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CPW-Fed Microstrip Patch Antenna for Millimeter Wave Applications

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Abstract: The antenna elements have been consuming more power and inoperative area with high operational frequency. Therefore, an advanced antenna element design is necessary to cross over the above faults. In this research work, the CPW-Fed microstrip patch antenna is designed using EHF range for millimeter-wave applications. CPW-fed and combinations of DGS-CPW-fed microstrip patch antennas are novel methods, these designs are enhancing many characteristics of microwave circuits, such as narrow bandwidth, cross-polarization, low gain, etc. The researchers are facing many issues in this research area, therefore Fed-CPW design has been taken as a challenging issue. Investigators are working on wideband antennas, as well as patch antennas that can be used for both single- and dual-band applications. In addition to multiband applications, DGS, CPW-Fed Slot antennas are loaded with filters, these enhancements are providing waveguides and amplification tuning. The proposed research deals with a CPW-Fed Microstrip Patch satellite antenna, which is specially modeled to operate at various high-frequency values as well as Extremely High Frequency (EHF) range. A T-Shaped Microstrip patch antenna, which is dimensioned at 11.4x2.5x1.6 mm3 has been placed on Rogers R04003 substrate. The proposed antenna has CPW-Fed with ground dimensions which are considered as 5.9mm*8mm & feed dimensions as 3.8mm*9mm. Due to CPW-feed, the proposed antenna has achieved huge bandwidth i.e 13GHz. Hence the proposed antenna design is compact and suitable at higher frequencies. Simulation results approve that it is a good antenna model. The performance measures like return loss, gain, and VSWR has been improved compared to earlier models. Moreover, this CPW-fed microstrip patch antenna approach is most useful for 5G applications and simulation results are outperforms with designed frameworks. The proposed antenna resonates from 24GHz to 37.6GHz, with good impedance matching at |S11|<=-10dB. The obtained VSWR is in the range of 1 and 2. The gain at resonant frequencies is ranged from 4 to 6 dB. The proposed antenna is useful to deploy in 5G applications as it is resonating in millimeter-wave frequencies. The following model is very useful for 5G applications and provides resonant frequencies 4 to 6 dB. The impedance matching is also improved by 15% compared to earlier models. The following experiment is designed on the HFSS software tool and CPW-Fed functionality is verified.

Keywords: CPW-fed, EHF range, millimeter waves

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1. Introduction

Microstrip Patch (MSP) antennas are low profile, inexpensive to manufacture, mechanically robust, and very versatile. They are Useful for high-performance applications: aircraft, satellite, missiles, cell phones, and electronic devices. A patch antenna with a simple microstrip representation is shown in below figure 1. The main construction of MSP is simple with a patch at the top and ground plane is separated by the substrate part and a microstrip feed is provided. The voltage standing wave ratio of any antenna design is depending on resonance frequency; so typical frequencies are varied from 24GHz to 37.6GHz at CPW-FED. The following design level verifications are performed on the HFSS s software tool.

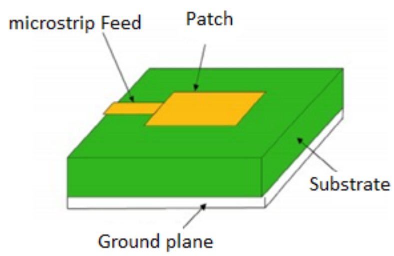

Fig. 1 - Basic microstrip antenna

Millimeter-wave (MMW) applications consist of extremely high frequencies [30-300 GHz] which is useful for a variety of mobile and wireless networks such as 5G applications. EHF (extremely high frequencies) Band allows high data rates up to 10gbps in 5G applications. Therefore, MMW antenna wavelength from 1 mm to 10 mm attains high gain and large bandwidths for particular approaches. All these fundamental requirements like high-gain, unidirectional radiation, and Bandwidth. Recently, MMW has attracted significant attention among academics, which enables systems with high data rate connectivity, mobility, and finer resolution. The antenna design for MMWs is difficult because of its manufacturing and measurement difficulties that arise owing to the antenna's tiny size. For this reason, it is difficult to design an MMW antenna, that to both simple to fabricate and measure. An MMW antenna operating at 13 GHz has been developed, constructed, and tested using a simple coplanar waveguide.

A CPW (coplanar waveguide) antenna is portrayed by its wide data transfer capacity, minimal effort, lightweight, lower size, simplicity of manufacturing, and simplicity of use of Solid-state active devices. On another side, it is identified that planar surface antenna integration avoids hole connections on the substrate. Antenna components that have been appropriate for CPW feed configuration become more critical as the CPW transmission line's usage. As a result, it is recommended for the CPW-fed patch antenna to any narrowband applications. A CPW-fed microstrip PA is represented in figure 2 below. Because of placing the Patch region and ground plane area on the same side of the substrate, the energy will be emanated bi-directionally, which prompts a low antenna to pick up. The main theme of this work is to attain high gain and unidirectional radiation.

VSWR (voltage standing wave ratio) is a combination of reflection coefficients that indicates energy recovered from the antenna, and the radiation pattern is also known as S11 or return loss in this technique. The better antennas are suitable to the transmission systems which are giving power gain to an antenna and less the VSWR. The electrical energy lost in the load is known as return loss. Return loss is usually measured in decibels (dB). At one frequency, a resistance of exactly 50 ohms may be obtained. With a wide-band antenna, the VSWR displays 50 ohms impedance is needed to be improved.

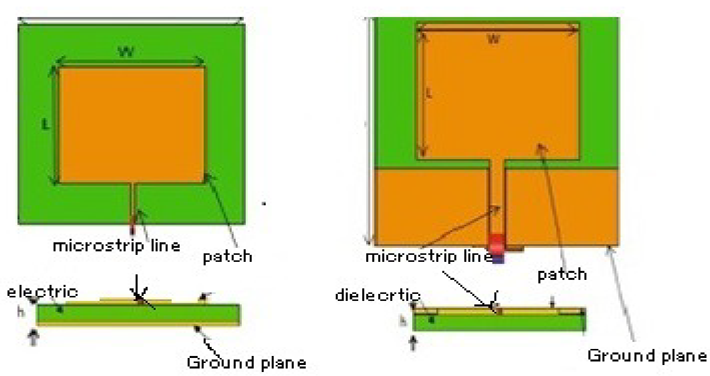

Fig. 2 - Microstrip patch antenna with CPW-feed

The above figure 2 clearly explains about Microstrip Patch Antenna with CPW-feed structures, in this model ground plane, microstrip lines and patches are used to get high radiation patterns. The dielectric is providing compensation between the ground plane and microstrip line

Mohamed Tarbouch et.al discussed different types of feed networks available and their effects in the paper Tarbouch, M et.al (2017). Raj Gaurav Mishra et.al discussed the design of CPW FED antenna but achieved only at 2 to 14GHz of the frequency band in Mishra, R. G et.al (2017). In the monopole antenna model having two L-shaped elements and square-spiral patch in the Beigi, P et.al (2018). The operating frequencies are increased by adopting a square spiral. PIN diodes were incorporated to meet the multiband operation. The CPW feed line is provided at the feed point and DGS is used to attain impedance match in UWB in the paper.

2. Literature Survey

In this section a brief discussion of MMW (millimeter wave) based Patch antenna applications are explained with the latest references. The use of MMW frequency in the 5G communication network is helping to meet the demand for a large volume of traffic and speed. MMW is also being investigated as a possible solution to the problem of data limits. While adopting the MMW spectrum, enhances the effectiveness of 5G communication systems. There are several difficulties in CPW one of the most significant problems is band maximum and transmission loss, which may have been reduced by directing the antennas beams.

S NO	Author	Key point	Limitation or drawback of Technique
1	Tarbouch, M et.al (2017)	A compactable fed orthogonal micro strip antenna design using Hilbert technique for advanced wireless applications.	This antenna design facing area issues in real time applications.
2	Mishra, R. G et.al (2017)	The wideband application based CPW fed antenna design (Micro strip)	For small distance applications this antenna is not suitable.
3	Mishra, R et.al (2016)	A rectangular patch antenna design for ultra-band applications. This design is implemented through line feed mechanism in rectangular patches.	The following antenna design is very complex on real time applications.
4	R. Mishra et.al (2015)	In this work the width of patch antenna and its characteristics are analyzed through comparison of applications in HFSS tool.	This work is limited to real time implementation.
5	Touhami, N. A et.al (2014)	A planar pentagon CPW based fed antenna design for UWB applications.	The following antenna model implementation on HFSS tool and real time design is very complex.
6	Rahman, M., & Imran, M. (2017)	Miniaturized tri-notched based CPW-PA design for UW (ultra-wide) band applications.	The transmission as well as reception of following antenna design getting delay compared to earlier antennas.
7	Ghaderi, M. R., & Mohajeri, F. (2011)	The optimized prearranged arrays are manufactured for outcomes verification, and a comparing between calculated and observed radio results has been performed and determined to be in close analysis.	This work has limitations when using this antenna at high directional condition
8	Rahman, M., & Imran, M. (2017).	The transmitter is then adjusted for tri-notch operations in order to ignore global compatibility for the microwaves accessibility of WiMAX band with 3.3–3.6 GHz and WLAN radio frequencies lesser WLAN (05.152–05.326) and higher Network (05.735–05.845) GHz).	The coplanar monopole antenna design with notch realization for 8 to 8.5 GHz. This fabrication process is very complex compared earlier models.
9	P. Beigi et.al (2018)	In this work a strip based mono pole antenna is implemented using multi band	This antenna cannot support wide band applications

		applications.	
10	Sk.Khader Zelani et.al (2018)	An electromagnetic antenna array, is an insulating substrate, and an alternating magnetic protector with an effective operating frequency make up the reflectors. Then, under the Circular polarization, the tightly spaced AMC reflector is used to increase feasibility, providing bidirectional emission, compact design, and gain amplification.	In this methodology-based antenna design only suitable for critical as well as wide spectrum 5G applications. So, there should be improvement in design to cross over the above limitations

Mathur, R., & Dwari, S. (2018) the ultra-wide band application-based MIMO Fed antenna with CPW technology is implemented, in this work hexagonal monopole ring elements are to be using for better radiation pattern. Moreover, this work is to be improve with latest radiation elements to cross over the above limitations. Dommetti, V. S., & Cheruku, D. R. (2017) briefly explains about A square patch reflector stimulated by a microstrip antenna input is used to build the monoclinic antennas. The designed antenna operates in the Ultra-wideband (UWB) frequency, which spans frequencies of 2.4 to 12.4 GHz. A basic rectangular microstrip reflector is used to improve the separation among the crystal lattice radios in the arrays. Katragadda, S., & Jayasree, P. V. Y. (2021). The optimum value is 4.8 decibels (dB). Packet Correlations are interesting to find the coefficients and benefit communication efficiency. The directional gain of the antenna is decided by a frequency range i.e 143.32%, which fulfills its hyper-range responsiveness. M. M. Honari et. al(2106), suggested PA with a highly efficient of 10.8 dB & supports the data rate ranging 24-30 GHz with a diameter of 6.0 GHz. Similarly, reference antenna and patterns may be directed at various desirable angles as well as frequencies M. Mantash et.al (2017). The model is ideal for 5G telecommunications because of its compactness Mantash, M., & Denidni, T. A. (2017). A brief explanation about the pattern of transmission of electromagnetic radiation may be altered when they reach a material going to have a negative reflectivity. As a result, frame may be achieved by combining the DRA with the suggested NRIM arrays Bhaskar, V. S et.al (2018). The beam-tilting antenna can steer the primary beam by 39° in the xz-plane across the 5–5.5 GHz range, according to modelling and experimentally Mirzavand, R et.al (2019). The frequency ranging of 5-5.5GHz, the directional antennas reflectivity is higher than 10 dB. Moreover, the observed and calculated findings are in good accordance Ayyadurai, K., & Muthu, G. M. (2019). A collinear waveform (CW)-fed mm microstrip antenna with a directional beam width is developed in this article Kakhki, M. B et.al (2018). The beamforming feature is accomplished by including a correct elliptical slot and a proper radiated component of altered Gielis curved into the circular polarized construction (MGCs) Goudarzi, A et.al (2020). Using above explains it is identified that CPW-Fed Microstrip Patch Antenna for MMW Applications Agarwal, S., & Singh, D. (2018).

3. CPW-Fed Microstrip Patch Methodology

High gain and directivity will be the basic challenge for the wide-band applications Xu, H et.al (2018). The CPW antenna is proposed to achieve the requirement. It is imprinted on the substrate i.e. Rogers RO 4003C with the permittivity value of ($\mathcal{E}r$= 03.38) & also a loss tangent of 00.0027. The input impedance is coordinated to a 50Ω transmission line, and it is operating from 24GHz to 37.6 GHz. Figure 3 shows the proposed antenna design and their parameters are indicated in table 1. The proposed antenna formed by a T- Shaped patch is defined with the following dimensions as Ground plane of 5.9mm*8mm, Substrate of Rogers RO4003 (1.6mm), Patch of 11.4mm*2.5mm, feed of 3.8mm*9mm & Feedline, ground spacing of 0.2mm, and then the CPW fed is provided to the suggested design of antenna to achieve high gain and large bandwidth Alibakhshikenari, M et.al (2019). The special design like the patch & ground plane is placed on the same plane or side of the substrate instead of either side, the proposed method is called as Co-Planar Waveguide fed (CPW-Fed) Hussain, M et.al (2021). As the chosen patch size and shape is simple, the design complexity is also less for the proposed antenna Zaidi, A et.al (2019). Finally proposed antenna is designed using HFSS software, then simulated to verify output parameters like return loss, VSWR, gain, axial ratio, 2-D radiation pattern, and current distribution Malathi, S., et.al (2020). Justified results are obtained and are discussed as detail in the following content Goudarzi, A et.al (2020).

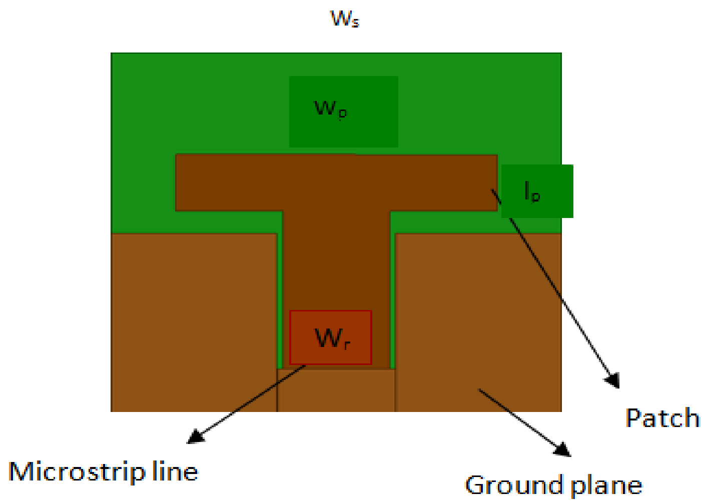

Fig. 3 - Proposed CPW-Fed MPA

The above figure 3 clearly explains about designed CPW MPA fed antenna model in this Wp, Wr is representing the width of the antenna as well as Lp demonstrate the patch size of antenna by using HFSS tool decreasing the antenna measurement and attaining better performance Majumdar, A et.al (2018). The dimensions like 5.9mm and 8mm of ground width, patch 11.4x2.5mm are fixed for speed and power consumption issues Wang, C. T et.al (2018)

Table 1 - Dimensions of proposed system design parameters

PARAMETER	DIMENSIONS
Ground	5.9mm*8mm
Substrate	Rogers RO4003(1.6mm)
Patch	11.4mm*2.5mm
Feed	3.8mm*9mm
Feed line and ground spacing	0.2mm

Table 1show the proposed system's antenna extents, through this parameter have been improved to get high gain and bandwidth, it is recognized that comprehending the proposed antenna design is more enhanced in feed line and substrate Anooz, R. S. A et.al (2021).

4. CPW-Fed MPA Simulation

The proposed CPW-Fed MPA Output parameters are analyzed using the graphical representation of the obtained results.

4.1 Return Loss

The designed antenna obtained return loss is plotted as S11 Vs frequency, to identify the impedance matching. It is resonating at 7 different frequencies with |S11| <-10dB. This plot clearly explanations about dB setup vs frequency variations, in this fed MPA design can improve the functionality and give more efficient operations.

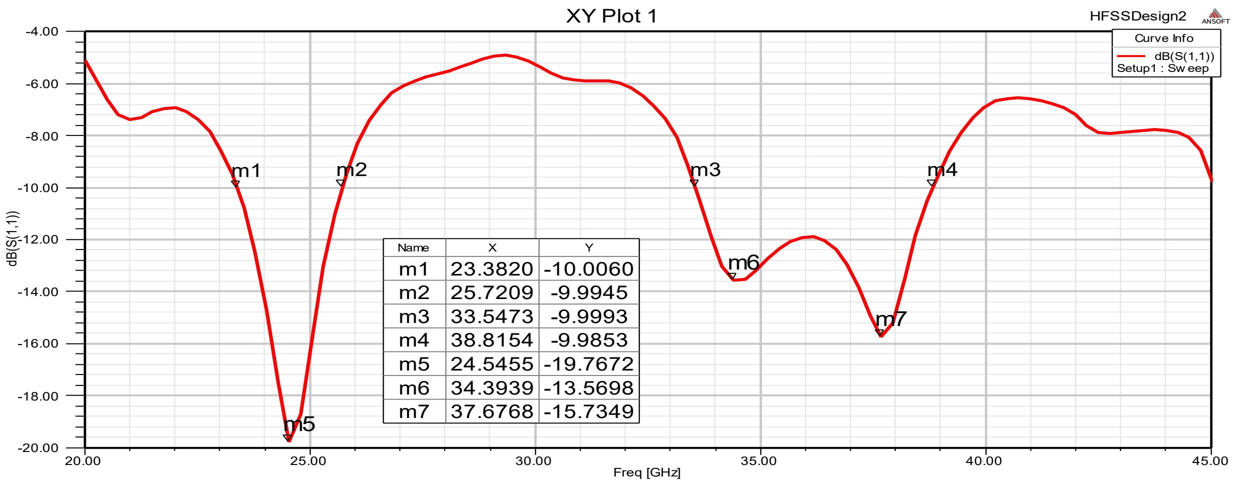

Fig. 4 - Return loss for proposed CPW-Fed MPA

The resonating frequencies (in GHz) are 23.38, 25.7, 33.5, 38.8, 24.5, 34.3, 37.67 as observed in the figure 4. The ideal range of VSWR is ~ 27 dB, suppose to observe clear picture of above figure the attained calculations are near to ideal so conclude that satisfying the VSWR.

4.2 VSWR

The ideal range of VSWR should be 1<VSWR<2.Through the identification the RF (resonating frequencies) of CPW-Fed MPA got the VSWR values with great judgment and shown in figure.5.

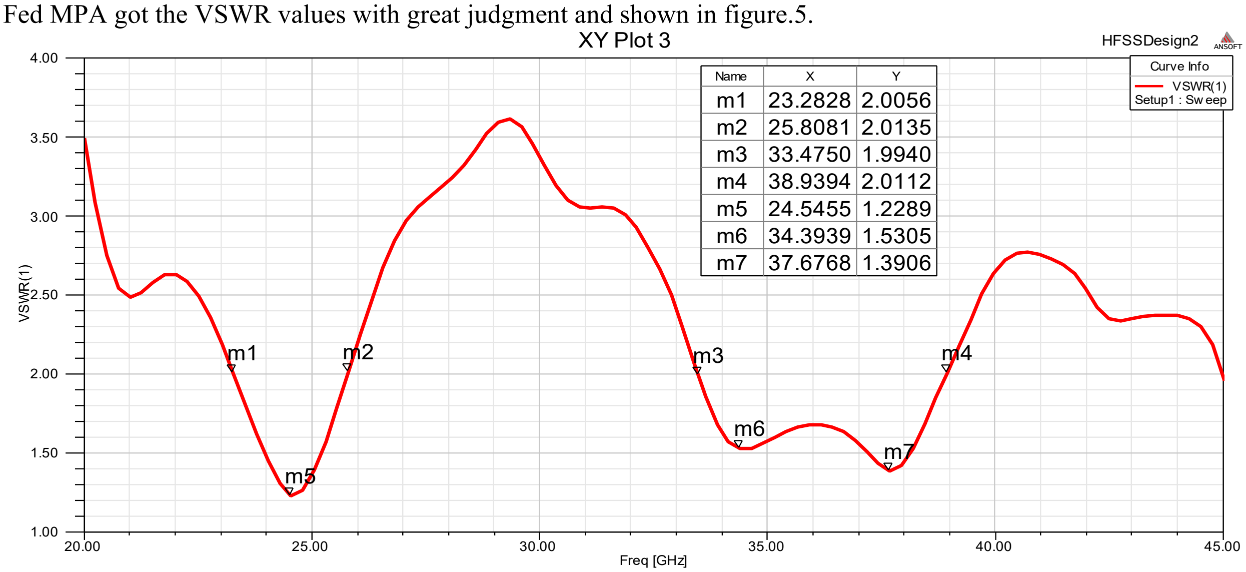

Fig. 5 - VSWR for proposed CPW-Fed MPA

The observations made that the designed approach has infidel values at 23.38GHz, 25.7 GHz, 33.5 GHz, and 38.8 GHz. They have been discarded and the 24.5 GHz, 34.3 GHz, 37.67 GHz are considered as operating frequencies with the justified values of return loss and VSWR

4.3 Gain

The obtained gain at resonating frequencies is presented to observe the max directivity of the proposed antenna at each operating frequency. The gain obtained at the 24.54GHz is 4.85dB as shown in the figure 6. The gain obtained at the 34.39 GHz is 06.64dB are represented in figure 7. The gain obtained at the 37.67 GHz is 9.23dB as presenting in the fig 8. The return loss and VSWR parameters are major elements to get information from Theta and ph1 axis. The radiation pattern is more effective to this frequency like 24.5GHz and 34.39 GHz.

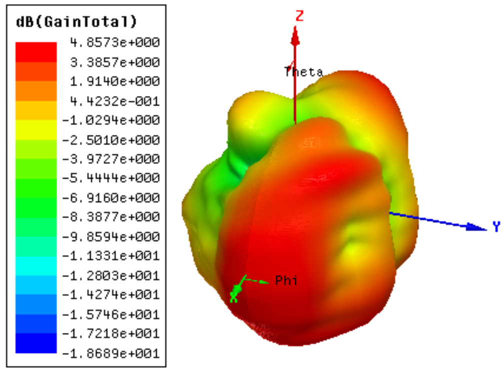

Fig. 6 - Gain for the proposed antenna at 24.54GHz

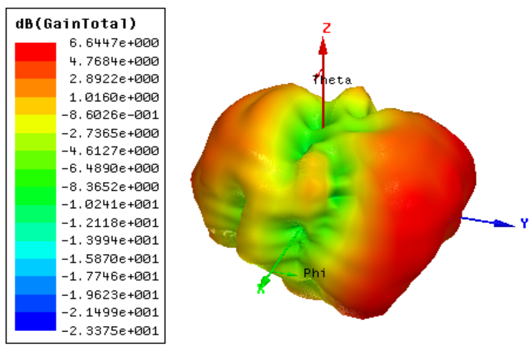

Fig. 7- Gain for the proposed antenna at 34.39 GHz

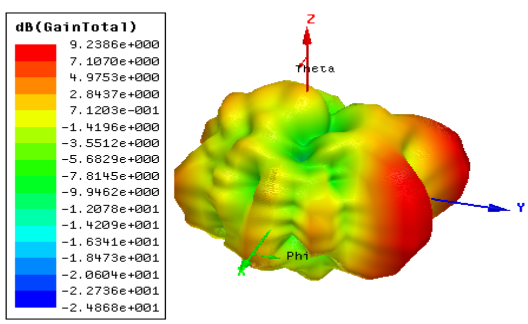

Fig. 8 - Gain for the proposed antenna at 37.67 GHz

The above figure 8 is clearly explains about gain analysis on antenna element, in this designed Fed antenna with RF pattern is giving better performance in radiation.

4.4 Pattern of Radiation

The Pattern of Radiation is a graphical representation of the radiation and energy patterns of an antenna. This pattern of radiation provides the angular dependency of the max directive radio waves. The 2-D patterns of radiation which is obtained at RF are represented by figures 9,10,11 respectively.

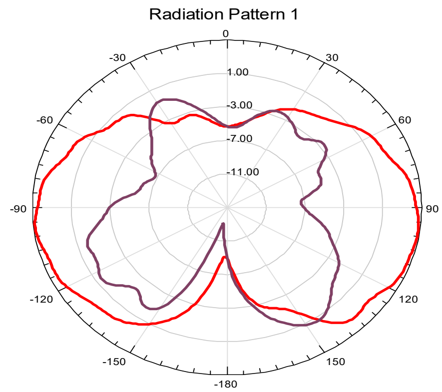

Fig. 9 - 2-D radiation pattern for the proposed antenna at 24.54GHz

The above figure 9 clearly explains about 2-D radiation pattern mechanism in pi-plot, in this implemented model i.e CPW fed microstrip patch antenna can suitable for 5G applications. The main lobe is very powerful which is highlighted in red color line, the proposed model is suitable for WLAN (wireless LAN network). The wide range of patch slots are there in CPW fed microstrip design.

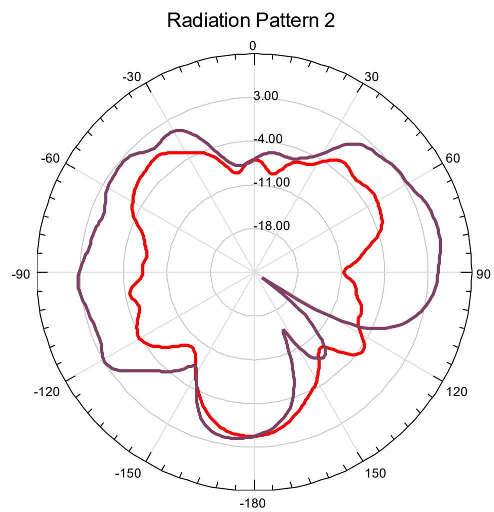

Fig. 10 - 2-D RP for the proposed system at 34.39GHz

The above figure 10 is clearly explains about 2-D RP analysis in this microstrip patches are attracting many features like light weight and small size. The fabrication is simpler as well as providing interest elements like light weight, small size and high radiation pattern. The Centre tapped antennas design is more flexible for side plane conducting radio energy.

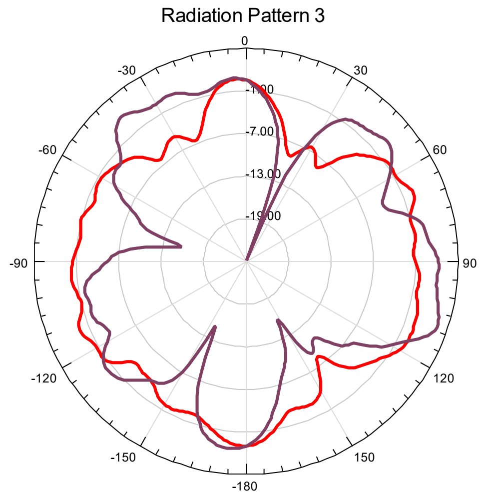

Fig. 11 - 2-D RP for the proposed antenna at 37. 67GHz

The figure 11 is clearly explains about 2-D RP model for proposed antenna on HFSS model, in this 37.67GHz frequency is maintained by microstrip patch antenna with fed.

4.5 Axial Ratio

The Axial Ratio is depending on the major axis and minor axis ratio in a circularly polarized antenna. The Axial Ratio (AR) of an antenna is representing that whether the proposed antenna is polarized circularly or not. The AR of the circularly polarized antenna is 1 (0 dB) and the others would be greater than 1 (>0 dB). The proposed PA axial ratio at operating frequencies is presented in fig 12, 13, 14 respectively. The proposed antenna system is circularly polarized.

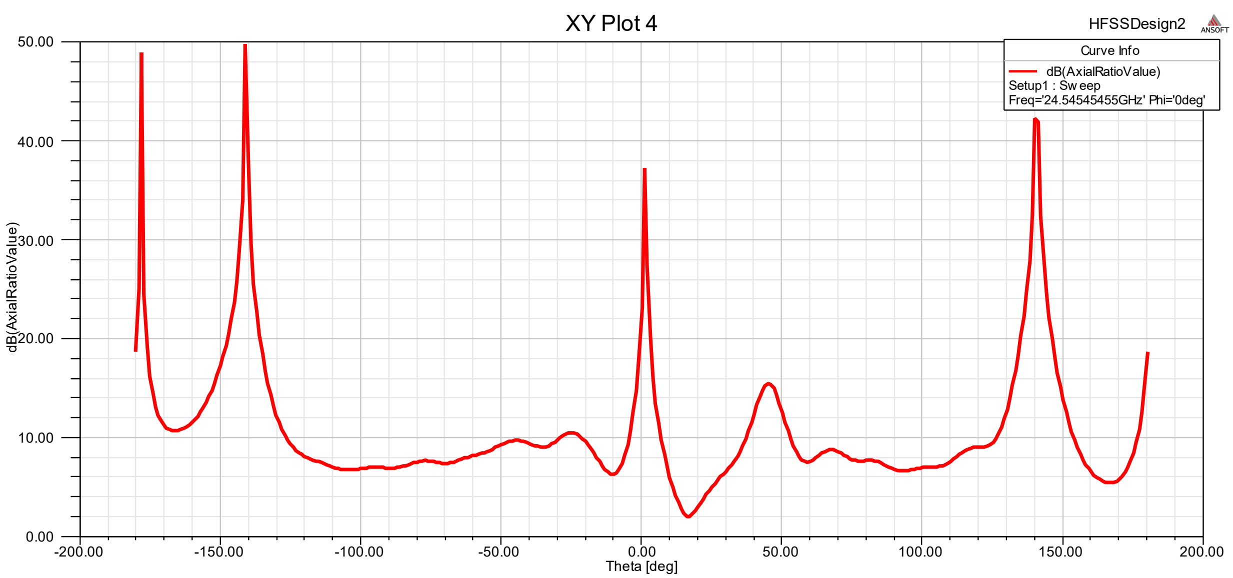

Fig. 12 - The Axial Ratio (AR) for the proposed antenna at 24.54GHz

The bandwidth and impendence metrics are giving peak gain CPW antenna based on two square ring slits. The middle of square slots is used to give CPW fed radiation, center frequency as well as circularly polarized elements are providing more improved radiation pattern shown in figure 12

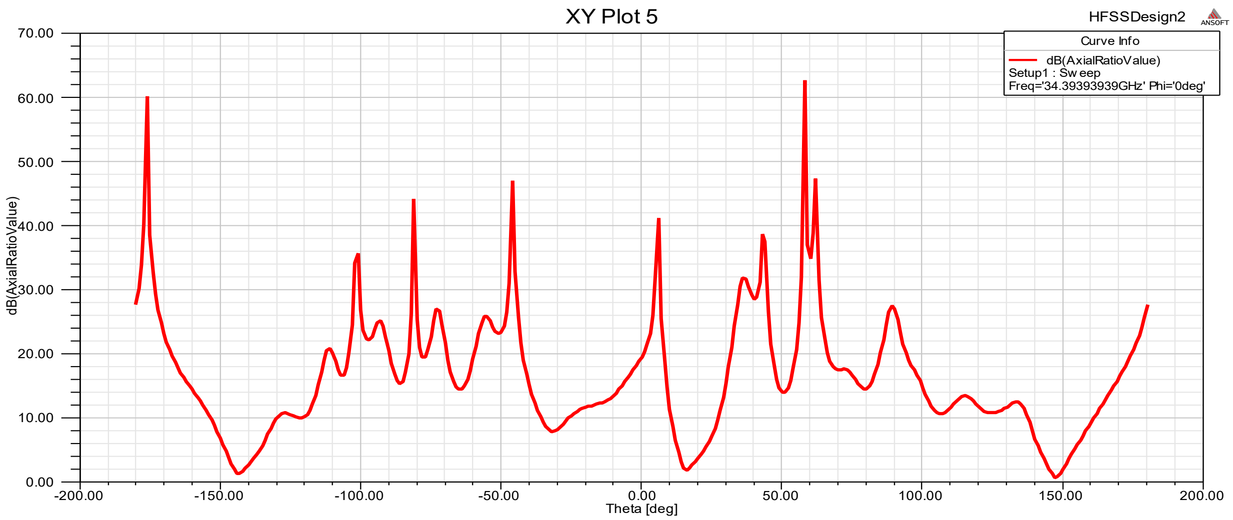

Fig. 13 - The AR (Axial Ratio) for the proposed antenna at 34.39 GHz

The Axial ratio is parameter which is used to get frequency response from deigned FED CPW antenna. In this at 34.39 GHz is Centre frequency it is balancing VSWR with high gain ratio.

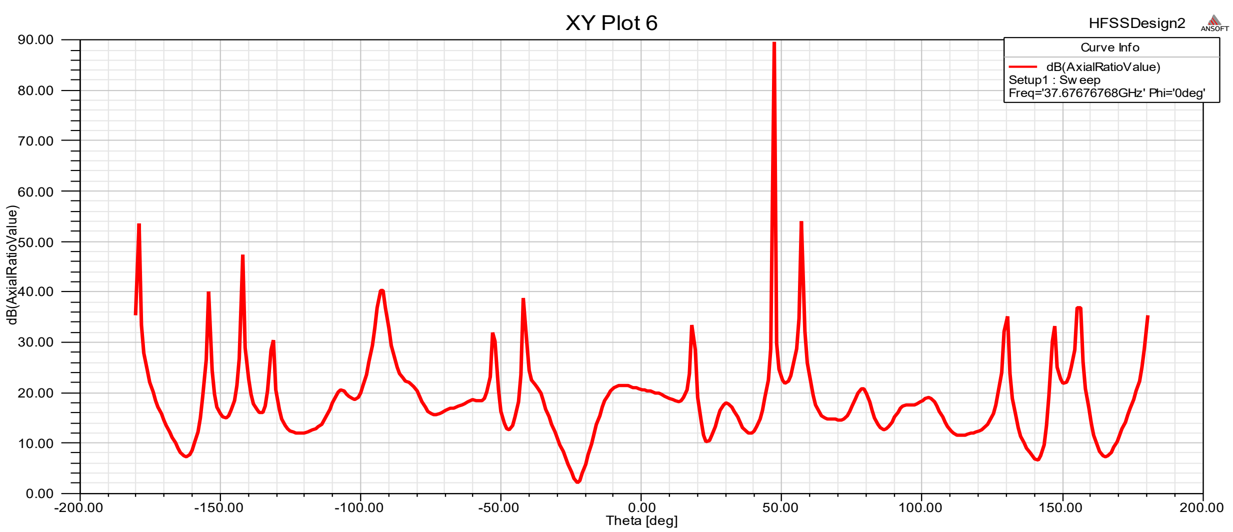

Fig. 14 - The Axial Ratio (AR) for the proposed antenna at 37. 67GHz

Figure 14 is clearly explaining about Axial Ratio of proposed design at 37.67 GHz, in this theta and dB level analysis performed.

4.6 Distributions of Current

The current distribution mainly depends on fed points and load impedance, these are usually adjusted with dipoles lengths like 0.1, 0.2, and 0.3. The distribution of surface current of the proposed system antenna at operating frequencies is presented in fig 15,16,17.

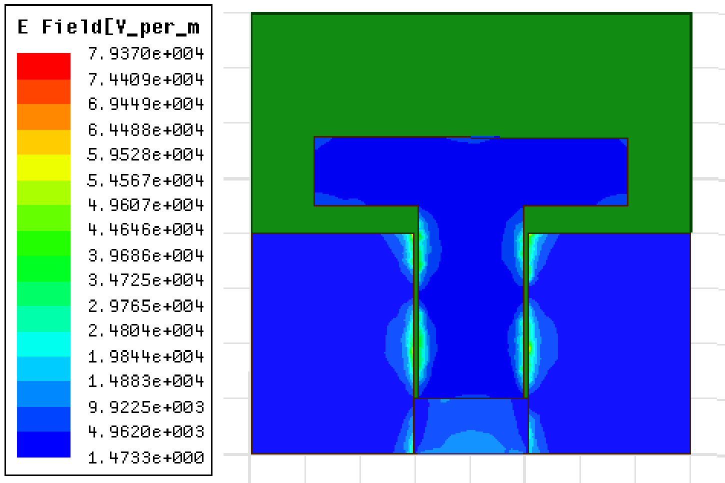

Fig. 15 - The distribution of surface current for the CPW-Fed MPA at 24.54GHz

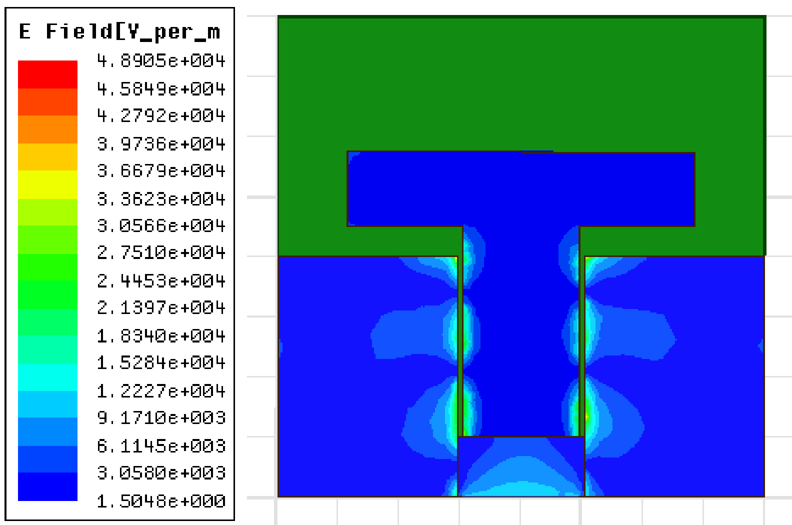

Fig. 16 - The distribution of surface current for the CPW-Fed MPA at 34.39GHz

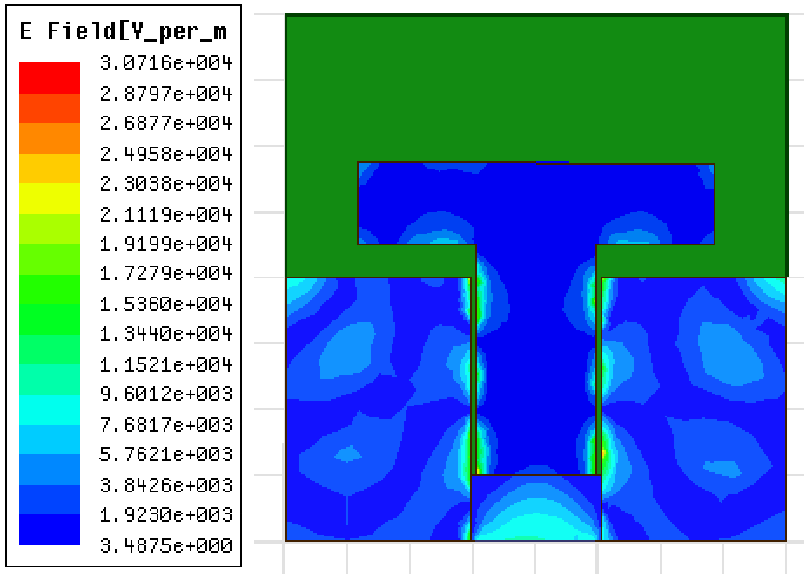

Fig. 17 - The distribution of surface current for the CPW-Fed MPA at 37.67GHz

5. Results Discussion

The proposed CPW fed antenna output parameters are shown in below table 2. This work is clearly noticed that the designed antenna is resonating from 24.5 GHz to 37.6GHz and achieving a bandwidth of 13GHz at millimeter-wave frequencies. Despite altering the antennas beam steering, two slots were utilized to enhance emitter terminal matching. The slot size, as well as their angle (θ) relative to the Z-axis, must be modified accordingly. This adjustment is intended to do it in the HFSS tool. The width of Fed CPW antenna slots is trained with Wp3, these are VSWR< 1 BW of antenna. The UWB bands are reducing the middle frequencies from 3 to 6 mm. so the Wp3 is raised to 13.34GHz to cover all UWB ranges. The suggested antennas are suitable for mm band systems and 5G communications infrastructure that need a directional beam with good antenna arrays. The proposed design is implemented on HFSS 15.0.3 version, which is best in performance compared to earlier versions.

Table 2 - The proposed CPW-Fed MPA output parameters

S. No	RF (GHz)	RL (Return Loss) (dB)	VSWR	Gain (dB)
1	24.54	-19.7	1.2	4.8
2	34.39	-13.56	1.5	6.64
3	37.67	-15.73	1.3	4.9

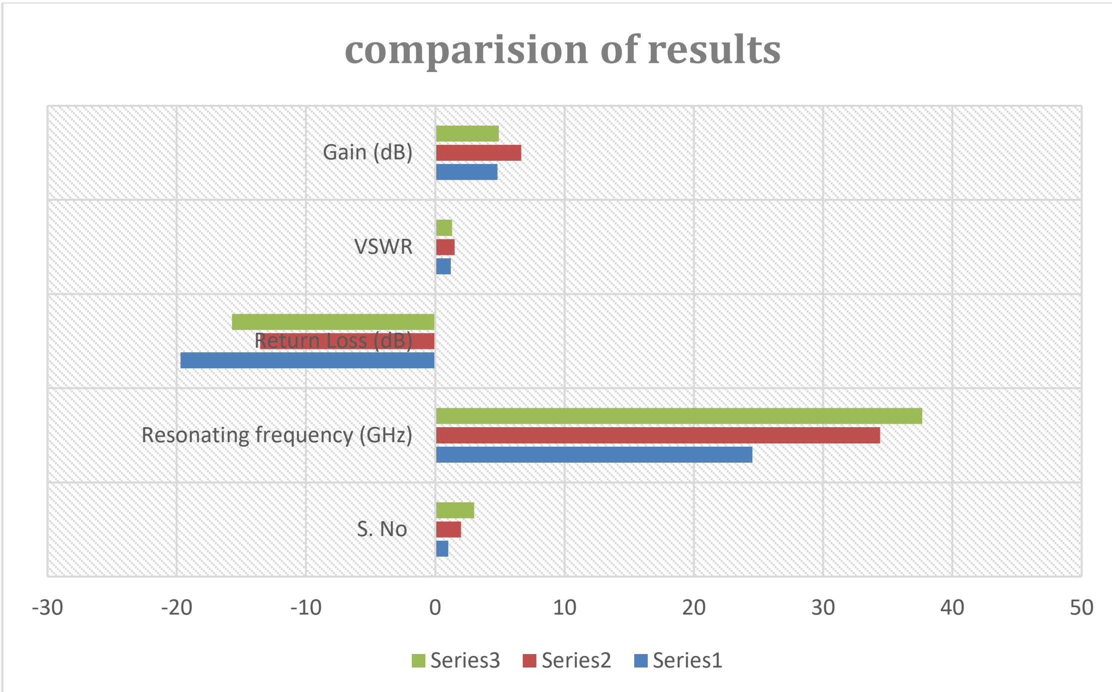

Fig. 18 - Output parameters of the proposed antenna

Table 2 and fig 18 briefly explain about performance measures of a designed antenna with different frequency ranges. The resonating frequencies of 24.54 GHz, 34.39 GHz, and 37.67 GHz are providing return loss dB from -19.7 to -15.73 and the corresponding VSWR is 1.2 to 1.3 had been getting. The performance measures estimation is a very important antenna analysis, in this, the above return loss and gain parameters are attained from the HFSS tool. The axis for this graph is frequency range and the y-axis is representing that dB.

6. Conclusion

A CPW-fed (coplanar waveguide) MMW-fed antenna through a directional array is developed for multipurpose applications. The outstanding research work is going on antennas CPW-fed by coplanar waveguides (CPWs). When compared to a microstrip line, the coplanar waveguide provides benefits such as reduced radiation loss, less dispersion, a uniplanar design, and the ability to attach shunt-lumped components or active devices without a through-hole. To the proposed antenna a suitable elliptical slot and a proper radiated component of altered MSP curve are used to produce the beam guiding characteristics. To enhance the antenna design, a complete input impedance is improved through Fed elements. A CPW fed antenna is proposed and efforts are made to achieve high bandwidth at the EHF range. To realize this CPW-fed is used to MSP antenna, and resonating from 24.5 GHz to 37.6GHz i.e 13GHz of wide bandwidth is obtained. The designed antenna is suitable for future 5G applications at millimeter waves.

References

[1] Tarbouch, M., Terchoune, H., & Barrou, O. (2017, October). Compact CPW-Fed Microstrip Octagonal Patch Antenna with Hilbert Fractal Slots for WLAN and WIMAX Applications. In Proceedings of the Mediterranean Symposium on Smart City Applications (pp. 432-444). Springer, Cham.

[2] Mishra, R. G., Mishra, R., Kuchhal, P., & Kumari, N. P. (2017, November). Design and analysis of CPW-Fed microstrip patch antennas for wide band applications. In 2017 International Conference on Inventive Computing and Informatics (ICICI) (pp. 651-654). IEEE.

[3] Mishra, R., Jayasinghe, J., Mishra, R. G., & Kuchhal, P. (2016). Design and performance analysis of a rectangular microstrip line feed ultra-wide band antenna. International Journal of Signal Processing, Image Processing and Pattern Recognition, 9(6), 419-426.

[4] Mishra, R., Kuchhal, P., & Kumar, A. (2015). Effect of Height of the Substrate and Width of the Patch on the Performance Characteristics of Microstrip Antenna. International Journal of Electrical and Computer Engineering, 5(6).
[5] Touhami, N. A., Yahyaoui, Y., Zakriti, A., Bargach, K., Boussouis, M., Lamsalli, M., & Tribak, A. (2014). A compact CPW-fed planar pentagon antenna for UWB applications. Progress In Electromagnetics Research C, 46, 153-161.
[6] Rahman, M., & Imran, M. (2017). CPW Fed Miniaturized Tri-Notched Ultra-Wideband Antenna. Advanced Engineering Technology and Application, 6(1), 1-10.
[7] Ghaderi, M. R., & Mohajeri, F. (2011). A compact hexagonal wide-slot antenna with microstrip-fed monopole for UWB application. IEEE antennas and wireless propagation letters, 10, 682-685.
[8] Rahman, M., & Imran, M. (2017). CPW Fed Miniaturized Tri-Notched Ultra-Wideband Antenna. Advanced Engineering Technology and Application, 6(1), 1-10.
[9] Beigi, P., Nourinia, J., & Zehforoosh, Y. (2018). Compact CPW-fed spiral-patch monopole antenna with tuneable frequency for multiband applications. Journal of Instrumentation, 13(04), P04014.
[10] Zelani, S. K., Siddaiah, P., & Prasad, K. S. (2018) A Novel AMC Loaded CPW Fed Wide Band Antenna for 5G Applications. Volume 7, Special Issue (Internet of Things),Oct. 2018, PP. 235-245
[11] Mathur, R., & Dwari, S. (2018). Compact CPW-Fed ultrawideband MIMO antenna using hexagonal ring monopole antenna elements. AEU-International Journal of Electronics and Communications, 93, 1-6.
[12] Dommetti, V. S., & Cheruku, D. R. (2017). Review and Analysis of Contemporary Polymer Coats based Electromagnetic Shielding Strategies. Indian Journal of Science and Technology, 10(18).
[13] Katragadda, S., & Jayasree, P. V. Y. (2021). MIMO antenna miniaturization standards for future 5G. International Journal of Intelligent Unmanned Systems, Vol. 10 No. 1, pp. 159-167.
[14] Honari, M. M., Mirzavand, R., Melzer, J., & Mousavi, P. (2016). A new aperture antenna using substrate integrated waveguide corrugated structures for 5G applications. IEEE Antennas and Wireless Propagation Letters, 16, 254-257.
[15] Mantash, M., & Denidni, T. A. (2017, October). Millimeter-wave beam-steering antenna array for 5G applications. In 2017 IEEE 28th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC) (pp. 1-3). IEEE.
[16] Bhaskar, V. S., Tan, E. L., & Holden, L. K. H. (2018). Design of wideband bowtie slot antenna using sectorially modified gielis curves. IEEE Antennas and Wireless Propagation Letters, 17(12), 2237-2240.
[17] Mirzavand, R., Honari, M. M., Aslanzadeh, S., Saghlatoon, H., & Mousavi, P. (2019). Evaluation of one-staged 3-D printed frequency selective surface using carbon-fiber-reinforced thermoplastic composite. IEEE Transactions on Components, Packaging and Manufacturing Technology, 9(11), 2298-2304.
[18] Ayyadurai, K., & Muthu, G. M. (2019). Dual-band beam tilting antenna with low profile negative refractive index metamaterial. IET Microwaves, Antennas & Propagation, 13(4), 466-471.
[19] Kakhki, M. B., Mantash, M., Kesavan, A., Tahseen, M. M., & Denidni, T. A. (2018). Millimeter-wave beam-tilting Vivaldi antenna with gain enhancement using multilayer FSS. IEEE Antennas and Wireless Propagation Letters, 17(12), 2279-2283.
[20] Goudarzi, A., Gharaati, A., Honari, M. M., Mirzavand, R., & Mousavi, P. (2020, July). A Steerable Beam Patch Antenna for Millimeter-Wave Band Application. In 2020 IEEE International Symposium on Antennas and Propagation and North American Radio Science Meeting (pp. 591-592). IEEE.
[21] Agarwal, S., & Singh, D. (2018). CPW-fed concurrent, dual band planar antenna for millimeter wave applications. International Journal of Microwave and Wireless Technologies, 10(9), 1088-1095.
[22] Xu, H., Zhou, J., Zhou, K., Wu, Q., Yu, Z., & Hong, W. (2018). Planar wideband circularly polarized cavity-backed stacked patch antenna array for millimeter-wave applications. IEEE Transactions on Antennas and Propagation, 66(10), 5170-5179.
[23] Alibakhshikenari, M., Virdee, B. S., See, C. H., Abd-Alhameed, R. A., Falcone, F., & Limiti, E. (2019). Super-wide impedance bandwidth planar antenna for microwave and millimeter-wave applications. Sensors, 19(10), 2306.
[24] Hussain, M., Awan, I. A., Rizvi, S. M., Alibakhshikenari, M., Falcone, F., & Limiti, E. (2021, August). Simple Geometry Multi-Bands Antenna for Millimeter-Wave Applications at 28 GHz, 38 GHz, and 55 GHz Allocated To 5G Systems. In 2021 46th International Conference on Infrared, Millimeter and Terahertz Waves (IRMMW-THz) (pp. 1-2). IEEE.
[25] Zaidi, A., Baghdad, A., Awan, W. A., Ballouk, A., & Badri, A. (2019, April). CPW fed wide to dual band frequency reconfigurable antenna for 5G applications. In 2019 International Conference on Wireless Technologies, Embedded and Intelligent Systems (WITS) (pp. 1-3). IEEE.
[26] Malathi, S., Kethavathu, S. N., & Aruna, S. (2020). V Band Frequency Reconfigurable Antenna for Millimeter Wave Applications. Telecommunications and Radio Engineering, 79(15).

[27] Goudarzi, A., Gharaati, A., Honari, M. M., Mirzavand, R., & Mousavi, P. (2020, July). A Steerable Beam Patch Antenna for Millimeter-Wave Band Application. In 2020 IEEE International Symposium on Antennas and Propagation and North American Radio Science Meeting (pp. 591-592). IEEE.
[28] Majumdar, A., Ghosal, A., Singha, S., & Roy, S. K. (2018, March). A CPW fed antenna for millimetre wave applications. In 2018 Emerging Trends in Electronic Devices and Computational Techniques (EDCT) (pp. 1-3). IEEE.
[29] Wang, C. T., Tang, T. C., Lin, C. W., Hsu, C. W., Hsieh, J. S., Tsai, C. H., ... & Yu, D. (2018, May). InFO_AiP technology for high performance and compact 5G millimeter wave system integration. In 2018 IEEE 68th Electronic Components and Technology Conference (ECTC) (pp. 202-207). IEEE.
[30] Anooz, R. S. A., Hatem, G. M., Hasnawi, I. H. Y., & Nemah, M. N. (2021, February). Design Apollonian Gasket Antenna for Millimeter-Wave Applications. In IOP Conference Series: Materials Science and Engineering (Vol. 1094, No. 1, p. 012038). IOP Publishing.