Design of Multiband Array Antenna in MM-Wave for 5G Applications

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Abstract – The Present works brings a new approach in designing a multiband 5G based on microstrip antenna array using EBG structure. A 5*2 matrix array has been apprehended on Rogers 5880 dielectric substrate. The design is to improve the return loss characteristics of the radiating patch and having multiband operation. The defected ground structure is analyzed and further upgradation in performance metrics like directivity has been adapted with a suitable EBG structure which is used in the radiating structure. Numerous parameters like radiation pattern and VSWR have been premeditated in detail. The introduction of EBG layer, directivity is observed to improve to 8.4dBi and 12dBi at 28GHz and 37.5GHz. The overall return loss of the antenna array is found to be -15 dB and -16 dB at 28 GHz, 37.51 GHz respectively.

Keywords: 5G, mm-wave, Array antenna, Defected Ground Structures (DGS), Electromagnetic Band Gap Structures (EBG)

1. Introduction

There is a general perception in today's communication technology market that mobile Data would be the next oil and we would face exponential demand for data access in coming days. These predictions come in the face of rapid advancements in the communication technologies. When it took over a decade to move from 2G to 3G systems, today even 4G is getting outdated with the latest 5G trials in various research organizations across the world. Which means the access to data would be easier than ever before and consumers would love to harness this data in all possible ways in day to day life. Already many countries like Middle East have started adopting 5G technology in applications like Autonomous Public Transits systems and providing remote healthcare to general public. Now given the fact that we have started utilizing 5G infrastructure to improve human life, there remains the need for developing smart and reliable RF front ends for these future mobile devices. And this is a major challenge for today's scientific community as the present RF/Microwave spectrum is already crowded and further jamming of the systems would result in increasing overlapping of services and poor spectrum utilization.

Now 5G systems require a whole new level of Frequency spectrum allocation and new RF circuit design methodologies to suit the demands of upcoming technology advancements [1- 4].

2. Technologies developed for 5G

So when we talk about such crucial technological advancement on one side, the research community is striving hard to bring up the necessary circuitry and signal processing improvements. These range from frequency selection, complex waveform generation, range extension, better handling of handoff in case of moving receivers, antenna configurations and few others. As we very well know that the performance of the wireless communication equipment largely depends on the most crucial link component i.e. the Antenna structure. How a designer packs this radiating patch inside the available space of the PCB board is the most important challenge researchers are facing today. The fact that frequency utilized for the future 5G systems argues well for much more compact antennas [5] [6]. This not only yields further space on the wireless boards, but also paves way for implementing array structures in the same. It is a proven fact an array antenna systems has much better performance than the conventional single antenna systems, we can surely forecast that the 5G systems would have antenna arrays incorporated in their architectures [7]. A whole lot of interesting possibilities like Beam steering [8], adaptive beam forming become possible in the wake of antenna array implementation in the proposed systems. Antennas which utilize different polarizations have also been realized [9 -10]. This work focuses on designing a multiband antenna array operating in the mm wave range, and performing parametric analysis on the radiating structure to comply with the systems requirements.

3. Design Methodology

The Proposed Patch Array is designed using defected ground structures (DGS) and Electromagnetic Band Gap (EBG) [11 - 14]. The simulations are performed using CST design tool for better analysis of the radiating structure. As microstrip antenna has three layers such as patch, substrate and ground. Rogers 5880 of height 1.6mm is used as a dielectric substrate here for the simulation. The choice of the substrate in based on the high gain requirements of the

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5G wireless applications. The Radiating patch and the Ground is etched using Copper sheet of 35 microns thickness.

The radiating patch dimensions are calculated using general transmission line equation (Equation 1).

$$\mathbf{W} = \frac{c}{2f_0\sqrt{\frac{\varepsilon_r+1}{2}}} \qquad (1)$$

And the overall dimensions of the Array Antenna are given in Table.1

Table.1 Parameters of the Single Patch

Length (mm)	Height (mm)	Width (mm)
Xmin= -7.8	Ymin= -8.6	Zmin= 0.2
Xmax= -4.6	Ymax= -6	Zmax= 0.235

Figure.1 shows the simulated view of the radiating patch array. A 5x2 matrix array has been realized with the above mentioned dimensions Table.1. To reduce the complexity of the array architecture, a simple line feed is used as the power input path.

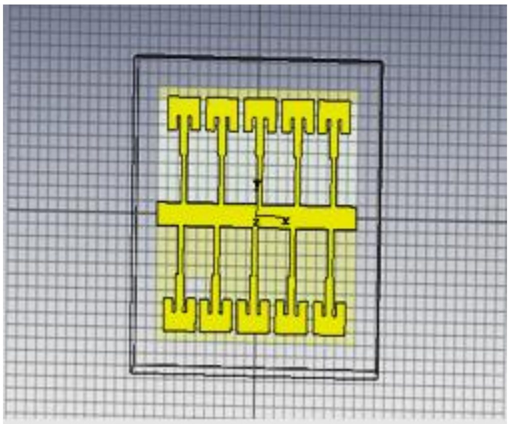
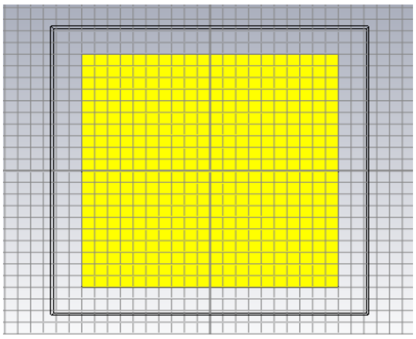
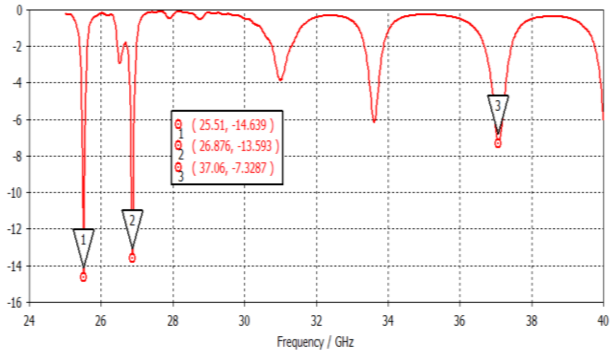


Figure.1 Front view of the array antenna

The Antenna Array is firstly simulated with a default ground structure Figure.2 (a), and it can be observed from Figure.2 (b) that the resonant frequency are obtained at 25.51 GHz and 37.06 GHz. Out of the two resonant frequencies, it is desirable that we move the resonance from 25.51 GHz to 28 GHz or closer and also to be noted in the fact that the return loss at 37.06 GHz needs considerable improvement to be considered for the 5G applications [15 - 16].



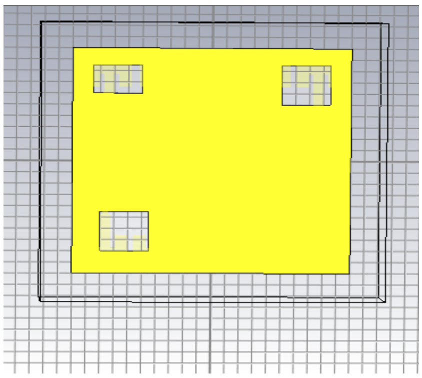
(a)



(b)

Figure.2 (a) Simulated View of the Antenna with Normal Ground (b) Simulated S11 (dB)

In general is observed that, use of defected ground structure [17 - 19] enhances the return loss performance of the radiating patch to a good effect of the 5G Based antenna systems. In here, three rectangular slots are etched out in the ground for the same Figure.3 (a). And from the simulated return loss, the resonant frequency of 28 GHz is successfully achieved, with considerable shift and improvements in return loss parameters at 37.54 GHz to -15 dB Figure.3 (b).



(a)

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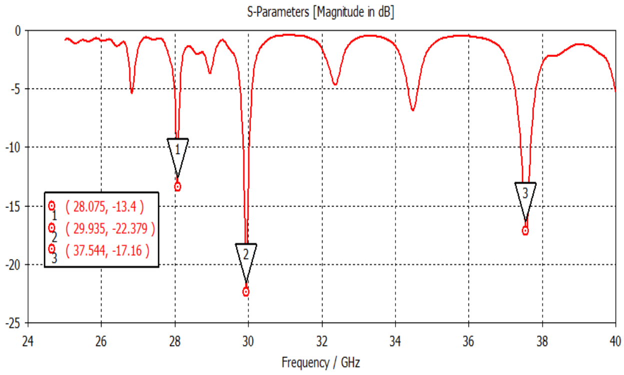
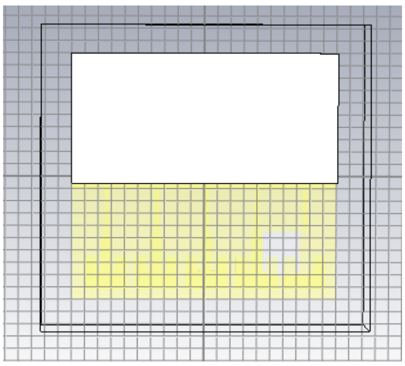


(b)

Figure.3 (a) Antenna Array with DGS Structure
(b) Simulated S11 (dB)

In order to achieve an optimal Return loss in both the operating frequencies, namely 28 GHz and 37.54 GHz, an EBG layer in introduced below the defected ground structure Figure.4 (a). Now the simulated S11 parameter shows considerable improvement to -15.9 dB and -16.39 dB at 28.01 GHz and 37.51 GHz respectively. The EBG layer used here can help in improving the directivity of the overall array design, which might be beneficial in case the antenna be used in beam steering applications [20 - 23].



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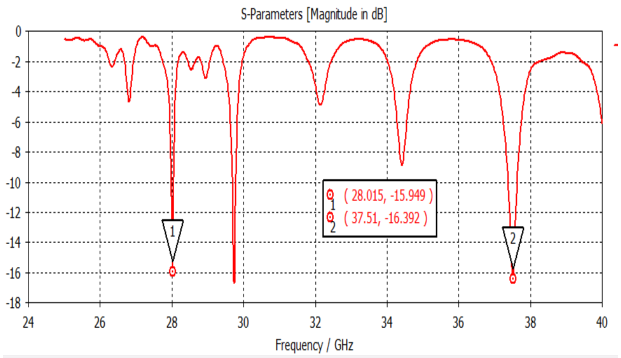
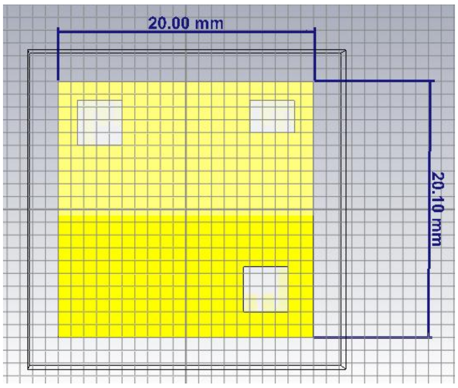


(b)

Figure.4 (a) Simulated of Antenna Array with EBG Structure (b) Simulated S11 (dB)

It can be seen in Figure.5 (a) that the square slots are etched at the two corners of the ground, in order to improve the return loss characteristics of the proposed array structure. And Figure.5 (b) shows the EBG structure used with an air gap of 1mm.



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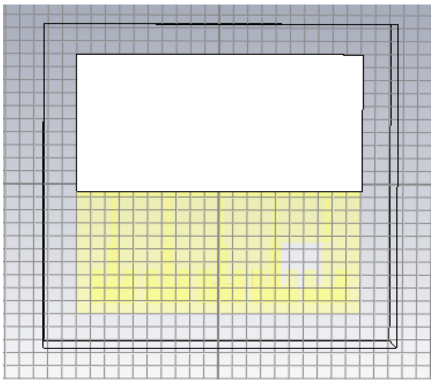

(b)

Figure.5 (a) Final view of DGS structure in the ground plane (b) View of the EBG structure

4. Parametric Analysis of the Simulated Antenna

The parametric analysis of the antenna was carried on the designed antenna array using CST EM solver and the various performance metrics like, Return loss (S11), Gain, Directivity, Current Distribution and Radiation pattern have been analyzed. As discussed in the earlier section, the antenna array was found to be radiating at multiband frequencies of 28 GHz, 37.5 GHz and with the respective return loss of -15.949 dB, -16.39 dB Figure.6. A notch frequency is also observed at 29.3 GHz, which is beyond the scope of this work, and can be eliminated by employing filtering mechanisms in future works.

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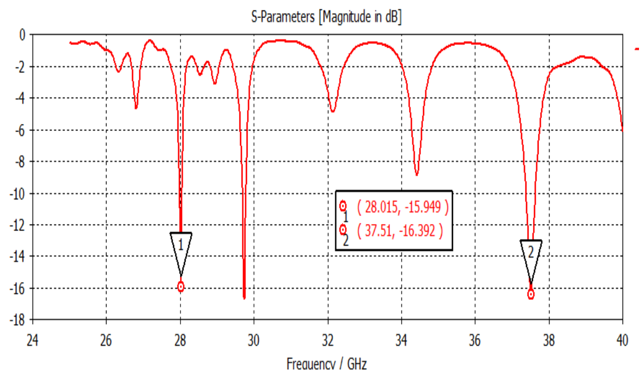


Figure.6 Simulated Return Loss of the Proposed Antenna Array

The gain of the simulated antenna is observed to hover at 4.8dB and 10.1 dB at 28.9 GHz and 37.67 GHz respectively Figure.7 which is well within the desired range of 5 dB as required by the radiating patch. And the directivity is observed as 7.7 dBi and 12 dBi at 28 GHz and 37.5 GHz respectively for without EBG layer simulation. With the introduction of EBG layer the directivity is observed at 8.4 dBi and 12 dBi at 28 GHz and 37.5 GHz respectively, which confirms the usage of EBG to be beneficial in our array structure.

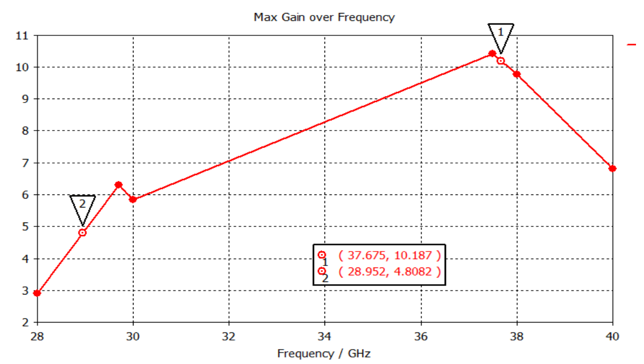
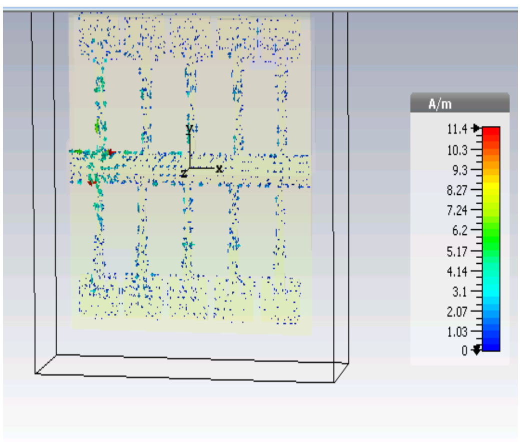
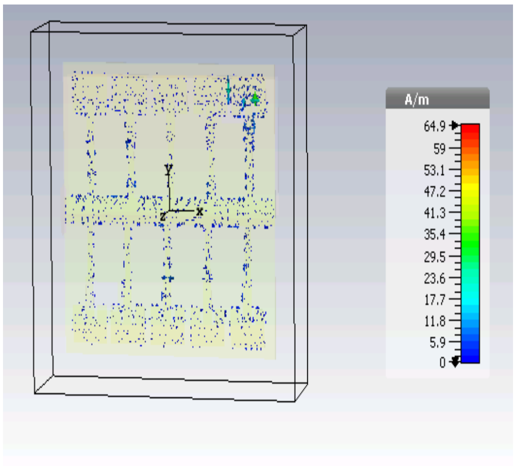


Figure.7 Representation of Gain vs Frequency of the Simulated Patch



(a)

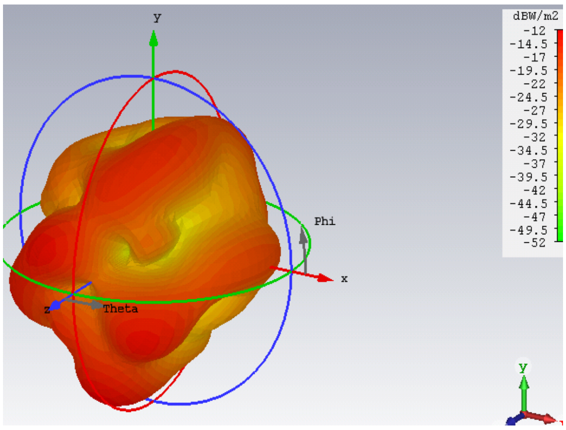


(b)

Figure.8 (a) Current distribution at 28 GHz; (b) Current Distribution at 37.51GHz

The effective current distribution in the antenna structure is show in Figure.8 for the multiband operating range. It can be clearly seen that various edges of the array contribute to the two frequencies and further improvement of the performance metrics can be effected by small incremental changes in these edges of the microstrip structure.

Further, the 3D model of the Radiation pattern can be observed in Figure.9 for the desired operating frequencies. We can observe a near Omni directional radiation pattern, which is well suitable for 5G based communication systems.



(a)

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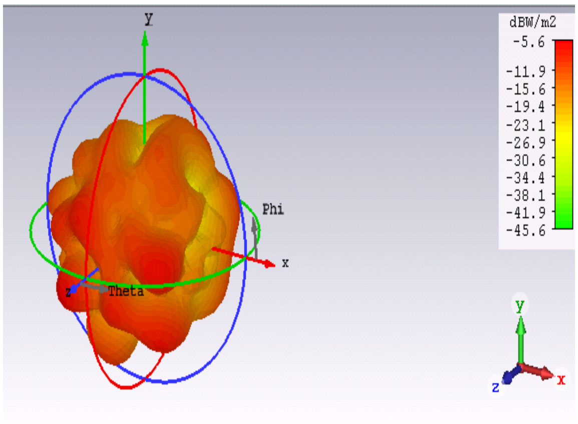

(b)

Figure.9 Radiation Pattern at Various Operating Frequencies (a) 28 GHz; (b) 37.51 GHz

Further various far field parameters have been analyzed for the simulated antenna, and presented in following sections. The far field patterns have been separately analyzed for all the operating frequencies, viz 28 GHz, 37.51 GHz and results are tabulated.

Table.2 Comparative Metrics at 28GHz

Parameter	Directivity (dBi)	Gain (dB)	E Field (dBV/m)	H Field (dBA/m)	Power Pattern (dB/Wm^2)
Main Lobe Magnitude	7.04	2.79	13.4	-38.1	-12.1
Main Lobe Direction (Degrees)	55.0	55.0	57.0	57.0	55.0
Angular Width (3dB) (Degrees)	39.1	39.1	37.8	37.8	39.1
Side Lobe Level (dB)	-3.0	-3.0	-2.8	-2.8	-3.0

Table.3 Comparative Metrics at 37.51GHz

Parameter	Directivity (dBi)	Gain (dB)	E Field (dBV/m)	H Field (dBA/m)	Power Pattern (dB/Wm^2)
Main Lobe Magnitude	8.24	6.62	18.3	-33.2	-6.32
Main Lobe Direction (Degrees)	1.0	1.08	5.0	5.0	1.0
Angular Width (3dB) (Degrees)	42.2	42.2	48.5	48.5	42.2
Side Lobe Level (dB)	-4.5	-4.5	-3.5	-3.5	-4.5

Table.2 shows the characteristics of the designed antenna for the required frequency of operation. It can be observed form Table.2 and Table.3, the far field characteristics are much suitable for future mm-wave applications. The radiation patterns for both the resonant frequencies are offset by close to 50 degrees. This one iteration which needs to be done in future works to improve the overall performance of the radiating array.

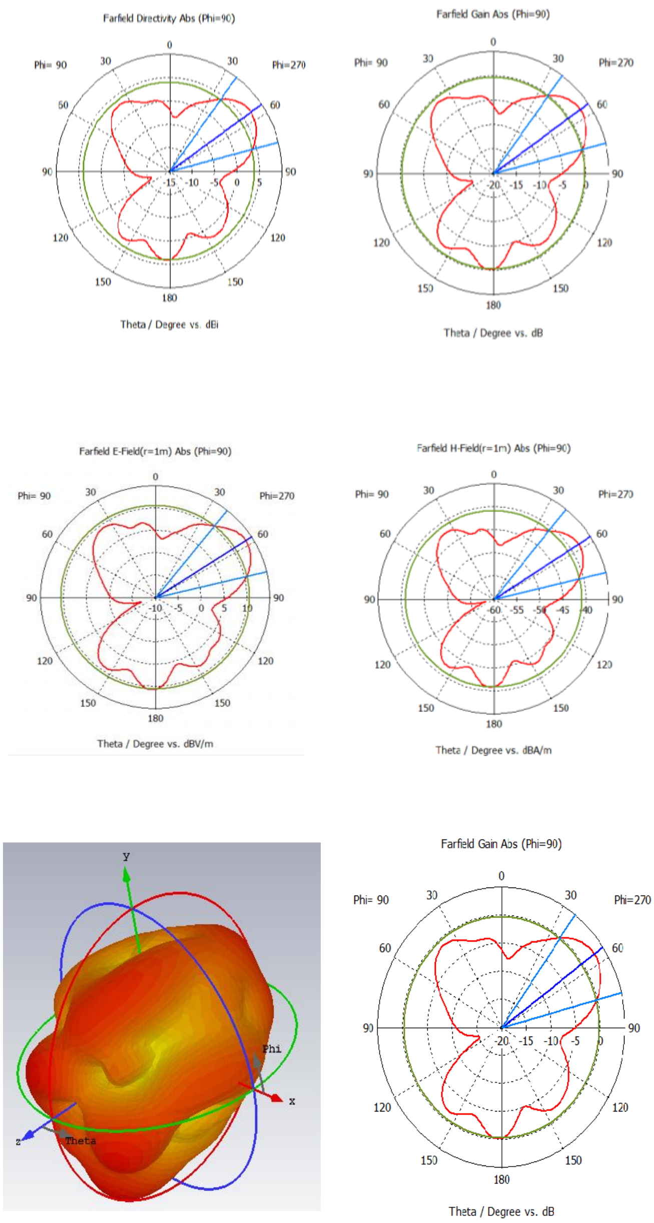

Figure.10 Far Field Pattern for the simulated antenna at 28 GHz

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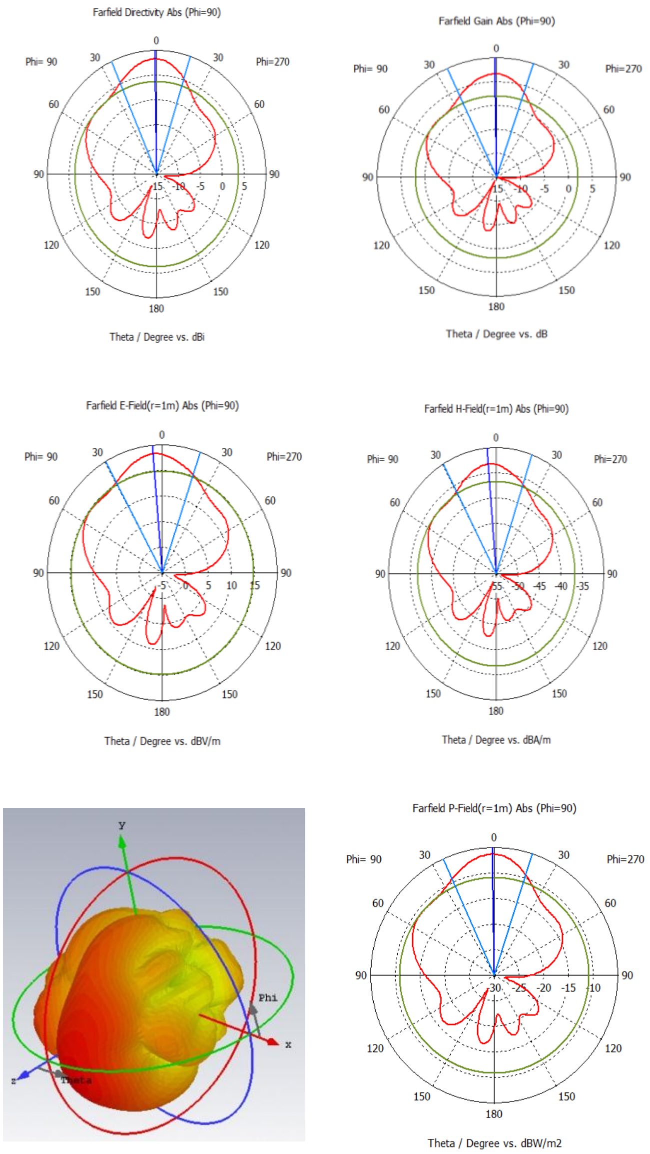

Figure.11 Far Field Pattern for the simulated antenna at 37.51GHz

It can be observed form Figure 10, that for 28 GHz, the directivity of 7.0dBi is achieved at 55.0 degrees. The E-field and H-field are found to be 13.4 dBV/m and -38.1 dBA/m, respectively. And the 3dB angular width is 39.1 Degrees. The power field is also found in the range of angular width of 55 degrees as -12.1dB/Wm2. Likewise, far field pattern for 37.51GHz is shown in Figure 11. The results have also been tabulated in Table.2, Table.3 respectively.

Also to be noted from Figure.12 that the total Efficiency of the simulated radiating patch has been plotted. We observe that at 28 GHz the efficiency in dB is obtained as -8.13 dB, which when converted to absolute terms and percentage is observed as 81.38%. Similarly for the second resonant frequency the efficiency was found to be 35.73%, which ought to be improved in future works.

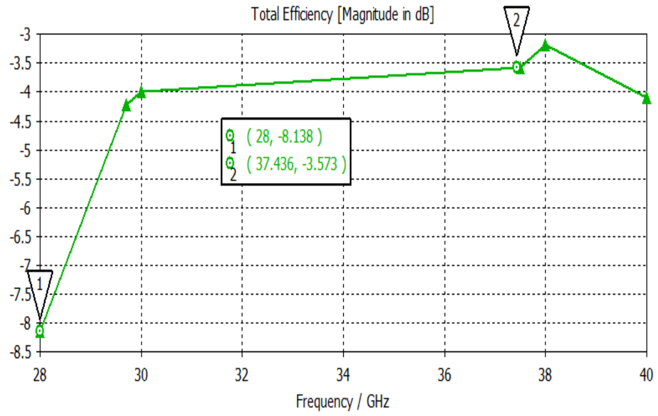

Figure.12 Total Efficiency of the Proposed Radiating Structure

Figure.13 below depicts the radiation efficiency obtained during the simulation. At 28GHz we observe a radiation efficiency of - 4.247 dB, or 42.47% absolute terms, as with the second resonant frequency, we observe a radiation efficiency of -1.6178 dB or 16.17%.

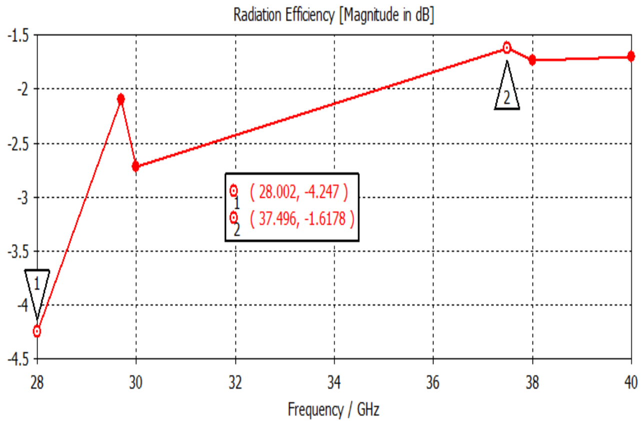

Figure.13 Radiation Efficiency of the simulated Antenna

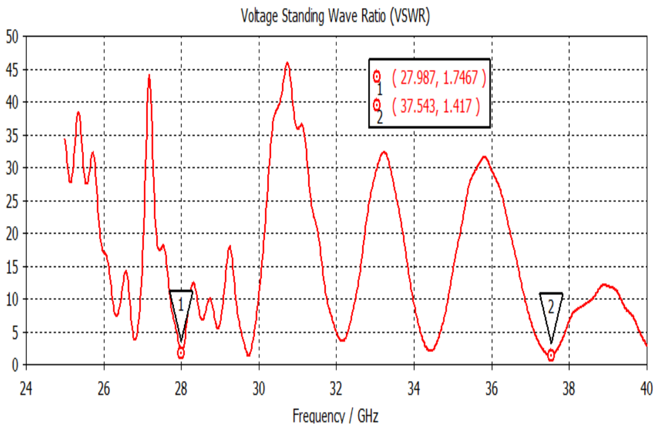

Figure.14 Far Field Pattern for the Simulated Antenna at 37.51GHz

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The Voltage Standing Wave Ratio (VSWR) is depicted in Figure.14. The VSWR value of 1.7 and 1.4dB in obtained at the two resonant frequencies of 28 GHz and 37.54 GHz. The performance of the radiating patch obtained through the simulations argues well for the application of the design in the future millimeter wave application, with minor improvements in few of the parameters.

5. Conclusion

A 5G based microstrip patch antenna was implemented using a suitable electromagnetic solver and the antenna parameters were studied. The Overall dimension of the 5 * 2 antenna array was 20mm * 20mm, which argues well for compact future 5G based wireless transmitters and receivers. The gain and return loss characteristics were also observed and were analyzed for various combinations like with and without EBG layers. An improvement in S11 and directivity was observed during the simulation. In future works the radiation pattern needs to be brought to a uniform direction by iterating few edges of the radiating patch with the help of the radiation pattern and current distribution analysis.

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