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High Gain Waveguide Annular Dielectric Resonator Antenna

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Abstract
A very simple and novel structure of dielectric resonator antenna (DRA) to achieve high gain and excellent coupling is presented in this article. A low permittivity annular DRA made of glass achieves a very high gain of 13.23 dBi and excellent coupling. The DRA is fed by the rectangular waveguide which can be operated in X-band. The proposed structure is suitable for high power applications. The DRA resonates at 10.8 GHz and achieves 5.3 % impedance bandwidth. The proposed structure ensures a coupling efficiency greater than 98%.

Keywords: Coupling Enhancement, Dielectric Resonator Antenna (DRA), high gain, rectangular waveguide.

1. Introduction

The advancement in wireless communication needs high frequency band and compact antennas. At high frequencies the conventional metallic antenna exhibits conduction loss due to skin effect and this characteristics of the metallic antenna limits its applications at high frequencies [1]. As an alternative the dielectric resonator antenna (DRA) can be employed as it has no conducting parts and in effect no conduction loss. High power handling capacity, compact size, high gain, thermal stability, wide band width and high radiation efficiency are the key advantages of DRA [2]. DRAs are available in different shapes like rectangular, conical, triangular, spherical, hemispherical, cylindrical, annular etc [3-6]. There are different types of feeding mechanisms such as coaxial probe feed, microstrip line feed, coplanar waveguide feed, aperture coupling feed, conformal strip feed, waveguide feed etc [7-9]. Among these feeds the metallic waveguide can handle high power and it is immune to the electromagnetic interference, since it provides excellent shielding between the interior and exterior. The combination of dielectric resonator antenna (DRA) and waveguide feed makes a good choice in high frequency high power applications [10].

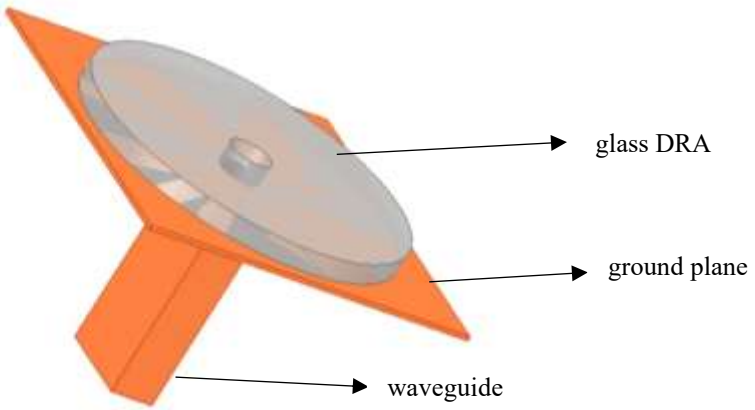
Many authors have presented the operation of DRA with different feeding techniques for good coupling efficiency, however the investigations on waveguide fed DRA is limited. Direct coupling of high permittivity DRA using waveguide feed is reported in the literature [11]. But in the case of low permittivity DRA direct coupling is inefficient. The slot on the ground plane that excites the DRA produces inductive susceptance [12] and this causes impedance mismatch and efficient coupling does not happen. In [13] a co-axial probe feed DRA, coupled to the waveguide exhibits good coupling. But drilling of the DRA to insert probe is necessary for this structure and it produces unnecessary air gaps. These air

gaps reduces the permittivity of DRA. In the structure explained in [14] by inserting a second DRA inside the waveguide below the slot, the coupling enhancement is achieved for a waveguide fed cylindrical DRA. The insertion of the DRA under the exciting slot is a complex procedure. A co-axial probe fed embedded DRA placed inside the waveguide loaded with hard walls is reported by Zhang Y. et.al. [15]. This structure is very complex and difficult to implement. Enhanced coupling is reported by A. B. Kakade et. al. [16] in which three layer DRA are used. In this structure the alignment is difficult and the cost is increased. A stair-shaped waveguide fed DRA [17] and tapered waveguide fed DRA [18] are implemented to improve the coupling. But fabrication complexity of these structures are high. In the reported investigations, the maximum gain of the waveguide fed DRAs are in the range 6 dBi to 11 dBi. High gain is achieved by stacked DRAs, parasitic dielectric elements, waveguide reflectors or by exciting the DRA in higher order mode [19].

In this article, a waveguide fed annular glass DRA for coupling and gain enhancement is described. The excellent coupling and high gain are realized in this structure without the help of any additional component. The annular glass DRA itself produces excellent coupling and high gain. The structure is simulated using Ansoft HFSS. The result is validated using CST Microwave studio. The parametric analysis has been conducted to optimize the different parameters involved in the design.

2. Design and Configuration

Figure 1. Configuration of the proposed antenna



An annular glass DRA with permittivity 5.5 is excited by a rectangular slot made on the ground plane at the shorted end of the waveguide. The outer radius of the DRA is 46 mm and inner radius is 6 mm and heigh is 6 mm. The DRA is excited in the $TE_{01\delta}$ mode and the resonant frequency is determined using formula [20] and obtained as 11.2 GHz.

$$f_r = \frac{c}{2\pi x \sqrt{\varepsilon_r}} \sqrt{\left(\frac{2.405}{\sqrt{a^2-b^2}} + \left(\frac{\pi}{h}\right)^2\right)} \quad \text{---------- (1)}$$

where

c – velocity of light

ε_r – permittivity of DRA

a - outer radius of DRA

b – inner radius of DRA

h – height of DRA.

Figure 1 shows the anteena configuration. WR-90 waveguide of dimension da x db x dl and ground plane of dimension g x g x t are employed in this structure. A slot in rectangular shape with length l, width w is made at the centre of the ground plane. The annular glass DRA with outer radius a, inner radius b and height h is placed on the ground plane centrally. There is no offset for the slot position or DRA position.

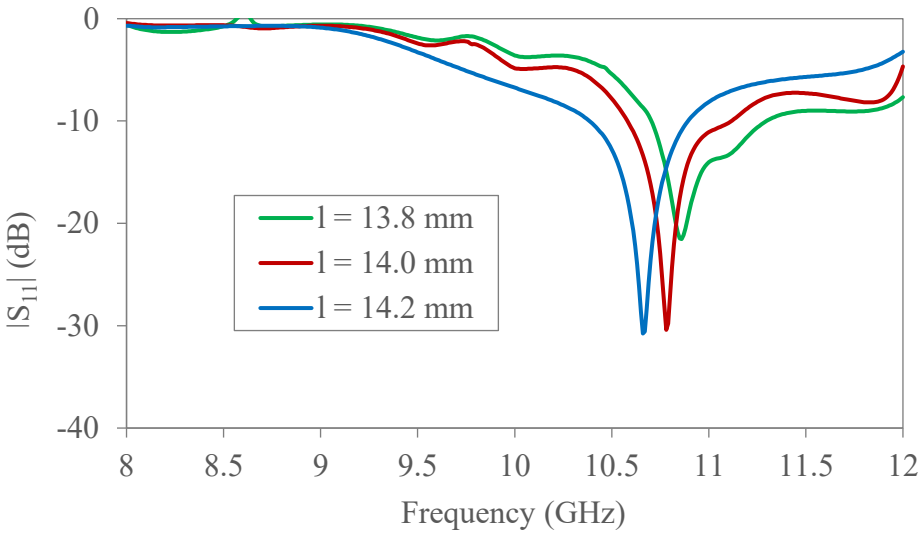
3. Parametric Study

The resonant frequency and coupling efficiency depend on various parameters of the DRA. Slot length, slot width, slot thickness, outer radius of the DRA, inner radius of the DRA, height of the DRA and dimension of the ground plane are the major factors that determine the resonant frequency and coupling of the antenna.

3.1 Slot length l

The slot length is changed from 13.8 mm to 14.2 mm with a step size of 0.2 mm and it is observed that when the length increases the resonant frequency decreases that is shown in Figure 4. This is due to the fact that the increase in slot length causes capacitive effect and in turn reduces the resonant frequency. It is optimized at 14.0 mm, at which good coupling and more bandwidth are obtained.

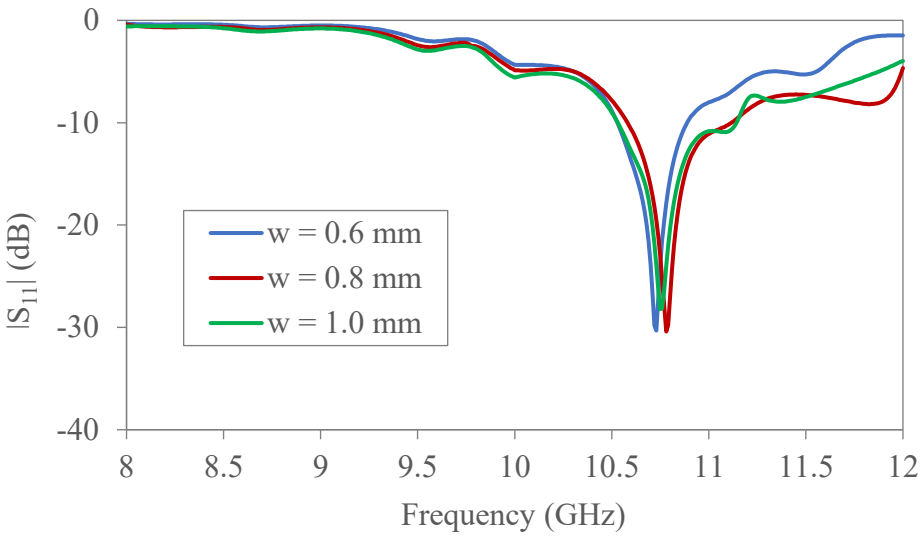
Figure 2. $|S_{11}|$ as a function of the length of the slot.



3.2 Slot width w

The slot width slightly affects the coupling and it is optimized at w = 0.8 mm which gives maximum coupling and high gain. The increase in the slot width is limited by cross-polarization effects. From the parametric analysis of slot width w, it is observed that as the width of the slot is increased or decreased from 0.8 mm, the resonant frequency is decreased. The variation of $|S_{11}|$ with respect to slot width w is depicted in Figure 3.

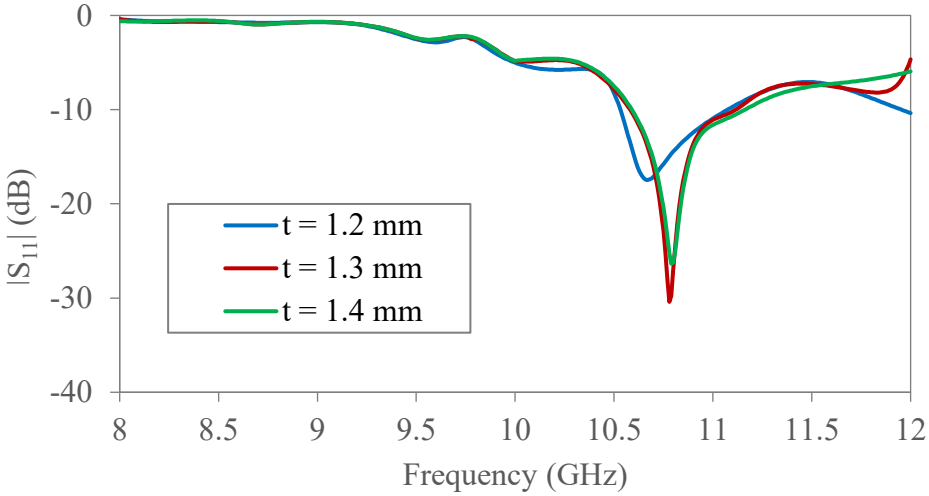
Figure 3. $|S_{11}|$ as a function of the width of the slot.



3.3 Slot thickness t

The thickness of the slot is same as that of the ground plane. Figure 4 shows the variation of $|S_{11}|$ with respect to the variation the slot thickness. When the thickeness increases, resonant frequency also increases. The maximum coupling is obtained at t = 1.3 mm and the optimized value is taken as 1.3 mm.

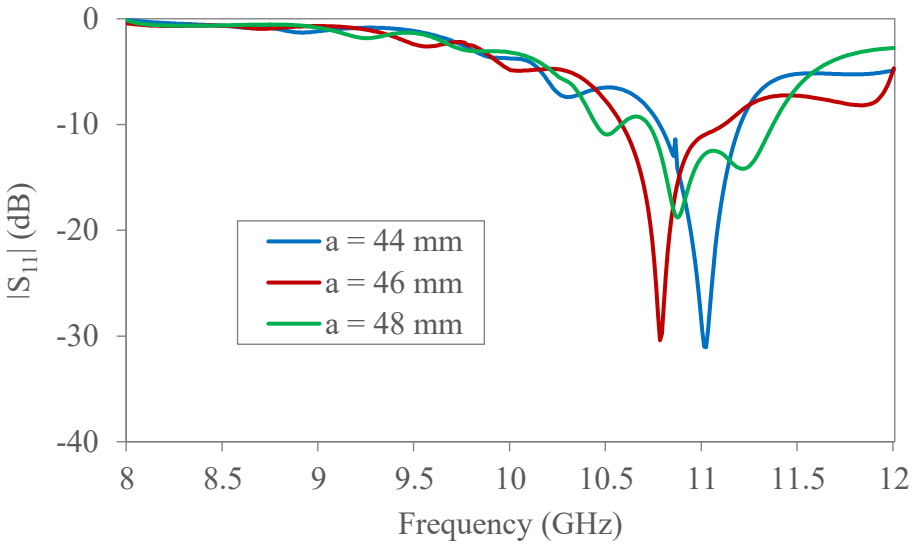
Figure 4. $|S_{11}|$ as a function of the slot thickness



3.4 Outer Radius of the DRA a

The resonant frequency depends on the dimension of the DRA. Figure 5 depicts the variation of $|S_{11}|$ as the function of outer radius of the glass DRA. As the outer radius increases or decreases from 46 mm, the resonant frequency increases. The coupling decreases when the radius decrease. The radius is optimized at 46 mm as this radius gives high gain and good coupling.

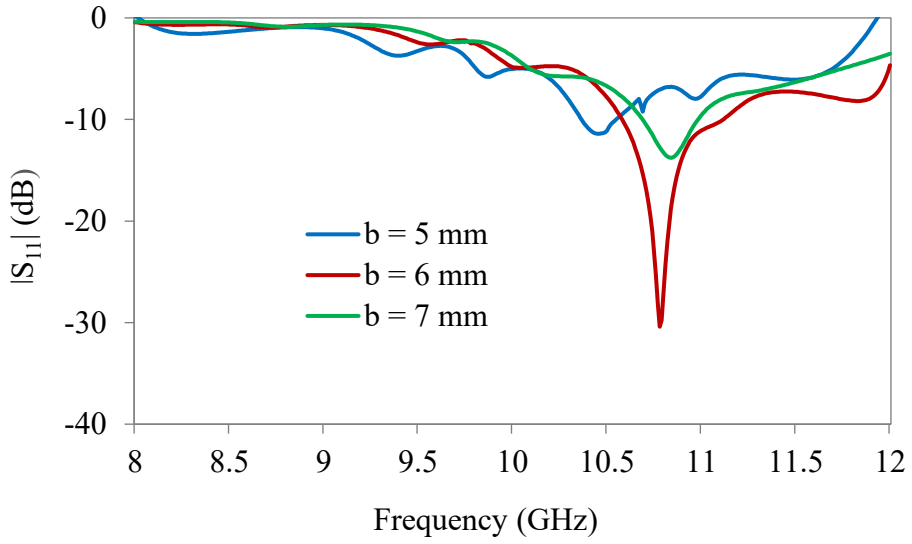
Figure 5. $|S_{11}|$ as a function of outer radius of DRA



3.5 Inner Radius of the DRA b

Inner radius of the DRA plays an important role in the coupling of the DRA. As the inner radius changes from 6 mm the resonant frequency changes and the coupling is affected adversely. The Figure 6 shows the changes of $|S_{11}|$ when the inner radius varies from 5 mm to 7 mm in a step of 1 mm. The inner radius b is optimized as 6 mm, at which the coupling is excellent.

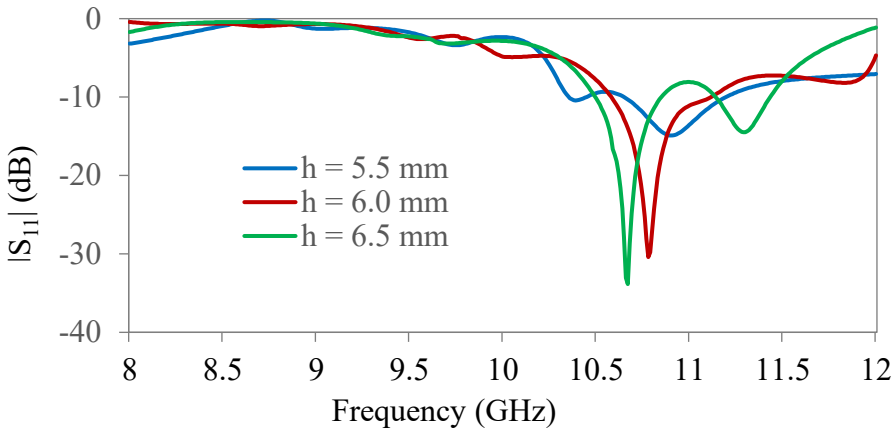
Figure 6. $|S_{11}|$ as a function of inner radius of the DRA



3.6 Height of the DRA h

Figure 7 shows the variation of the return loss against the variation of the height of the DRA. As the height increases the resonant frequency decreases. There is a drastic change in the coupling when the height changes from 6.0 mm. The optimized value of height is taken as 6.0 mm as the coupling and resonant frequency are considered.

Figure 7. $|S_{11}|$ as a function of the height of the DRA



3.7 Dimension of the ground plane

The ground plane is used to reduce the back radiations. When the dimension of the ground plane is increased the back radiation is reduced. But as the dimension increases, the compactness decreases. As an optimization, it is taken as 100 mm x 100 mm. Optimized parameters are given in Table 1.

Table 1. Optimized parameters.

parameter	value	parameter	value
da	22.86 mm	l	9.4 mm
db	10.16 mm	w	0.95 mm
dl	60 mm	a	46.0 mm
g	100 mm	b	6.0 mm
t	1.3 mm	h	6.0 mm

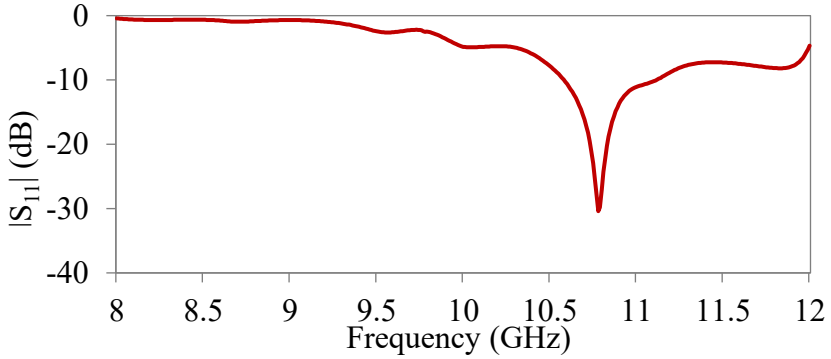
4. Results and Discussions

The simulations of the designed antenna were carried out using Ansoft HFSS. The reflection coefficient, gain, radiation pattern, impedance, and field distribution are plotted and analyzed.

4.1 Reflection Coefficient

The simulated $|S_{11}|$ parameters are shown in Figure 8. The resonant frequency is observed as 10.8 GHz, which is in very near to the computed resonant frequency with an impedance bandwidth of 5.3 % extending from 10.55 GHz to 11.12 GHz. A high gain of 13.23 dBi is observed with this structure.

Figure 8. Reflection coefficient of the proposed antenna



4.2 Coupling Efficiency

The coupling efficiency is directly related to the reflection coefficient and maximum coupling is achieved at the resonant frequency 10.8 GHz. It can be calculated as 98% using the formula

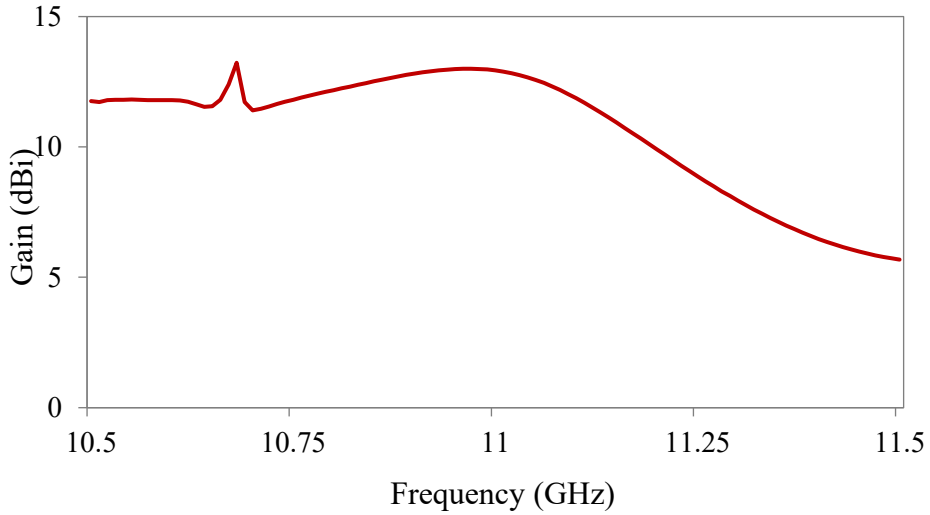
$$\eta_{coupling} = \frac{P_c}{P_{in}} = 1 - |\Gamma|^2 \quad \text{---------- (2)}$$

where *Pc* is the power coupled to the antenna, *Pin* is the input power and Γ is the reflection coefficient [21].

4.3 Gain

Gain of the proposed antenna is depicted in Figure 9. A maximum gain of 13.23 dBi is obtained at 10.68 GHz and in the resonant band it remains almost constant.

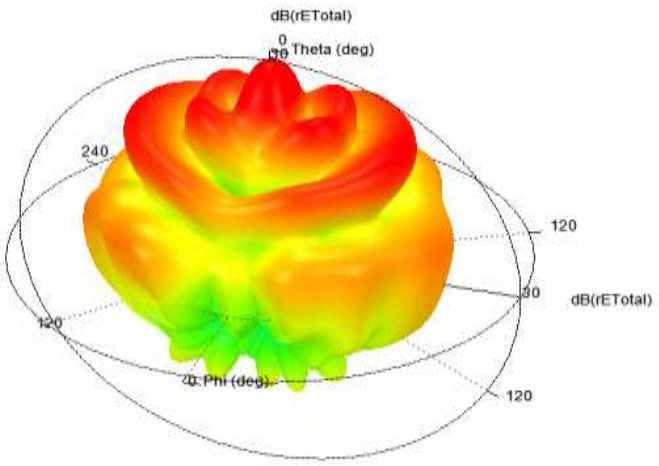
Figure 9. Gain of the proposed antenna



4.4 Radiation Pattern

Figure 10 shows the 3D radiation pattern. The directivity, polarization, and mode of operation can be deduced from the pattern. The antenna is operated in $TE_{01\delta}$ mode. The maximum radiation is obtained at theta and phi are at 0°.

Figure 9. Gain of the proposed antenna



6. Conclusion

A very simple DRA structure for high gain and excellent coupling is proposed. The proposed structure ensures a coupling efficiency higher than 98% and a high gain of 13.23 dBi. High gain which is grater than 11.6 dBi is maintained in the entire bandwidth . The proposed antenna finds applications in radar communications, satellite communications and defense and aerospace systems. By proper scaling of waveguide and DRA dimensions, the operation of the proposed antenna can be extended to higher frequency range.

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