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DESIGN AND SIMULATION OF MM WAVE SIERPINSKI ANTENNA LOADED WITH UNIPLANAR EBG FOR 5G APPLICATIONS

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Abstract - *A multi-band mm Wave micro strip antenna with low-cost FR4 substrate, high gain and speed, small in size is proposed in this paper. The multi band is achieved using the Sierpinski fractal structure with an optimized ground plane. The resonances observed are at 29.05 GHz, 35.75 GHz and 41 GHz with 10 dB impedance bandwidths of 4 GHz, 2.06 GHz, and 2 GHz respectively. The candidate bands for upcoming 5G applications. The proposed unloaded Multi band antenna has low gain and speed throughout these bands, hence a uniplanar optimized EBG structure is proposed to gain enhancement across the intended bands of operation and reduction of size with high speed . The EBG unit cell was loaded onto the multi-band antenna to obtain Peak Gain of 5.37 dBi and 14.37 dB in the 28 and 68 GHz bands, respectively. The proposed EBG loaded antenna is simulated and characterized.*

Key Words: EBG – Electromagnetic Band Gap, Sierpinski Fractal Structure, 5G, FR(FR-4)-Flame Retardent.

1. INTRODUCTION

With the exponential growth of mobile traffic [1], it is expected that the bandwidth hungry applications need an appropriate hardware platform to meet these specifications [2].mmWave bands have been projected, by FCC and other telecommunications expert groups, as the candidate bands for future cellular telephony, due to high bandwidth and to ease spectral congestion in the sub 6 GHz band [3].

The choice of mmWave poses a unique challenge for deployment, since the propagation loss and penetration losses are high [2], the antennas need to compensate for the loss, hence high gain antennas with gain of at least 10 dBi are desirable. This would mean that to enhance coverage a beamtilting topology needs to be adopted. It must also be noted that even though aperture antennas offer high gain, they are impractical for integration within a mobile terminal. With the recent industry trends, 28 GHz and 37-40 GHz bands have been rigorously promoted for 5G mobile telephony, companies such as Samsung, Ericsson, Sony, and Verizon are involved in hardware designs around these bands [4]. There are chances, that both the bands would be utilized for different cases of 5G, hence the RF front-end must be capable of handling these bands, to be useful in future.

Multiband antennas would reduce the electrical real estate on the mobile terminal [5], this would be an essential feature, since smart phones are crowded with multiple antennas for various applications [6]. In [3], conventional resonant micro strip patch antenna was designed at single frequency and an array was implemented to demonstrate beam tilt with high gain. Many designs reported in the literature have illustrated antenna designs specifically operating at single band, for instance, [7] shows only a single frequency of operation. The antenna is a single resonant antenna, gain is naturally high due to the array-action. Incorporation of SIW structures might increase the radiation efficiency but this increases the production cost although gain is not increased. mmWave antennas specifically targeting 38 GHz band are demonstrated in [8-9].

Hence, high gain multiband antennas would be necessary for the 5G mobile terminals. Thus, antennas which resonate at the proposed 5G bands with high gain are desirable candidates for the mobile terminals [3]. It should also be noted that the candidate antennas must be compact in size to fit in a typical smart phone motherboard. Also, antenna should favor array design for beam tilt.

The fundamental problem with multiband antennas is its poor gain and hence low radiation efficiency across the bands of operation as reported in [11-13] wherein the resonances are at 28 and 38 GHz but the gain is in the range of 4-9 dBi.

In this paper, multiband is created by incorporation of Sierpinski fractal structure on the radiating plane on low-cost 31 mil FR4 substrate. The dimensions in the radiating plane are tuned for the candidate mmWave bands of 5G. The tuning also allows for the design of increased impedance-bandwidth at the intended bands. Even though, the optimized fractal antenna works in three distinct bands, the gain is less than 2 dBi at 28 GHz and less than 3 dBi at 38 GHz. Hence, a uniplanar EBG structure [14] is loaded with the primary radiating structure for gain enhancement in both the bands. It is observed that the geometry of the loaded EBG would influence the gain and impedance bandwidths. A detailed study is presented in the following sections.

2. ANTENNA DESIGN

FR4 epoxy board with ε_r = 4.3, loss of 0.02, 30 mil thickness, was the chosen substrate for its low cost and its compatibility with the standard PCBs. Though, thicker substrates give higher cross-polarization levels, it is a trade-off with cost of the substrate. It might also be noted that the dielectric constant would be slightly away from the above mentioned value at the frequency of the operation up to 86GHz. The radiation patch was designed to be away from the connector The square patch is designed based on the standard empirical formulae for a typical micro strip antenna with FR4 substrate at 38 GHz operating frequency. A 2.4mm x2.4mm square patch is fed by 12mm long, 0.6mm wide line to achieve an impedances match at 38GHz.

2.2 MULTIBAND SIERPINSKI ANTENNA

A Fractal structures are popular technique to create multiband operation, hence A Sierpinski carpet of 1st iteration was designed as the radiating patch, and square slot of 1 mm was etched out from the radiating patch, this slot would support higher modes to achieve multiband operation. The radiating plane and the ground plane is depicted in Fig-1

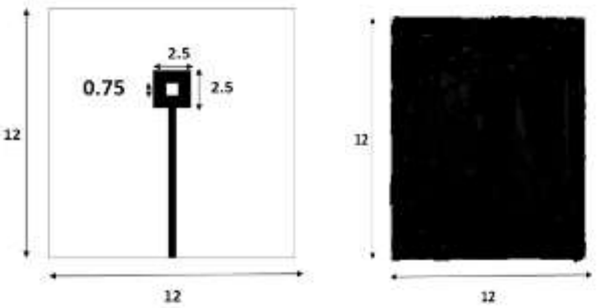

FIG-1: Top and ground plane of the Multi band antenna

2.2 EBG Unit cell design

The unit cell was analyzed with the Floquet port. The top plane of the uniplanar cell, was placed away from the port at 4.4 mm, half wavelength at 34 GHz, for all the cases. Three cases of EBG unit cells were analyzed where-in the top plane had a square metallic patch with dimensions 1x1 mm, 2x2 mm and 4x4 mm respectively, the gap between patches would be 0.5mm, 1mm and 1mm for the respective cases. The periodic boundary condition was assigned for the side-walls as shown in Figure 2. The procedure has been adopted from [10]. The frequency was swept from 24 to 42 GHz, to observe the reflection-phase at the port. The simulation results are shown in Figure 3, it could be deduced that the reflection-phase goes to near zero for both the bands (28 and 38 GHz) for the square patch width of 2mm, a near-zero phase is an indication that the periodic structure behaves as an artificial magnetic conductor (AMC) [10], which in-turn would act as a band stop filter at the specific bands and hence reduce surface waves. The results indicate that loading the proposed multiband antenna with the optimized uniplanar EBG would enhance gain at both the bands. If the dispersion diagram is plotted, then the band-gaps would be observed near the zero degree reflection-phase for these corresponding bands.

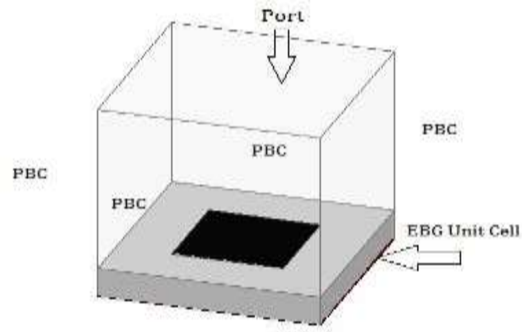

Fig-2 Simulation setup to analyze EBG unit cell

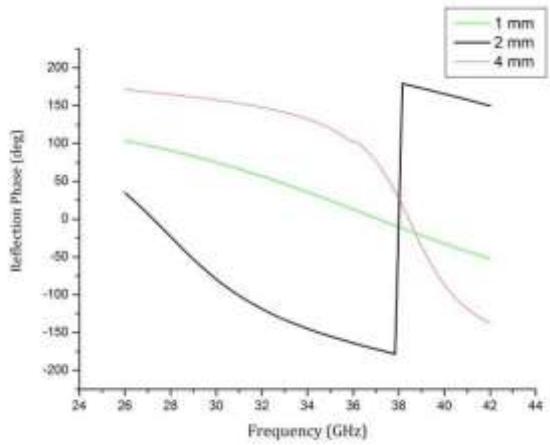

Fig -3 Reflection-phase for various EBG unit cell

3. Loading with uniplanar EBG

Uniplanar EBG would reduce surface waves which results in gain enhancement. The multi band Sierpinski antenna acts as the primary base, onto which uniplanar EBG was loaded. The top layer of the antenna was populated with square metallic patches of various sizes. It was observed that the EBG structures would enhance gain at specific frequencies and orientations, hence the uniplanar geometry also was optimized for gain enhancement at both the frequencies. It should also be noted that the designed uniplanar EBG would also alter the impedance match since the operating modes are slightly disturbed. A mushroom type EBG was avoided to decrease spurious radiation from the vias.

The square metallic patches were found to be optimum for simultaneous gain enhancement for both the operating bands at 24-86 GHz. The size of these patches and its density also affects the overall performance.

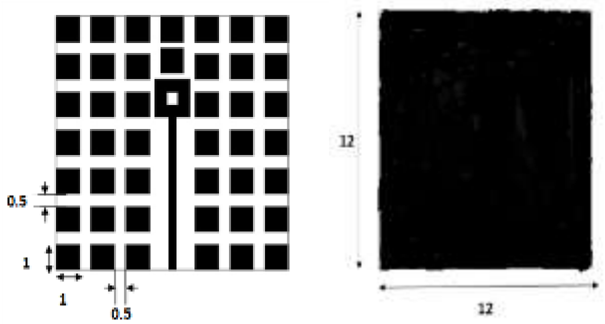

Fig -4 proposed antenna loaded with EBG unit cell

Table -1: Shows the important parameters for the geometrical configuration EBG loaded antenna

Antenna Part	Parameter	Value
Patch	Length	2.5 mm
	Width	2.5 mm
Substrates	Dielectric constant	4.3
	Height	1.6 mm
	Loss tangent	0.02
	Length	12 mm
	Width	12mm
Ground	Length	7 mm
	Width	12mm
EBG	Length	1 mm
	Width	1 mm
	Gap	0.5 mm

4. RESULTS AND DISCUSSION

Analysis of the sierpinski fractal antenna is performed. The E-plane and H-plane radiation patterns for 38 GHz (primary band) and 68 GHz (which falls in the 24-86 GHz band) are shown in Figures 5 and 6. Though, the antenna exhibits Multi bands, the band at 83 GHz is not analyzed, since 83 GHz band has not been among the candidate bands for 5G.

It is observed that peak gain for both E and H plane pattern at 28 GHz is below 2 dB. Also, the back-lobe radiations is relatively higher, which prohibits the antenna's utility in a typical mobile terminal application. At 38 GHz, the peak gain for E plane is 3.35 dBi and for H plane is 0.62 dBi, path loss at mmWave frequencies require antenna terminals with higher gains. Hence, uniplanar EBG structures are explored.

The H plane pattern is almost omnidirectional with maximum cross-pol level of 25 dB, which is desirable, at 28GHz. The E plane pattern at 28 GHz has a lot of speckles due to pronounced effect of surface waves and higher order modes, due to higher dielectric constant and relatively electrically thick substrate. It must also be noted that the cross-pol level is also elevated due to these higher order modes. The H plane pattern has a variation of 6 dB at 38 GHz. The cross-pol is below 22 dB at 38 GHz. On the other hand, the E plane pattern variation upto 9 dB at 38 GHz, it also observed that the pattern has a lot of speckles similar to the lower band and the cross-pol level is more than 7 dB, this could be attributed to increased modes at the higher frequency of operation.

The 31 mil substrate would be 0.0728λ at 28 GHz and 0.0988λ at 38 GHz, hence the substrate is electrically thicker at the higher band. The gain of the unloaded triple band antenna varies from -10 dBi to -3.51 dBi in the band 27 to 39 GHz, which indicates poor gain in this band. In order to enhance gain, the uniplanar EBG unit cells are periodically loaded onto the proposed Sierpinski antenna.

The gains for E and H planes for both the bands of interest are investigated with three different EBG structures, square patches of 1mm, 2mm and 4 mm respectively. It is observed that uniplanar EBG exhibits frequency and size dependence.

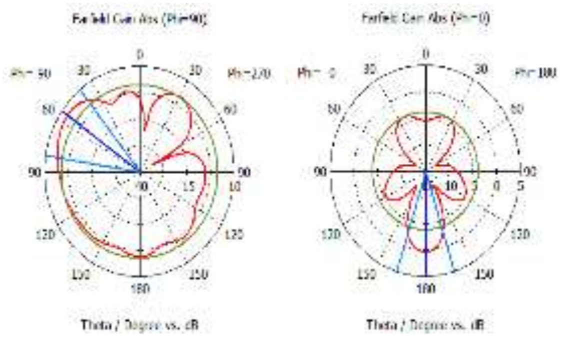

Fig- 5: H-plane and E-plane at 38GHz

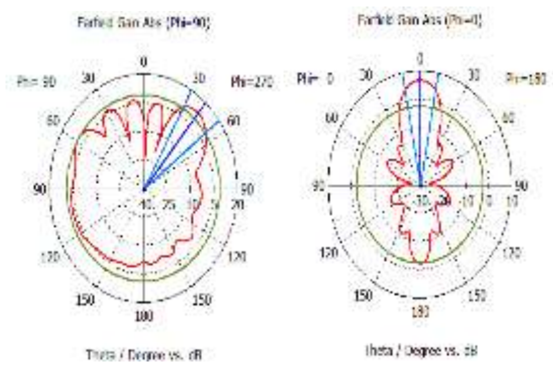

Fig- 6: H-plane and E-plane at 68GHz

Gain enhancement of 5 dB at 24GHz and 16 dB at 68 GHz in the end-fire direction is observed as shown in Fig- 7.

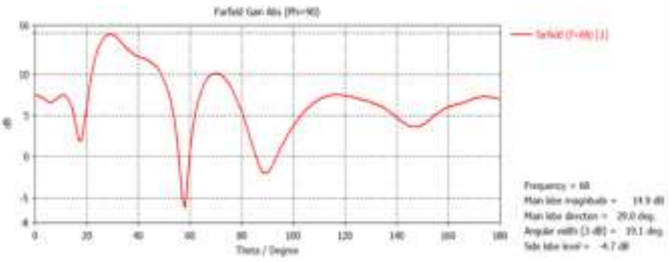

Fig- 7: Gain at 68GHz

The overall gain enhancement is shown in Table-2

Table -2: Various gain at different frequency

FREQUENCY	GAIN
24GHz	5.366 dB
28GHz	6.236 dB
38GHz	7.950 dB
42GHz	11.33 dB
58GHZ	13.18 dB
68GHZ	14.81 dB

The S-parameter plot was analyzed to see at which frequencies the antenna radiates and how much energy that is radiated. In figure we can see that the antenna has a bandwidth ranging from 55 GHz and above the specified upper frequency of 86 GHz.

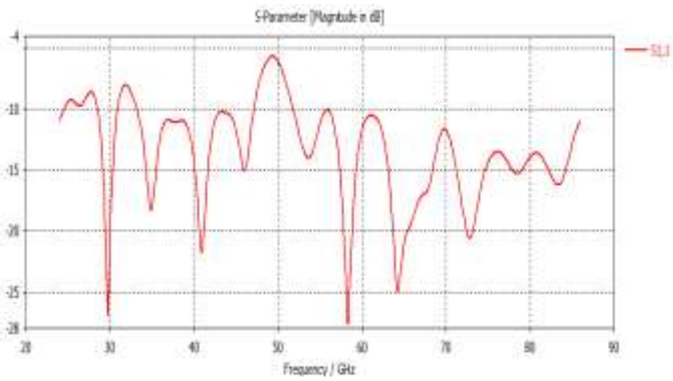

Fig- 8: S-parameter

S1;1 with values below 10 dB from 24- 86 GHz Frequency. But here two notches are occurred. This is not affecting the antenna performance highly. S1;1 to have as low value as possibly to assure that the antenna radiates most of the power applied to it .Often antennas must satisfy bandwidth requirement that is given in terms of VSWR. For instance, an antenna might claim to operate from 24-86GHz with VSWR<3. This implies that the VSWR is less than 3.0 over the specified frequency range shown in fig-9

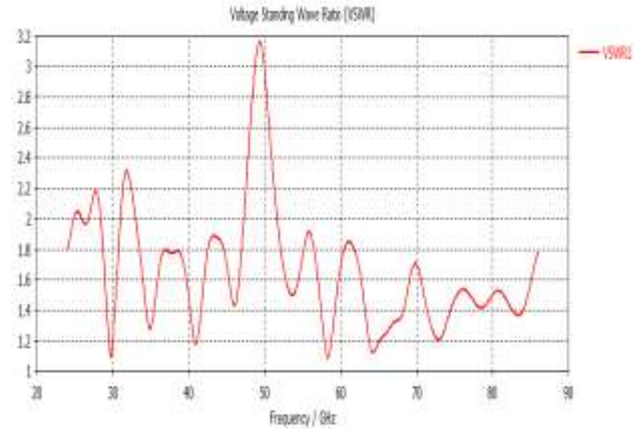

Fig- 9: VSWR

4. CONCLUSIONS

A low cost Multi band mmWave antenna is presented in this paper. Uni-planar simplistic EBG structure is proposed for gain enhancement for the bands at 28 GHz and 38 GHz. Reflection phase analysis of the EBG unit cell is presented. The triple band Sierpinski antenna was periodically loaded with the optimum EBG unit cells. An impedance match was obtained at 29.05 GHz, 35.75 GHz and 41 GHz. The peak end-fire gain ranged from 2.33 dBi to 14.31 dBi at 24- 86 GHz bands. The proposed antenna was fabricated and characterized.

A compact antenna design for fifth generation wireless communication system is proposed and discussed in this work. The proposed antenna operates successfully at two different frequencies which are 24.25 GHz and 38 GHz. The simulated antenna shows better performance in term of frequency drop, gain achieved and radiation pattern as well. This antenna has physical size with a compact size, simple structure and high efficiency to cover all the requirement of 5G. All these properties make it a good candidate for future milli meter wave application.

From the simulated results, it is observed that the half/quarter/sixth part of Patch antenna structure the gain is increased and radiation pattern obtained with EBG are much better than without EBG. In this investigation, with a serial feed array structure the high gain 8.3dBi has been achieved. It is clearly observed that the impedance bandwidth and radiation efficiency are improved significantly by implementing proposed 4x1 patch array with Square EBG. The gain improved significantly by introducing EBG square unit structure. The proposed array antenna would be suitable as base station antenna of the WLANs.

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