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Silicon Dielectric Resonator Antenna

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ABSTRACT

Any wireless network essentially requires an antenna for the network to enable wireless communication. In this paper, a silicon-based dielectric resonator antenna, exciting in Hybrid mode, is presented for such applications. The proposed CDRA is designed to operate at 2GHz and simulated at the same center frequency to obtain perfect radiation patterns. This paper gives the key concept of DRA and also, a single element CDRA made with silicon is shown along with some measurement results. The proposed CDRA has the desired patterns, and various other parameters such as Return loss, Gain, Polarization, etc., are further discussed here. The CDRA is simulated in Ansys HFSS, successfully and then fabricated to verify the parameters.

Keywords*: Silicon, DRA, Excitation Mode, CDRA, Radiation Patterns, Return Loss, Gain, Polarization*

INTRODUCTION

A cylindrical dielectric resonator antenna (CDRA) is a type of antenna that utilizes a cylindrical dielectric resonator (DR) as its radiating element. It is a compact and efficient antenna design that offers several advantages in terms of size, bandwidth, and radiation efficiency. The key aspects of cylindrical dielectric resonator antennas, are:

A. Key Aspects:

Structure: A CDRA consists of a cylindrical dielectric resonator made of a high-permittivity material such as ceramic or glass. The resonator is typically placed on a ground plane or a dielectric substrate, which acts as a supporting structure.

Working Principle: The cylindrical dielectric resonator functions based on the principle of resonance. When excited by an electromagnetic wave, the resonator resonates at a specific frequency determined by its dimensions and dielectric properties. This resonance generates a standing wave pattern, and the radiated energy is concentrated in the vicinity of the resonator.

B. Advantages:

CDRA offers several advantages over other types of antennas:

Compact Size: CDRA's cylindrical shape allows for a more compact form factor compared to other traditional antennas, making it suitable for applications where space is limited.

High Radiation Efficiency: The use of a dielectric resonator helps in achieving high radiation efficiency by minimizing losses and enhancing the power radiated from the antenna.

Broadband Operation: CDRA can be designed to operate over a relatively wide frequency band, offering good impedance matching and low return loss.

Omnidirectional Radiation: With careful design, CDRA can provide nearly omnidirectional radiation patterns, making it suitable for applications where coverage in all directions is desired.

CDRA finds applications in various wireless communication systems, including mobile devices, satellite communication, wireless local area networks (WLANs), radio frequency identification (RFID), and microwave point-to-point links. Its compact size and high efficiency make it particularly suitable for small form-factor devices and wireless systems requiring high-performance antennas.

DESIGN AND SIMULATION

A. CDRA – Cylindrical Dielectric Resonator Antenna

Cylindrical dielectric resonator antennas (CDRAs) support various resonant modes, which are the standing wave patterns that occur within the cylindrical dielectric resonator. These modes determine the radiation characteristics and performance of the antenna.

The selection of the mode depends on factors such as the resonator's dimensions, dielectric properties, and excitation conditions.

Different modes may have different radiation patterns, resonant frequencies, and impedance characteristics. The choice of mode is often made based on the desired radiation pattern, bandwidth, and other performance requirements of the antenna for a specific application. Here are some of the commonly observed modes in CDRAs:

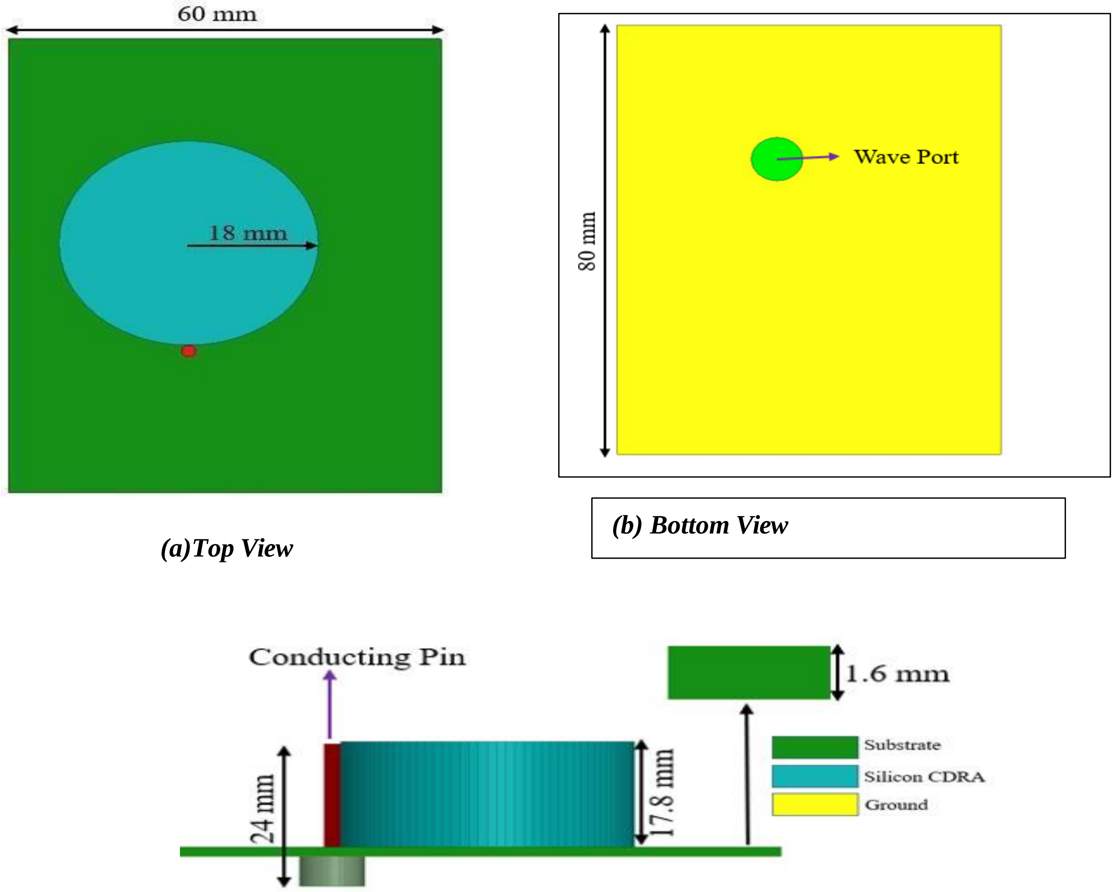
i. **TE_{01} Mode:** This is the fundamental mode in cylindrical resonators, where the electric field has one nodal plane along the axis of the cylinder and no electric field component in the azimuthal direction. It exhibits omnidirectional radiation patterns in the azimuthal plane.
ii. **$TE_{01\delta}$ Mode:** This mode is similar to the TE_{01} mode but with an additional electric field component in the azimuthal direction. It possesses a null in the radiation pattern along the axis of the cylinder.
iii. **TM_{01} Mode:** In this mode, the magnetic field has one nodal plane along the axis of the cylinder, and the electric field is azimuthally polarized. It exhibits a maximum radiation pattern in the plane perpendicular to the cylinder's axis.
iv. **TE_{11} Mode:** This mode has two nodal planes—one along the axis of the cylinder and another along the circumference of the cylinder. It exhibits a dipole-like radiation pattern with two lobes in the azimuthal plane.
v. **TM_{11} Mode:** Similar to the TE_{11} mode, the magnetic field has two nodal planes—one along the axis and another along the circumference. The electric field is azimuthally polarized, and the radiation pattern is similar to that of a dipole.
vi. **Higher-order Modes:** CDRAs can also support higher- order modes with more complex field distributions and nodal planes. These modes have multiple nodal planes along the axis and/or the circumference of the cylinder.

It's worth noting that the design and analysis of CDRAs involve solving Maxwell's equations and applying appropriate boundary conditions to determine the resonant frequencies and mode distributions within the dielectric resonator. Numerical techniques such as finite element method (FEM) or method of moments (MoM) are commonly employed to analyze and optimize the performance of CDRAs.

B. CDRA Design in HFSS

The CDRA design and simulation is entirely carried out in HFSS. The resonator material is chosen as silicon with permittivity of 11.9 and having the optimized radius as 18mm and height as 17.8mm. The CDRA is placed on a FR- 4 substrate piece having the dimension of 80mx60mm.

To excite the CDRA, a co-axial feeding method is adopted, with a slight modification to the feeding. The central probe is extended above the substrate, up to the height of CDRA. This make is possible for the coupling mechanism to be even throughout the height of CDRA and not cause any blank spots. However, the software design of the CDRA with all the dimensions is a shown in Fig.2.1, below:



(a)Top View

(b) Bottom View

(c) Side View

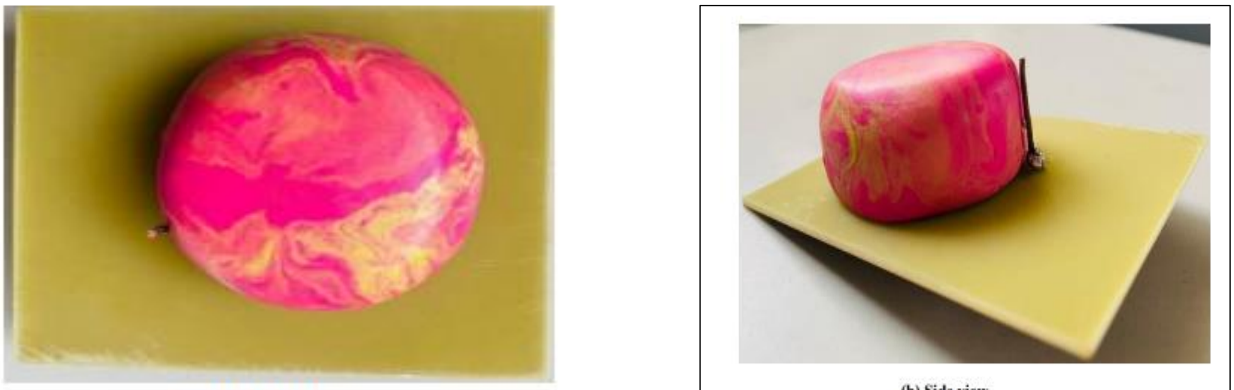
Fig.2.1 CDRA dimension in (a) Top view (b) Bottom view and (c) Side view

The conducting pin show in Fig.2.1 (c), has a conducting pin, which is essentially a conductor and simulated as PEC in HFSS. The overall height of the pin is 24 mm, finally matching the height of CDRA. The color code of the materials is also given in Fig.2.1 (c).

FABRICATION AND RESULTS

A. CDRA Fabrication:

The CDRA is finally fabricated and in the fabrication a slight modification is performed in regard of the resonating element. The original material chosen for simulation is Silicon and the material used in the fabrication is Silicone (an iso-trope od Silicon), having the same material properties as that of Silicon. The fabricated CDRA is shown in Fig.3.1, below:



(a) Top View

(b) Side view

Fig. 3.1 (a) Top view and (b) Side view of fabricated Silicone based CDRA

The overall dimensions of the CDRA match the simulation dimensions and have the same setup as in the simulation. It is simply the replication of the simulation model.

B. Return Loss Measurement:

As in any other antenna, the CDRA has a return loss characteristic. The simulated return loss of the CDRA, is observed to be -33.029 dB at 2GHz. In comparison the measured return loss of the CDRA with silicone, is observed to be -32.92dB at 2 GHz. The return loss measurement of the CDRA using a VNA is shown in Fig.3.2, below:

Fig. 3.2 Return Loss measurement of CDRA

The simulated and measured return loss values show a deviation of approximately 1dB. However, the return loss measured in this case is still the best and can considered as a very low reflection design.

C. Radiation Pattern:

The simulated Radiation Pattern of the CDRA is shown in Fig.3.3. The radiation pattern shows very good directional characteristics and to specific, the radiation patterns observed in the CDRA is similar to the Microstrip Patch Antenna, where the main beam perpendicular to the plane of the antenna and therefore suggesting the broad- side radiation characteristics.

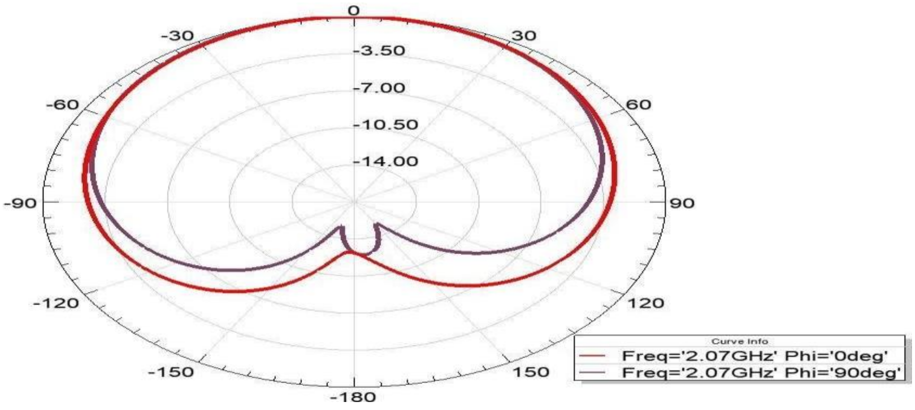


Fig. 3.3 Return Loss measurement of CDRA

The Radiation Pattern shown in Fig. 3.3, above, is the simulated pattern at 2.07 GHz. However, this pattern remains still for even for the center frequency. One, noticeable property from the radiation pattern is that, there is 0 dB difference between the Co-Pol and Cross-Pol levels, indicating the polarization of the antennas, which is discussed, further.

D. Gain and Polarization:

a. Gain:

The Gain available with the DRA's is most commonly observed to of good value and in fact a better value, when compared to the metallic patch antennas. This is possible with DRA's because it has very less ohmic losses due to not having metal as a radiator. Hence, very less ohmic loss contributes to mode propagation efficiency.

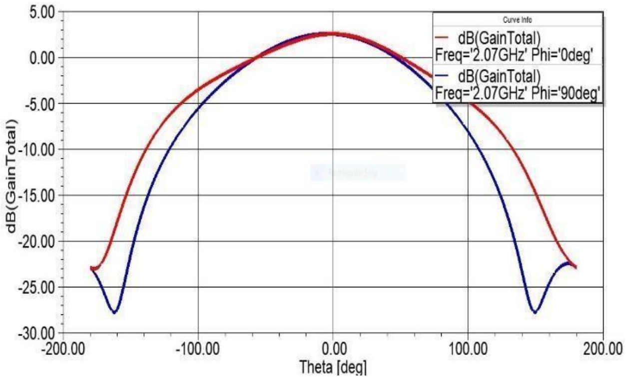


Fig. 3.4 Theta vs Gain

Fig. 3.4, shows the Gain at 2.07GHz, for Phi = 0deg and phi = 90deg and it is clear that pattern seems to support the broadside radiation. The gain observed from Fig.3.4 is 2.58dB and both the Co-Pol and Cross-Pol levels seem to be in same level. Since, the difference between them is 0 dB, polarization has to be defined. This can be can be done by observing the E-filed vector within the volume of the CDRA. The Frequency verses Gain plot, shown in Fig.3.5,below, gives an idea of how the Gain is varying with respect to the given frequency range.

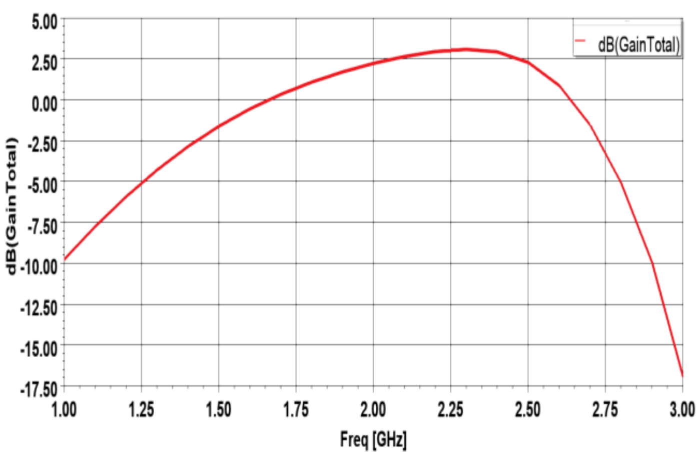


fig.3.5 Frequency vs Gain

From Fig. 3.5, the Gain is constant over a certain band and then in the either section, the total gain falls below 0dB and at 2GHz the gain is 1.89 dB.

b. Polarization:

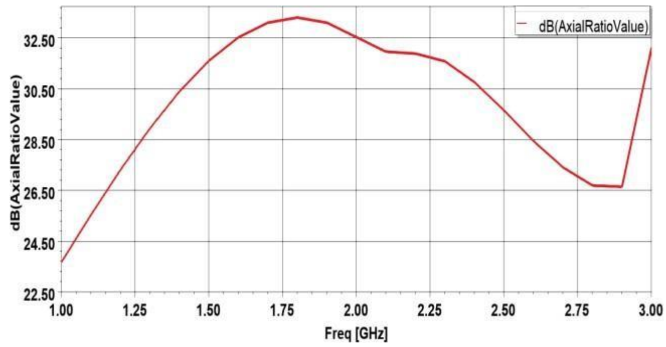


Fig.3.6 Axial Ratio

From Fig. 3.6, which shows the Frequency verses Axial Ratio, it is evident that the DRA has Linear Polarization. Hence, CDRA is a linear polarized Dielectric Resonator Antenna.
On the other hand, to understand the resonating modes in DRA's, we need to plot the E-Field in Magnitude and Vector for. In the E-Field vector, the top and side views show the vector is present and hence, suggesting the $HE_{11\delta}$ Mode. In this mode, both the E-Field and H-Field are present and this is why we are seeing the vector in both top and side view of the CDRA volume.

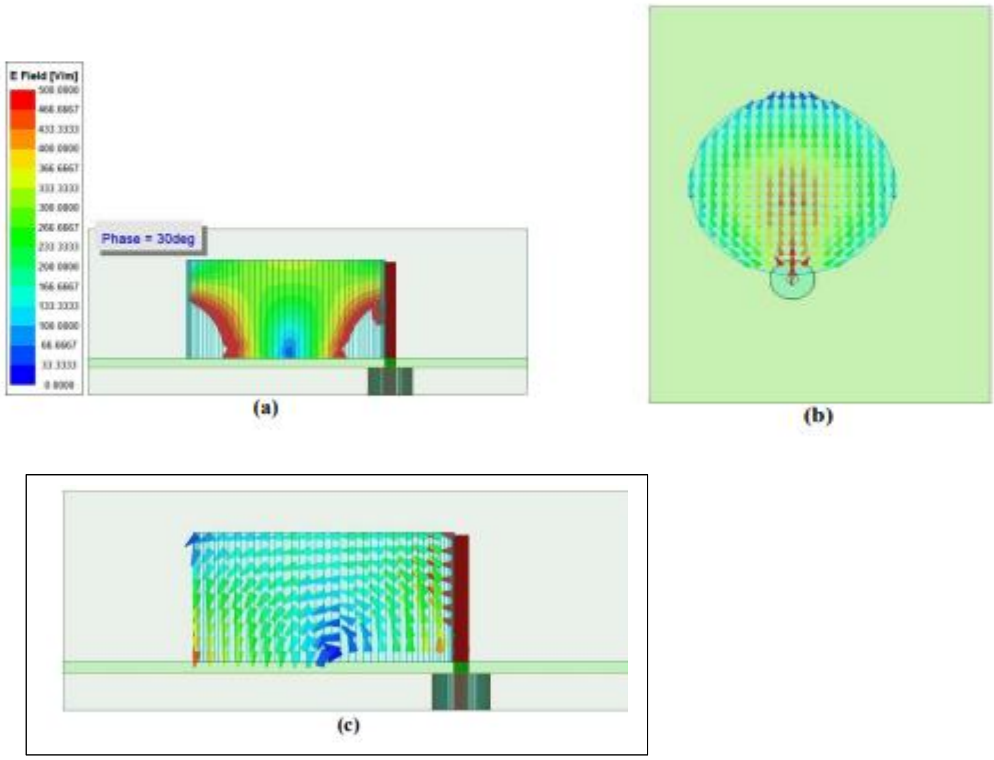


Fig. 3.6 (a) E-Field Magnitude (b) E-Field vector (Top) (c) E-Field vector (Bottom)

CONCLUSION

A 2GHz Silicon Dielectric Resonator Antenna (CDRA) operates perfectly at the center frequency and show excellent radiation patterns for the optimized dimensions. Despite of using an Iso-tope of the original simulated material, the design seems to hold good resonance characteristics. The proposed CDRA resonates with $HE_{11\delta}$ Mode, which is useful in application where the antenna size is crucial and maximum gain is expected. The single element CDRA offers a Gain of 2.58 dB and having a return loss of -32.93 dB and such antennas can be used in many 5G and 6G communication applications and Beamforming applications.

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