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High Gain 2x2 Slotted Array Antenna for 5G Mobile Applications

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***Abstract*—New optimized 2x2 slotted array antenna is designed using HFSS to operate at 28.1 GHz, using RT6010 substrate with height of 1.6 mm, tangent loss of 0.0023 and dielectric constant of 10.2 and overall dimension of 12x12 mm^2, for 5G mobile applications. The 2x2 slotted linear array antenna achieved a high gain of 18.3 dB at 28.1 GHz with 10 dB bandwidth of 1.39 GHz, and with 83.21% of size reduction.**

***Keywords*—Technology, electronics, optoelectronics, photonics, telecommunications, signals. circuits, systems, applications**

I. Introduction

THIS research aims to develop a new design for the slot antenna array for the unlicensed millimeter-wave (30 GHz to 300 GHz) band applications for 5G mobile devices. Slot antenna's main advantages are its simplicity in terms of design, robustness, size and easy adaptation to the mass production using Printed Circuit Board (PCB) technology. Critical review on the literature for various type of slotted antenna for 5G applications were done, mainly on the shape and size of the slot and the operating frequency, as these determines the radiation pattern. Further, the feeding techniques, substrate used and loss tangent considered were also reviewed.

From the literature review it could be observed that the mm-wave frequency band has been used to design the slot antenna array, due to frequency spectrum shortage below 6 GHz and due to the other fact of higher data rate demand. It is summarized that mostly researchers designed slot antenna array at 28 GHz and designed various slots with different dimensions and feeding techniques. Most of the researchers used RT5880 as the substrate and assumed 0.0009 loss tangent for their designs. HFSS and CST were used for the simulation, but majority of the researchers have used HFSS software. As far as the feeding technique is concerned, majority of the researchers have used microstrip feed line.

The limitation or gap identified, was that most of the researchers failed to achieve the gain of 12 dB which are the requirements for the mobile applications. Further compact design was not achieved by all the researchers and the design was still complex. Hence, optimizing the compact size, achieving the 12 dB gain, wider bandwidth and higher data rate are challenging to be fitted into the current smartphone for 5G mobile devices.

The proposed antenna in this research is to be designed to operate at 28 GHz [15] to operate in the mm-wave antenna system, with improved features such as smaller size as compared to the slot antenna array proposed by [12], less complex design and to be fit easily into the lower or upper edges of the currently used smart phones. The scope apart from compact size, is to ensure the gain of achieving 12 dB for mobile applications with wider bandwidth. This could be achieved by optimizing the sizes and dimensions of the sots and feeding techniques.

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II. Proposed Methodology

A. Design Specification

The proposed microstrip rectangular patch antenna design calculation is done based on the design parameter considerations taken into account from Table I.

TABLE I
MICROSTRIP RECTANGULAR PATCH ANTENNA DESIGN SPECIFICATIONS

Antenna design parameters	**Specifications**			
Operating Frequency	28 GHz	28 GHz	28 GHz	28 GHz
Tangent Factor	0.02	0.0013	0.0009	0.0023
Dielectric constant	4.4	3	2.2	10.2
Feeding impedance	50 ohms	50 ohms	50 ohms	50 ohms
Substrate to be used	FR4	RT3003	RT5880	RT6010

The proposed antenna dimensions are calculated with the operating frequency, f_r fixed at 28 GHz, height of substrate, h is 1.6 mm, dielectric permittivity of the FR4, RT3003, RT5880 and RT6010 substrates, ε_r are 4.4, 3, 2.2 and 10.2, and speed of light, c being 3×10^8m/s. The fundamental antenna design equations [1] involved are shown below stepwise.

Step 1
Width of the patch is calculated as shown below,

$$W = \left[\frac{C}{2 f_0} \sqrt{\frac{2}{\varepsilon_r + 1}} \right] \tag{1}$$

Step 2
The effective dielectric constant is calculated as shown below,

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left[1 + \frac{12h}{W} \right]^{\frac{1}{2}} \tag{2}$$

Step 3
The effective length is calculated as shown below,

$$L_{eff} = \frac{C}{2 f_0 \sqrt{\varepsilon_{eff}}} \tag{3}$$

Step 4

The extension of the length is calculated as shown below,

$$\Delta L = 0.41h\left[\frac{\left(\varepsilon_{reff}+0.3\right)\left(\frac{W}{h}+0.264\right)}{\left(\varepsilon_{reff}-0.258\right)\left(\frac{W}{h}+0.8\right)}\right] \tag{4}$$

Step 5

The length of the patch is calculated as shown below,

$$L = L_{eff} - 2\Delta L \tag{5}$$

Step 6

The width of the ground plane is calculated as shown below,

$$W_g = 6h + W \tag{6}$$

Step 7

The length of the ground plane is calculated as shown below,

$$L_g = 6h + L \tag{7}$$

Thus, the length and width of the patch and the ground plane are calculated theoretically and are tabulated in Table II as per equations (1) to (7).

TABLE II
MICROSTRIP RECTANGULAR PATCH ANTENNA DESIGN PARAMETERS

Substrate	**FR4**	**RT3003**	**RT5880**	**RT6010**
Parameter	Dimensions in mm			
Height of substrate, h	1.6	1.6	1.6	1.6
Width of patch, W	3.26	2.68	4.24	2.26
Effective dielectric constant, ε_{reff}	3.35	2.35	7.56	7.18
Effective Length, L_{eff}	2.93	3.49	1.95	1.99
Extension of the Length, ΔL	0.63	0.56	0.59	0.54
Length of patch, L	1.67	2.38	0.75	0.92
Width of the ground plane, W_g	12.86	12.28	13.84	11.86
Length of the ground plane, L_g	11.27	11.98	10.35	10.52

TABLE III
PATCH AREA AND GROUND PLANE DIMENSIONS

Design	**WxL**	**WgxLg**
Proposed Design using FR4	5.44 mm^2	144.93 mm^2
Proposed Design using RT3003	6.38 mm^2	147.11 mm^2
Proposed Design using RT5880	3.18 mm^2	143.24 mm^2
Proposed Design using RT6010	2.08 mm^2	124.77 mm^2

The values shown in Table II and III are based on the design specifications given in Table I. From the calculated design parameters and based on the patch area and ground plane dimensions of Table III, it could be concluded that the microstrip patch antenna designed using RT6010 substrate results in compact size.

B. Optimized Antenna Design using HFSS

Microstrip slot patch antenna using RT6010 is designed using HFSS software and analysis has been carried out to determine the optimized design parameter to achieve the 5G requirements. Fig. 1 and Fig. 2 shows the proposed single element microstrip rectangular patch and slotted patch antenna designed using HFSS.

The optimized final slotted microstrip patch antenna dimensions using the RT6010 substrate is shown in Table V, and the optimized dimensions are shown in Fig. 3 to Fig. 7. The same is designed using the software HFSS and the single element rectangular slotted microstrip patch antenna designed using HFSS is shown in Fig. 8 and Fig. 9. The optimized 2x2 slotted rectangular microstrip patch antenna without and with metallic contact using HFSS is shown in Fig. 10 and 11.

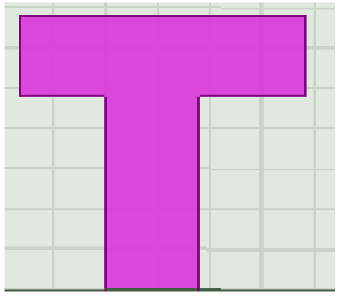

Fig.1. Proposed single element rectangular patch antenna designed using HFSS

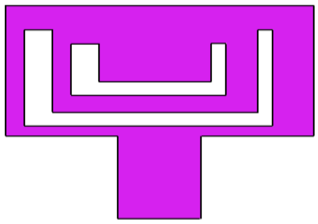

Fig. 2. Proposed single element rectangular slotted patch antenna designed using HFSS

TABLE V
OPTIMIZED SLOTTED RECTANGULAR MICROSTRIP PATCH ANTENNA GEOMETRIES

Parameters	**Optimized Design Dimension (mm)**	**Parameters**	**Optimized Design Dimension (mm)**
L1	2.0	L5	1.7
L2	1.0	W8	0.3
W1	2.7	W9	0.2
W2	1.1	W10	1.5
W3	0.5	W11	2.0
L3	1.0	L6	4.8
W4	0.3	L7	0.5
W5	0.2	W12	0.6
W6	0.8	W13	4.4
W7	1.5	W14	5.6
L4	1.5	R	1.0

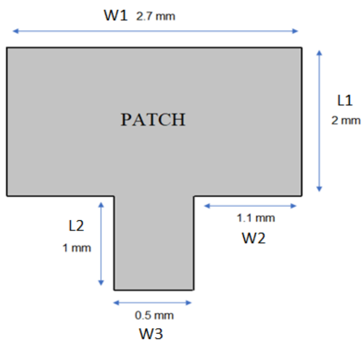

Fig. 3. Optimized proposed rectangular patch antenna design dimensions

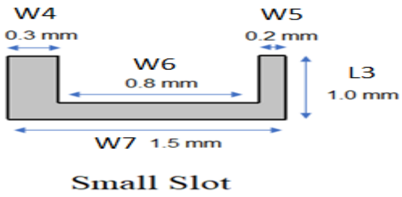

Fig. 4. Optimized U-shaped small slot dimensions in the rectangular patch

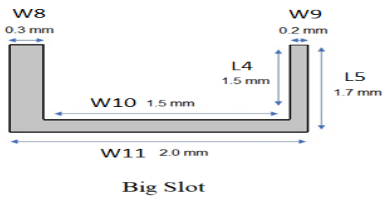

Fig. 5. Optimized U-shaped big slot dimensions in the rectangular patch

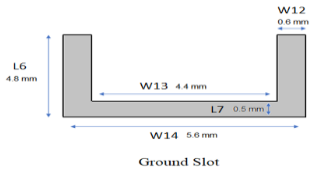

Fig. 6. Optimized U-shaped slot dimensions introduced in the ground plane

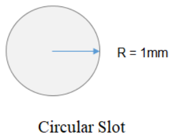

Fig. 7. Optimized circular slot dimension introduced in the ground plane

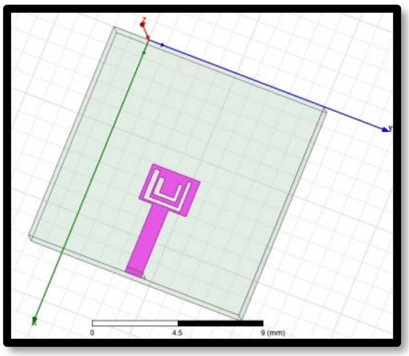

Fig. 8. Optimized single element slotted patch antenna using HFSS

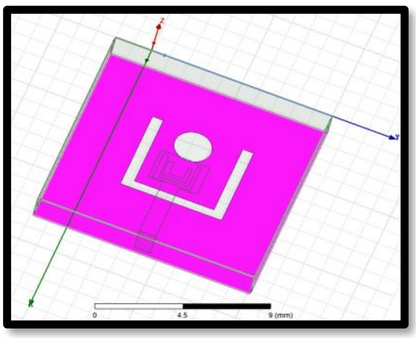

Fig. 9. Optimized single element slotted patch antenna showing slot and circle in the ground plane using HFSS

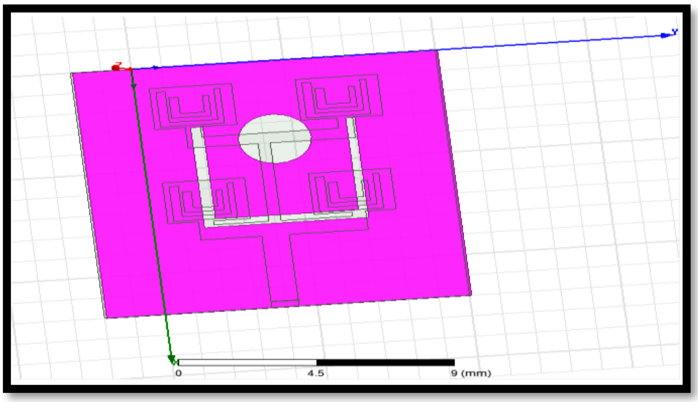

Fig. 10. Optimized 2x2 slotted patch antenna without metallic contact using HFSS

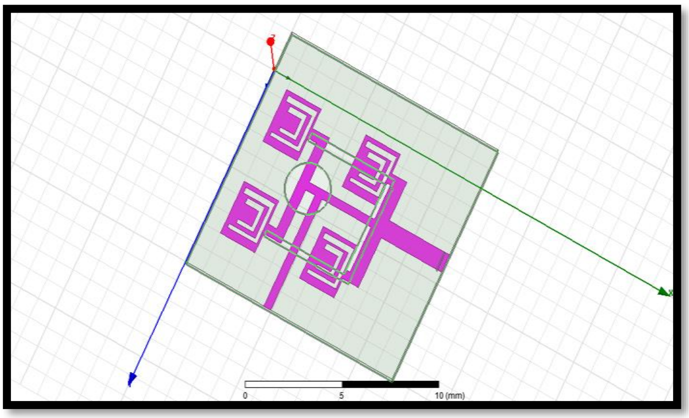

Fig. 11. Optimized 2x2 slotted patch antenna with metallic contact using HFSS

III. SIMULATION RESULTS

The return loss (dB) and VSWR are compared for the single rectangular patch with Small and Big U-slot and with U-slot & circle in the ground plane using various substrates such as FR4, RT3003, RT5880 and RT6010 as shown in Fig. 11 and Fig. 12. It is observed that a return loss of -16.95 and VSWR of 1.33 at 28.6 GHz has been achieved by RT6010, meeting the minimum antenna requirement, comparatively metallic contact is introduced in between the two 1x2 slotted rectangular microstrip linear array. The return loss measured dB for the optimized 2x2 slotted rectangular patch array with

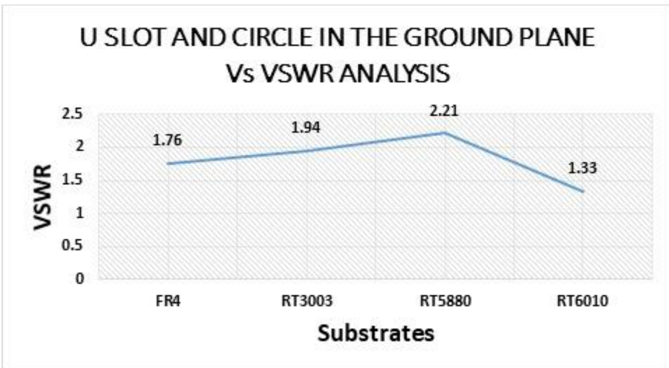

Fig. 11. Return Loss of single rectangular patch with Small and Big U-slot and with U-slot & circle in the ground plane using various substrates

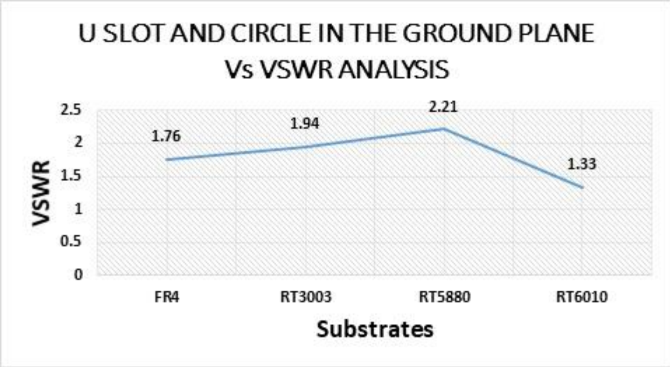

Fig. 12. VSWR of single rectangular patch with Small and Big U-slot and with U-slot & circle in the ground plane using various substrates

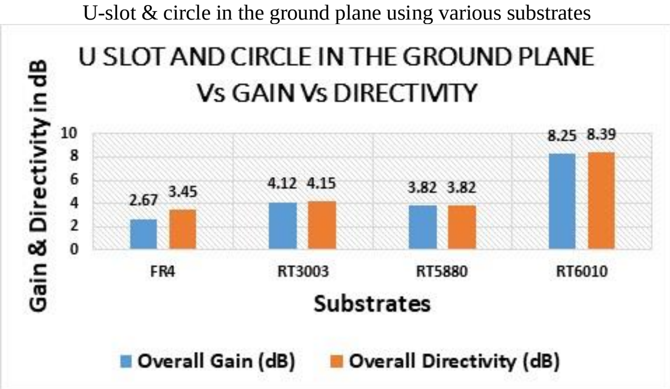

Fig. 13. Gain and directivity of single rectangular patch with Small and Big U-slot and with U-slot & circle in the ground plane using various substrates

Further, the overall gain and directivity are high for RT6010 substrate, as compared to other substrates, which is 8.25 dB and 8.39 dB, respectively, as shown in Fig. 13. Further observed that the return loss is more less than -10 dB and VSWR is very close to unity and less than two, only when the substrate used is RT6010 comparatively. Based on these inferences, it is concluded to use RT6010 substrate is the best to design the proposed slot based microstrip patch antenna.

The return loss measured in dB for the optimized 2x2 slotted rectangular patch array using RT6010, is shown in Fig. 14 and it is observed to be -14.65 at 27.6 GHz while the corresponding VSWR measured is shown in Fig. 15 and it is observed to be 1.45.

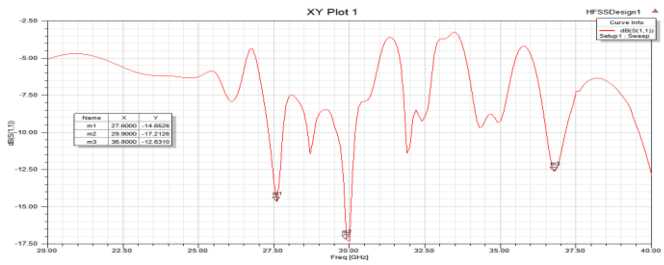

Fig. 14. Return Loss of optimized 2x2 slotted rectangular patch array using RT6010

The Gain and directivity in dB are shown in Fig. 16 and it is observed to be 18.32 dB and 3.29 dB, respectively at 27.6 GHz. But the antenna resonated at 27.6 GHz only, rather than at 28 GHz.

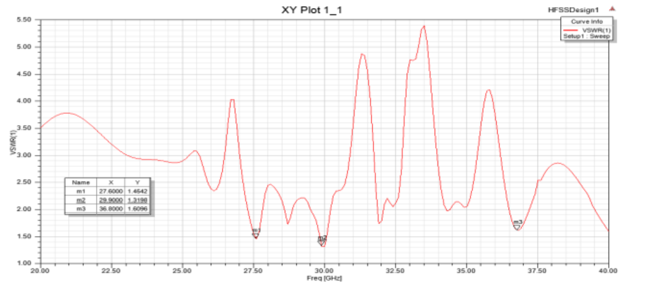

Fig. 15. VSWR of optimized 2x2 slotted rectangular patch array using RT6010

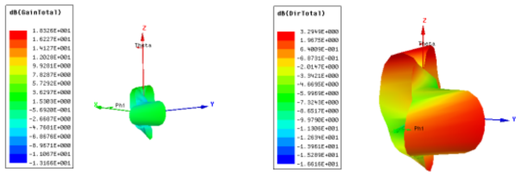

Fig. 16. Gain and Directivity of optimized 2x2 slotted rectangular patch array using RT6010

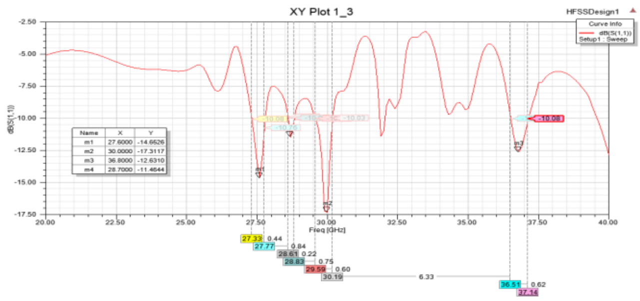

Fig. 17. Bandwidth analysis of optimized 2x2 optimized slotted rectangular patch array using RT6010

Further, the 2x2 slotted array antenna resonated at 27.6 GHz, 28.7 GHz, 30 GHz and 36.8 GHz with -14.65 dB, -11.46 dB, -17.31 dB and -12.63 dB return loss, respectively, as shown in Fig. 17. The antenna resonated at four bands, namely lower, mid1, mid2 and higher frequency which are illustrated as shown in Table VI.

TABLE VI
BANDWIDTH ANALYSIS OF OPTIMIZED 2X2 SLOTTED MICROSTRIP PATCH ANTENNA

Parameters	**Lower frequency band**	**Mid frequency band 1**	**Mid frequenc y band 2**	**Higher frequency band**
Frequency Range (GHz)	27.33 – 27.77	28.61 – 28.83	29.59 – 30.19	36.51 – 37.14
Centre Frequency (GHz)	27.6	28.7	30	36.8
Bandwidth (GHz)	0.44	0.22	0.6	0.62
Percentage of Bandwidth Improvement	1.59%	0.76%	2%	1.68%
Higher 5G Mobile Band Application	Commercial deployments in USA, Japan & Korea		NIL	NIL
Application	3GPP New Radio (NR), Fixed Services (FS) and Fixed Satellite Services (FSS)			

Finally, the gain achieved by 2x2 array achieved 18.32 dB of gain but resonated at 27.6 GHz instead at 28 GHz. Hence, a in the metallic contact using RT6010, is shown in Fig. 18 and it is observed to be -22.94 at 28.1 GHz while the corresponding VSWR measured is shown in Fig. 19 and it is observed to be 1.15.

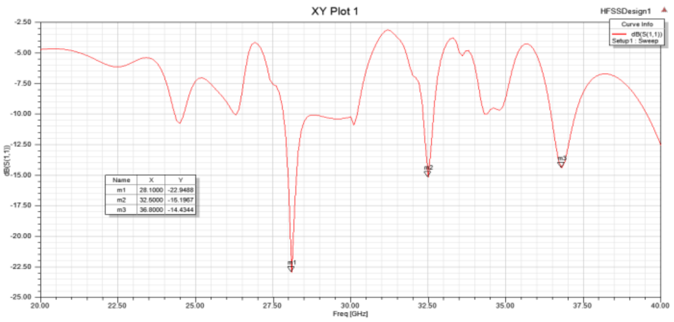

Fig. 18. Return Loss of optimized 2x2 slotted rectangular patch array with metallic contact using RT6010

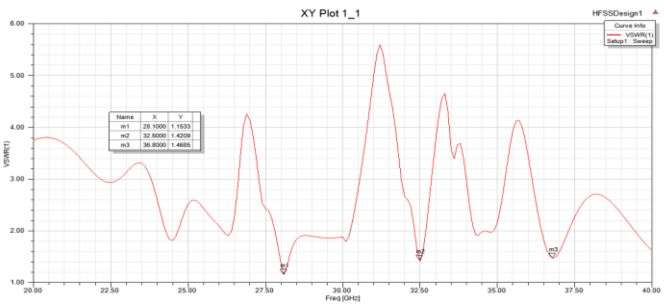

Fig. 19. VSWR of optimized 2x2 slotted rectangular patch array with metallic contact using RT6010

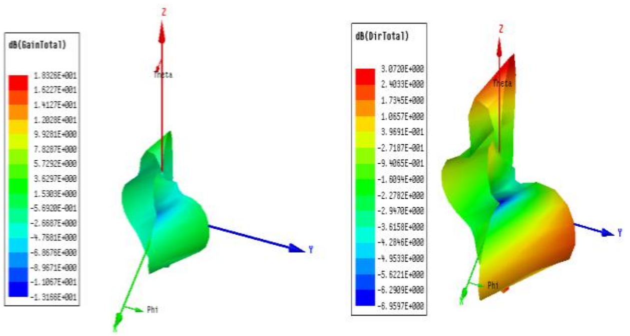

Fig. 20. Gain and Directivity of optimized 2x2 slotted rectangular patch array with metallic contact using RT6010

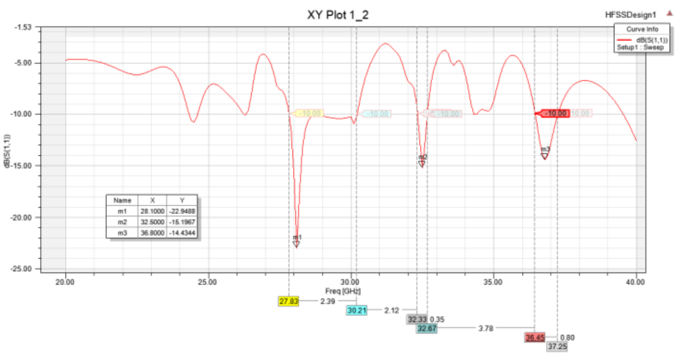

Fig. 21. Bandwidth analysis of optimized 2x2 optimized slotted rectangular patch array with metallic contact using RT6010

The Gain and directivity in dB for the 2x2 optimized slotted rectangular patch array using RT6010 with metallic contact are shown in Fig. 20 and it is observed to be 18.32 dB and 3.07 dB, respectively at 28.1 GHz. Generally, for a microstrip patch antenna, the return loss and VSWR must usually be less than -10 dB and almost near to unity.

Further, the 2x2 slotted array antenna resonated at 28.1 GHz, 32.5 GHz and 36.8 GHz with -22.94 dB, -15.19 dB and -14.43 dB return loss, respectively, as shown in Fig. 21. The antenna resonated at three bands, namely lower, mid and higher frequency which are illustrated as shown in Table VII.

TABLE VII
BANDWIDTH ANALYSIS OF OPTIMIZED 2X2 SLOTTED MICROSTRIP PATCH ANTENNA

Parameters	Lower frequency band	Mid frequency band	Higher frequency band
Frequency Range (GHz)	27.83 – 30.21	32.33 – 32.67	36.45 – 37.25
Centre Frequency (GHz)	28.1	32.6	36.8
Bandwidth (GHz)	2.39	0.35	0.8
Percentage of Bandwidth Improvement	8.5%	1%	2.2%
Higher 5G Mobile Band Application	Commercial deployments in USA, Japan & Korea	Public proposal in Korea, Australia and Europe	NIL
Application	3GPP New Radio (NR), Fixed Services (FS) and Fixed Satellite Services (FSS)		

From Table VII, it is understood that the optimized 2x2 slotted microstrip rectangular patch antenna has resonated at three different frequencies covering lower, mid and high frequency band, with bandwidth, improved covering the higher 5G mobile band applications.

The bandwidth improved at 28.1 GHz, 32.6 GHz and 36.8 GHz are 8.5%, 1%, 2.2%, with 2.39 GHz, 0.35 GHz and 0.8 GHz bandwidth respectively. This improved bandwidth shall be used for applications for commercial deployment in USA, Japan and Korea and for public proposals in countries such as, Korea, Australia and Europe, covering 3GPP New Radio (NR), Fixed Services (FS) and Fixed Satellite Services (FSS) applications and the Ka Band of Microwave frequency range for 5G cellular application.

Furthermore, the 2x2 optimized slotted antenna with metallic contact results are compared with the literature review and is tabulated in Table VIII. It is observed that at resonant frequency of 28.1 GHz, gain of the optimized slotted microstrip linear rectangular patch array with metallic contact is improved highly compared to the existing designs ranging from 50.87% to 13.75%. Thus, the optimized 2x2 slotted linear array antenna with metallic contact achieved 18.32 dB of high gain which is sufficient for 5G mobile communication requirement.

From Table IX, it is observed that the 2x2 slotted linear array with metallic contact has a bandwidth improved by 86.6% and 42.3% of [2] and [12] and have achieved 2.39 GHz bandwidth at 28.1 GHz.

Further From Table X, it is observed that the 2x2 slotted linear array with metallic contact has a return loss improved by

25.76% and 55.59% of [9] and [11] and have achieved -22.9 dB return loss at 28.1 GHz.

Also, the optimized 2x2 slotted linear array with metallic contact has the same size as the 1x2 slotted linear array, which is 12mm x 12mm of compact size and is highly reduced compared to the existing designs ranging from 97.6% to 30.435, as per Table XI. The summary of the outcomes achieved by proposed slotted antenna is shown in Table XII.

TABLE VIII
COMPARISON OF GAIN OF THE EXISTING AND PROPOSED 2X2 SLOTTED LINEAR ARRAY ANTENNA AT 28 GHZ

Sno	Gain in dB			Percentage of gain improved
	Existing Designs		Proposed 2x2 slotted linear array	
1	[12]	9	18.32	50.87%
2	[9]	10		45.41%
3	[11]	11.57		36.85%
4	[2]	11.9		35.04%
5	[14]	15.6		14.84%
6	[10]	15.8		13.75%

TABLE IX
COMPARISON OF BANDWIDTH OF THE EXISTING AND PROPOSED 2X2 SLOTTED LINEAR ARRAY ANTENNA AT 28 GHZ

Sno	Bandwidth in GHz			Percentage of Bandwidth improved
	Existing Designs		Proposed 2x2 slotted linear array	
1	[2]	0.32	2.39	86.6%
2	[12]	1.38		42.3%

TABLE X
COMPARISON OF RETURN LOSS OF THE EXISTING AND PROPOSED 2X2 SLOTTED LINEAR ARRAY ANTENNA AT 28 GHZ

Sno	Return Loss in dB			Percentage of size reduced
	Existing Designs		Proposed Design	
1	[9]	-17	-22.9	25.76%
2	[11]	-10.17		55.59%

TABLE XI
SUMMARY OF OUTCOMES ACHIEVED BY PROPOSED SLOTTED ANTENNA

Elements	S11 (dB)	Gain (dB)	Directivity (dB)	VSWR	Bandwidth (MHz)
Single@28.6 GHz	-16.95	8.25	8.39	1.33	550
1x2 @28.3 GHz	-15.7	12.56	12.98	1.39	870
2x2 @ 27.6 GHz	-14.65	18.3	3.29	1.45	NIL
2x2 @ 28.1 GHz, with metallic contact	-22.9	18.3	3.07	1.15	2390

IV. CONCLUSION

Thus, the newly designed slotted rectangular patch antenna is simulated using HFSS, analysed and its performance is evaluated in terms of gain, VSWR, return loss, directivity and bandwidth. The analysis done is based on various substrates, patch length & width, ground plane width & length, Big& small slots in the patch, and U & circle slot in the ground plane. An improved performance meeting the 5G antenna requirements was achieved using 1x2 and 2x2 slotted antenna array.

The 2x2 slotted linear array antenna with metallic contact simulated using RT6010 substrate with reduced compact size with 83.21% of size reduced compared to [12]. Also, achieved a high gain of 18.3 dB at 28.1 GHz with 10dB bandwidth of 1.39 GHz, with bandwidth improvement of 86.6% and 42.3% compared to [2] and [12]. Thus, a compact high gain using 1x2 and 2x2 slotted linear rectangular microstrip patch antenna array operating at 28.3 GHz and 28.1 GHz is successfully designed for 5G mobile applications.

Although the designed slotted patch array antenna obtained high gain ranging from 79.29% improvement to 7.6%, the bandwidth improved didn't result in a wider bandwidth. Future work is recommended to focus on improving wider bandwidth but retaining the compact size and high gain.

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