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Design, Analysis and Parametric Study of Rectangular Dielectric Resonator Antenna Arrays

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Abstract

A Rectangular array dielectric resonator antennas are applicable for microwave range of frequencies and the proposed antennas are built with a dielectric constant ε_r of 10.2, the Rectangular array DRAs are excited by a Coaxial Probe feed line mechanism. These antennas are suited for mobile broadband applications like 4G, 5G services. The modeled antenna is placed on a ground plane with a size of 116 × 116 × 0.0029 mm^3.The antenna parametric results were intent through CST Microwave Studio Suite 2017 and around the frequency of 10 GHz, a High gain of 10 dB result given by these proposed Array DRAs are better than the existed conference proceeding titled as high permittivity design of rectangular dielectric resonator antenna for C band applications.

***Keywords**: Dielectric resonator antennas (DRAs), Probe feed and CST Studio Suite*

1. Introduction

The technology grows from the 1st generation, such as 1G to 2G, 3G, 4G and so on up to 5G. Each and every of the generations of the technology has several variations and innovations. The fifth generation (5G) technology is anticipated to finish the fourth generation technology and provides solutions to the shortage arising from 4G[1] like restricted information measure and speed, As 5G is developed and implemented there'll be a significant demand particularly on the user instrumentality and base station infrastructures [1]. Almost all mobile communication systems use current cellular spectrum in the range of 300 MHz gigahertz. Hence, this spectrum (below 3 GHz band) has been overcrowded. That is why modern communication system has been shifting upward to the mm wave band. In 5G requirements, the antenna should at least have a gain of 12 dBi and bandwidth more than 1 GHz [2]. There are several researchers done on wireless antenna for millimeter wave band[3-6].

Due to their attractive features and immense characteristic applications, DRAs are largely using in present day wireless communications. These are having dielectric constant ranging from 10 to 100 for high frequency applications. In 1939 Ritchmyer showed that dielectric objects in the form of toroids could function as microwave resonators, if the shapes, permittivities and feed mechanisms are appropriately chosen. Many years later in 1983, McAllister *et al*. showed that a cylindrical dielectric slab placed atop a ground plane, and excited by a probe fed through the ground plane into the dielectric, will radiate in a direction normal to the ground plane when the excitation frequency is at or near the resonant frequency of the dielectric slab. Soon thereafter the investigation extended to orthorhombic resonators. Dielectric resonator antenna (DRA) [6-7] has been of interest due to their low loss, high permittivity, light weight and ease of

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excitation. In addition, wide bandwidth, and high radiation efficiency are inherent advantages of DRAs.

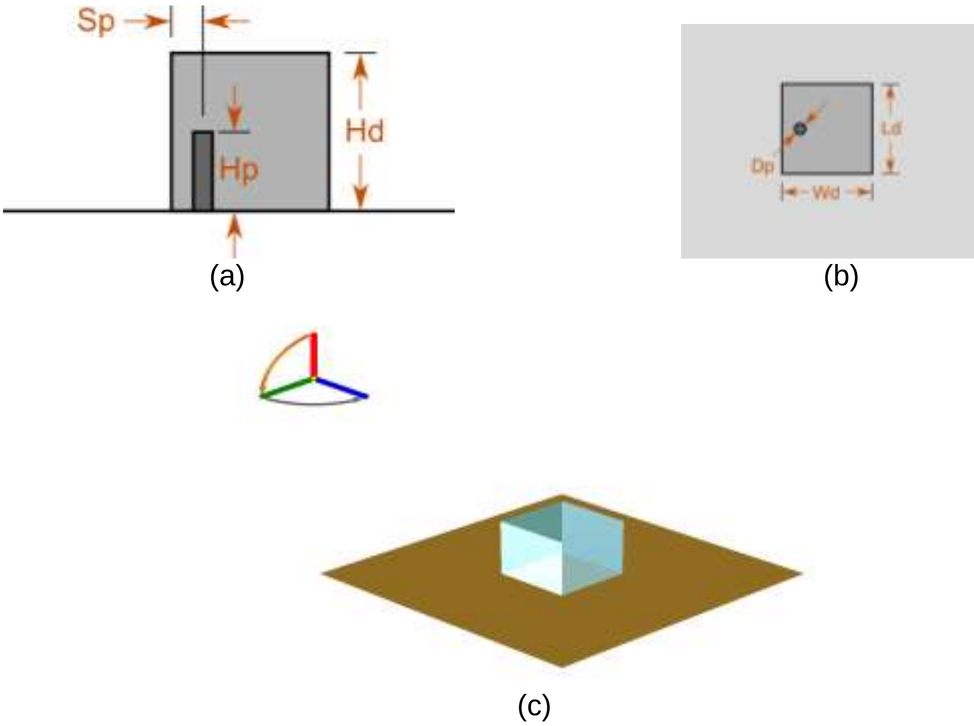
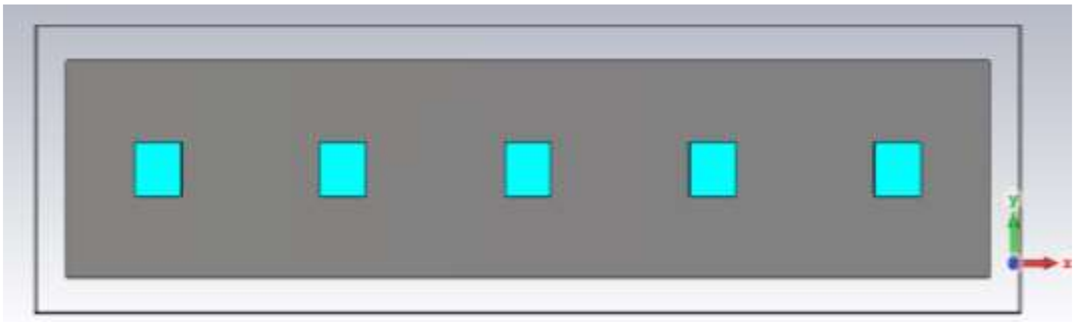


Figure 1. Rectangular DRA; (a) Side View with Feed, (b) Top View of DRA and (c) Complete view of Rectangular DRA

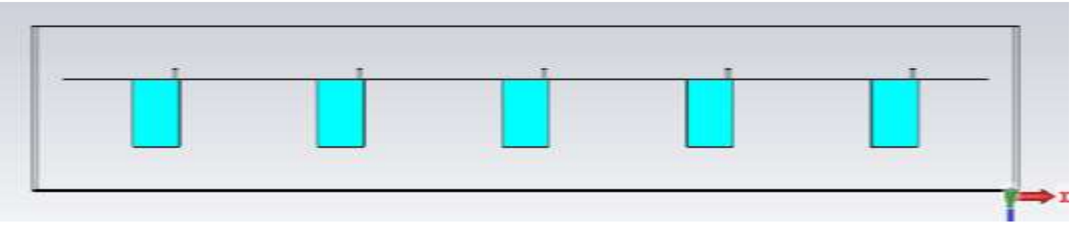
The rectangular-shaped DRAs over practical advantages over cylindrical and hemispherical ones in that they are easier to fabricate and have more design flexibility [8]. The resonant mode of the feeding slot was also utilized to widen the bandwidth [9]. Recently, a higher-order mode of a DRA was used to increase the bandwidth [10] or to design a dual band DRA [11].

The coupling between a DRA and the planar transmission line is easily controlled by variable the position of the DRA with reference to the line. The dimensions and dielectric constant of the dielectric resonator antennas are chosen properly for designing purpose. We can avoid ground losses, better parametric results by the DRAs over the Microstrip patch antennas to increase the antenna bandwidth. The lowest dielectric constant material adopted in DRA design is reported in [12–14], where commodity plastics with relative dielectric constant smaller than 3 have been utilized for the realization of super shaped DRAs. The basic principle of operation of dielectric resonators is similar to that of the cavity resonators [15].

Various feeding techniques, relatively wide bandwidths compared to Microstrip antennas, wide temperature ranges and high power-handling capabilities due to high dielectric strengths have been reported. The performance of DRA will so be easily optimized by experimentation and suitability of the dielectric constant of the fabric and/or by the DRA shapes[21]. The rectangular DR may be fed using a number of techniques, including slot, probe, co-planar, aperture and microstrip line. This particular DR is fed using a coaxial probe located close to one of the walls, at its centre. By varying the height of the probe, the real part of the impedance may be adjusted, although a small frequency shift may occur. Therefore, different completely different radiation characteristics are obtained by exciting different shapes, feeding methods and enhancement techniques. The rectangular and cylindrical dielectric resonator antenna designs are optimized and analyzed by using CST Studio Suite 2017 simulation code to get antenna constant results like return loss, Radiation Patterns, directivity and Gain values.



(a)



(b)

Figure 2. Rectangular Array Shaped DRA: (a) Top View of Array DRA and (b) Bottom view of Array DRA with Feed

2. Design Analysis of DRAs

The collaborate arrangement of the modeled Array shaped DRAs are constructed in the above Figure 2. The antennas are constructed with rectangular shapes fed by a probe feed which is supported by a 116 × 116 × 0.0029 mm^3 substrate with relative permittivity of 10.2 material. Coaxial feeding technique can be used at any desired location inside the DRA to match better impedance. The feed dimension parameters like Probe inset, Probe Diameter, Probe Height, Coaxial Length and Coaxial Diameter values are also presented in the below table. These dielectric resonators are excited by different feeding line methods like microstrip line, Coaxial Probe to get better bandwidth enhancement and radiation patterns. The Carved antennas are analyzed to be operated in the C-band frequency range with the dimensional values which are aligned in the Table 1. The operation of a microwave resonator has an infinite number of resonant modes, each corresponding to a particular resonant frequency at which the stored electric energy is equal to the magnetic energy [Volakis]. The excited modes in basic structures may be classed into TEmnp+δ, TMmnp+δ and hybrid modes HEmnp+δ, where indices denote the variation of fields along the X-,Y- and Z-direction[22].

The excited mode depends on the type of excitation, while the coupling mechanism affects the centre frequency and Q-value of the DR. The feed probe used for the antenna presented here, excites the lowest order TM to z mode. For certain geometrical DR shapes, analytical formulas exist, allowing the calculation of the resonant frequency and Q-values of the lowest fundamental modes.

In practice, slightly smaller and much larger values of relative permittivity may be used when designing DRAs. It should also be noted that smaller and larger values of input resistance might be achievable. A relative permittivity of 10 and an input resistance of 50 Ohm should be chosen if no specific values are required for the design. Approximate design guidelines are outlined below.

- The input resistance may be increased by increasing the probe height. It should be noted that a change in probe height will result in a resonance frequency shift.

- The overall dimensions of the structure may be decreased by increasing the relative permittivity of the DR.

- The frequency may be increased (decreased) by decreasing (increasing) all the length parameters of the model.

In this design, coaxial Probe feed line is employed as a feeding mechanism shown in Figure 1. The DRA is fed directly with microstrip line at identical plane, and it's fully grounded at the rear. This approach is usually used for coupling an antenna. The number of coupling will be controlled by adjusting the S worth [21]. The benefits of this feeding are simple fabrication, matching and convenient for DRA array [20].

Table 1. Dimensional Parameters of Proposed Designs

Parameter	Value	Parameter	Value
Relative permittivity	10.2	Probe Inset	0.58 mm
Dielectric Width	5.81 mm	Probe Diameter	0.29 mm
Dielectric length	5.81 mm	Probe Height	2.41 mm
Dielectric Height	5.81 mm	Metal Thickness	0.0029 mm
Input resistance	50	Coaxial Length	0.871 mm
Wavelength	29.9	Coaxial Diameter	0.661 mm

3. Numerical Survey

By analyzing the RDRA structural dimensions, we get theoretical resonant frequency of the desired dominant mode of Rectangular DRA is presented below in the equations.

$$k_x^2 + k_y^2 + k_z^2 = \varepsilon_r k_0^2 \tag{1}$$

$$\therefore k_0 = 2\Pi f_0 \tag{2}$$

$$\because k_x = \frac{m\Pi}{r_w}, k_y = \frac{n\Pi}{r_l}, k_z = \frac{p\Pi}{r_h}$$

Where,

r_w Designates the Width of the RDRA,

r_l Designates the Length of the RDRA,

r_h Designates the Height of the RDRA and

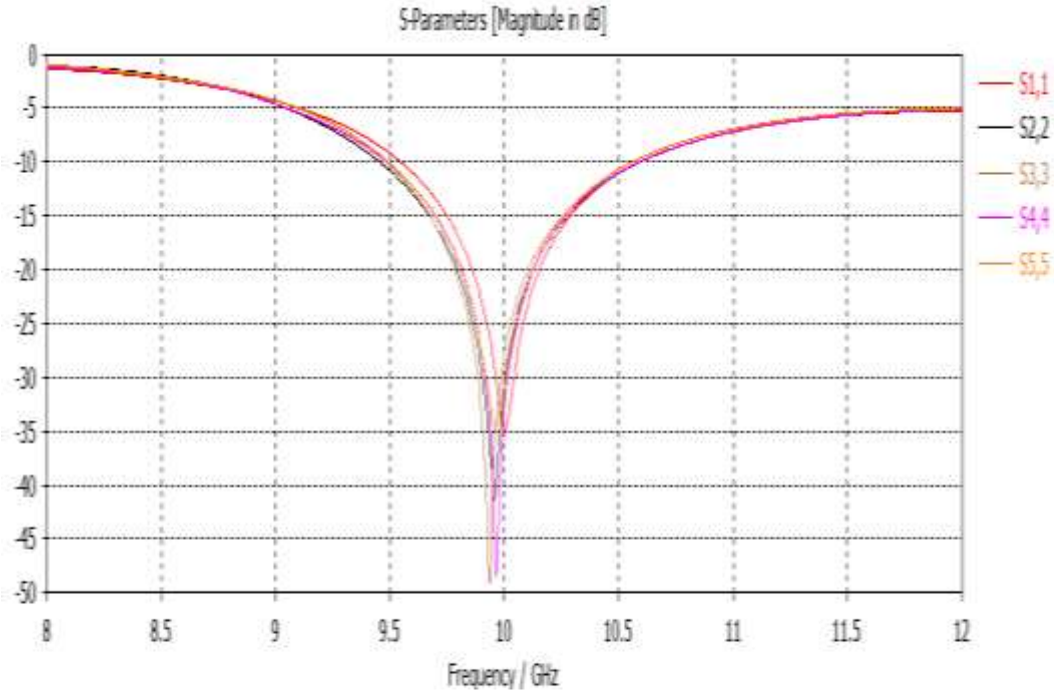
m,n,p are the dominant mode values.

4. Simulated Results and Discussions

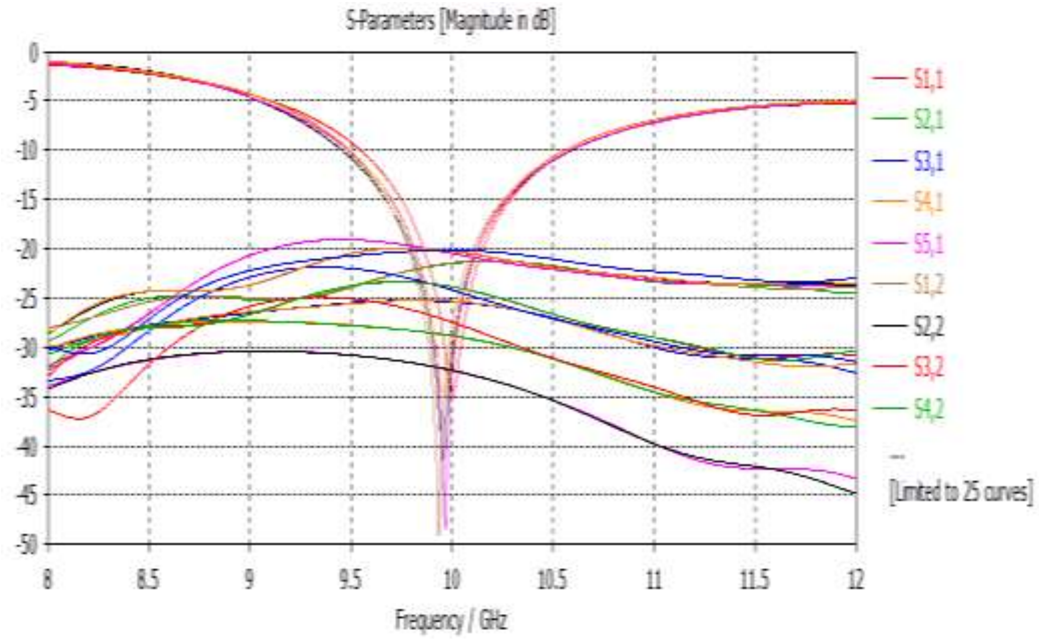
All the different antenna parametric results are shown in different sections which are presented below. In these Arrays, the Figure 2 describes the S-parametric analysis in detail.

4.1. S-Parameters Analysis

According to [15], the performance of DRA array depends on the geometry and dimension of the DRA elements, spacing between elements, number of elements, mode of operation and feed arrangement. During this section, the parametric studies for linear array DRA are discussed in order to induce the optimum dimension of overall antenna and a good antenna performance. The parametric study was carried out for two cases that are the number of elements (n) and the spacing between parts(d). The following Figure 3 describes the S-Parameter study in (A) gives the plot for S11, S22, S33, S44 and S55. In (B) shows the plot for S-parameters for all, *i.e.*, S11, S21, S31, S41, S51, S32, S33, S34, S35.... up to S55. In this paper we designed at center frequency 10, therefore each and every individual DRA exhibits nearer to 10 GHz only.



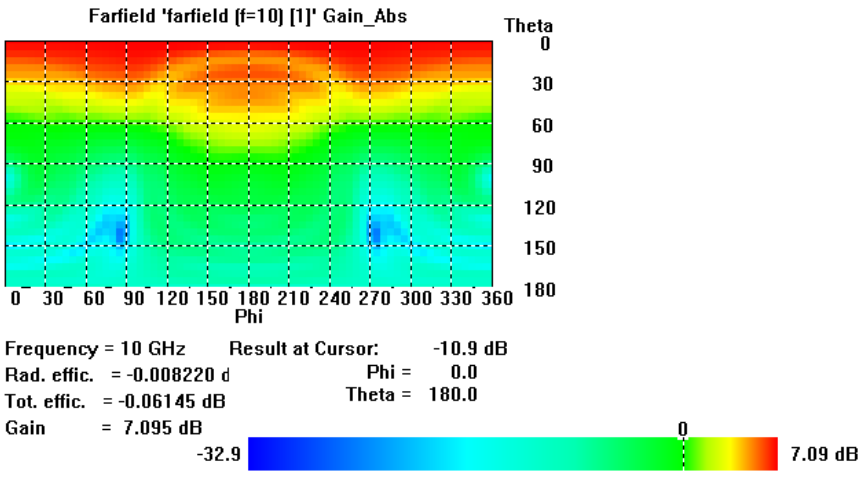
(A)



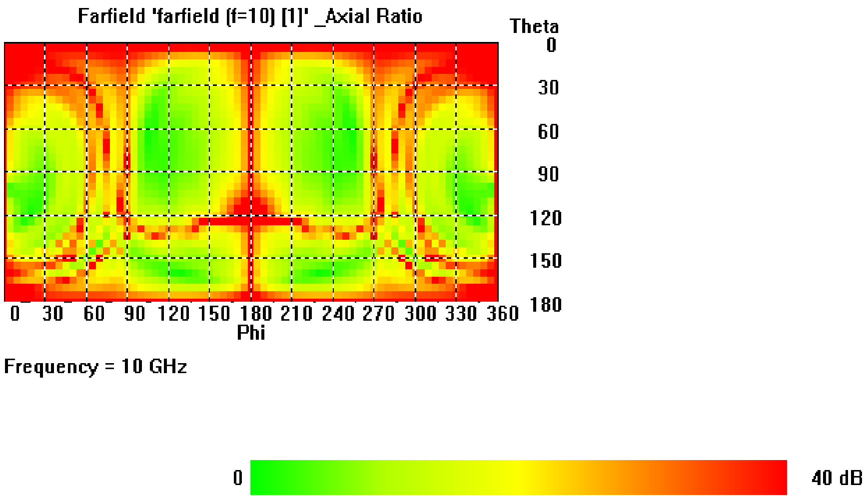
(B)

Figure 3. S-Parameters Analysis

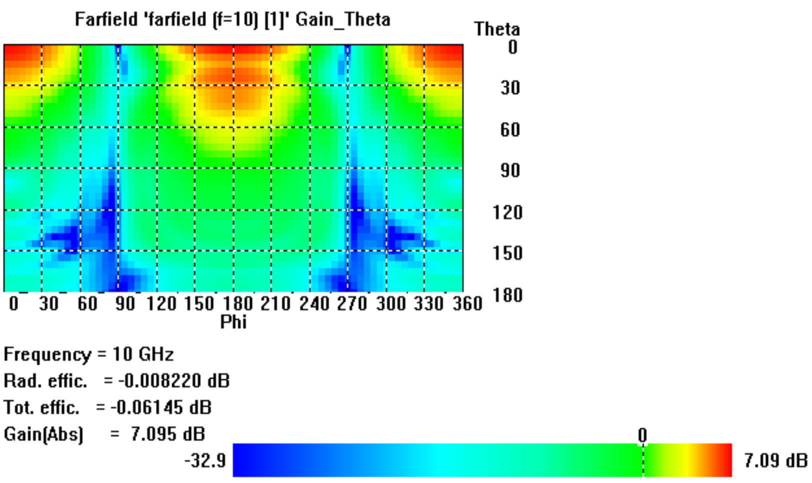
4.2. 2D Far Field Results



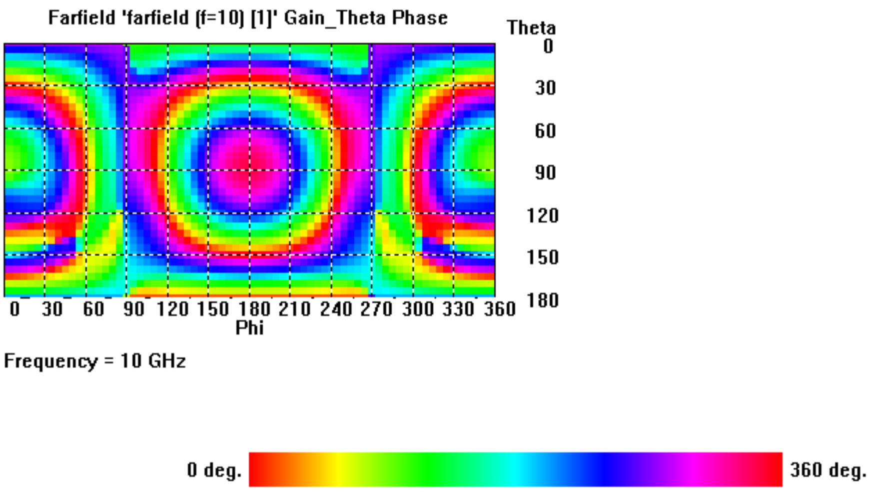
(a) Gain_ Absolute



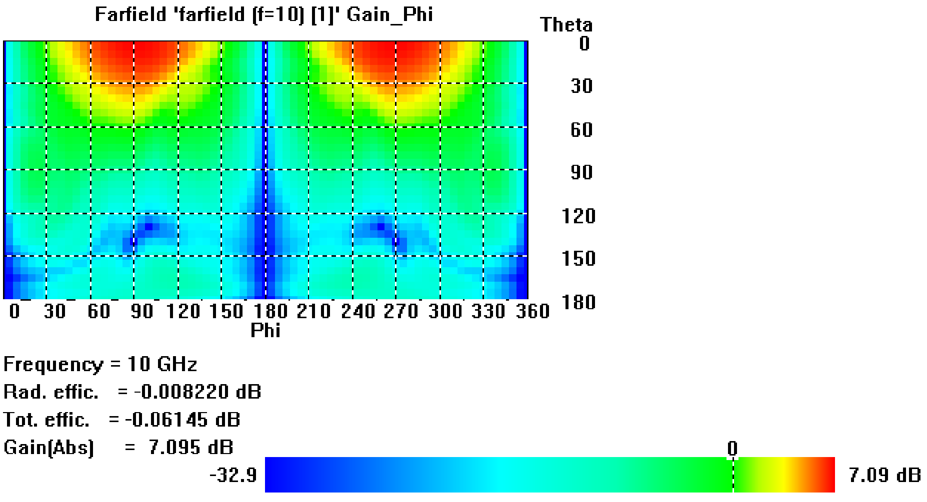
(b) Axial Ratio



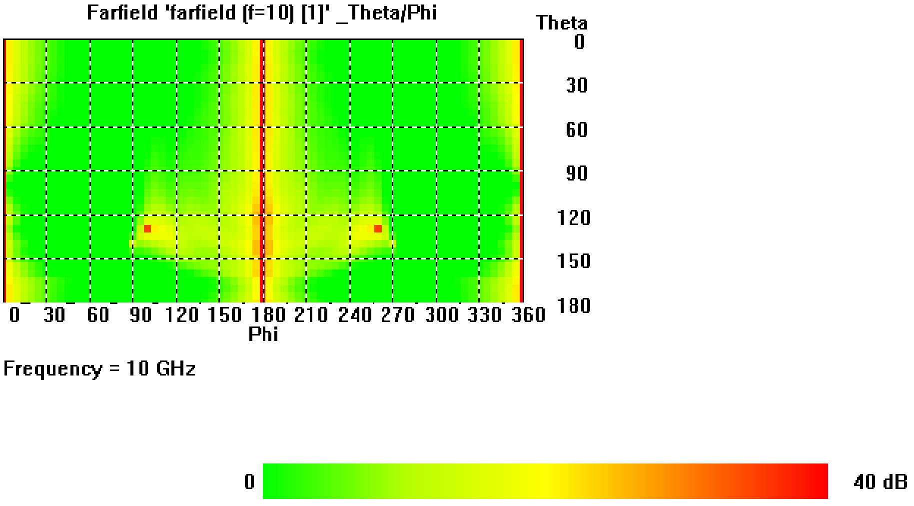
(c) Gain_ Theta



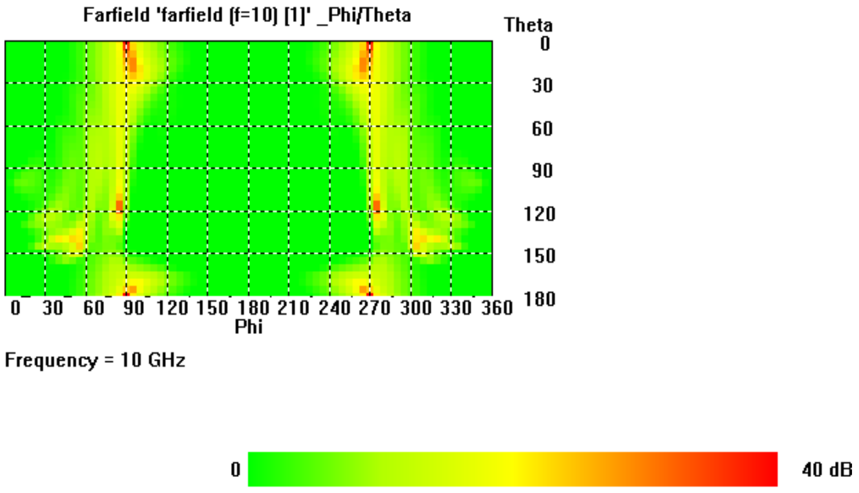
(d) Gain_Theta Phase



(e) Gain_Phi



(f) Theta/ Phi



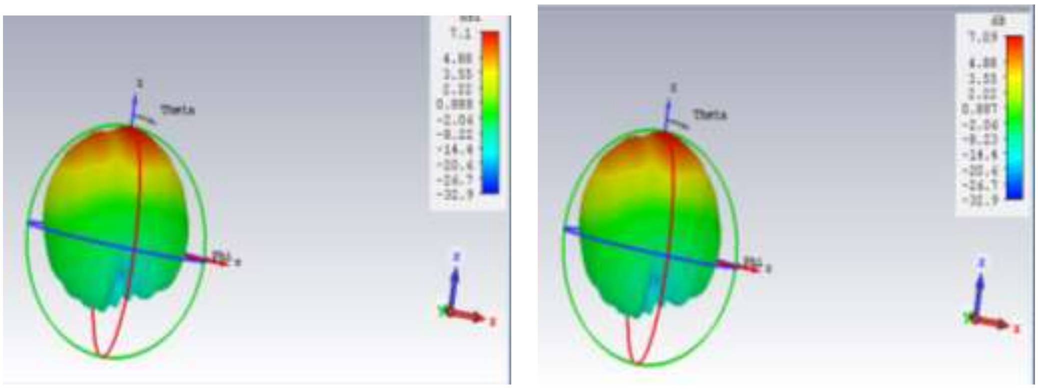
(g) Phi / theta

Figure 4. Shows the 2D Far Field Pattern of DRA1 in Array

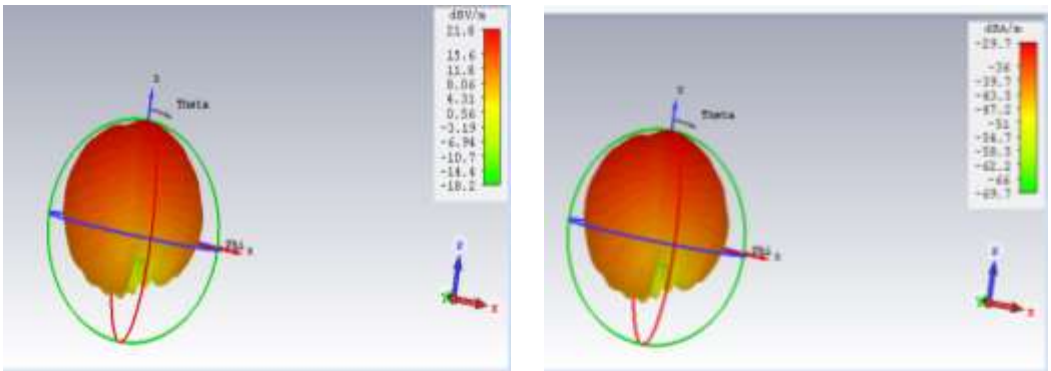
In the Figure 4 gives the farfield patterns of DRA1 in the Array at center frequency 10 GHz. It gives the clear cut analysis for Absolute Gain, Axial ratio, Theta, Theta Phase, Phi, Phi Phase, Theta/phi and Phi/ Theta respectively.

4.3. 3D Far Field Results

The Following results shows the sample view of Directivity, Gain, E- Field and H-Field Respectively for only one DRA



(a) Directivity (b) Gain



(c) E - Field (d) H - Field

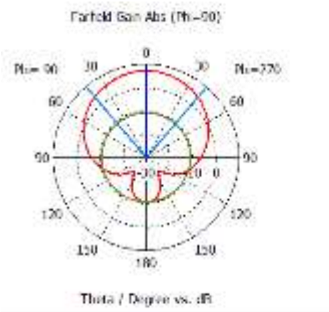
Figure 5. Shows the 3D Far field pattern of DRA1 in Array

Table 2. Performance Comparison between Parameters of Proposed Design

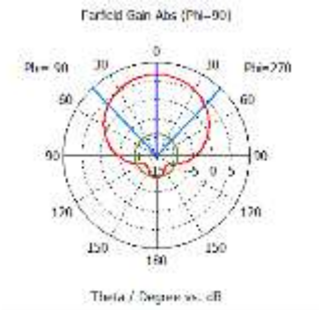
Parameter	DRA1	DRA2	DRA3	DRA4	DRA5
Radiation Efficiency	-0.00822 dB	-0.003604 dB	0.0020 dB	-0.0022 dB	-0.0026 dB
Total Efficiency	-0.6145 dB	-0.1031 dB	-0.1178 dB	-0.116 dB	-0.07778 dB
Gain	7.095 dB	6.773 dB	6.528 dB	6.554 dB	6.159 dB
Directivity	7.103 dBi	6.776 dBi	6.526 dBi	6.556 dBi	6.162 dBi
E max	21.81 dBV/m	21.44 dBV/m	21.17 dBV/m	21.21 dBV/m	20.85 dBV/m
H Max	-29.71 dBA/m	-30.08 dBA/m	-30.35 dBA/m	-30.31 dBA/m	-30.67 dBA/m

Table 2 gives the detailed performance comparison of Array in 3D Far field patterns for parameters like Radiation Efficiency, Total efficiency, Gain, Directivity, E Max and H Max . In this comparison the gain is similar for all cases of DRA arrays.

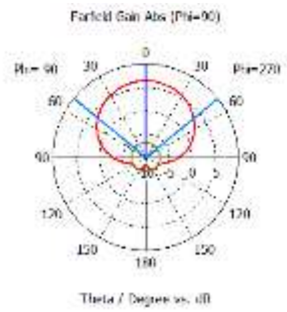
4.4. 2D Radiation Pattern



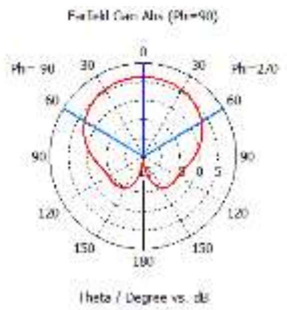
(A) Polar Plot For DRA1



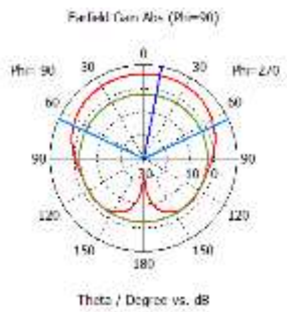
B) Polar Plot For DRA2



(C) Polar Plot For DRA3



(D) Polar Plot For DRA4



(E) Polar Plot For DRA5

Figure 6. Polar Plots for Array Rectangular DRA

Table 3. Performance Comparison between DRAs of Proposed Design

Parameter	DRA1	DRA2	DRA3	DRA4	DRA5
Main Lobe Magnitude (dB)	7.09	6.77	6.36	6.21	5.96
Main lobe direction (deg)	0.0	0.0	0.0	0.0	11.0
Angular width(3 dB)	80.5	86.8	101.1	117.9	130
Side Lobe level (dB)	-18.0	-15.8	-13.1	-10.2	-8.6

Table 3. gives the overall performance polar plot for the proposed design and also for different parameters like Main lode magnitude, main lobe direction, Angular width, side Lobe level.

5. Conclusion

The Probe excited rectangular dielectric resonator antennas are constructed by the calculated dimensional values. The presented DRAs will works in the microwave to millimeter range frequencies. By optimizing the design parametric dimensions, a high gain of 10dB appears in the proposed design. As per the design, by simulating arrays and altering the feed mechanisms through these DRAs, Directivity and Gain factor will increases. In this work, RDRA gives better impedance bandwidth the best far field results.

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References

[1] T. Rappaport, S. Sun and R. Mayzus, "Millimeter wave mobile communications for 5G cellular", It will work!," IEEE Access, vol. 1, **(2013)**, pp. 335-349.
[2] H. Wong, K. B. Ng, C. H. Chan and K. M. Luk, "Printed antennas for millimeter wave application", International Workshop on Antenna Tech., **(2013)**, pp. 411-414.
[3] K. S. Chin, H. T. Chang and J. A. Liu, "28-GHz patch antenna arrays with PCB and LTCC substrates", Cross Strait Quad-Regional Radio Science and Wireless Technology Conference, vol. 1, **(2011)**, pp. 355-358.
[4] K. F.Tong, K. Li and T. Matsui, "Performance of millimeter-wave coplanar patch antennas on low-k materials", PIERS Online, vol. 1, no. 1, **(2005)**, pp. 46-47.
[5] D. Wang, H. Wong, K. B. Ng and C. H. Chan, "Wideband shorted higher-order mode millimeter- wave patch antenna", IEEE Antennas and Propagation Society International Symposium, **(2012)**, pp. 5-6.
[6] K. M. Luk and K. W. Leung, Eds, "Dielectric Resonator Antennas", Baldock, U.K.: Research Studies, 2003.vol. A247, **(1995)**, pp. 529-551.
[7] Petosa, "Dielectric Resonator Antenna Handbook", Norwood, MA: Artech House, **(2007)**.
[8] Y. Gao, B. L. Ooi and A. P. Popov, "Dual-band hybrid dielectric resonator antenna with CPW-fed slot", Microw. Opt. Tech. Lett., vol. 48, **(2006)**.
[9] Y C. M. Su, H. T. Chen, F. S. Chang and K. L. Wong, "Dual-band slot antenna for 2.4/5.2 GHz WLAN operation", Microw. Opt. Tech. Lett., vol. 35, no. 4, **(2002)**, pp. 306–308.
[10] Z. Fan and Y. M. M. Antar, "Slot-coupled DR antenna for dual frequency operation", IEEE Trans. Antennas Propag., vol. 45, no. 2, **(1997)**, pp. 306–308.
[11] Y. Gao, B. L. Ooi and A. P. Popov, "Dual-band hybrid dielectric resonator antenna with CPW-fed slot", Microw. Opt. Tech. Lett., vol. 48, no. 1, **(2006)**, pp. 170–172.
[12] M. Simeoni, R. Cicchetti, A. Yarovoy and D. Caratelli, "Plasticbased supershaped dielectric resonator antennas for wide-band applications", IEEE Transactions on Antennas and Propagation, vol. 59, no. 12, **(2011)**, pp. 4820–4825.
[13] M. Simeoni, R. Cicchetti, A. Yarovoy and D. Caratelli, "Supershaped dielectric resonator antennas", in Proceedings of the IEEE Antennas and Propagation Society International Symposium, **(2009)**, pp. 1–4.

[14] M. Simeoni, R. Cicchetti, A. Yarovoy and D. Caratelli, "Circularly polarized supershaped dielectric resonator antennas for indoor ultra wide band applications", in Proceedings of the IEEE International Symposium on Antennas and Propagation Society, **(2010)**, pp. 1–4.
[15] D. M. Pozar, "Microwave Engineering", John Wiley & Sons, New York, NY, USA, **(2012)**.
[16] R. D. Richtmyer, "Dielectric resonators", J. App. Phy., vol.10, **(1939)**, pp. 391-398.
[17] S. A. Long, M.W. McAllister and L. C. Shen, "The resonant cylindrical dielectric cavity antenna", IEEE Trans. Antennas Propagat., vol. AP-31, **(1983)**, pp.406–412.
[18] R. K. Mongia and A. Ittipiboon, "Theoretical and experimental investigations on rectangular dielectric resonator antennas", IEEE Trans.Antennas Propag., vol. 45, no. 9, **(1997)**, pp. 1348–1356.
[19] K. M. Luk and K. W. Leung (eds.), "Dielectric Resonator Antennas", Research Studies Press, London, UK, **(2003)**.
[20] Petosa and A. Ittipiboon, "Dielectric resonator antennas: A historical review and the current state of the art", IEEE Antennas and Propag. Mag., vol. 52, **(2010)**.
[21] Petosa, "Dielectric Resonator Antenna Handbook", Norwood: Artech House Inc., **(2007)**.
[22] C. A. Balanis, "Antenna Theory, Analysis and Design", John Wiley & Sons, New York, Second ed., **(2009)**, pp. 727-730.
[23] C. A. Balanis, "Antenna Theory: Analysis and Design", Third ed. New Jersey: John Wiley & Sons, Inc., **(2005)**.
[24] J. L. Volakis, "Antenna Engineering Handbook", Fourth ed.: McGraw-Hill, Inc., **(2007)**.
[25] "High Permittivity Design of Rectangular and Cylindrical Dielectric Resonator Antenna for C-Band Applications", Advanced Science and Technology Letters, vol.147, (SMART DSC-2017), pp. 34-41.

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