

# Dual Band Slotted Printed Circular Patch Antenna With Superstrate and EBG Structure for 5G Applications

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## ABSTRACT

Slotted circular printed layered patch antenna is designed, simulated and fabricated for 5G (Fifth Generation) wireless communication applications. The antenna consists of slots in the main radiating circular patch element for miniaturizing the size of the radiating element and providing dual band radiation characteristics. The feed line is separated on bottom substrate layer with EBG (Electromagnetic Band-Gap) embedded for enhancing the gain characteristics of the antenna. Superstrate layer is also used for improving the gain of the antenna where the distance from the radiating antenna element is optimized for maximizing the impedance bandwidth and radiation characteristics. The feed realization and impedance matching of the radiating slotted circular patch antenna is done by inducing slot at the middle ground plane of the slot embedded circular patch antenna system. The proposed configuration provides power radiation gain values of more than 5 dB for the Ka band of communications, whereas the impedance bandwidth of the antenna is verified for the dual resonances at 27.5 and 28.5 GHz. Dual band radiation characteristics are attained by embedding and optimizing the slot length and width in the circular patch radiator element that is placed on the upper face of the substrate RT Rogers Duroid 5880 layer. The length of the microstrip feed line embedded in the lower layer of the substrate is optimized for providing required bandwidth characteristics for the dual frequency point radiations. The antenna configuration is designed, modeled and simulated in CST (Central Standard Time) Microwave studio. The antenna is fabricated and measured vs simulated frequency response, gain patterns and current density plots are presented for the verification of antenna operation in the desired frequency bands.

**Key Words:** Dual Band, Patch Antenna, Electromagnetic Band-Gap, Superstrate.

## 1. INTRODUCTION

Wireless communications with latest trends of high data rate requirements and growth in the use of portable devices pose a challenge for higher system bandwidth and enhanced channel capacity. These modern system specifications can be realized with the advent of 5G communication

system that provides solution for the growing data traffic. The mitigation of increased path loss effects and higher frequency communications of the 5G systems can be attained by designing antenna systems with various techniques. Dual feed radiator can be designed in loop configuration for 5G communications

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by using multiple feeds and maintaining conventional pattern characteristics of the loop antenna and also minimizing the network losses between receiver and transmitter [1]. Wide band radiation characteristics can be achieved for 5G systems by using tapered slot radiating element fed by substrate integrated feeding line with multiple beam characteristics for MIMO (Multiple Input Multiple Output) communications [2]. High gain printed antennas provide suitability for the 5G systems for compensating path losses by using four element arrays that are designed by triangular shaped slots embedded in substrate fed by integrated feeding microstrip feeding lines [3]. Antenna systems can be designed for simultaneously supporting both 4G and 5G standards by combining MIMO antenna systems with array of slot radiating elements covering the 2100 MHz frequency band for 4G and 28 GHz for 5G systems respectively [4].

ANN (Artificial Neural Networks) allows calculations of the antenna dimensions for accurately modeling the slot antenna radiation and polarization characteristics that provides suitability for MIMO systems for the 5G networks [5]. Low side lobe antenna arrays are designed for achieving low cross polarization levels by substrate integrated feeding lines and tapered T junction dividers suitable at 28 GHz for 5G systems [6]. Electromagnetic exposures for radiations at higher frequencies that are required for the fifth generation systems can be analyzed by the power density function instead of specific absorption rates and using various configurations of array antennas [7]. Wideband antenna with reduced losses and high gain is designed by using dipole antenna based on magneto electric properties and excited by waveguide integrated coupled slot line where the gain is enhanced by stacking additional substrate layers [8].

Side lobe levels of more than -18 dB can be achieved that are suitable for fifth generation communication systems by using linear array of 7 elements and parasitic patch elements coupled through stacked substrate at 28 GHz frequency band [9]. Phased array beam steering antenna for three dimensional radiations coverage can be design for 5G applications at 28 GHz by using three arrays of slot radiator based elements and switching between the arrays provides larger coverage area along with enhanced bandwidth [10].

Wireless Communications provides many challenges for the designers in terms of lower cost systems, greater coverage area and high gain requirements. EBG structures provide various benefits in providing enhancement in antenna characteristics for wireless communication. EBG can be used for providing reduction in radar cross section by using layered configuration based on checkboard structures [11]. Gaussian beam is utilized for concentration the radiation along a direction which is achieved by coupling EBG and periodic slow structures [12]. The high mutual coupling between monopole radiating elements for MIMO systems is reduced by incorporating layered EBG for UWB (Ultra-Wide Band) applications [13]. Dielectric resonator antennas are used in wireless communication applications by different researchers due to high efficiency and low loss characteristics with comparison to conventional metallic patches. For exciting HEM<sub>11</sub> mode of Dielectric resonator antenna, the dielectric resonator can be placed above a metallic bottom ground plane with some dielectric substrate and it can also be placed without any substrate. For exciting the mode of TM<sub>11</sub> other than HEM<sub>11</sub> dielectric resonator mode, the excitation is done in the region between the copper ground plane and the circular dielectric resonator. The antenna is not categorized as dielectric resonator antenna

family but rather considered as dense dielectric patch antenna when it is excited in this mode and reflected as part of the patch antenna category. Apart from retaining a low profile trait, the efficiency of this type of antenna at higher frequencies is estimated to be better than normal traditional metallic patch antenna as the efficiency of the conventional patch antenna becomes less at higher frequencies [14]. Gain enhanced antenna array system is essential at Millimeter wave frequency ranges for overcoming the degradation in the signal strength due to oxygen molecular absorption. One of the main techniques for gain enhancement is by using efficient antenna array system where radiation from the feed network can be isolated from the main radiating antenna elements [15]. In addition, for additional gain augmentation superstrate technology can be used [16-17]. Gain enhancement is achieved by placing dielectric substrate with an approximation thickness of  $0.25 \lambda$  above the radiator at a spacing of  $0.5 \lambda$  for getting multiple reflections for the radiating element. Superstrate layer acts as a lens where all the radiations from the main beam are focused in one particular direction that results in a considerable gain enhancement in the antenna.

Coplanar waveguide fed slotted three arms for achieving bandwidth from 5.75-14.51 GHz using artificial magnetic conductor for wideband applications [18]. EBG is used for achieving reconfigurability in terms of polarization and frequency tuning at broadband by using metallic patch arrays [19]. For improving the width of the band gap, an EBG structure is presented in [20], consisting of tapered Koch fractal structures.

EBG can be employed for achieving lower pass band attenuation and stopband below -20 dB [21], where the pass band ripples are reduced by Chebyshev tapering

and defected ground plane structure is used for enhancing stopband bandwidth characteristics. EBG structures can be used for millimeter wave wireless communication applications [22] for reduced mutual coupling for array antennas based on miniaturized EBG cells at 60 GHz. Circularly polarized antenna is designed by using linearly polarized EBG antenna with layer of meander line polarizer from 29.5-30 GHz with less than 1 dB axial ratio is achieved [23]. Matching devices can be incorporated for compensating degraded axial ratio [24], by using iris based matching system and self-polarized EBG structure centered at 9 GHz providing 20 dB gain. The radiator can be embedded within EBG for better efficiency and characteristics [25]. Multimode and multibands can be simultaneously attained by using mushroom like EBG [26], where omnidirectional as well as patch like radiation patterns are achieved for the various bands and modes are realized by tuning various parameters of EBG. The comparison summary for various antenna designs suitable for 5G systems is shown in Table 1.

In this paper a novel layered slotted antenna is presented with the feed line on the bottom layer and the radiating slotted circular patch is placed on a separate top layer. The feeding is done through a slot in the middle ground plane that is between the two substrate layers. The length and width of the slot is optimized for impedance matching and maximum bandwidth of the proposed slotted circular printed patch antenna. Novel EBG is embedded on the bottom substrate layer of Rogers 5880 for improving the gain characteristics. Proposed antenna is made further directional by using superstrate layer whose distance from the radiating antenna layer is optimized. EBG structure details are presented. The simulation of the

proposed slotted circular layered antenna is done in CST Microwave Studio for frequency response, gain and current distribution plots for the verification of the operation of the antenna for 5G applications.

## 2. SLOTTED CIRCULAR LAYERED PRINTED ANTENNA DESIGN

The proposed novel slotted circular patch antenna with layered superstrate and ground plane is shown in Fig. 1. The slotted circular printed patch antenna along with the superstrate and EBG embedded bottom layer is optimized for operation of the antenna at 28 GHz for 5G applications. The top superstrate layer consists of substrate Rogers 5880. The thickness of the substrate Rogers 5880 is 0.508 mm with dielectric constant of 2.2. The purpose of this

layer is to enhance the gain characteristics of the proposed slotted layered circular printed patch antenna. The second layer consist of radiating slotted circular patch antenna etched on a substrate layer of Rogers 5880 as shown in Fig. 1. The radiating element consists of the copper cladding with a thickness of 0.035 mm. The separation of the superstrate layer and the second radiating slotted circular printed patch antenna layer is optimized for providing maximum gain enhancement. The slot embedded in the printed radiating antenna element provides the size reduction in the overall size of the circular printed patch antenna. The bottom side of the second substrate layer of Rogers 5880 consists of the copper ground plane with copper cladding of 0.035 mm. For feeding the circular slotted radiating copper element through a microstrip transmission line etched in the bottom side of the third

TABLE 1. COMPARISON OF SLOTTED CIRCULAR LAYERED PATCH ANTENNA WITH 5G AND EBG BASED ANTENNAS IN LITERATURE VS MAXIMUM GAIN

[1]	Rogers RO3003	23x15	3
[2]	Rogers RT5880	30x8	9.6
[3]	Rogers RT5880	23x22.4	13.5
[4]	Rogers RO3003	60x30	8.2
[5]	Rogers RT5880	24x15	6.8
[6]	Rogers RO4350B	70x63.5	13.97
[7]	Rogers RT5880	40x5.7	12
[8]	Rogers RO3003	27x41	15
[9]	Taconic TLY-5	96x20	14
[10]	Nelco N9000	42.3x10.5	8
[11]	Rogers RT5880	112x112	10
[13]	FR4	60x50	5
[18]	FR4	50x80	10.65
[22]	Rogers RO3006	25x20	8
[26]	Rogers RT5880	70x70	6
Proposed Work	Rogers RT5880	20x20	9.35
[1]	Rogers RO3003	23x15	3

substrate, slot is embedded in the middle copper ground plane. The slotted line cut in the ground plane whose length and width are optimized for achieving the proper matching of the feed line with the radiating circular copper slotted patch antenna. The length and width of the slotted cut in the ground plane is also optimized for providing maximum impedance bandwidth for the operating of the antenna. The slot cut is provided in the copper cladding plane with the placement just beneath the radiating circular slotted patch antenna for radiation and efficiency of the antenna element. The feed line is etched at the bottom side of the third substrate of Rogers 5880. One end of the line is soldered with the SMA connector and the other end of the line is open ended.

The length of the line is optimized for providing feeding to the radiating slotted patch antenna element placed at the top substrate layer. The microstrip transmission line width is optimized for providing impedance matching of 50 ohms with the SMA connector. The EBG layer is placed along the microstrip transmission line on the bottom side

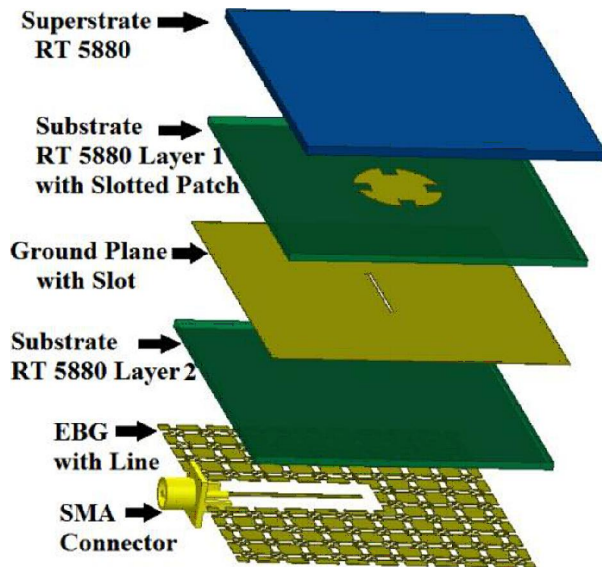


FIG. 1. LABELED DIAGRAM OF THE PROPOSED SLOTTED CIRCULAR PATCH ALONG WITH THE EBG GROUND PLANE AND SUPERSTRATE LAYER

of the third Rogers 5880 substrate. The EBG structure provides improved radiation characteristics. The overall size of the EBG layer and the unit cells are optimized for providing radiations in the same frequency bands of 27.5 and 28.5 GHz for the specifications of slotted circular printed radiating antenna element.

The single element of the circular patch antenna is designed by specifying the height of the substrate  $h$ , frequency of operation  $f_r$  and dielectric constant of the substrate  $\epsilon_r$ , and calculating  $a$  using [27]:

$$a = \frac{F}{\left\{ 1 + \frac{2h}{\pi\epsilon} \left[ \ln \left( \frac{\pi F}{2h} \right) + 1.7726 \right] \right\}^{1/2}} \quad (1)$$

Where

$$F = \frac{8,791 \times 10^9}{f_r \sqrt{\epsilon_r}} \quad (2)$$

The detailed dimension diagram of the slotted circular patch radiator top layer embedded with EBG and transmission line bottom layer and middle copper ground slotted line layer is shown in Fig. 2. The top radiating slotted circular printed patch element dimensions diagram is presented in Fig. 2(a). Both the length and width of the substrate is optimized at 20mm. The diameter of the circular printed patch antenna is optimized at 5.74 mm. The slots are introduced in the radiating patch antenna as shown in Fig. 2(a) with its length and width optimized at 0.96 mm and 1 mm respectively. With these slots the overall size of the radiating element is reduced, as it provides increase in the overall electrical length of the radiating circular printed antenna element. The dimension layout of the middle ground plane with the embedded slotted line is shown in the Fig. 2(b). The slotted line is cut in the ground plane with its placement for feeding the radiating element at the middle. The length and width of ground plane is the same as that of the substrate of 20 mm.

The slot line length and width is optimized at 5.6 and 0.2 mm respectively. The bottom substrate layer with EBG structure and microstrip feed line dimensions layout is shown in Fig. 2(c). The microstrip transmission feed line is connected to the SMA connector from one end and the other end is terminated right at the middle of the slot placed at the middle

ground plane. The length and width of the microstrip feed line is optimized at 11 and 0.37 mm respectively. Whereas the substrate length and width of the bottom Rogers 5880 layer is same as that of the top substrate layers having the dimension of 20 mm. The dimensions of the proposed slotted layered printed circular patch antenna are summarized in Table 2.

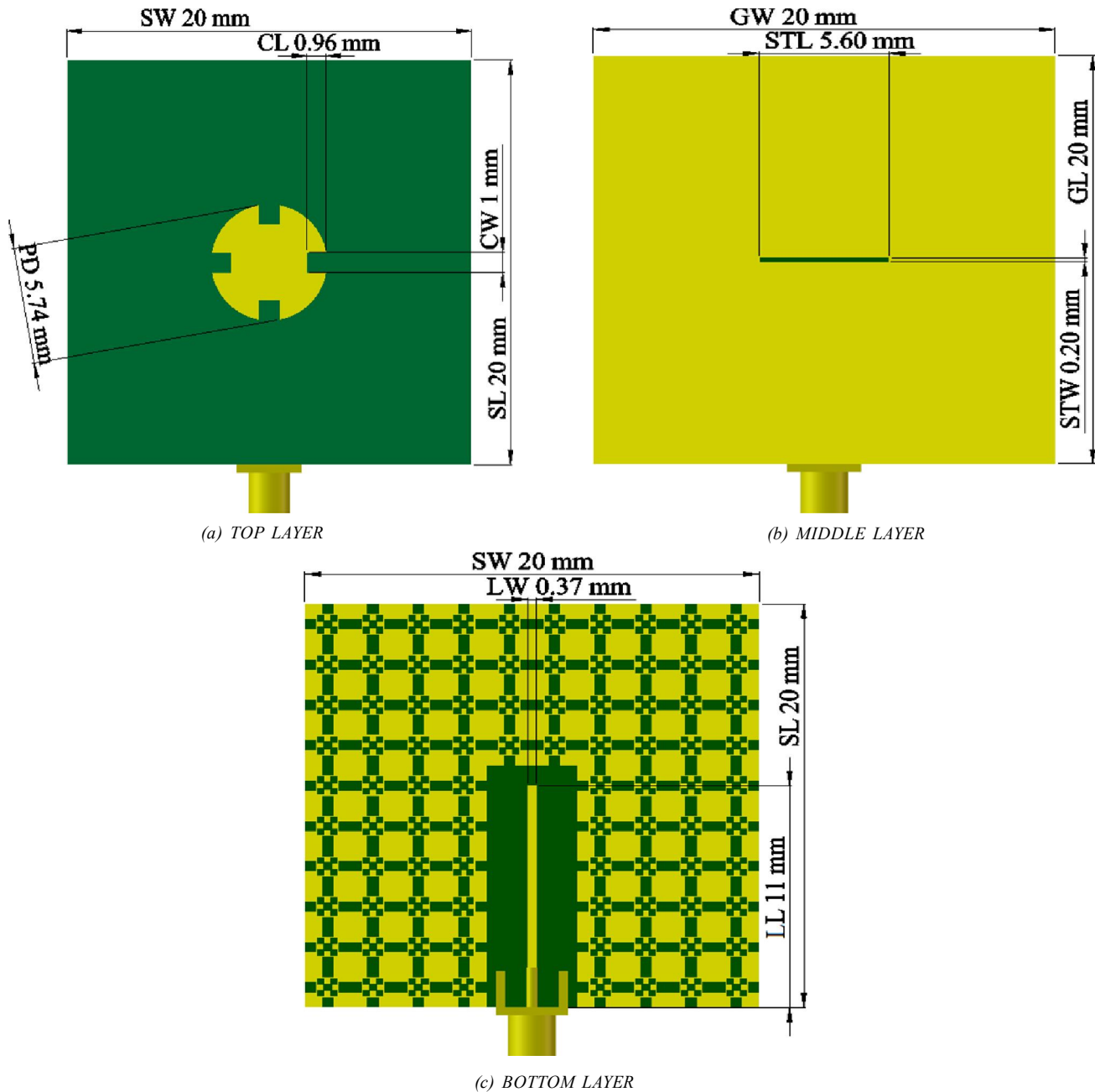


FIG. 2. DIMENSIONS DIAGRAM OF THE PROPOSED SLOTTED PRINTED CIRCULAR LAYERED ANTENNA

The radiated power of the cavity model is expressed as [27]:

$$P_{\text{rad}} = |V_0|^2 \frac{(k_0 a_e)^2}{960} \int_0^{\pi/2} [r_{02}^2 + \cos^2 \theta J_{02}^2] \sin \theta d\theta \quad (3)$$

Where the radiated power is based on the fields formulated as:

$$E_\theta = -j \frac{k_0 a_e V_0 e^{-jk_0 r}}{2r} \{ \cos \varphi J_{02} \} \quad (4)$$

$$E_\varphi = -j \frac{k_0 a_e V_0 e^{-jk_0 r}}{2r} \{ \cos \theta \sin \theta J_{02} \} \quad (5)$$

And the current densities are given by:

$$J'_{02} = -J_0(k_0 a_e \sin \theta) - J_2(k_0 a_e \sin \theta) \quad (6)$$

$$J_{02} = J_0(k_0 a_e \sin \theta) + J_2(k_0 a_e \sin \theta) \quad (7)$$

Where  $a_e$  is the effective radius of the circular patch and  $k_0$  is the propagation constant.

### 3. SIMULATION AND ANALYSIS

The proposed slotted circular printed patch radiator is designed and optimized in CST Microwave Studio. The dual band measured vs simulated S11 frequency response of the slotted circular EBG based antenna is presented in Fig. 3. The optimization of the slotted printed circular layered patch antenna along with the EBG plane is achieved by tuning the slot length and width induced beneath the radiating element in the ground plane layer. The transmission line length and width placed at the bottom of the third Rogers 5880 substrate is also optimized for impedance matching and maximum bandwidth characteristics of the radiating antenna element. As shown in Fig. 3, the slotted circular printed layered patch antenna is optimized to operate in the  $K_a$  Band with center frequency at 27.646 and 28.156 GHz with insertion loss of -13.589 and -15.779 dB respectively for 5G applications. The bandwidth of the proposed slotted printed circular patch antenna system at the two resonance frequency points provides the impedance bandwidth of 309 and 501 MHz.

TABLE 2. SLOTTED CIRCULAR LAYERED PATCH ANTENNA LABELS, DESCRIPTIONS AND DIMENSIONS

Label	Description	Dimensions (mm)
PD	Patch Diameter	05.74
SL	Substrate Width	20.00
SW	Substrate Length	20.00
CL	Patch Slot Length	00.96
CW	Patch Slot Width	01.00
GL	Ground Length	20.00
GW	Ground Width	20.00
STL	Slot Length	05.60
STW	Slot Width	00.20
LL	Line Length	11.00
LW	Line Width	00.37

The parametric analysis of the printed slotted antenna with various lengths of the feed line and embedded circular patch slot length are presented in Figs. 4-5 respectively. The gain vs frequency plot of the slotted printed circular layered patch radiator is demonstrated in Fig. 6, over the whole frequency band. The plot shows the gain characteristic of the antenna from 26-30 GHz, with the gain of more than 3 dB from 26.5-29.5 GHz with a band of 4 GHz, and a gain of more than 5 dB from 27-29.1 GHz covering a frequency band of 2.1 GHz. For the frequency band of 27.483-28.452 GHz the impedance bandwidth of less than -10 dB insertion loss, the gain of the proposed slotted circular printed layered patch antenna is more than 7 dB. The peak gain in this band is of 9.29 dB at 27.765 GHz, while at 27.48 GHz the antenna exhibits gain of 7.24 dB and at 28.48 GHz frequency resonance the antenna demonstrates gain of 7.92 dB. At the center frequency of the proposed printed circular slotted layered patch

antenna of 28 GHz, the antenna has a gain of 8.03 dB. Thus by using the proposed layered configuration the antenna exhibits an increase in the gain characteristics.

The 3D gain pattern plots of the proposed circular printed slotted printed layered patch radiator are demonstrated in Fig. 7. As seen from the four plots over the frequency band covering the frequency points of 27.48, 27.76, 28 and 28.48 GHz, the shape of the radiation pattern remains directional with a gain of more than 7 dB throughout the frequency band. The surface current plots of the proposed slotted circular printed layered patch antenna along with the microstrip transmission feed line and EBG at the bottom of the ground plane is shown in Fig. 8. The surface currents are plotted for the frequencies of 27.48 and 28 GHz as shown in Fig. 8(a-b) respectively. As seen from the surface currents, for the antenna to be effectively

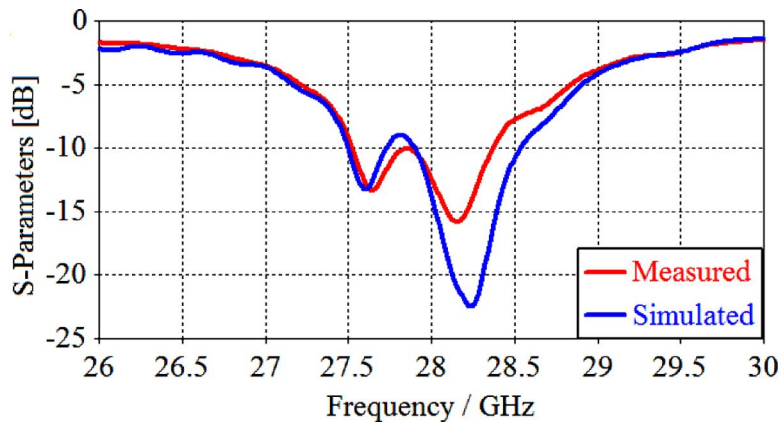


FIG. 3. MEASURED VS SIMULATED FREQUENCY RESPONSE OF THE SLOTTED PRINTED CIRCULAR LAYERED ANTENNA ELEMENT

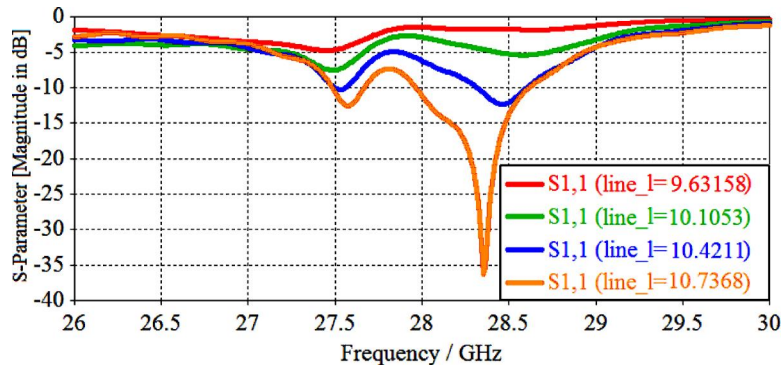


FIG. 4. PARAMETRIC ANALYSIS FREQUENCY RESPONSES OF SLOTTED CIRCULAR ANTENNA FOR VARIOUS FEED LINE LENGTHS IN MM



radiating at 28 GHz, the antenna element has strong current distribution at the outer radius of the slotted circular printed patch antenna, with the EBG place at the ground plane and the feeding line also having

strong current distributions enhancing the overall gain characteristics of the proposed antenna. The proposed antenna is fabricated and radiation patterns are measured that is presented in Figs. 9-10 respectively.

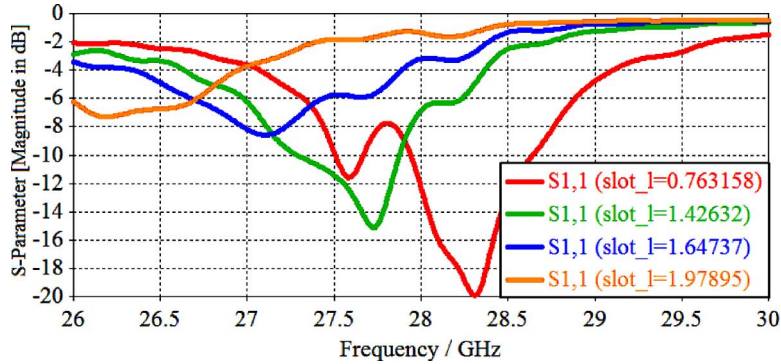


FIG. 5. PARAMETRIC ANALYSIS FREQUENCY RESPONSES OF SLOTTED CIRCULAR ANTENNA FOR VARIOUS CIRCULAR PATCH EMBEDDED SLOT LENGTHS IN MM

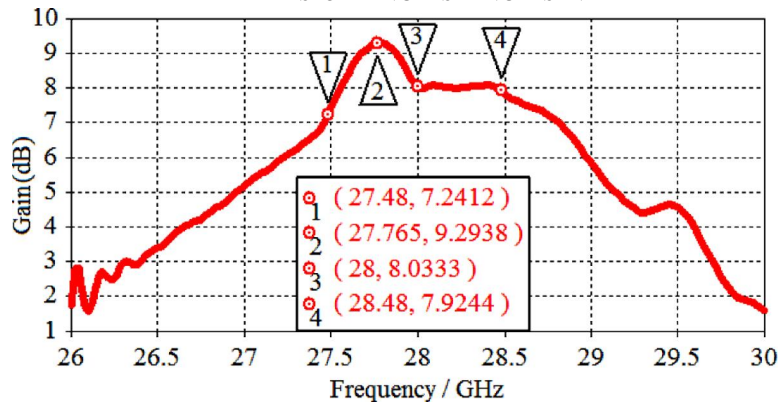


FIG. 6. GAIN VS FREQUENCY PLOT OF THE SLOTTED CIRCULAR PRINTED LAYERED PATCH ANTENNA ELEMENT

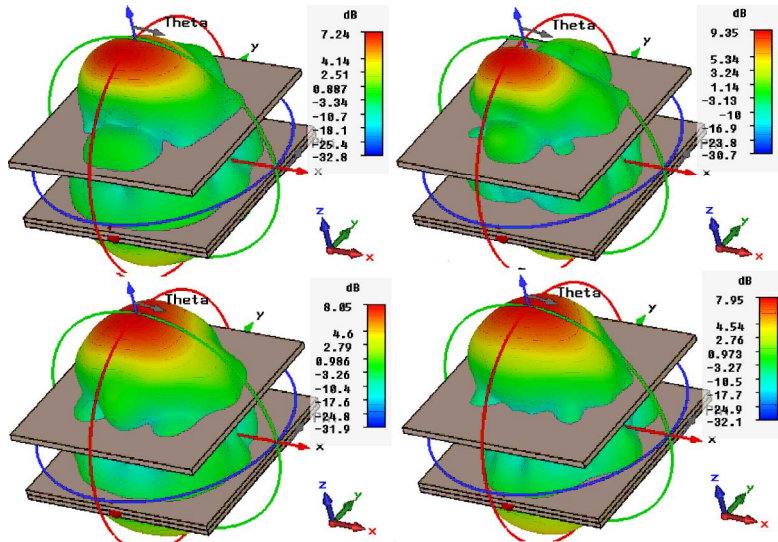


FIG. 7. 3D GAIN PLOTS OF THE PROPOSED SLOTTED PRINTED CIRCULAR LAYERED ANTENNA ELEMENT AT FREQUENCIES, (A) 27.48 GHZ, (B) 27.765, (C) 28 GHZ, (D) 28.48 GHZ

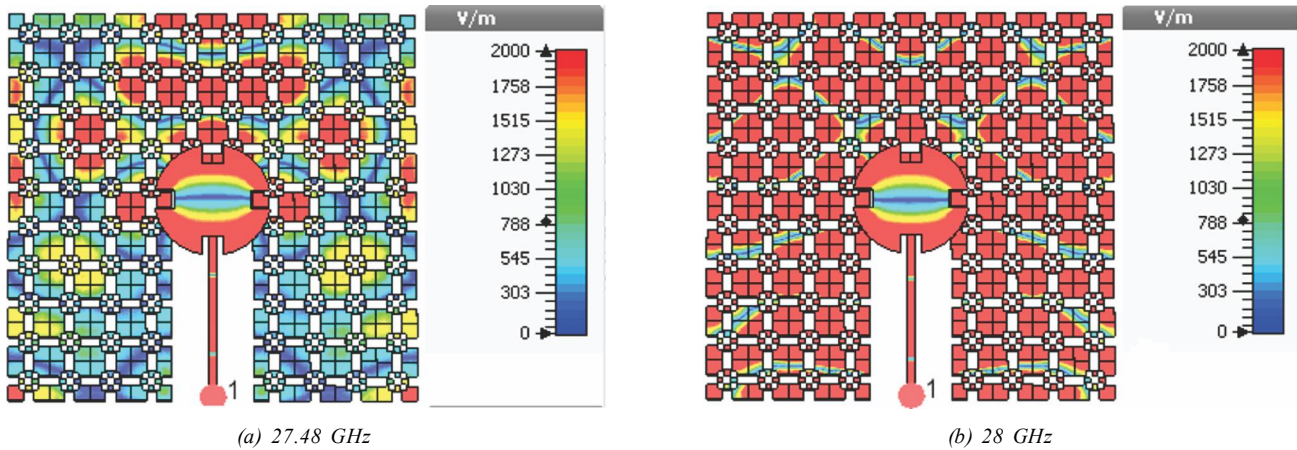


FIG. 8. SURFACE CURRENTS OF THE PROPOSED SLOTTED PRINTED CIRCULAR LAYERED PATCH ANTENNA AT FREQUENCIES



FIG. 9. FABRICATED PROTOTYPE OF THE PROPOSED ANTENNA WITH RADIATING ELEMENT, SLOT LINE AND EBG GROUND PLANE LAYERS

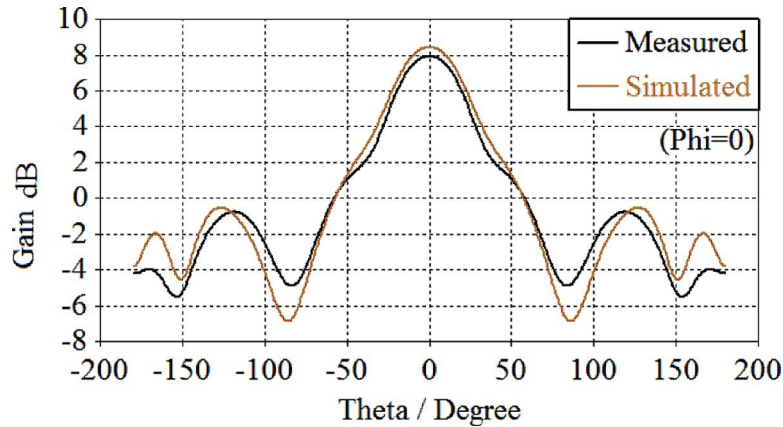


FIG. 10. MEASURED AND SIMULATION 2D RADIATION PATTERNS FOR THE PROPOSED ANTENNA AT 28 GHZ

#### 4. CONCLUSION

Slotted circular printed layered patch antenna is proposed having gain enhanced characteristics. The proposed antenna is constructed having layered topology with a superstrate top layer and EBG and feed line embedded in the bottom substrate layer of Rogers 5880 having dielectric constant of 2.33. The proposed antenna is modeled, designed and analyzed in CST Microwave Studio for 5G applications. The frequency response and surface current plots are verified for the operation of the antenna in the 28 GHz frequency band. The ground slot length and width is optimized at 5.6 and 0.2 mm for impedance matching of the proposed slotted circular patch antenna. The overall band of antenna is enhanced to 969 MHz with the combination of bottom EBG and top superstrate substrate layers. The printed antenna operates at 28 GHz with gain of more than 8 dB which is suitable for 5G applications.

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