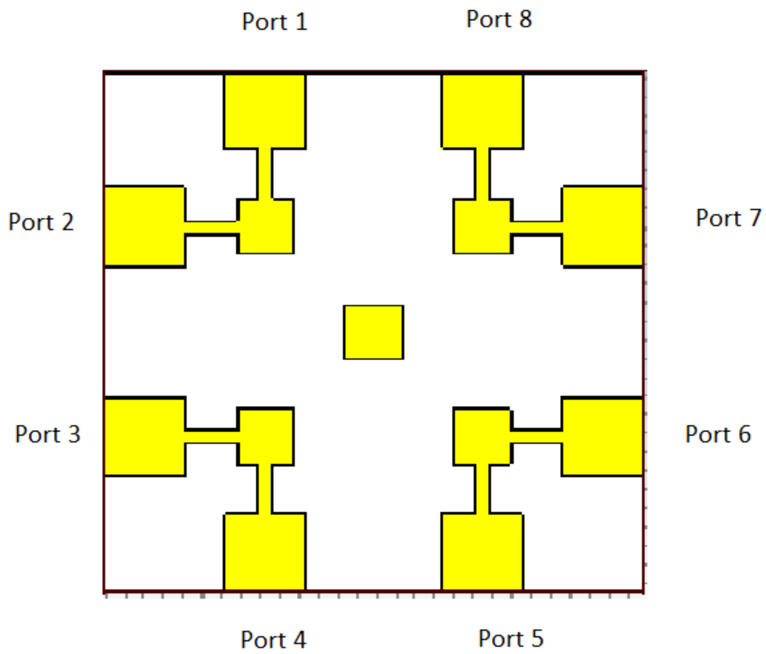

Fig.9. Five element antenna arrays

The return loss and correlation coefficient simulated results for the proposed antenna array are as shown in Fig. 10 and Fig.11 respectively. The return loss (S11) is -58.7 dB and the correlation coefficient is zero between the different ports of antenna at the frequency 27.72 GHz. The current distribution is as shown in Fig.12. We can see that due to multiple ports, the currents in the entire patches are directed towards center patch when all the ports are excited with zero-degree phase. The axial ratio is 3.1 dB at this frequency. It shows that polarization is nearly circular as in Fig. 13.

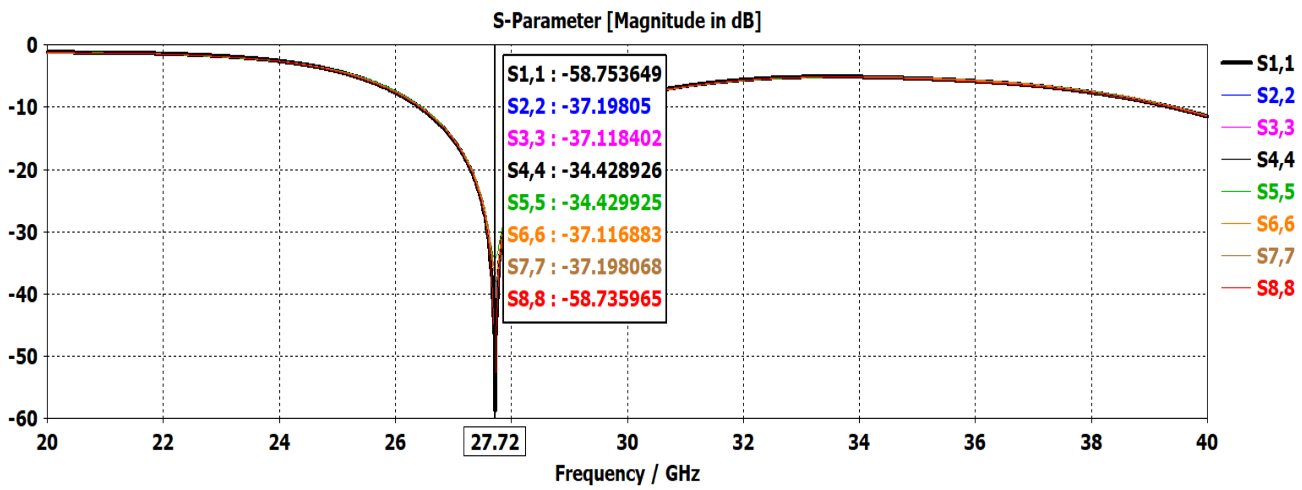

Fig.10. S parameter (dB) Vs Frequency graph

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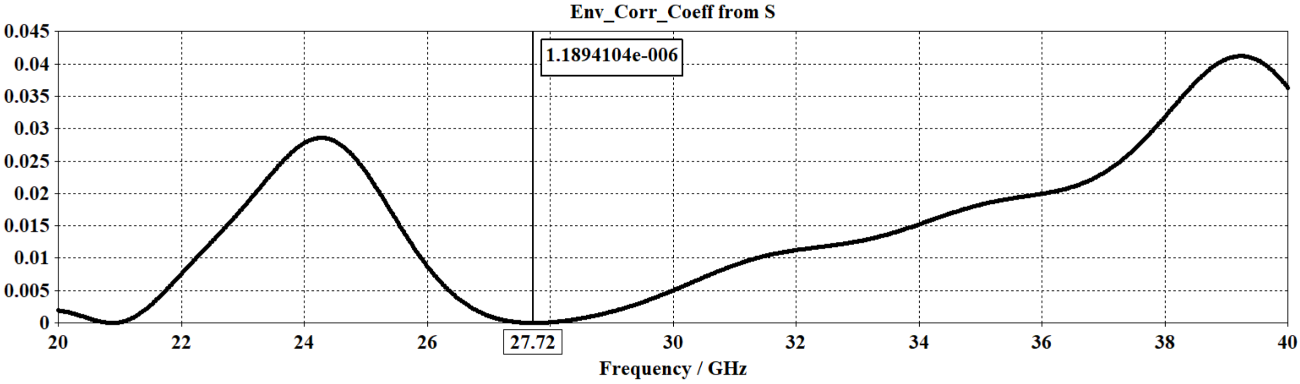

Fig.11. Correlation Coefficient vs frequency graph

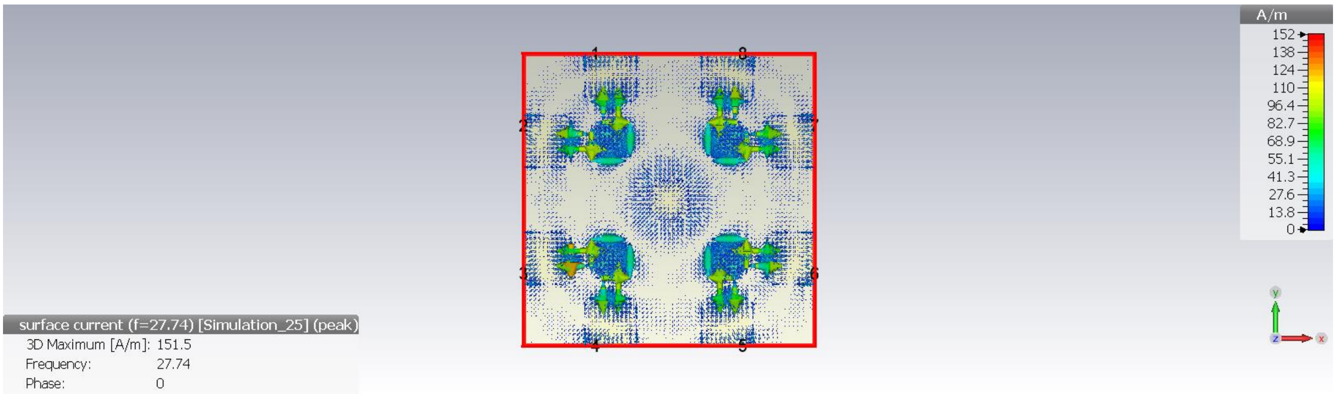

Fig.12. Current distribution on five element array

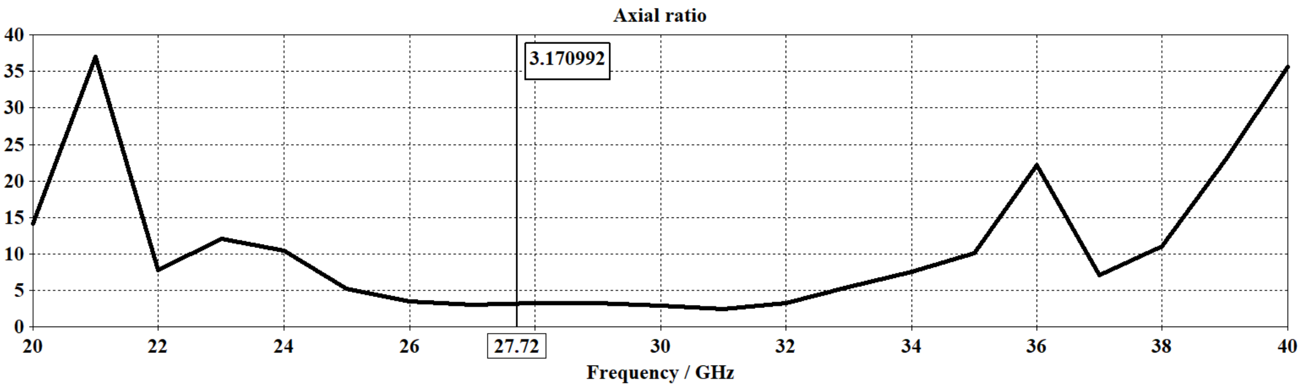

Fig. 13. Axial ratio (dB) vs frequency

VI. MULTIPLE BEAM PATTERN

The final optimized antenna array structure has five patch elements and eight ports. Further the multiple beams in different directions are also achieved by changing the relative phase difference among the inputs at different ports. The main beam can be split in two, three and four beams respectively. By varying the phase difference between the inputs, the optimized results in the form of polar plot and 3D plot is shown below in Fig. 14 and Fig. 15. To verify the simulated results, angles at which the phases vary were calculated. Four different cases are verified as below:

Case 1: When, the single patch element with two ports having phase difference of 45 degrees is simulated, the main resultant beam projected towards center. So, in the overall design of 5 patches the entire resultant beam projected at the center with high gain and narrow HPBW with 45 degrees at all ports.

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Case 2: When there is a phase difference of 0 degree ports 1 and 2 and 100 degree between ports 3 and 4 main beam shifts away from center, so when the ports 5,6,7 and 8 are excited in the same manner, a null occurs at the center with two beams.

Case 3: When there is a phase difference of 180 degree between two ports of same patch and 45 degree with those of other patches, the main beam at the left of center becomes null and we get three beams.

Case 4: When all the ports are excited in same phase of 150 degree a null occurs at the center and we get four beams.

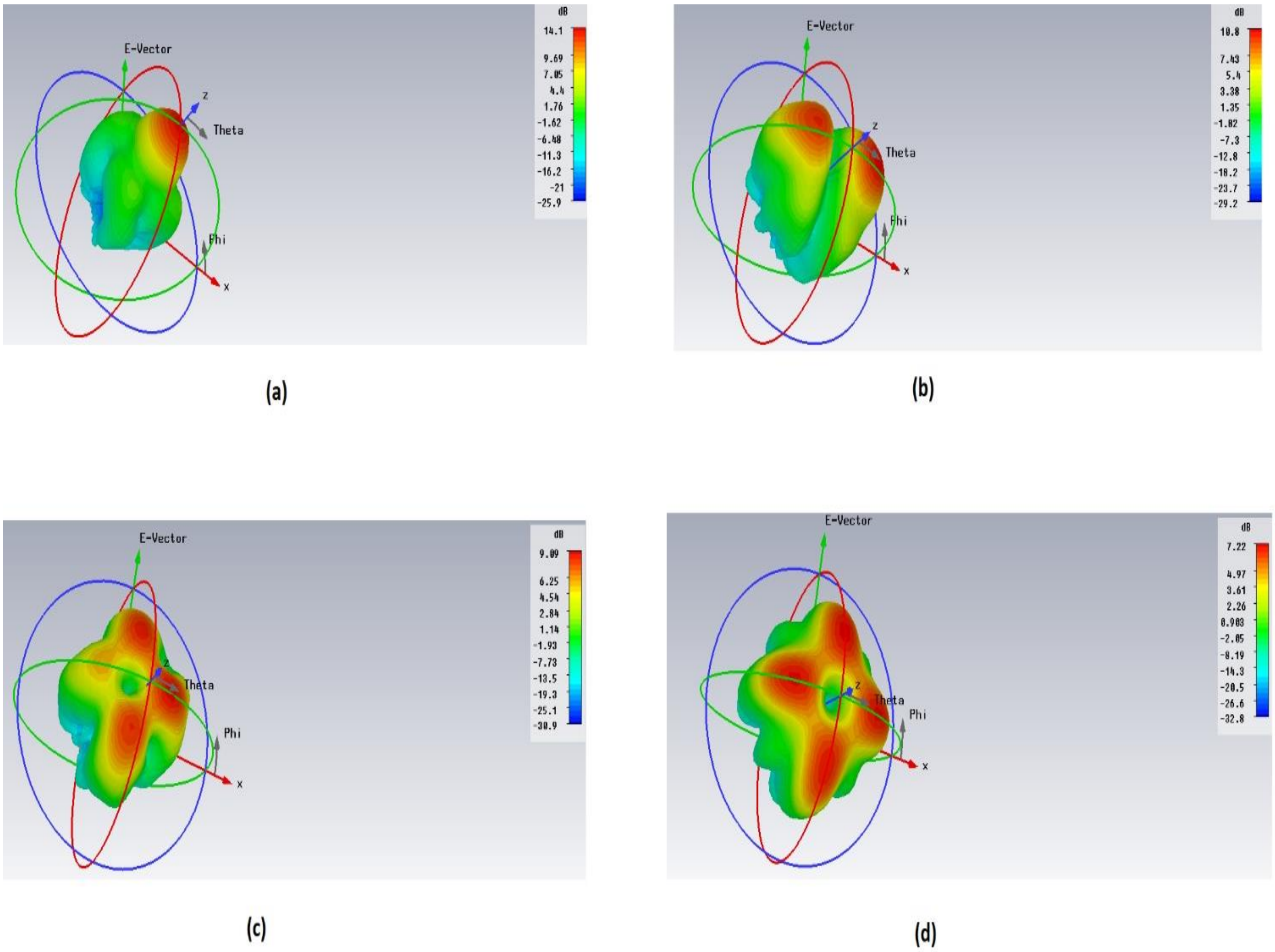

Fig 14. 3 D plots for four cases showing multiple beams

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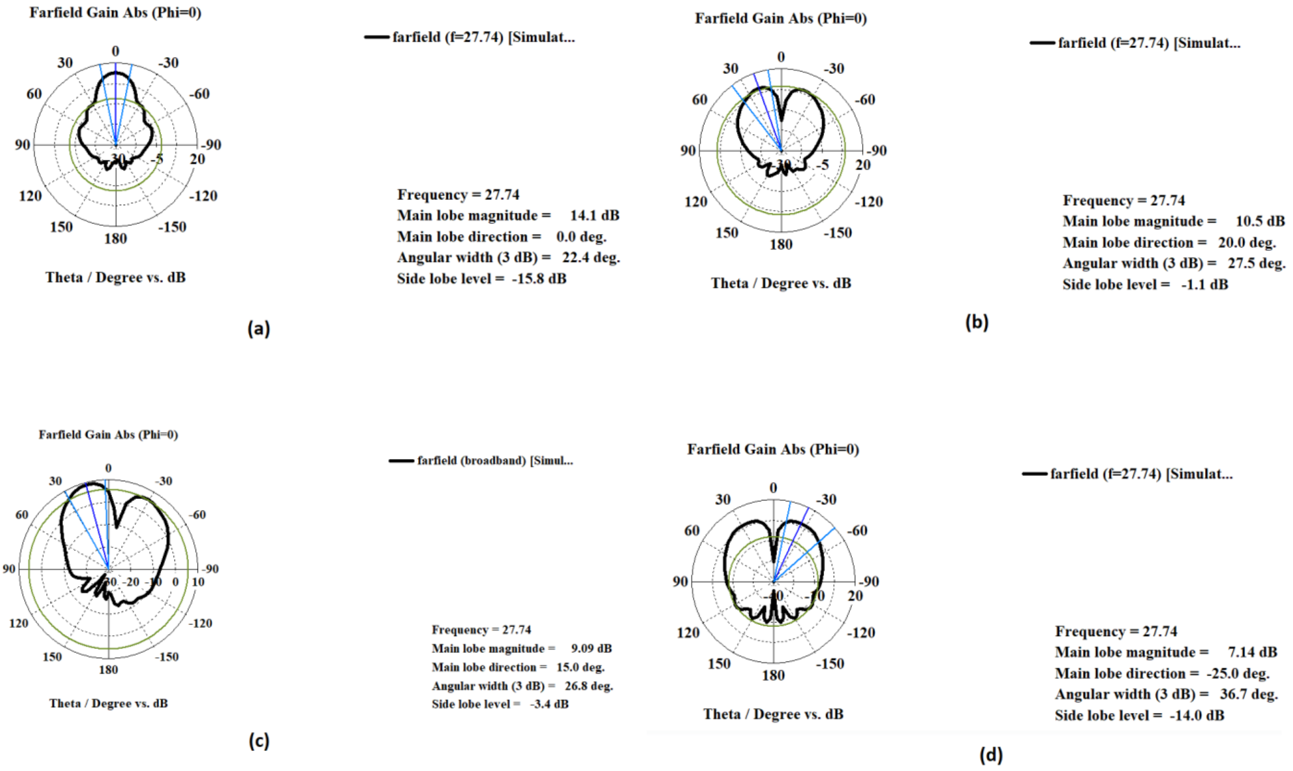

Fig.15. Polar plots for different cases of multiple beams.

It is observed that when there is a single beam, it is highly directive with a high gain and as the number of beams increase gain decreases and antenna becomes less directive as HPBW increases.

Comparison of results for previous structures with different array elements is as shown in Table. I. Here the comparison is among the Structure 1 (single patch element), Structure 2 (2 patch elements array), Structure 3 (4 patch elements array) and Structure 4 (5 patch elements array). It is observed that as array elements increases, gain increases and HPBW decreases.

Table I. Comparison of the Performance Parameters of Different Structures

	Structure 1 Fig. 6(a)	**Structure 2 Fig. 6(b)**	**Structure 3 Fig. 6(c)**	**Structure 4 Fig. 9**
Return loss (dB)	-57	-35.4	-37.79	-58.75
Maximum Gain (dB)	8.63	10.5	13.7	14.1
HPBW (degrees)	50.2	52.7	23.4	22.4

VII. BEAM STEERING APPLICATION

The main beam can be steered in different directions by changing the phase at different ports of the phased antenna array. The array inter element spacing is given by butler matrix equation (3) as follows [8-9]

$$\propto_i = \frac{(2i-1)-M}{M} \pi \quad (3)$$

Where 'M' is the number of input and output ports and 'i' is the input port number of butler matrix. For the five cases, the calculations from the formula (3) have been done and after simulation the beam steering can be obtained at angles 0, ±6, ±10 degrees respectively as in Table II. The beam steering pattern shows a maximum gain drop of 3.1 dB. The main beam can be steered at different directions of theta with phi=0. For these five cases, the radiation patterns for the gain are as shown in Fig.16. The comparison of the gain curves for all the five cases is also shown in Fig.17. It is observed that maximum gain is achieved at theta = 0 degree and as the main beam is steered at different position the gain decreases correspondingly.

Table II. Gain and HPBW Values for Five Different Cases of Beam Steering

Case	Gain (dB) phi=0 deg	Theta (deg)	HPBW (deg)
1	14.1	0	22.8
2	14	-6	23
3	12.8	6	24.1
4	11	10	27.7
5	12.7	-10	24.5

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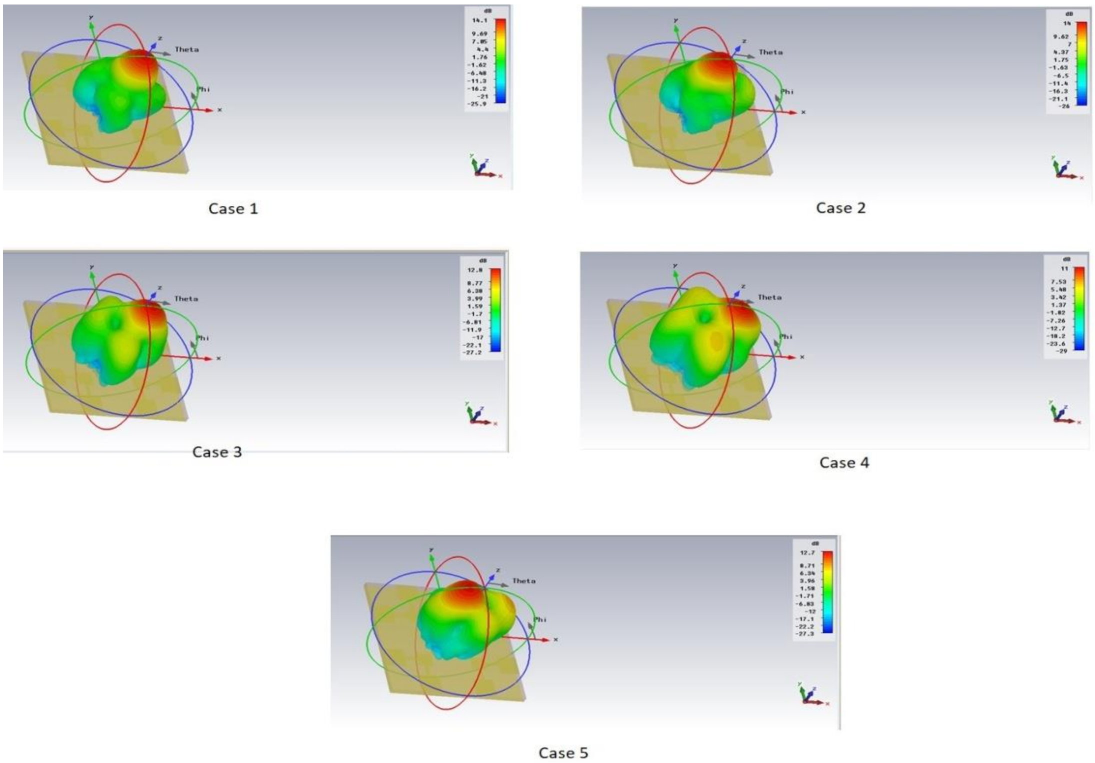

Fig.16. Radiation patterns of beam steering of Five cases.

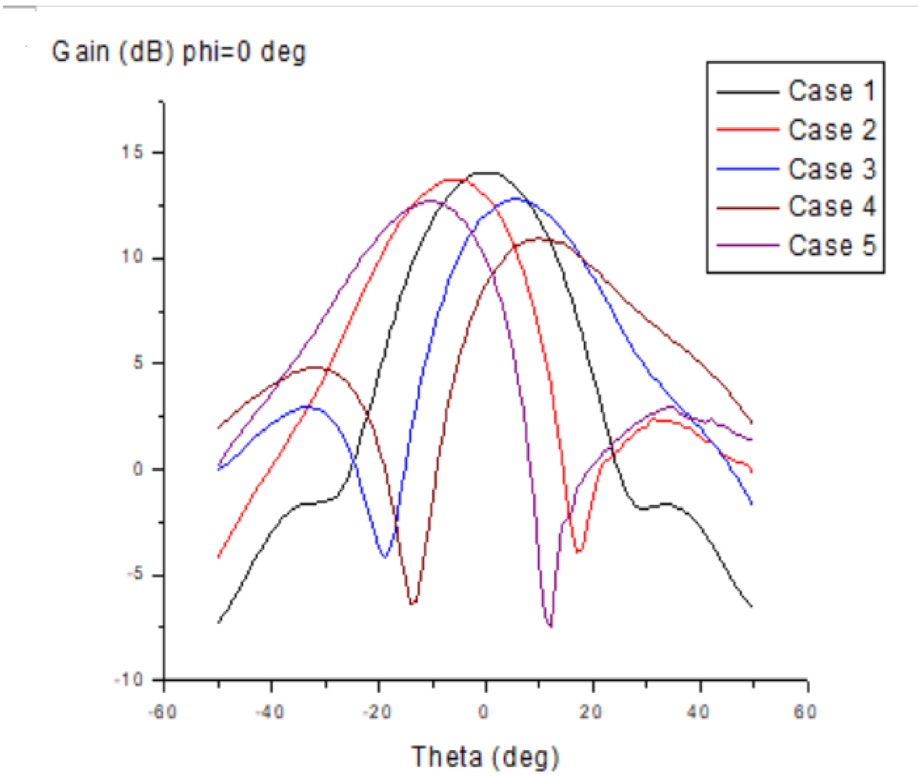

Fig.17. Comparison of gain patterns of the all five cases of steering

VIII. FABRICATED DESIGN AND RESULTS

The final 5 patch element structure is fabricated on the substrate Rogers RT5880LZ (ε =1.96) as shown in Fig.18. The fabricated antenna was tested by VNA. The comparison graph of simulated and measured S-parameter results is as shown in Fig.19. The measured and simulated results were very close to each other. The differences were observed due to environmental conditions at the time of measurement and fabrication.

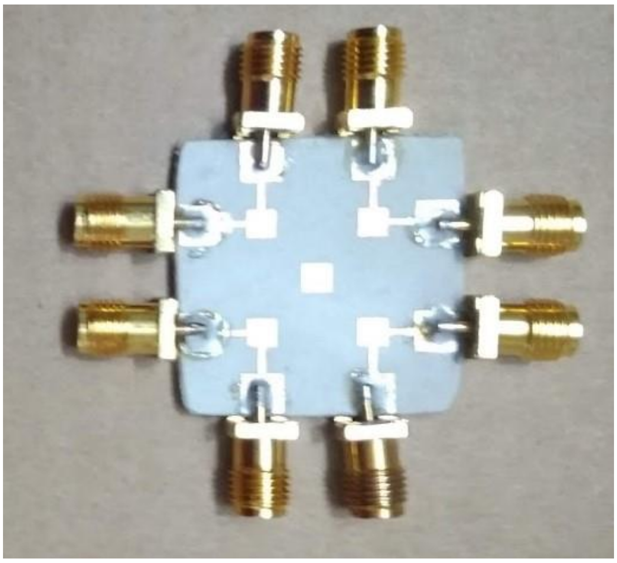

Fig.18. Fabricated 5 patch antenna array

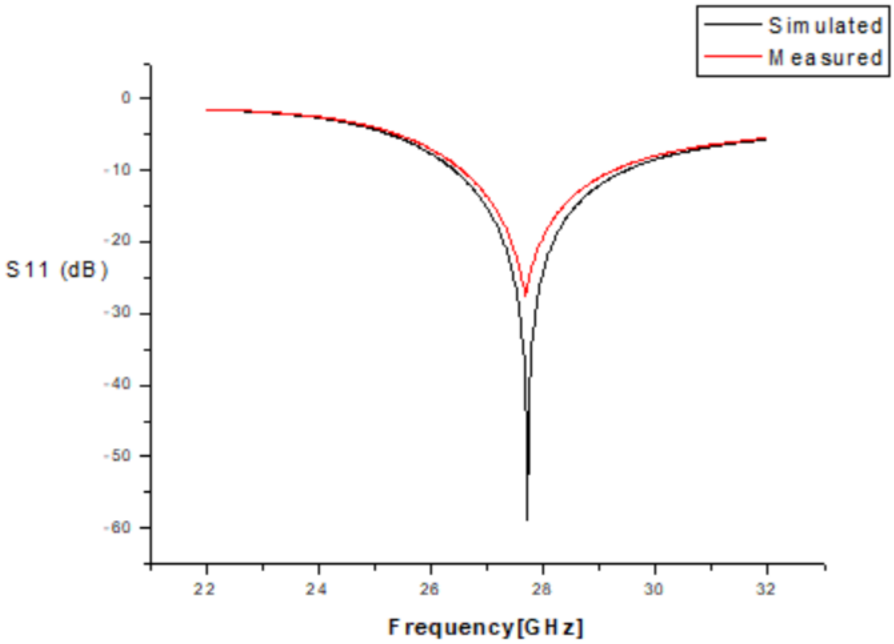

Fig.19. Comparison of simulated and measured results

IX. CONCLUSION

A phased array antenna with five patch elements and eight ports has been designed. The directive beam with multiple numbers of ports is steered in many directions under the control of multiple input phases. The multiple beams also achieved by setting the different phases at the input ports. The structure fulfills the main requirement for 5G applications, which is to catch the signal from different paths and steer the main beam according the need using phase shifters. The novelty in this work is its miniaturized structure with high gain and narrower

HPBW reported till the date.

X. ACKNOWLEDGEMENT

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