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Triple Band Dielectric Resonator Antenna Array Using Power Divider Network Technique for GPS Navigation/Bluetooth/Satellite Applications

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***Abstract:-*A 1x4 cylindrical dielectric resonator antenna (CDRA) array is successfully developed and presented in this paper. The claimed structure has introduced quarter wavelength transformer with power divider network. The adopted concept gives adequate response in terms of appropriate suppression, phase distribution and power division. By utilizing the aforesaid geometry, tri-band response has been achieved for various frequency ranges from 0.87 GHz to 1.04 GHz with 18% bandwidth, 2.37 GHz to 2.78 GHz with 17% bandwidth and 4.17 GHz to 5.21 GHz with 22% bandwidth, having peak gain of 2.43dBi, 7.72dBi, and 8.39dBi respectively. 1x4 element dielectric resonator antenna array are designed for comparison in terms of return loss, gain and radiation pattern. The proposed array is modelled using CST software. In order to verify the simulated result, the designed antenna is fabricated on FR-4 substrate and tested using VNA and anechoic chamber. The parametric analysis is carefully completed in order to fix key parameters such as microstrip line length, dielectric resonator height, and Defected Ground Structure (DGS). The analysis said that there is close agreement between the simulated and fabricated response. As the claimed antenna model resonates for the triple-band with aforesaid frequencies, it would be the appropriate candidate for GPS navigation/Wi-Fi, Bluetooth and satellite applications.**

Index Terms- CDRA, Microstrip Feed, Power divider, DGS, WLAN

I. INTRODUCTION

In the present era, wireless communication is dimmed necessity for daily life. With similar regards, very powerful, efficient communication radiators are required. Dielectric resonator antennas (DRA) have attractive characteristics which make them extraordinarily promoting and practically feasible antenna structure at microwave frequencies for Wi-Fi applications [1-2]. DRA has many considerable qualities like simple fabrication process, easy designing method, and cost-effectiveness so it could be utilised for different applications [3, 4]. In microstrip antenna, as frequency increases, the conduction loss increases due to the presence of metal [5]. Because of said reason, the dielectric resonator antenna could be a useful alternative. Different geometry of DRAs like cylindrical, triangular, hemispherical and rectangular are investigated for receiving adequate antenna performance [6-9]. Different possible feeding techniques like aperture coupled, microstrip line feed, conformal strip feed, and conformal patch feed are adopted for various shapes DRAs for performance enhancement [10-13]. For modern wireless communication, single element DRA cannot accomplish the demand like multiband with wider bandwidth and higher directivity radiation. To fulfill the demand, arrays of an antenna is one of the key technique [14]. The aperture-coupled and co-axial probe feeding techniques are the preferences for the researchers for array design in contrast with microstrip line feed [15]. Few researchers have contributed in DRA array domain. The research has been done to develop 8 element DRA array structure where claimed bandwidth is 17% with 13 dBi gain [16]. The authors designed an alumina ceramic based cylindrical dielectric resonator using annular shape microstrip feed line. They achieved 27% bandwidth with 7.95 dBi gain [17]. Researcher presented linear antenna array structure which used four cylindrical shape dielectric resonators. The said design achieved 500 MHz impedance bandwidth with gain of 10dBi [18]. CP-DRA array antenna has been reported by researchers where they had used high cost Eccostock HIK material as rectangular DR which achieved 17% impedance bandwidth between 6.2 GHz to 7.35 GHz frequency [19]. By utilising various feeding techniques for different shape DRA structures, the adequate bandwidth with reasonable gain could be achieved [20-25].

In claimed array design, a quarter wavelength transformer with power divider network is implemented to justify design requirements such as power division, sufficient suppression and proper phase distribution. The authors have utilized four cylindrical shaped DR (CDR) elements, which resonates for tri-band in the frequency ranges from 0.86 to 1.04 GHz(18%), 2.37 to 2.79 GHz(17%) and 4.17 to 5.21 GHz(22%). The proposed antenna has been fabricated using FR4 substrate and Alumina Ceramic based CDR. The aforesaid CDRA structure is simulated using CST software.

II. ANTENNA DESIGN

This section includes calculations behind the geometry and designing details of DRA.

A. Designing calculation of power divider network with quarter wavelength transformer:

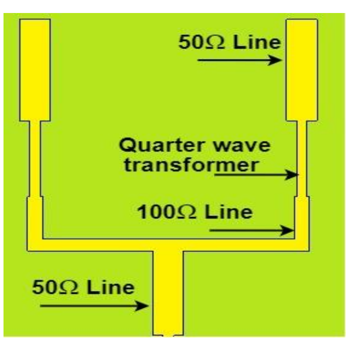


Fig. 1: Quarter wavelength transformer with power divider

The 50Ω feed line is designed for impedance matching with measurement cable. When feed line is divided in two parts, each line has now impedance of 100 Ω so, to make it 50Ω, a quarter wavelength transformers is utilised as show in Fig. 1.

Quarter wavelength transformers are simply a transmission line which has desire impedance. Quarter wavelength transformers impedance (Z_0) can be finding using Eq. 1.

$$Z_0 = \sqrt{Z_i Z_L} \quad (1)$$

Where $Z_i = Input\ impedance$

$Z_L = Out\ impedance$

The quarter wavelength transformer length can be calculated by Eq. 2.

$$Lenght = {}^{\lambda g}/_{4} \quad (2)$$

$Where\ \lambda g = wavelength$

$$\lambda g = {}^{\lambda_0}/_{\varepsilon_{reff}} \quad (3)$$

$Where \quad \lambda_0 = free\ space\ wavelenght$

$\varepsilon_{reff} = effective\ of\ dielectric\ constant$

The quarter wavelength transformer width can be calculated using Eq. 4

$$Width = \frac{8\, e^{A} x\, h}{e^{2A} - 2} \quad (4)$$

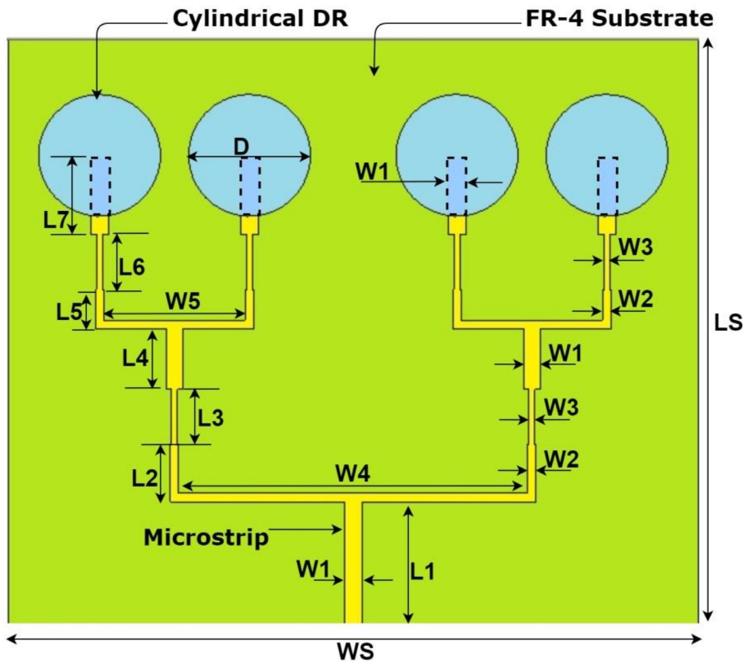
$where \quad h = \ height\ of\ the\ substrate$

$$A = \frac{z_1}{60}\sqrt{\frac{\varepsilon_r + 1}{2}} + \frac{\varepsilon_r + 1}{\varepsilon_r - 1}\left(0.23 + \frac{0.11}{\varepsilon_r}\right)$$

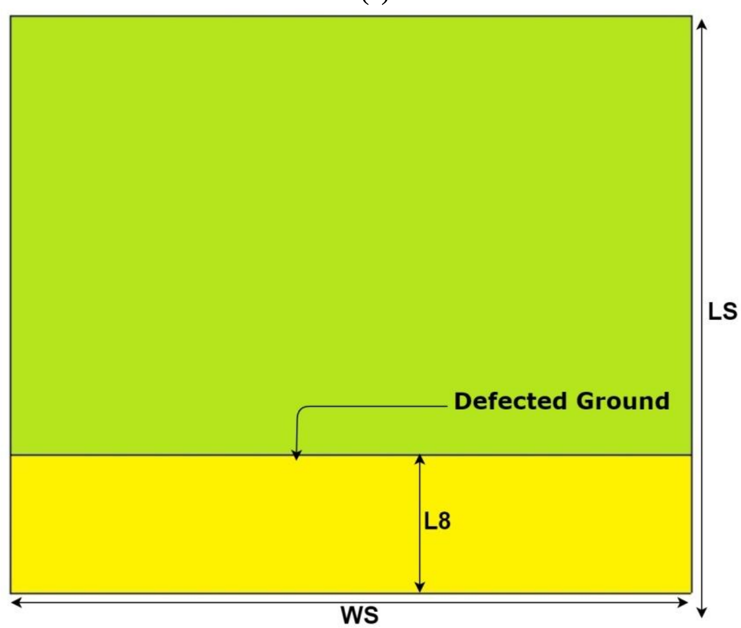
$where\ \varepsilon_r = relative\ permittivity\ of\ the\ substrate$

B. Designing of 1 x 4 CDR elements antenna array:

After successful development of quarter wavelength transformer power divider network, 1 × 4 CDRA array is considered for antenna performance enhancement. The proposed CDRA array structure is shown in Fig. 2.



(a)



(b)

Fig. 2: Proposed 1 x 4 element antenna array (a) Top view (b) Back view

A quarter wavelength transformers with power divider technique is utilised with equal spacing between both elements. The 50Ω feed line is designed for impedance matching with measurement cable. As discussed earlier, when feed line is divided in two parts, each line is having an impedance of 100 Ω, so quarter wavelength transformer is used for impedance matching (50 Ω). Similarly, power divider process is carried out for subsequent section design. The top view and back view of the design are shown in Fig. 2(a) and 2(b) respectively. The four identical CDRs made from alumina ceramic are placed above FR-4 substrate with height of 1.6 mm. A quarter wavelength transformers with power divider technique is utilised with equal spacing between both elements. The distance between two pairs of CDRs and distance between each CDR from the aforesaid pair is carefully fixed to get the optimum response. As seen in Fig. 2(b), dimensions of ground plane are carefully finalised by multiple iterations to get the acceptable return loss. In array antenna, some of the disseminated power from individual element will have an effect on nearby elements which called mutual coupling. Mutual coupling can distort the antenna parameter. To avoid mutual coupling we kept $\lambda/4$ distance between two elements. All necessary dimension details are given in Table 1.

Table 1: Proposed 1 x 4 element antenna array dimensions

Parameter	Value (mm)	Parameter	Value (mm)	Parameter	Value (mm)
WS	113	L3	9	D	20
LS	96	L4	10	W1	2.8
DH	14	L5	6.4	W2	1.4
HS	1.6	L6	9	W3	1.00
L1	20	L7	12	W4	57
L2	9.4	L8	23	W5	23

III. PARAMATERIC STUDY

A number of parameters like microstrip feed length, CDR height and length of defected ground are examined to check it's effect on the CDRA array antenna performances. In proposed design, 50Ω microstrip feed with a quarter wavelength transformer is adopted to excite CDR for desire response.

The difference in return loss (represented by colour lines) is shown in Fig. 3(a) for various length of microstrip feed (L7) as parametric study. Here, tri band could be achieved by varying the length of DR's underneath strip. The close observation suggests that when DR's underneath strip length is 12 mm (shown in black colour), the adequate return loss (S_{11}) could be achieved for targeted frequency bands.

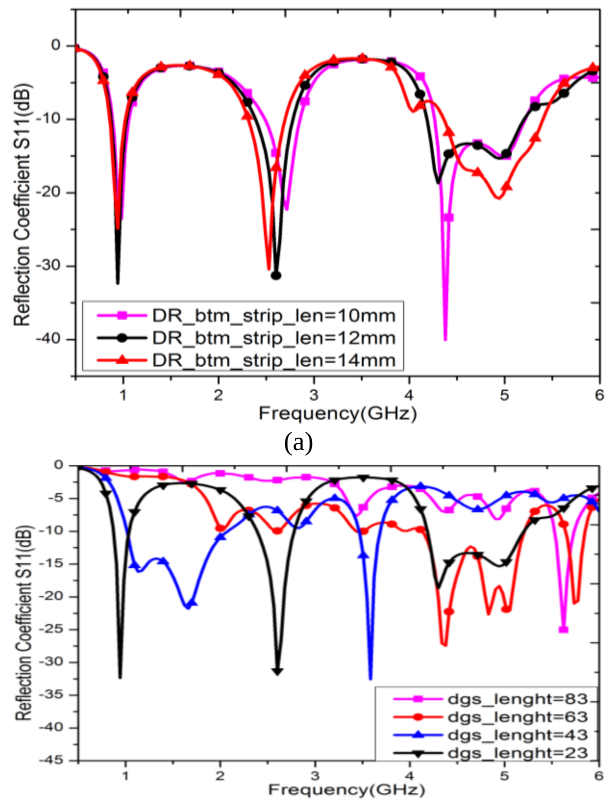


Fig. 3: Simulation of parametric study: (a) variation in length of microstrip feed line (b) variation in DGS length

Fig. 3(b) represents the analysis on return loss against Defected Ground Structure (DGS) variation. Here, the parametric study has been done with length variation of ground plane to a certain level and examine the reflection coefficient (S_{11}). The study suggests that when ground plane height is 23mm, adequate return loss for triple band could be attained so it is fixed along with aforesaid finalised parameter.

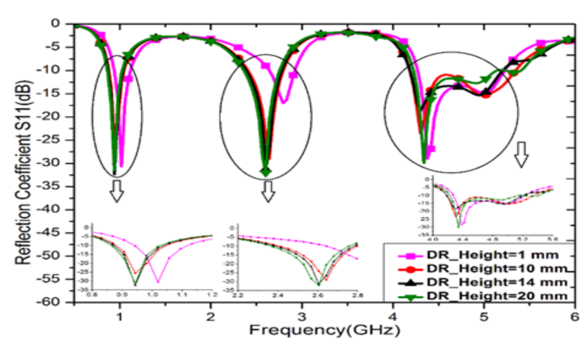


Fig. 4: Return loss comparison for different dielectric resonator height

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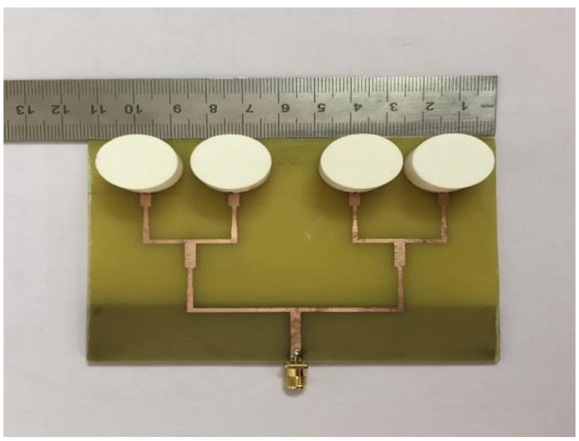
Similarly, another important parameter which plays a major role in antenna performance is CDR height. The effective study has been done by varying the height of the CDR to get the required response. Fig. 4 gives relative study for the same. The close examination recommends that CDR with 14 mm height gives significant return loss with satisfactory bandwidth.

IV. RESULTS AND DISCUSSION

Fig.5 (a) shows the designed CDRA prototype. The fabrication process has been completed using PCB machine. Fig. 5(b) depicts the actual response from the developed antenna.



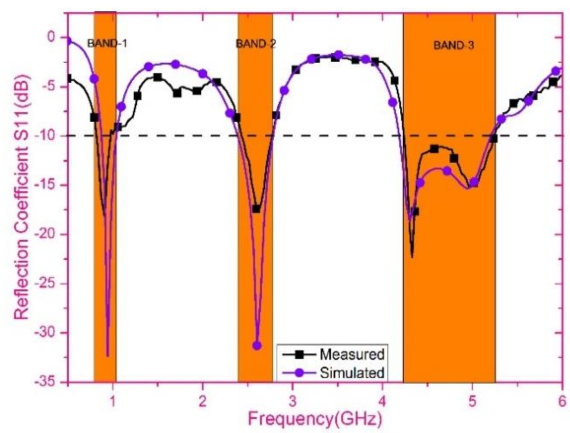
(a)

(b)

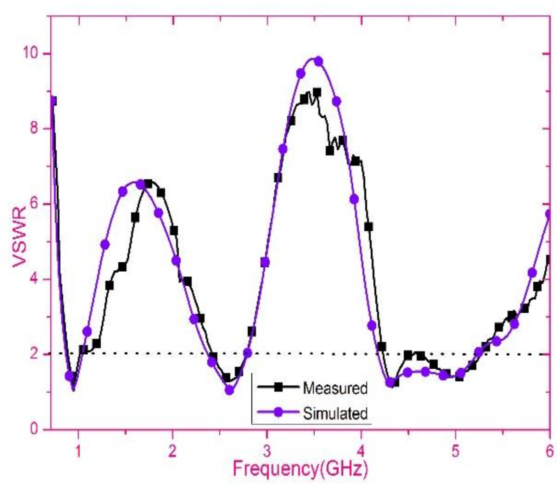
Fig. 5: (a) Proposed fabricated antenna (b) Measured result of 1x4 CDRA using VNA

The study has been completed using KEYSIGHT N9918A network analyzer. It is very clear from Fig. 5(b) the output of VNA that the simulation response and the actual response are matching with each other. The triple band can be easily visible in Fig. 5(b). Here, the important observation is no frequency shift occurring in either of bands in comparison with software response.

The Fig. 6(a) explains the comparison of simulated and actual results in terms of return loss vs. frequency variation. The black color line represents measured output where the violet color line represents simulated output. The triple bands are highlighted using orange color bars. Here, the overlapping of lines shows strong relation between both the responses.



(a)



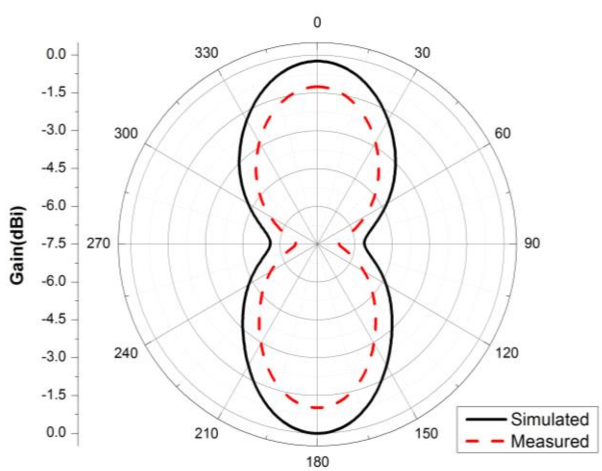
(b)

Fig. 6: Comparison of simulated and measured result of (a) reflection coefficient (S_{11}) (b) VSWR

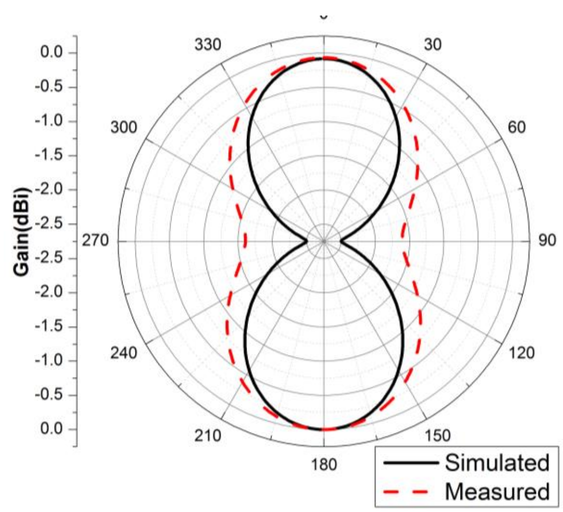
Fig. 7: Radiation patterns measurement of fabricated 1x4 CDRA in anechoic chamber

Simulated bandwidth where return loss is less than 10 dB(generally) are found about 16% (from 0.87 GHz to 1.04GHz) in first band, 17% (from 2.37 GHz to 2.78 GHz) in second band and 22% (from 4.17 GHz to 5.21 GHz) in third band. The measured operating frequency ranges for CDRA are near to simulated bandwidth. It can be easily seen that resonant peaks of measured S_{11} parameter are little shifted due to imprecise placing of the CDR on substrate and also due to glue material (fevi-quick) used to fix CDR with substrate. Fig. 6 (b) shows the simulated and measured result of Voltage Standing Wave Ratio (VSWR) of proposed CDRA. The VSWR is also measured using vector network analyzer. It is to be considered as cross verification of resonant frequencies where VSWR is near about 1.

To obtain radiation pattern and gain parameter of CDRA, the antenna has been put in anechoic chamber as show in Fig. 7. The anechoic chamber provides the ideal atmosphere for antenna measurements. Fig. 8 shows the comparison of simulated and measured two-dimensional radiation patterns in E- plane (ϕ = 0) and H-plane (ϕ = 90) for claimed CDRA at 0.9 GHz, 2.4 GHz, and 5.0 GHz frequencies. Good agreement could be observed between simulated and measured radiation patterns of the antenna array for afore said operating frequencies. The minor deviation in the broad side occurs due to imprecise placing of the CDR on substrate as well as the effect of glue material (fevi-quick) used to fix CDR on substrate. The main lobe magnitude and 3dB beam width are 2.43 dBi and 85.7, 7.72 dBi and 53.5, 8.39 dBi and 63.4 for the frequencies 0.9 GHz, 2.4 GHz and 5.0 GHz respectively.



(a)



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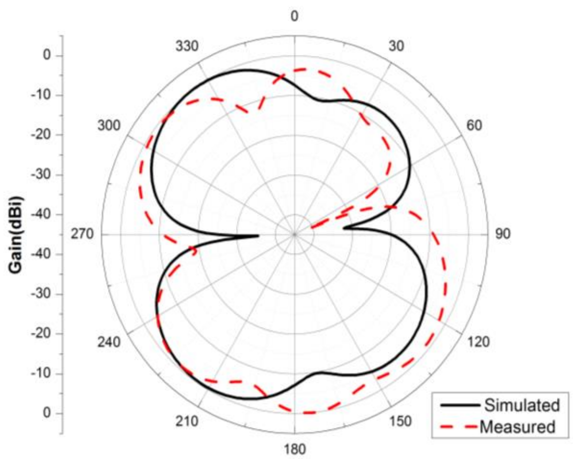

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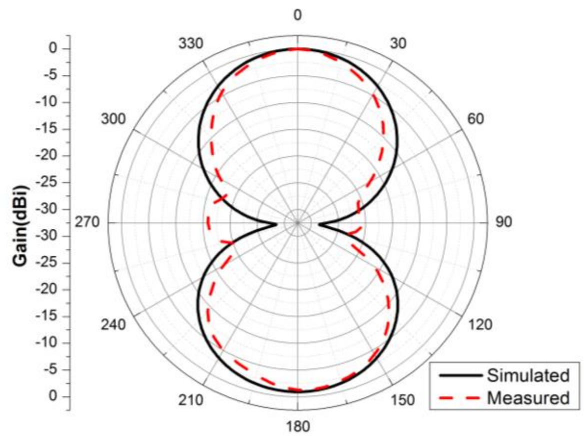

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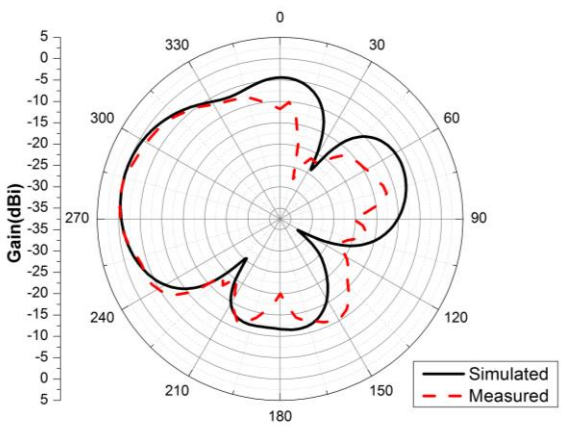

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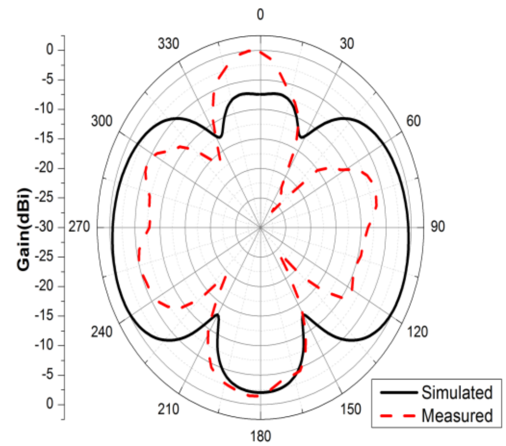
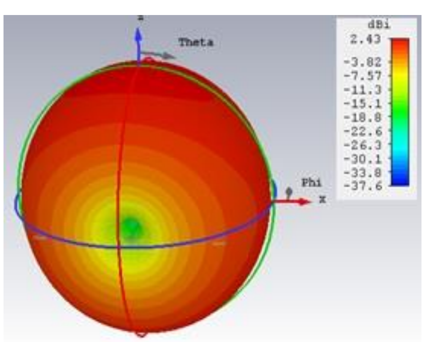
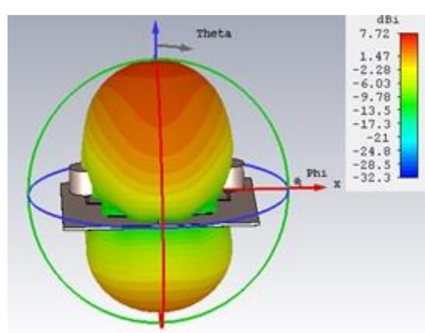


(f)

Fig. 8: simulation and measured radiation pattern of H Plane (a, c, e) and E Plane (b, d, f) for the frequencies of 0.9GHz, 2.4GHz and 5 GHz respectively



(a)



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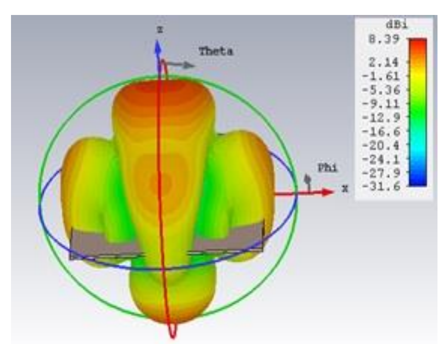

(c)

Fig. 9: 3D radiation pattern for frequency (a) 0.9 GHz (b) 2.4 GHz (c) 5 GHz

Fig. 9 shows the 3D radiation pattern for targeted frequencies. The gain of 2.43dBi, 7.72dBi and 8.39 dBi are achieved for 0.9 GHz, 2.4 GHz and 5 GHz frequencies respectively. The major radiation is in desired direction as show in Fig. 9. It is found from the systematic analysis that adequate gain could be achieved by finding an optimum set of elemental amplitude excitation as well as optimum inter spacing with quarter wavelength transformer power divider technique. The phase excitation of 1x4 DRA array all elements are kept at zero degree which would reduce the complexity level of microstrip feed design. The proposed model gives 73.36% of radiation efficiency.

To emphasize the originality of proposed research, the authors have shown its comparison with previously published research in Table 2. Careful observation shows, the previous research utilized simple power divider network having 50Ω microstrip line which was further divided into two 75Ω microstrip lines and four 100Ω microstrip lines. In proposed work, a quarter wavelength transformer with power divider technique is utilised with equal spacing between both the elements. The 50Ω feed line is designed for impedance matching with measurement cable. When feed line is divided in two divisions, each line has an impedance of 100 Ω so, to make it again 50Ω, a quarter wavelength transformer techniques has been adopted. In both the research, DGS technique has been utilized for better rejection in desired bands, however in proposed structure, there isn't any slot provided in DGS even though triple bands have been achieved. Another important observation could be noticed here that overall size of proposed antenna array is reduced significantly which is much needed necessity.

Table 2: Comparison of proposed DRA array with previous research

Parameters	**[25]**		**Proposed Work**	
Type of Feed	Simple Power Divider		**Quarter wavelength transformer power divider microstrip**	
DRA Shape	Cylindrical		Cylindrical	
DRA Material (εr)	Alumina Ceramic		Alumina Ceramic	
	(εr =9.8)		(εr =9.8)	
Substrate(εr)	FR4 (εr =4.4)		FR4 (εr =4.4)	
Total antenna size	120 mm x 120 mm		**113 mm x 96 mm**	
1st band	Bandwidth	2.23 - 3.37 GHz	Bandwidth	**0.88-1.06 GHz**
	Gain	8.01dBi	Gain	**2.43dBi**
	ReturnLoss	-19.18dB	ReturnLoss	**-32.34dB**
2nd band	Bandwidth	4.00 - 4.26 GHz	Bandwidth	**2.38-2.79 GHz**
	Gain	7.4 dBi	Gain	**7.72dBi**
	ReturnLoss	-17dB	ReturnLoss	**-26.53dB**
3rd band	Bandwidth	5.2 - 5.42 GHz	Bandwidth	**4.18-5.23 GHz**
	Gain	9 dBi	Gain	**8.39 dBi**
	ReturnLoss	-23.16dB	ReturnLoss	**-18.65dB**

Table 3. Comparison of proposed DRA array with others antenna array structures

References / Parameters	[17]	[18]	[19]	[24]	Proposed antenna array
Type of Feed	Annular shaped microstrip feed	Aperture coupled	Microstrip	Microstrip	**Quarter wavelength transformer power divider microstrip**
DRA Shape	Cylindrical	Cylindrical	Rectangular	hemispherical	**Cylindrical**
DRA Material (ε_r)	Alumina Ceramic (εr =9.8)	Rogers 3010 (ε_r = 10.2)	Eccostock HIK (ε_r= 20)	Eccostock HIK (ε_r = 20)	**Alumina Ceramic (εr =9.8)**
Substrate(ε_r)	FR4 (εr =4.4)	substrate Rogers 5870 (εr =2.3)	Arlon AD270 (εr =2.7)	Arlon AD270 (εr =2.7)	**FR4 (εr =4.4)**
Total antenna size	115 mm x 80 mm	100 mm x 85 mm	135 mm x 48 mm	135 mm x 48 mm	**113 mm x 96 mm**
Bandwidth (%)	27	7	17	7.2	**22**
Gain (dBi)	7.95	10	13.6	10	**8.39**
No. of Band	Single (3.5-4.72 GHz)	Single (7.5-8 GHz)	single (6.2-7.35 GHz)	Single (6.3-6.8 GHz)	**Tri-band (0.88-1.06, 2.38-2.79, 4.18-5.23) GHz**

The Table 3 depicts comparison of claimed DRA parameters and its response with previously developed antenna structures in recent years. Here, the comparison is shown on the basis of various parameters such as feeding techniques, DRA shape, DRA material and type of substrate. From Table 3, it could be noticed that the proposed antenna geometry proves its suitability by its overall size with satisfactory response in terms of frequency bands, gain and bandwidth.

V. CONCLUSION

The 1x4 CDRA array structure is successfully designed and fabricated for applications of Wi-Fi, wireless LAN and satellite communication. The power divider technique using quarter wavelength transformer in the microstrip feed line is utilised for the structure excitation. The demonstrated prototype gives good response for the frequency spectrum from 0.87 GHz to 1.04 GHz, 2.37 GHz to 2.78 GHz and 4.17 GHz to 5.21 GHz with 18%, 17% and 22% bandwidth respectively and rejections are -20 dB below. Here, the peak gain of 2.77dBi, 7.72dBi and 8.39dBi is recorded for the frequencies 0.9 GHz, 2.4 GHz and 5 GHz respectively. The presented array prototype is developed and fabricated using FR4 substrate which provides cost effectiveness for bulk production. The presented antenna array design shows very close relation between simulated and measured results. By systematic parametric study, various parameters such as length of the microstrip line, height of the dielectric resonator and ground plane are finalised which collectively contributes in desired antenna performance.

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