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 (~ $0.58\lambda_0$) 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 2*a* = 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.