Vol. 2 No. 4 (2024)

Spectrum of Engineering Sciences

SPECTRUM OF ENGINEERING SCIENCES

Online ISSN 3007-3138

Print ISSN 3007-312X

Comparative Study of Dual Band Rectangular, Cylindrical and Triangular Dielectric Resonator Antennas (DRA)

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Abstract

A comparison of Dual Band Rectangular, Cylindrical and Triangular Dielectric Resonator Antenna coupled to a narrow slot aperture that is fed by a microstrip line for C and X Band operation is proposed in this paper. C and X Bands are microwave bands that span 4-8 GHz and 8-12 GHz, respectively. Antenna constraints, such as dimensions and frequencies, are determined using a mathematical formulation. The software package used to design the three DRA shapes is CST Microwave Studio. The Bandwidth, Gain and Directivity of three shapes of DRA are evaluated, and it is finally observed that the Triangular DRA has a wider bandwidth than Rectangular and Cylindrical, while Rectangular DRA has a high value of Directivity and Gain at some Resonant Frequencies.

Spectrum of Engineering Sciences
SPECTRUM OF ENGINEERING SCIENCES
Online ISSN
3007-3138
Print ISSN
3007-312X

The results of the present work may provide design guidelines for the development of efficient DRA at C and X Band frequency operations, and designers should have to make a tradeoff between Bandwidth and Directivity and Gain, depending upon their requirements.

Index Terms: Bandwidth, Cylindrical Dielectric Resonator Antenna (CDRA), Dielectric Resonator Antenna (DRA), Directivity, Gain, Rectangular Dielectric Resonator Antenna (RDRA), Triangular Dielectric Resonator Antenna (TDRA).

I. INTRODUCTION

Dielectric Resonator Antenna (DRA) is a class of antenna which allows communication in the range from microwave to millimeter waves with very small dielectric losses. Advantages of using DRA over other conducting surface antennas are that it prevents the conductor loss [1] and surface wave losses at higher frequencies [1-2]. There are various shapes of the DRA, which have been studied, like Rectangular [3], Cylindrical [4], Conical [5] and many more by many researchers. The rising journey of the Dielectric Resonator Antenna started in the early 1980s [6]. It was the best alternative to MPAs; however, it has not been fully explored [7] up to now in terms of its applications in most fields, such as its use in satellite technology and at the industry level [8]. For many years, the community of antenna has been greatly involved in the analysis and research of Dielectric Resonator Antenna. Many new features need to be explored to meet the requirements of the miniaturization of portable devices [1], handheld and other devices for communication in all bands used for communication [2-3].

The two antennas, i.e. DRAs and MPAs, have much contribution to modern wireless communication as compared to conventional

Vol. 2 No. 4 (2024)

Spectrum of Engineering Sciences

Online ISSN
3007-3138
Print ISSN
3007-312X

SPECTRUM OF ENGINEERING SCIENCES

Antennas [7-9]. The DRA has most attractive features like, small size, light weight, design flexibility, low loss and ease of excitation [11]. So, for many years, DRAs have been investigated because they have the most attractive features [4-5]. As DRA is made of high permittivity material, having less conductor loss [22]. The radiation efficiency of DRA is high [15]. DRA provides flexibility in terms of its geometry. This has made it easy for the designers to select such type of DRA geometry which is suitable for the desired results. We can excite various modes inside radiating elements of DRA, producing various radiation patterns for different applications and these various modes depend on feeding mechanism as well as the shape of Resonator [13][14]. This paper is concerned with Rectangular, Cylindrical and Triangular DRA, resonating for Dual Bands at frequencies 6 and 7 GHz, 8 and 9 GHz and 10 and 11 GHz using a similar feeding technique i.e. Slot Aperture.

This Paper focuses on a meaningful comparative study where the researchers have considered three geometric shapes of Dielectric resonator antenna. For single band, the Rectangular, Cylindrical and Triangular DRAs were simulated in CST Studio through which the analysis of parameters, such as Gain, Directivity and Bandwidth. Each of the different shapes of DRA has been individually analyzed for the above parameters, and then the overall comparison has been made among them.

Section II of this paper is dedicated to the configuration of Dual band Rectangular, Cylindrical and Triangular DRA respectively. In Section III, the results of Dual band RDRA, CDRA and TDRAs have been given. In Section IV the present work has been concluded.

Vol. 2 No. 4 (2024)

Spectrum of Engineering Sciences

SPECTRUM OF ENGINEERING SCIENCES

Online ISSN
3007-3138
Print ISSN
3007-312X

II. ANTENNA CONFIGURATION

The proposed DRA of different shapes have different parameters and dimensions depending on the desired frequency bands at which they are desired to be operated. To excite the proposed DRAs at the selected Dual bands, their parameters can be varied to achieve the expected results. This section describes the design configuration of Rectangular, Cylindrical and Triangular DRA.

A. Rectangular DRA

Rectangular DRA is one of the most used shapes of DRA. For analysis, specification the DRA is treated as a slab of dimensions having length, Width and Height. One attractive feature of Rectangular DRAs is its two degree of freedom providing best choice of selection for the designer to change on of the three dimensions while keeping other two constant provided the resonant frequency and relative permittivity kept constant. For each design of Rectangular DRA, the substrate material R04000 of permittivity 3.38 and thickness has been calculated for resonant frequency which are shown in the Table. and is same for dual band designs of Cylindrical and Triangular DRA.

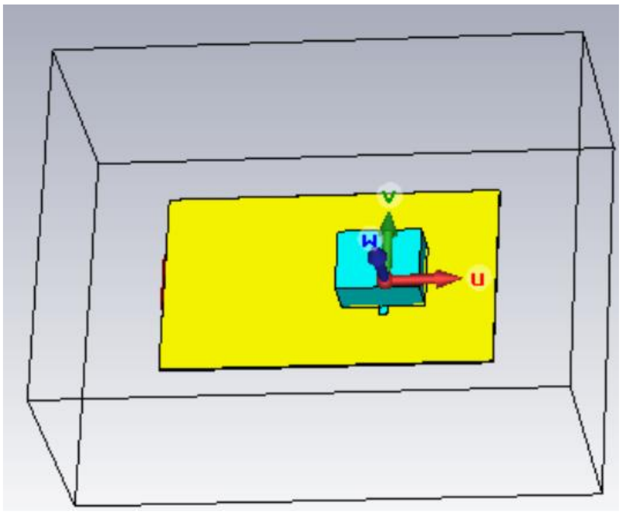

Fig. 01: Geometry of RDRA

Vol. 2 No. 4 (2024)

Spectrum of Engineering Sciences

SPECTRUM OF ENGINEERING SCIENCES

Online ISSN 3007-3138

Print ISSN 3007-312X

For each design of Rectangular DRA for bands (6-7, 8-9 and 10-11) an MC-20 Ceramic material of relative permittivity has been taken. A 50-ohm microstrip line along with the slot Aperture are used for feeding/excitation of Rectangular DRA and is same for all designs of Cylindrical and Triangular DRA. Table shows the dimensions of slot Aperture technique which is same for all designs. The two modes supported by Rectangular DRA are TE and TM modes in which TE mode is used most commonly while TM is not observed experimentally.

$$f_{1,2} = \frac{C}{2\pi\sqrt{\varepsilon}} * \sqrt{K_{x1.x2}^2 + K_{y1,y2}^2 + K_{z1,z2}^2} \qquad (1)$$

Here $f_{1,2} = f_1 f_2$ shows the Dual Band frequencies where as,

$$K_{y1,y2} = \sqrt{K_{1.2}^2 - K_{x1,x2}^2 - K_{z1,z2}^2} \qquad (2)$$

The wavenumber can be calculated by the following formula:

$$K_{1,2} = \frac{2\pi\sqrt{\varepsilon} f_{1,2}}{C} \qquad (3)$$

Where c is speed of light and ε is dielectric permittivity of dielectric material. The values of the geometric parameters are listed in Table I for the specified Dual Band Resonant Frequencies.

TABLE I
RECTANGULAR DRA DESIGN PARAMETERS

Dimensions(mm)	Design I (6 & 7) (GHz)	Design II (8 & 9) (GHz)	Design III (10 & 11) (GHz)
Length	9.52	5.9	3.9
Width	7.5	7.028	6.1
Height	5.5	5.4	5.45

B. Cylindrical DRA

The Dual Band Cylindrical DRA is shown in the figure whose dimensions are represented by Radius (r) and Height (h). The degree of freedom offered by CDRA is one, which means that one

Vol. 2 No. 4 (2024)

Spectrum of Engineering Sciences

Online ISSN 3007-3138

Print ISSN 3007-312X

of the two dimensions can be kept variable while keeping other dimension, frequency and Permittivity fixed. The frequencies selected for dual band are in the form of couple like 6-7 GHz for one dual Band 8-9 for second dual band and 10-11 for third dual band antenna. All designs are simulated using CST Microwave Studio. A material named Roger RO4000is selected as substrate material having permittivity 3.38 and thickness as shown in Table. because of its attractive features like low cost [16], [17] and surface loss reduction [18-20]. Each Cylindrical DRA design for each dual band takes the same dielectric material named MC-20 Ceramic Material having permittivity of 20. A 50-ohm Microstrip line coupled with Slot Aperture are used for the excitation of Cylindrical DRA and the dimensions are shown in Table II.

The h/a ratio formula for Dual band Cylindrical DRA is given as follows [5]

$$\frac{h}{a} = \frac{E_s}{\varepsilon^4} + \sum_{i=1}^{4} \frac{1}{\varepsilon^4 - 1} \left[\frac{A_i}{\varepsilon^{\frac{B_i f_2}{f_1}} + C_i} + D_i \right] \tag{4}$$

Here f_1 shows lower band frequency and f_2 shows higher band frequency respectively.

TABLE II
SLOT APERTURE TECHNIQUE PARAMETERS

Dimensions(mm) of Slot Aperture	Design I (6 & 7) (GHz)	Design II (8 & 9) (GHz)	Design III (10 & 11) (GHz)
Slot Length	9.52	5.9	3.9
Slot Width	7.5	7.028	6.1

Vol. 2 No. 4 (2024)

Spectrum of Engineering Sciences

SPECTRUM OF ENGINEERING SCIENCES

Online ISSN

3007-3138

Print ISSN

3007-312X

TABLE III
SUBSTARTE THICKNESS

Substrate Material	Design I (6 & 7) (GHz)	Design II (8 & 9) (GHz)	Design III (10 & 11) (GHz)
Thickness (mm)	9.52	5.9	3.9

Similarly, the radius of Dual Band cylindrical DRA(a) can be found by the following design formula:

$$a = \frac{C}{2\pi\sqrt{\varepsilon_r f_1}}\left[\frac{E_s}{\varepsilon_r^4} + \sum_{i=1}^{4}\frac{1}{\varepsilon_r^4 - 1}\left(\frac{A_i}{\frac{B_i h}{\varepsilon_r{}^a} + C_i} + D_i\right)\right] \qquad (5)$$

Where a and h represent its radius and height respectively and ϵ_r is the relative permittivity of dielectric material. For Dual Band Resonant Frequencies, the value of height and radius are listed in Table IV.

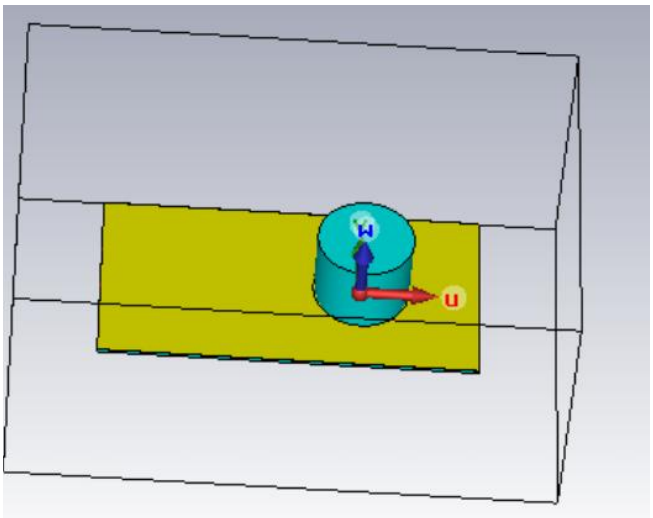

Fig. 02: Geometry of CDRA

Spectrum of Engineering Sciences
SPECTRUM OF ENGINEERING SCIENCES
Online ISSN
3007-3138
Print ISSN
3007-312X

TABLE IV
CYLINDRICAL DRA PARAMETERS

Dimensions(mm)	Design I (6 & 7) (GHz)	Design II (8 & 9) (GHz)	Design III (10 & 11) (GHz)
Radius	9.52	5.9	3.9
Height	7.5	7.028	6.1

C. Triangular DRA

The geometry of Triangular DRA has miniaturization characteristics over CDRA and RDRA because of its smaller dimensional area without compromising its feature and feasibility. Two dimensions of Triangular DRA are length (l) and height (h1). Length of DRA has been taken same for all of the design of Triangular DRA. The Triangular DRA has been designed for Dual Band 6-7 GHz, 8-9 GHz and 10-11 GHz respectively using CST Microwave Studio.

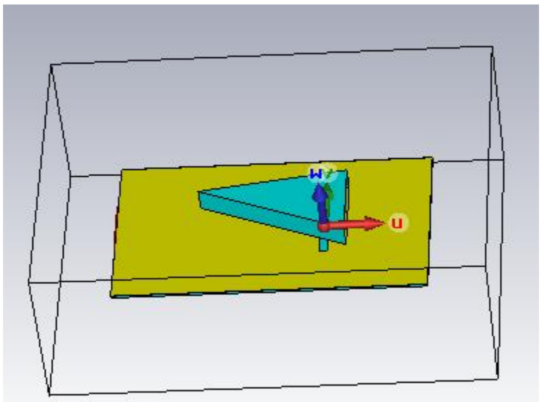

Fig. 3. Geometry of the TDRA

The substrate Material is RO4000 having permittivity of 3.38 and thickness as shown in Table. The MC-20 Ceramic Material is used as a Dielectric Material having permittivity of 20. The Triangular DRA was fed by 50-ohm standard microstrip line coupled with slot aperture of identical dimension. The dimensions of microstrip line coupled with slot aperture are listed in Table III. The Resonant Frequency of TM mode is approximately given by [20].

Vol. 2 No. 4 (2024)

Spectrum of Engineering Sciences

SPECTRUM OF ENGINEERING SCIENCES

Online ISSN 3007-3138

Print ISSN 3007-312X

$$f_r = \frac{1}{2\sqrt{\varepsilon}} * \left[\left(\frac{4}{3l_s}\right)^2 (m^2 + mn + n^2) + 0.1578\left(\frac{1}{2h}\right)^2\right]^{1/2} \quad (6)$$

where c is speed of light, ϵ is the dielectric constant, ls is the side length and h is the height of resonator. The indices l, m and n satisfy the condition l + m + n = 0 but they all cannot be zero. The parameters of Triangular DRA are listed in Table V.

TABLE V
TRIANGULAR DRA PARAMETERS

Dimensions(mm)	Design I (6 & 7) (GHz)	Design II (8 & 9) (GHz)	Design III (10 & 11) (GHz)
Side Length	9.52	5.9	3.9
Height	7.5	7.028	6.1

III. RESULTS AND DISCUSSION

A. Return Loss Vs Frequency Characteristic

The simulation study of Return Loss versus Frequency characteristic of single band Rectangular, Cylindrical and Triangular DRA at resonating frequencies 6-7 GHz, 8-9 GHz and 10-11 GHz has been carried out using CST Microwave Studio. The Simulation result of Return Loss of Three shapes of DRA is shown from fig 4-9 for comparison purpose. From Fig 4-11, the resonant Frequency Range and -10 dB return loss Bandwidth of three shapes of DRA are extracted and the results are given in Table VI. From Table VI, it can be seen that the Triangular DRA has much wider Bandwidth than that of the Rectangular and Cylindrical DRA at same resonating Frequency using same feeding technique, Dielectric material and Substrate material.

Spectrum of Engineering Sciences
SPECTRUM OF ENGINEERING SCIENCES
Online ISSN
3007-3138
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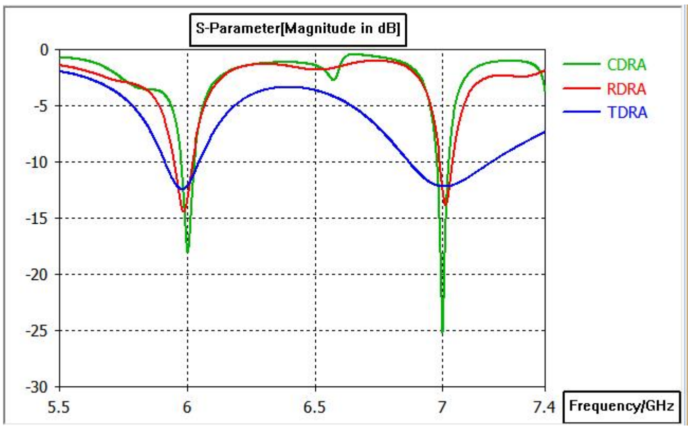

Fig. 4. Variation in Bandwidth of RDRA, CDRA and TDRA at 6 GHz

Fig.4. shows that at 6 GHz, the bandwidth of Rectangular, Cylindrical and Triangular DRA is 0.0705, 0.0528 and 0.134 GHz which shows that the Triangular DRA has two times wider bandwidth than Rectangular DRA and Cylindrical DRA at 6 GHz.

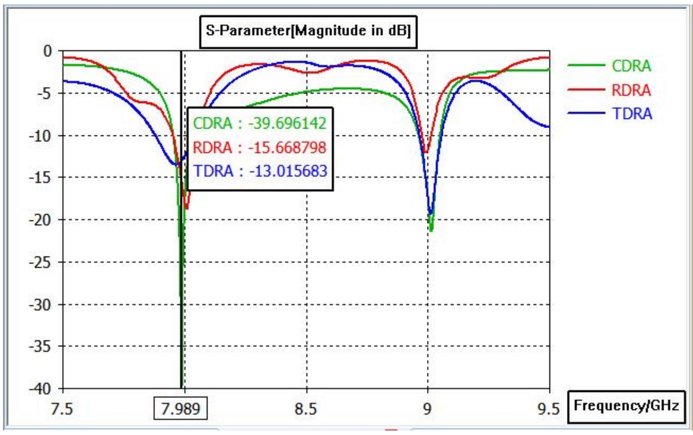

Fig. 5. Variation in Bandwidth of RDRA, CDRA and TDRA at 7 GHz

Fig.4. shows that at 7 GHz, the bandwidth of Rectangular, Cylindrical and Triangular DRA are 0.0495, 0.0467 and 0.326 GHz and it is concluded that the Triangular DRA has ap- proximately six times wider bandwidth than Rectangular and Cylindrical DRA at 7 GHz. Fig.5. shows that at 8 GHz, the bandwidth of Rectangular, Cylindrical and Triangular DRA are 0.101, 0.0750 and 0.163 GHz and it is concluded that the Triangular DRA has two times wider bandwidth than Rectangular and Cylindrical DRA at 8 GHz.

Vol. 2 No. 4 (2024)

Spectrum of Engineering Sciences

Online ISSN 3007-3138

Print ISSN 3007-312X

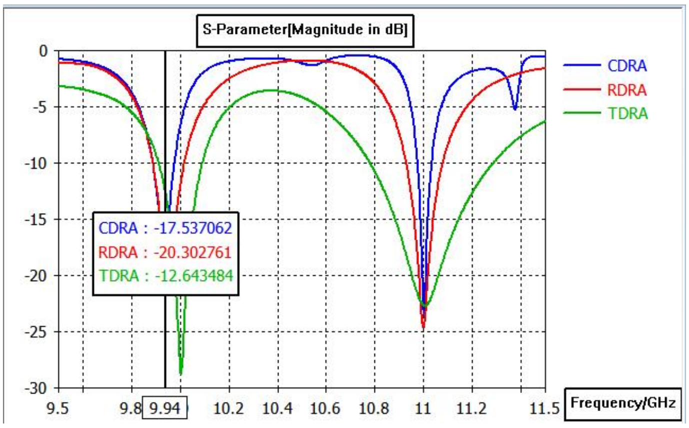

Fig. 6. Variation in Bandwidth of RDRA, CDRA and TDRA at 8 GHz

Fig.7. shows that at 9 GHz, the bandwidth of Rectangular, Cylindrical and Triangular DRA are 0.038, 0.088 and 0.090 GHz and it is concluded that the Triangular DRA has wider bandwidth than Rectangular and Cylindrical DRA at 9 GHz. Fig.8. shows that at 10 GHz, the bandwidth of Rectangular, Cylindrical and Triangular DRA are 0.129, 0.0893 and 0.177 GHz and it is concluded that the Triangular DRA has wider bandwidth than Rectangular and Cylindrical DRA at 10 GHz. Fig.9. shows that at 11 GHz, the bandwidth of Rectangular, Cylindrical and Triangular DRA are 0.150, 0.0590 and 0.518 GHz and it is concluded that the Triangular DRA has wider bandwidth than Rectangular and Cylindrical DRA at 11 GHz. Fig.10. and Table VI clearly shows that the Triangular DRA.

TABLE VI
COMPARISON OF BANDWIDTH OF DUAL BAND RDRA,CDRA AND TDRA.

Resonant Dual Band Designs	Rectangular DRA		Cylindrical DRA		Triangular DRA	
	Band Frequencies (f_1, f_2)	BW (GHz)	Band Frequencies (f_1, f_2)	BW (GHz)	Band Frequencies (f_1, f_2)	BW (GHz)
Design I	5.949 - 6.019	0.070	5.977 - 6.028	0.052	5.911 - 6.047	0.134
Design II	6.988 - 7.037	0.049	6.976 - 7.024	0.046	6.865 - 7.197	0.326
Design III	7.952 - 8.053	0.101	7.953 - 8.028	0.075	7.879 - 8.042	0.163

Spectrum of Engineering Sciences
Online ISSN
3007-3138
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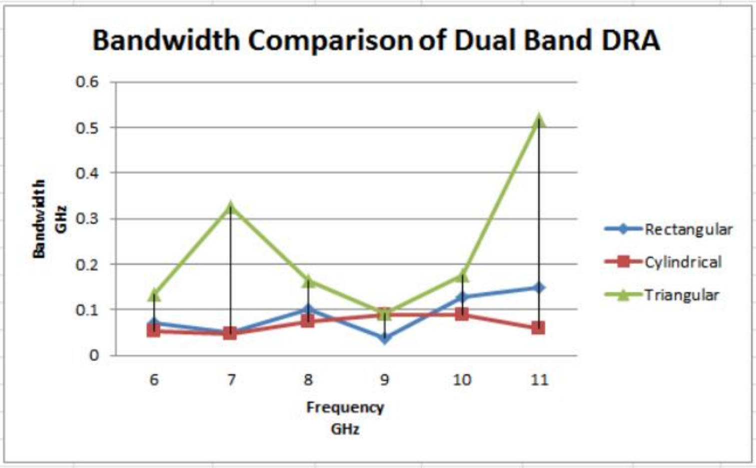

Fig. 7. Bandwidth Comparison of Single Band DRA

B. Gain Vs Frequency Characteristic

The Gain of the Antenna is the ratio of its radiation intensity to that of an isotropic antenna radiating the same total power as accepted by real Antenna [17]. Fig. 11 and Table VII show the Gain result of comparison obtained from the simulation of Rectangular, Cylindrical and Triangular DRA at resonating frequency 6, 7, 8, 9, 10 and 11 GHz in CST Microwave Studio. The Gain of three shapes of DRA are extracted and are given in Table VII. From Table VII and Fig.11, it is clear that the Gain of Triangular DRA is higher than Rectangular and Cylindrical DRA at C and X-Band.

TABLE VII
COMPARISON OF GAIN OF DUAL BAND RDRA,CDRA AND TDRA.

Dual Band Designs	Rectangular DRA Gain (dB)	Cylindrical DRA Gain (dB)	Triangular DRA Gain (dB)
Design I	7.39	6.76	6.44
Design II	8.83	3.31	6.29
Design III	7.14	7.75	6.88

C. Directivity Vs Frequency Characteristic

Directivity is the ratio of radiation intensity in a given direction to the average power radiation in all directions. Fig. 11 and Table VIII show the Directivity result of comparison obtained from the

Vol. 2 No. 4 (2024)
Spectrum of Engineering Sciences
Online ISSN 3007-3138
Print ISSN 3007-312X

simulation of Rectangular, Cylindrical and Triangular DRA at resonating frequency 6, 7, 8, 9, 10 and 11 GHz in CST Microwave Studio. The directivity of three shapes of DRA are extracted and are given in Table VIII. From Table VII and Fig. 11, it is clear that the directivity of Triangular DRA is higher than Rectangular and Cylindrical DRA at C and X-Band.

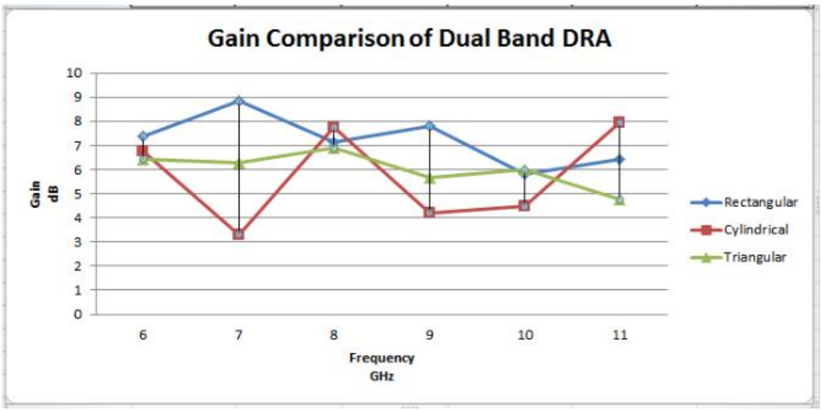

Fig. 8. Gain Comparison of Dual Band DRA

Fig 12-17 shows the simulated Gain result of Rectangular, Cylindrical and Triangular DRA for comparison purpose at resonating Frequencies 6, 7, 8, 9, 10 and 11 GHz. From fig.12- 17, The Gain at different Resonating Frequencies of three shapes of DRA are extracted and are given in Table 7. From Table 7, The Directivity of Triangular DRA at C and X Band is higher than that of the Rectangular and Cylindrical DRA.

TABLE VIII
COMPARISON OF DIRECTIVTY OF SINGLE BAND RDRA,CDRA AND TDRA.

Dual Band Designs	Rectangular DRA Directivity (dB)	Cylindrical DRA Directivity (dB)	Triangular DRA Directivity (dB)
Design I	7.50	6.76	6.43
Design II	9.11	3.25	6.31
Design III	7.37	7.81	6.95

Vol. 2 No. 4 (2024)

Spectrum of Engineering Sciences

Online ISSN
3007-3138
Print ISSN
3007-312X

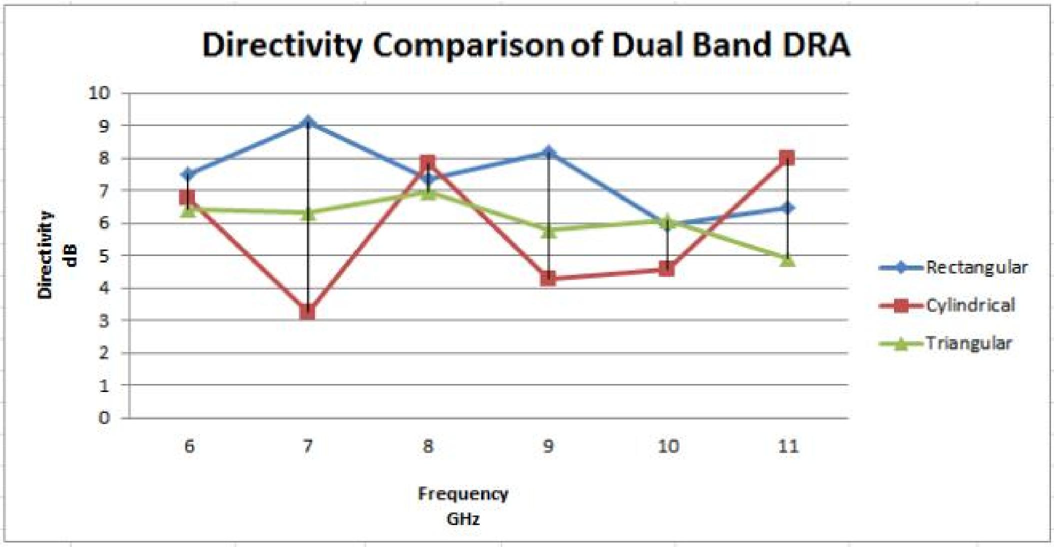

Fig. 9. Directivity Comparison of Dual Band DRA

IV. CONCLUSION

In this paper, Cylindrical Dielectric Resonator Antenna, Rectangular Dielectric Resonator Antenna and Triangular Dielectric Resonator Antennas have been analyzed and designed for dual bands whose frequencies lie in two different bands of spectrum i.e. C-band and X-band. The simulation of these three types of antennas made it possible to compare the gain, directivity, return loss and frequency characteristics of Cylindrical Dielectric, Rectangular and Triangular Dielectric Resonator Antennas. From the results it is clear that a dual band Triangular DRA yields a wide band when compared with the other two designs, but at the same time the Rectangular Dielectric Resonator Antenna shows better results in terms of directivity and gain for the dual bands of 6-7GHz, 8-9GHz and 10-11GHz than the other two designs. Finally, it is deducted from the whole study of Dual Band CDRA, TDRA and RDRA that keeping in mind the requirements, desired application and needs to make a trade-off between these parameters to select the best suitable design among the proposed designs for dual band applications. These types

Vol. 2 No. 4 (2024)

Spectrum of Engineering Sciences

Online ISSN

3007-3138

Print ISSN

3007-312X

of Dual band Antenna designs can play a vital role in the field of wireless LANs, subsurface communication, bio medical technology telemetry aerospace technology and satellite communications [9-22].

REFERENCES

[1] H. T. Rai, G. W. Mu, & R. Q. Lu. (2024). Integrated Dielectric Resonator Antenna to Traditional Antenna for Better Bandwidth and Gain. National Journal of Antennas and Propagation, 6(2), 9-16.

[2] H. El-Sawaf, W. M. Abdel-Wahab, N. Ghafarian, A. Palizban, A. Ehsandar and S. S. Naeini, "A 3D-Printed DRA Shared-Aperture Array for Low Cost Millimeter-Wave Applications," in IEEE Transactions on Antennas and Propagation, vol. 70, no. 12, pp. 11595-11607, Dec. 2022, doi: 10.1109/TAP.2022.3209254.

[3] Bendjedi H, Mekki S, Mehenni N, Elfergani I, Desai A, Zegadi R, Palandoken M, Karaçuha K, Hamida AF, Rodriguez J, Zebiri C. Design Innovative High-Gain MIMO Cylindrical DRA with Surface-Mounted Horn for Enhanced WLAN Connectivity. IEEE Access. 2025 Oct 14.

[4] Gupta, P.K., Mishra, M., Tiwari, G. and Mukherjee, B., 2025. A low-profile DRA on convex conformal ground plane for C and X band applications. *International Journal of Electronics*, pp.1-15.

[5] Chakraborty, P., Karmakar, A. and Saha, A., 2024. A review on dielectric resonator antennas: past and present. *Wireless Personal Communications*, *134*(3), pp.1367-1388.

[6] Volakis, J.L., Rengarajan, S.R., Hao, Y. and Shields, M., 2025. Highlights of Antenna Innovations (1974–2024): New developments over recent decades. *IEEE Antennas and Propagation Magazine*.

Spectrum of Engineering Sciences
SPECTRUM OF ENGINEERING SCIENCES
Online ISSN
3007-3138
Print ISSN
3007-312X

[7] Bhattacharya, S. and Ray, S.C., 2023. Broadbanding and multi-frequency in dielectric resonator antennas: a comprehensive review. *International Journal of Microwave and Wireless Technologies*, *15*(4), pp.709-725.

[8] Tong, C., Kremer, H.I., Yang, N. and Leung, K.W., 2022. Compact wideband circularly polarized dielectric resonator antenna with dielectric vias. *IEEE Antennas and Wireless Propagation Letters*, *21*(6), pp.1100-1104.

[9] Sharma Archana, Khare Kavita and S. C. Shrivastava, Dielectric Resonator Antenna for X band Microwave Application, International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, Vol. 2, Issue 6, June 2013.

[11] Harkare, A.H., Kothari, A.G. and Bhurane, A.A., 2023. Evolution of gain enhancement techniques in dielectric resonator antenna: applications and challenges. *International Journal of Microwave and Wireless Technologies*, *15*(5), pp.891-905.

[12] Halimi, M.A., Khan, T., Surender, D., Nasimuddin, N. and Rengarajan, S.R., 2023. Dielectric resonator antennas for RF energy-harvesting/wireless power transmission applications: A state-of-the-art review. *IEEE Antennas and Propagation Magazine*, *66*(1), pp.34-45.

[13] Abd Rahman, N.A., Mohd Yasin, M.N., Ibrahim, I.M., Jusoh, M., Noor, S.K., Ekscalin Emalda Mary, M.R., Zamin, N. and Nurhayati, N., 2022. A review of circularly polarized dielectric resonator antennas: recent developments and applications. *Micromachines*, *13*(12), p.2178.

[14] Sharma, M., Talwar, R., Pandey, D., Nassa, V.K., Pandey, B.K. and Dadheech, P., 2024. A review of dielectric resonator antennas

Spectrum of Engineering Sciences
SPECTRUM OF ENGINEERING SCIENCES
Online ISSN
3007-3138
Print ISSN
3007-312X

(DRA)-based RFID technology for Industry 4.0. *Robotics and Automation in Industry 4.0*, pp.303-324.

[15] Zhang, C., Ma, L., Zhao, Z., Xiao, P., Tian, G., Li, H. and Li, G., 2024. Achieving high efficiency and bandwidth enhancement of DRA arrays: Synergic effects of LiMg4AlO6 microwave dielectric ceramic and 2D metamaterials. *Applied Materials Today*, *41*, p.102450.

[16] Xiao Sheng Fang, Theory and Experiment of Three-Port Polarization- Diversity Cylindrical Dielectric Resonator Antenna, IEEE TRANSAC- TIONS ON ANTENNAS AND PROPAGATION, VOL. 62, NO. 10, OC- TOBER 2014.

[17] Y. Gao, Z. H. Feng, and L. Zhang, Compact CPW-fed dielectric resonator antenna with dual polarization, IEEE Antennas Wireless Propag. Lett., vol. 10, pp. 544547, 2011.

[18] L. F. Zou and C. Fumeaux, A cross-shaped dielectric resonator antenna for multifunction and polarization diversity applications, IEEE Antennas Wireless Propag. Lett., vol. 10, pp. 742745, 2011.

[19] Abhishek Kumar Gautam and Mahender Singh, Comparative Study Of Rectangular Dielectric Resonator Antenna Using Transcendental Equation, Emerging trends in Engineering & Management for Sustainable Development 2016, International conference, Feb 2016.

[20] Lo, H. Y. and K. W. Leung, Excitation of low profile equilateral triangular dielectric resonator antenna using a conductive conformal strip, Microwave and Optical Technology Letters, Vol. 29, No. 5, 317319, June 2001.

[21] A. Gupta, R. K. Gangwar and S. P. Singh," THREE ELEMENT DUAL SEGMENT TRIANGULAR DIELECTRIC RESONATOR

Spectrum of Engineering Sciences
SPECTRUM OF ENGINEERING SCIENCES
Online ISSN
3007-3138
Print ISSN
3007-312X

ANTENNA FOR X-BAND APPLICATIONS Progress In Electromagnetics Research C, Vol. 34, 139 150, 2013.
[22] Wang, H. and Yang, L., 2023. Dielectric constant, dielectric loss, conductivity, capacitance and model analysis of electronic electroactive polymers. *Polymer Testing*, *120*, p.107965.