CB-CPW Fed Elliptical Patch-Slotted Antenna For 5G Applications

Anagha. P.
M. Tech Student, Dept. of ECE
College of Engineering Trivandrum
Thiruvananthapuram, India
anaghapalakurumbil@gmail.com

Dr. Haris P. A.
Prof, Dept. of ECE
College of Engineering Trivandrum
Thiruvananthapuram, India
harisabdul.k@cet.ac.in

Abstract—
A conductor-backed coplanar waveguide(CB-CPW) fed elliptical patch-slotted antenna for 5G applications is presented in this paper. The defected ground structure proposed in the design with an area of $16.5mm \times 5mm$ makes the antenna more efficient. Also, an improved impedance matching is achieved by directly coupling the CPW feed line to the patch. CPW, semi-circular background, dielectric, and transmission line are the different layers of the antenna, and FR-4 epoxy with ϵ_r= 4.4 and loss tangent= 0.02 is used as dielectric. The size of the designed CPW-fed antenna is only $40\times40\times1mm^3$. A bandwidth of 3GHz (4.5GHz-7.5GHz), which covers the 5G band, and a maximum gain of 4.46dB was obtained.

Index Terms—**CPW, DGS, return loss, gain.**

DOI Number: 10.48047/nq.2023.21.6.nq23208 NeuroQuantology2023;21(6):2083-2089

I. INTRODUCTION

5G is the fifth generation of wireless network technology, with special features including the fastest data transfer speed, low latency, and improved capacity compared to 4G[10]. Different types of new antennas are required for supporting the 5G network. The operating ranges of 5G are from 3 to 100 GHz, which covers higher frequencies than in previous generations.

The size of the antenna is one of the concerns discussed in 5G antennas. Using microstrip antennas is one of the solutions, due to their thin structure. But, it offers only lower gain, narrow bandwidth, and lower power handling capability[11]. So reducing the size of the antenna is a challenging task without sacrificing the performance of antenna. Therefore, CPW fed antennas may be used as another solution.

Coplanar waveguide or CPW is one of the transmission lines that are commonly used in microwave-related circuits. The CPW has a lot of benefits. While maintaining the integrity of the circuit, it can be merged with some other microwave devices to be made smaller. It is possible to achieve wideband effects in the antennas and also in the circuits. The next advantage of the CPW is its transmissibility is having better dispersive feature compared to the microstrip line. Since the CPW can broadcast in both odd and even modes, the antenna design is quite adaptable. To this end, CPW designs have attracted a lot of study attention. Here, in this proposed antenna conductor-backed coplanar waveguide is used.

Introducing a slot or a DGS structure to the ground is one of the methods to improve the antenna performance. It is mainly used in microwave engineering as a planar structure in order to regulate and influence the electromagnetic wave's propagation on electronics boards and the planar transmission lines. In a DGS, the ground plane just below the transmission line is etched with a periodic pattern of slots or discontinuities. The frequency response of the transmission line can be altered by using this pattern to produce stop bands or an impedance discontinuity that is frequency-dependent. Filters, antennas, and couplers are just a few examples of the different microwave parts that can benefit due to the introduction of DGS structures. They can be also utilized to make microwave circuits smaller and are able to integrate with other electronic parts. A review of defected ground structure is discussed in [24]. They have discussed about various features like size miniaturization, manipulation of the band, reduction of the mutual coupling, and cross-polarization suppression and also the DGS structures are classified based on the applications. Different designs with defected ground structures are studied and reviewed.

A rectangular-shaped DGS structure or slot in the ground was introduced in this paper. A slot is a non-radiating opening in an antenna that can greatly affect the antenna's performance. The radiated fields can be changed, and antenna properties like impedance matching, radiation characteristics, and bandwidth can all be enhanced by adding slots to the structure. Slots in antennas are important for a number of reasons, including bandwidth enhancement, controlling the radiation pattern, and reducing the cross-polarization. Different papers of the antenna with slots were referred. A stair-shaped slotted antenna with CPW fed was introduced in [1]. Here, circular polarisation was achieved when a longitudinal slot etched in stair shaped slot. The bandwidth obtained was about 2.7 GHz (1.8-4.5 GHz). And the size was $62{\times}62{\times}3mm^3$. In [2], a regular hexagonal wide slot antenna was presented. It offers an impedance bandwidth of 86% and an AR bandwidth of 50% by adding an L-shaped monopole patch into the slot and including two grounded strips that are shaped like an inverted L around two of the slot's opposite sides along with a rectangular cut close to the strip. The size was $63 \times 75 \times 1.6mm^3$ and a bandwidth of 1.8-3.8 GHz was achieved. In [8], a meandered slotted antenna was presented. Usually, for excitation, the feed strip is used. Here, impedance matching is accomplished with a feed strip of trident shape. To achieve a compact dimension a meandering slot is employed and the size was about $30{\times}20{\times}1.6mm^3$. A bandwidth of 2.33-3.56 GHz was achieved. A square-slotted antenna is presented in [9], and a reduced size of $60 \times 60 \times 0.8mm^3$ was achieved. Here, 2inverted L-shaped strips are used for exciting a circular polarization. The key factor in extending the impedance bandwidth is the improved feed arrangement. In [19], a patch antenna with a CPW feed for 5G applications was presented. The meta-surface employed increases the gain and the bandwidth and a $40 \times 40 \times 1.6mm^3$ sized CPW fed patch antenna was fabricated. A CPW-fed monopole antenna using DGS was presented in [12]. To increase the impedance bandwidth and produce elliptical polarisation over a wide bandwidth, a hook-shaped slot is merged with an inverted C-shaped radiator fed by an asymmetric CPW feed. A monopole antenna with horizontal and vertical sections is introduced in [7], and the I-shaped stub attached to this antenna makes the upper band and the phase difference between the currents form the lower band. In [17], asymmetrical bevel slots were added to the ground plane in order to produce wideband characteristics and circular polarisation. The ground is covered with several slot forms before the proposed antenna is decided to have a broad bandwidth between 6.50 and 14.10 GHz. In [5], it describes the gain and bandwidth increase of a coplanar waveguide (CPW) fed monopole antenna employing a defective ground structure (DGS) with a hexagonal ring shape for a frequency range of 0.1GHz–20GHz. Using HFSS, a comparison of the antenna with and without DGS is performed. Different CPWfed antennas for 5G applications are presented in [13]-[16], [18], and [20]. More antennas are essential to the development of 5G technology. Higher frequencies are used by 5G networks than by 4G networks. Faster data transmission is made possible by these higher frequencies, but more antennas must be set up. The data is sent and received between devices and the network through antennas.

In [21], a CPW-fed antenna with a metamaterial structure is given to increase the efficiency of spectrum use. A dualband, which has resonant frequencies at 2.4 GHz and 5.5 GHz is achieved. By adjusting the feeder line and split ring resonator(SRR) parameters, the required bandwidth is obtained. The proposed antenna in this paper has a reduced size and enhanced bandwidth. A CPW-fed MIMO antenna with ultra-wideband is proposed in [22]. The antenna is compact and designed for wireless communication networks. Four radiating elements having jug-shape make the antenna ultra-wideband. The modified defected ground structure and tapered feed in the antenna improved the performance[23]. A super wideband antenna is proposed by using three elliptical patches and a circular slot in the middle of the patch. The bandwidth achieved is significantly high(1.91-43.5 GHz). In [25], a conductor-backed CPW-fed antenna is presented with a size of $30 \times 30 \times 0.9mm^3$. A patch antenna in a circular shape with defected ground structure widens the bandwidth. Fractal slots are added to the corners of the ground and a comparison of antenna with and without the DGS is done.

First section is the introduction, the second section covers the analysis and design of the antenna, the third section is the results and discussion and the last section is the conclusion.

II. ANALYSIS AND DESIGN OF ANTENNA

A. ANTENNA ANALYSIS

Fig. 1 represents the structure of the coplanar waveguide and the conductor-backed coplanar waveguide.

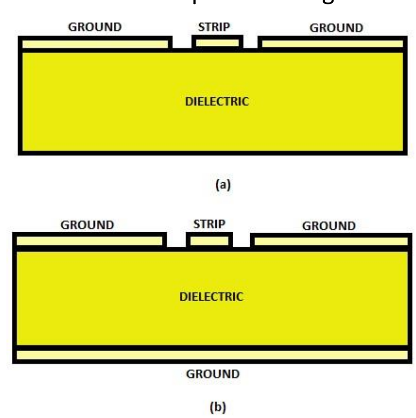

Fig. 1. (a) CPW and (b) CB-CPW.

The additional ground structure on the back side of the dielectric makes conductor-backed coplanar ground(CB-CPW) different from the traditional coplanar ground(CPW). Signals are transferred over the circuit board using a transmission line called conductor-backed coplanar waveguide(CB-CPW). It is made up of, a ground plane on one side of the circuit board and a length of metal(the conductor) on the other side. The metal strip, which is often wider than the signal trace in a conventional microstrip transmission line, carries the signal as it moves along it. Since the broader trace can carry more current, CB-CPW is an excellent option for applications where greater power levels are required. The input impedance on the other side of a board give the signals a return path and protect it from outside interference. The distance between the ground plane and the trace has an impact on the transmission line's characteristic impedance, hence it is also significant. The main advantage of the conductor-backed coplanar waveguide is its low loss, which makes it suitable for higher-frequency applications. It provides excellent isolation between adjacent traces or signal paths. They are easy to fabricate, making them an attractive option for many circuit designers. CB-CPW has a wide bandwidth, making it suitable for using in broadband applications. It is a planar structure, which simplifies its integration with other planar components and circuits. It also reduces radiation loss and also has a good thermal performance due to the presence of the ground plane, which provides a shield against unwanted radiation. Therefore conductor-backed coplanar waveguide, due to their several advantages makes them a great option for the designing of circuit,especially for microwave and mm-waveapplications[6].

The dimensions of the antenna can be calculated by using the following equations.

The width of the patch for a CB-CPW fed antenna is given by,

$$Width(W) = c_0/(2f_0 * \text{sqrt}\ (\varepsilon r+1/2))$$

The length of the patch for a CB-CPW fed antenna is given by,

$$Length(L) = c_0/(2f_0 * \text{sqrt}(\varepsilon r+1/2)) * (2n-1)$$

where, c_0 is the speed of light, f_0 is the operating frequency, and $\varepsilon r$is the relative permittivity.

The characteristic impedance of the CB-CPW fed antenna is given by,

$$Z_0 = 120\pi/\text{sqrt}(\varepsilon r+1/2) * (W/h+1.1)$$

The bandwidth is given by,

$$Bandwidth, B = \frac{f_2 - f_1}{f_0} \times 100\% = \frac{\delta - 1}{Q\sqrt{\delta}} \times 100\%$$

The absolute value of the reflection coefficient is given by,

$$|\Gamma| = \left|\frac{Z_{in} - R_0}{Z_{in} + R_0}\right| = \left[1 + \frac{4}{Q^2 S^2}\right]^{-1/2}$$

And,

$$\frac{\delta + 1}{\delta + 1} = \frac{1}{|\Gamma|} = \left[1 + \frac{4}{Q^2 G^2}\right]^{1/2}$$

And the equation for the gap, G is given by,

$$G = \frac{f}{f_0} - \frac{f_0}{f} = \pm\frac{\delta - 1}{Q\sqrt{\delta}}$$

where Z_0 is the characteristics impedance of the CB-CPW fed antenna, h is the height of the dielectric substrate, f_2 is the upper frequency of the bandwidth, f_1 is the lower frequency of the bandwidth, f_0 is the frequency at resonance, δ is the voltage standing wave ratio, Q is the quality factor, Z_{in} is the input impedance, R_0 is the characteristic impedance of the feed line.

The slots adding to the antenna improves its performance. In order to achieve better impedance matching and for a desired bandwidth, the width of the slot can be designed. The slot's width typically ranges from 0.1 to 0.5 times that of the CPW transmission line. It's crucial to take into account how the slot may affect the CPW transmission line. The slot may have an impact on the CPW transmission line's characteristic impedance and phase velocity, which may therefore have an impact on the performance of the antenna. To reduce these effects and obtain the desired antenna performance, the slot's width and location should be tuned. This can be done by the trial and error method.

B. ANTENNA DESIGN

Here, a CB-CPW fed elliptical patch slotted antenna is designed, with overall dimensions of $40 \times 40 \times 1mm^3$. The first step of designing the proposed structure is the selection of a dielectric substrate. Here FR-4 epoxy with ϵ_r= 4.4 and loss tangent= 0.02 is used. The advantages of using FR-4 epoxy are, it provides high mechanical strength, and high thermal conductivity, and is cost-effective, versatile, and are widely available.

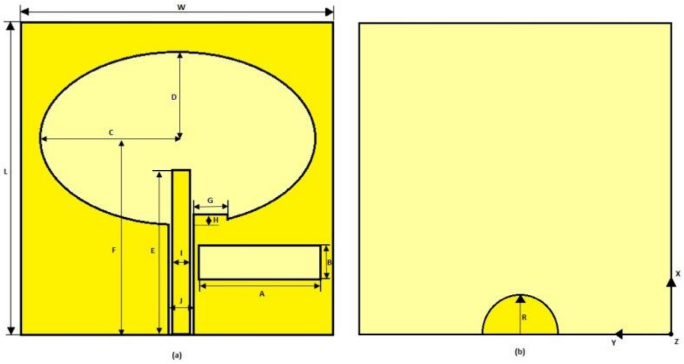

Fig. 2. Proposed CB-CPW antenna: (a)front side view, (b) back side view.

The proposed antenna has 4 layers. They are dielectric layer with thickness of 1mm, the transmission line fed to the antenna, the two ground conductors on the opposite sides of the transmission feed line are the coplanar waveguide, which comprises the third unit and last one is ground which is placed on the back side of the device with semi-circular shape. There is also a patch in rectangular shape which protruded into the elliptical slot which is parasitic patch to the structure. The bandwidth can be improved without increasing the volume due to this parasitic patch[3]. Impedance matching will improve when the ground and patch are placed on the same plane[4]. A defected ground structure is added to the design for improving the performance of the antenna. The DGS added here is a rectangular slotted structure after parameter optimization. The proposed CB-CPW fed antenna is given in Fig. 2 and the antenna dimensions are given in TABLE I.

As shown in the Fig. 2, W and L are the length and width of the antenna, A and B are the length and width of the rectangular slot, C and D are the major and minor radius of the elliptical slot, E and I are the length and width of the transmission line, G and H are the length and width of the parasitic patch attached to the ground, R is the radius of semi-circular back ground attached, F is the distance to the focus of the ellipse, and J is the distance between the feed slot.

For optimizing the slot area, two different dimensions are compared. They are $16{\times}5mm^2$ and $16.5{\times}5mm^2$. The results of the comparison are discussed in the next section. The important antenna parameters such as reflection coefficient, gain, bandwidth, voltage standing wave ratio, and 2-D radiation pattern with electric field and magnetic field are measured

TABLE I
DIMENSIONS OF PROPOSED CB-CPW FED ANTENNA.

Antenna dimensions	Values
L	40mm
W	40mm
A	16.5mm
B	5mm
C	18mm
D	12mm
E	20mm
F	24mm
G	4.5mm
H	1.5mm
I	2mm
J	2.4mm
R	4.5mm

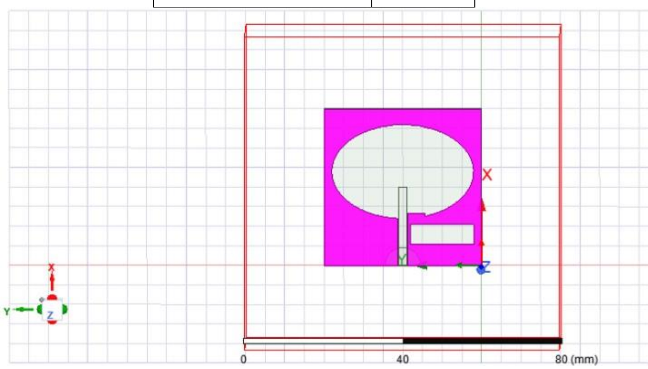

Fig. 3. CB-CPW fed antenna with rectangular slot area $16.5mm \times 5mm$.

and analysed. These are measured using the software Ansys HFSS.

The proposed CB-CPW fed antenna with a rectangular slot of area $16mm{\times}5mm$ is given in Fig. 3. In Fig. 4, the antenna with different slot thickness is given.

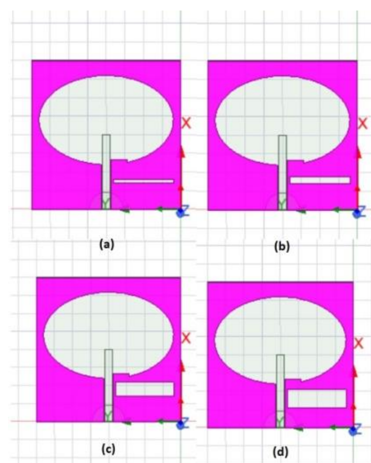

Fig. 4. CB-CPW fed antenna with slot thickness(a)1mm, (b)2mm, (c)4mm, (d)5mm.

III. RESULTS AND DISCUSSION

The reflection coefficient, gain, voltage standing wave ratio, and radiation pattern obtained from the simulation are discussed in this section.

A. REFLECTION COEFFICIENT

The principle of the DGS structure is that it disturbs the current distribution on the ground plane and this changes the characteristics of the transmission line. The defected ground structure or the slot given in the ground was adjusted by taking different measures. A slot in the ground, with a fixed slot length of 16mm, and by taking the different dimensions of slot width as 1mm, 2mm, 4mm, and 5mm, the influence of reflection coefficients on slot area was observed and studied. The comparison of reflection coefficients as slot size increases are given in TABLE II. As an inference, we can observe that by increasing the slot thickness, the performance of the antenna is also increasing. The slot with 5mm thickness has better performance.

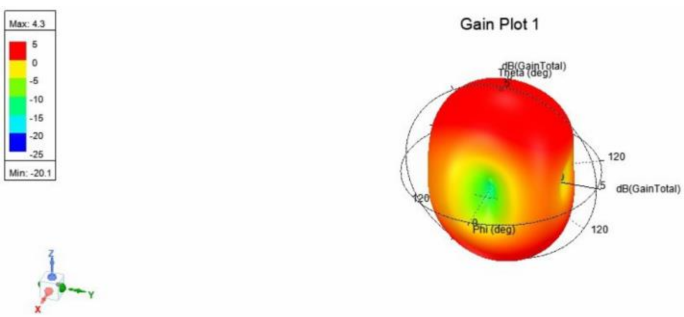

TABLE II

COMPARISON OF CB-CPW ANTENNA BASED ON DIFFERENT SLOT WIDTHS.

Slot width	Reflection coefficients
1mm	-25dB
2mm	-29dB
4mm	-31dB
5mm	-41dB

The reflection coefficients of the CB-CPW fed antenna having two different slot areas was compared. Comparison of the reflection coefficient, for CB-CPW fed antenna with slot of area

$16mm \times 5mm$, and $16.5mm \times 5mm$ is given in Fig. 5.

The S_{11} plot of the antenna with rectangular slot area of $16mm \times 5mm$ is given in red color and S_{11} plot of the antenna with rectangular slot area of $16.5mm{\times}5mm$ is given in green color. The S_{11} usually measures the reflections from the antenna. From Fig. 5, for the antenna with slot area of $16mm{\times}5mm$, it is observed that the resonant frequency, f_0= 4.9GHz, and the S_{11} obtained is -41.4dB. The upper frequency, f_2= 6GHz, and the lower frequency, f_1= 4.7GHz. Therefore, the obtained bandwidth, $f_2 - f_1$= 1.3GHz.

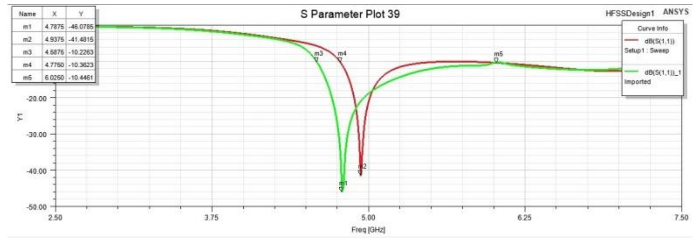

Fig. 5. Comparison of S_{11} for antenna with slot $16mm \times 5mm$(red color) and $16.5mm \times 5mm$(green color).

For the slot with an area of $16.5mm \times 5mm$, the resonant frequency, f_0= 4.78GHz, and the S_{11}= -46.4dB. The obtained upper and lower frequencies are f_2= 7.5GHz, and f_1= 4.5GHz respectively. Therefore, the bandwidth, $f_2 - f_1$= 3GHz. Here, we can observe an enhancement in the bandwidth by adding a DGS structure or a slot in the ground. TABLE III, given above shows the comparison of the reflection coefficient and operation frequency obtained for the antenna with slot area, $16mm \times 5mm$ and $16.5mm \times 5mm$.

TABLE III

COMPARISON OF CB-CPW ANTENNA BASED ON DIFFERENT SLOT AREAS.

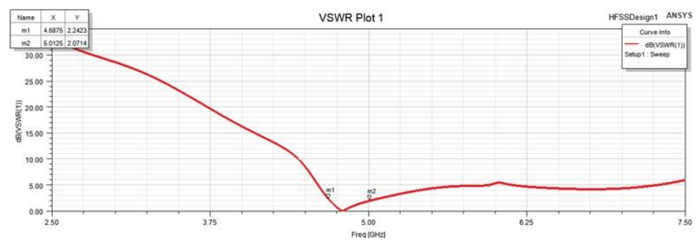

Fig.9.VSWRplotfortheantennawithslotarea $16.5mm \times 5mm$.

Slot area	Operating frequency	Reflection coefficients
$16mm \times 5mm$	4.93GHz	-41.4dB
$16.5mm \times 5mm$	4.78GHz	-46.0dB

B. GAIN

Fig. 6. Gain plot for antenna with slot area $16mm \times 5mm$.

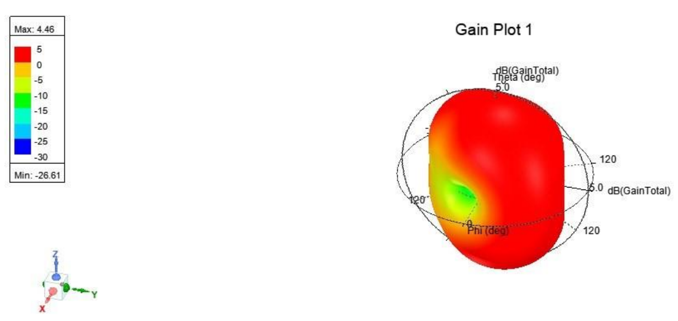

Fig. 7. Gain plot for antenna with slot area $16.5mm \times 5mm$.

The gain plot for the antenna with two different slots was compared. The gain plot of the antenna with slot area of $16mm\times5mm$ and $16.5mm\times5mm$ is given in Fig. 6 and Fig. 7 respectively. From TABLE IV, it is clear that the maximum

TABLE IV
COMPARISON OF THE MAXIMUM ANTENNA GAIN WITH SLOT AREA.

Slot area	Max. antenna gain
$16mm\times5mm$	4.3dB
$16.5mm\times5mm$	4.46dB

gain obtained for the antenna with a rectangular slot of area $16.5mm \times 5mm$ is 4.46dB and the maximum gain obtained for the antenna with rectangular slot of area $16mm \times 5mm$ is 4.3dB. So, the gain of the antenna increases as the area of the slot increases.

C. VSWR

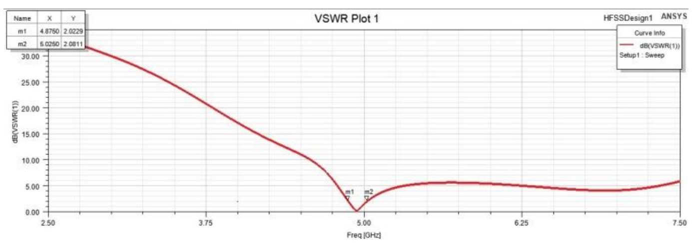

Fig. 8. VSWR plot for the antenna with slot area $16mm\times5mm$.

Here, in Fig. 8 and Fig. 9, the VSWR plot for the antenna with slot area $16mm \times 5mm$ and $16.5mm \times 5mm$ is given. The antenna with increased slot area was getting better performance. From the graph, it is observed that the value of VSWR is 0.1 for the antenna with slot area $16mm \times 5mm$ and the value of VSWR is nearly .05 for the antenna with slot area $16.5mm \times 5mm$.

D. RADIATION PATTERN

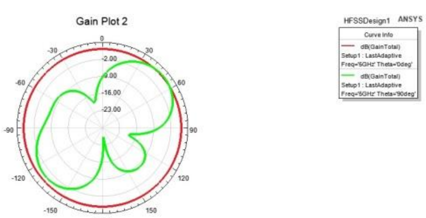

Fig. 10. 2-D radiation pattern:- electric field(green) and magnetic field(red) for antenna with slot area $16mm\times5mm$.

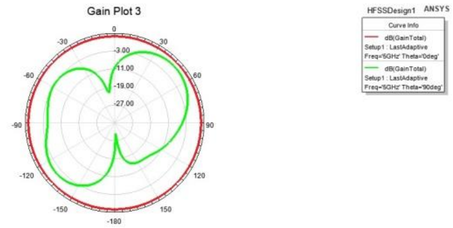

Fig. 11. 2-D radiation pattern:- electric field(green) and magnetic field(red) for antenna with slot area $16.5mm\times5mm$.

Fig. 10 and Fig. 11 show the 2-D radiation pattern at 5GHz for the 2 different slotted antenna, $16mm \times 5mm$ and $16.5mm \times 5mm$ are given respectively. The electric field is obtained by taking the theta value as 90 degrees and the magnetic field is obtained by taking the theta value as 0 degrees.

IV. CONCLUSION

The proposed conductor backed-CPW fed elliptical patch-slotted antenna is suitable for 5G applications. By using the CB-CPW feeding technique, the size was reduced to $40 \times 40 \times 1mm^3$. The overall performance of the antenna was increased by adding a DGS to the ground plane. A rectangular DGS with an area of $16.5 \times 5mm^2$ was chosen after parameter optimization. Antenna parameters such as reflection coefficient, gain, voltage standing wave ratio, and radiation pattern were measured and analysed. The proposed antenna is resonating at a frequency of 4.78GHz and a bandwidth of 3GHz was obtained.

REFERENCES

[1] C. J. Wang and C. H. Chen, ”CPW-Fed Stair-Shaped Slot Antennas With Circular Polarization,” IEEE Transactions on Antennas and Propagation, vol. 57, no. 8, pp. 2483-2486, Aug. 2009.
[2] S. W. Zhou, P. H. Li, Y. Wang, W. H. Feng and Z. Q. Liu, ”A CPW-Fed Broadband Circularly Polarized Regular-Hexagonal Slot Antenna With L-Shape Monopole,”IEEE Antennas and Wireless Propagation Letters, vol. 10, pp. 1182-1185, 2011.
[3] P. B. Parmar, B. J. Makwana and M. A. Jajal, ”Bandwidth Enhancement of Microstrip Patch Antenna Using Parasitic Patch Configuration,” 2012 International Conference on Communication Systems and Network Technologies, Rajkot, pp. 53-57, 2012.
[4] A. George and R. Nakkeeran, ”CB-CPW fed compact antenna for WLAN applications,” 2013 International conference on Circuits, Controls and Communications (CCUBE), pp. 1-4, 2013.
[5] A. Saxena, S. Joshi, A. Gupta, S. Saxena, and D. Kumar, ”Gain and bandwidth enhancement of CPW-fed patch antenna for wideband applications,” 2016 IEEE International Conference on Recent Trends in Electronics, Information Communication Technology (RTEICT), Bangalore, India, pp. 1622-16257, 2016.
[6] M. Saini, S. Singh, ”Novel CPW-fed UWB Monopole Patch Antenna for 5G Mobile Technology,” 2017 14th IEEE India Council International Conference (INDICON), 2017.

[7] R. K. Saini, S. Dwari and M. K. Mandal, "CPW-Fed Dual-Band Dual-Sense Circularly Polarized Monopole Antenna," IEEE Antennas and Wireless Propagation Letters, vol. 16, pp. 24972500, 2017.

[8] X. Fang, G. Wen, D. Inserra, Y. Huang and J. Li, "Compact Wideband CPW-Fed Meandered-Slot Antenna With Slotted YShaped Central Element for Wi-Fi, WiMAX, and 5G Applications,"IEEE Transactions on Antennas and Propagation, vol. 66, no. 12, pp. 7395-7399, Dec. 2018.

[9] J. Pourahmadazar, C. Ghobadi, J. Nourinia, N. Felegari and H. Shirzad, "Broadband CPW-Fed Circularly Polarized Square Slot Antenna With Inverted-L Strips for UWB Applications," IEEE Antennas and Wireless Propagation Letters, vol. 10, pp. 369-372, 2019.

[10] H. Ullah and F. A. Tahir, "A High Gain and Wideband CPW-Fed Antenna for Millimeter-Wave Applications," 2020 IEEE International Symposium on Antennas and Propagation and North American Radio Science Meeting, Montreal, QC, Canada, pp. 273-274, 2020.

[11] Z. Ding, D. Zhang and C. Ma, "Broadband Antenna Design With Integrated CB-CPW and Parasitic Patch Structure for WLAN, RFID, Wi-max, and 5G Applications," IEEE Access, vol. 8, pp. 42877-42883, 2020.

[12] M. Sahal, V. Tiwari and D. Bhatnagar, "Wideband CPW fed circularly polarized antenna using planar transmission line DGS," 2020 7th International Conference on Signal Processing and Integrated Networks (SPIN), Noida, India, pp. 1100-1104, 2020.

[13] X. Li, H. Zhu and Z. Huang, "A CPW-Fed Miniaturized Dual-Band Antenna for 5G Applications," 2020 IEEE MTT-S International Conference on Numerical Electromagnetic and Multiphysics Modeling and Optimization (NEMO), Hangzhou, China, pp. 1-3, 2020.

[14] B. B. Q. Elias, P. J. Soh, M. K. A. Rahim, A. A. Al-Hadi, H. Aliakbarian and S. Yan, "Design and Optimization of a Flexible CPW–Fed Slotted Planar Monopole for WLAN/WBAN and 5G," 2020 14th European Conference on Antennas and Propagation (EuCAP), Copenhagen, Denmark, pp. 1-5, 2020.

[15] M. Aboualalaa, "Dual-band Co-planar Waveguide Slot Antenna for 5G sub-6 GHz Applications," 2020 IEEE MTT-S International Conference on Numerical Electromagnetic and Multiphysics Modeling and Optimization (NEMO), Hangzhou, China, pp. 1-4, 2020.

[16] V. Shah et al., "CPW - Fed Square and Semi - Circular Patch Antenna for UWB, 4G 5G Applications," 2021 4th Biennial International Conference on Nascent Technologies in Engineering (ICNTE), NaviMumbai, India, pp. 1-4, 2021.

[17] G. Anjaneyulu and J. S. Varma, "Design of a CPW fed Microstrip Patch Antenna with Defective Ground Structure for Wireless Applications," 2021 6th International Conference on Inventive Computation Technologies (ICICT), Coimbatore, India, pp. 25-30, 2021.

[18] S. H. Ates, N. Akcam and T. Okan, "Bandwidth and Gain Enhancement using FSS on CPW-fed Rectangular Patch Antenna for 5G mm-Wave Applications," 2022 International Congress on Human-Computer Interaction, Optimization and Robotic Applications (HORA), Ankara, Turkey, pp. 1-4, 2022.

[19] P. Kansal, A. K. Mandpura and N. Kumar, "CPW Fed Microstrip Patch Antenna for 5G Communication," 2022 IEEE Silchar Subsection Conference (SILCON), Silchar, India, pp. 1-4, 2022.

[20] H. Saad, M. Farhan and R. Abd-Alhameed, "Design a CPW-Fed Circular Polarization Printed Antenna for 5G Sub-Band Applications," 2022 8th International Conference on Contemporary Information Technology and Mathematics (ICCITM), Mosul, Iraq, pp. 262-266, 2022.

[21] X. Wu, X. Wen, J. Yang, S. Yang and J. Xu, "Metamaterial Structure Based Dual-Band Antenna for WLAN," in IEEE Photonics Journal, vol. 14, no. 2, pp. 1-5, April 2022.

[22] S. Ahmad et al., "A Compact CPW-Fed Ultra-Wideband Multi-Input-Multi-Output (MIMO) Antenna for Wireless Communication Networks," in IEEE Access, vol. 10, pp. 25278-25289, 2022.

[23] M. Ayyappan and P. Patel, "On Design of a Triple Elliptical Super Wideband Antenna for 5G Applications," in IEEE Access, vol. 10, pp. 76031-76043, 2022.

[24] B. Dwivedy, "Consideration of Engineered Ground Planes for Planar Antennas: Their Effects and Applications, a Review," in IEEE Access, vol. 10, pp. 84317-84329, 2022.

[25] S. Manjula and K. K. Naik, "CPW-Fed Circular Shaped Patch Antenna with Minkowski Fractal DGS using Flexible Substrate for Wireless Applications," 2022 7th International Conference on Communication and Electronics Systems (ICCES), Coimbatore, India, pp. 549-553, 2022.