Chapter 2

Literature Review

2.1 Introduction

S. A. Long et al. first proposed the use of the dielectric resonator (DR) as a radiator in 1983, naming it as the "resonant dielectric cavity antenna" in his paper [6]. The name later changed to a more meaningful "dielectric resonator antenna" (DRA). In [6], a cylindrical DRA (CDRA) is excited in the dominant TM_{110} mode (or $HEM_{11\delta}$ mode, to be accurate) with a coaxial probe feed. The resonant frequency of the TM_{110} mode is calculated using the magnetic-wall model of the CDR, which shows that it varies with the dielectric constant (ε_r) and the aspect ratio (a/h) of the DRA. Results of the paper demonstrates that the TM_{110} mode radiates maximally in the broadside direction, and the radiation pattern is also dependent on the ε_r and the a/h of the DRA. Later in 1984, Kajfez et.al [7] computed the resonant frequencies, quality factors and near-field distributions of the five lowest modes of an isolated (source-free) CDR i.e., $TE_{01\delta}$, $TM_{01\delta}$, $HEM_{11\delta}$, $HEM_{12\delta}$ and $HEM_{21\delta}$ modes. This landmark study opened up the possibility of using other radiating modes of the DRA than the $HEM_{11\delta}$ mode. However, the DRA research gained worldwide publicity around 10 years later when a comprehensive review paper on the DRA design was published by Mongia et.al [8]. The works in [6]–[8] marked the beginning of a new era of the DRA research by exploiting unique design features of DRAs such the flexibility to use standard feed mechanisms [2], [4], [31], use of various DRA shapes [2], [6], [31]–[34], use of different radiating modes [2], [7], [11], [35] etc. Recently, beautiful crystal and glass wares were proposed as decorative DRAs [36]. The first textbook on DRAs - *Dielectric resonator antenna, Research studies press Ltd., England edited by K. M. Luk and K. W. Leung* was published in 2003 [2], and a second one *Dielectric resonator antenna handbook, Artech house INC USA, edited by Aldo Petosa* in 2007 [37].

Over the last three and a half decades, the DRA technology has matured significantly to compete with the existing microstrip patch antenna (MPA) technology. There are mainly three key works reported on the comparison of DRA and MPA [4], [12], [38]. In all the above works, a CDRA is compared against a circular MPA with respect to the dominant broadside modes

($HEM_{11\delta}$ for DRA and TM_{11} for MPA). In [38], the DRA and the MPA are compared at two different frequencies of 4 GHz and 7 GHz (C-band), and are found to perform almost identically. The coaxial probe feed mechanism is used in [38]. In the Ka-band frequency of 35 GHz, a DRA was shown to radiate 16 % more efficiently than the MPA, both excited by microstrip feed, and the bandwidth of the CDRA is more than 13% [12]. But in [4], an extensive investigation of the DRA versus the MPA in the S and C-band for three different feed mechanisms is undertaken both numerically and experimentally. The above work draws similar conclusions as in [15] between the two types of antennas, but also compares among the feed mechanisms. The microstrip feed is advantageous for integration purposes while the coaxial feed is preferred for efficiency concerns. For the last one decade, the CDRA research has been focusing on the higher order modes (HOM) for enhancement of DRA performance. So a thorough review of the past works on HOM-DRAs, especially their undesired and useful effects is presented in this chapter, with the purpose of formulating design solutions to the objectives identified in the previous chapter.

2.2 Higher order mode (HOM) of DRAs

The dominant broadside mode or the $HEM_{11\delta}$ mode of a CDRA is sufficiently explored, as these can be easily excited with standard feed mechanisms, and produce gain in the range of 4-6 dBi [21], [39]. The CDRA can also be operated at HOMs, such as the $HEM_{111+\delta}$, $HEM_{12\delta}$, $HEM_{121+\delta}$, $HEM_{21\delta}$ etc. The following points are worth noting about the HOMs in DRAs.

(i) For DRAs operating in the fundamental mode, the HOMs cause pattern distortion and cross-polarization. For example the $HEM_{21\delta}$ is the major cause of cross-polarization in the $HEM_{11\delta}$ radiation of a CDRA [27], [40], [41].

(ii) Certain HOMs can provide gain as high as 9.5 dBi even with a single DRA, without using any stacking or superstrate techniques [42]. Also, the HOMs can be excited along with other modes to enable multi-band[43] or wideband operations [9].

(iii) The excitation of HOMs is difficult due to the higher order (multi-polar) field variations inside the DRA [7]. To couple to such modes, intricate feeding techniques are required which increases the sensitivity of the design to fabrication errors. Fortunately there exists certain HOMs that can be excited with simple feeds also [11].

(iv) Resonant frequencies of certain HOMs are nearby each other (e.g.: $TM_{01\delta}$ and $HEM_{21\delta}$ modes of a CDRA). So when exciting a desired HOM, suppression of the undesired mode should be achieved.

2.3 Unwanted Effects of HOMs and its Mitigation

The dominant (fundamental) broadside mode of a CDRA, designated as $HEM_{11\delta}$ mode radiates in the broadside direction with dissimilar patterns in the E-plane and the H-planes [39], [44], [45]. The pattern in the E-plane is much broader than that in the H-plane. In addition, the cross-polarization in the H-plane is also much higher than that in the E-plane [45]. DRAs with reduced ground plane designs have been found to equalize the radiation patterns between the two principal planes [45], as well as increase the boresight gain of the DRA [11], [46]. It has been reported that the $HEM_{21\delta}$ mode is the dominant higher order mode that causes the high level of cross- polarization [27], [40], [41]. For a circular MPA, the higher order TM_{21} mode does similar effect to the TM_{11} mode radiation [47]. Guha et.al., proposed a mode filtering technique to suppressing the $HEM_{21\delta}$ mode of a CDRA from the $HEM_{11\delta}$ mode [27]. The technique in [27] [40] uses insertion of metallic object inside the DRA (metallic perturbation),whereas in [41] the same purpose is achieved by dielectric perturbation of the CDRA. In [27] metal bar is inserted parallel to the feed on the top center of the CDRA and in [40] a pair of horizontally oriented metal pins protruded (face to face) symmetrically with in CDR, both techniques are excited by the coaxial probe feed mechanism. The above techniques involve DRA machining, achieving which with perfection the real challenge. Abhishek Singh et.al proposed a wideband CDRA with directive radiation pattern and low cross-polarization [48]. In this, the DRA is fed from dual-coaxial probes in the differential feed arrangement. It provided directional radiation patterns with low cross-polarization levels over a large impedance bandwidth, at the cost of complex feeding technique.

2.4 Useful HOMs and Applications

Certain HOMs can be purposely excited in the DRA for various applications, especially for gain enhancement. Gain enhancement of the fundamental mode of a CDRA is achieved through the loading of additional structures such as cavity [49], short horns [50], DRA arrays [51], electromagnetic band-gap (EBG) structures [52] and superstrates [53]. The broadside $HEM_{12\delta}$

mode of a CDRA is excited with novel feed techniques giving gain ~ 8–9 dBi at ~7.5 GHz [10], [54]. Broadside radiation with peak gain in excess of 8 dBi has been demonstrated for the HEM_{113} mode [55], [9]. A composite aperture (slot) feed is proposed to excite simultaneously the $HEM_{11\delta}$ and $HEM_{12\delta}$ modes for dual-band broadside radiation [35]. A simple slot fed CDRA is proposed for high gain (11.6 dBi), wide band (2.6 %) operation in the 5.82 GHz WLAN band by exciting both the HEM_{133} and the HEM_{123} modes in close vicinity through the proper choice of the DRA parameters [11]. The same two modes are excited in a LTCC based CDRA with a substrate integrated waveguide (SIW) to provide 10.8 dBi gain with 2.15 % bandwidth at 35 GHz. [24]. Wide bandwidth of 25.1 % is obtained by merging the HEM_{113} and the HEM_{115} modes [9]. In [56], the higher order $TM_{01\delta}$ and the $HEM_{12\delta+1}$ modes of a CDRA are utilized to operate as a three-port polarization-diversity antenna. In [57], a pattern diversity DRA is proposed by using both the fundamental $HEM_{11\delta}$ mode and the higher order $TM_{01\delta}$ mode. A 5.8 GHz pattern-reconfigurable CDRA using the $HEM_{21(1-\delta)}$ mode and PIN diode switches is proposed for high gain and quasi-end fire radiation pattern [58]. For other DRA geometries also the HOMs are employed for various uses. For example for a rectangular DRA, gain enhancement using the $TE^{x}_{\delta 15}$ mode [59], dual-band operation using TE_{111} and TE_{113} modes [60] etc. can be found in literature. However, the most useful work on the HOM DRA is published by Yong-Mei Pan et.al. which shows that using a HOM, the antenna size can be increased therefore, will be more tolerant to fabrication errors [61]. The fundamental TE_{111} mode of a rectangular DRA is compared with the higher order TE_{115} and the TE_{119} modes, all producing broadside radiation. For the TE_{115} mode DRA, the size is 7.4 times larger and for the TE_{119} mode DRA, the size is 14 times larger than the TE_{111} mode DRA with $\varepsilon_r = 10$. It has been shown that for identical fabrication error, the frequency shift of a higher-order mode is less than that of the lower-order modes.

The above literature review provides guidelines in achieving the research objectives framed in chapter 1. The research to be started with the modal analysis of the CDRA, then to investigate factors that influence the modal characteristics, compare various excitation methods for fundamental and higher order modes, and finally to employ these understandings to design a compact CDRA for low cross-polarization and high gain.

2.5 Conclusion

This chapter presented a comprehensive survey of the literature on high performance DRAs by exploiting the higher order modes (HOMs). This review tells us that further research is required to develop methods for improving the quality of radiation such as increasing the gain and decreasing the cross-polarization using simple DRA designs. Accordingly, for the cross-polarization reduction, suitable higher order mode suppression technique which is both simple and effective must be incorporated in the basic DRA design. And for the gain enhancement, an appropriate higher order mode of a DRA must be chosen, in place of the fundamental mode. Investigations on the cross-polarized radiation of the DRA will be carried out in the next chapter.