# Double Step Junction for Coupling Enhancement of Rectangular Waveguide fed Cylindrical DRA

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**Abstract:** A novel method for the coupling enhancement of rectangular waveguide fed cylindrical dielectric resonator antenna (DRA) is proposed in this paper. The enhanced coupling is provided by steps with reduced narrow wall dimension inserted between the rectangular waveguide and the ground plane. The steps act as an impedance matching transformer that provides very good coupling greater than 98%. The maximum gain of the proposed antenna is 8.83 dBi at 9.35 GHz, which is much greater when compared with dipole antennas. The double step junction coupled waveguide fed DRA proposed in this article is linearly polarizied in nature. The co-polarized signals are at least 20 dB stronger than the corresponding cross-polarized signals in the direction of maximum radiation.

**Keywords**: capacitive waveguide junction; coupling enhancement; dielectric resonator antenna; rectangular waveguide; radiation pattern.

## Introduction

The term 'dielectric resonator' was coined by Robert D. Richtmyer of Stanford University in 1939 [1]. He showed that nonmetallic dielectric objects (toroid) can function as microwave resonators. Richtmyer also demonstrated that the dielectric resonator when exposed to free space must radiate because of the boundary conditions at the dielectric-to-air interface. The possibility of constructing very small antennas using dielectric resonators was described in [2]. Dielectric resonator antenna (DRA) is very much suitable for high frequency applications, especially in millimeter wave range due to the absence of conductor loss. DRAs offer many other attractive features like small size, light weight, high power handling capacity, wide bandwidth, and ease of excitation [3]. When the frequency range of interest for many systems has progressed upwards to millimeter and near millimeter range the conductor loss of metallic antennas becomes severe and the efficiency of microstrip patch antennas reduces significantly. As the only loss of a DRA is due to the imperfect dielectric material, which is very small in practice, it can be used as a suitable alternative to patch antennas at millimeter range of frequencies. In addition, DRAs exhibit a relatively large bandwidth, approximately 10% for a dielectric constant of $\varepsilon_r = 10$; whereas patch antennas have a typical bandwidth of only 1% – 3% in their basic form. Theoretical and experimental investigations have been reported by many investigators on DRAs of various shapes such as hemispherical [4], cylindrical [5], cylindrical ring [6], and rectangular [7].The design parameters such as permittivity, resonant frequency, input impedance, coupling mechanisms and radiation patterns vary for different shapes and hence the analytical model for analyzing each geometrical configuration is different. Simplified analysis and mechanical fabrication play an important role in selecting the shape of DRAs. Since hemispherical DRA has zero degree of design freedom, bandwidth remains fixed and is difficult to optimize for particular requirements. While cylindrical DRA has one degree of freedom and different values of radius-height pairs give different values of bandwidth, and directivity.

DRAs can be excited with direct microstrip [8], aperture coupled microstrip [9], coaxial probe [10], coplanar waveguide [11] conformal strip [12], metallic waveguide etc. [13]. All these techniques except waveguide feeding suffer from feed line losses at high frequencies. The metallic walls of the waveguide offer excellent shielding between the interior and exterior regions, avoiding radiation loss even in the millimeter wave band of frequencies.DRA can be excited by slots cut at the broad wall, narrow wall or at the shorted end of the waveguide. In the literature, very few studies have been reported on waveguide fed DRA either at the shorted end or at the broad wall or narrow wall. Though DRA with high permittivity can be efficiently excited by an empty waveguide [14], coupling is very poor with DRA of low dielectric constant. The reason for poor coupling of waveguide shorted end slot coupled DRA is the inductive susceptance offered by the DRA loaded slot. A few techniques are reported in the literature for increasing the coupling of waveguide fed DRA. A second dielectric resonator placed inside the waveguide close to the slot in the ground plane provides increased coupling [15]. This technique requires another dielectric resonator antenna to increase the coupling that increases the cost of the system. In addition keeping the dielectric resonator inside the waveguide seems to be very difficult. Coupling enhancement can also be achieved by using a capacitive waveguide junction, inserted between the rectangular waveguide and ground plane [16]. But the narrow wall dimension of the capacitive waveguide junction proposed in [16] is very small that makes fabrication difficult at high frequencies, especially at millimetre wave range of frequencies. Another technique for coupling enhancement using multilayer DRA is proposed in [17]. Though this technique does not require any additional structure, multilayer DRA (layered DRA, each layer with different dielectric constants) fabrication is very difficult.

In this paper a novel coupling enhancement technique of rectangular waveguide fed dielectric resonator antenna by inserting two steps between the rectangular waveguide and the ground plane is proposed. The steps act as an impedance transformer that provides good coupling. Very good coupling is obtained by the proposed technique. The double step junction coupled waveguide fed cylindrical DRA achieves a very high gain with a maximum value of 8.83 dBi. The 10 dB bandwidth of the proposed antenna is 6.1%.

**Antenna Design**

Configuration of the double step junction coupled waveguide fed cylindrical DRA is shown in Fig. 1. The structure consists of a rectangular waveguide with two steps at the end, which is terminated in thick metallic ground plane with a rectangular slot at the centre. The waveguide used is X band waveguide with dimension 22.86 mm x 10.16 mm. The steps are constructed in such a way that it will reduce only the narrow wall dimension (b) of the waveguide, keeping the broad wall dimension constant. The cylindrical DRA is placed above the ground plane with slot at the centre. The radius and height of the cylindrical DRA is represented by $r$ and $h$ respectively. *2t1*, *2w1* represent the thickness and width of step1 and *2t2*, *2w2* represent the thickness and width of step2. Length, width and thickness of the slot are denoted by *2L3*, *2w3* and *2t3* respectively. The steps with reduced narrow wall dimension provide the required capacitive susceptance to neutralize the inductive susceptance of direct coupled waveguide fed DRA.

Comparison between the normalized admittance plot of waveguide shorted end slot coupled (direct coupled) cylindrical DRA and double step junction coupled waveguide fed cylindrical DRA is shown in Fig. 2. Dimension of the slot in the direct coupled waveguide fed cylindrical DRA is same as that used in the double step junction coupled waveguide fed CDRA. Susceptance of the direct coupled waveguide fed cylindrical DRA is inductive over the entire operating frequency range. The normalized susceptance at resonant frequency is zero for the double step junction coupled waveguide fed CDRA. This is due to the steps that provide the required capacitive susceptance. The normalized conductance is maximum at resonant frequency. Cylindrical DRA with radius $r$ = 7.0 mm, height $h$ = 5.0 mm and dielectric constant, $\varepsilon_r$= 9.8 is used in the design of direct coupled waveguide fed cylindrical DRA and double step junction coupled rectangular waveguide fed cylindrical DRA. Different parameters are found out by conducting a thorough parametric study using Ansoft HFSS. The dimension of the slot is: *2L3* = 9.5 mm, *2w3* = 1.0 mm and *2t3* = 1.3 mm. Dimensions of the steps are: *2t1*= 4.0 mm, *2w1* = 6.5 mm, *2t2* = 8.0 mm and *2w2* = 3.4 mm. Comparison between the normalized admittance plot of waveguide shorted end slot coupled (direct coupled) cylindrical DRA and double step junction coupled waveguide fed cylindrical DRA is shown in Fig. 2. Dimension of the slot in the direct coupled waveguide fed cylindrical DRA is same as that used in the double step junction coupled waveguide fed cylindrical DRA. Susceptance of the direct coupled waveguide fed cylindrical DRA is inductive over the entire operating frequency range. The normalized susceptance at resonant frequency is zero for the double step junction coupled waveguide fed CDRA (Cylindrical DRA). This is due to the steps that provide the required capacitive susceptance.

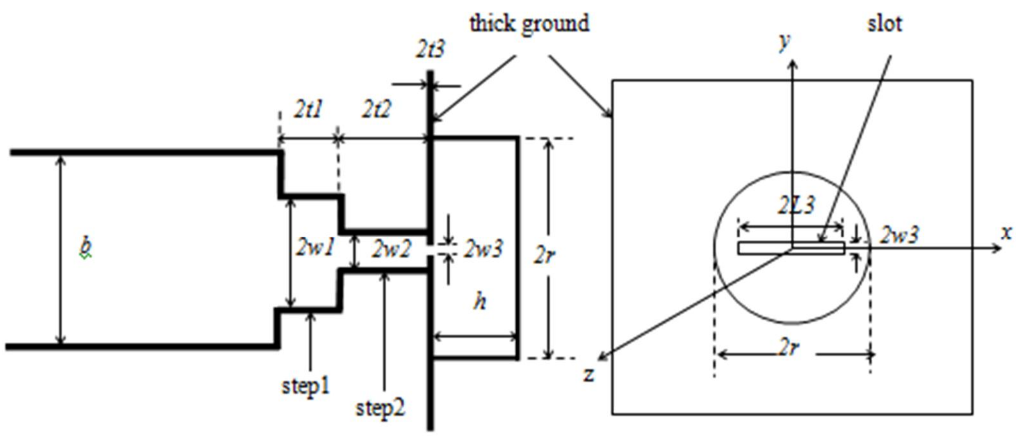



Figure 1. Longitudinal cross section of double step junction coupled waveguide fed cylindrical DRA

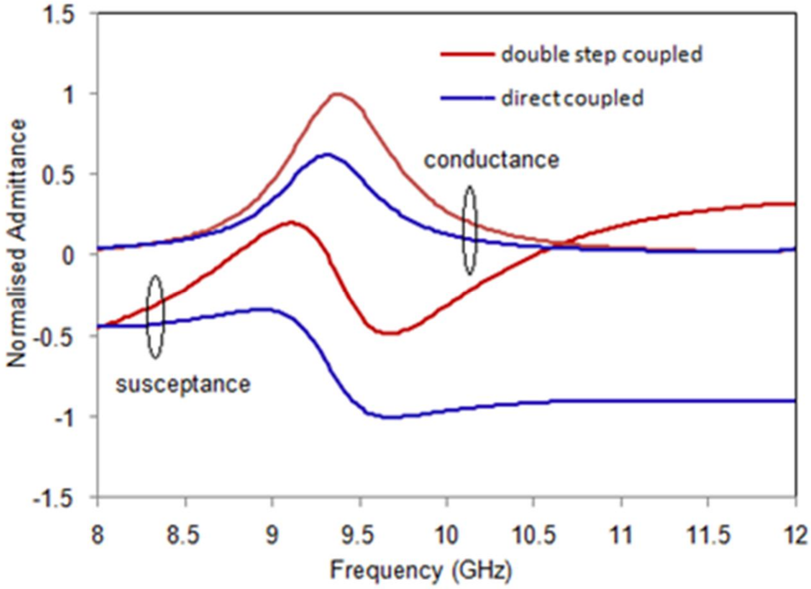



Figure.2. Comparison between the normalized conductance/ susceptance of direct coupled and double step junction coupled waveguide fed Cylindrical DRA with *r* = 7.0 mm, *h* = 5.0 mm, *2t1* = 4.0 mm, *2w1* = 6.5 mm, *2t2* = 8.0 mm, *2w2* = 3.4 mm, *2t3* = 1.3 mm, *2w3 = 1.0* mm and *2L3* = 9.5 mm

The effect of the dimension of cylindrical DRA on reflection coefficient is studied by conducting a thorough parametric study using HFSS. Fig. 3 shows the effect of radius on resonant frequency and matching. The resonant frequency decreases as the radius of DRA increases. Maximum matching is obtained for radius *r* = 7.0 mm. The effect of height on reflection coefficient is also studied and is shown in Fig.4. As height of the antenna is varied from 4.5 mm to 5.5 mm, the resonant frequency decreases from 9.68 mm to 9.0 mm. From these two figures, it is clear that the resonant frequency is very much affected by the size of the DRA.

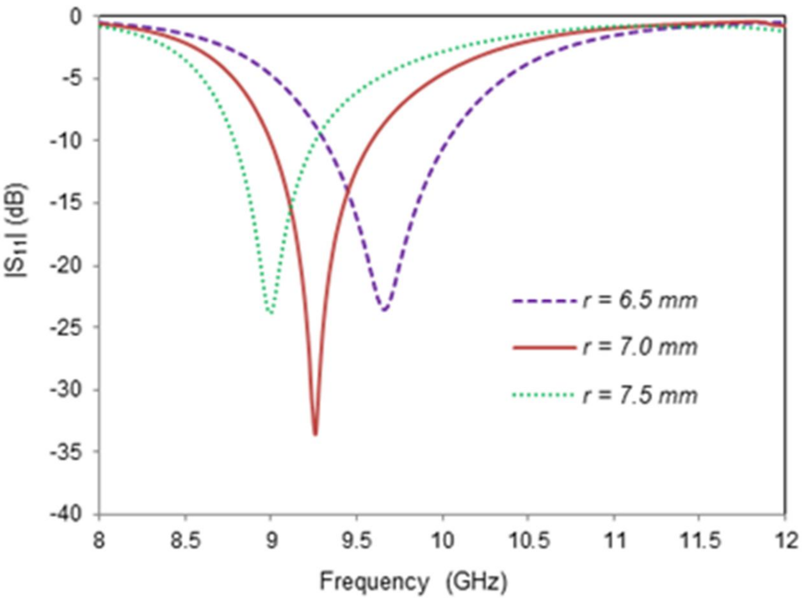



Figure 3. Reflection coefficient of double step junction coupled waveguide fed CDRA as a function of radius *r* of CDRA with *h* = 5.0 mm, *2t1* = 4.0 mm, *2w1* = 6.5 mm, *2t2* = 8.0 mm, *2w2*= 3.4 mm, *2t3*= 1.3 mm,*2w3 = 1.0* mm and*2L3* = 9.5 mm

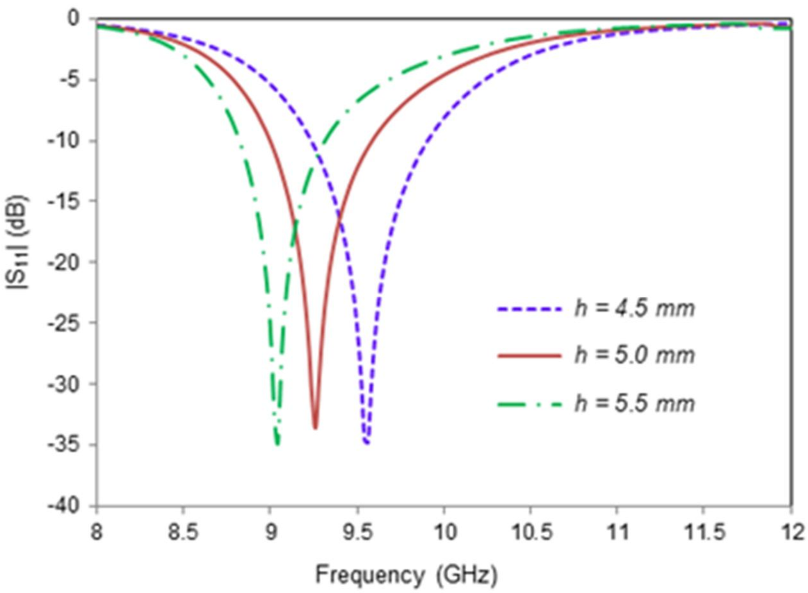



Figure 4. Reflection coefficient of double step junction coupled waveguide fed CDRA as a function of height *h* of CDRA with *r* = 7.0 mm, *2t1* = 4.0 mm, *2w1* = 6.5 mm, *2t2* = 8.0 mm, *2w2*= 3.4 mm, *2t3*= 1.3 mm, *2w3 = 1.0* mm and*2L3* = 9.5 mm

The proposed structure consists of two resonant structures: the dielectric resonator antenna and the slot. Therefore the dimension of the slot like the length, width and thickness is very much important in determining the resonant frequency. The effect of the slot dimension on resonant frequency and matching is studied using Ansoft HFSS. Fig. 5 shows the effect of slot length in resonant frequency. As the slot length is increased from 9,0 mm to 10 mm, the resonant frequency decreases from 9.54 GHz to 9.04 GHz. The resonant frequency corresponding to DRA resonant frequency along with maximum matching is obtained for slot length, *2L3* = 9.0 mm.

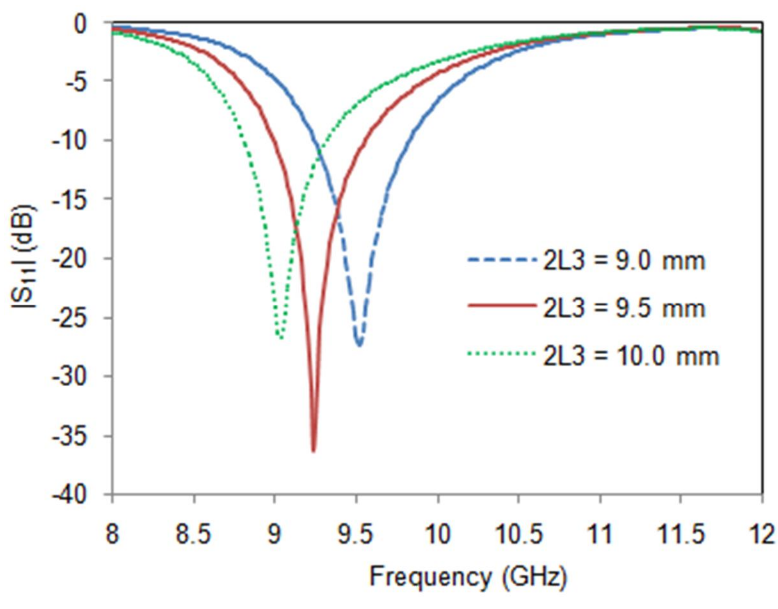



Figure 5. Reflection coefficient of double step junction coupled waveguide fed CDRA as a function of slot length *2L3* with *r* = 7.0 mm, *h* = 5.0 mm, *2t1* = 4.0 mm, *2w1* = 6.5 mm, *2t2* = 8.0 mm, *2w2*= 3.4 mm, *2t3*= 1.3 mm,*2w3 = 1.0* mm and *2L3* = 9.5 mm

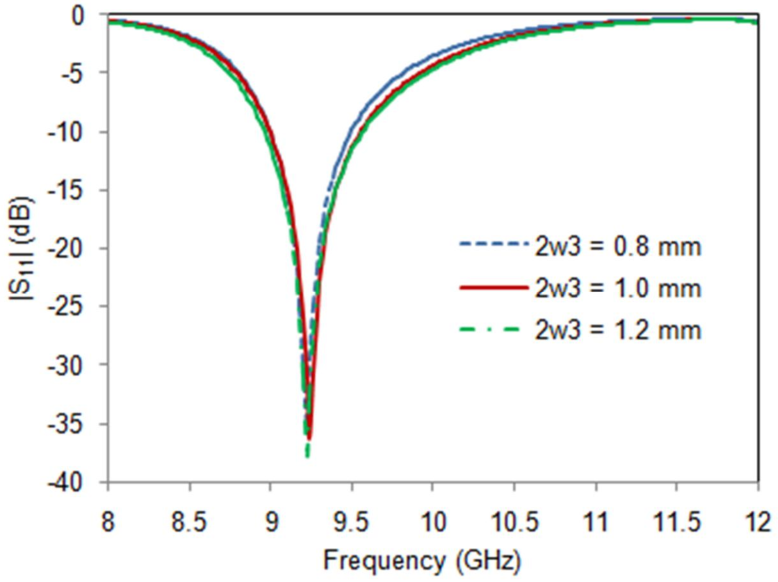



Figure 6. Reflection coefficient of double step junction coupled waveguide fed CDRA as a function of slot width, 2w3 with *r* = 7.0 mm, *h* = 5.0 mm, *2t1* = 4.0 mm, *2w1* = 6.5 mm, *2t2* = 8.0 mm, *2w2*= 3.4 mm, *2t3*= 1.3 mm, and*2L3* = 9.5 mm

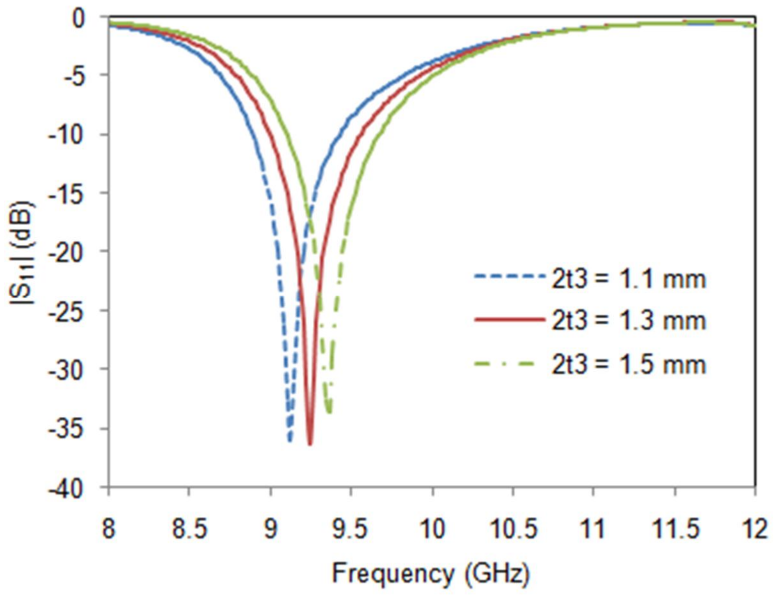



Figure 7. Reflection coefficient of double step junction coupled waveguide fed CDRA as a function of slot thickness, *2t3* with *r* = 7.0 mm, *h* = 5.0 mm, *2t1* = 4.0 mm, *2w1* = 6.5 mm, *2t2* = 8.0 mm, *2w2*= 3.4 mm, *2w3*= 1.0 mm, and *2L3* = 9.5 mm

The effect of slot width and thickness is shown in Fig. 6 and Fig. 7 respectively. The effect of slot width on resonant frequency is much less when compared with slot length and width. As the slot width is varied from 0.8 mm to 1.2 mm, the resonant frequency is almost constant, which is clear from the figure. The effect of slot length and slot width on reflection coefficient can be explained by considering the slot as a waveguide with very small dimension. As the cross sectional dimension of the waveguide decreases, cut off frequency increases. The resonant frequency is very much affected by the variation in slot thickness. Fig. 7 shows that the resonant frequency increases as the slot thickness is increased. The resonant frequency corresponding to DRA resonance is obtained for slot thickness, *2t3* = 1.3 mm. With the optimized parameters, the structure is fabricated and measured using R & S ZVL 13 Vector Network analyzer. The measured reflection characteristics along with simulated characteristics is shown in Fig. 8. The measured resonant frequency is 9.44 GHz, which shows a small shift of 180 MHz when compared with the simulated resonant frequency (9.26 GHz). The shift in resonant frequency is

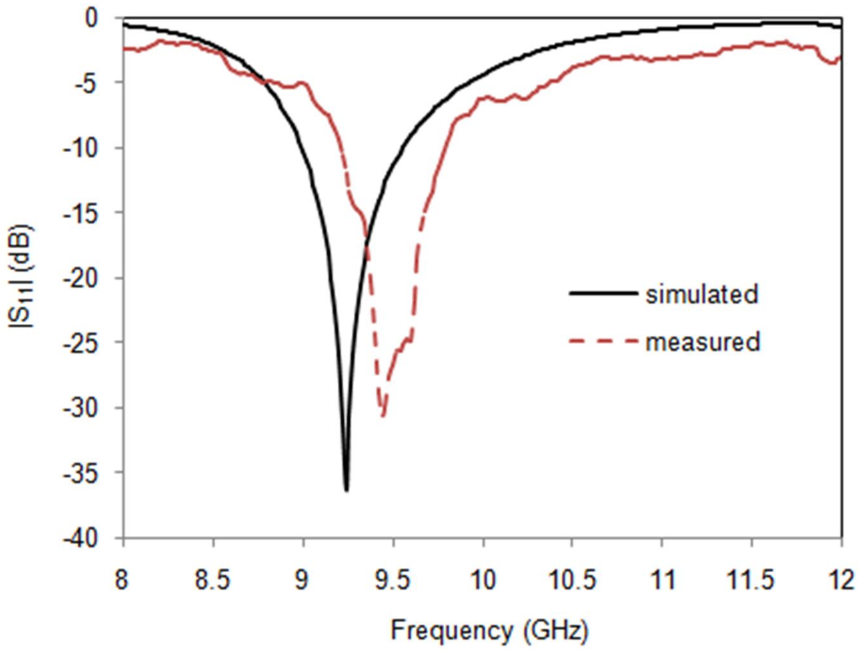



Figure 8. Measured and simulated reflection coefficient of double step junction coupled waveguide fed CDRA with *r* = 7.0 mm, *h* = 5.0 mm, *2t1* = 4.0 mm, *2w1* = 6.5 mm, *2t2* = 8.0 mm, *2w2*= 3.4 mm, *2t3*= 1.3 mm, *2w3 = 1.0* mm and *2L3* = 9.5 mm

mainly due to the air gap present between the ground plane and CDRA [18]. Due to the presence of air gap, effective permittivity of the DRA decreases, this causes the resonant frequency to shift upwards. The air gap also causes the bandwidth to increase. Measured 10 dB bandwidth is 6.1% extending from 9.22 GHz to 9.8 GHz. Gain of the double step junction coupled waveguide fed CDRA is measured and is shown in Fig. 9. Gain of the double step junction coupled waveguide fed cylindrical DRA is 8.83 dBi, which is much higher than the gain of the dipole antenna.Radiation patterns in E and H planes at 9.44 GHz is measured and compared with the simulated radiation pattern. Fig. 10 represents the radiation patterns at 9.44 GHz in E plane and H plane. Good agreement is observed between the measured and simulated co-polarization signals. The measured cross-polarization signals are at least 20 dB below the corresponding co-polarization signals and thus act as a linearly polarized antenna.

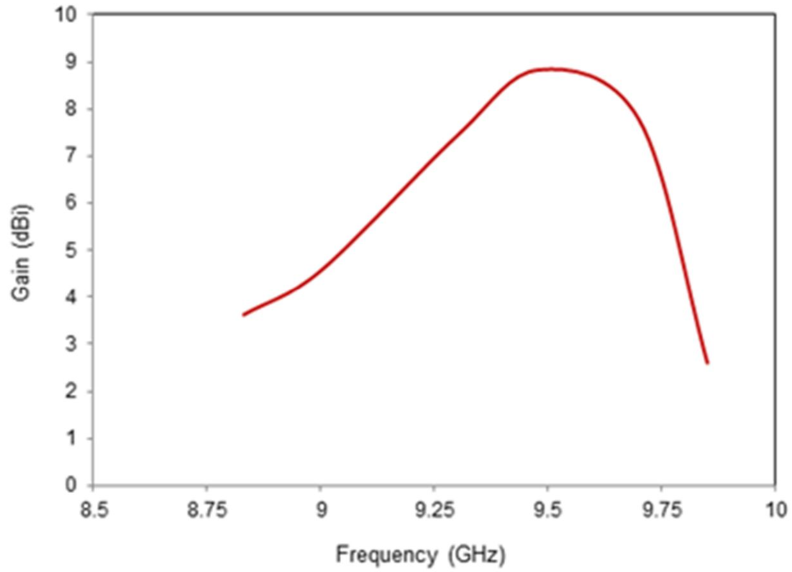
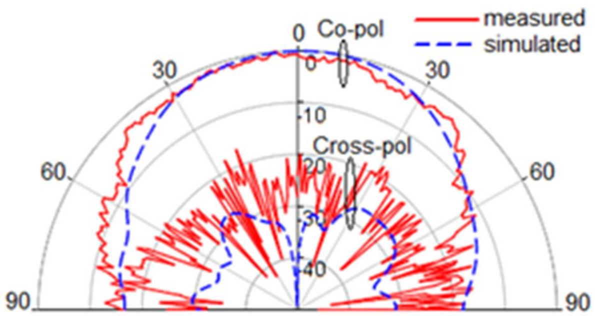
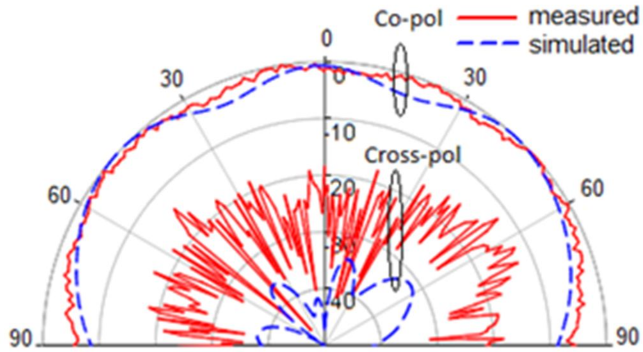



Figure 9. Measured gain of the double step junction coupled waveguide fed cylindrical DRA with *r* = 7.0 mm, *h* = 5.0 mm, *2t1* = 4.0 mm, *2w1* = 6.5 mm, *2t2* = 8.0 mm, *2w2*= 3.4 mm, *2t3*= 1.3 mm,*2w3* = 1.0mm and*2L3* = 9.5 mm




(a)




(b)

Figure 10. Radiation pattern of double step junction coupled waveguide fed cylindrical DRA at 9.44 GHz: (a) in H plane and (b) in E plane

## Conclusion

A novel method for the coupling enhancement of rectangular waveguide-fed cylindrical DRA by inserting steps with reduced narrow wall dimension between the waveguide and ground plane is demonstrated in this article. Very good matching, greater than 98% is obtained for the proposed antenna. A thorough parametric study has been conducted to study the effect of various parameters on resonant frequency and matching. The double step junction coupled waveguide fed Cylindrical DRA gives a maximum gain of 8.83 dBi. The measured 10 dB bandwidth is 6.1%. Radiation patterns with low cross polarization levels are obtained. The proposed technique can be applied to millimeter wave frequencies and dielectric resonator antennas of different shapes.

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