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## ABSTRACT

This thesis presents the investigations of a cylindrical dielectric resonator antenna (CDRA) with respect to the cross-polarization and the gain of the CDRA, that leads to invention of simple design techniques for reducing the cross-polarization and enhancing the gain. The investigation starts with the antenna characterization of a CDRA to study the dependence of the resonant (input impedance, resonant frequency, bandwidth etc.) and the radiation performance (co-polar gain, cross-polar gain, pattern symmetry, directivity etc.) on the feed-point of the CDRA for three standard feed mechanisms namely the microstrip line, the microstrip slot (or aperture) and the coaxial probe. The above study also provides a functional comparison amongst the three feeds, in exciting the dominant broadside mode of the CDRA – the  $HEM_{11\delta}$  mode. Investigations reveal that the quality or the purity of the radiation from the DRA is deteriorated by the perturbation of the operating mode by the feed mechanism. The coaxial feed is identified to cause the highest level of feed perturbation, but due to its fabrication, impedance matching and measurement difficulties (on account of its non-planar nature) this feed is opted out. The microstrip feed being a planar version of the coaxial feed is thus selected due to its obvious advantage over the coaxial probe that the feed perturbation effect can be experimentally demonstrated simply by changing the CDRA position on the microstrip. To quantify the radiation deterioration, two indices are specified – symmetry of the radiation pattern and the cross-polarized radiation level. After detailed analysis, it is concluded that for a microstrip fed DRA, the feed perturbation introduces higher order modal fields of the  $HEM_{21\delta}$  mode (with partial excitation of  $TM_{01\delta}$  mode) of the DRA, that disturbs the  $HEM_{11\delta}$  mode radiation. This study suggests that the DRA designs should minimize the feed perturbation effects also, in addition to optimizing the impedance matching. Among the two indices specified above, the cross-polarization is relatively easier to measure than the pattern symmetry due to the limitations imposed by the experimental methods. Thus, further focus is on reducing the cross-polarization of a microstrip fed CDRA, for which the higher order  $HEM_{21\delta}$  mode is investigated in detail. A dual-slot feed mechanism is opted as it excites the higher order  $HEM_{21\delta}$  mode dominantly by suppressing the fundamental  $HEM_{11\delta}$  mode. This mode is numerically and experimentally characterized to have a resonant frequency  $\sim 1.5$  times that of the  $HEM_{11\delta}$  mode,

and gain  $\sim 2$  dB lower than that of the  $\text{HEM}_{11\delta}$  mode. From the knowledge of the relative orientations of the electric field of the  $\text{HEM}_{21\delta}$  mode and the  $\text{HEM}_{11\delta}$  mode in the CDRA, a parasitic metal strip made from an adhesive copper tape, is loaded on the CDRA that suppresses the  $\text{HEM}_{21\delta}$  radiation. Once the technique is validated experimentally, it is applied to the basic  $\text{HEM}_{11\delta}$  mode CDRA fed with a microstrip line, and with some modifications. Resulting DRA exhibits, a cross-polarization of 8 dB lower than that in the conventional design. However, this technique has been found very sensitive to the strip dimensions and its alignment on the DRA. Therefore, a better and simpler technique of optimizing the ground plane size for reducing the cross-polarization is investigated in the next phase. Analysis show that at the operating frequency of the DRA, when the lateral dimension of the substrate is slightly higher than half a free-space wavelength ( $\sim 0.58\lambda_0$ ) the cross-polarization becomes a global minimum. By this method, the cross-polarization is reduced by  $\sim 7$ – $10$  dB in measurement. In addition, it is revealed the above optimum substrate size is independent of the substrate shape (square or circle) or the properties of the DRA (dielectric constant and aspect ratio) for a given substrate type. And most importantly, this technique is relatively insensitive to fabrication errors of the substrate size to within  $\sim \pm 15$  mm of the optimum, for an isolation of  $\sim 30$  dB between the co and the cross-polarizations.

Though the fundamental  $\text{HEM}_{11\delta}$  mode of the CDRA gives moderate gain of  $\sim 5$ – $6$  dBi so suitable higher order modes of the CDRA are investigated for high gain. For the first time, the high gain  $\text{HEM}_{13\delta}$  mode is excited dominantly with a standard microstrip slot feed. The microstrip slot is chosen based on the initial investigations presented above that it is inherently a low cross-polarization feed and provides a near-perfect ground plane boundary for the CDRA. Simulations show that the  $\text{HEM}_{13\delta}$  mode is supported by CDRA with aspect ratio (radius to height ratio or  $a/h$ )  $> 1$ , and it resonates at a frequency which is approximately 2.2 times that of the fundamental  $\text{HEM}_{11\delta}$  mode. This mode radiates in the broadside direction with gain in the range of 8–10 dBi. The simulations are verified through prototype fabrication and measurement.

Throughout the thesis, the following common attributes are maintained. The work is carried out entirely in the EEE Department, BITS Pilani, Pilani campus. All the simulations are conducted on commercial EM simulation tool ANSYS HFSS, and a few are cross-verified with CST

Microwave Studio. For all experimental results, an available CDRA with dielectric constant  $\epsilon_r = 24$ ,  $\tan\delta = 0.002$ , diameter  $2a = 19.43$  mm and height  $h = 7.3$  mm ( $a/h = 1.33$ ) is used. To fabricate the feed mechanism, readily available and cost effective FR4 substrate ( $\epsilon_r = 4$ ,  $\tan\delta = 0.02$ , thickness = 1.6 mm) is used as it maintains good contrast with the  $\epsilon_r$  of the CDRA to help good coupling. Antenna characterizations are conducted by using Keysight vector network analyzer (N9928A), Keysight signal generator (N5173B), and Agilent power meter (E4418B) in a compact anechoic chamber.

**Keywords:** Cylindrical dielectric resonator antenna, Higher order mode, Magnetic quadrupole mode, Radiation pattern symmetry, Asymmetric structures, High gain broadside mode, Slot feed, microstrip feed, Coaxial probe feed, Feed perturbation, Cross polarization, Linear polarization, Ground size optimization.

# TABLE OF CONTENT

|   |      |
|---|------|
| CERTIFICATE.....  | i    |
| ACKNOWLEDGEMENT.....  | iii  |
| ABSTRACT.....   | v    |
| TABLE OF CONTENT.....                                       | viii |
| LIST OF FIGURES.....  | xii  |
| LIST OF TABLES.....   | xvi  |
| LIST OF ABBREVIATION.....                                   | xvii |
| Chapter 1.....  | 1    |
| Introduction.....   | 1    |
| 1.1 Background.....   | 1    |
| 1.2 General features of the DRA.....                        | 2    |
| 1.3 DRA versus MPA – Performance Comparison.....            | 3    |
| 1.4 Feed mechanisms for DRAs.....                           | 5    |
| 1.4.1 Coaxial probe fed DRA.....                            | 5    |
| 1.4.2 Microstrip line fed DRA.....                          | 6    |
| 1.4.3 Microstrip slot (aperture) fed DRA.....               | 6    |
| 1.4.3 Coplanar waveguide (CPW) fed DRA.....                 | 6    |
| 1.4.4 Substrate integrated waveguide (SIW) fed DRA.....     | 7    |
| 1.5 Performance characteristics of DRAs.....                | 8    |
| 1.5.1 Electromagnetic mode and Near-field distribution..... | 8    |
| 1.6 DRA modeling and Numerical predictions.....             | 16   |
| 1.7 Eigen mode analysis of a CDR using HFSS.....            | 17   |
| 1.8 Antenna Characterization.....                           | 20   |
| 1.9 Motivation and Thesis Objectives.....                   | 21   |
| 1.10 Organization of Thesis.....                            | 23   |
| 1.11 Conclusion.....  | 24   |
| Chapter 2.....  | 25   |
| Literature Review.....                                      | 25   |
| 2.1 Introduction.....                                       | 25   |

|   |    |
|---|----|
| 2.2 Higher order mode (HOM) of DRAs .....   | 26 |
| 2.3 Unwanted Effects of HOMs and its Mitigation .....   | 27 |
| 2.4 Useful HOMs and Applications .....  | 27 |
| 2.5 Conclusion.....   | 29 |
| Chapter 3 .....   | 30 |
| Feed Perturbation Analysis of a Cylindrical Dielectric Resonator Antenna.....                                     | 30 |
| 3.1 Introduction .....  | 30 |
| 3.2 The Feed Mechanisms .....   | 30 |
| 3.2.1 Microstrip line feed .....  | 32 |
| 3.2.2 Microstrip slot feed .....  | 34 |
| 3.2.3 Coaxial probe feed .....  | 35 |
| 3.3 Analysis of Simulation Results.....   | 36 |
| 3.3.1 Effect of the Feed-point on the CDRA performance .....  | 36 |
| 3.3.2 Comparison among the feed mechanisms for the optimum feed point .....                                       | 37 |
| 3.3.3 Selection of the optimum feed-point .....   | 41 |
| 3.4 Prototypes and Measurement.....   | 44 |
| 3.5 Identification of the perturbing higher order mode.....   | 47 |
| 3.6 Feed perturbation and the dielectric constant of the CDR.....   | 53 |
| 3.7 Conclusion.....   | 54 |
| Chapter 4 .....   | 56 |
| Investigations on the Higher order $HEM_{21\delta}$ -like mode of the CDRA for cross-polarization reduction ..... | 56 |
| 4.1 Introduction .....  | 56 |
| 4.2 Eigen Mode Analysis of the CDRA .....   | 56 |
| 4.3 The Feed Designs.....   | 58 |
| 4.3.1 Dual-microstrip feed .....  | 59 |
| 4.3.2 Dual-slot feed .....  | 61 |
| 4.4 Experimental Results .....  | 63 |
| 4.5 Effect of External Perturber on the $HEM_{21\delta}$ -like mode .....   | 68 |
| 4.6 Microstrip fed CDRA with Metal Strip Wrapping .....   | 69 |
| 4.7 Conclusion.....   | 73 |

|  |     |
|--|-----|
| Chapter 5 .....  | 75  |
| Substrate or Ground size optimization for Cross-polarization Reduction of the CDRA.....                          | 75  |
| 5.1 Introduction .....   | 75  |
| 5.2 Operating Principle .....  | 75  |
| 5.3 Substrate Size Optimization.....   | 81  |
| 5.3.1 Square Substrate.....  | 81  |
| 5.3.2 Effect of Substrate Edges B and B'.....  | 84  |
| 5.3.3 Circular Substrate.....  | 85  |
| 5.3.4 Effect of Substrate Permittivity .....   | 86  |
| 5.3.5 Effect of Permittivity and Aspect ratio of the CDR at the Optimum Substrate Size<br>(0.58 $\lambda$ )..... | 87  |
| 5.4 Prototype Measurement .....  | 88  |
| 5.6 Conclusion.....  | 92  |
| Chapter 6 .....  | 93  |
| High gain CDRA design using Higher Order Mode.....   | 93  |
| 6.1 Introduction .....   | 93  |
| 6.2 Slot Excited CDRA .....  | 93  |
| 6.3 Parametric Analysis .....  | 94  |
| 6.3.1 Lower modes and Radiation pattern .....  | 94  |
| 6.3.2 Identification of the modes .....  | 99  |
| 6.3.3 Effect of dielectric constant and aspect ratio of the CDR on the high gain mode .                          | 102 |
| 6.4 Experimental Verification.....   | 105 |
| 6.5 Improved Design for Impedance Matching .....   | 107 |
| 6.6 Experimental Verification of the Improved Design.....  | 108 |
| 6.7 Conclusion.....  | 112 |
| Chapter 7 .....  | 113 |
| Conclusion and Future Scope .....  | 113 |
| 7.1 Highlight of Thesis.....   | 113 |
| 7.2 Scope for Future Works .....   | 116 |
| References .....   | 117 |
| List of publications.....  | 123 |



Brief Biography of the Candidate..... 125  
Brief Biography of the Supervisor ..... 126

# LIST OF FIGURES

|   |    |
|---|----|
| Fig.1.1 Schematic representation: (a) Cylindrical microstrip patch antenna (MPA) (b) Cylindrical dielectric resonator antenna (DRA) .....   | 4  |
| Fig. 1.2 Schematic representation of the DRA feed mechanisms (a) coaxial probe (b) microstrip line (c) microstrip slot (aperture) (d) Co-planar waveguide (e) Substrate integrated waveguide (SIW) .....  | 8  |
| Fig. 1.3 Schematic representation of the isolated CDR (a) Working coordinate specifications (b) Side view showing the plane of symmetry at $Z = 0$ .....  | 9  |
| Fig. 1.4 Sketch of the near-field distribution of first five common radiating modes of the CDR (Solid lines for the E-field and broken lines for the H-field): (a) $TE_{01\delta}$ (b) $HEM_{11\delta}$ (c) $HEM_{12\delta}$ (d) $TM_{01\delta}$ (e) $HEM_{21\delta}$ .....   | 10 |
| Fig. 1.5 Schematic model of a CDRA supported by finite ground plane (for arbitrary feed mechanism) .....  | 12 |
| Fig. 1.6 Three-dimensional broadside radiation pattern of the $HEM_{11\delta}$ mode of the CDRA shown (a) with respect to the DRA axes (b) separately above the DRA .....   | 13 |
| Fig. 1.7 HFSS model for eigen mode analysis of CDR ( $\epsilon_r = 38$ , $2a = 10$ mm, $a/h = 1.141$ ) ...  | 18 |
| Fig. 1.8 Near-field plots for the five lowest resonant frequencies of the CDRA using HFSS: (a) $TE_{01\delta}$ (b) $HEM_{11\delta}$ (c) $HEM_{12\delta}$ (d) $TM_{01\delta}$ (e) $HEM_{21\delta}$ .....   | 20 |
| Fig. 1.9 DRA characterization facility at the parent institution.....   | 21 |
| Fig. 3.1 Schematic of microstrip line fed CDRA.....   | 33 |
| Fig. 3.2 Schematic of microstrip slot fed CDRA .....  | 34 |
| Fig. 3.3 Schematic of coaxial probe fed CDRA .....  | 35 |
| Fig. 3.4 Reflection coefficients of the CDRA employing different feeds. (Microstrip, $l_s = 2$ mm, Microstrip slot, $l_s = 33$ mm, Coaxial probe, $l_s = 0$ mm) .....   | 37 |
| Fig. 3.5. The near-field distribution (E-field) of the $HEM_{11\delta}$ mode in the CDR for various feed boundary conditions: (a) Isolated CDR of diameter $2a$ and height $2h$ (b) CDR of diameter $2a$ height $h$ kept on a ground plane (c) Microstrip fed CDR ( $2a, h$ ) (d) Microstrip slot fed CDR ( $2a, h$ ) (e) Coaxial probe fed CDR ( $2a, h$ ) ..... | 40 |
| Fig. 3.6 Simulated radiation pattern of the CDRA with different feeds. (Microstrip, $l_s = 2$ mm, Microstrip slot, $l_s = 33$ mm, Coaxial probe, $l_s = 0$ mm) .....  | 42 |
| Fig. 3.7 Fabricated feed mechanisms (a) Microstrip (b) Microstrip slot (c) Coaxial probe .....  | 44 |
| Fig. 3.8 Measured vs simulated reflection coefficients of the CDRA with three different feeds (Microstrip $l_s = 2$ mm, Microstrip slot $l_s = 33$ mm, Coaxial-probe $l_s = 0$ mm).....   | 45 |
| Fig. 3.9 Measured vs simulated radiation patterns (normalized) of the CDRA with different feeds. (Microstrip, $l_s = 2$ mm, Microstrip slot, $l_s = 33$ mm, Coaxial probe, $l_s = 0$ mm).....   | 47 |
| Fig. 3.10 Near-field distribution (H-field) of the CDRA for $l_s = 2$ mm and 8 mm respectively at specific RF phases. (All plots use the same 0–31 A/m range) .....   | 50 |

|  |    |
|--|----|
| Fig. 3.11 Illustration of forming a mixed modal field pattern (H-field) by combining the $TM_{018}$ and the $HEM_{218}$ modal patterns as observed in Fig. 3.10(c) .....   | 51 |
| Fig. 3.12 Simulated and measured reflection coefficients of the microstrip fed CDRA for $l_s = 2$ mm and 8 mm .....  | 52 |
| Fig. 3.13 Radiation patterns of the CDRA for $l_s = 2$ mm and 8 mm. (a) Simulated (b) Measured .....   | 53 |
| Fig. 4.1 Top view of the E-field and the H-field intensities from the eigen mode analysis of the CDR for (a) $TM_{018}$ mode (b) $HEM_{218}$ mode .....  | 58 |
| Fig. 4.2. HFSS model of dual microstrip fed CDRA.....  | 59 |
| Fig. 4.3 Radiation patterns (HFSS) of the dual-microstrip fed CDRA (a) $\phi = 0^0$ and $\phi = 90^0$ planes (b) $\phi = 45^0$ and $\phi = 135^0$ planes.....  | 60 |
| Fig. 4.4 HFSS model of the dual slot-fed CDRA .....  | 61 |
| Fig. 4.5 Radiation patterns (HFSS) of the dual-slot fed CDRA ( $W \times L = 1$ mm $\times$ 11 mm, $l = 5$ mm, $dl' = 4.4$ mm) (a) $\phi = 0^0$ and $\phi = 90^0$ planes (b) $\phi = 45^0$ and $\phi = 135^0$ planes ..... | 63 |
| Fig. 4.6 Fabricated prototype dual-slot fed CDRA .....   | 64 |
| Fig. 4.7 Measured versus simulated reflection coefficient of the dual-slot fed CDRA ( $W \times L = 1$ mm $\times$ 11 mm, $l = 5$ mm, $dl' = 4.4$ mm) .....  | 65 |
| Fig. 4.8 Measured versus simulated co-polar radiation patterns (normalized) of the dual-slot fed CDRA ( $W \times L = 1$ mm $\times$ 11 mm, $l = 5$ mm, $dl' = 4.4$ mm) in the $\phi = 45^0$ and $135^0$ planes .....      | 66 |
| Fig. 4.9 Measured and simulated peak gain versus frequency of the dual-slot fed CDRA ( $W \times L = 1$ mm $\times$ 11 mm, $l = 5$ mm, $dl' = 4.4$ mm).....  | 66 |
| Fig. 4.10 Near-field (H-field in A/m) pattern (HFSS) of the dual-slot fed CDRA ( $W \times L = 1$ mm $\times$ 11 mm, $l = 5$ mm, $dl' = 4.4$ mm) at (a) 2.98 GHz (Slot mode) (b) 4.996 GHz (CDR mode).....                 | 67 |
| Fig. 4.11 Prototype of the dual-slot fed CDRA with metal strip wrapping on the CDR.....  | 68 |
| Fig. 4.12 Measured reflection coefficient of the dual-slot fed CDRA ( $W \times L = 1$ mm $\times$ 11 mm, $l = 5$ mm, $dl' = 4.4$ mm) with and without the metal strip wrapping ( $g = 1$ mm).....                         | 69 |
| Fig. 4.13 Microstrip fed DRA designs (a) Without strip (b) With strip (Only the top side of the substrate is shown).....   | 69 |
| Fig. 4.14 Simulated H-plane radiation patterns for the CDRA without and with strip loading ( $dl = 2$ mm, $w = 3$ mm). Without strip DRA ( $w = 0$ ) pattern is plotted at 3.44 GHz and all others at 3.37 GHz .....       | 70 |
| Fig. 4.15 Simulated reflection coefficients of CDRA without and with strip loading ( $dl = 1.7$ mm, $w = 3$ mm, $g = 2$ mm) .....  | 71 |
| Fig. 4.16 Simulated H-plane radiation patterns of CDRA without strip at 3.44 GHz and with strip loading at 3.37 GHz ( $dl = 2$ mm, $w = 3$ mm, $g = 2$ mm .....  | 71 |
| Fig. 4.17 Photograph of the fabricated prototypes of CDRA with strip loading .....   | 72 |
| Fig. 4.18 Measured reflection coefficients ( $ \Gamma_{in} $ ) of CDRA without strip and with strip loading ( $dl = 1.7$ mm, $w = 3$ mm, $g = 2$ mm) .....   | 72 |

|   |    |
|---|----|
| Fig. 5.1. Configuration of the microstrip fed CDRA.....   | 76 |
| Fig. 5.2. Top view of the microstrip fed CDRA. (A-A' and B-B' are the two pairs of the substrate edges) .....   | 78 |
| Fig. 5.3. Simulated field and power flow patterns at 3.45 GHz for a substrate of side 90 mm or $1\lambda_0$ (a) Electric (E) and Magnetic (H) field vector plots (b) Real Poynting vector on the adjacent substrate edges A and B .....                         | 80 |
| Fig. 5.4. Variation in the CDRA gain with the substrate side length ( $L_s$ ) (a) Co-polar (b) Cross-polar .....  | 83 |
| Fig. 5.5. Reflection coefficient of the CDRA for large ( $L_s= 115$ mm) and small ( $L_s= 50$ mm) substrate designs.....  | 84 |
| Fig. 5.6. H-plane radiation pattern of the CDRA for large ( $L_s = 115$ mm) and small ( $L_s = 50$ mm) substrate designs at $f_0$ . (HFSS Large: $f_0 = 3.47$ GHz, HFSS Small: $f_0 = 3.48$ GHz, CST Large: $f_0 = 3.42$ GHz, CST Small: $f_0 = 3.45$ GHz)..... | 84 |
| Fig. 5.7. Variation in the CDRA gain with the substrate diameter ( $D_s$ ) (a) Co-polar (b) Cross-polar (Circular).....   | 86 |
| Fig. 5.8. Prototype CDRA (a) Square substrate ( $L_s = 115$ mm and 50 mm) (b) Circular substrate ( $D_s = 115$ mm and 50 mm) .....  | 89 |
| Fig. 5.9. Measured versus simulated reflection coefficient of the CDRA for large ( $L_s = 115$ mm) and small ( $L_s = 50$ mm) substrate designs (Square) .....  | 89 |
| Fig. 5.10. Measured versus simulated H-plane radiation pattern of the CDRA for large ( $L_s = 115$ mm or $1.31\lambda_0$ at $f_0 = 3.413$ GHz) and small ( $L_s = 50$ mm or $0.57\lambda_0$ at $f_0 = 3.396$ GHz) substrate designs (Square) .....              | 90 |
| Fig. 5.11 Measured versus simulated E-plane radiation pattern of the CDRA for large ( $L_s = 115$ mm or $1.31\lambda_0$ at $f_0 = 3.413$ GHz) and small ( $L_s = 50$ mm or $0.57\lambda_0$ at $f_0 = 3.396$ GHz) substrate designs (Square) .....               | 90 |
| Fig. 5.12. Measured versus simulated reflection coefficient of the CDRA for large ( $D_s = 115$ mm) and small ( $D_s = 50$ mm) substrate designs (Circular).....  | 91 |
| Fig. 5.13. Measured versus simulated H-plane radiation pattern of the CDRA for large ( $D_s = 115$ mm or $1.30\lambda_0$ at $f_0 = 3.40$ GHz) and small ( $D_s = 50$ mm or $0.57\lambda_0$ at $f_0 = 3.41$ GHz) substrate designs (Circular) .....              | 91 |
| Fig. 6.1 Schematic diagram of the slot fed CDRA. (Substrate thickness ( $t$ ) = 1.6 mm, substrate size ( $L_G$ or $W_G$ ) = 70 mm. substrate $\epsilon_r = 4$ & $\tan\delta = 0.02$ , slot size ( $L_S \times W_S$ ) = 10 mm $\times$ 1 mm) .....               | 94 |
| Fig. 6.2 Input reflection coefficient versus frequency for the first three mode of the slot fed CDRA as the function of $L_{match}$ . (CDR : $\epsilon_r = 24$ , $\tan\delta = 0.002$ , $2a = 19.43$ mm and $h = 7.3$ mm).....                                  | 95 |
| Fig. 6.3 Simulated radiation pattern of the slot fed CDRA (a) First mode at 2.78 GHz for $L_{match} = 5$ mm (b) Second mode at 4.045 GHz $L_{match} = 3$ mm (c) Third mode at 6.116 GHz $L_{match} = 10$ mm.....  | 97 |

|   |     |
|---|-----|
| Fig. 6.4 Peak gains versus $L_{\text{match}}$ for the three modes of the CDRA (CDR: $\epsilon_r = 24$ , $\tan\delta = 0.002$ , $2a = 19.43$ mm and $h = 7.3$ mm).....   | 98  |
| Fig. 6.5 Peak gain versus ground size for the third (high gain) mode for $L_{\text{match}} = 10$ mm (CDR: $\epsilon_r = 24$ , $\tan\delta = 0.002$ , $2a = 19.43$ mm and $h = 7.3$ mm) .....  | 98  |
| Fig 6.6. Near-field (Electric field) vector distributions (a) First mode at 2.78 GHz (b) Second mode at 4.045 GHz .....   | 100 |
| Fig. 6.7 (a) Near-field vector distributions of the high gain (HEM <sub>13<math>\delta</math></sub> ) mode at 6.116 GHz (CDR : $\epsilon_r = 24$ , $\tan\delta = 0.002$ , $2a = 19.43$ mm and $h = 7.3$ mm, $L_{\text{match}} = 10$ mm, $L_G = W_G = 70$ mm) (a) Electric ( $E$ ) field from HFSS (b) Schematic illustrations of the electric field distribution of the (i) HEM <sub>11<math>\delta</math></sub> mode (ii) HEM <sub>13<math>\delta</math></sub> mode..... | 101 |
| Fig. 6.8 Near-field distribution (E-field V/m) (a) For $\epsilon_r = 15$ , $a/h = 1$ (b) For $\epsilon_r = 35$ , $a/h = 1$ (referred to Table 6.1) .....  | 103 |
| Fig. 6.9 Fabricated prototype of the slot fed CDRA (CDR : $\epsilon_r = 24$ , $2a = 19.43$ mm, $h = 7.3$ mm, $\tan\delta = 0.002$ , Substrate : $L_G = W_G = 70$ mm, $t = 1.6$ mm, $\epsilon_r = 4$ , $\tan\delta = 0.02$ , Slot : $L_S = 10$ mm, $W_S = 1$ mm, $L_{\text{match}} = 10$ mm).....  | 105 |
| Fig. 6.10 Input reflection coefficient versus frequency for the slot fed CDRA (Fig. 6.9).....   | 106 |
| Fig. 6.11 Radiation patterns for the slot fed CDRA at 6.116 GHz (simulated) and 5.997 GHz (measured). (a) E-plane (b) H-plane.....  | 107 |
| Fig. 6.12 Schematic representation of the improved slot fed CDRA with shunt stub matching (Other parameters as in Fig. 6.9) .....   | 107 |
| Fig. 6.13 Reflection coefficients of the slot fed CDRA for different stub location ( $d_{\text{stub}}$ ) and stub length ( $l_{\text{stub}}$ ) .....  | 108 |
| Fig. 6.14 Fabricated prototype of the simple slot fed CDRA (Stub : $d_{\text{stub}} = 0$ mm, $l_{\text{stub}} = 4$ mm, Other parameters as in Fig. 6.9 .....  | 109 |
| Fig. 6.15 Measured versus simulated reflection coefficients of the slot fed CDRA ( $L_{\text{match}} = 10$ mm, $d_{\text{stub}} = 0$ mm, $l_{\text{stub}} = 4$ mm) (a) Upper band showing only the HEM <sub>13<math>\delta</math></sub> resonance (b) Lower band showing weakly excited HEM <sub>11<math>\delta</math></sub> resonance.....   | 110 |
| Fig. 6.16 Measured versus simulated radiation patterns of the slot fed CDRA. (a) E-plane (b) H-plane (Simulation: 6.116 GHz for without stub, 6.125 GHz for with stub, Measurement: 5.997 GHz for without stub, 5.981 GHz for with stub) .....  | 111 |

## LIST OF TABLES

|  |     |
|--|-----|
| Table 1.1 Principal planes and patterns for the DRA .....  | 15  |
| Table 1.2 Five lowest resonant frequency of the CDR [7], $\epsilon_r = 38$ , $2a = 10.5$ mm, $a/h = 1.141$<br>.....  | 18  |
| Table 3.1 Design Parameters for the CDR and the Feed mechanisms.....   | 31  |
| Table 3.2 CDRA characteristics: Microstrip feed for various feed points ( $l_s$ in Fig. 3.1 .....  | 33  |
| Table 3.3 CDRA characteristics: Microstrip slot feed, for various feed points ( $l_s$ in Fig. 3.2)   | 34  |
| Table 3.4 CDRA characteristics: Coaxial probe feed, for various feed points ( $l_s$ in Fig. 3.3)   | 35  |
| Table 3.5 Comparison of the CDRA Performance for the three different feed mechanisms<br>using ANSYS HFSS and CST Microwave studio (MWS) .....  | 43  |
| Table 3.6 Comparison of the measured CDRA performance among the feed mechanisms ....   | 45  |
| Table 3.7 Measured performance of the microstrip fed CDRA for varying $l_s$ .....  | 52  |
| Table 3.8 Radiation characteristics of the CDRA for varying dielectric constants of the CDR<br>( $\epsilon_r$ ).....   | 53  |
| Table 4.1 Resonant frequencies of the CDR – HFSS Eigenmode vs Theory .....   | 57  |
| Table 4.2 Common design parameters of the two feed geometries .....  | 59  |
| Table 4.3 Radiation characteristics of the dual-slot fed CDRA for varying slot length ( $L$ )<br>( $W=1$ mm, $l = 5$ mm, and $dl' = 4.4$ mm).....  | 62  |
| Table 4.4 Comparison of the performance characteristics of the $HEM_{21\delta}$ mode of the CDRA<br>excited by the dual-microstrip feed ( $dl = 8.1$ mm) and the dual-slot feed ( $W=1$ mm, $L = 11$<br>mm, $l = 5$ mm, $dl' = 4.4$ mm)..... | 62  |
| Table 4.5 Simulated and measured characteristics of the dual-slot fed CDRA.....  | 65  |
| Table 5.1 Far-field components of $HEM_{11\delta}$ and $HEM_{21\delta}$ modes [2] .....  | 77  |
| Table 5.2 Design parameters of the CDRA .....  | 78  |
| Table 5.3 Performance characteristics of the CDRA for different substrate side lengths<br>(HFSS).....  | 82  |
| Table 5.4 Effect of the substrate edges B-B' (Fig. 5.2) on the CDRA performance (HFSS) ...   | 85  |
| Table 5.5 Effect of substrate permittivity on optimum substrate size (HFSS) .....  | 87  |
| Table 5.6 Effect of permittivity and aspect ratios of the DR on the CDRA performance for the<br>optimum substrate size $0.58\lambda_0$ .....   | 88  |
| Table 6.1 Resonant frequencies and peak gains of the high gain mode of the CDRA for<br>various dielectric constants ( $\epsilon_r$ ) and aspect ratios ( $a/h$ ) of the CDR for $2a = 19.43$ mm.....   | 104 |
| Table 6.2 Performance comparison of the slot-fed CDRA without and with the stub for the<br>$HEM_{13\delta}$ mode.....  | 110 |

## LIST OF ABBREVIATION

|          |  |
|----------|--|
| MPA      | Microstrip Patch Antenna                 |
| DRA      | Dielectric Resonator Antenna             |
| DR       | Dielectric Resonator                     |
| CDRA     | Cylindrical Dielectric Resonator Antenna |
| Q-factor | Quality factor                           |
| BW       | Bandwidth                                |
| MIC      | Microwave Integrated Circuits            |
| TE       | Transverse Electric                      |
| TM       | Transverse Magnetic                      |
| HEM      | Hybrid Electromagnetic                   |
| CPW      | Coplanar waveguide                       |
| SIW      | Substrate Integrated Waveguide           |
| CDR      | Cylindrical Dielectric Resonator         |
| HOM      | Higher Order Mode                        |
| D        | Directivity                              |
| G        | Gain                                     |
| VSWR     | Voltage Standing Wave Ratio              |
| HFSS     | High Frequency Structure Simulator       |
| FEM      | Finite Element Method                    |
| FIT      | Finite Integration Technique             |
| EM       | Electromagnetic                          |
| Cx-polar | Cross-polar                              |