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NOVEL RECTANGULAR MULTIBAND DIELECTRIC RESONATORANTENNA WITH SLOT FOR BROADBAND APPLICATIONS

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ABSTRACT:

A rectangular dielectric resonator antenna (RDRA) is integrated with a cylindrical slot on the top face to get enhanced bandwidth of 6.66%. Based on the slot based RDRA design, a cross cavity based RDRA is proposed to improve the bandwidth from 6.66% to 45.45% and enhance the realized gain upto 13.37 dBi. The slot is filled with ethyl acetate to improve radiation efficiency. The proposed designs are worked upon to reduce the slot depths from 0.75λ for cylindrical slot to 0.22λ for cross slot to reduce fabrication complexities. The proposed design provides the bandwidth of 45.45% with a gain of 13.37 dBi which is considerable at Ku band which is suitable for next-generation Remote-Sensing Community Frequency Range (10.9-22 GHz) . A simple design with considerable broad bandwidth, linearly polarized and high-gain solution for 22 GHz remote sensing application of drugs, tobacco, explosives etc. is presented with a radiation efficiency of 52%.

***Keywords**: Rectangular Dielectric resonator antenna, Cross Slot, High gain, K Band, Broadband, Linearly polarized*

I. INTRODUCTION

Dielectric resonator antenna (DRA) are gaining importance due to its compactness, light weight, high gain and high radiation efficiency [1,2]. However, they have limited application in remote sensing applications and satellite communication. The literature suggests that rectangular dielectric resonator antenna (RDRA) have higher degree of freedom and is easy to fabricate [3] . Simple RDRA at a remote sensing frequency range i.e Ku band will have the problem of limited gain and reduced bandwidth. The RDRA with cross slot suggested here improves the bandwidth upto 45.45% with reasonable gain of 13.37 dBi and radiation efficiency of 52%. The increased radiation efficiency is due to high relative dielectric constant of the liquid ethyl acetate filled in the slot (εr = 6.08 and tanδ = 0.059) and the RDRA of lower dielectric constant (εr = 2.2 and tanδ = 0.0009) which in turn results in enhanced bandwidth [3]-[5].

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 [6]. These desirable features of DRA has made it ideal for remote sensing applications. In this paper, a simple design of a rectangular DRA with cross slot at the top face filled with ethyl alcohol is proposed for the first time. Initially, a cylindrical slot of 0.75λ depth was drilled on the top face of RDRA of same magnitude. However, introduction of such a long slot may weaken the strength of the DRA as well as it is not a very feasible solution. Though the return loss for a cylindrical slot RDRA filled with ethyl acetate was better; but the gain obtained was 3 dBi with a radiation efficiency of 33.5%. The impedance bandwidth obtained in this case is only 6%. Hence, the slot was changed to cross type to increase the surface area on the top face of the DRA. This slot was only 0.22λ deep as a result of which it is easy to fabricate. This RDRA is fed by conformal microstrip transmission line, and four resonant modes are excited to achieve enhanced impedance bandwidth. In the feeding, the transmission line is extended along the side face of the DRA to obtain maximum current density and linear polarization. The length of the conformal strip is fixed and designed in multiples of 0.25λ to achieve maximum gain of 13.37 dBi for this configuration. The slots were filled with organic compound ethyl acetate to create a higher dielectric region in order to enhance radiation efficiency[7]. Both the RDRAs configurations are presented in Figure1.

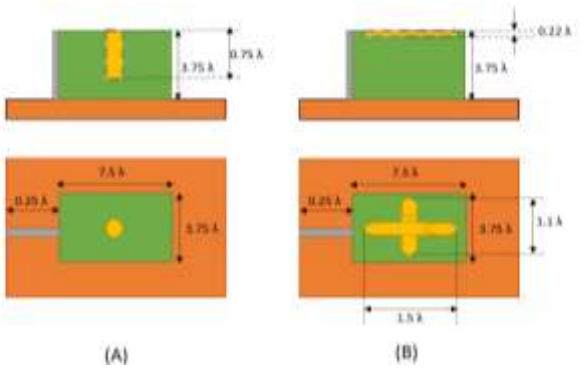


Figure1. (A) RDRA with cylindrical slot filled with ethyl acetate

(B) RDRA with cross slot filled with ethyl acetate

In Figure1, the geometries of a standard rectangular DRA with cylindrical slot (Design A) and proposed RDRA with cross slot (Design B); both slots filled with ethyl acetate are demonstrated. By appropriately optimizing the cavity for maximum gain and impedance bandwidth, the RDRAs in Design A and Design B have length(l) and height(h) =3.75λ and width (w) = 7.5λ where w> l=h as proposed by Petosa et al. [5] The RDRA and the substrate layer are of same material with dielectric constant εr = 2.2 to increase the effective height of the DRA in order to improve the antenna bandwidth and gain.

In Section II, the physical operation of the Design A in Figure1 is explained, and then the proposed 22 GHz RDRA (Design B) is presented in Section III. The measured results show a broad impedance bandwidth of 45.45% and a measured gain of up to 13.37 dBi, which is suitable for remote sensing frequency range i.e Ku band.

I. PHYSICS OF OPERATION

This section presents the physical operation of the designs proposed in this study. The RDRAs with slot are designed and optimized using the full-wave electromagnetic solver ANSYS HFSS [8].

A. RDRA with Cylindrical Slot

The RDRA is designed according to the design conventions given by Mongia et al [9]. However, the design is further optimized with slot to get desirable results.

$$fDRA= \sqrt{kx2 + ky2 + kz2} \quad (1)$$

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

$$\tan (lkx/2) = (kxl/kx)\ , kxl = \sqrt{ky2 + kz2} \quad (3)$$

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 22GHz the length and height are calculated as 3.75λ and the width is calculated to be 7.5λ with the simulation results deviated by 0.5% of calculated center frequency and results are obtained at 22.5 GHz. The cylindrical slot placement is decided at the center of the top face so as not to deviate from the fundamental TEz11 mode of operation [9]. The RDRA is thus made to operate at its fundamental mode even after the cylindrical slot at the center. The depth of the cylindrical slot is decided after experimentations and optimization to obtain maximum radiation efficiency. The slot depth was decided to be 0.75λ i.e multiple of quarter wavelength [5]. Further increase in depth of cylindrical slot does not have any considerable increase in antenna parameters as well as it may weaken the strength of the DRA. Figure 2 shows the return loss plot versus frequency.

B. RDRA Performance Parameters

Though the feeding mechanism is chosen to be of a conformal microstrip line of 50Ω; still strong E field but a weaker H field patterns are observed inside DRA due to inclusion of a slot. The E-field and H-field distribution can be observed in Figure 3(a) and (b).

The slot could have been kept empty without filling it with any other dielectric, but such slot would create an area of lower dielectric constant and would not support in increasing the radiation efficiency which is actually the challenge to obtain along with enhanced bandwidth.[9,10]

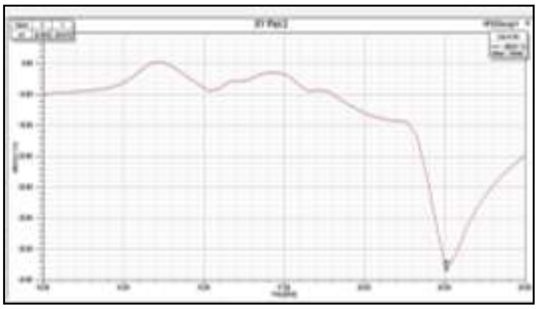


Figure2. S11 plot versus frequency for RDRA with cylindrical slot

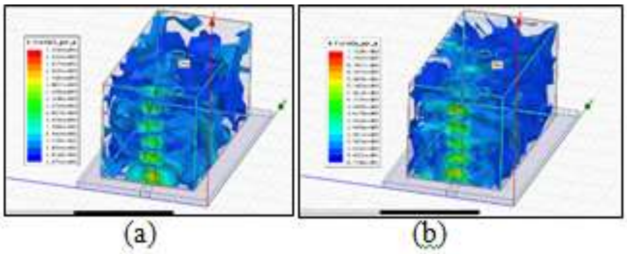


Figure 3. (a) E-field patterns (b) H-field patterns

The decision to select liquid ethyl acetate was finalized as it is a non-electrolyte and the feed does not have direct contact with the liquid dielectric. It also has the advantage of low cost, low toxicity, and stable dielectric constant through the target frequency band. Also, the freezing point of ethyl acetate is below −89.3° which provides the possibility of the antenna to work in low-temperature environment.[7].

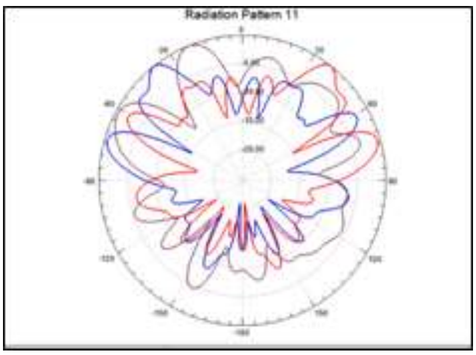


Figure 4. Radiation pattern of RDRA with cylindrical slot

The gain obtained by plotting the radiation pattern as can be observed from Figure 4 is relatively low i.e. 3.46 dBi and this RDRA with cylindrical slot provides a radiation efficiency of 33.5%. Even if the radiation efficiency is compromised, still the bandwidth obtained is only 6.66% and as can be seen from simulated results of Figure4, the gain is also considerably low. Hence new modifications needed to be implemented for better gain, percentage bandwidth and radiation efficiency.

Section III will discuss the modifications in Design A to get Design B with enhanced performance.

I. PERFORMANCE ENHANCEMENT

This section will suggest the changes in Design A to Design B shown in Figure1 for improved performance.

A. RDRA with Cross Slot

Including cuts in the DRA structure have been proven to improve the bandwidth of the antenna [11]. Increasing the effective area of the cuts will enhance the bandwidth. Increasing the diameter of the cylindrical slot will result in weakening the tensile strength of the DRA structure [12]. Hence, the idea to increase the cross section by including a cross instead of cylindrical slot was simulated. The slot depth also reduced to 0.22λ from 0.75λ to give the desired results. Here also the slot is filled with ethyl acetate to create the area of higher dielectric constant. The detailed dimensions of this RDRA are mentioned in Table1.

Table1. Dimensions of RDRA with cross slot (in mm)

Design	***l***	***h***	***w***	**ε_r**	**tanδ**
RDRA	3.75λ	3.75λ	7.5λ	2.2	0.0009
Cross Slot	1.1λ	-0.22λ	1.5λ	1	0
Ethyl Acetate	1.1λ	-0.20λ	1.5λ	6.08	0.059

The cross slot has also provided to obtain the design with four resonant frequencies which in turn has increased the impedance bandwidth. This can be observed with the return loss plot shown in Figure5. It can be observed the return loss (-27dB) value is less than what was obtained in Design A but still it is sufficient for an antenna.

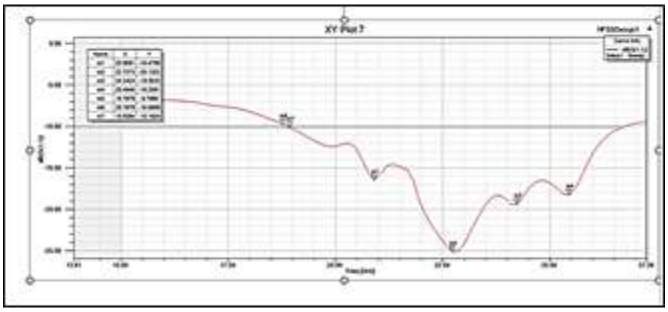


Figure5. S_{11} plot versus frequency for RDRA with cross slot

B. Improved Bandwidth and Efficiency

Design B operating at center frequency of 22 GHz shows drastic increase in bandwidth from 18.7 GHz-28.7 GHz shown in Figure5 that comprises of 45.45% increase in impedance bandwidth. This increased bandwidth paves way for this antenna to be used in multiple applications in Ka and Ku bands. The simple design and the use of materials that are easily available has made this design are real contender to be used in various applications. If modified further for circular polarization this design will also be effective for satellite communication [13].As we know that the radiation efficiency is directly proportional to the relative dielectric constant of the DRA [14]. Hence in order to improve the radiation efficiency we have inserted ethyl acetate in the cross slot on the top face [15]. This has provided with a improved radiation efficiency of 52%. The value of Axial Ratio is very large indicating the linear polarization of the waves. The radiated power for this RDRA through simulations was obtained as 4.4 dB at 22 GHz.

C. Improved Gain and Field Distribution

The gain obtained for this RDRA is obtained to be 13.37dBi which is quite impressive in these range of frequencies. The radiation pattern presented in Figure6 represents the maximum gain of 13.37dBi.The E-fields and H-fields are represented in Figure 7 (a) and (b) respectively. It can be observed that the weak H-fields in Design A are also improved in Design B. this in turn has added to increased radiated power and radiation efficiency [16].

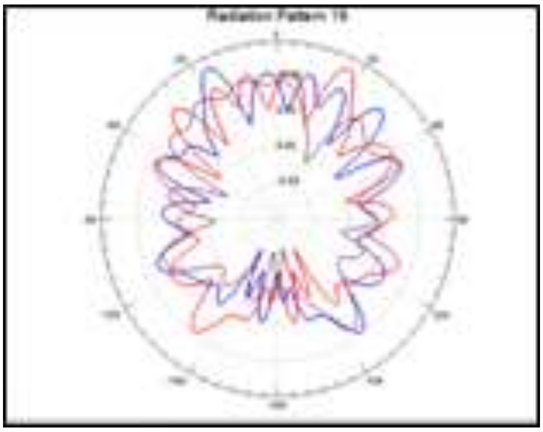
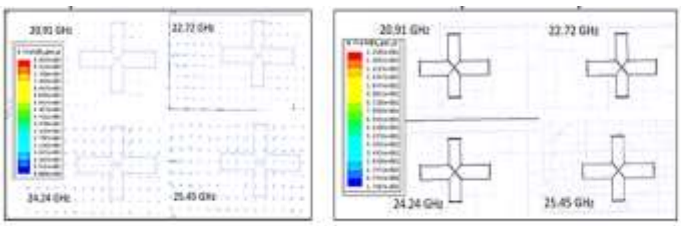


Figure6. Radiation Pattern for RDRA with cross slot

It can be observed that the E-field and H-field distribution have become stronger for higher resonant frequencies. Hence it can be concluded that the antenna is suitable for operation at these frequencies as well.



(a) (b)

Figure7. (a) E-field distribution for four resonant frequency modes 20.91GHz, 22.72 GHz,24.24 GHz,25.45 GHz(b) H-field distribution for four resonant frequency modes 20.91GHz, 22.72 GHz,24.24 GHz,25.45 GHz

Section IV will present the comparison of the Designs A and Design B with the work published by other researchers in the same frequency band.

II. COMPARISON

Researchers all around the world are working to obtain a sustainable antenna design which provides all the performance parameters. However, in the process complicating the design and hence 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 that other DRA 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 such a high frequency range. It should be noted that the ethyl acetate is not filled up to the brim of the slot and is kept at 0.20λ in order to avoid spilling from the vibrations the DRA will generate when feed is applied. Overall a simple design with broadband features and good efficiency is presented for future utilization.

Table2. Comparison of the Current Designs with the Reported research Work

Ref.	DRA Type	ε_r	%Bandwidth	Gain
[17]	Cylindrical	1.02	1.9%	5.0 dBi
[18]	Rectangular	10.1	17.1%	7.1 dBi
[19]	Rectangular	10.1	12%	27 dBi
[20]	Rectangular	12	25.6%	8.2 dBi
	This work Design A	2.2	6.66%	3.46 dBi
	This work Design B	2.2	45.45%	13.37 dBi

III. CONCLUSION

This paper suggested a novel mechanisms to introduce slots on top face of the rectangular DRA which improves the DRA bandwidth and enhance the DRA gain for K band frequencies. The DRA size is can further be miniaturized by keeping a tradeoff between its width and length with respect to the slot. The increase in the slot area has increased its performance parameters. The measured results show an improved bandwidth of 45.45% and an enhanced gain of up to 13.37 dBi. The enhancements in the bandwidth and gain along with a radiation efficiency of 52% is a rare phenomenon. Arrays of the same can be incorporated for increased radiation efficiency and bandwidth.

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