Design and Analysis of Dielectric Resonator Antenna (DRA) for Wideband Applications

SYNOPSIS OF THE THESIS

Submitted in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

by

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2011PHXF415P

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December 2015

1. Introduction

Modern broadband communication systems require lightweight compact antennas with high gain and wide bandwidth. In the last few decades, two classes of novel antennas have been explored for such wireless communications that are Microstrip Patch Antenna (MPA) and the Dielectric Resonator Antenna (DRA). Both are highly appropriate for the development of modern wireless communication. However, patch antennas possess conduction losses due to the skin effect and narrow impedance bandwidth while DRA do not have any metallic loss, and hence it is highly efficient Dielectric Resonator Antennas (DRAs) are open resonating structures made out of high permittivity low-loss dielectric materials [1]. DRA has some interesting characteristics like high radiation efficiency, small size, high power handling capacity, low losses, wide operational bandwidth and ease to integrate with existing technologies as compared to the other resonating antennas [2-3]. In addition to these interesting characteristics, their resonance frequencies, their excited modes and their radiation characteristics are determined by their dielectric constant, their geometry and their coupling mechanism.

Thus concept of a small DRA with wideband operation in the 4-7 GHz frequency band is presented in this thesis. Two new configurations; Asymmetric and Tetraskelion shaped DRA that offer significant enhancements to parameters such as small size, wide operational bandwidth, high gain and high radiation efficiency are fabricated and investigated. In conclusion, this work offers a new, efficient and relatively simple alternative for antennas to be used for multiple requirements in the wireless communication system.

2. Motivation

Antenna designers are facing problem of widening bandwidth, and improving gain, in addition to miniaturization and optimization of radiation properties. Many existing wireless applications and radar applications operate over wideband frequency bands and, thus require broad band antennas. Using metal separator, multilayer structures, materials with different dielectric constants and air gap between layers have been reported for increasing gain and impedance bandwidth. Although using two or more

DR instead of one DR will increase impedance bandwidth and gain of antennas, it will also increase the thickness and the weight of DRA; and can lead to a complex fabrication process. Decreasing the thickness of the dielectric layers in DRAs, results in less impedance bandwidth [4]. By choosing appropriate dimension of DR the improvement is further possible for achieving the wide band response.

Another challenge to the antenna designers is the miniaturization of antenna. This can be achieved by using high permittivity materials, because guided wavelength of antenna is inversely proportional to the permittivity of the dielectric material. However, the high permittivity material restricts the bandwidth, which limits its usefulness as an antenna. By using metal separator, multilayer structures, materials with different permittivity's and air gap between layers one can think of increasing gain and impedance bandwidth.

The motivation for this work has been inspired by identifying the issues subjected to the design of DRAs and the need for compact, highly efficient and low cost antenna. These antennas are also suitable for quality wideband operation with the possibilities of compatibility with microwave integrated circuits, (MICs). The latest advances in the DRA technology focuses on proposed DRA elements to meet the challenges posed by emerging communication systems as mentioned above.

3. Objectives

In order to achieve these research goals, the point wise objectives are listed below:

1. To select a suitable microwave dielectric material for wideband dielectric resonator antennas.
2. To propose a suitable coupling technique and to optimize the size of antenna to miniaturize the DRA and maximize the coupling.
3. To analyze the dielectric resonator antennas (DRAs) for enhancing the bandwidth and improving the radiation characteristics by using simulation.
4. To fabricate and characterize the design of the proposed DRA.
5. Comparison among simulated and experimental results of the developed DRA design.

4. Description of the Research Work

This section describes the research work in brief, carried out to address the research objectives. This research work is divided as: material selection methodology for selection of best dielectric material as DR element for the proposed DRA, optimization of DRAs for geometric analysis and suitable feeding mechanisms; and fabrication, measurements and analysis of Asymmetric DRA and Tetraskelion DRA, which forms the various chapters of this thesis.

4.1 Material Selection Methodology

Ashby's material selection strategy is used to optimize class of materials depending on their properties for desired application performance. The optimization and selection of best appropriate material for the greater precision is based on their properties which are known as material attributes (material indices and performance indices). The material indices considered in this work are permittivity (ε_r), tangent loss (tan (δ)) and temperature coefficient of resonant frequency (τ_f), which affect the performance of the Dielectric Resonator Antenna and hence form the performance indices. Four important performance indices considered are resonant frequency (f_r), size of antenna (λ), impedance bandwidth (BW) and radiation efficiency (η) of antenna.

In the Ashby approach to material selection [5-6] a function is sought to describe the performance (p) of the element under consideration. In general, this function has the form: p = {F, G, M}, where F, G and M express the functional requirements, geometric parameters and material indices, respectively.

Using the performance indices, material selection charts are plotted and depending upon desired criteria of DR material for DRA, the materials which fulfill the performance requirement are selected. It was observed that Roger TMM10 (ε_r=9.8) is the best possible material followed by TMM10i (ε_r=10) and RO3010 (ε_r=10.2), out of all the materials taken into consideration.

This material is also verified for rectangular DRA and hybrid DRA that provides better bandwidth as compared to other dielectric materials. Thus, Roger TMM10 (ε_r =9.8) dielectric material is used for the design, simulation and fabrication of proposed DRA mentioned this thesis.

4.2 Optimization of DRA

4.2.1 DRA Geometry Analysis

A comparative study of different rudimentary geometries (rectangular, cylindrical and hemispherical) of DRAs design is carried out for selecting the favorable shape of DRA. These rudimentary geometries of DRA give a better understanding of design parameters of an antenna and their effect on return loss, impedance bandwidth, gain, efficiency and resonant frequency. Each geometry provides some benefits but also has some limitations in term of radiation properties and ease of fabrication. Therefore, it is very important to optimize the basic shapes of a DRA in order to design the complete antenna. It can be observed that the rectangular antenna not only achieves wider impedance bandwidth, but also its gain is considerably higher than other DRAs. Also as compared to other DRAs, rectangular DRAs make it easy to fabricate. A DRA with rectangular cross section is very adaptable as it provides more degrees of freedom than cylindrical and hemispherical shape. So in this work, the basic geometry that was considered for the further improvement in the design is RDRA.

4.2.2 Feeding Mechanisms for RDRA

Dielectric resonators are three dimensional cavity resonators and thus, have the ability to excite multiple modes. The excitation of these modes also depends on the feeding mechanism. Some commonly used feeding techniques such as microstrip fed, coaxial probe fed; aperture slot fed and coplanar waveguide fed are analyzed using CST Microwave Studio to choose the suitable feeding technique for proposed DRA. It is noted that the simple RDRA provides stronger coupling, best resonance and highest bandwidth with the coaxial probe excitation. So coaxial probe feeding is used for the investigation of DRA.

This great flexibility of the DRAs in terms of their shape and feeding mechanisms in combination with their other advantageous inherent properties make them suitable candidates for many commercial applications.

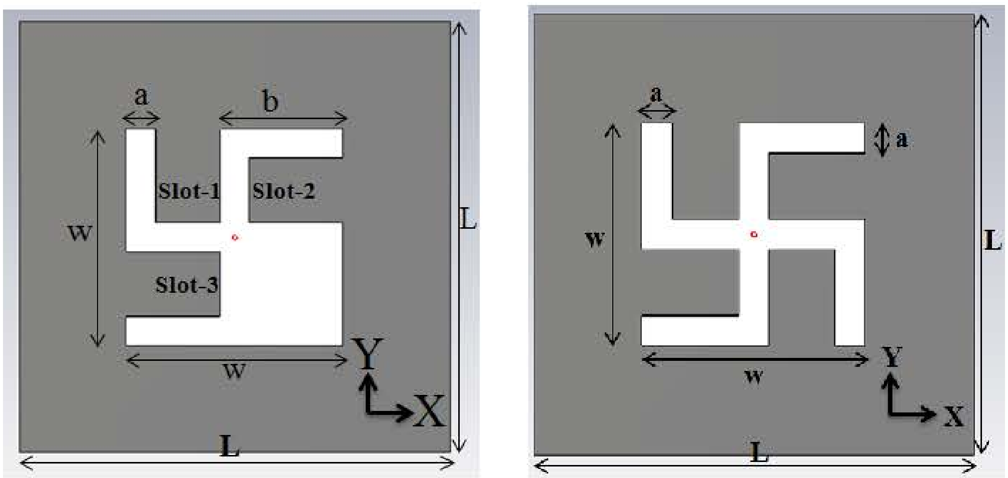
Then a technique for the bandwidth and gain enhancement using air gap-slots is verified for Gammadion Cross DRAs which guarantees larger impedance bandwidth and higher gain with compact shape. It is found that the length and position of the slot can be used to widen the DRA bandwidth or to tune the DRA frequency. It can be observed that the bandwidth impedance can be increased from 9% to 31.6% compared to the reference DRA. From the dimensions of DRA, it can be observed that, by using the Gammadion Cross DRA the volume was decreased by almost 50% compared to reference DRA.

4.3 Proposed DRAs – Fabrication and Analysis

Following this slot technique, fabrication and characterization of two novel shapes Asymmetric DRA and Tetraskelion DRA are investigated and analyzed.

4.3.1 DRA Configuration

The geometries of the proposed DRA (Asymmetric and Tetraskelion) are shown in Fig. 1.



(a) **(b)**

Fig. 1 Proposed DRA geometry: (a) Asymmetric, (b) Tetraskelion

DRA is fabricated on symmetrical ground plane having the dimension of L x L (L = 6 cm). By using parametric study, we considered L=6 cm for ground plane's dimension.

By taking L=6 cm, infinite ground plane is assumed. The design has been made, keeping in mind feasibility of fabrication. In case, we increase this length, the size of the whole antenna will also increase which will limit the practical utility of proposed antenna. For DRA, the dimensions along *x*-, and *y*-, directions are equal (w = 3 cm) and along *z*-, direction is h (h = 1.5 cm). The strip width (a) of the proposed DRA is taken as 0.4 cm. The dimension of DR slots are, 0.9 x 1.3 x 1.5 cm^3 along *x*-, *y*- and *z*-, direction for Slot-1 and Slot-4 while 1.3 x 0.9 x 1.5 cm^3 along *x*-, *y*- and *z*-, direction for Slot-2 and Slot-3. The proposed DRAs are centrally fed by a coaxial probe of length l, and are designed at 5.2 GHz using CST Microwave Studio™.

4.3.2 Fabrication and Experimental Results

To demonstrate the idea, a prototype of DRA was fabricated and verified experimentally. In our measurements, the reflection coefficients of the DRAs were measured using vector network analyzer (VNA), while the radiation patterns, antenna gains, and efficiencies were measured using a basic antenna measurement setup i.e. Compact Antenna Test Range (CATR) System. The structure of proposed DRA was then fabricated using abrasive jet machine, diamond cutter, diamond filer and diamond drill machine as demonstrated in Fig. 2.

(a) (b) (c)

Fig. 2 Fabrication machine: (a) Diamond cutter, (b) Diamond Filer, (c) Diamond Drill

4.3.2(a) Asymmetric DRA (Proposed Antenna-1)

The fabricated structure of the Asymmetric DRA with slots is shown in Fig. 3. Snapshot of the measured $|S_{11}|$ response of Asymmetric DRA is shown in Fig. 4. The simulated and measured $|S_{11}|$ response of the Asymmetric DRA is shown in Fig. 5. The measured result shows that the Asymmetric DRA resonate at 5.2 GHz, offering an impedance bandwidth of 51% for $|S_{11}| < -10$ dB from 4.1 to 6.7 GHz. However, the simulated result shows that DRA also offers 51.9% impedance bandwidth (3.9-6.6 GHz) for $|S_{11}| < -10$ dB. The simulated and the measured (*xy*-plane and *yz*-plane) radiation patterns at 5.2GHz is shown in Fig. 5.

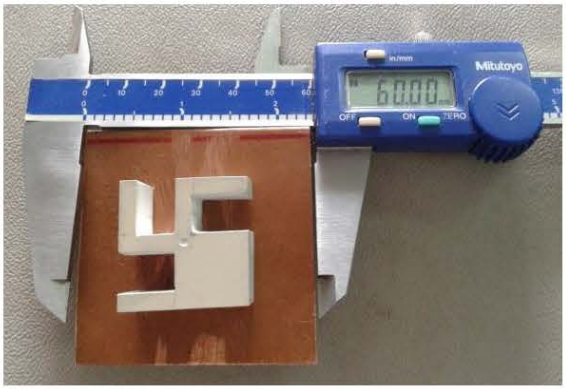


Fig. 3 Photograph of fabricated Asymmetric DRA

Fig. 4 Snapshot of measured $|S_{11}|$ plot for the Asymmetric DRA

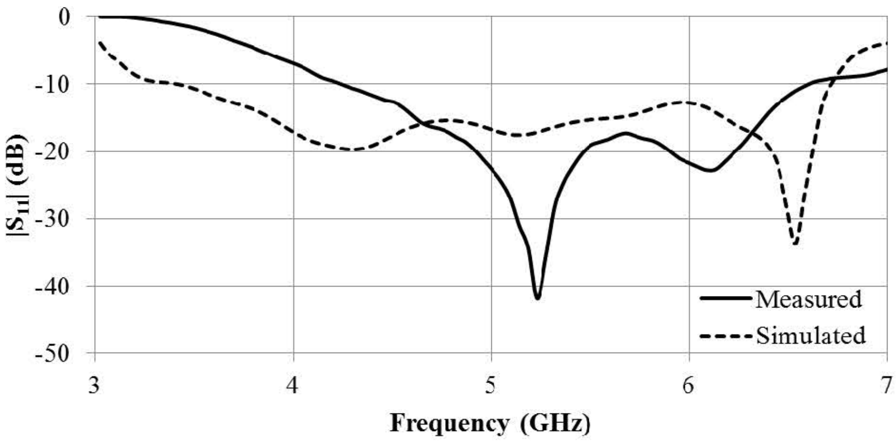


Fig. 5 Comparison of simulated and measured $|S_{11}|$ plot for the Asymmetric DRA

The gain and radiation efficiency plot versus frequency is shown in Fig. 7. The measured peak gain is 8.2 dBi at ~6.6 GHz. For the complete bandwidth of operation, the measured and simulated gain is in a good agreement and above 5 dBi. The peak efficiency measured is 95.6% at 5.2 GHz. The efficiency is above 90% for the complete bandwidth of operation of DRA. Thus, the proposed DRA offer low losses and are comparable to the other regular geometries in the DRA family. The field distribution of electric and magnetic fields in the DRA at 5.2 GHz frequency is studied using CST Microwave Studio and is shown in Fig. 8, it is clear that for the whole frequency band of operations, the propagating mode is similar to the $TE_{\delta 21}$ like-mode.

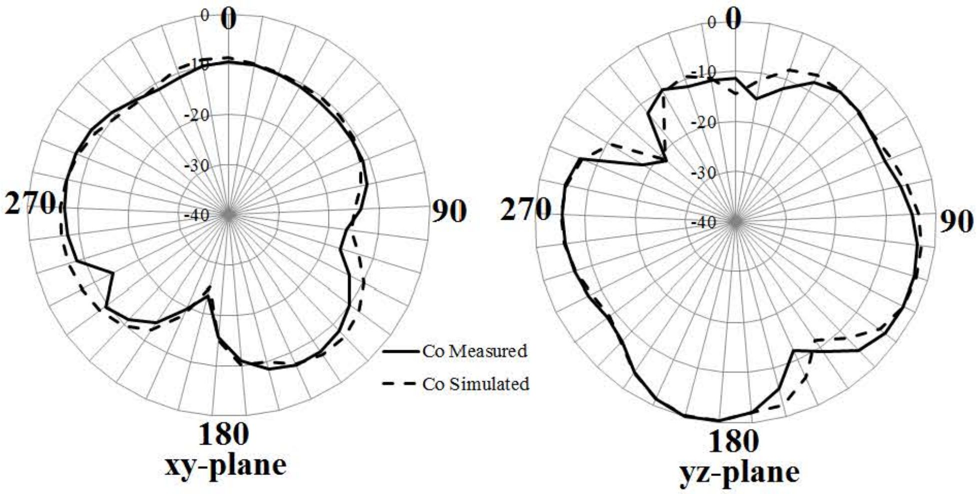


Fig. 6 Comparison of measured and simulated radiation patterns of the Asymmetric DRA at 5.2 GHz

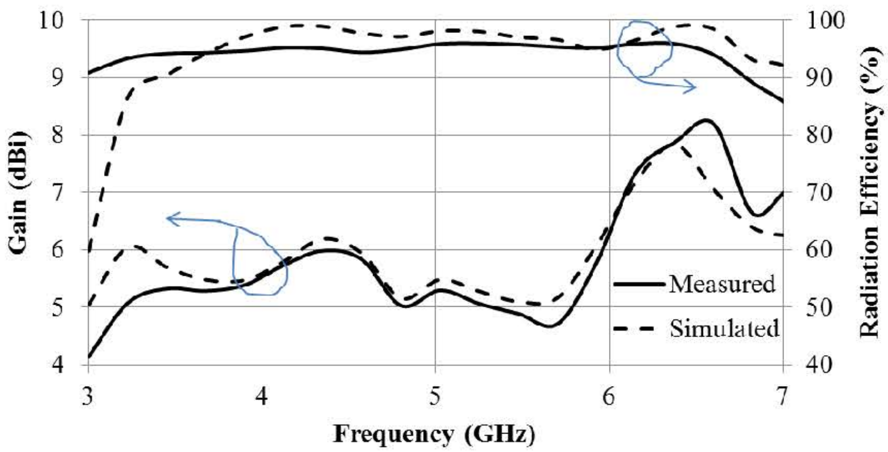
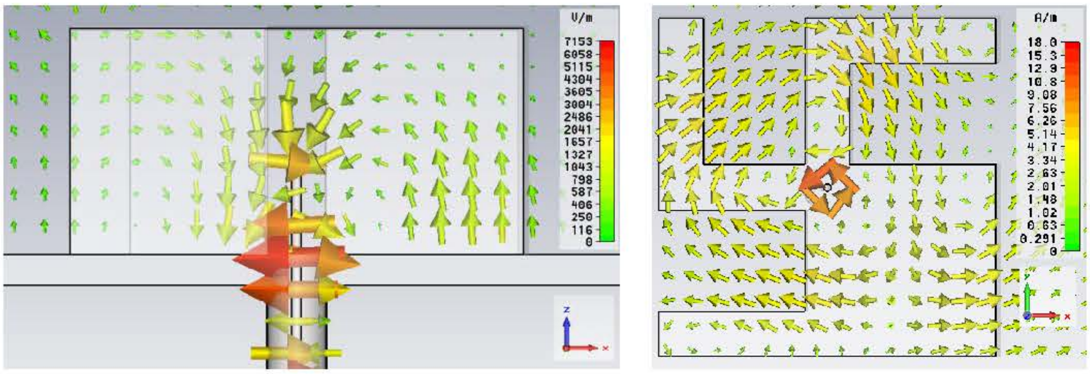


Fig. 7 Measured and simulated antenna gain as a function of frequency for Asymmetric DRA



(a) (b)

Fig. 8 Field Distribution at 5.2 GHz: (a) Electric Field, (b) Magnetic Field

4.3.2(b) Tetraskelion DRA (Proposed Antenna-2)

The fabricated structure of the proposed Tetraskelion DRA geometry is shown in Fig. 9. The snapshot of measured $|S_{11}|$ response of Tetraskelion DRA is shown in Fig. 10. The experimental and simulated result is shown in Fig. 11 which shows the comparison between simulated and measured variations of reflection coefficient versus frequency for proposed DRA. The measured results shows that DRA offers 51.1% impedance bandwidth (4.1–6.5 GHz) for $|S_{11}| < -10$ dB at 4.7 GHz while simulated result shows that Tetraskelion DRA resonates at 5.25 GHz, offering an impedance bandwidth of 57.5% for $|S_{11}| < -10$ dB from 3.85 to 6.96 GHz.

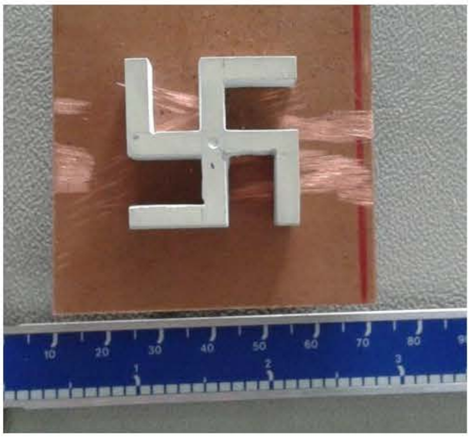


Fig. 9 Photograph of fabricated Asymmetric DRA

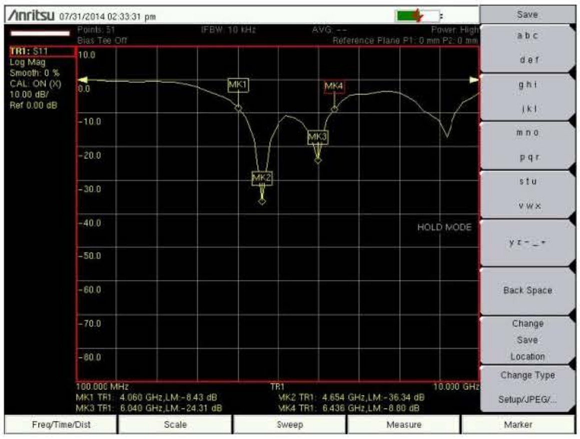


Fig. 10 Snapshot of measured $|S_{11}|$ plot for the Asymmetric DRA

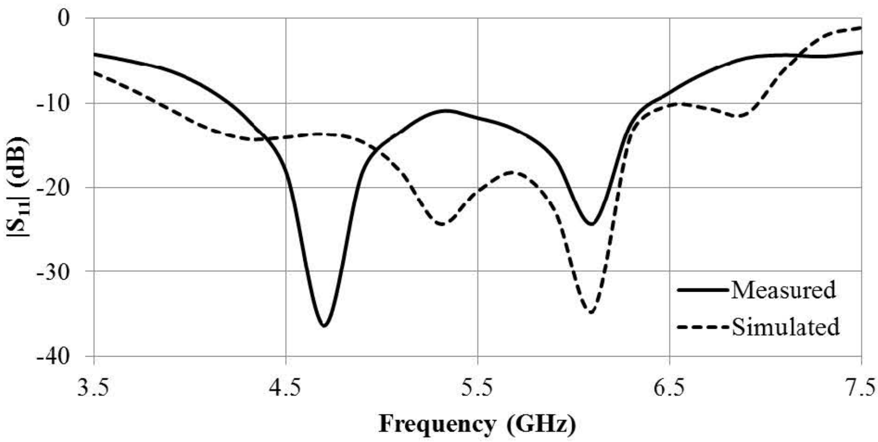


Fig. 11 Comparison of simulated and measured reflection coefficient for the Tetraskelion DRA

The radiation pattern has been measured at 5.25 GHz. The simulated and the measured (*xy*-plane and *yz*-plane) radiation patterns are shown in Fig. 12. The null in the broadside direction is clearly visible, which verifies the presence of $TE_{\delta 21}$-like mode for the Tetraskelion DRA. Hence the estimation of our analysis of modes excited is quite justified.

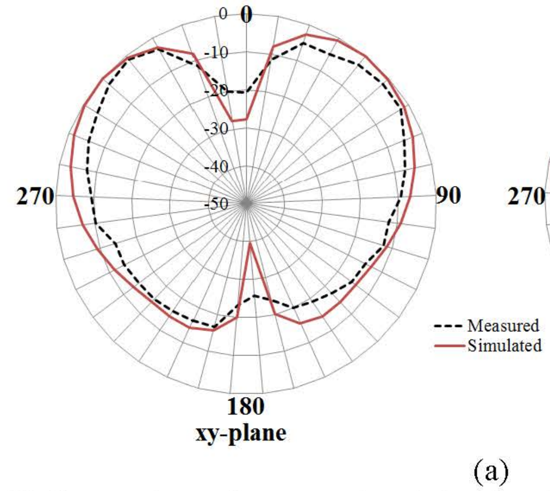


Fig. 12 Comparison of measured and simulated radiation patterns of the Tetraskelion DRA. (a) 5.25 GHz. (b) 6 GHz

The plot of measured and simulated total efficiency versus the frequency as well as the gain versus frequency is shown in Fig. 13. The peak gain is measured at 5.25 GHz, which is 4.1 dBi. For the complete bandwidth of operation, the measured and simulated gain is in good agreement. The efficiency of the antenna is also considerably high. The peak efficiency measured is 95.6% at 5.25 GHz. For the bandwidth of operation of the DRA, the efficiency is above 90%.

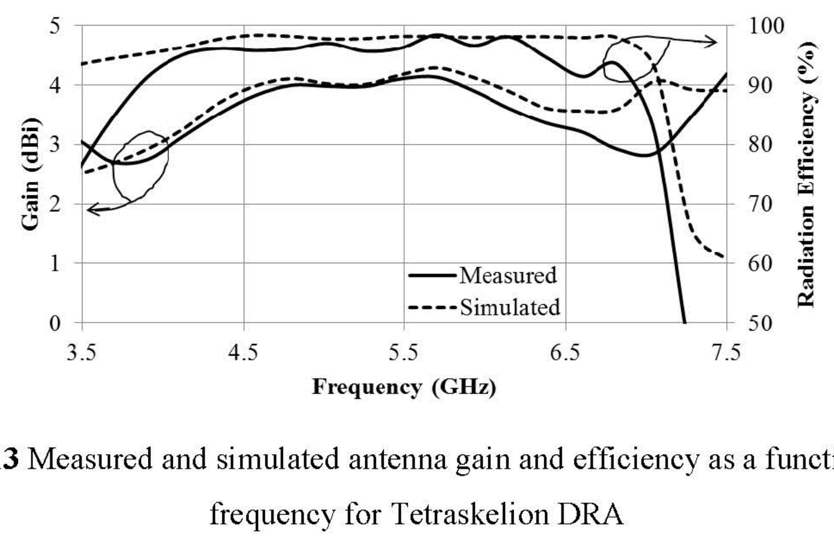
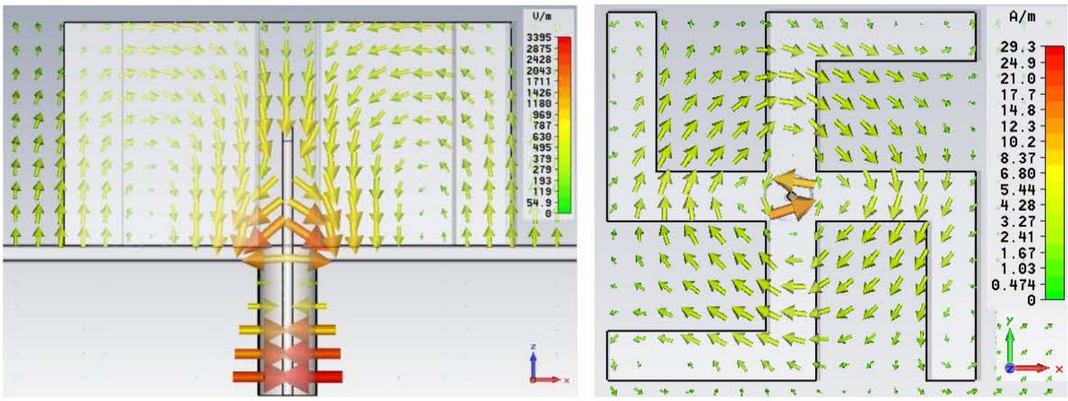


Fig. 13 Measured and simulated antenna gain and efficiency as a function of frequency for Tetraskelion DRA

The field distribution of electric and magnetic fields in the DRA at 5.25 GHz frequency is studied using CST Microwave Studio and is shown in Fig. 14. The field inside the dielectric region of Tetraskelion DRA is quite similar to the field lines of Asymmetric DRA. However, the null in the broadside suggests that there will be no radiation in the broadside direction and thus the pattern must be directive.



(a) **(b)**

Fig. 14 Field Distribution at 5.25 GHz: (a) Electric Field, (b) Magnetic Field

The comparison of the best case of the proposed Asymmetric DRA and Tetraskelion DRA structures with other previous proposed references [7-10] is as tabulated in Table 5.1. With reference to the table, the bandwidths of the proposed antennas are significantly wider than those of the previous ones. It can be observed that the proposed antennas not only achieve wider bandwidth, but also its volume is considerably less than other DRAs. Keeping in mind the common points of comparison, it can be seen that our proposed antenna has the best results so far.

TABLE-1 Comparison of the Proposed Tetraskelion DRA

Shape	ε_r	*V*	*H*	*BW*	f_r	*Ref*
Rectangular	10	23.06	2.4	4.6	5.2	7
Rectangular	9.8	9.39	2.9	33	3.9	8
Rectangular	10	6.54	1.9	32.6	4.6	9
Cylindrical	15	6.63	0.87	1.7	5.8	10
Asymmetric	**9.8**	**8.24**	**1.5**	**51**	**5.2**	**PS-1**
Tetraskelion	**9.8**	**6.48**	**1.5**	**57.5**	**5.25**	**PS-2**

ε_r – Permittivity, *V* – Volume, *H* – Height, *BW* – Bandwidth (%), f_r – Resonant frequency (GHz), *PS* – Proposed Structure

5. Conclusion

Roger TMM10 having permittivity (ε_r) of 9.8 as DR material is a potential candidate for wideband DRA. In this thesis, the permittivity (ε_r) of dielectric material is taken as 9.8 for the design, simulation and fabrication of DRA. Rectangular DRA fed by coaxial probe provide better resonance level as compared to other rudimentary geometries. A slot-technique for the bandwidth and gain enhancement of DRA has been introduced and demonstrated.

A novel linearly polarized Asymmetric DRA and Tetraskelion DRA, centrally fed by a coaxial probe has been successfully implemented. This antenna has a simple-interesting structure and relatively reduced volume of 8.24cm^3 and 6.48cm^3 for Asymmetric DRA and Tetraskelion DRA respectively. The Asymmetric DRA offers an impedance bandwidth of 51% (from 4.1 to 6.7 GHz) at 5.2 GHz resonance while Tetraskelion DRA resonates at 5.25 GHz, offering an impedance bandwidth of 57.5% (from 3.85 to 6.96 GHz). The measured peak gain of the Asymmetric DRA is 5.3 dBi at the resonant frequency with a high radiation efficiency of 98% while peak gain over the complete bandwidth of operation is 8.2 dBi. However, the peak gain of the Tetraskelion DRA is 4.1 dBi at the resonant frequency with a high radiation efficiency of 95.6%. This makes the DRA suitable for practical use in the wireless communication systems such as WLAN, WiMax, Vehicular Communication and C-band.

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7. List of Publications from this work

Peer Reviewed Journals:

[1] **Jitendra Kumar** and Navneet Gupta, "Performance Analysis of Dielectric Resonator Antennas." *Wireless Personal Communications,* 2014, 75: 1029-1049. **(SCI and SCOPUS Indexed, Publisher: Springer-Verlag Berlin)**

[2] **Jitendra Kumar** and Navneet Gupta, "Investigation on microwave dielectric materials for dielectric resonator antennas. *International Journal of Applied Electromagnetics and Mechanics,* 2015, 47: 263-272. **(SCI and SCOPUS Indexed, Publisher: IOS Press, Japan)**

[3] **Jitendra Kumar** and Navneet Gupta, "A Comparative Study of Different Feeding Mechanisms for Rectangular Dielectric Resonator Antenna." *IUP Journal of Telecommunications.* 2015, 7: 39-47. **(Publisher: IUP Publications, India)**

[4] **Jitendra Kumar** and Navneet Gupta, "Linearly Polarized Asymmetric Dielectric Resonator Antenna for 5.2 GHz WLAN applications" *Journal of Electromagnetic Waves and Applications,* 2015, 29: 1228–1237. **(SCI and SCOPUS Indexed, Publisher: Taylor & Francis, UK)**

[5] **Jitendra Kumar** and Navneet Gupta, "Bandwidth and Gain Enhancement Technique for Gammadion Cross Dielectric Resonator Antenna." *Wireless*

Personal Communications, 2015. **(SCI and SCOPUS Indexed, Publisher: Springer-Verlag Berlin, In Press)**.

[6] **Jitendra Kumar,** Biswajeet Mukherjee, and Navneet Gupta, "A Novel Tetraskelion Dielectric Resonator Antenna for Wideband Applications." *Microwave and Optical Technology Letters*, 2015, 57: 2781-2786. **(SCI and SCOPUS Indexed, Publisher: Wiley-Blackwell)**

Peer Reviewed Conferences:

[1] **Jitendra Kumar** and Navneet Gupta, "Symmetrical T-Shaped DRA with Unique Microstrip Excitation for Wideband Applications," *Proceedings of 8th International Conference on Microwaves, Antenna, Propagation & Remote Sensing, ICMARS 2012*, Jodhpur, India, December 11-15, 2012, pp. 606-609.

[2] **Jitendra Kumar** and Navneet Gupta, "Compact Wideband Rectangular Dielectric Resonator Antenna with Slots and Air Gaps for C-band Applications." *9th IEEE International Conference on Industrial and Information Systems (ICIIS-2014),* IIITM Gwalior, India. 15-17 December 2014, pp. 1-4.

[3] **Jitendra Kumar** and Navneet Gupta, "Investigation on Rudimentary Geometries of Dielectric Resonator Antenna," *The 36th Progress In Electromagnetics Research Symposium Proceedings (PIERS 2015)*, Prague, Czech Republic. 06-09 July 2015, pp. 2149-2152.