Dielectric Resonator Antenna

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***Abstract*—This paper presents the design and analysis of a cavity-backed, annular-slot-fed hemispherical dielectric resonator antenna (DRA) operating at 3.5 GHz. After the antenna is designed, the resonant frequency of the antenna is observed by changing the relative permittivity, slot width and dielectric radius.**

***Index Terms*—annular slot, return loss, lumped port, dielectric resonator antenna, dielectric material.**

I. INTRODUCTION

A basic dielectric resonator antenna (DRA) typically includes a ceramic block ,which is called the dielectric resonator, mounted on a substrate and often backed by ground plane. DRA's generally operate at microwave frequencies and higher. Changes in the shape, size, and permittivity of the dielectric material effects the antenna's operational behavior. As the relative permittivity (ε_r) of the dielectric material increases, both the bandwidth and the resonant frequency decrease. Similarly, increasing the size of the dielectric material tends to lower the resonant frequency. Additionally, the Q-factor, tends to increase with higher relative permittivity.

Due to their high radiation efficiency, wide bandwidth, and compact size, DRA's are used in a variety of fields. They are encountered in applications such as wireless communication systems, satellite communication, radar systems, and millimeter-wave technology. DRAs significantly improve the functionality of these systems, making them essential components in modern technology.

This paper consists of four sections. Section I is Introduction, followed by Section II, which is about the design of the antenna. Then, results of parametric analysis are discussed in Section III. Finally, Section IV as a conclusion.

II. ANTENNA DESIGN

The design of the dielectric resonator antenna (DRA) features a cavity-backed structure with an annular-slot-fed hemispherical dielectric resonator. A lumped port is used to feed the model across an annular slot. The model consists of a hemispherical dielectric resonator with a radius of 12.5 mm and a permittivity of 9.5, centered at the origin. Additionally, the model includes an octagon at the upper part to represent the air volume and a hemispherical cavity as the ground, which has a radius of 25 mm. Table 1 shows the dimensions of the dielectric resonator antenna.

The design follows the guidelines from the HFSS Dielectric Resonator Antenna PDF, with a targeted resonant frequency of 3.5 GHz. However, after performing simulations, the resonance frequency achieved was 3.45 GHz, and the return loss at the peak was -61 dB, as shown in Fig. 2. Therefore, parametric analyses are carried out to determine the optimal parameters for operating at 3.5 GHz.

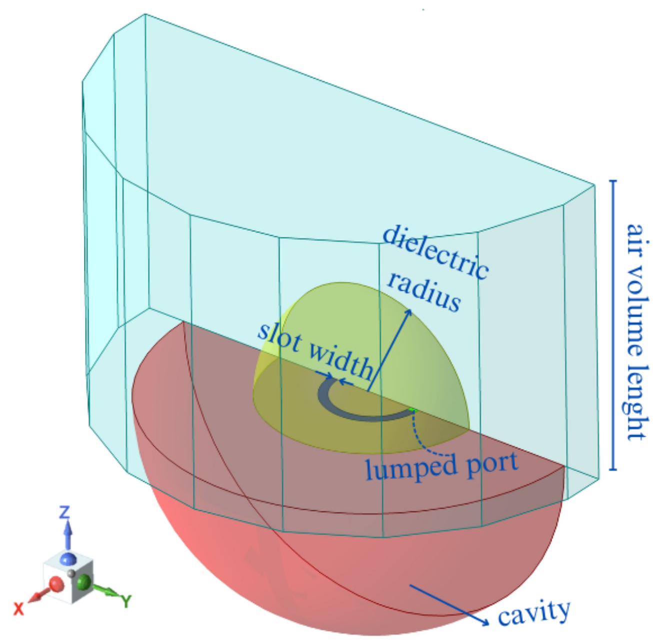

Fig. 1. dielectric resonator antenna

TABLE I
INITIAL VALUES

Dimensions	Values
Annular slot width	1 mm
Relative permittivity of the dielectric	9.5
Radius of the dielectric	12.5 mm
Air volume height	35 mm

III. THE RESULTS OF PARAMETER ANALYSIS

In this section the parametric analysis feature of the ANSYS HFSS is used to determine how the antenna's performance changes with different modifications.

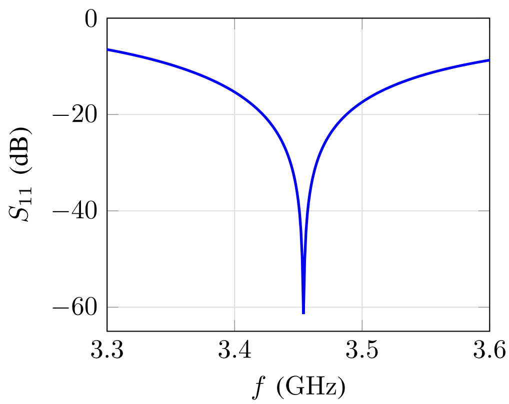

Fig. 2. S11 plot when values set to nominal.

A. Dielectric Constant (ε_r)

When the relative permittivity increases, the material can store more electromagnetic energy which leads to an decrease in the velocity of the electromagnetic wave, resulting in a reduction in the resonant frequency. In Fig. 3, which illustrates the relationship between frequency and return loss (S11) for the relative permittivity from 8 to 12.5, it can be observed that as the value of the dielectric constant increases, the resonant frequency decreases as expected.

TABLE II
VALUES OF RELATIVE PERMITTIVITY, RESONANT FREQUENCY, BANDWIDTH AND RETURN LOSS

Relative Permittivity (ε_r)	**Resonant Frequency (GHz)**	**Bandwidth (GHz)**	**Return Loss (dB)**
8.0	3.76	0.15	-25.57
9.5	3.45	0.18	-61.43
11.0	3.21	0.22	-28.89
12.5	3.01	0.27	-23.80

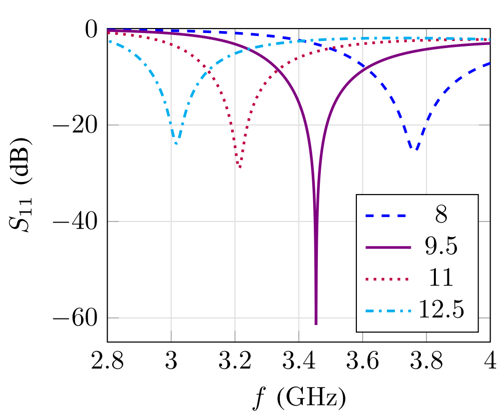

Fig. 3. S11 plots by changing the relative permittivity of the dielectric material.

B. Radius of the Hemispherical Dielectric Resonator

Similar to the effect of relative permittivity, when we increase the size of the dielectric material, we expect the effective volume to increase, leading to a reduction in the resonant frequency. In Fig. 4, which illustrates the relationship between frequency and return loss (S11) for dielectric material sizes ranging from 12 mm to 13 mm, it can be observed that as the size of the dielectric increases, the resonant frequency decreases.

TABLE III
VALUES OF DIELECTRIC MATERIAL RADIUS, RESONANT FREQUENCY, BANDWIDTH AND RETURN LOSS

Radius (mm)	**Resonant Frequency (GHz)**	**Bandwidth (GHz)**	**Return Loss (dB)**
12.0	3.56	0.23	-20.91
12.25	3.50	0.22	-26.9
12.5	3.45	0.22	-61.4
12.75	3.45	0.20	-26.5
13.0	3.35	0.19	-20.6

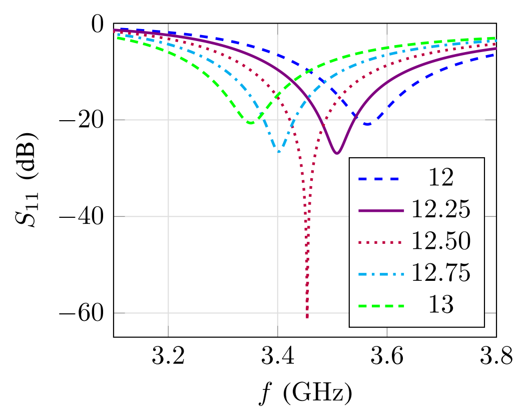

Fig. 4. S11 plots by changing the radius of the dielectric material (mm).

C. Width of the Annular Slot

Simulations for inner radius of the annular slot swept from 4.2 mm to 5.2 mm. Whilst outer radius was kept constant at 5.8 mm. As a result, the width of the slot swept from 0.6 mm to 1.6 mm. As compared to changing the dielectric constant, changing the width of the slot did not do a significant change in the resonant frequency which can be seen from Fig. 5.

D. Cavity radius and air volume length

Unlike the other results, the parametric analysis for cavity radius and air volume did not affect the resonant frequency and increased the return loss value. It can be seen from Fig. 6 and Fig. 7 which are the S11 graphs which illustrate the relationship between frequency and return loss.

TABLE IV
VALUES OF WIDTH OF THE ANNULAR SLOT, RESONANT FREQUENCY, BANDWIDTH AND RETURN LOSS.

width (mm)	Resonant Frequency (GHz)	Bandwidth (GHz)	Return Loss (dB)
1.6	3.46	0.21	-25.57
1.4	3.46	0.21	-28.54
1.2	3.46	0.21	-33.32
1.0	3.45	0.22	-61.43
0.8	3.44	0.22	-35.17
0.6	3.44	0.22	-25.57

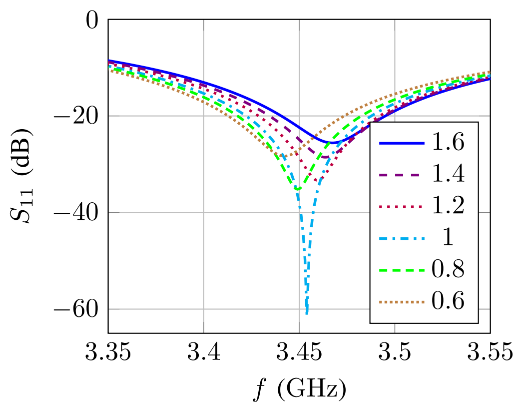

Fig. 5. S11 plots by changing the width of the annular sloth (mm).

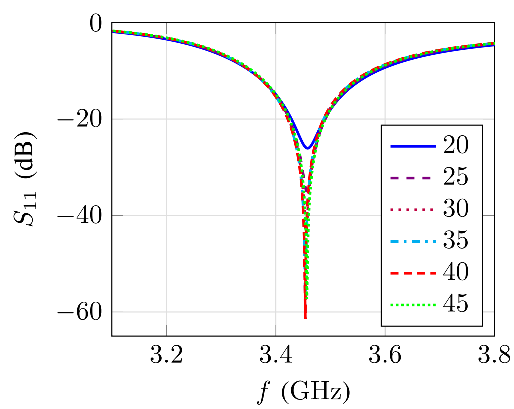

Fig. 6. S11 plots by changing the length of the air volume (mm).

E. Optimized antenna

The parametric analysis shows that decreasing the permittivity leads to an increase in the resonant frequency. Similarly, reducing the dielectric radius results in a higher resonant frequency. After conducting a detailed analysis, it was observed that changing the permittivity value is the best option for setting the resonant frequency to 3.5 GHz, as it provided the best return loss value. The final values of the optimized antenna are shown in Table 5. Additionally, the final S11 plot can be seen in Fig. 8, where the permittivity is 9.25.

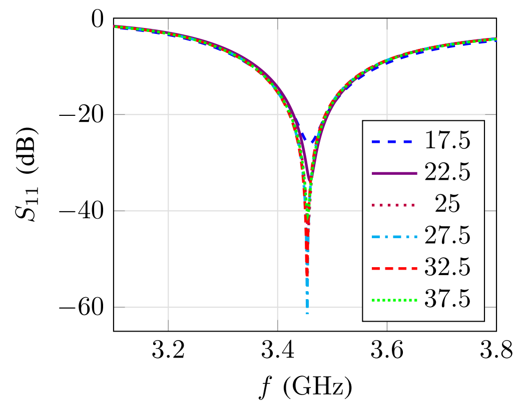

Fig. 7. S11 plots by changing the radius of the cavity (mm).

TABLE V
FINAL VALUES

Dimensions	Values
Slot width	1 mm
Permittivity of dielectric	9.25
Radius of dielectric	12.5 mm
air volume height	35 mm

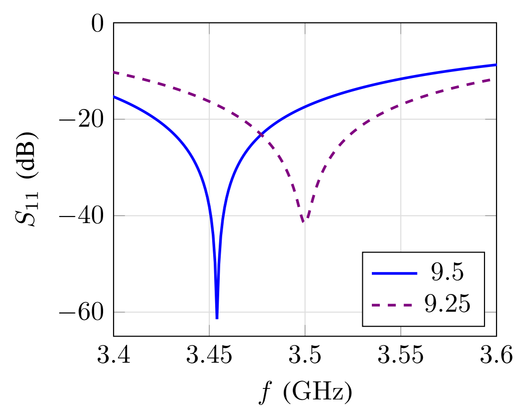

Fig. 8. S11 plot for the optimized antenna.

F. Radiation Pattern of the Hemispherical Dielectric Resonator

Fig. 5 shows the dielectric resonator antenna's 3D gain plot which operates at 3.5 GHz frequency. As shown in the figure, the slot antenna's radiation is directed mostly in +Z direction, making its radiation pattern directional. The maximum gain of the antenna was calculated as 5.57 dB.

IV. CONCLUSION

In this paper, the dielectric resonator antenna, which is used in various fields due to its easy production, high gain, and low cost [3], is investigated using the HFSS ANSYS program. After running the necessary simulations, it is found that the relative permittivity and size of the dielectric material have a significant effect on the resonant frequency. Finally, the

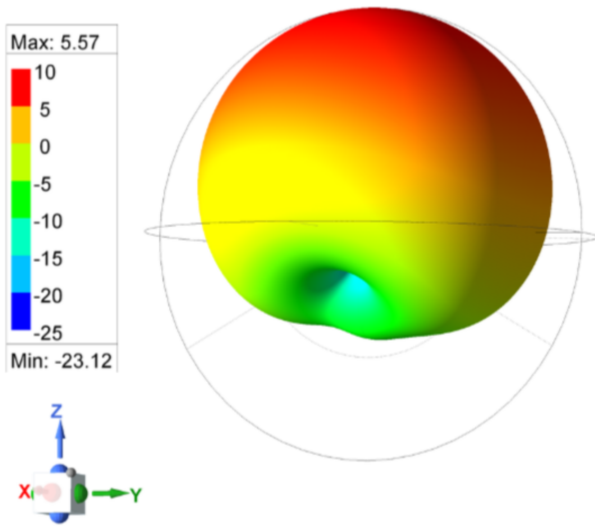

Fig. 9. 3D polar plot of the optimized antenna at 3.45 GHz.

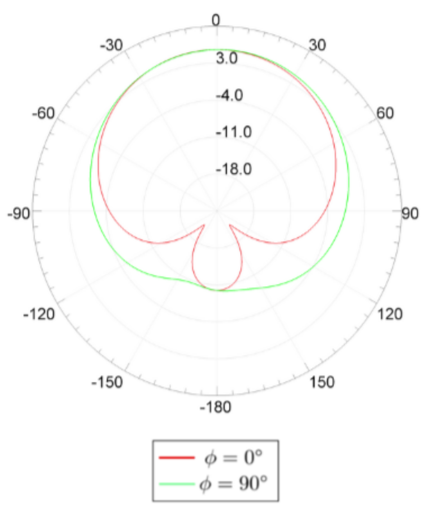

Fig. 10. 2D plots for Φ = 0° and 90°.

optimized values are given for a DRA that operates at 3.5 GHz.

References

[1] ANSYS HFSS: High Frequency Electromagnetic Field Simulation Software.

[2] Constantine A. Balanis Antenna Theory: Analysis and Design, 4th ed. ,Hoboken, NJ: John Wiley, 2016.

[3] Chakraborty, P., Karmakar, A. & Saha, A. A Review on Dielectric Resonator Antennas: Past and Present. Wireless Pers Commun 134, 1367–1388 (2024).