

An Interlaced Microstrip Patch Antenna Array with Multiband Characteristics for 5G Mobile Communication

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Abstract— This paper presents a low profile multiband Microstrip Patch Antenna with an interlaced nine slots for 5G millimeter wave communication. The structure is built on a Rodger 3003 substrate having dielectric constant of 3 and loss tangent of 0.0010. The proposed design resonates at multiband mmwave frequencies i.e. 28GHz, 52GHz and 60GHz offering a bandwidth of 1.04GHz, 1.2GHz and 1.1GHz and radiation efficiency of 93.6%, 88%, 84% respectively at each resonant frequency. The return loss is -16.8dB at 28GHz, -16.1dB at 52GHz and -52dB at 60GHz. The antenna is imprinted on a Rodger 3003 substrate having dielectric constant of 3.0 and loss tangent of .0010. The single element maintains a compact size of 10x10x.324mm³. The 2x4 Array configuration has an overall volume of 28 x 16 x 0.324mm³ with an enhanced maximum achieved gain of 15.2dB at 27GHz, 12.4dB at 39GHz and 13.3dB at 60GHz. The proposed array arrangement has a return loss of -22dB at 27GHz, -32dB at 39GHz, and -35.01dB at 60GHz spot frequency. The array exhibits a maximum radiation efficiency of 92% at 27GHz.

Keywords— Internet of things (IoT), Millimeter Waves (mm-Wave), 5G Mobile Communication.

I. INTRODUCTION

During the past few decades, a drastic increase has been observed in the requirement of higher data rates due to the evolution of advanced technologies i.e. clouding computing, Internet of things (IoT), device to device communications, Internet TV, online virtual environment (hologram technology), that existing third generation & Fourth (4th) generation networks will become obsolete due to its bandwidth limitation.

2G, 3G and 4G technologies are facing bandwidth shortage and requirement of higher data rates therefore prompt developments and innovations are required for excessively emergent wireless devices. In order to address this global challenge of bandwidth limitation and accommodate many more types of devices than just smart phones, it is obligatory to adopt Fifth Generation technology operating on millimeter wave frequencies. This copious spectrum lies in millimeter wave

frequencies, offering hundred times more capacity than current 4G technology. The fifth generation (mmwave) unfastens a door to the extreme bandwidth capacity and Gigabit throughput, powering the densely populated network and empowering the network operators by unleashing the true potential of 5G. [1]

The main objectives of 5th generation millimeterwave (mmWave) is enhancing the current capacity of the existing networks with promising network coverage at reduced infrastructure cost. With more emphasis towards greener technologies and compactness of devices, reduced power utilization is the main objective of 5G mmWave technology. The primary and major concern is the capacity of the network which is directly linked with rising capacity of the network and data rate requirements. The general agreement on which all the 5G mmWave groups are working is to achieve a data rate of 10Gb/s for stationary devices, 1Gb/s for mobile devices, and a minimum of 100Mb/s for devices operating in densely urban areas. [2]

5G mmWave is not yet standardized and research groups ITU radio-communication group is working for the development of this technology under the International Mobile Telecommunication (IMT-2020) [2].

5G technology relies on the concept of using higher frequency spectrum, hence; to realize the perception of millimeter wave the International Telecommunication Unit (ITU) pledges to use broad spectrum of 30 to 300 GHz for mmWave communication. The 5G mmWave sanctioning the network operator and service providers to allocate a higher frequency channel instead using a traditional channel of 20MHz, thus accommodating more devices.

The main research areas in 5G mmwave which are under the limelight are reducing the power utilization, antennas design and frequency utilization

Despite offering tremendous bandwidth and higher data rates, millimeter waves (mmWave) is super sensitive to high path loss and becomes significant in the adverse atmospheric conditions. Mostly higher attenuations in signals occur due to vapors as well as air molecules in the atmosphere. At frequencies below 30GHz, attenuation is very low i.e. 12dB per

kilometer at sea level, while this significant increase has been observed at above 30GHz. Since, this work is focused on the high frequencies bands i.e 27GHz, 39GHz and 60GHz, thus designing a mmWave antenna at these higher millimeter wave bands brings challenges for the engineers in the constrained mmWave environment. A number of mmWave designs however were proposed by researchers and credentials are discussed below based on the design structure of antenna and the desired improved design requirements.

Aliakbari et al. used a microstrip feedline instead of circular shape patch antenna. This fabrication technique is used to achieve higher gain and achieved operating frequency are 28GHz to 38 GHz [3]. Rogers substrate have low dielectric losses as well as low dispersion losses hence such a substrate being a superlative choice was used for Ultra High Frequencies (UHF) equipped devices [4] [5].

T shaped slotted antenna design is proposed by Goyal and Sharma [6] which resulted in reduced congestions for frequency bands below 5GHz and provided better data rate. For this design 50 Ohm coaxial line is used to feed the radiating patch and both length and width were kept 5mm whereas thickness is adjusted as 1.5mm. Also substrate Rogers RT 5880 with relative permittivity of 2.2, thickness of 1.57mm and loss tangent of 0.0009 was used. 60GHz has been selected as the operating frequency of antenna.

Klionovski et al [7] designed a Wide Angle Beam Steering patch Antenna at resonating frequencies of 27-33GHz. Antenna had dual polarization and broader radiation patterns. Two layers of Rogers R3003 having standard thickness of 0.5mm is used as dielectric substrate. dielectric substrate material are used having thickness of 0.5mm, circular radius of 3.8mm and permittivity of 3. A square conducting patch of dielectric is used with edges of patch convex shaped and dimensions of top and bottom layers set as 2.65mm and 2.85mm respectively.

A compact patch antenna with Rogers-5880 dielectric substrate was designed with dimensions of 21 x 21 mm². It resonated at 10GHz and 28GHz with a gain of 5.51 and 8.03 respectively [8].

A dual band Antenna with etched U-shaped slot is designed at resonating frequencies of 28GHz and 38GHz. It offers a gain of 3.75dB and 5dB at above stated frequencies respectively. Substrate material sandwiched between ground and patch is FR-406 [9].

Thomas et. al [10] introduced a MIMO Antenna Array design for wireless 5G based applications. This arrangement has a gain of .6dB with an operating frequency of 28GHz. FR4 is selected as the Substrate material having a permittivity of 4.6 and loss tangent of 0.001.

All of the above cited researches has a main concern associated of the complexity of the antenna design as per the 5G needs, reduced gain, low return loss and higher VSWR. The cited work is summarized in Table 1.

The main aim of this proposed research work is intended towards designing an efficient and effective Microstrip patch antenna which is capable of operating on multiple resonating mmWave frequencies but without compromising on antenna

performance parameters and the size in the constrained mmWave environment.

Table 1 Comparison of proposed mmWave Antenna with Literature

Reference Paper	Antenna Size (mm)	Frequency GHz	Achieved Gain (dB)	VSWR	Return Loss (dB)
[3]	6.8x6.8	28, 38	4.5	2	-20
[6]	3.6x3.2	60	6.34	1.9	-38
[7]	47x35	28 & 34	6	2	-
[8]	21x21	10,28	7.5	1.4	-
[9]	3x7	28, 38	3.7	-	-
[10]	120 x 40	28	6.6	-	-15
This Work	16x28	27.5, 39, 60	15	1.21	-35

II. ANTENNA THEORY AND DESIGN

A. Designing a Single Element Patch

Microstrip patch antenna design is reliant on a single element which in this research is kept rectangular shaped as shown in Fig. 2. Dimensions of this patch element are of absolute importance for easier incorporation of such mm-Wave antenna in mobiles and other electronic devices. Mostly antennas are designed on operating frequency, dielectric constant and standard height of the substrate. Hence in our research a base frequency of 27GHz is chosen whereas Rogers 3003 substrate material is used. Its standard height 'hs' is kept as 0.254mm, dielectric constant of 3, and magnetic permeability is specified as 1. Table 2 is showing the values of all the optimized parameters for the specified antenna design. The width 'Wp' of this patch antenna can be computed as:

$$W_p = \frac{1}{2f_c \sqrt{\mu_o \epsilon_o}} \sqrt{\frac{2}{\epsilon_r + 1}} = \frac{c}{f_c} \sqrt{\frac{2}{\epsilon_r + 1}} \quad (1)$$

Where, μ_o is magnetic permeability of free space, f_c is the center frequency, ϵ_o is electric permeability of free space, c is the speed of light and ϵ_r is dielectric constant of the substrate.

For this specified design, physical length L_p of the patch element can be computed as:

$$L_p = \frac{c}{f_c} \sqrt{\frac{2}{\epsilon_{eff}}} - 2\Delta L \quad (2)$$

Where ϵ_{eff} is the effective dielectric constant of substrate, L is taken as the length of the radiating patch and ΔL is the extended non physical length. Moreover we can calculate ϵ_{eff} as follows:

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left[1 + 12 \frac{hs}{W_p} \right] \quad (3)$$

Where hs is the height of the substrate.

Also,

$$\Delta L = \frac{(\epsilon_{eff} + 0.3)\left(\frac{W_p}{h_s} + 0.264\right)}{(\epsilon_{eff} - 0.258)\left(\frac{W_p}{h_s} + 0.8\right)} \quad (4)$$

TABLE 2. OPTIMIZED PARAMETERS OF THE BASE ELEMENT & UNIT CELL

Parameter	Description	Optimized Values (mm)	Parameter
Wp	Patch Width	3.5	Wp
Lp	Patch Length	2.9	Lp
p	Patch Height	.035	p
Ws	Substrate Width	10	Ws
Ls	Substrate Length	10	Ls
Hs	Substrate Height	0.254	Hs
Wg	Ground Width	10	Wg
Lg	Ground Length	10	Lg
Hp	Ground Height	10	Hp
Lf	Feedline Length	4.43	Lf
Gp	Gap between the feedline and Element	0.21	Gp
W1	First Slot Width	0.10	W1
W2	Second Slot Width	0.15	W2
L2	Second Slot Length	1.3	L2

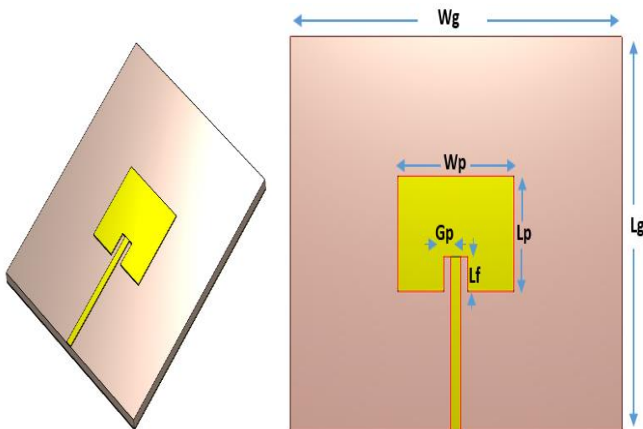


Fig.1 3D Isometric View and Front View of Base Element

B. Inset Feedline

Fig. 2 is showing the Isometric and Front view of antenna in which an inset feedline is added in antenna design. This feedline is used to increase the bandwidth as well as to minimize the return loss.

When the load and line impedance is perfectly matched at the inset feed point, we can then express the input impedance equation as follows:

$$Z_{input}(L = L_f) = R_{input}(L = 0) \frac{\cos^2(\pi L_f)}{L_p} \quad (5)$$

When the length of the inset feedline is zero, R_{input} is then considered the input resistance at the radiating. L_f , here is taken as the length of feedline which can be varied in the range of 0.2mm to 1.1mm using CST software parametric sweep feature. Hence the best match of the return loss (S_{11}) vs Frequency' can be extracted from the specified range. Therefore at the feedline length of 0.885mm the antenna is deliberated to be optimized. 'Gp' slit of 1mm is kept between the countour of inset feed and the patch. All the values are listed in the Table 2.

C. Parameter Assessment

The above stated Microstrip patch antenna is improved by varying the width 'Wp' of the patch between 3.3mm to 3.7mm where as the step difference is taken as 0.2mm. This patch antenna is simulated with variation in the width and three standard widths used were i.e. 3.3mm, 3.5mm and 3.7mm. However from the observations it was seen that at lower widths there was no significant change in the bandwidth but improvements in the return loss were observed upto some extent. With the increase in the width, significant improvement was seen in the return loss (S_{11}) i.e. 22.5dB and the frequency is progressed towards the resonating frequency i.e. 27GHz. Also input impedance is matched as a result a more tuned antenna is obtained.

Inset feeding technique is adopted to excite the Single Element of Patch Antenna. Inset feeding is planner in structure and hence easy to implement. In order to find the matching point of impedance; length and gap of feedline is varied. In this technique the inset feedpoint is moved towards the center of patch from the radiating edge and hence gradually decrease to zero at the center point of patch.

Hence it is observed that a prominent frequency change is detected with minor changes in the length of inset feedline and as a result it degrades the return loss due to the introduction of mismatch in the load and feedline. However no variation is observed with variation in width of the Inset feed.

D. Multiband Characteristics

The front projected view and 3D isometric view is delineated in Fig 3 , two types of slots having physical dimension of 0.10mm x 1.59mm and 0.15mm x 1.3mm are introduced in a base element. These slots are organized in an arc path producing an interlaced structure and hence, create two new sets of frequencies besides the 28GHz main frequency band.

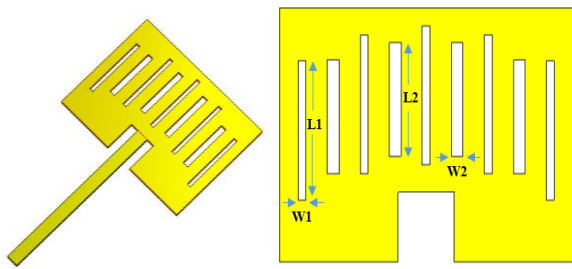


Fig. 2 3D Isometric View(Left) and Front View (Right) of Unit Cell

III. 2X4 ANTENNA ARRAY

A 2x4 Antenna Array structure of single patch element is repeated and is intended to overcome the higher attenuation losses downside of 5G mm-Waves, therefore, an eight elements Array as shown in Fig. 4 is arranged in four columns and two rows.

This Configuration of Array has dimensional measurements of $W_a=28.3\text{mm}$ and $L_a=16.1\text{mm}$. A uniform distance of $G_1=7\text{mm}$ is observed between each element. Also G_2 is 6.45mm and G_3 is taken as 2.78mm .

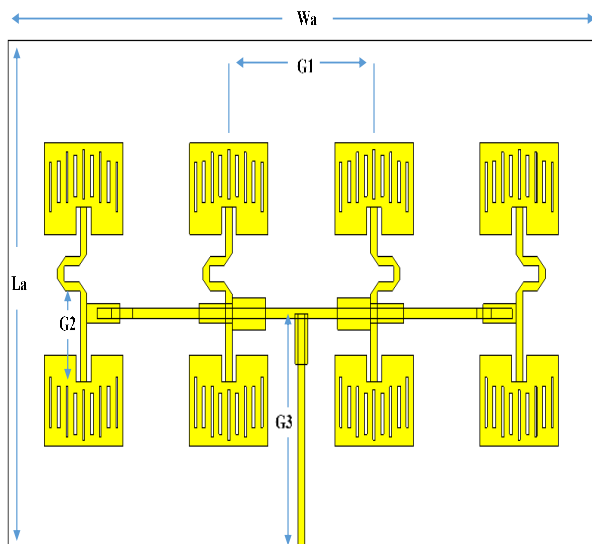


Fig. 4 Array configuration with overall dimension of $16.1\text{mm} \times 28.3\text{mm}$ (each element maintains a uniform distance of 7mm).

E. Corporate Feedline Network

A corporate feedlines is designed with 1:2 power divider pattern in order to excite the 2x4 Array. This 1:2 divider circuit was aimed for operating frequency of 27GHz and was placed on a roger 3003 Substrate of the same thickness $W_a=28.3\text{mm}$.

On the splitter Arms of power divider a quarter wave impedance transformer is used for equal bifurcation of the power into the feeding arms. However the traveling signal waves suffer from power losses due to such discontinuities at the corner or

bends and results in impedance mismatching of the line due to the capacitive nature of the antenna characteristics. Hence such losses are mitigated by using mitered bends. Such bends maximize power transmission by introducing chamfered edges instead of using sharp 90 degree bends. Hence shunt capacitance in highly tunable circuits is minimized and results in reinstating the original characteristics impedance Z_o of the feeding line.

Fig. 5 is demonstrating the feeding Network of 2x4 Array used for excitation of Array. Mitered bends as shown in Fig. 5 can result in self cancellation of radiations, as the power enters in the array with a 180 degree phase shift. Hence a line delay is added that can result in ensuring the in phase radiation of all the eight Array elements.

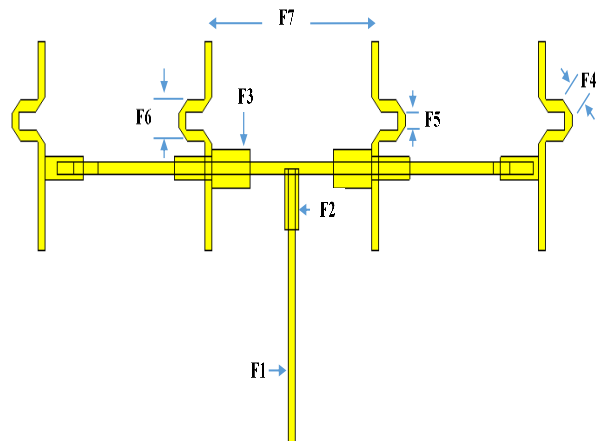


Fig. 5 Corporate Feedline Network with Quarter Wave Transformers at junctions for Excitation of 2x4 Array with Uniform Spacing

IV. RESULT AND DISCUSSION

This section is designated to cover the results of the simulated design. These results are analyzed on different characteristic parameters i.e. return loss (s11), Voltage standing wave ratio (VSWR), Input Impedance. Also Gain, directivity and radiation patterns are taken into account when insight comparison of Array is made with unit cell and base element.

F. Return Loss

Return loss (S11) of any designated antenna has to be less than -10dB , in order to proficiently utilize the maximum incident power. For proposed design the return loss shows improved results when the patch width is varied between 3.3mm and 3.7mm . Also adding the step size of 0.2mm brought the frequency closer to the base frequency of 27GHz . Fig. 6 is demonstrating the return loss variations with respect to the width changes. At $W_p=3.7\text{mm}$ is perceived that matching between load and antenna is observed however at 3.5mm return loss is -14dB showing mismatching conditions. Table 3 is depicting the return loss of initial design, the unit cell, and 2x4 Array. Also Fig. 7 is showing the simulations of all three respectively. Resonance frequency of initial design is 27.5GHz and S11 is -32.5dB . Introduction of slots in the initial design make the design to resonate at 27.5GHz , 41GHz and 62GHz frequencies. Also the S11 for frequency is -26dB , -15dB and -30dB . Finally

the 2x4 Array design has resonating frequencies of 27.5GHz, 39GHz and 60.01GHz and the S11 is sustained at -22.1dB, -32dB and -35.01dB.

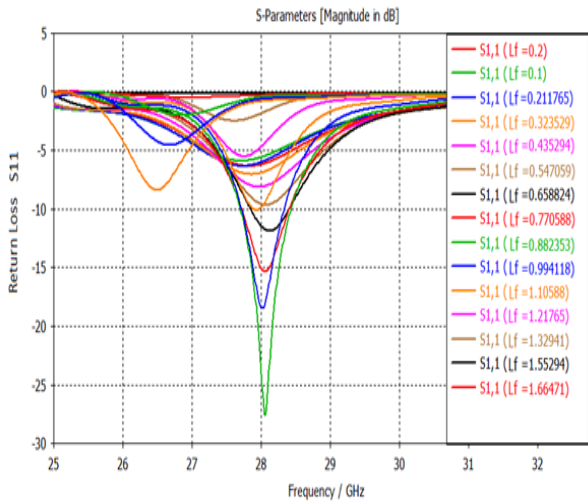


Fig. 6 Effect of Varying Width of the Patch on the Return Loss

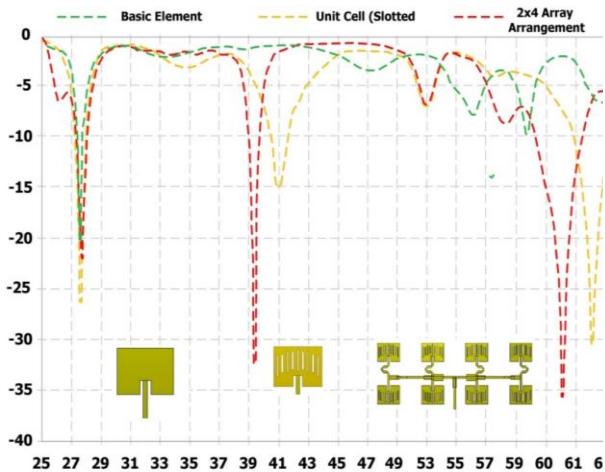


Fig. 7 Return loss of Basic Element, Unit Cell and 2x4 Array configuration

TABLE 3. RETURN LOSS OF THE BASIC DESIGN, UNIT CELL AND 2X4 ARRAY.

Antenna	Base Element	Unit Cell (Interlaced Element)	2x4 Array Arrangement
Frequency (GHz)	27.5	27.5	41
Return Loss (S11)	-32.5	-26	-15

G. VSWR

For Microstrip Antenna efficiency, VSWR is deliberated to be less than 2 and is one of the key parameter in efficient antenna designing. Fig. 8 is depicting a VSWR plot of 2x4 Array arrangement verses the variations in frequency. At resonating frequencies of 27.5GHz, 39GHz and 60GHz VSWR is maintained at 1.21, 1.3 and 1.2 respectively. Hence the Array arrangement is fulfilling the base parameter demand of VSWR which is implicit to be less than 2 for efficient and perfectly matched impedance of transmission line and antenna.

H. Input Impedance

Another key parameter in antenna efficiency is impedance matching and it is considered that if transmission line and antenna are matched than length of transmission line is ineffective and results in minimal losses. On the Contrary input impedance changes significantly with load variation due to mismatching. At resonating frequencies of 27.5GHz, 39GHz and 60.01GHz the 2x4 Array arrangement indicated input impedances of 52 Ω, 53 Ω and 49 Ω respectively. Microstrip transmission feedline has impedance of 50 Ω and hence it is observed that input impedance of 2x4 Array and transmission line impedance are almost matched. Fig. 9 is depicting the

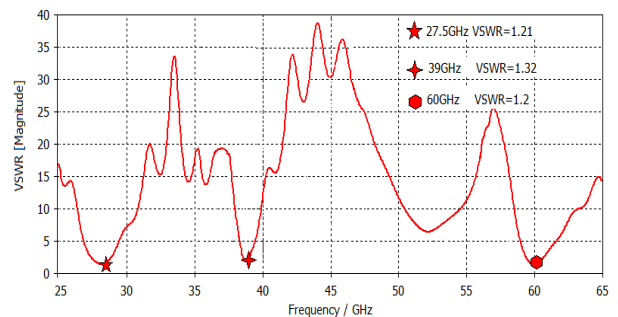


Fig. 8 VSWR Plot of 2x4 Antenna Array

impedances of base design, unit cell and 2x4 array design.

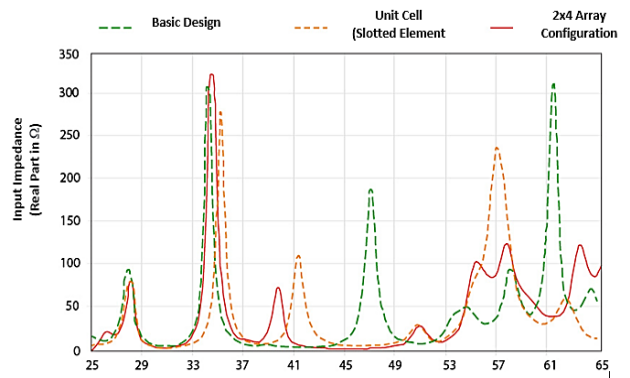


Fig. 9 Real part of the Input Impedance of the basic design, Unit Cell (Slotted element) and 2x4 Array Configuration

I. Gain Plots of Proposed Design

Fig. 10 and Fig. 11 are depicting the Radiation Patterns both E Plane and H Plane of the Unit Cell and Array arrangement respectively at variable frequencies. It is inferred from these patterns that behaviors of unit cell and array are diverse in the frequency bands. Unit cell for instance is behaving more like directional antenna at 27GHz and 62GHz; whereas at 41GHz spot frequency, E Plane and H Plane spread almost equally in all direction making the antenna behavior (b) milar to omnidirectional antenna.

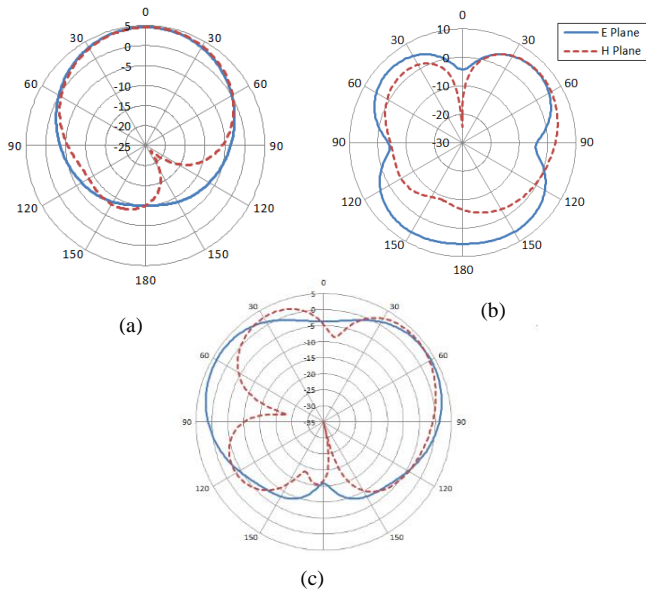


Fig. 10 Radiation Pattern of the Unit Cell (Slotted Element) at mmWave frequencies of (a)27GHz (b) 41GHz (c)62GHz

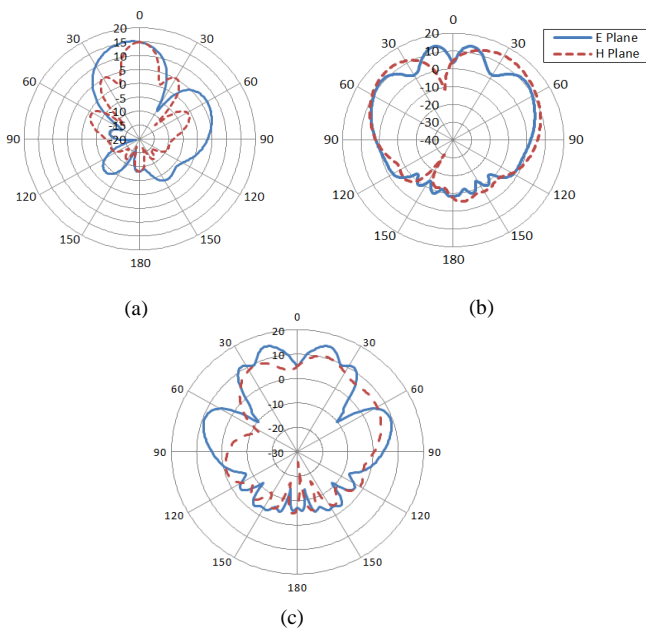


Fig. 11 Radiation Pattern of the 2x4 Array at mmWave frequencies (a) 27.5GHz (b) 39GHz (c) 60GHz

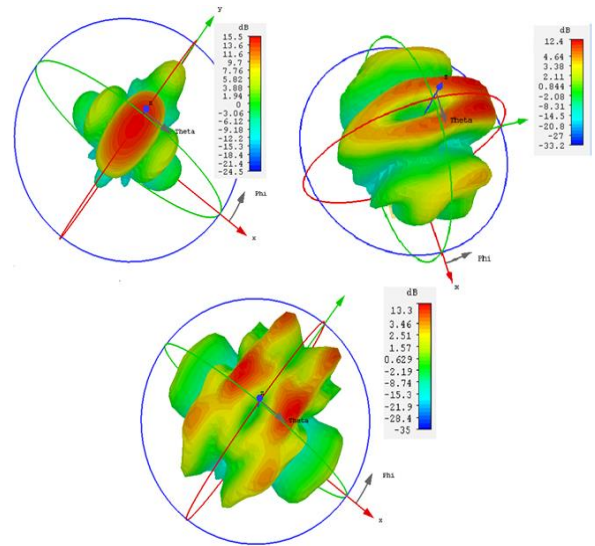


Fig. 12 3D Radiation Pattern of 2x4 Array Configuration at 27.5 GHz (top left) 39GHz (top right) and 60GHz(bottom)

Futher it can be inferred at spot frequencies of 27GHz, 41GHz and 62GHz unit cell array has 94.2°, 61.6° and 53° degrees the half power beamwidths respectively. Also at the resonating frequencies of 27.5GHz, 39GHz and 60.01GHz the half power beamwidth angles are 18°, 12.9° and 14.2° respectively. However for H plane ($\Phi=90$) the above stated angles are maintained at 35.5° 45.8° and 25° for respective frequencies. Fig. 12 is representing 3D view of these radiation patterns.

CONCUSLION

5G technology is sensitive to minor changes of atmospheric deviations hence this research was focused on highlighting flexible solutions to address the mm-wave communication challenges. A Novel Microstrip Patch Antenna is introduced along with 2x4 array design resonating at triband millimeter wave frequencies. The design is presented in three facton i.e. base element, unit cell and Array arrangement and proportioned step wise improvement was highlighted. Initial step covered the base element design which is extended by adding multiple slots in it. Slot addition equipped the design with multiple resonant frequency bands.

The unit cell (slotted element) is replicated to form an array configuration to overcome issues like path loss and attenuation in the stilted millimeterwave (mmWave) enviroment. Novel Array practice, improved the overall gain by a factor of 3.5 i.e. from 4.5 to 15.5 at mmWave resonant frequencies, hence, is effective in addressing the 5G mm-Wave multiband frequency requirements. All three stages are simulated in CST and were analyzed on performance parameters of antenna.

The Mitered band approach further reduces the return loss and provides a better matched antenna design. Wi-Gig applications that require higher gains can use such antenna designs as proposed antenna’s radiates at Tribands i.e. 27.5 GHz, 39.3GHz and 60.1GHz. Also a licensed bandwidth of

715MHz is covered at 27.5GHz frequency which is proficient for 5G cellular communication.

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