ACKNOWLEDGEMENT

I gratefully acknowledge Dr. Praveen Kumar A.V., Assistant Professor, Department of Electrical and Electronics Engineering, BITS Pilani, Pilani campus, Rajasthan for introducing me to the world of Microwave Engineering and Antenna Design. I sincerely appreciate his impeccable knowledge in the subject of Antenna design, and the way he guided and trained me to fulfil my thesis objectives. His timely advices helped in shaping my professional and personal lives. Indeed, my gratitude to him is beyond words. Also I would like to thank Mr. Mahesh Chandra Saini, technical staff of the Communication Lab for supporting in the fabrication and the measurement of various antennas that I designed for this thesis. You have been of great support to me throughout the years.

I sincerely express my profound gratitude to Prof. Souvik Bhattacharya, Vice-Chancellor, BITS Pilani for providing me the opportunity to carry out my Doctoral studies at BITS. I convey my sincere thankfulness to Prof. A.K. Sarkar, Director, BITS Pilani, Pilani campus. I thank Prof. Chandra Shekhar, Emeritus Prof. of EEE Department for his constant encouragement and support. I also express my gratitude to Prof. Srinivas Krishnaswamy, Dean, Academic – Graduate Studies & Research Division (AGSRD) and Prof. Jitendra Panwar, Associate Dean, Academic – Graduate Studies & Research Division, for providing me valuable support throughout the doctoral programme.

I would also like to thank my doctoral advisory committee (DAC) members, Prof. Navneet Gupta, and Dr. Rahul Singhal, for their guidance throughout my PhD programme. I would like to thank Prof. Vinod Kumar Chaubey, Head of EEE Department for motivating me throughout my degree programme.

I also want to thank staff members of EEE Department, Mr. Ravinder Kumar Yadav, Mr. Tulsi Ram Sharma, Mr. Ashok Saini, Mr. Manoj Kumar, Mr. Amitabh Jangir, Mr. Birdi Chand, Mr. Sanjay Bharbava, Mr. Ramavatar and Mr. Surendra for their help in the laboratory and other official works. I would like to thank Mr. Bhim Singh, Mr. Raj Kumar and Mr. Raju of the Central Workshop, BITS Pilani, for providing fabrication facility and rendering necessary technical assistance. Dr. S. Santosh Kumar, Senior scientist, CSIR-CEERI Pilani is acknowledged for his assistance in various forms. Physics Department, BITS Pilani is also kindly mentioned here with gratitude for providing lab facilities during my early years of research. The Department of Science and Technology (DST), India is also acknowledged for facilitating the vector network analyzer and antenna simulation tools (ANSYS HFSS and CST Microwave Studio) in EEE department, BITS Pilani through the Fund for Improvement of S&T Infrastructure in Universities and Higher Educational Institutions (DST-FIST, Grant Ref: SR/FST/ETI-346/2013).

I cannot conclude this section without mentioning the support from my faculty member Dr. Sainath Bitragunta, Dr. Syed Mohammad Zafaruddin, Dr. Nitin Chaturvedi, Dr. Mahesh Angira Dr. Kavindra Kandpal, Dr. Vinay Chamola and senior colleagues Dr. Aishwarya Pandey, Dr. Prachi Sharma, Dr. Jitendra Kumar, Dr. Satish Mohanty, Dr. Abhishek Joshi, Dr. Pramila Mahala. I would also like to thanks to my fellow colleagues, Mr. Ritish Kumar, Mr. Rahul Sharma, Mr. Ziyaur Rahman, Mr. Ashish Verma, Mr. Premsai Regalla, Mr. Ashish Patel, Mr. Karri Babu Ravi Teja, Mr. Harshvardhan S, Mr. Devesh Samaiya, Mr. Tejasvi Alladi, Mr. Dhananjay Mishra, Dr. Ravinder Kumar, Ms. Hema Dave, Mr. Prashant Upadhyay, Mr. Prateek Bindra, Mr. Krishna Veer Singh, Mr Puneet Khatri, Mr. Anukaran Khanna, Mr. Akhilesh Kumar Mishra, Mr. Abheek Gupta, Ms. Ankita Dixit, Ms. Teena Gakhar. There are many other people whose names do not appear here but whose love, support and contributions in various forms have motivated me and helped me to complete this work. Finally, I am thankful to my Parents, Brothers, my wife Mrs. Divya Ojha and my wonderful little daughters Ganga and Janaki, without whose love, patience and support it would have been impossible to complete this work.

Anuj Kumar Ojha

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 ~ 1.5 times that of the $HEM_{11\delta}$ mode,

and gain ~2 dB lower than that of the $HEM_{11\delta}$ mode. From the knowledge of the relative orientations of the electric field of the $HEM_{21\delta}$ mode and the $HEM_{11\delta}$ mode in the CDRA, a parasitic metal strip made form an adhesive copper tape, is loaded on the CDRA that suppresses the $HEM_{21\delta}$ radiation. Once the technique is validated experimentally, it is applied to the basic $HEM_{11\delta}$ 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 ~ 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 ~ ±15 mm of the optimum, for an isolation of ~ 30 dB between the co and the cross-polarizations.

Though the fundamental $HEM_{11\delta}$ mode of the CDRA gives moderate gain of ~ 5–6 dBi so suitable higher order modes of the CDRA are investigated for high gain. For the first time, the high gain $HEM_{13\delta}$ 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 $HEM_{13\delta}$ mode is supported by CDRAs 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 $HEM_{11\delta}$ 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 ε_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 (ε_r = 4, $tan\delta$ = 0.02, thickness = 1.6 mm) is used as it maintains good contrast with the ε_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.

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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