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A 32 element circular-shaped corporate feed antenna array for millimeter-wave femtocells

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Abstract
A millimeter-wave circular antenna array using corporate feed for fifth-generation(5G) femtocell applications were designed and analyzed. The evolution of the proposed antenna is from a single to a thirty-two-element patch antenna. This array antenna indicates low return loss at multiple frequency bands like 20GHz, 25GHz, 30GHz, and 35GHz with reflection coefficient values like -23.35dB, -16.87dB, -16.91dB, and -9.54dB when measured using a vector network analyzer, including almost 93% antenna efficiency and obtained maximum gain values like 6.18dBi, 3.10dBi, 3.94dBi, and 2.95dBi when measured in an anechoic chamber. The 8×4 circular array antenna has achieved better accord between simulated and measured results. The proposed antenna attains good circular polarization with 3dB axial ratio values of 0.344dB at 28.23GHz and 2.49dB at 38.63GHz and follows left-hand circular polarization (LHCP) at all the considered resonating frequencies which can be used for manufacturing of 5G femto-base stations.

Keywords
Millimeter-wave, Circular array, Corporate feed, 5G frequencies, Femtocells applications.

1.Introduction
A wide variety of technologies are included in various networks under the 5G umbrella. The international telecommunication union (ITU) has given the name "fifth-generation mobile communication systems" to recent millimeter-wave communication technology.

Millimeter-wave technology, in general terms, encompasses the electromagnetic spectrum between 30 to 300 GHz, which refers to wavelengths ranging from 10 to 1 mm. The growing memory capacity in handheld connectivity is predicted to produce a high data rate of 10 Gbit/s, which relates to the progression of graphics and data-storage technology. All indoor wireless communication systems have mixers, amplifiers, antennas, and filters which are essential components of a radio frequency (RF) radio frequency front-end circuit. The demand for microstrip antennas in femtocells plays an important role which can work in both unlicensed or licensed spectrums.

Femtocells are energy efficient, low cost, self-installable, and can be easily manufactured with fifth generation (5G) frequency bands [1]. As the size of the antenna required for 5G femtocells is small, low-profile antennas like millimeter-wave antennas can be easily preferred where it carries low power and provide enormous bandwidth for communication purpose. In 2019, the Telecom Regulatory Authority of India (TRAI) has given 5G service and sufficient spectrums which are made for the auction. Furthermore, Asia Pacific Conference and World Broadcast Conference 2019 made suitable studies on the corresponding frequencies ranging from 24GHz to 28GHz and 37GHz to 40GHz bands for 5G Communications [2] as shown in *Table 1*. 5G is a combination of technological developments and capacity limitations that are forcing the network evolution toward an integrated network known as heterogeneous network (HetNet) 5G promises to deliver a 20Gbps maximum data rate and a 100Mbps customer experience data rate, as well as a 100-fold improvement in traffic capacity through its use of 5G. By installing small cell technology, it is possible to support much more capacity in dense regions, as well

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as increased signal coverage in areas where building blockage affects signal strength. There will be a requirement for femtocells to be installed every 200–250 meters on a wide range of infrastructure, including utility poles, streetlights, and subway stations. Conventional cell towers will also be required to be replaced by small cells. Shortening the distance between the transmitter and the receiver is perhaps the most probable elucidation of this issue. Because macrocells have inadequate domestic coverage, femtocells have been proposed as a way to enhance the delivery quality of service (QoS) of indoor customers [3].

Table 1 5G frequency bands

	<1GHz		3GHz	4GHz	5GHz		24-28GHz	37-40GHz
USA	600MHz (2X35MHz)	2.5GHz (LTEB41)	3.55-3.7GHz	3.7-4.2GHz		5.9-7.1GHz	24.25-24.45GHz 24.75-25.52GHz 27.5-28.35GHz	37-37.76GHz 37.6-40GHz 47.2-48.2GHz
CANADA	600MHz (2X35MHz)						27.5-28.35GHz	37-37.76GHz 37.6-40GHz
EUROPE	700MHz (2X30MHz)		3.4-3.8GHz			5.9-6.4GHz	24.5-27.5GHz	
UK	700MHz (2X30MHz)		3.4-3.8GHz				26GHz	
GERMANY	700MHz (2X30MHz)		3.4-3.8GHz				26GHz	
FRANCE	700MHz (2X30MHz)		3.46-3.8GHz				26GHz	
ITALY	700MHz (2X30MHz)		3.6-3.8GHz				26.5-27.5GHz	
CHINA			3.3-3.6GHz		4.8-5GHz		24.5-27.5GHz	37.5-42.5GHz
S KOREA			3.4-3.7GHz				26.5-29.5GHz	
JAPAN			3.6- 4.2GHz	4.4-4.9GHz			27.5-29.5GHz	
AUSTRALIA			3.4-3.7GHz				24.25-27.5GHz	39GHz
INDIA	700MHz (2X35MHz)		3.3-3.6GHz					

Global Snapshot of 5G Spectrum
Around the world, these bands have been allocated or targeted

New 5G Band
Licensed
Unlicensed
Existing Band

1.1Motivation

Self-installable femtocell base stations (BS) are typically tiny in terms of size and power consumption, but they are also affordable in cost for 5G frequency bands. Enormous bandwidth with low power shared spectrum is often achieved using miniaturized antennas at Femto BS to achieve the compactness and easy fabrication of diverse antennas for both mobile BS and terminals [4]. 5G frequencies are expected to play an important role in a wide range of current and future wireless applications. Some of these qualities are the availability of a large spatial-spectral range, high resolution, and tiny wavelength. Furthermore, the construction of wireless communication systems for mm-wave applications is of appeal to both researchers and professionals. Our wireless future completely depends on high-definition applications where mobile data rates expand to multi gigabits per second range and usage of steerable antennas and mm-wave spectrum came into existence. To achieve the above objective antennas like circular arrays using corporate feed structures are designed, simulated, and validated using measured results for millimeter-wave applications [5].

1.2Objectives

The objective of the study is to propose different millimeter-wave microstrip array antennas for 5G femtocells applications. Femtocells are miniaturized base stations that have all the properties of regular base stations like voice, video, and data communications which work at the Gbps range. For these small base stations, miniaturized antennas which work at millimeter-wave frequency bands i.e., from 20GHz to 40GHz are required. After a tremendous literature survey, a list of problems was summarized, and proposed different antenna arrays were to overcome the existing issues. The objectives of this research article include the design of a circular array antenna using the corporate feed technique from a single element to 32-element array antennas.

1.3Methodology

The process flow in the design process of an antenna starts with the application of the antenna. The usage of an antenna plays an important role in any communication systems equipment. Today's 5G wireless communication systems like femtocells had a great requirement for miniaturized microstrip antennas. So, various millimeter-wave antennas were proposed, designed, simulated, and validated with measured results. The methodology starts with the determination of frequency depending on the application. Once the operating frequency is fixed, choose the type of antenna structures like an array, log periodic, or fractal, and also choose the proper feeding technique like microstrip line feed, probe feed, aperture coupled feed, etc. Then consider one of the 5G frequencies like 28GHz or 38GHz and calculate the dimensions of an antenna according to design equations available for standard patches. Create and simulate an antenna model using a high-frequency structure simulator (HFSS) tool and observe all the performance metrics like resonating frequencies, impedance bandwidth, radiation pattern, etc. to check whether the metrics are up to the mark and suitable for the above-said applications. If it satisfies all the conditions, make the fabrication process of the antenna model and if the results are not satisfying, remodel the antenna with different dimensions and repeat the process until all the performance metrics achieves. Once the fabricated prototype is modeled, measure the voltage standing wave ratio (VSWR) and reflection coefficient using a vector network analyzer (VNA) and save the readings. Next, measure the radiation pattern of the antenna in the anechoic chamber and check for the gain characteristics. Measured metrics are permanent and true. So, if the measured results are not matching with the simulated one then remodel the antenna in the HFSS tool and repeat the entire process until the antenna meets its specifications.

1.4Literature survey

For 5G mobile communications, a circular-shaped elliptical slot dual-band four-element patch antenna is proposed and the measured radiation pattern of the proposed array antenna was not discussed [6]. A 16-element slot-coupled Vivaldi antenna array unit cell at the mm-wave frequencies of 28 GHz and 38 GHz is designed which offers high gain and bandwidth but includes complex construction of antenna [7]. A microstrip circular patch antenna with a modified L-shaped aperture slot that is coupled to a microstrip feedline is proposed [8]. A phased array eight-element 28 GHz antenna with air hole slots for 5G applications with enhanced half power beamwidth (HPBW) is presented, where the inclusion of circuit elements and liquid crystal display (LCD) panel has to be studied on mobile handsets [9]. A switch-based micro-electro-mechanical switch (MEMS) based antenna which works at 35.4 GHz frequency with a bandwidth of 6.64% is based on the concept of reconfigurability is presented but the fabricated prototype is not mentioned with validation results [10]. A planar spiral monopole antenna is built and studied to operate at dual-band frequencies such as

28 and 38 GHz. The suggested antenna has a huge bandwidth of 93% efficiency and a maximum peak gain of 4.73 dBi. [11]. A conservative huge multi-input multi-output (MIMO) double-band array antenna for millimeter-wave communications is introduced which has two indistinguishable direct staged exhibits receiving antenna components that have been utilized at various sides of the cell phone and have a frequency scope of 25 to 40 GHz [12]. A 1×12 slotted resonant array antenna at 38 GHz is designed and developed with a gain of 16 dBi is presented in this paper [13]. The dielectric constant $\varepsilon\_r=2.2$ was used to develop an aperture associated with a stacked microstrip antenna exhibiting wideband performance. Because this antenna has a deeper substrate, it can scan blind spots in a phased array [14]. An antenna array microstrip antenna for 5G smartphones is proposed that operates in the spectral region of 21-22GHz using a Nelcon N9000 substrate with a $\varepsilon\_r>10$ that has excellent directivity and efficiency but suffers from the disadvantage of using a lossy coaxial feed [15]. A mesh grid patch antenna with a resonant frequency of 28GHz and a substrate material similar to that used in mobile telephone printed circuit board (PCB) is presented. It has a high gain compact array structure with a small impedance bandwidth [16]. A Vivaldi antenna with a frequency range of 27.4-28.6GHz, high gain and efficiency, three-dimensional beam steering, and significant mutual interaction between array members is presented [17]. With FR4 substrate and narrow bandwidth, a U-shaped filter employing arrays for 5G millimeter-wave micro lens antenna with a low profile, high efficiency, and gain enhancement [18]. The reconfigurable antenna structure array with a frequency spectrum of 24-28GHz and $\varepsilon\_r=27$ has a wide band, a steady gain of 3600, and significant mutual coupling [19]. A multi-layer patch with Rogers 5880 substrate, low coupled with limited bandwidth, and lost between the feed line and connectors [20]. According to free space calculations, the antenna has high efficiency of approximately 99.98 percent in the V-band, which is about the 60 GHz frequency range. Its performance was improved by the creation of several arrays with various ordering. The planar arrays of 1 2, 1 4, and 2 2 elements in the conceptual dimensions were designed by using parallel-fed and tapered feed line techniques [21]. The main goals of current mm-wave antenna elements research are the attainment of high-gain features and agile directional antennas with wide-scan capabilities. The following sections provide an overview of current advancements in antenna systems for elevated purposes while emphasizing the benefits and drawbacks of the most pertinent designs that can be found in the academic and engineering literature [22]. Various independent datasets are designed for each user in a millimeter-wave down-link multi-user-massive MIMO mixed wideband communication system. According to the simulation results, 256×16 MIMO systems are better suited for eight users, while 128×16 MIMO systems are better for 4 users from different data streams. For millimeter-wave Multi User-massive MIMO networks to attain greater order throughputs, it is strongly advised to have more distinct datasets per user [23]. With the advantages of superior properties such as high thermal conductivity, phased array antennas constructed on the conductive material carbon materials film were developed for 5G millimeter-wave applications. In comparison to a copper linear array, the Graphene-assembled film (GAF) linear proposed antenna has an operating bandwidth that is 212.5 percent wider and side lobes that are 5 dB lower [24]. The bottom plate of the substrate-integrated double-line is built with coupling slots for the proposed antenna's microstrip-to-substrate-integrated double-line transition. Employing bilayer printed circuit board technology, a 16×8 component slot reflector is designed and constructed for verification. From 23.35 to 27.55 GHz, the estimated -10 dB impedance spectrum is available is 16.5% [25].

Based on the above literature a 38GHz millimeter-wave circular array antenna using corporate feed for 5G femtocell applications is designed and proposed contemplations are examined in section 2. Section 3 presents the outcomes and conversations of different circular array antennas that work at 5G frequency groups. Section 4 has the presented the measured results. Eventually, the paper is concluded in Section 5.

2.Design of an antenna

The process flow in the design process of an antenna starts with the application of the antenna as shown in *Figure 1.* The usage of an antenna plays an important role in any communication systems equipment.

The proposed circular antenna array is designed stage-wise from a conventional single antenna structure.

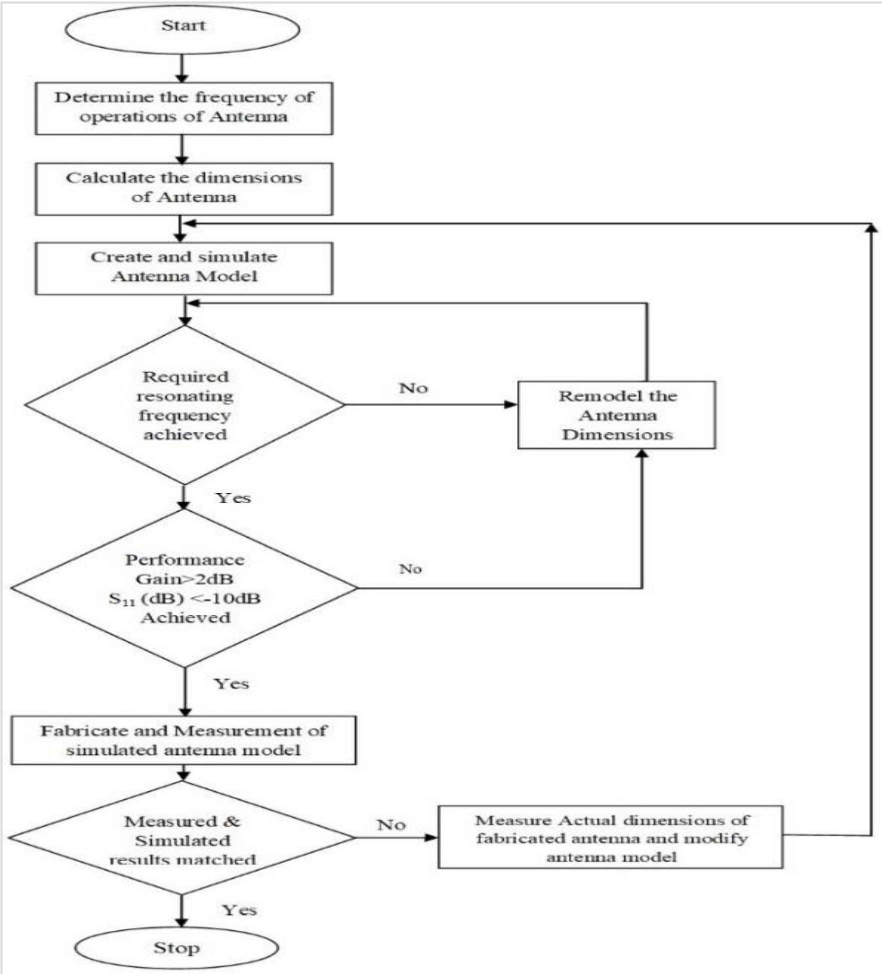


Figure 1 Process flow for the design of antenna

2.1Single element circular patch

The single-element circular patch antenna is constructed using the substrate's height and dielectric constant to obtain the reflection coefficient and impedance bandwidth. The single-element antenna is constructed on Arlon Diclad 880™ substrate material with δ=0.0009 and ε_r= 2.2 with the thickness of the substrate as 0.508mm. The single element substrate size is chosen to be 10mm×12mm where the ground plane is considered as a full plane with a width of 12mm and a length of 10mm at the lower side of the substrate as shown in *Figure 2*. To accomplish the required frequency of 38GHz, a circular patch with a certain radius (a) is considered as given in Equation (1).

The design procedure depends on resonant frequency (f_r in Hz), the dielectric constant (ε_r), and the compactness of the substrate (h in cm).

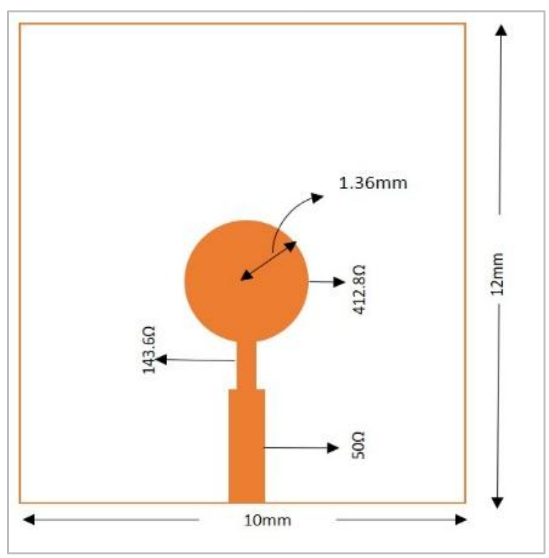


Figure 2 Single element circular patch

The radius of the circular patch a is as follows (Equation 1)

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

Where $\mathrm{F} = \frac{8.791 \times 10^9}{\mathrm{f_r}\sqrt{\varepsilon_r}}$

In terms of Jacobian functions, the input resistance at any radial distance $\rho' = \rho_0$ is given as Equation 2.

$$\mathrm{R_{in}}(\rho' = \rho_0) = \frac{1}{\mathrm{G_t}} \frac{\mathrm{J_1^2(k\rho_0)}}{\mathrm{J_1^2(ka_e)}} \quad (2)$$

where $\mathrm{G_t}$ is the combination of dielectric losses, radiation, and conduction specified as Equation 3-6.

$$G_t = G_{rad} + G_c + G_d \quad (3)$$

Where

$$G_{rad} = \frac{(k_0 a_e)^2}{480}\int_0^{\pi/2}[J_{02}'^2 + \cos^2\theta J_{02}^2]\sin\theta \, d\theta \quad (4)$$

$$G_c = \frac{\epsilon_{m0}\pi(\pi\mu_0 f_r)^{-1.5}}{4h^2\sqrt{\sigma}}[(ka_e)^2 - m^2] \quad (5)$$

$$G_d = \frac{\epsilon_{m0}\tan\delta}{4\mu_0 f_r h}[(ka_e)^2 - m^2] \quad (6)$$

The impedance of the circular patch is computed using the MATLAB tool assuming 50Ω microstrip line feed [26]. Assuming resonant frequency 38GHz with substrate material Arlon Diclad 880™ substrate with ε_r= 2.2 and height of substrate 0.508mm with dielectric constant 0.0009 and the patch impedance and circular patch radius are calculated using Equation (2) and obtained values as 1.36mm and 412.8Ω. The circular patch is fed by a 50Ω microstrip line with dimensions 3.916×1.565mm^2. To compare the impedance of the circular patch to the feed line, a short λ/4 stub of impedance 143.6 Ω is inserted. The dimensions of the stub considered here are 1.513×0.1779mm^2. All the dimensions of the microstrip feed lines are calculated from the available online calculator.

2.21X2 circular patch array antenna

An array antenna is extended using a single element to obtain multiple resonant frequencies. Array antennas are built here and are based on a corporate feed network.

The power splitting in terms of 2^n considering n=2,4, etc. are executed by using the Corporate feed network [27]. This is accomplished by using quarter-wave impedance transformers to match the 50Ω microstrip feed line to two circular patches as shown in *Figure 3*.

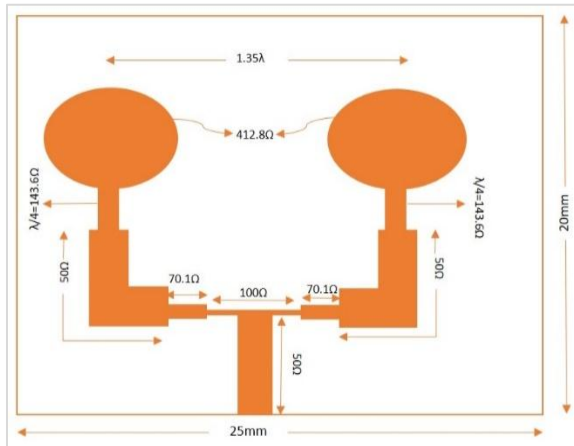


Figure 3 1×2 circular patch array antenna

To match various impedance sources to load impedance a quarter-wave transformer is used which is also called an λ/4 transformer. Any transformer section having an impedance Z_1 can be calculated as $Z_1 = \sqrt{Z_{cr}Z_{50}}$ where Z_{cr} are the 50 ohms line characteristic impedance and Z_{50} is the circular patch input impedance [28]. The array antenna which uses a corporate feed network having lengths and widths which are evaluated at different impedances is tabulated as shown in *Table 2*. These values are only used in antenna structures mentioned in this paper.

2.31×4,4×2, 8×4 circular patch array antennas

The effect of unwanted reflected power is canceled due to corporate feed or parallel feed networks which also have wide bandwidth when compared to other array formats [29].

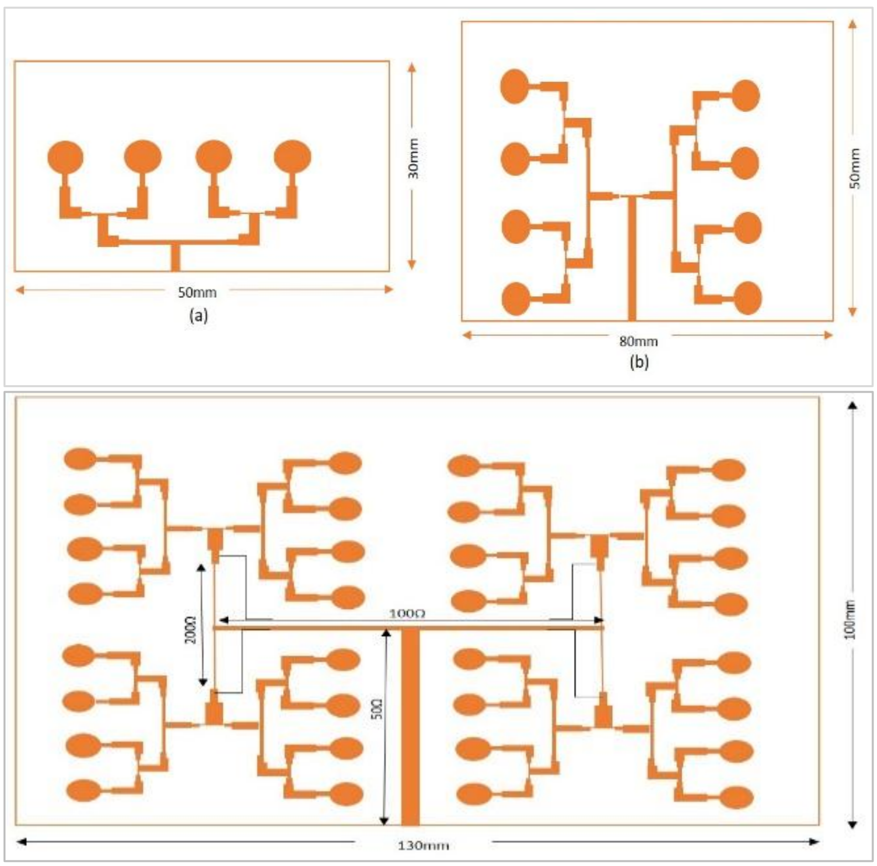
Table 2 Corporate feed dimensions

S. No.	Corporate feed dimensions for *28GHz*			
	Impedance	**Electrical length**	**Length (mm)**	**Width (mm)**
1	50Ω	180^0	3.916	1.565
2	50Ω	90^0	1.958	1.565
3	70.1 Ω	180^0	1.987	0.910
4	100 Ω	180^0	2.02	0.455
5	200 Ω	180^0	2.08	0.539

S.No.	Corporate feed dimensions for 38GHz			
	Impedance	**Electrical length**	**Length (mm)**	**Width (mm)**
1	50Ω	180^0	2.885	1.565
2	50Ω	90^0	1.442	1.565
3	70.1 Ω	180^0	1.464	0.910
4	100 Ω	180^0	1.488	0.455
5	200 Ω	180^0	1.533	0.539
6	143.6 Ω	90^0	1.513	0.1779

The array networks are extended to 4-Element, 8-Element, and 32-Element for high reflection coefficient at 26GHz, 28GHz, 37GHz to 39GHz with considerable gain and bandwidth. The feeding technique is also extended with the same dimensions as mentioned in *Table 2*. The separation between the patch elements in any of the array antennas is considered to be 1.35λ as shown in *Figure 4* to *Figure 6*.

Figure 4(a) describes the dimensions of the 1X2 patch array antenna is duplicated for 4 element array antenna which is joined by a 50**Ω**-70.1**Ω**-100**Ω**-70.1**Ω**-50**Ω** feed network. A difference of 1.35λ is maintained between the circular patches. The 8×4 antenna array is designed and executed using the ANSOFT HFSS version 19 tool which is commercially available in the market.



(c)

Figure 4 (a) 1×4 Circular Array Patch Antenna (b) 4×2 Circular Array Patch Antenna (c) 8×4 Circular Array Patch Antenna

The analysis of the mm-wave antenna is gauged in terms of efficiency, gain, axial ratio radiation characteristics, and reflection coefficient which narrates the polarization. *Figure 4(b).* Shows the 8-Element array antenna which uses two 1×4 array structures joined by 70.1Ω-100Ω-70.1Ω feed lines connected by 50Ω input feed. The 50Ω feed has been extended and adjusted for a spacing between the 4-Element to the next 4-Element, which is 21.65mm in length. The objective of the paper is achieved finally by combining four 4×2 patch array antennas into an 8×4 circular patch array antenna. The feed has to go to four arrays simultaneously. To achieve that first 50Ω is divided into two 100Ω and later it is divided into two 200Ω feed lines as shown in *Figure 4(c).* As stated earlier all individual 4×2 array antennas are fed by 50Ω only with the same dimensions. To match 200Ω feed lines to 50Ω a quarter-wave transformer is used which leads to the impedance of 100Ω. And here the vertical length of shown 200Ω is considered 30.5mm and the horizontal length of 100Ω is considered 53.5Ω finally for input 50Ω vertical length is considered 42.345mm. The analysis is accomplished on one element,1×2,1×4, 4×2, and 8×4 antenna arrays and furnished in the following Section 3.

3.Results and discussion

The 1×4, 4×2and 8×4 circular array patch antennas are designed and simulated using the Ansoft HFSS version 19 tool which is commercially available in the market. The analysis of the mm-wave antenna is gauged in terms of radiation characteristics, efficiency, gain, reflection coefficient, and an axial ratio that narrates the polarization. The reflection coefficient recounts the impedance mismatch of the load.

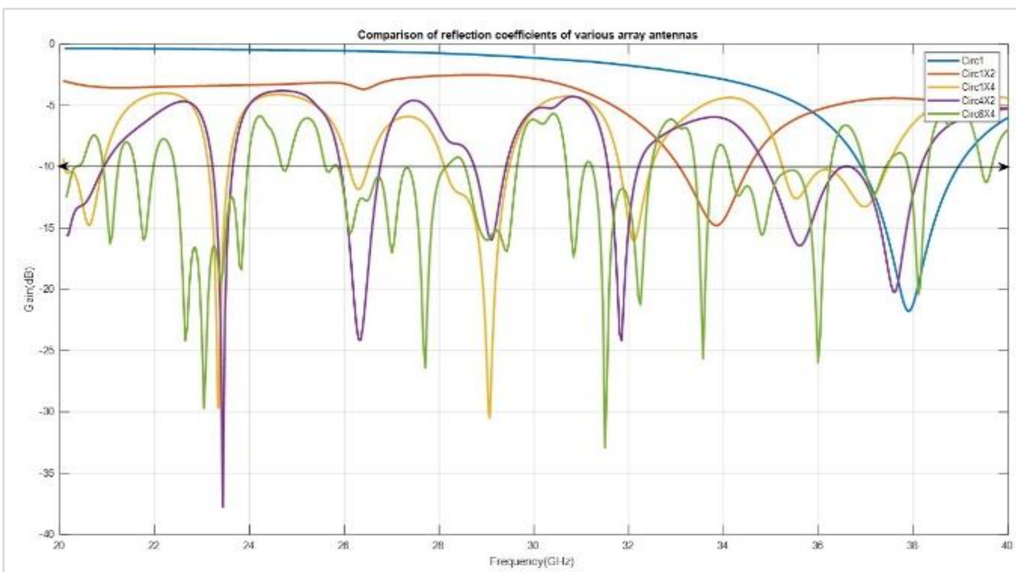


Figure 5 Comparison of reflection coefficients of various circular patch array antennas

The reflection coefficient versus frequency characteristics for different circular patch array antennas is shown in *Figure 5.* The single element circular patch antenna has diverged at one frequency 37.9GHz with an S_{11}(dB) of -21.78dB but with sustainable high impedance bandwidth of 2.06GHz and gains as 8.17dB. The size of the antenna is 10X12 mm^2 which is an insignificant size for fabrication as well as measurement. So array antennas are proposed in this paper. As we know array antennas are generally multiband antennas. As the millimeter-wave bandwidth is very large, each country has chosen different frequency bands for 5G Communications but many of the countries are concentrating on frequency bands like 26GHz to 29GHz range and 37GHz to 39GHz. Even though proposed array antennas are radiating at multiple bands, performance metrics like S_{11}(dB), Gain, Bandwidth, and Efficiency are considered only on a few working bands. When two circular patches are considered making a 1×2 Circular patch array antenna the resonating frequency has changed to 33.86GHz with a reflection coefficient value ha -14.77dB but there is an improvement in the gain of 1.3dB i.e 9.41dB. Four element circular patch antennas are designed and analyzed as 1×4 circular patch array antenna where this type of proposed antenna is radiating at multiple frequency bands out of which only four frequency bands are considered like 23.33GHz, 26.31GHz, 29.06GHz, and 37GHz with reflection coefficient values as -29.9dB, -11.82dB,-30.47dB and -13.24dB. The gain values are also ranging from 8 to 10.7dB which is considerably high. Next, this particular antenna is extended to an eight-element array antenna, it is also acting like a multi-band antenna where four frequencies are considered to be working bands like 26.34GHz, 29.11GHz, 35.63GHz, and 37.62GHz with reflection coefficient values like -24.12dB,-15.93dB,-16.4dB and -20.22dB. In this type of antenna, the reflection coefficient values obtained are higher in a lower frequency band, therefore antenna efficiency is lower at these frequencies [30]. The maximum antenna efficiency can be obtained at a 37.62GHz frequency. The 4×2 circular patch array antenna has a wide bandwidth 3.3GHz ranging from 34.84GHz to 38.14GHz whereas our proposed circular patch array antenna resonating frequency exists with a considerable gain of 11.03dB at 38.01GHz. The various antenna arrays with the simulation results are tabulated in *Table 3.*

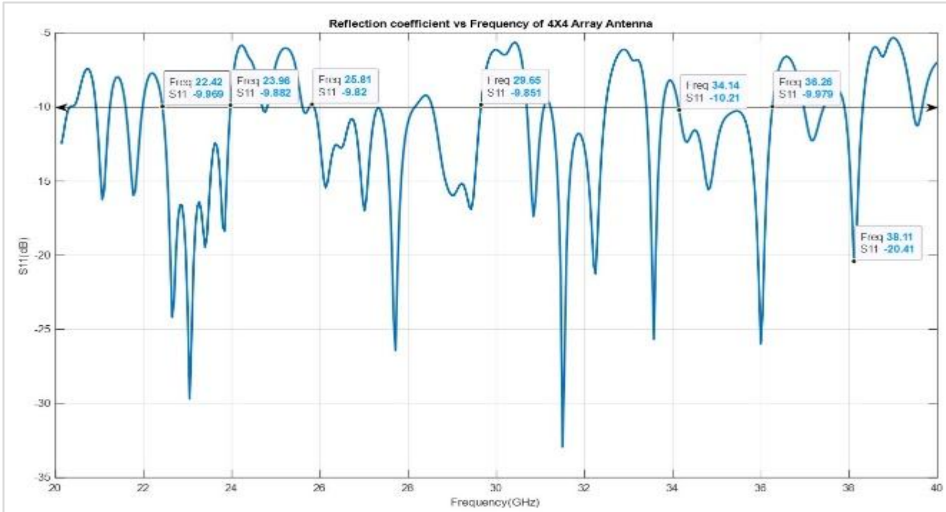
Performance metrics like radiation characteristics, VSWR, reflection coefficient, axial ratio, and 3dB gain are analyzed and compared the results with measured in one of the 8X4 Circular array antennae. Fabrication is performed for this antenna because it has wideband attributes where the most extreme working groups like 26GHz, 28GHz, 37GHz, 38GHz, and 39GHz are considered operating frequencies for millimeter wave communications.

Table 3 Simulated results of various array antennas

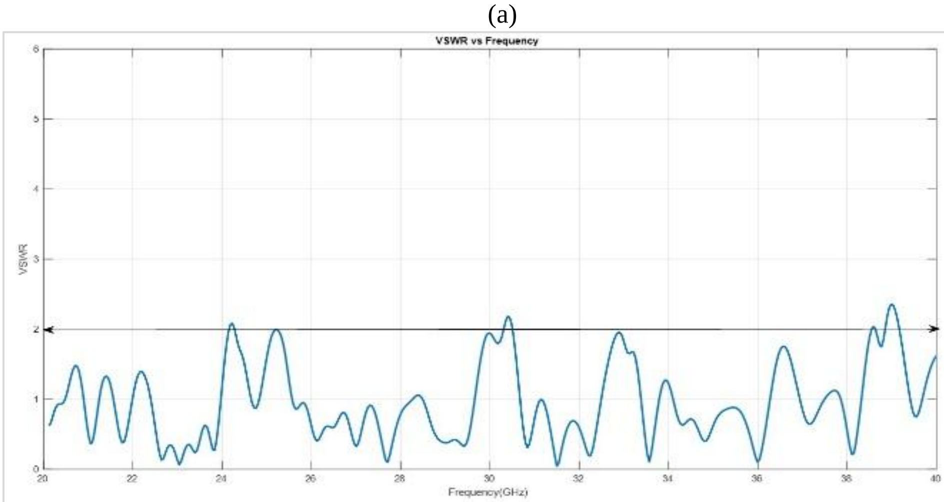
S. No.	***1X1* Circular Patch**				
	Frequency (GHz)	S_{11} **(dB)**	***Gain* (dB)**	**Imp BW (GHz)**	**Efficiency (%)**
1	37.9	-21.78	8.17	2.066	102
			1X4 Circular Patch Array Antenna		
1	23.33	-29.66	8.19	0.42	96.5
2	26.31	-11.82	9.06	0.42	98.9
3	29.06	-30.47	10.73	1.35	100
4	37	-13.24	8.92	2.2	102
			4X2 Circular Patch Array Antenna		
1	23.43	-37.76	9.28	0.44	96
2	26.34	-24.12	10.33	0.88	97.3
3	29.11	-15.93	13.3	0.70	98.4
4	35.63	-16.4	10.95	3.3	99.2
5	37.62	-20.22	11.21	3.3	99

Various multiple frequency bands exist in the return loss plot with high efficiency and impedance bandwidth. The reflection coefficient values are observed as -13.57dB, -10.75dB, -10.58dB, -14.25dB and -10.71dB at resonating frequencies like 26.03GHz, 28.01GHz, 37GHz, 38.01GHz and 39.47GHz is as shown in *Figure 6(a).* The fractional bandwidth (FBW) is calculated at three different frequency band regions considering the range from 25.15GHz to 28.14GHz where the FBW is about 11.2%. In the second range, which is considered from 34.14GHz to 37.25GHz the FBW is 8.7% and its value is still decreased to 5.4% when it is considered from 36 GHz to 38GHz. The amount of electromagnetic energy reflected by impedance discontinuity is indicated by the return loss. For any commercial applications, VSWR<=2 is suitable because the return loss would be -9.54 dB or -10dB [31]. The VSWR values like 1.52,1.8,1.83,1.48 and 1.82 at resonating frequencies like 26.03GHz, 28.01GHz, 37GHz, 38.01GHz, and 39.47GHz are obtained for the 8X4 circular patch array is as shown in *Figure 6(b).*

There is a decrease in 3dB gain values and reflection coefficient values as the frequency ranges are increasing except 38.01GHz as shown in *Figure 7(a)* to (e) and these are summarized in *Table 3.* The observation was done with radiation performance which is degrading with an increased level of side lobes due to the feeding network [32].

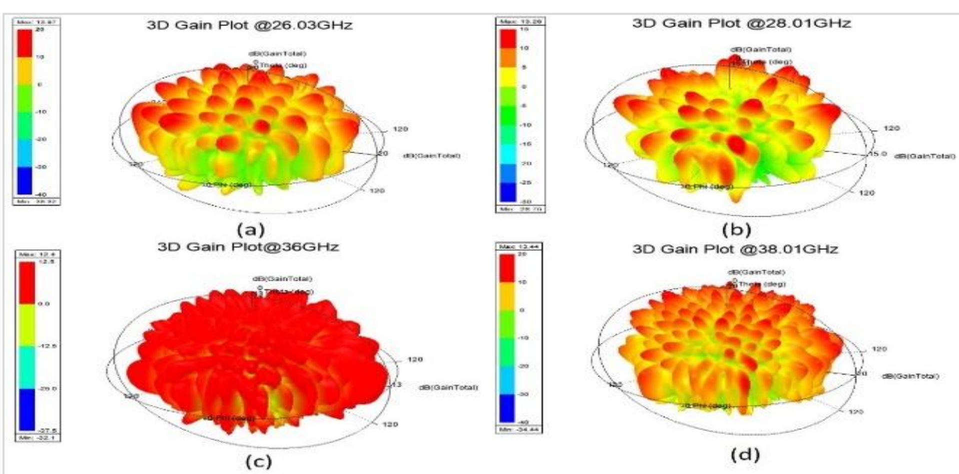


(a)

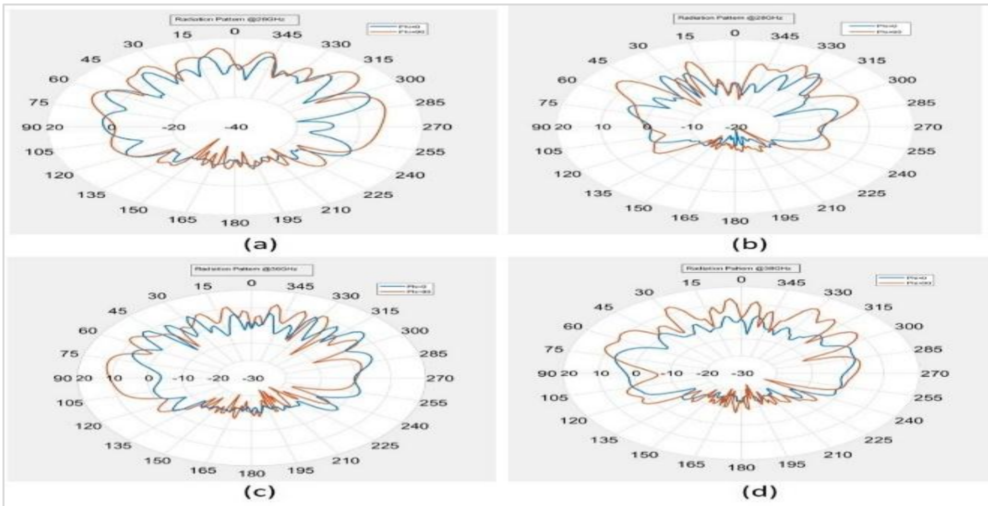


(b)

Figure 6 (a) Reflection Coefficient of 8×4 Circular Patch Array Antenna (b) Voltage Standing Wave Ratio vs Frequency Plot of 8×4 Circular Patch Array Antenna



(i)



(ii)

Figure 7 (i). 3D Gain Plots of 8×4 Circular Patch Array Antenna @various frequencies from (a): (d)
(ii) Radiation patterns of 8×4 Circular Patch Array Antenna @multiple frequencies from (a): (d)

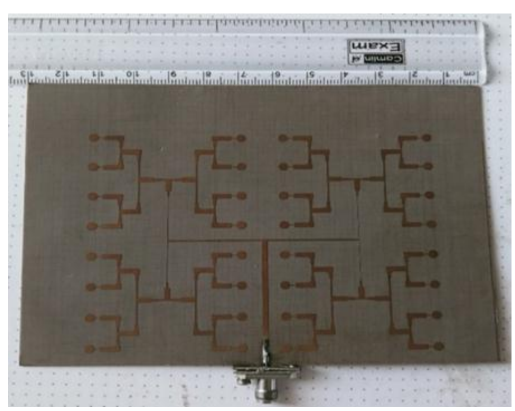
The proposed 8X4 Circular patch antenna radiation patterns at mm-wave frequencies like 26.03GHz, 28.01GHz, 37GHz, 38.01GHz, and 39.47GHz are estimated in both YZ-plane and XY-planes as shown in *Figure 7(b) (a):(e).* It is noticed that the radiation pattern at $\emptyset = 0^o$(E-plane) has more number of sidelobes compared to $\emptyset = 90^o$(H-plane). This is because, at millimeter-wave frequency bands, the radiation pattern is disturbed because of the increasing propagation modes [33], in which their maximum gains are 6.97dBi, 6.26dBi, 5.72dBi, 5.44dBi, and 5.20dBi. All the simulated values of the 8×4 circular patch antenna are tabulated in *Table 4.*

Table 4 Simulated results of 8X4 circular patch array antenna

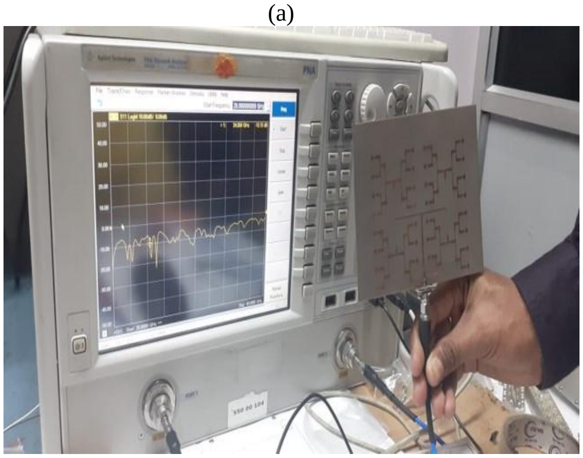
S. No.	8X4 circular patch array antenna				
	Frequency (GHz)	***S_{11}* (dB)**	***Gain* (dB)**	**Imp BW(GHz)**	**Efficiency (%)**
1	26.03	-13.57	6.97	2.29	93
2	28.01	-10.57	6.26	2.29	93
3	37	-10.58	5.72	0.48	94
4	38.01	-14.25	5.44	0.44	93
5	39.47	-10.71	5.20	0.22	90

4.Measured results

The substrate Arlon Diclad 880™ with a δ=0.0009 and ε_r= 2.2 is used for the fabrication of an 8×4 circular array antenna with the thickness of the substrate of 0.02" [34]. *Figure 8(a)* represents the fabricated prototype in both top and bottom views. The Agilent E8363C PNA Network Analyzer is utilized for the estimation of antenna execution qualities. The range of the network analyzer is from 10 MHz to 40 GHz. There is an occurrence of a wide frequency band when deliberate reflection coefficient versus frequency is plotted with the occurrence of moderate S_{11}(dB) values. The reflection coefficient esteems are seen as -23.35dB, -16.87dB, -16.91dB, -9.54dB and -9.43dB at resonating frequencies like 20GHz, 25GHz, 30GHz, 35GHz and 40GHz [35, 36] is as displayed in *Figure 9(a).*



(a)

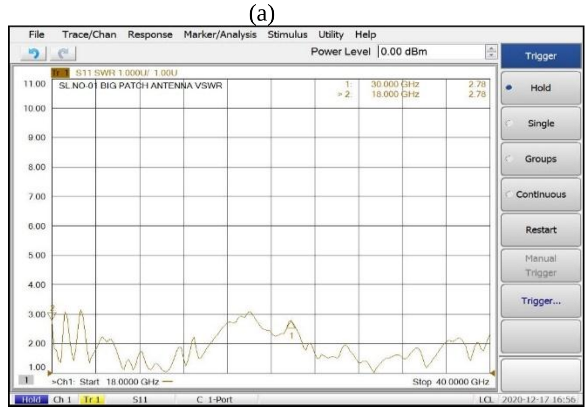


(b)

Figure 8 (a) Photograph of Fabricated Prototype of 8×4 circular array antenna (b) Measurement setup for 8×4 circular array antenna

In *Figure 9(b),* measured VSWR versus resonant frequencies had values of 2.02, 2.0, 1.33, 1.33, and 1.15 at 40GHz, 35GHz, 30GHz, 25GHz, and 20GHz. The radiation patterns for the proposed 8X4 Circular patch antenna at mm-wave frequencies like 20GHz, 25GHz, 30GHz, 35GHz, and 40GHz are estimated and gains are determined as 6.18dBi, 3.10dBi,3.94dBi,2.95dBi, and 0.23dBi utilizing Far-field arrangement in the Anechoic chamber [37] as shown in *Figure 10.* A complete list of abbreviations is shown in *Appendix I.*

(a)



(b)

Figure 9 (a) Measured S_{11}(dB) vs Frequency plot for 8×4 circular array antenna (b) Measured VSWR vs Frequency plot for 8×4 circular array antenna

The simulated and deliberated results are organized in *Table 5* which particularly describes the reflection coefficient values. It is located that the simulated reflection coefficient values are bad while in comparison to measured results.

Table 6 suggests the contrast of present array antenna designs with the proposed antenna array which fits at 5G frequencies. This table includes the performance metrics like bandwidth, array size, resonating frequencies, gain, etc. These metrics indicate that the proposed millimeter-wave array antenna is best suitable for self-installable low-profile Femto-base stations in 5G communications other than existing antenna designs.

Table 5 Simulated vs measured results comparison

S. No.		**8×4 circular patch array antenna**		
		Frequency (GHz)	**Simulated**	**Measured**
1	S_{11} (dB)	20GHz	-11.50	-23.35
2	Gain (dBi)		6.43	6.18
3	S_{11} (dB)	25GHz	-10.33	-16.87

S. No.		8×4 circular patch array antenna		
		Frequency (GHz)	Simulated	Measured
4	Gain (dBi)		5.03	3.10
5	S_{11} (dB)	30GHz	-5.93	-16.91
6	Gain (dBi)	30GHz	5.14	3.94
7	S_{11} (dB)	35GHz	-11.48	-9.54
8	Gain (dBi)	35GHz	4.48	2.95

Table 6 The proposed antenna with other existing antennas comparison

S. No.	Design	Structure	Dimension (mm^2)	Resonant frequencies	Gain (dBi)	Bandwidth (GHz)
1	[11]	Series fed 1×12 array antenna	5.7×2.85	38GHz	16	-
2	[10]	Eight leaf-shaped bow-tie antenna	4.6×36.8	28,38 GHz	9	45% (FBW)
3	[9]	Dual-band spiral planar monopole antenna	4×8	28,38 GHz	10.4, 12.7	6.35 GHz, 8.4 GHz
4	[8]	Pattern Reconfigurable antenna with MEMS switches	4×5	35.4 GHz	5.68	4.39% (FBW)
5	[7]	5G phased array antenna with air-hole slots	130×42	28.2GHz	10.33	7.09% (FBW)
6	[6]	A wideband circularly polarized antenna	6×6	29GHz	15.83	13.8% (FBW)
7	[5]	1×4 slot-coupled Vivaldi antenna	73.4×19.3	28,38 GHz	15	46% (FBW)
8	[4]	Elliptical Slot Circular Patch Antenna Array	6×6	28,45 GHz	7,6, 7.21	1.3GHz, 1GHz
9	Proposed	Millimeter Wave Circular Array Antenna Using Corporate Feed	130×100	26.03, 28.01, 37,38, 39.47 GHz	6.97, 6.26, 5.72, 5.44, 5.20	11.2%, 8.7%, 5.4% (FBW)

5.Conclusion

Circular array antennae like one element, 1×2, 4×2, and 8×4 arrays are designed and simulated. Based on the performance of the 8×4 circular array antenna is fabricated and results were measured which are quite comparable with executed results from HFSS. The proposed 8×4 array antenna is resonated at 26, 28, 37, 38, and 39.47GHz with excessive gain and efficiency. The 32- element array antenna also accomplished left-hand circular polarization with axial ratio values less than 3dB at all considered frequencies. The radiation pattern at E-plane and H-plane is disturbed since at millimeter frequency bands there is an increase in the number of modes. Due to the compactness in size of the 8×4 array antenna, it can be easily integrated with 5G femtocells which are currently used in indoor communications.

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None.

Conflicts of interest

The authors have no conflicts of interest to declare.

Author's contribution statement

Harini V: Conceptualization, investigation, writing – original draft, writing – review and editing-data collection, **Sairam M V S:** Conceptualization, writing – original draft, analysis and interpretation of results. **Madhu R:** Study conception, design, data collection, supervision, investigation on challenges and draft manuscript preparation.

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Appendix I

S. No.	Acronym	Description
1	5G	Fifth Generation
2	BS	Base Station
3	FBW	Fractional Bandwidth
4	GAF	Graphene-Assembled Film
5	HetNet	Heterogeneous Network
6	HFSS	High-Frequency Structure Simulator
7	HPBW	Half Power Beamwidth
8	ITU	International Telecommunication Union
9	LCD	Liquid Crystal Display
10	LHCP	Left-hand Circular Polarization
11	MATLAB	Matrix Laboratory
12	MEMS	Micro-Electro-Mechanical Switches
13	MIMO	Multi Input Multi Output
14	PCB	Printed Circuit Board
15	QoS	Quality of Service
16	RF	Radio Frequency
17	TRAI	Telecom Regulatory Authority of India
18	VNA	Vector Network Analyzer
19	VSWR	Voltage Standing Wave Ratio