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Radiation properties of dielectric resonator antenna with coplanar parasitic strips

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Abstract
In this study, a coplanar parasitic metallic strip has been employed to analyze the performance of dielectric resonator antennas (DRAs). The parasitic strip is positioned on the same plane as the 50Ω microstrip feed. By integrating the DRA with the coplanar strip and microstrip line, an impedance bandwidth of up to 17.33% is achieved at an optimal operating frequency of 2.77 GHz. Additional parameters such as return loss, impedance, polarization, and radiation behavior of the antenna are also examined. The antenna exhibits broad radiation patterns with low cross-polarization levels, confirming that it maintains linear polarization throughout the entire impedance bandwidth range.

Keywords: DRA, coplanar, parasitic strip, radiation, impedance bandwidth

Introduction
Dielectric Resonator Antennas (DRAs) have become prominent alternatives to traditional radiating elements for high-frequency communication systems, particularly in millimeter-wave and beyond applications. These antennas are typically fabricated using materials with high dielectric constants and high Q-factors, mounted on a grounded substrate of low permittivity [1]. The resonant frequency of a DRA depends not only on its shape and geometry but also on the dielectric constant of the material employed. DRAs can take various forms such as cylindrical, rectangular, spherical, disk, hemispherical, or half-split cylindrical structures [1].
Any of these dielectric structures can act as a radiator when appropriately excited at a specific frequency. Since DRs possess minimal conductor losses and high radiation efficiency, they are suitable for use in microwave and millimeter-wave antennas and filters. While most DRs exhibit high-Q modes that confine energy, certain low-Q modes can also be excited to radiate efficiently over a wider frequency range [2, 3]. The radiation behavior of a DRA varies with the excited mode, and factors such as geometry, feeding structure, and feed position play crucial roles in determining performance.
Among the various feeding techniques available [4, 5], the open-ended microstrip feed is one of the simplest and most effective [6, 7]. By carefully selecting the length and position of the microstrip feed line, the resonant frequency and impedance characteristics of the antenna can be optimized. Previous studies [8, 9] have demonstrated that mounting a conducting strip on the DRA surface can further enhance impedance bandwidth and alter polarization characteristics.
In this research work, an improved cylindrical DRA is proposed that achieves enhanced impedance bandwidth through the addition of a coplanar parasitic strip adjacent to the microstrip feed. The design aims to improve radiation performance while maintaining simplicity and compactness in structure.

DRA with Coplanar Parasitic Strip
A key objective in antenna design is to achieve a wider impedance bandwidth while maintaining compactness and simplicity. Numerous bandwidth enhancement techniques have been reported, including modifications in feed geometry and alterations to the shape of the Dielectric Resonator Antenna (DRA). Although DRAs can be made more compact, this often results in reduced bandwidth. One of the effective ways to overcome this limitation is by mounting a metallic strip or patch on the upper surface of the DRA, which improves the impedance bandwidth characteristics [10-12].

Among various DRA configurations, the cylindrical DRA is particularly preferred because of its ease of fabrication, capability to excite multiple modes, and flexibility in tuning performance. Variations in the height or radius of a cylindrical DRA can significantly influence its resonant frequency and Q-factor, providing designers with wide adaptability. Compared to hemispherical or rectangular DRAs, the cylindrical structure allows simple construction and effective excitation of both broadside and omnidirectional radiation patterns.

As highlighted in earlier research [11], introducing a metallic patch on the top surface of a cylindrical DRA can reduce the resonant frequency by approximately 30.6%. However, in this study, a different approach is adopted to broaden the operating bandwidth: the use of a coplanar parasitic strip. In this configuration, both the microstrip feed and the dielectric resonator share the same plane as the parasitic element. Although the parasitic strip is not directly connected to the feed line, it influences the antenna's radiation and impedance characteristics through electromagnetic coupling.

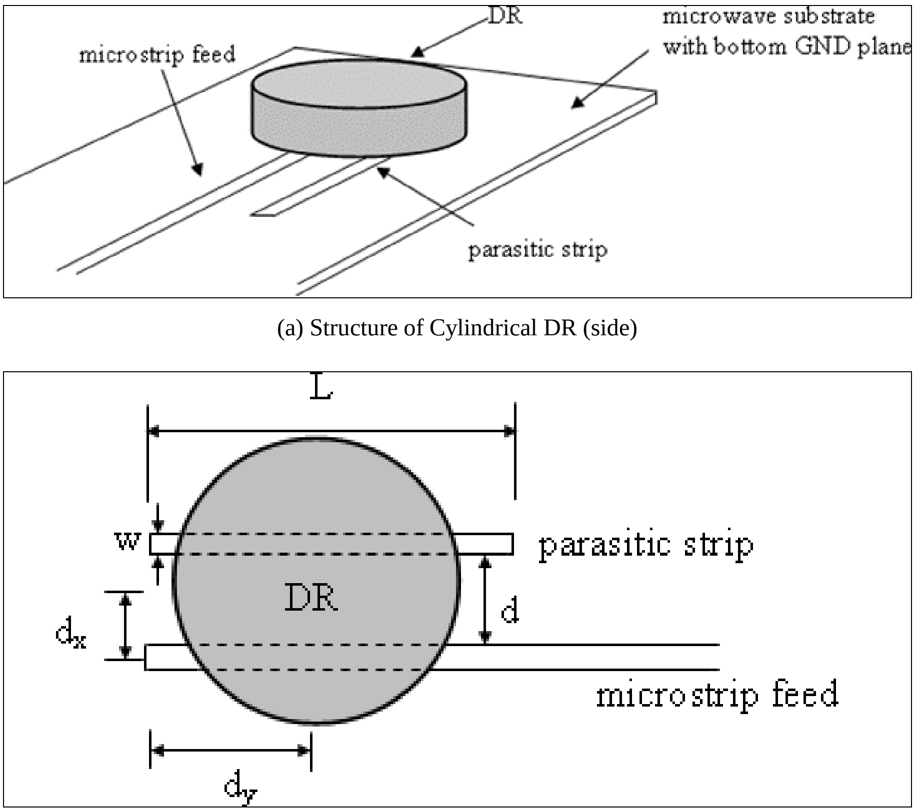
The parasitic strip can be designed such that its resonant frequency is either the same as or different from that of the driven antenna element. By carefully choosing its dimensions and placement, various beneficial effects such as improved bandwidth and modified polarization can be achieved. This coplanar parasitic approach thus provides an efficient and straightforward technique to enhance the overall performance of cylindrical DRAs.

Structure of proposed antenna

The structural configuration of the proposed cylindrical Dielectric Resonator Antenna (DRA) with a coplanar parasitic strip [13] is illustrated in Figure (1). The design incorporates a cylindrical dielectric resonator that operates with a 50Ω microstrip feed line and has a dielectric constant (ε_1) of 20.8. The antenna is mounted on a substrate with a permittivity (εr) of 4. The coupling condition between the microstrip and DRA is optimized to ensure efficient electromagnetic energy transfer [13]. The microstrip feed line offers a straightforward mechanism for feed position adjustment and impedance matching.

A 50Ω SMA connector is attached at one end of the transmission line to facilitate excitation. Reflections occurring at the open end of the microstrip line produce standing waves corresponding to a wavelength (λ_0) determined by the operating frequency. When the DRA is positioned at a point on the feed line where the electric field intensity is maximum, efficient capacitive coupling takes place [14].

In this configuration, various antenna parameters such as reflection coefficient (S_{11}), input impedance (Z), and radiation characteristics (**S_{12})** are analyzed and discussed in subsequent sections.



(a) Structure of Cylindrical DR (side)

(b) Structure of Cylindrical DR (Top)

Fig 1: Structure of Cylindrical DRAntenna.

The position ofDR is off-centered on the microstrip feed so the broadside HEM11d mode is excited. Theoretically, the following equation givesthe frequency of resonance for the HEM11δ mode [2]:

$$f_0 = \frac{6.324c}{2\pi a}\left[0.27 + 0.36\left(\frac{a}{2h}\right) + 0.02\left(\frac{a}{2h}\right)^2\right] \quad (1)$$

Here, 'c' represents the speed of light. A metallic strip with a length LLL and width www is positioned at a distance ddd from the microstrip feed to modify the feed mechanism of the dielectric resonator (DR) antenna, as illustrated in Fig. 1. The strip length is selected to be slightly more than half the length of the feed strip, i.e., L=45mmL = 45 \text{mm}L=45mm, with a width of w=1mmw = 1 \text{mm}w=1mm for the initial design. The calculated resonant frequency is 2.67 GHz, which is very close to the measured value of 2.605 GHz, as shown in Fig. 2 [13]. From the figure, it can be observed that the return loss remains below -10 dB over a bandwidth of 7.37%, ranging from 2.545 GHz to 2.74 GHz. Consequently, the lower Q-factor significantly enhances the impedance bandwidth, which is found to be wider for the excited $HEM_{11\delta}$ mode. The input impedance, being frequency-dependent, exhibits improved and consistent impedance matching across the operating band.

Results and Discussions

The variation in operating frequency and corresponding reflection characteristics for different distances ddd from the microstrip feed are clearly illustrated in the return loss plot shown in Fig. 3 [13]. When the metal strip is positioned at a distance of d=2.5 mmd = 2.5 \text{mm}d=2.5 mm from the feed, a shift in the dominant DRA mode is observed from 2.60 GHz to 2.80 GHz. As the parasitic strip is moved farther away from the feed, a dip appears in the lower region of the impedance band, resulting in a leftward frequency shift. Conversely, a rightward shift in the primary mode occurs as the distance increases, continuing until d=12.5 mmd = 12.5 \text{mm}d=12.5 mm (or 0.10λ00.10\lambda_00.10λ0). At this point, the impedance bandwidth spans from 2.545 GHz to 3.01 GHz, corresponding to a fractional bandwidth of 16.7%.

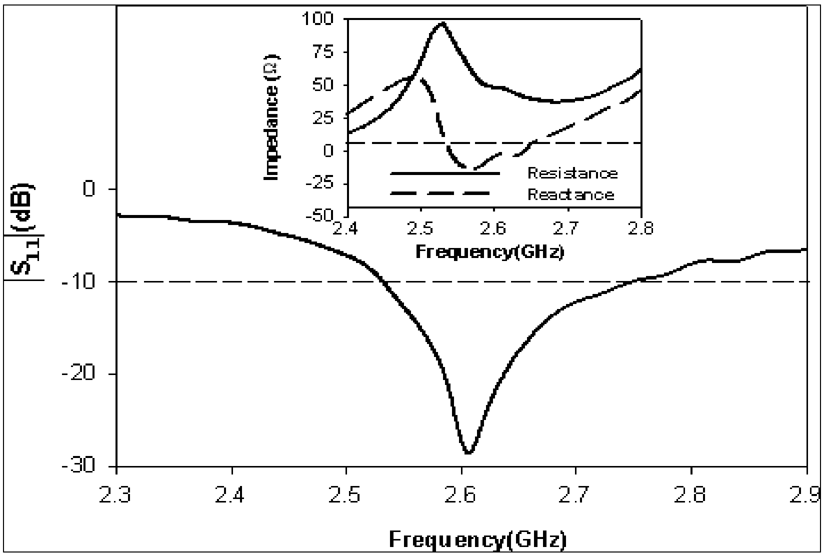


Fig 2: Graph Plot for Return loss and input impedance (inset) of the DRA using microstrip feed only [Kumar et. al. cit.].

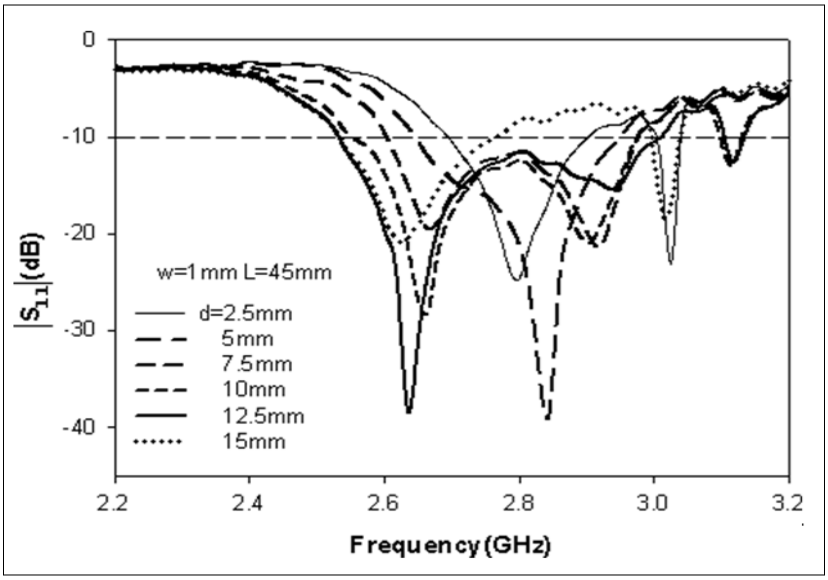


Fig 3: Plot for Return loss of the DRA with microstrip feed and parasitic stripforvarious positions (d).

The graphical representation of the input impedance corresponding to the return loss plot (shown in the inset) for the optimum parameters L=45 mmL = 45 \text{ mm}L=45 mm, w=2 mmw = 2 \text{ mm}w=2 mm, and d=12.5 mmd = 12.5 \text{ mm}d=12.5 mm is presented in Fig. 4 [13]. The variation of input impedance across the optimal frequency band has also been analyzed.

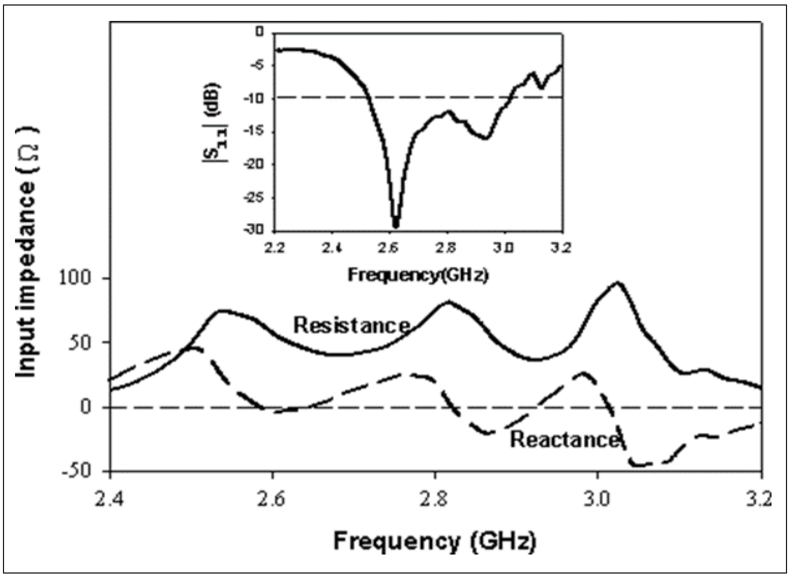


Fig 4: Graphical plot of input impedance with respect to the return loss (inset) for optimum values of L = 45 mm, w = 2 mm and d = 12.5 mm.

Radiation Pattern

The radiation patterns within the operating frequency band were measured for the two principal planes, namely the X-Z and Y-Z planes. As illustrated in Fig. 5, the radiation patterns at 2.63 GHz, 2.78 GHz, and 2.93 GHz correspond to the lower, central, and upper regions of the operating band, respectively. The co-polarized radiation patterns are observed to be wide and exhibit good similarity across these frequencies. The cross-polarization level in the X-Z plane is found to be below -30 dB at the upper end of the operating band, while the Y-Z plane demonstrates improved cross-polarization performance at the lower frequencies. A slight asymmetry in the radiation patterns is attributed to the feed connection and the single-sided excitation of the DRA. Within the operating band, a peak (or central) gain of approximately 5 dBi is achieved.

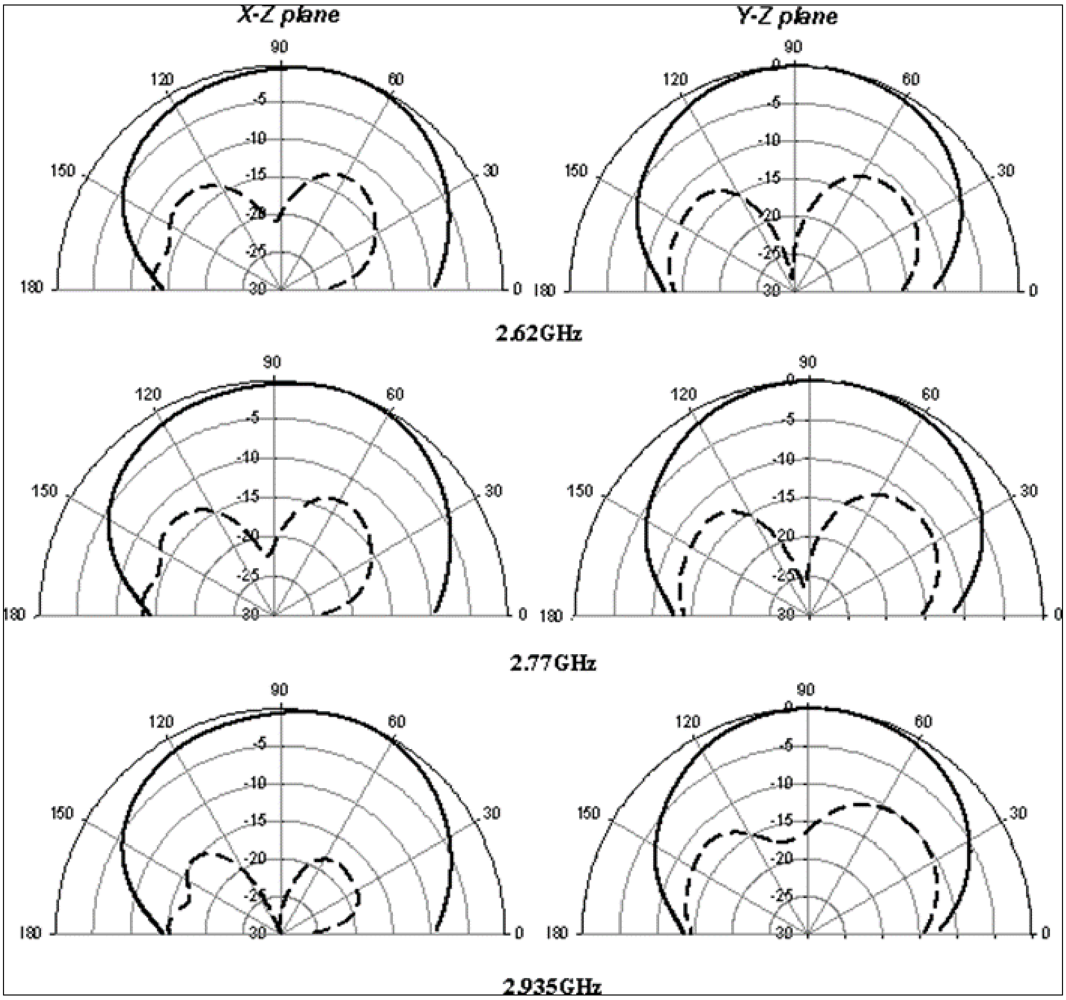


Fig 5: Graph plotfor Radiation patterns at 2.62, 2.77 and 2.935 GHz [Kumar et. al. cit.]

Conclusion: This study presents a dielectric resonator (DR) antenna fed by a microstrip line integrated with a coplanar parasitic strip. At the mean operating frequency of 2.77 GHz, the proposed antenna achieves an impedance bandwidth of 17.33%. Throughout the entire operational band, the antenna maintains a linearly polarized radiation pattern. The inclusion of the parasitic strip enables effective mode excitation, thereby broadening the impedance bandwidth through the simultaneous excitation of dual radiating modes. In addition, improved cross-polarization characteristics result in consistently wide and stable radiation patterns across the full bandwidth range.

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