ADDITIONAL COMMENTS

(1) **Q-factor measurement** (Pg 66, eq. (3.19)): As per the Khanna-Garault method [10], the displacement 'x' is used to set the bandwidth level in the $S_{21}$ curve, for calculating the $Q$. If the bandwidth is measured between the points 'x' dB below the maximum $S_{21}$ level (0 dB in fig. 6), on either side of the resonant frequency, then the resulting $Q = Q_x$. If the points are measured at 'x' dB above the minimum $S_{21}$ point (-40 dB in fig. 6), then $Q = Q_x$. The $Q_i$ and $Q_o$ are related to each other as $Q_o = (1 + k)Q_i$, $k$ being the coupling factor between the stripline and the DR. This allows calculation of both $Q$'s from the same $S_{21}$ curve.

(2) **Derivation for radiation efficiency** (Pg 90, eq (3.28)):

The unloaded $Q$ is $Q_u = \omega E_i / P_{inc}$.

where $E_i =$ energy stored in the DR

$P_{inc} =$ total lost power = $P_{rad} + P_{ohmic}$ (radiation + ohmic losses)

Thus, $P_{inc} = \omega E_i / Q_u$, (1)

Similarly the ohmic loss, $P_{ohmic} = \omega E_i / Q_{ohmic}$, (2)

Now, $P_{rad} = P_{inc} - P_{ohmic} = \omega E_i / Q_u - \omega E_i / Q_{ohmic}$, (3)

Putting (1) and (3) in the eqn. $\eta = P_{rad} / (P_{rad} + P_{inc})$ we get eq. (3.28)

(3) **Radiation patterns** (Chapter 4): The radiation of all antennas referred in this chapter are polarised along the direction of the feed strip. The orientations of the 2-D ($X, Y, Z$) and 3-D (phi, theta, Y) patterns are related to each other as, $XZ$-plane to phi=0° plane and $YZ$-plane to phi= -90° plane.
APPENDIX A

A CYLINDRICAL DIELECTRIC RESONATOR ANTENNA FOR DUAL-FREQUENCY OPERATION

An experimental investigation on a cylindrical dielectric resonator antenna (DRA) for dual-frequency operation is presented. The antenna exhibits linear and identical polarisation characteristics in both frequency bands with broad radiation patterns and good gain.

A.1 INTRODUCTION

Wireless mobile applications demand multi-band antennas, which show efficient radiation characteristics in multiple frequency bands. Different resonator shapes and feed structures have been reported for dual-band operation [Chapter 2]. The present work shows that if properly excited, dual radiating modes with good radiation characteristics can be generated in a simple cylindrical DRA. Antenna measurements are performed with HP 8510C vector network analyser.

A.2 ANTENNA GEOMETRY

A cylindrical dielectric resonator of permittivity $\varepsilon_r = 68.5$ is used as the antenna element. The resonator has a diameter $d = 24$ mm and height $h = 11$ mm. A $50 \, \Omega$ microstrip feed line of width 3 mm and length 80 mm is fabricated on a microwave substrate of permittivity $\varepsilon_r = 4$ and size 110 mm x 110 mm x 1.6 mm. The proposed antenna geometry is shown in Figure 1.
A.3 RESULTS

The position \((x_o, y_o)\) of the DR is adjusted about the feed line. Different resonant frequencies are observed with varying levels of radiation in the bands. For an optimum feed position \((x_o, y_o) = (70 \text{ mm}, 47.5 \text{ mm})\), dual resonances are obtained as shown in Figure 2. These are at 1.692 GHz and 2.455 GHz, with a frequency separation of 763 MHz. The \(-10 \text{ dB} \) bandwidths are 1.95 % at frequency 1 (1.667 GHz to 1.7 GHz) and 1.67 % at frequency 2 (2.441 GHz to 2.482 GHz).

From the measured transmission coefficients \((S_{21})\), it is found that the polarisations are linear and are the same in both frequency bands. The measured radiation patterns \((E\text{ and } H\text{- planes})\) are shown in Figure 3. Patterns are relatively
broad for the two resonant frequencies with cross-polarisation levels less than \(-15\) dB. Measured maximum gain is 7 dBi in band 1 and 5.5 dBi in band 2.

![Graph showing return loss from 1.4 GHz to 2.6 GHz.](image)

**Figure 2:** Measured return loss of the DRA

![Radiation patterns in E-plane and H-plane.](image)

**Figure 3:** Measured radiation patterns (a) band 1 (b) band 2
CONCLUSION

A cylindrical DRA for dual-frequency operation has been demonstrated. The antenna is simple in structure and compact in size. The reflection, impedance, polarisation, and radiation features of the antenna are studied and found suitable for dual-frequency wireless applications.
APPENDIX B

A CIRCULARLY POLARISED CYLINDRICAL DIELECTRIC RESONATOR ANTENNA

The work presents the experimental investigation on a cylindrical dielectric resonator antenna (DRA) with a conducting strip loaded on its top surface enabling circular polarisation. The antenna exhibits circular polarisation with an axial ratio (AR) < 3 dB over a bandwidth of 3.14 % and a beam width of 60°.

B.1 INTRODUCTION

The circularly polarised (CP) system, when compared with the linearly polarised (LP) system, allows a more flexible orientation between the transmitting and receiving antennas. In addition, the CP fields of an antenna are less sensitive to the propagation effect than the LP fields. As a result, the CP antennas are widely used in satellite communications. In the present design, two orthogonal modes necessary for CP are excited by loading a metallic strip, diametrically on the top surface of a cylindrical DRA. Strip loading results in a slight downshift of the resonant mode of the DRA and also generates a lower orthogonal mode. The separation between the two modes can be lowered by reducing the strip length and at an optimum length, the two modes merge to give CP.

B.2 ANTENNA GEOMETRY

The antenna geometry is shown in Figure 1. A cylindrical DR of permittivity $\varepsilon_r = 20.8$, diameter $2a = 24$ mm and height $h = 7.3$ mm is fed by a 50 $\Omega$ microstrip transmission line of length 80 mm and width 3 mm, fabricated on a
microwave substrate of permittivity $\varepsilon_r = 4$ and size 140 mm (length) x 110 mm (breadth) x 1.6 mm (height). The DR is placed symmetrically on the feed line with an overlapping distance of $d = 7.5$ mm, as shown in figure which excites the $TM_{110}$ mode at 3.055GHz that radiates in the broadside direction.

A metallic strip of length $L = 2a$ and width $w = 3$ mm is adhered diametrically on the top surface of the DR. Width $w$ is so chosen that the frequency shift of the original DRA mode due to strip loading is minimum. The DR is positioned on the feed in such a way that the metallic strip makes an angle of $45^\circ$ with the feed strip as shown in Figure 1.

Figure 1: Top view of the cylindrical DRA geometry showing the DR coated with metal strip
B.3 RESULTS

Figure 2 shows the variation in reflection characteristics of the DRA for with variation in $L$. The original DRA mode (in the absence of strip loading) is indicated by the thin solid curve. It is observed form the figure that, the resonant frequency is reduced from 3.055 to 3.025 GHz, but the impedance matching is improved much on strip loading. In addition, there is a lower resonant mode generated at 1.9 GHz. As the length $L$ is reduced, the lower mode is shifted towards right (higher frequency) considerably while a slight shift of the original mode to the left is observed. At $L = 10$ mm or $\sim 0.1\lambda_o$ where $\lambda_o$ is the free space operating wavelength of the DRA, both modes merge to form an impedance band of 2.65 to 3.13 GHz or 16.6%. The effect of strip width $w$ is also studied and the excitation of the lower-orthogonal mode is observed only when $w = 3$ mm.

![Figure 2: Return loss of the DRA for varying strip length $L$](image_url)
The axial ratio in the boresight is measured as shown in Figure 3. An axial ratio bandwidth (AR < 3dB) of 90 MHz or 3.14 % is obtained with minimum AR of 1 dB at 2.87 GHz. Also the axial ratio is found to be below 3 dB over a beam width of ±30° from the boresight.

Figure 3: Boresight axial ratio of the DRA for a strip length \( L = 10\text{mm} \)

Measured radiation patterns at 2.87 GHz for X-Z and Y-Z planes of the DRA are shown in Figure 4. It is clear that the broadside nature of the patterns is unaffected by the strip loading.
A cylindrical DRA giving circular polarisation has been presented. The antenna is simple in structure as it comprises only a cylindrical DRA and a loading strip. Measured axial ratio is within 3 dB over a bandwidth of 3.14 % and a beamwidth of 60°.
APPENDIX C

A WIDEBAND CYLINDRICAL DIELECTRIC RESONATOR ANTENNA

A cylindrical dielectric resonator antenna with a parasitic conducting strip, loaded coplanar with the 50 Ω microstripline feed has been verified experimentally here. The antenna offers an impedance bandwidth as high as 17.33 % at a centre frequency of 2.77 GHz. The radiation patterns are broad and the low cross-polarisation levels confirm that the antenna is linearly polarised over the entire impedance bandwidth.

C.1 INTRODUCTION

The present design shows how the impedance bandwidth of a cylindrical DRA can be enhanced by adding a parasitic coplanar strip adjacent to the microstrip feed. At an optimum strip position and dimensions, dual radiating modes of similar polarisations are excited in close vicinity to form a linearly polarized and wide impedance band.

C.2 ANTENNA GEOMETRY

The antenna structure is shown in Figure 1. A cylindrical DR of permittivity \( \varepsilon_{e1} = 20.8 \), diameter \( 2a = 27.3 \text{ mm} \) and height \( h = 8.4 \text{ mm} \) is fed with a 50 Ω microstrip transmission line of 80 mm (length) x 3 mm (width), fabricated on a microwave substrate of permittivity \( \varepsilon_{e2} = 4 \) and size 140 mm (length) x 110 mm (breadth) x 1.6 mm (thickness). The condition that \( \varepsilon_{e1} \gg \varepsilon_{e2} \), for effective coupling between the feed and the DR is satisfied.
Figure 1: Top view of the DRA geometry

A metallic strip of length $L$ and width $w$ is adhered at a distance of $d$ from the microstripline to modify the feed for the DR as shown in Figure 1. The length of the strip is chosen slightly higher than half the feed strip length i.e. $L = 45$ mm and a width of $w = 1$ mm to start with. The strip length ($L$), width ($w$), distance from the feed ($d$) and the position with respect to the DR ($d_x$ and $d_y$) are optimized experimentally.

C.3 RESULTS

A maximum bandwidth of 17.33 % obtained for $L = 45$ mm, $w = 2$ mm, $d = 12.5$ mm, $d_x = 2.9$ mm and $d_y = 11.35$ mm. This enhancement in bandwidth is the result of dual radiating modes excited in close vicinity as a result of the strip loading. Depending on the dimensions and the relative position of the parasitic strip, the magnitude and phase of the energy coupled to the strip vary, which excites an additional radiating mode of higher frequency. The return loss and impedance variation at the optimum design parameters are shown in Figure 2, which justify the excitation of dual modes.
Figure 2: Measured input impedance corresponding to the return loss plot shown in inset for optimum values of \( L = 45 \text{ mm}, w = 2 \text{ mm}, d = 12.5 \text{ mm}, d_x = 2.9 \text{ mm} \) and \( d_y = 11.35 \text{ mm} \)

Radiation patterns are measured for the two principal planes viz X-Z and Y-Z planes. Figure 3 shows the radiation patterns at 2.62, 2.77 and 2.935 GHz i.e., in the neighbourhood of the lower, centre and upper ends of the operating band respectively. The co-polar patterns are broadsided with good cross-polar levels. At the upper end of the band, the cross-polarisation of the X-Z plane is better than \(-30 \text{ dB}\). On the other hand, the Y-Z plane shows good cross-polarisation at the lower end of the band. The small degree of asymmetry in the patterns is due to the effects of the SMA connector and feed cable on one side of the antenna. Half power beam widths (HPBW) measured from the radiation patterns are 97°
APPENDIX D

A HALF-CYLINDRICAL DIELECTRIC RESONATOR ANTENNA

A compact half-cylindrical dielectric resonator antenna (DRA) made from a high permittivity ceramic material is investigated. The DRA shows broadside radiation characteristics with good gain across the matching band that covers the 2.4 GHz- WLAN band.

D.1 INTRODUCTION

Many techniques have been proposed to achieve compact DRAs in which the most successful are half volume DRA designs. As the bandwidth of a DRA is limited by the dielectric constant of the DR being used, various feed designs are employed to get the desired impedance bandwidth. A half-cylindrical DR geometry as the one presented here can support multiple radiating modes and if properly excited, impedance bands corresponding to those modes having similar radiation characteristics can be merged to provide the band suitable for a particular application. In this work, a compact half-cylindrical DRA suitable for WLAN application is presented. A resonant mode is excited close to the broadside TM_{12h} mode thereby forming the WLAN band of 2.4 to 2.484 GHz.

D.2 ANTENNA GEOMETRY

The antenna geometry is shown in Figure 1. A half-cylindrical dielectric resonator (DR) of permittivity $\varepsilon_{r1} = 69$, diameter $2a = 26$ mm and height $d = 12$
mm is fed by a 50 Ω microstrip transmission line of length $L = 10$ cm and width
$w \sim 3 \text{mm}$, fabricated on a microwave substrate of permittivity $\varepsilon_{\text{r}} = 4.7$ and size 140
mm x 110 mm x 1.64 mm. The DRA is operated in the broadside $TM_{128}$ mode by
properly choosing the feed position. The feed position is optimized
experimentally as $(x_o, y_o) = (5 \text{ mm}, 40 \text{ mm})$, where $x_o$ and $y_o$ are defined
respectively as the vertical and horizontal distances from the stripline to the DR as
shown in Fig.1 (b).

For a given $TM_{vpn}$ mode, the resonant frequency is given as

$$f = \frac{c}{2\pi a \sqrt{\varepsilon_{\text{r}}}} \sqrt{X_{vp}^2 + \left(\frac{\pi a}{2d} (2m+1)\right)^2}$$ (1)

where $X_{vp}$ is the root of the characteristic equation $J'_v (X_{vp}) = 0$, $J_v$ is the $v^{\text{th}}$
Bessel function of the first kind, $c$ is the velocity of light, $v \geq 0$, $p = 1,2,3...$ and $m = 0,1,2 \ etc$. For the DRA of the present case, the $TM_{128}$ mode frequency is calculated by
(1) as 2.475 GHz.

D.3 RESULTS

Measured return loss of the DRA as a function of frequency is plotted in
Figure 2. The antenna has a 2:1 SWR bandwidth ranging from 2.32 to 2.5 GHz
(7.45 %) that includes the 2.4 GHz WLAN band of 2.4 to 2.485 GHz. It is noted
that the return loss is minimum at the frequency of 2.455 GHz, which agrees
reasonably well with the theoretical value calculated above. It is noted that the
bandwidth includes a lower resonance at 2.365 GHz, close to the $TM_{125}$ resonance to form the band of interest. Figure 3 shows the input impedance of the DRA.

Figure 1: Geometry of the half-cylindrical DRA

![Diagram of half-cylindrical DRA with microstrip feed, substrate, and bottom GND plane.]

Figure 2: Measured Return Loss of the DRA

![Graph showing measured return loss vs. frequency in GHz. Peaks are noted at specific frequencies.]
Measured radiation patterns at 2.45 GHz are shown in Figure 4. Patterns are relatively broad with good cross-polar levels. The YZ-plane pattern is symmetric because of the symmetry of the DR about that plane.

But in the XZ-plane, the radiation is stronger at $\theta = 120^\circ$ as shown in the figure. This may be due to the asymmetry of the DR about that plane where its curved surface also contributes to the radiation in that direction. Radiation patterns at other frequencies in the band also show similar characteristics. The antenna offers a peak gain of 4.58 dBi at 2.44 GHz.
CONCLUSION

A study on microstripline fed half-cylindrical dielectric resonator antenna has been presented. The DRA offers good reflection and radiation characteristics in an impedance band suitable for 2.4 GHz WLAN application.