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Narrow beamwidth conical dielectric resonator antenna

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The document depicts a novel technique of reducing beamwidth by modifyingthe geometry of Dielectric Resonator Antenna. This work can serve up as a source of narrow beam DRA model. The beam is made more directive by reducing the beamwidth and, to this end, diverse geometries such as hemispherical (HS), snap head (SH), concave (CV), Cone[CN] have been stacked on already prevailing rectangular dielectric resonator antennas (RDRA) to reduce beam-width, high gain of the antenna for applications in wireless local area networks (WLAN), line of sight (LOS) communication, etc.The submitted concept is endorsed by numerous interesting numerical results, involving HFSS full-wave electromagnetic simulations. Further, the conical lens structure seems to present the highest gain of 8.23 dBi with a reasonable beamwidth of 48.33°in E plane and33.44^0 in H plane. Hence, conical geometry is fabricated and measured to present the best outcomeamongstall geometries. Its operating frequency band ranges from (5.55GHz to 5.89 GHz).The modelis additionallyexamined for circular polarisation. The orthogonal mode pair of higher-ordermode $\mathrm{TE}^{x}_{\delta 15}$and $\mathrm{TE}^{y}_{1\delta 5}$ has been excited at frequency 5.67 GHz and 5.74 GHz,correspondingly.The impedance matching bandwidth of 2.97% (5.55-5.89 GHz) in concurrence with axial ratio bandwidth of .61%(5.67-5.74 GHz) has been accomplished. This can be established as a forthcomingstrategy on beam control, which may substitute bulky phase shifters employed in radars.

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Keywords: Conical dielectric resonator antenna, Beamwidth, Axial ratio

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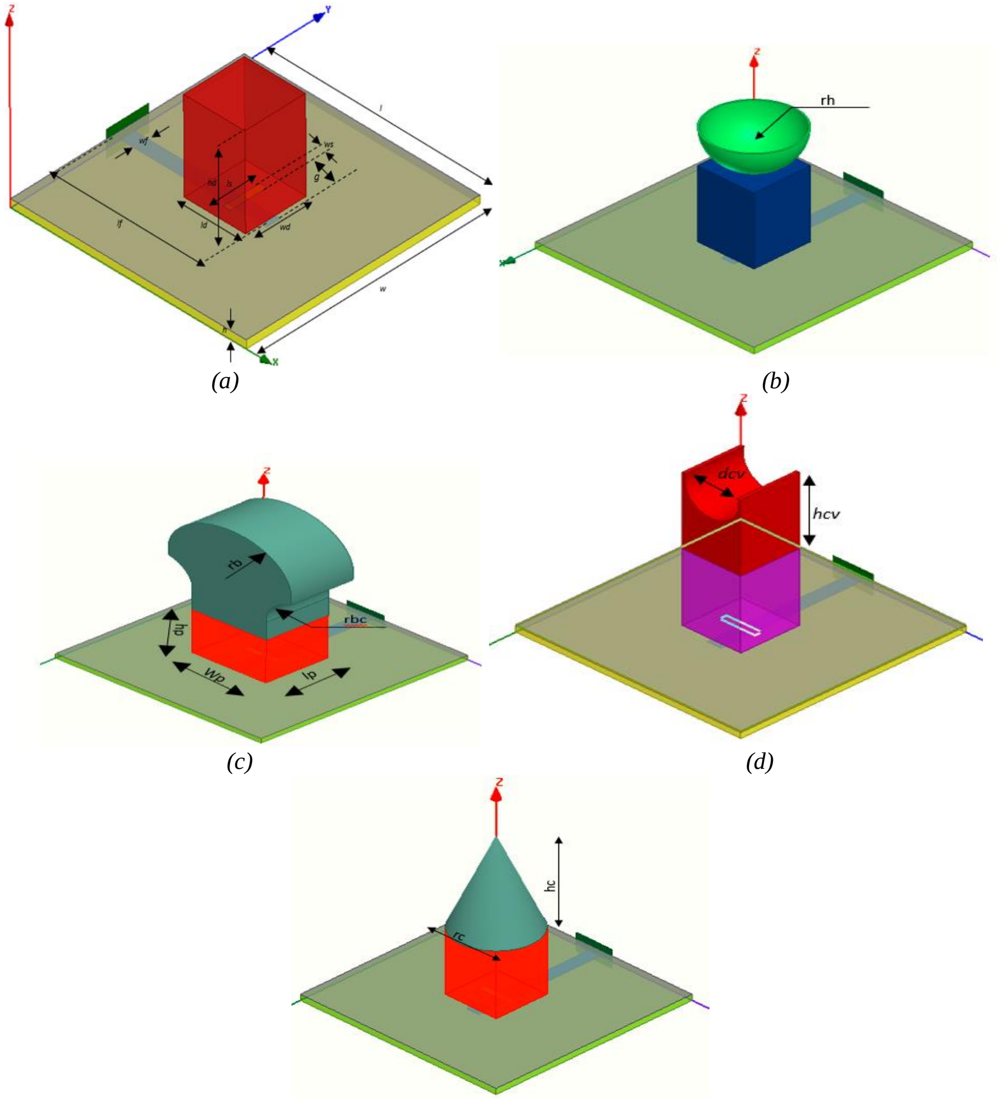
1. Introduction

In holding up with the headway made throughout the last few decades in high gain antennas for applications in line-of-sight (LOS) communication, there has been an escalatingchallenge for more dynamic beamwidth and direction-controlled antennas with a robust build to withstand the severe environment. Dielectric material does offer losses at all frequency bands. There is not any way to forestall dielectric losses neither are they negligible, but they can be managed by appropriate antenna design that can furnishelevated gain and efficiency.The most common antenna geometry in applications where higher gain and directivity is needed is the Yagi Uda antenna. Yagi Uda antenna also described as the beam antenna comprises of a driven element, reflector, and directors. They were extensivelyemployed as a television antenna; however, the size was very massive [1]. The gain of a Yagi Uda antenna is administeredpredominantly by the number of elements in the RF antenna. The Yagi Uda antenna conceived with 15 elements [2] had 3dB beamwidth of 28.87° in E-plane and 30.52° in the H plane. This style of antenna is big in size and undergoes many losses owing to the conducting part.With the advent of technology, the printed Yagi Uda antenna was created. To enhance the directivity, the Yagi Uda antenna has been widely used due to its planar geometry and ease in the design process [3]–[5]. A novel hybrid water antenna with tuneable frequency and beamwidth attribute was also suggested. The antenna employs an L-shaped strip feeder to efficiently broaden the operating bandwidth. Meanwhile, by shifting the number of director elements, the recommended antenna could be tuned to different beam widths and gains. The beamwidth is established by dictating the number of director elements [6]. Efforts had also been done to generatenumerousbeamwidthapplying a phased array [7]. Large bulky horn antennas have been employed for periods as directive antennas. Such antennas used in submissions like direction-finding in surveillance, but the consumption of rotary joints has constrained its life. Rectangular dielectric-loaded substrate integrated waveguide (SIW) H-plane horn antennas, operating at numerous frequencies in the range of 21 GHz to 28 GHz have been manufactured and tested for better gain and beamwidth [8][9]. The additionalrecommended method for directing antenna beamwidth is aperture width modification [10]. Another suggestedpractice is placing an RF lens in front of the broadband antenna for beamwidth compensation [11]. Frequency selective surface (FSS) superstrate is planned to control the beamwidth of a horn antenna array [12]. The capacitor and varactors diodes applied to produce variable beamwidth add to the complication of circuits. A phased array had beenapplied as a feed for reconfigurable PRS antenna, which scores in a simultaneous beamwidth control,conversed in [13][21].Beamwidth of Patch antennas is altered using power divider, a metallic reflector, and numerous PIN diodes [14]. The patch antenna deteriorates from many losses. Numerouspreviousstudies are reviewed in [15-16]. A tilted dielectric resonator antenna (TDRA) for a directional far-field pattern is considered in [17][18].An electronically controlled beam steerable dielectric resonator antenna is discussed in [19][20].The similar concept quoting the variation in the directivity and beamwidth of the DRA with the variation in the height of the radiator [21]-[24]

The paper studied the behaviour of dielectric resonator antenna with different shapes of lens such as concave, conical, convex, etc. Several geometries such as hemispherical (HS), snap head (SH), concave (CV), Cone (CN) have been researched, and the variation in their radiation pattern with varying boundary conditions have been analysed. By changing the shape of DRA divergence and convergence of the generated field inside the radiator changes which changes the beamwidth of antenna. Specific shape of the dielectric material focuses electromagnetic radiation into the desired pattern. Depending on the type of shape and application, the radiation can be focused to a certain point or spread out to cover a wider area. The functioning of specific shape can be compared with lenses which also commonly used to shape the beam of an antenna.Theanalysis of various geometries have been submitted in the next section followed by a reasonableevaluation and discussion of the simulated results. Further, CN-DRA has been fabricated and measured, displaying the good quality results contrasted to other geometries.

2. Antenna geometry

Fig. 1(a) depicts the geometry of a general rectangular DRA using FR-4 epoxy substrate with a permittivity $\varepsilon_r$of 4.4 and TMM13i for the rectangular dielectric resonator on top having a permittivity of 10. Further, the figurewith dissimilar geometries such as hemispherical (HS), snap head (SH), concave (CV), cone (CN) stacked with the RDRA have been introduced in Fig 1(b)-1(e). Dimensions for the same have been portrayed in Table 1.



(a) *(b)*

(c) *(d)*

(e)

Fig. 1. Different Geometries for Dielectric resonator antenna (DRA); (a) Rectangular; (b) Hemispherical [HS] (c) Snaphead [SH]; (d) Concave [CV]; (e) Cone [CN] (color online)

The feed line at the back of the FR-4 substrate is a 50Ω microstrip line with a copper ground on the other side of the dielectric along with a radiating slot in it. The width of the feed line, *wf*is defined using the equation,

$$w_f = \frac{7.48h}{e^{\frac{\varepsilon_r+1.41}{87}}} - 1.25t \qquad (1)$$

where h is the height of the substrate and t is the thickness of the copper cladding for ground and microstrip line. Further, the length of the slot (ls) is dependent on the frequency of operation, and is described by the equation,

$$l_s = \frac{0.566\lambda_0}{\varepsilon_r+\varepsilon_s} \qquad (2)$$

where $\lambda_0$is the wavelength of the operating frequency,ε_r is the dielectric constant for substrate and $\varepsilon_s$is the dielectric constant for the rectangular resonator on the top. Further, the width of the slot does not affect the antenna in any way and is kept to *0.2l*

Table 1. Description of dimensions marked in Fig. 1.

Name	Value	Unit	Description
l	50	mm	Length of Substrate
w	50	mm	Width of Substrate
h	1.56	mm	Height of Substrate
t	0.035	µm	The thickness of Copper Cladding
wf	3.5	mm	Width of Feedline
lf	32	mm	Total Length of Feedline
ls	7.84	mm	Slot Length
ws	1.5	mm	Slot Width
ld	13.15	mm	Length of Dielectric Resonator 1
wd	13.15	mm	Width of Dielectric Resonator 1
Hd	18	mm	Height of Dielectric Resonator 1
g	6	mm	Stub Length
hcv	18	mm	Height of Dielectric Resonator holding concave structure
dcv	13	mm	The diameter of the Concave structure
lp	15	mm	Length of Dielectric Resonator 2
wp	18	mm	Width of Dielectric Resonator 2
hp	15	mm	Height of Dielectric Resonator 2
rb	15	mm	The radius of the Snaphead
rbc	9	mm	The radius of Side snap head
rc	9.19	mm	The radius of cone
hc	21.2	mm	Height of cone

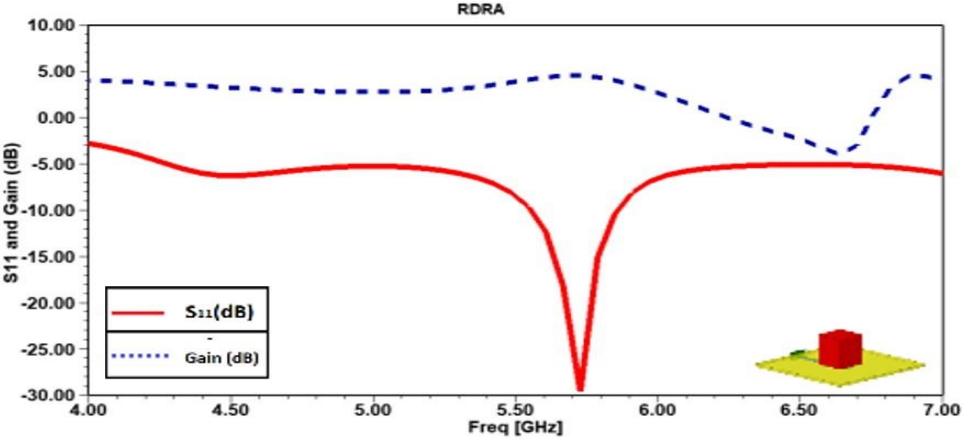
3. Simulated results

All the designs are optimized to operate at 5.7 GHz. The S-parameter and gain findings for different designs are presented in Fig. 2. The gain isnearly stable for the desired frequency span.The dielectric structure on top can be considered similar to an optical lens. The spherical wavelet radiated by the element below, as it passes through the dielectric resonator, the change in material changes the speed of the wave in different sections, and hence converting the spherical wavelet to a planar wavelet while controlling the direction of radiation. Hence, with change in shape of the dielectric resonator, the medium of travel for the radiated wavelet is vary and hence, controlling the beamwidth of the antenna. The directivity,gain as well as radiation patterns are noticed to be varied for distinct cases.By changing the shape of DRA divergence and convergence of the generated field inside the radiator changes which changes the beamwidth of antenna.Each shape changes the shape of wavelet differently.So, the shape of the wavelet decides the beamwidth of the antenna. More planar the wavelet is, more narrow the beamwidth will be.A concave/convex DRA has a much smoother transition in wavelet because change in medium from dielectric to air is very smooth. For conical geometry height in centre is large and elevation in corners is very small.So it reshapes the wavelet accordingly.So for conical structure, the medium changes very late in the centre, but it changes very rapidly on the sides

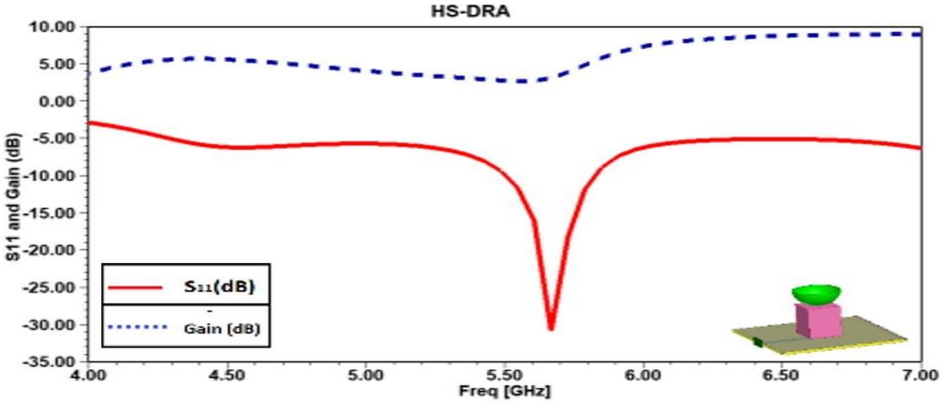
Conical lens structure seems to present the highest gain of 8.23 dBi with a reasonable beamwidth of 48.33^{o} in E plane and 33.44^{0} in H plane.Further, the radiation pattern for numerous geometries displaying E and H plane 3 dB beamwidth is submitted in Fig. 3, which shows a variation in the E plane and H plane beamwidth of the radiated beam from 48.33^{o} to$175\ ^{o}$.

It can be resolute that energy gets focused in one direction because of the lens behaviour of the structure, and hence it reduces the beamwidth of the antenna.Power transfer will getenhanced in a distinctfocus. As beamwidth is narrow down, gain and directivity will upsurge. There survives a transposedassociation between beamwidth and bandwidth of the antenna. Simulated efficiency findings with variation in frequency for General-DRA, CV-DRA, CN-DRA arerevealed in Fig. 4. The efficiency is better than 90% for all the designs.

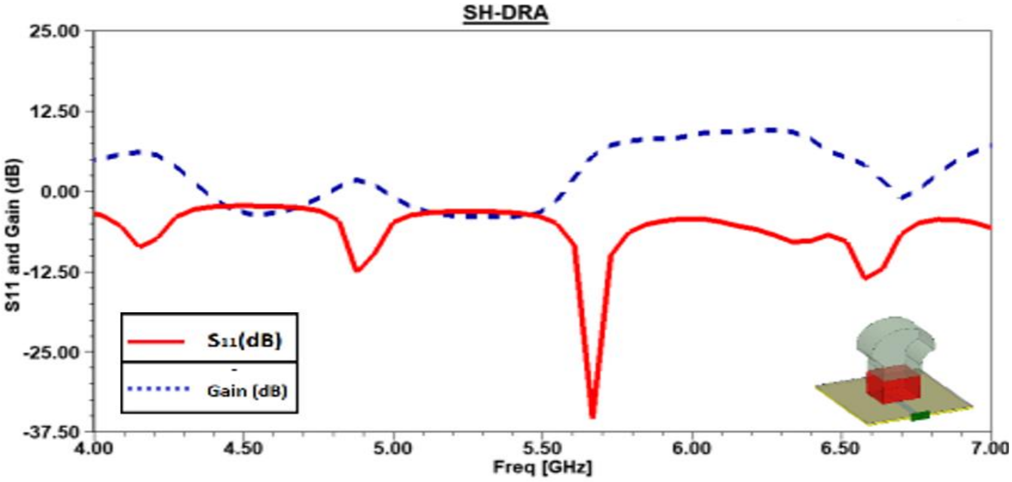
The CN-DRA geometry is additionalexplored for circular polarisation. The orthogonal mode pair of higher-order $TE^{x}_{\delta 15}$ $and\, TE^{y}_{1\delta 5}$has been excited at frequency 5.67 GHz and 5.74 GHz correspondingly as expressed in Fig. 5.As the antenna is directional and beamwidth is narrow, the axial ratio of CN-DRA antenna is examined concerning theta at the various value of phi that is 0^0, 90^0 and 180^0 as revealed in Fig. 6(a). It has been noticed that at theta=136^0 and phi=90^0, an axial ratio of .17 dB is acquired. Additionalscrutinizing axial ratio vs frequency in Fig. 6(b), axial ratio is beneath 3 dB in the frequency range (5.67GHz-5.74GHz), demonstrating circular polarisation. The LHCP and RHCP pattern of the antenna is verified in Fig. 6(c), exhibiting an LHCP radiation pattern with the distinction of 18dB concerning the RHCP pattern. The impedance bandwidth of 2.97 % (5.55-5.89 GHz) in concurrence with axialratio bandwidth of .61 %(5.67-5.74 GHz) has been accomplished for CN DRA geometry.



(a)



(b)



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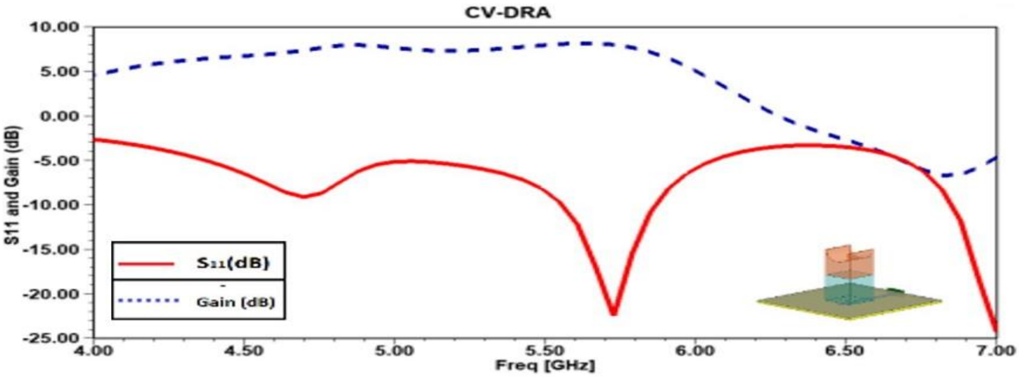

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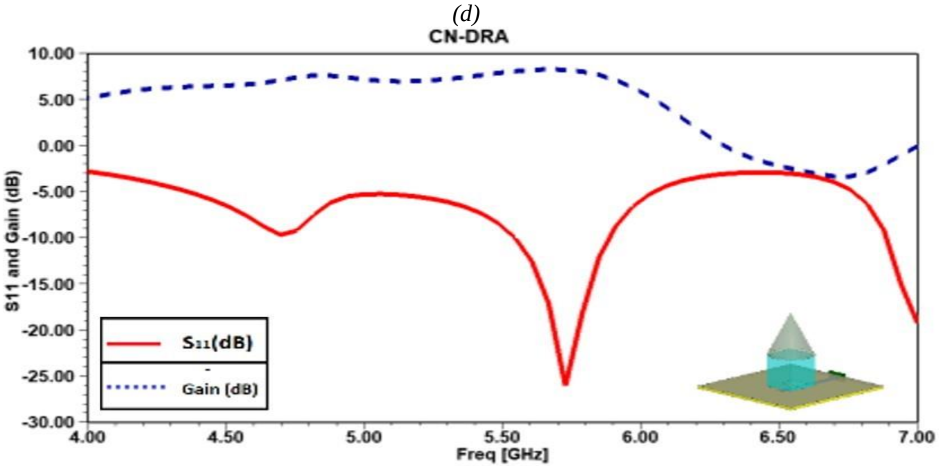
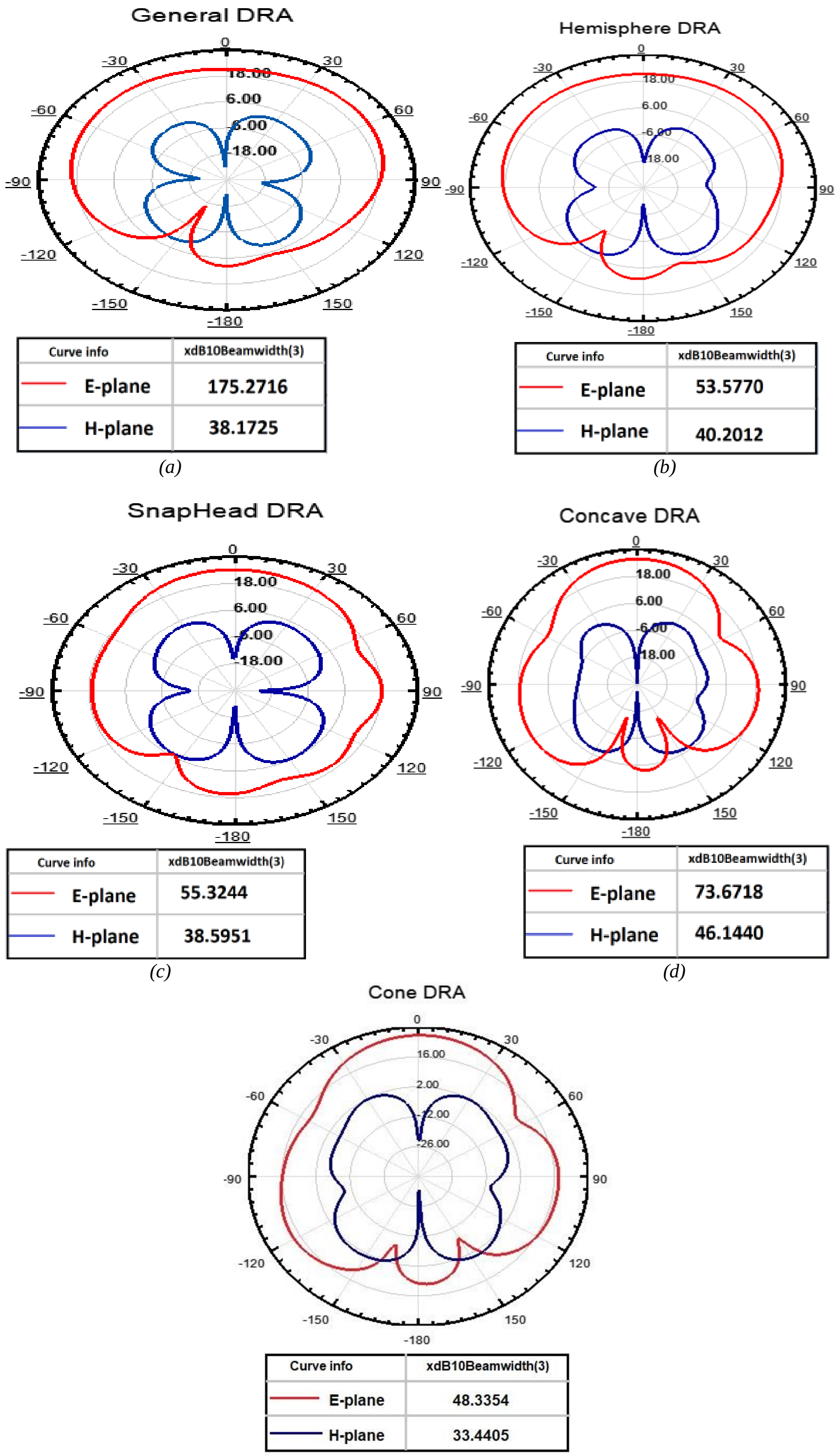


(e)

Fig. 2. Different Geometries for Dielectric resonator antenna (DRA); (a) Rectangular; (b) Hemispherical [HS] (c) Snaphead [SH]; (d) Concave [CV]; (e) Cone [CN] (color online)



(a) *(b)*

(c) *(d)*

(e)

Fig. 3. Different Geometries for Dielectric resonator antenna (DRA); (a) Rectangular; (b) Hemispherical [HS] (c) Snaphead [SH]; (d) Concave [CV]; (e) Cone [CN] (color online)

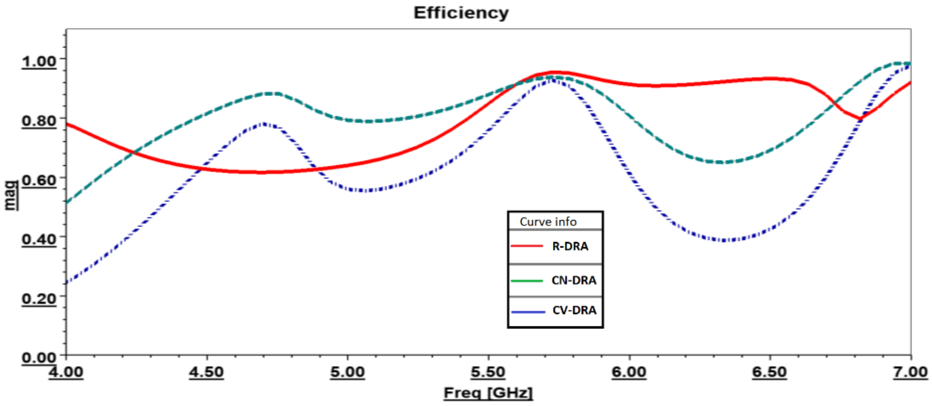


Fig. 4. Simulated efficiency Results for General-DRA, CV-DRA, CN-DRA

Table 2 illustrates a comparative assessment for the distinct geometries understudy, contrasting their respective beamwidth, gain, directivity, and efficiency. From Fig. 3 and Table 2, it can be pragmatic that the beamwidth of the antenna diminishes by almost a factor of 5 with the introduction of a stacked lens geometry on a rectangular DRA, with conical geometry presenting the best outcome with an extremely directive beam compared to the other geometries. Incredibly fewer literature sustains on narrow beam DRA. To enhance the comprehensiveness of the reported research work, comparisons among past works within the literature with the proposed stacked DRA have been produced in Table 3.

Table 2. Comparative analysis of different simulated geometries

DRA design	**Freq (GHz)**	**Beamwidth(degree)**		**Gain**	**Directivity**	**Efficiency**
		Phi=0	**Phi=90**			
General DRA	5.7	175.27	38.17	4.70dBi	4.95dBi	97.16%
Hemisphere DRA	5.7	159.88	37.31	3.54dBi	3.82dBi	94%
Snap head DRA	5.7	73.67	46.14	6.63dBi	7.73dBi	90%
Concave DRA	5.7	53.57	40.20	7.97dBi	8.30dBi	95.83%
Cone DRA	5.7	49.37	36.71	8.23dBi	8.57dBi	93%

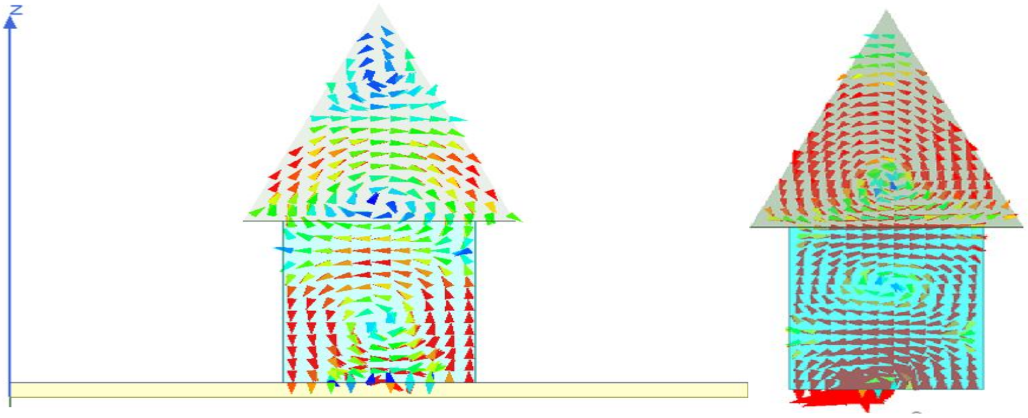


Fig. 5. CN-DRA $TE^{x}_{\delta 15}$ and $TE^{y}_{1\delta 5}$ modes at frequency 5.67 GHz and 5.74 GHz (color online)

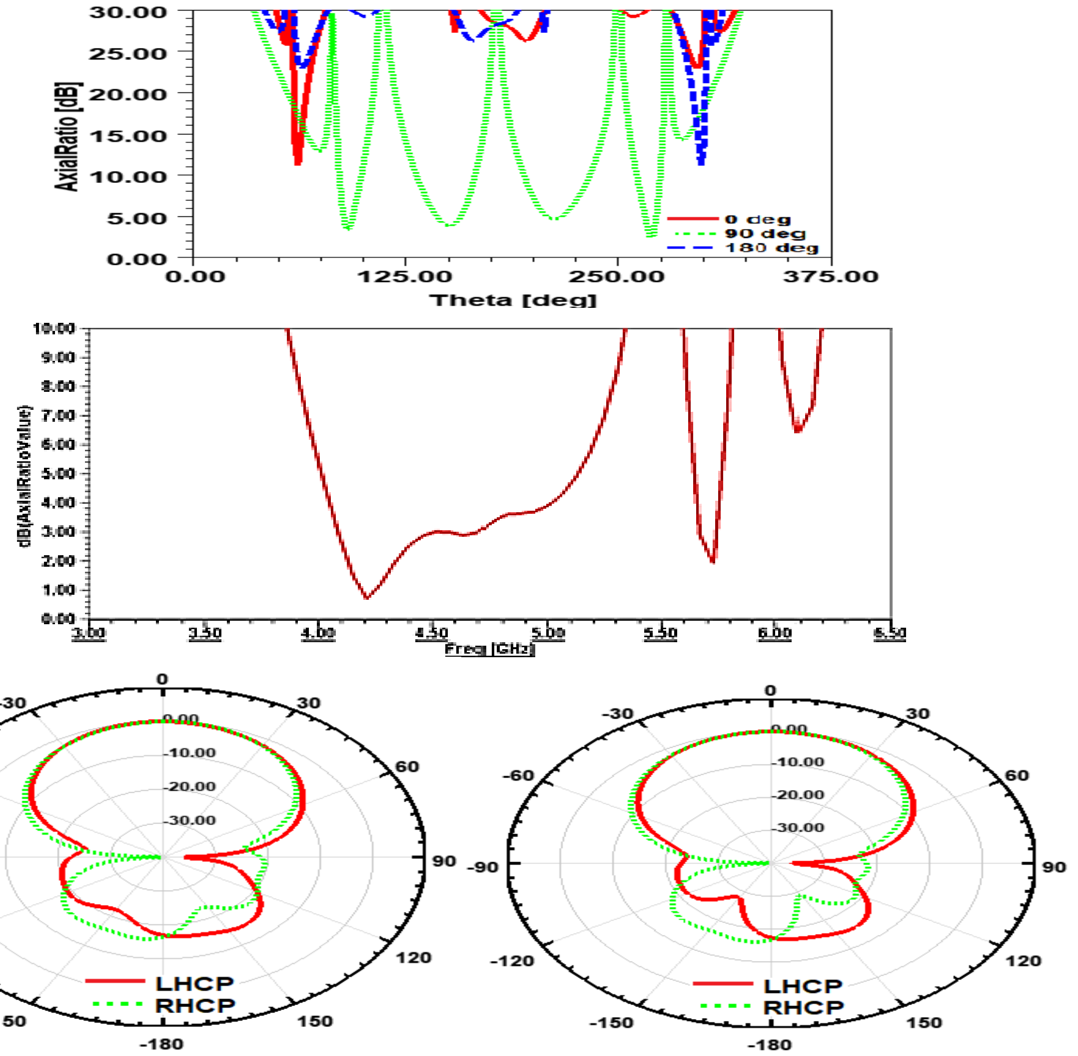


Fig. 6. Simulated CN-DRA (a) Axial Ratio Vs theta (b) Axial Ratio Vs Frequency (c) LHCP, RHCP Pattern at theta=136^0 and Phi=90^0, Frequency =5.64 and 5.7 GHz (color online)

Table 3. Comparing the proposed design with past works in the literature

Reference	**Antenna Geometry**	**Feeding Technique**	**Gain(dBi)**	**Beamwidth(degree)**
[6]	Hybrid water DRA (driven and directive elements) Yagi Uda antenna	L shaped	4.1dBi	80^{o}
[14]	Patch antenna using PIN diodes	Fed with a power divider, a metallic reflector	5.3 dBi	50^{o}
[17]	Tilted DRA	H shaped slot	6 dBi	50^{o}
[18]	Asymmetric RDRA with defected ground	Conformal Strip	8.3 dBi	90^{o}
Proposed	Conical DRA	Aperture coupled	8.23 dBi	48.33^{o}

4. Fabricated results

The prototype of conical geometry design is revealed in Fig. 7 . The S11 parameter is measured using a Vector network analyser while axial ratio is measured using SATIMO 20 GHz an Anechoic chamber.As yielded in Fig. 2 and Table 2, it can be studied that CN-DRA offers the highest gainof 8.23 dBi as compared to other geometries along with a directive beamwidth of 48.33^{o} in E plane and 33.44^{0} in H plane and very high efficiency. Hence, the geometry was fabricated for verification. All the measured results are in a close approximation of simulated results. A similarity between simulated and measured S-parameter results and gain are capitulated in Fig. 8(a). Fig. 8(b) poses a measured gain of 7 dBi as related with simulated 8.23 dBi gain. The simulated and measured radiation pattern is exhibited in Fig. 9.

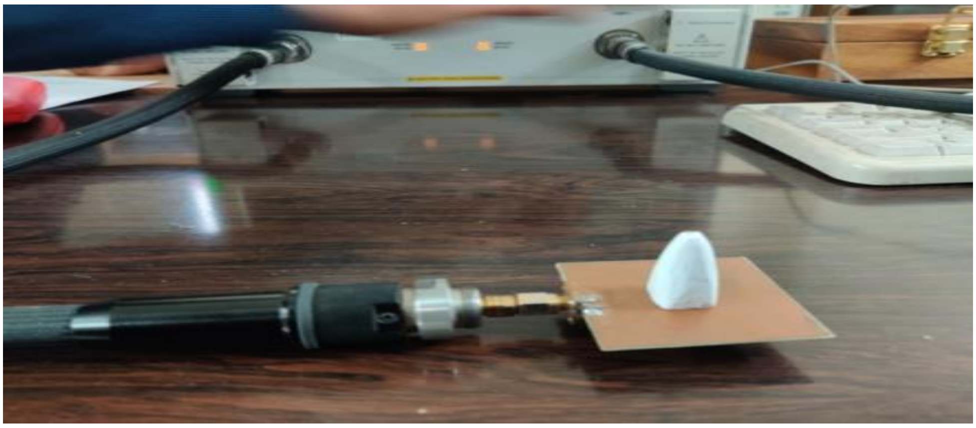


Fig. 7. Fabricated conical -DRA under measurement (color online)

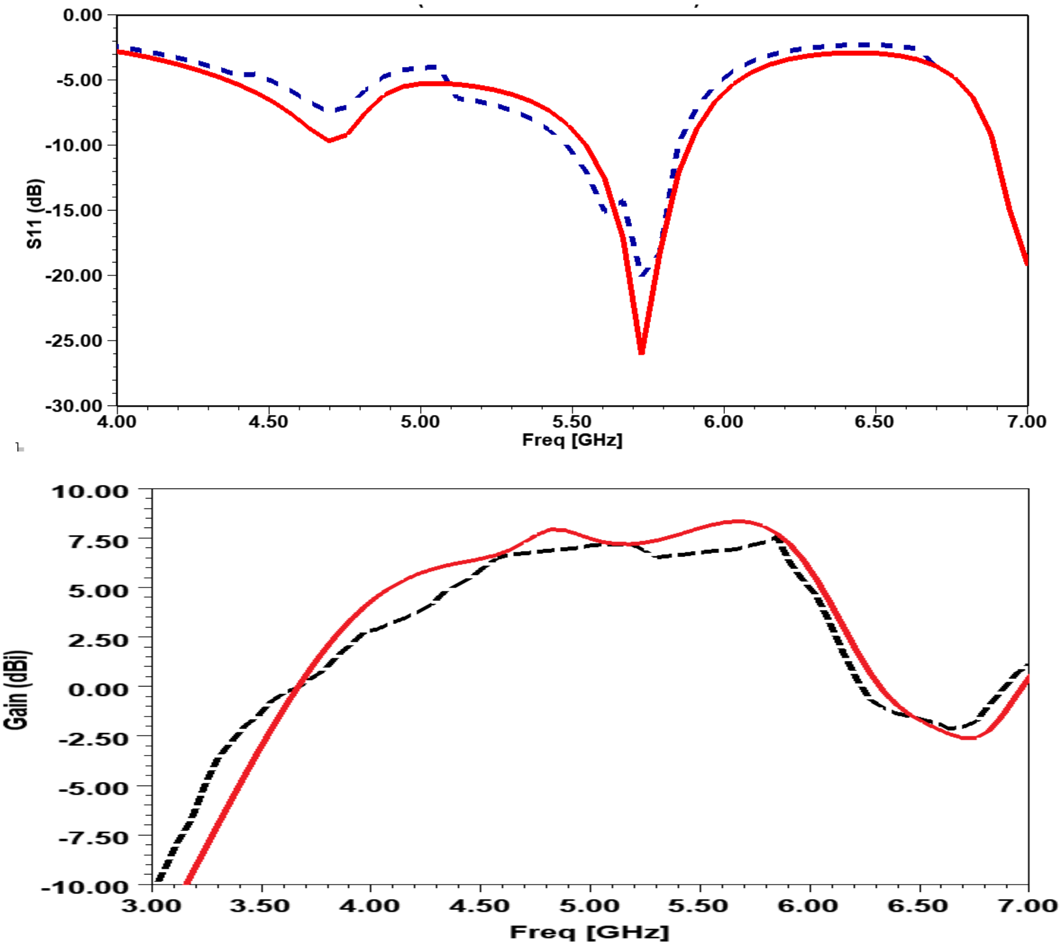


Fig. 8. Measured and Simulated S-Parameter and gain results for CN-DRA (color online)

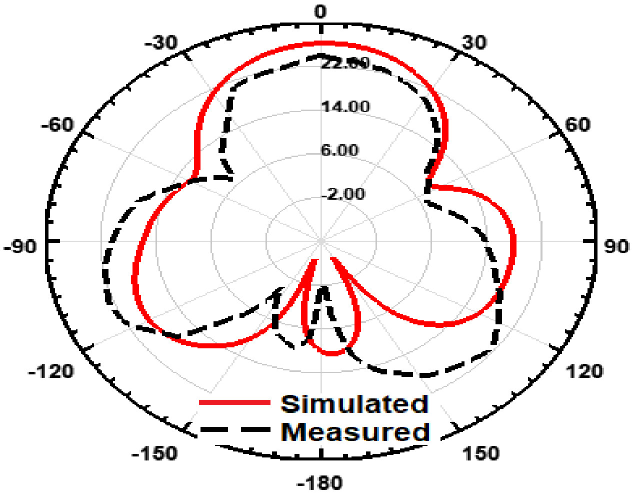


Fig. 9. Measured and Simulated Radiation Pattern at Frequency 5.7 GHz at Phi=0o for CN-DRA (color online)

5. Parametric analysis

To investigate optimized performance, a parametric study has been carried out. Whilst holding a parametric analysis, one parameter is diverse while others are stayedsteady. The impact of parameters like feedline dimensions, slot dimensions, and cone height on 3 dB beamwidth and reflection coefficient has been explored. The assessment helps in delivering improved outcomes. The survey is conducted on the Feedline dimension. The length of the feedline has been altered from 28mm to 32mm. As expressed in Fig. 10(a) S_{11} response of antenna remains almost similar in all instances. The consequence of varying feedline length on beamwidth is demonstrated in Figure 10 (b). E Plane and H plane beamwidth of 52.58 degrees and 42.91 degrees are obtained at the feedline dimension of 32mm. Fig. 11(a-b) illustrates the impact of a change of feedline width on S_{11} and beamwidth of the antenna. The width is varied from 2.5 mm to 3.5mm. The best parameters of beamwidth are obtained at a feedline width of 2.5mm. Additional evaluation is held on slot dimensions. Fig. 12(a-b) and Fig. 13 (a-b) reveal the result of variation in length and width of a slot on S_{11} parameters and beamwidth response. The slot length is varied from 7.46mm to 7.84mm while the slot width is varied from 1.3 mm to 1.6mm. The improved dimensions for length and width are 7.84mm and 1.6mm. Fig. 14 (a-b) depicts the consequence of adjusting cone geometry height on S_{11} and beamwidth of the antenna. The height is varied from 19.2mm to 23.3mm. The best possible cone height is 21.2mm. The E plane and H plane beamwidth of 48.33^{o} in E plane and 33.44^{0} in H plane are obtained at optimized dimensions.

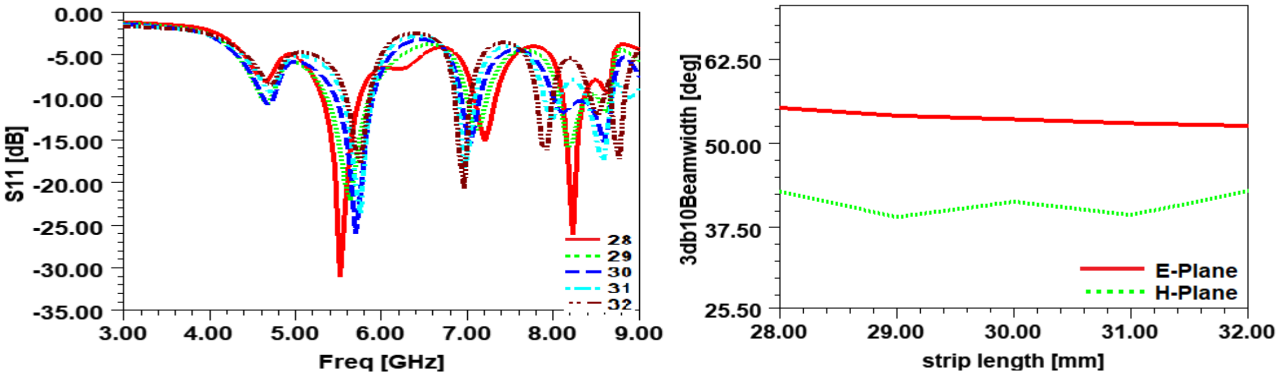


Fig. 10. (a) S_{11} vs Frequency for various Feedline length (b) 3 dB beamwidth vs Feedline length (color online)

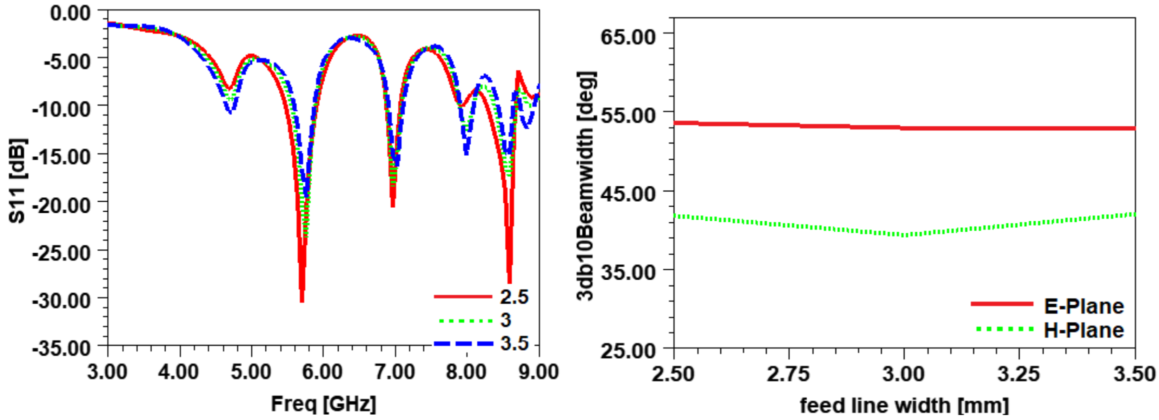


Fig. 11. (a) S_{11} vs Frequency for various Feedline width (b) 3 dB beamwidth vs Feedline width (color online)

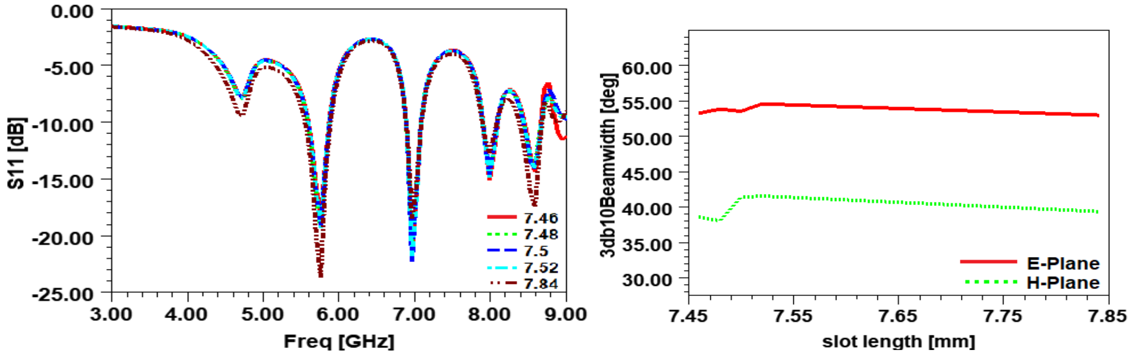


Fig. 12. (a) S_{11} vs Frequency for various slot length (b) 3 dB beamwidth vs slot length (color online)

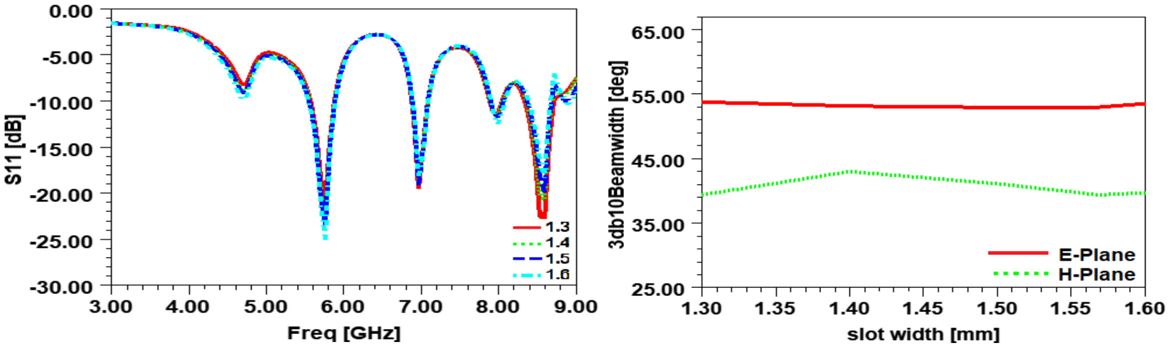


Fig. 13. (a) S_{11} vs Frequency for various slot width (b) 3 dB beamwidth vs slot width (color online)

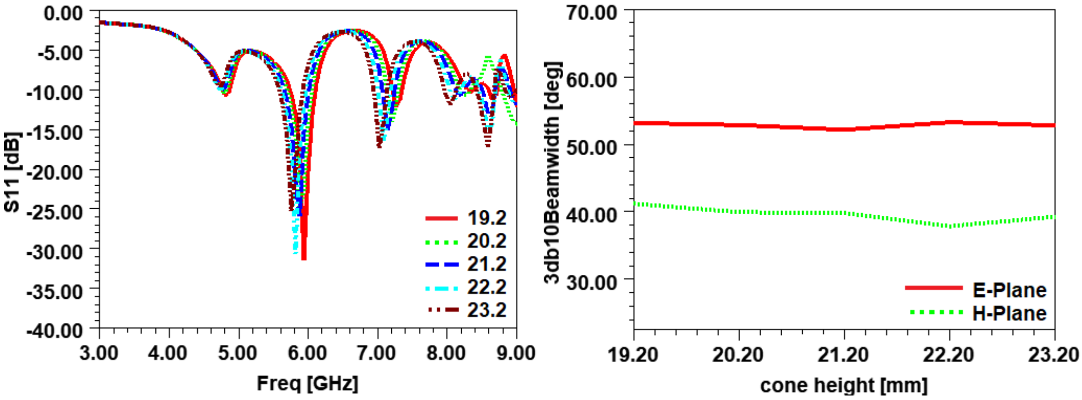


Fig. 14. (a) S11 vs Frequency for various cone height (b) 3 dB beamwidth vs cone height (color online)

6. Conclusion

High directivity and narrow beamwidth arerequisites for the line of sight transmissions. In this document, investigation have revealed that beamwidth can be precisely focused and manipulated by modifying shapes of DRA. A qualifying examination for divergent geometries stacked over a generic rectangular DRA has been offered for intensification of antenna gain, along with to style the beam more directive and later reducing the beamwidth. Dissimilar geometries such as hemispherical (HS), snap head (SH), concave (CV), Cone [CN] have been researched and contrasted. Conical geometry poses the maximum gain (8.23 dBi) linked to any other geometry along with satisfactorilycontrolled beamwidth of 48.33^{o} in E plane and 33.44^{0} in H plane. The Cone [CN] design also provides circular polarisation. The orthogonal mode pair of higher-order mode$TE^{x}_{\delta 15}$ and$TE^{y}_{1\delta 5}$ has been excited at frequency 5.67 GHz and 5.74 GHz,correspondingly. The impedance matching bandwidth of 2.97% (5.55-5.89 GHz) in association with circular polarization of .61%(5.67-5.74 GHz) has been achieved.

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