Orthogonal Feed Dual Band Rectangular Dielectric Resonator Antenna for Medical Image Sensing Applications

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Abstract

Malignant Tumor detection in the body at an early stage can eliminate deaths due to cancer. Wearable devices with antennas working in the range of 6-10GHz can help detect cancer early. A rectangular dielectric resonator antenna (RDRA) with orthogonal feed for circular polarization is presented for tumor detection with a resonant frequency of 6.5GHz and 9.5 GHz. The proposed RDRA with gain up to 5.1dBifor 6.5GHz, 70% axial ratio bandwidth, and 36% impedance bandwidth is obtained. A simple design with considerable broad bandwidth circularly polarized and a good gain solution for 6-10 GHz tumor sensing application is presented with a radiation efficiency of 95%.

Keywords: *Tumor, RDRA ,Circular Polarization Orthogonal Feed*

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1Introduction

Dielectric resonator antenna (DRA) are gaining importance due to their compactness, lightweight, high gain, and high radiation efficiency (S. A. Long et al 1983, A. Petosa et al, 2000). However, they have limited application medical applications (Katsura, C. et al, 2022). The literature suggests that rectangular dielectric resonator antenna (RDRA) have a higher degree of freedom and is easy to fabricate(A. Petosa et al, 2000). Simple RDRA at a tumor detection frequency range (Islam, M. T.et al, 2019) i.e C band and X band will have the problem of limited gain and reduced bandwidth. Since communication links need to be established circularly polarized antenna will be required. The RDRA with orthogonal feed suggested here improves the bandwidth up to36% with a reasonable gain of 4 dBi and radiation efficiency of 95%. Also, circular polarization is achieved for 70%of bandwidth with is a novelty as circular polarization is achieved for the entire bandwidth.The increased radiation efficiency is due to the RDRA of the dielectric constant (εr = 9.8 and $\tan\delta$ = 0.0001) which in turn results in enhanced bandwidth (A. Petosa Handbook, 2007).

Considering all the advantages, the other important feature of the DRA is its low loss as it is made entirely out of dielectric material as is required in many radar and communication applications. This property also helps to fabricate DRAs of exceedingly small size even at mm-wave frequencies, giving very high radiation efficiency (P. F. Hu et al, 2016). These desirable features of DRA have made it ideal for medical sensing applications. In this paper, a simple design of a rectangular DRA with orthogonal feed is proposed. As suggested by (Islam, M. T.et al, 2019). Figure 1 shows the block diagram of antenna requirements in medical applications. The antenna proposed here can be used as a wearable device for microwave imaging. The working principle of microwave imaging is to transmit signals across the body for the targeted tumor and receive the scattered signals back. Since different tissues have different dielectric constants, the scattered signals can be studied for the presence of any protein tissuei.e. tumor (Islam, M. T.et al, 2019). The tumor's dielectric properties are very different from regular breast tissue cells, the malignant tumor being of higher dielectric constant. This is used as an advantage for detection (M. Lazebnik et al., 2007). Several antennas are already reported for the same. (T. Henriksson et al, 2011,M. Klemm et al, 2011, A. Modiri et al, 2017). However, the dielectric resonator antenna is not explored for the same. Due to its nonconductivenature it will prove fruitful for a wearable device without proving to be hazardous and giving high radiation efficiency. The geometries of the proposed RDRA have a length(l) and width (w) =0.33λ and height (h)= 0.19λwhere h< l=w as proposed by Petosa et al. (A. Petosa Handbook, 2007) The RDRA with dielectric constant 9.8 and the substrate layer of with dielectric constant εr = 4.4is used toreduce size of DRA and improve return loss.

In Section 2, the physical operation of the proposed Design is explained and in Section 3 the simulated and measured results match the requirement with an impedance bandwidth of 36% and a measured gain of up to 5.1 dBi, which is suitable for medical sensing frequency range i.e C and X band.

2PHYSICS OF OPERATION

A. RDRA Dimension Calculations

This section presents the physical operation of the designs proposed in this study. The RDRAs with slots are designed and optimized using the full-wave electromagnetic solver CST Design Studio.

The RDRA is designed according to the design conventions (Mongia, R.K. and Bhartia, P.,1994). However, the design is further optimized to get desirable results.

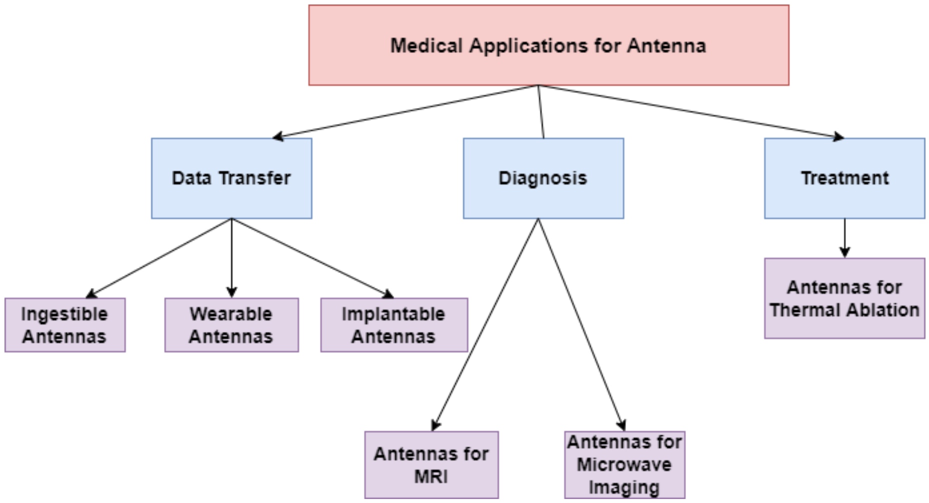


Figure1. Requirement of Antenna in Medical Applications

$$fDRA = \sqrt{kx^2 + ky^2 + kz^2} \quad (1)$$

$$ky = \pi/w, \; kz = \pi/2h \quad (2)$$

$$\tan(lkx/2) = (kxl/kx), \; kxl = \sqrt{ky^2 + kz^2} \quad (3)$$

where *kx, ky,*and*kz* are wavenumbers along x, y, and z directions respectively. The speed of light is represented by c.From the calculations and frequency of 6 GHz, the length and height are calculated as 0.33λ and the width is calculated to be 0.33λ with the simulation results deviated by 0.5% of the calculated center frequency, and results are obtained at 6.5 GHz. The orthogonal feed placement is decided at the center of the side face so as not to deviate from the fundamental TE^{z}_{111} mode of operation (R. K. Mongia and A. Ittipiboon, 1997). The RDRA is thus made to operate at its fundamental mode even after applying orthogonal feed for circular polarization (Kumar, R., & Chaudhary, R. K.,2018). The fundamental mode provides less power loss which is desirable as wearable devices already have power loss due to body tissues. The final E-field pattern shows likely TE^{z}_{111} mode. The feed used is orthogonal for better E fields to be obtained. Copper strips are used for orthogonal feed. The length of the orthogonal feed is decided after experimentations and parametric optimization to obtain maximum radiation efficiency. The orthogonalfeed length was decided to be 0.23λ for the port and side port 0.26λi.e multiple of quarter wavelength (A. Petosa Handbook, 2007). Further increase in length of feed does not have any considerable increase in antenna parameters as well as it reduces the radiation efficiency due to an increase in conducting material in the entire design. The ground plane is kept continuous to reflect the signals in the direction against the body parts. Figure 2 design of the fabricated RDRA with orthogonal feed. Table 1 indicates the dimensions of the RDRA and the feed.

Table1. Dimensions of RDRA (in mm)

Design	***l***	***h***	***w***	ε_r	***tanδ***
RDRA	0.33λ	0.19λ	0.33λ	9.8	0.0001

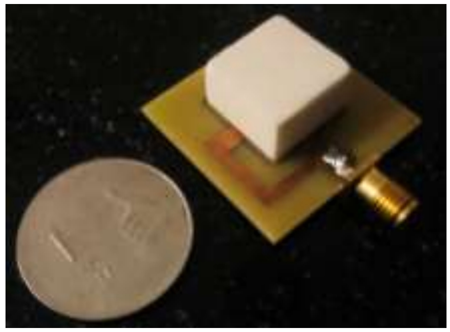


Figure 2.Rectangular Dielectric Resonator Antenna Simulated and Fabricated Design

B. RDRA Performance Parameters

The simulated and measured return loss can be observed in Figure 3 which shows a high degree of matching thus proving the calculated dimensions are correct. Though the feeding mechanism is chosen to be of anorthogonal microstrip line of 50Ω; hence strong E fields are observed inside DRA.

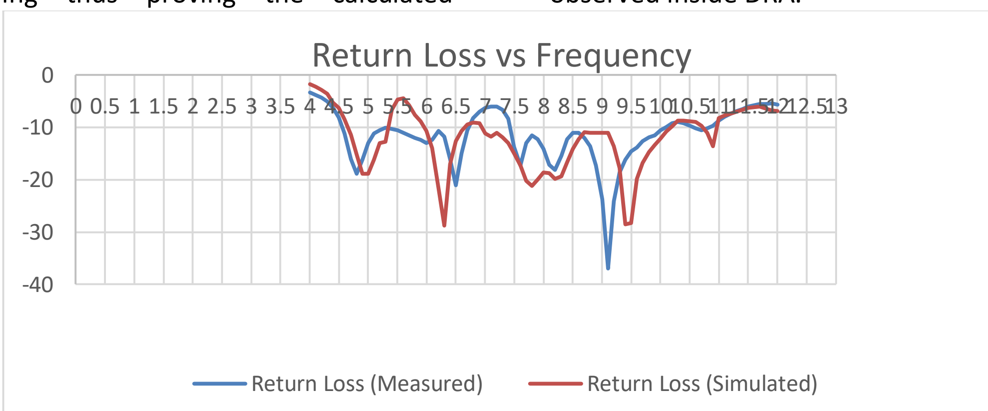


Figure3. Simulated and Measured Return Loss

The E-field distribution can be observed in Figures 4(a) and (b) for 6.5 and 9.5 GHz. It can be seen from Figure 4 that E field distribution in the x and y axis provides the fundamental mode of operation. This is required for less power loss thereby increasing the gain. The deviation in the E-field onthe y-axis is due to orthogonal feed.

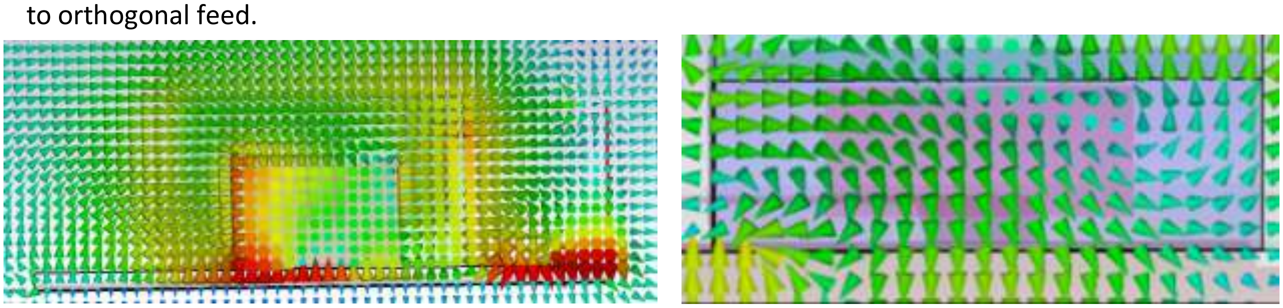
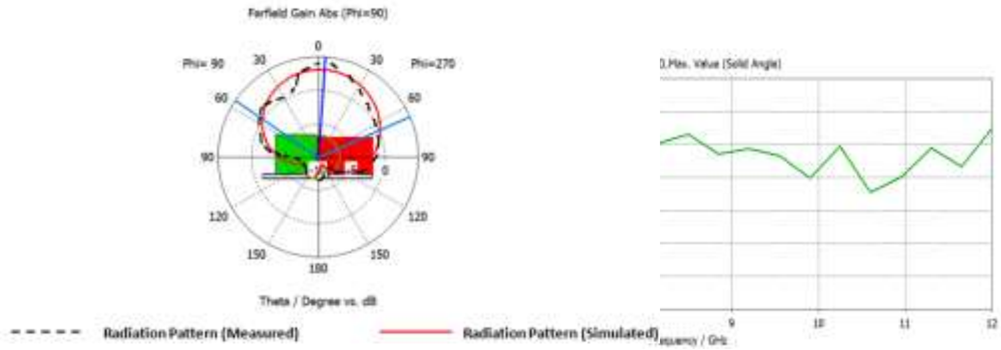


Figure4. (a) E-Field for 6.5 GHz (b) E-Field for 9.5 GHz

The gain obtained by plotting the radiation pattern as can be observed from Figure 5 (a) and Figure 5(b) is relatively goodi.e. 5.1 dBiat 6.5 GHz and 3.8 dBi at 9.5 GHz and this RDRA provided radiation efficiency of 95%. Though the radiation efficiency reduces as power loss due to tissue, still the performance of DRA is better thananother type of antennas due to low conductivity and low loss tangent. The measured and simulated radiation patterns show that the obtained radiation pattern is suitable for a wearable device.



(a) (b)

Figure5. (a) Measured and Simulated Radiation Pattern (b) Gain vs Frequency

The main issue of establishing a communication link in wearable devices is when body posture and movement change can be reduced by employing a circularly polarized antenna. The RDRA designed here provides an axial ratio below 3 dB for 70% bandwidth (Islam, M. T.et al, 2019). The axial ratio with respect to frequency is shown in figure 6 which provides a good tradeoff for wearable devices.

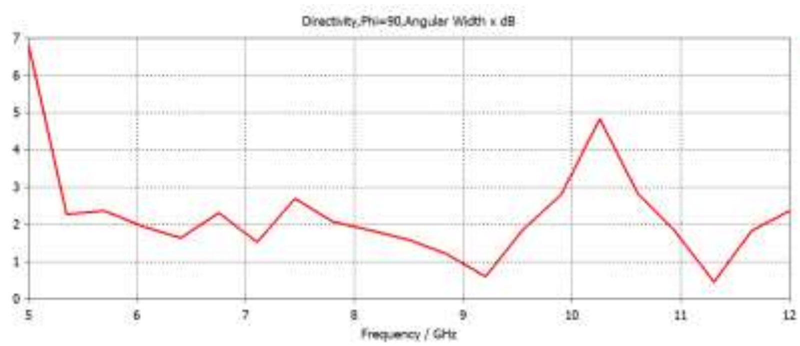


Figure6. Axial Ratio vs Frequency

3Results and Discussions

Researchers all around the world are working to obtain a sustainable wearable antenna design that provides all the performance parameters and is safe for medical sensing applications. However, the process complicates the design and hence the fabrication process. The design presented in this communication has incorporated all the theoretical aspects of RDRA thus presenting a simple design with equally good performance parameters. Table2 presents how the design presented is better than other wearable antenna designs reported.

It is very evident from Table 2 that the design presented in this communication is not only simple but also has the potential to provide good performance at the 6-10 GHz frequency range. Overall a simple design with broadband features and good efficiency is presented for future utilization.

4Conclusion

This paper suggested novel mechanisms to use DRA as a wearable device for medical applications. The orthogonal feed provides circular polarization in rectangular DRA which improves the DRA bandwidth and enhances the DRA gain for C and X band frequencies. The DRA size can further be miniaturized by keeping a tradeoff between its height and length. The measured results show an improved bandwidth of 36% and an enhanced gain of up to 5.1 dBi. The enhancements in the bandwidth and gain along with a radiation efficiency of 95% are a rare phenomenon along with 70% axial ratio bandwidth. Further investigations for SAR value will make this a feasible entity for further applications.

Table2. Comparison of the Presented Design with the Reported Research Work

Ref.	**Antenna Type**	**Bandwidth (GHz)**	**Dimension (mm)**	**Gain (dBi)**
Hossain, I., et al,2007	Monopole	3.80-11.85	30x30	Not reported
Syeed, M. et al, 2017	Vivaldi	3.01-6.8	40x40x1.6	5.9
Adnan, S.et al, 2011	Microstrip Patch	4.0-9.0	30x30	2-6
Kanj, H., & Popovic, M.,2005	Planar Patch	2.7-9.7	22.25x20	Not reported
Proposed	Rectangular Dielectric resonator antenna	4.5-6.8 and 10.2-7.5	(0.33x0.33x0.19)λ	3.8-5.1

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