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Performance Analysis of Cylindrical Dielectric Resonator Antenna with various slot configurations on Substrate Integrated Waveguide

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ABSTRACT

A Dielectric Resonator loaded Substrate integrated waveguide cavity backed slot antenna (SIDRA) is proposed for two slot polarizations and orientation. A SIW-fed cylindrical DRA using rectangular slot is used for obtaining bandwidth of about 5% at 6.15 GHz. For enhancing bandwidth, a plus shaped slot with bandwidth of about 8.80% and gain of 3.7 dB is proposed. The proposed antenna represents S_{11} < -10 dB for C-band with good bandwidth and gain characteristics. Study of cylindrical dielectric resonator antenna (CDRA) at C-Band (4 -8 GHz) is discussed and presented for Satellite Application. The parametric study of various slot position is discussed.

Keywords: Substrate Integrated Waveguide (SIW), Cylindrical Dielectric Resonator Antenna (CDRA), SIW Cavity backed slot Antenna (SCBSA), Plus shaped aperture slot

1. INTRODUCTION

Recent advances in wireless communications has resulted in development of antennas that can be integrated into wireless products. Dielectric Resonator Antenna (DRA) was first proposed by S.A.Long [1] in 1983. Dielectric Resonators having dielectric constant from $10 < \varepsilon_{rd} < 100$ are suited for antenna applications. DRA can be in several shapes such as rectangular, cylindrical and hemispherical in which cylindrical DRA offers better design flexibility and ease of fabrication [2]. DRA have attractive features like low profile, wide impedance bandwidth and zero conductor losses [3] and is most widely used in microwave and millimeter wave band. Also, DRA can be coupled by different feed mechanism such as coaxial probe, microstrip line [4], slot line [5] and coplanar waveguide. These excitation methods result in radiation loss. Metallic waveguides are preferred due to their better guiding wave options than compared to traditional transmission lines. But these waveguides are expensive and difficult to integrate with other planar circuits due to its high volume and massive structure [6].

Substrate Integrated Waveguide (SIW) acts as substitute to metallic waveguides [7, 8].The guided-wave properties of an SIW were analyzed in [9]. Design rules and wave mechanisms of the Substrate integrated waveguide was presented in [10]. In [11], the concept of an SIW slot antenna array consisting of 4×4 slots operating at 10 GHz was proposed. To achieve similar performance along with light weight, compact size, easy to fabricate and implement in mobile systems, SIW is one of the best candidate which shows excellent performance as reported [12]. SIW based rectangular dielectric resonator antenna is investigated at Ka-band [13] where impedance bandwidth is achieved to 8.60% and 4.70%. In [14], the SIW fed Cylindrical DRA array is simulated at 35 GHz with impedance bandwidth of 6.14% is observed.

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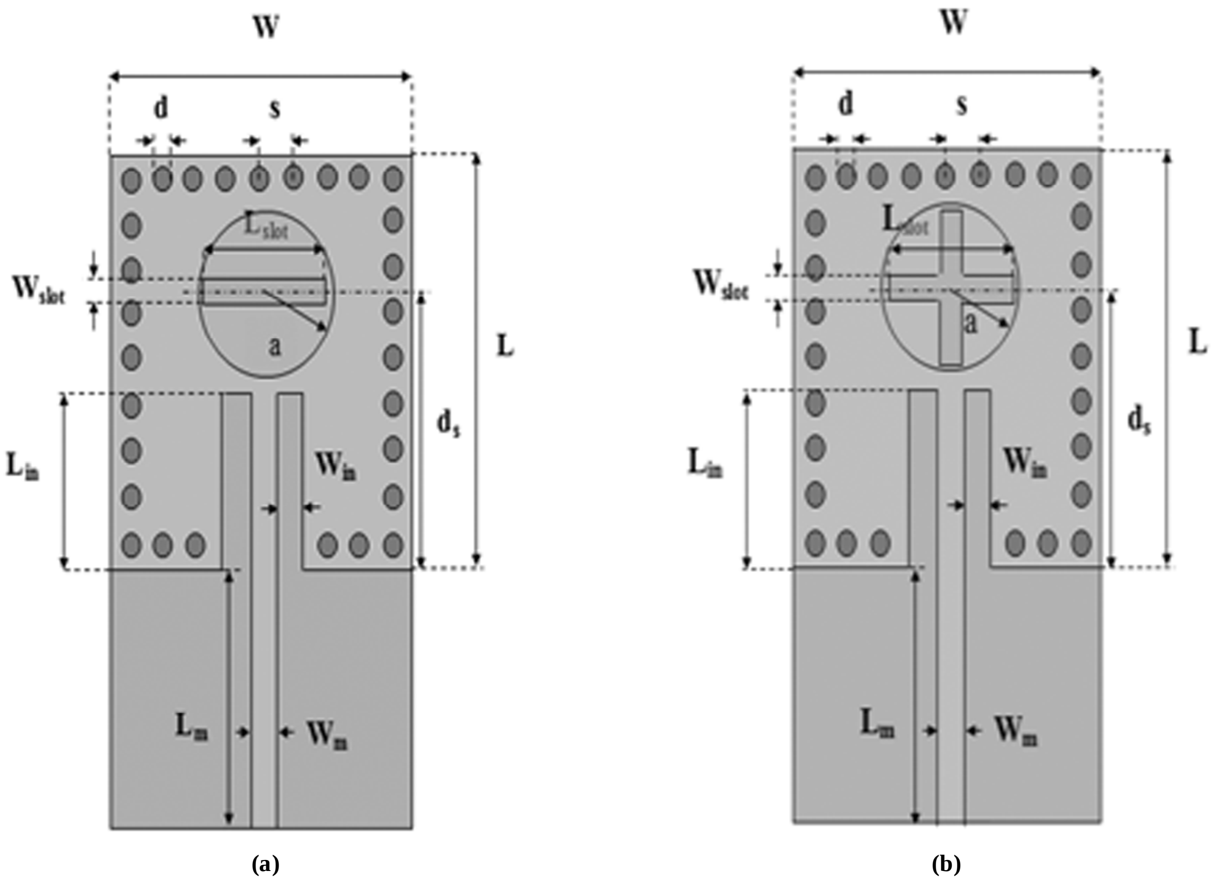

Figure 1: Top View of SIW fed CDRA with different Slot Configuration.
(a) CDRA with Rectangular slot: L = 50mm, W = 35mm, d = 0.8mm, s = l.4mm, W_{in}= 0.4mm, L_{in}= 14mm, W_m= 2.4mm, L_m= 22mm, L_{slot}= l2mm, W_{slot}= 1.5mm, d_s= 29mm (b) Proposed Antenna: d_s= 23.2mm, a = 10mm.

In this paper, a work is made to enhance the bandwidth of SIW based slot antenna by using DRA with two slot configurations such as rectangular and plus shaped aperture slots. The feeding SIW, as shown in Fig. 1, is formed in the bottom substrate and the Dielectric Resonator Antenna will be integrated on the top substrate. Using simple rectangular slot element, frequency bandwidth of 5% is obtained. And we found that good bandwidth of almost 8.80% can be achieved with very simple plus shaped aperture slot geometry. Then, simulated results are compared with various slot configurations. The design equations to calculate the width of SIW and theoretical analysis of cylindrical DRA is presented in Section II. Parametric study of length and width of slot is discussed in Section III. Simulation results are described in Section IV. Section V is the conclusion of the work.

2. ANTENNA DESIGN

2.1. SIW structure

The SIW are planar structures constructed using two periodic rows of metallic vias of diameter d or slots joining upper and lower metallic ground planes of substrate as shown in Fig. 1(a). The Substrate Integrated Waveguide operates at the dominant mode of TE_{10}. Due to periodic gaps, the SIW structures has possible leakage problem, thus resulting in attenuation or leakage of wave. The losses can be made small if $s/d < 2.5$, with $s/d = 2$. The radiation leakage can be minimized by keeping the spacing s small and the diameter d of the metal vias large. The parameters of SIW are chosen properly in order to minimize the transmission losses. Useful design rules and wave mechanisms of the planar waveguide is given in [10]. The width of SIW (w_{siw}) is calculated by using the conventional rectangular waveguide (w_{equ}) whose width is given by,

$$w_{equ} = w_{siw} - \frac{d^2}{0.95s}. \quad (1)$$

Where, d is the diameter of the via and s is the spacing between adjacent vias.

The effective dimension of the equivalent waveguide using Eq.1 is 35 × 72 × 1.6 mm^3. A rectangular slot with length (L_{slot}) and width (W_{slot}) is engraved on the broad wall of the SIW to efficiently couple the power to the SIDRA. The proposed antenna is designed on a compact FR-4 substrate with relative permittivity (ε_r) of 4.4 with loss tangent of 0.02, and fed by 50 Ω microstrip transmission line with length (L_m) and width (W_m) of 22 mm and 2.4 mm. The proposed SIW based CDRA is simulated by means of Ansoft High Frequency Structure Simulator (HFSS).

2.2. DRA Theoretical model Analysis

The structure of the proposed SIW with plus shaped aperture slot fed Cylindrical DRA is shown in Fig. 1(b). The cylindrical Dielectric Resonator (DR) is fed to excite at $TM_{01\delta}$ mode. The cylindrical Dielectric Resonator Antenna element is made of Rogers RT6010 (□ε_r = 10.2, tan δ = 0.0031) with thickness of H = 8mm. For given dielectric permittivity, the resonant frequency and Q-factor is selected by choosing the radius and height of CDRA [15]. By varying radius (a) and height (H) of DRA, the resonant frequency of mode can be made very close. The dimension of the cylindrical DR is estimated to operate at designed band of (4-8GHz). With the dielectric constant (ε_{rd}), the $k_o a$ can be expressed as,

$$k_0 a = \frac{\sqrt{3.83^2 + \left(\frac{\pi x}{2}\right)^2}}{\sqrt{\varepsilon_{rd} + 2}}. \quad (2)$$

Where, $x = a/H$.

The Q-factor for the given ε_{rd} is defined as,

$$Q = 0.008721\varepsilon_{rd}^{0.888413} e^{0.0397475\varepsilon_{rd}} \left\{1 - \left[0.3 - 0.2(x)\right]\left[\frac{38 - \varepsilon_{rd}}{28}\right]\right\} \left\{9.498(x) + 2058.33(x)^{4.322} e^{-3.501(x)}\right\}. \quad (3)$$

The Q-factor in Eq. 3 is used to evaluate the impedance bandwidth of the DRA and is given by,

$$BW = \frac{S - 1}{Q\sqrt{S}}. \quad (4)$$

Based on the Eq.2 the graph for $k_o a$ versus a/H is plotted. The crossing line between H and ε_{rd} = 10.2 will give the value of a/H ratio that operates in $TM_{01\delta}$ mode as shown in Fig. 2. With the set of given heights in Table I, cylindrical DR with height of 8 mm is chosen. For the value of x, the Q-factor and bandwidth of CDRA with various heights is analyzed using Eq. 3 and Eq. 4. The Q-factor versus a/H and the dimensions of the dielectric resonator are shown in the Fig. 3 and Table I.

In simple geometric shapes such as cylindrical DRAs the smallest possible ε_{rd} value makes Q-factor low which results in wider bandwidth. The cylindrical DR dimension of height H = 8mm and radius a = 10mm is chosen to achieve higher impedance bandwidth.

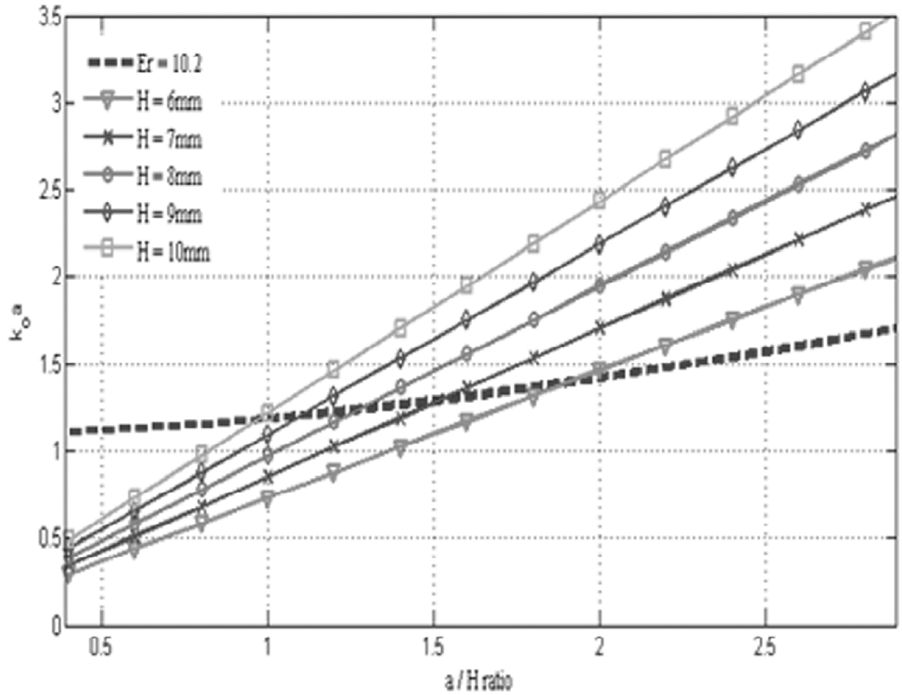

Figure 2: Dimension of Cylindrical DRA with ε_{rd} = 10.2.

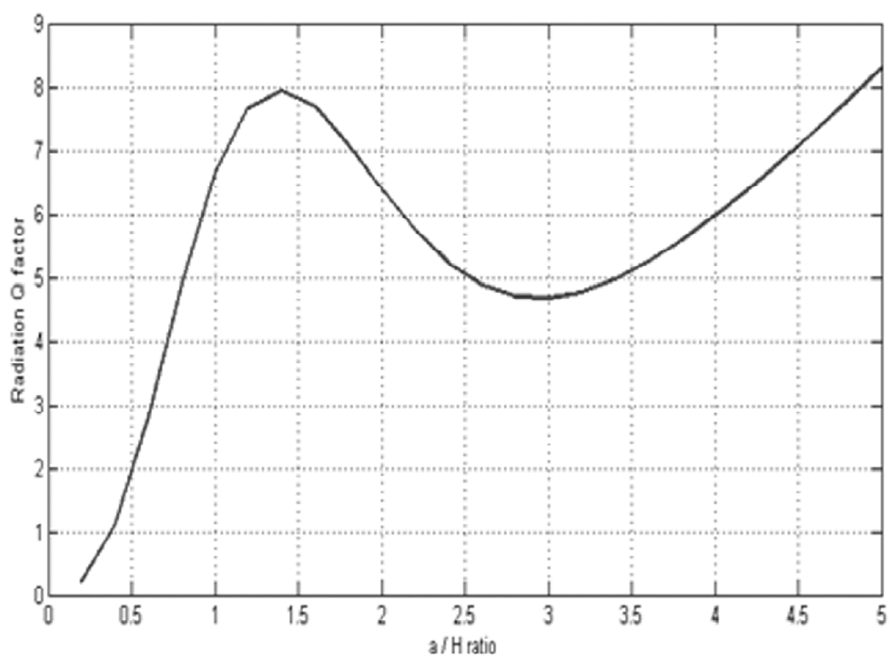

Figure 3: Q-factor of Cylindrical DRA with ε_{rd} = 10.2.

Table 1
Parameters of Cylindrical Dielectric Resonator Antenna

Height (H_{mm})	*$K_0 a$*	*a/H*	*Radius (a_{mm})*	*Quality Factor(Q)*	*Bandwidth(BW)*
6	1.394	1.911	11.4	6.74	10.52%
7	1.293	1.519	10.6	7.818	9.04%
8	1.273	1.272	10.1	7.772	9.10%
9	1.203	1.1	9.9	6.64	9.93%
10	1.181	0.97	9.7	6.38	11.22%

3. PARAMETRIC STUDY

Several design parameters affect the coupling between the slot and the Cylindrical DRA. Some parameters are length (L_{slot}) and width (W_{slot}) of the slot. These parameters have to be improved to obtain good radiation characteristics in the slot fed CDRA.

3.1. Slot Length L_{slot} Characterization

The response of slot length was investigated by varying the length of $\lambda_g / 2$, while keeping W_{slot} = 1.5mm constant. The frequency of the DRA get increases when the length of slot decreases. The coupling of energy between DRA and the slot can be adjusted by controlling the length of the slot. The slot impedance is changed by placing CDRA on the top of aperture so that it is matched at resonant frequency. The proposed antenna covers a band from 6.17 to 6.72 GHz for L_{slot} = 12mm. The return loss of the SIW fed cylindrical DRA with different length is simulated and shown in Fig. 4.

3.2. Slot Width W_{slot} Characterization

The response of slot width was investigated by keeping slot length as L_{slot} = 12mm. The slot width has the effect of increasing the bandwidth and the operating frequency of CDRA. The designed frequency of cylindrical DRA deviates from low (6.35 GHz) to high frequency (6.56 GHz) when the slot width changes from 0.5 mm to 1.5 mm. The simulated bandwidth rises from 5% at 6.35 GHz to 8.80% at 6.56 GHz. Notice that the size of the slot width W_{slot} has a negligible effect on the resonant frequency. The influence of the slot width W_{slot} on the return loss of the CDRA antenna is investigated in Fig. 5.

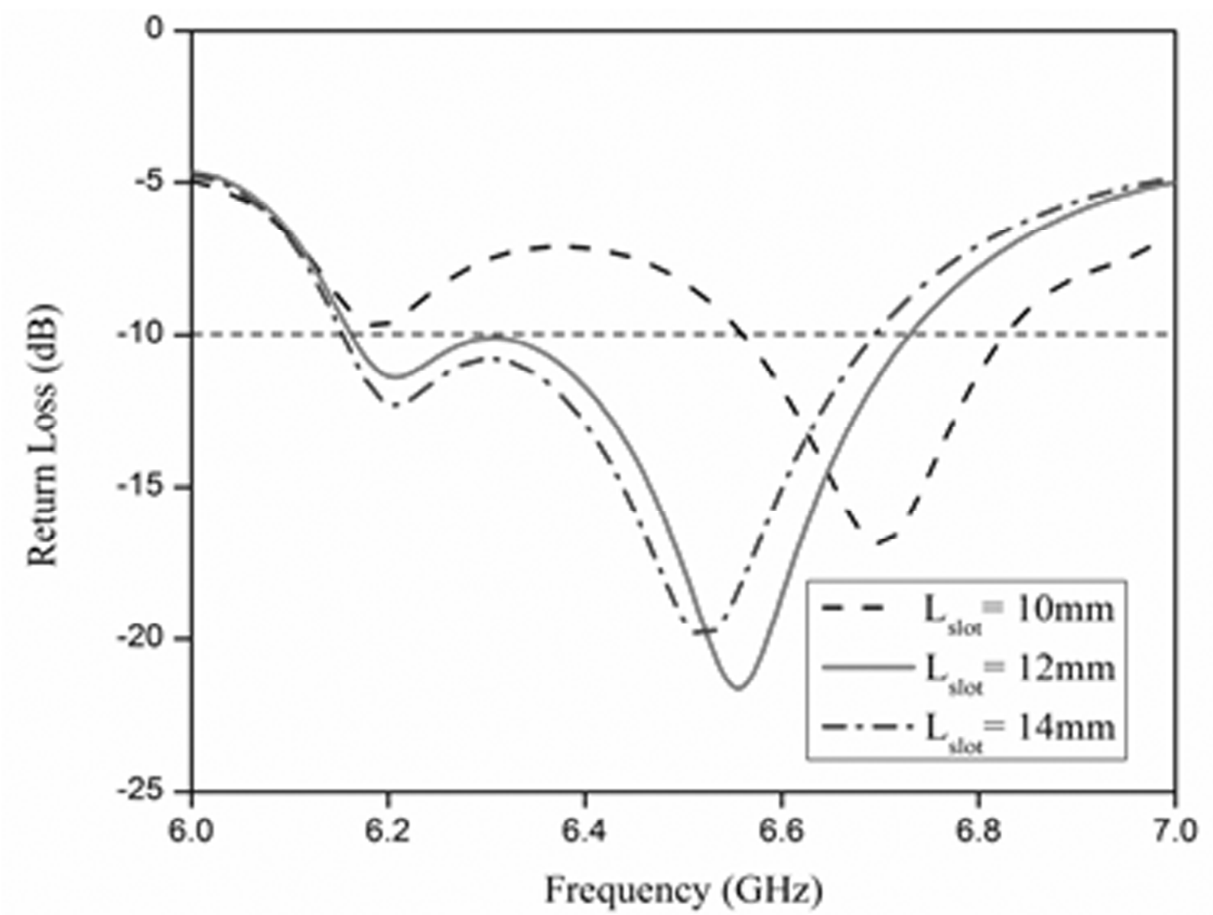

Figure 4: Resonant frequency variation for different slot length.

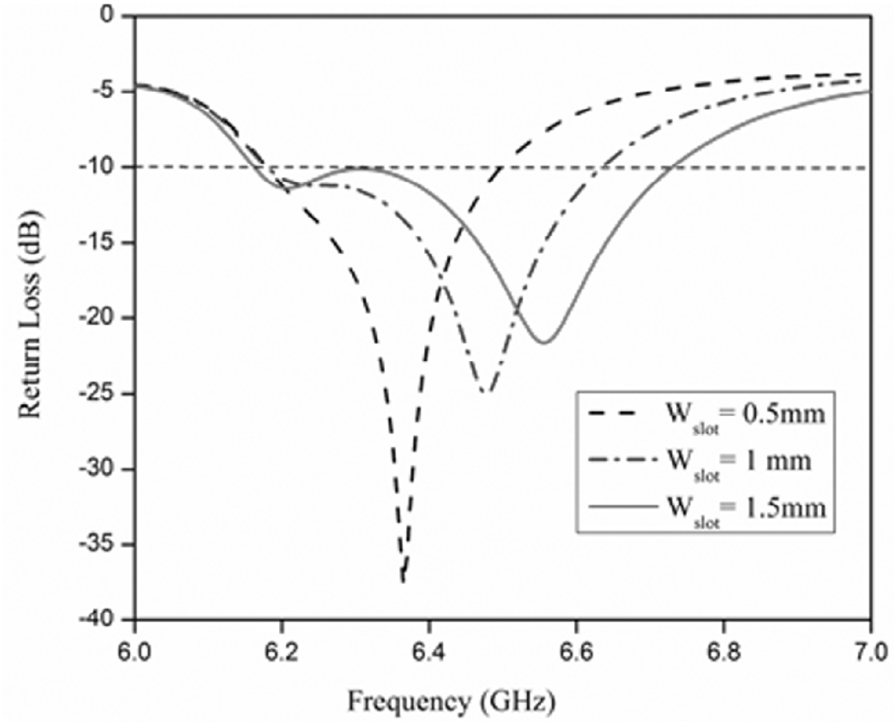

Figure 5: Resonant frequency variation for different slot width.

4. SIMULATION RESULTS AND DISCUSSION

4.1. Return Loss Characteristics

The design of the antenna was implemented and simulated by using commercial software ANSOFT HFSS V13. Figure 6 displays the return loss for two slot configuration of cylindrical dielectric resonator antenna. As, evident from the Table II, the antenna with plus shaped slot performs better compared to

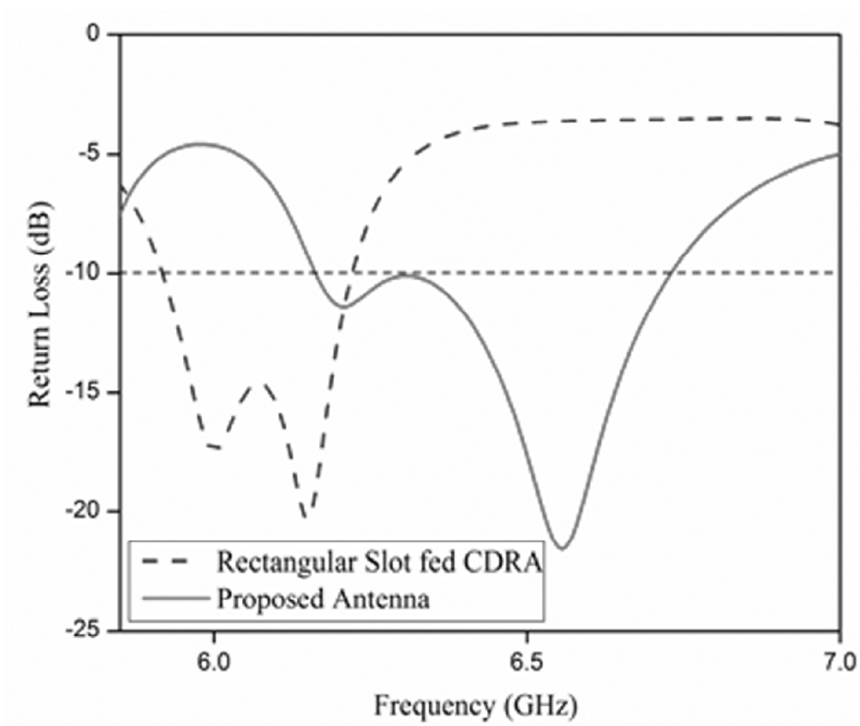

Figure 6: Simulated Return Loss of the Proposed Antenna.

rectangular slot configuration. For the case of plus shaped slot fed cylindrical DRA, the widest bandwidth from 6.17 to 6.72 GHz is obtained when compared to rectangular slot fed CDRA. Proposed antenna is resonating at 6.21 GHz and 6.56 GHz with the return loss of around -11.39 dB and -21.55 dB. The impedance bandwidth recorded at these resonant frequencies is 8.80%. Simulated result shows the cylindrical DRA with the plus shaped aperture slot has a better bandwidth compared to rectangular slot fed CDRA.

4.2. Radiation Pattern Characteristics

The Far field radiation pattern of the proposed antenna at resonant frequencies of 6.56 GHz is simulated and it is shown in. Fig. 7. It indicates that the proposed antenna exhibits dipole and omni-directional radiation characteristics in xz-plane and yz-plane for the co-polarisation component.

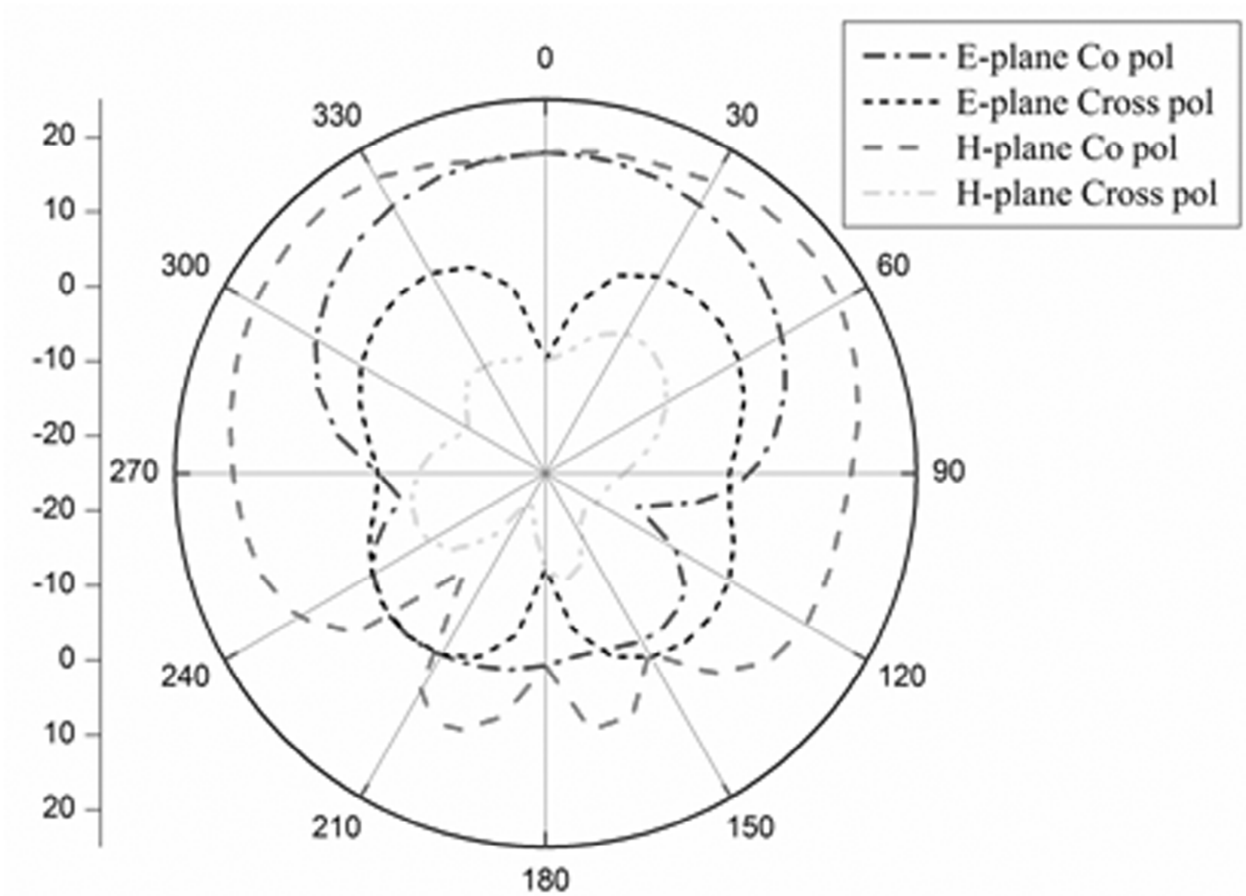

Figure 7: Radiation patterns of the Proposed Antenna at 6.56GHz.

Table 2
Contrast of Radiation characteristics of siw based cdra at various slot configurations

Antenna characteristics	*Rectangular slot with CDRA*	*Plus shaped aperture slot with CDRA*
Position of the slot (d_s) in mm	29 mm	23.2 mm
Resonant Frequency (f_0)	6.15 GHz	6.56 GHz
-10 dB Bandwidth(BW)	298 MHz	567 MHz
Impedance Bandwidth (%)	5%	8.80%
Gain (dB)	2.3	3.7

5. CONCLUSION

In this paper, a SIW cavity backed slot antenna have been presented for C band (4-8 GHz) application. It is observed that wider bandwidth performance is achieved by using the concept of DR loaded SIW design. The proposed Cylindrical DRA resonates at frequency of 6.56 GHz with moderate gain. Parametric study on length and width of the slot is presented. The proposed plus shaped slot structure performance is compared with conventional rectangular slot and is tabulated in Table II. The designed antenna exhibits bandwidth of 567 MHz from 6.17 to 6.72 GHz with impedance bandwidth of 8.80%. It has a peak gain of 3.7 dB. The proposed antenna has the advantages of low cost, planar form, wideband and easy integration, where it suitable for space applications.

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