Dielectric resonators (DRs) are an inevitable component in microwave telecommunication devices and are extensively used as filters, oscillators and dielectric resonator antennas (DRAs). To meet the requirements for use in such practical applications, the materials should possess stringent properties like (i) high dielectric constant ($\varepsilon_r$) for miniaturization, (ii) high unloaded quality factor ($Q_u$) or low dielectric loss for better selectivity and (iii) low temperature coefficient of resonant frequency ($\tau_f$) for frequency stability with thermal variations of the circuit.

Open dielectric resonators can radiate energy through their lower order modes and hence act as effective antennas. These DRAs have the advantages like reduced size, lower ohmic loss, mechanical simplicity, relatively large bandwidth, simple coupling schemes to nearly all commonly used transmission lines and different radiation characteristics using different modes of the resonator. The search for new DR materials with optimum balance of microwave dielectric properties for antenna applications and the fabrication of wide band DRAs with reasonable gain and radiation performances is one of the challenging problems in telecommunication field.

This thesis entitled “NOVEL LOW LOSS A(A_{1/4}B_{2/4}C_{1/4})O_3 DIELECTRICS AND THEIR APPLICATIONS IN BROADBAND ANTENNAS” is the outcome of a detailed investigation made on the synthesis, characterisation and microwave dielectric properties of $A(A_{1/4}B_{2/4}C_{1/4})O_3$ ($A = Ca, Ba, Sr, Mg, Zn, Ni, Co; B = Nb, Ta; C = Ti, Zr and Hf$) ceramics, tailoring their dielectric properties by different techniques, verification of the experimental results using theoretical modelling and fabrication of wide band antennas using the developed DR materials. Accordingly these results are classified into 9 chapters in the thesis.

Chapter 1 is a general introduction about low loss dielectric resonator materials, and a brief survey of their technological and industrial applications, especially as DRAs. A consolidated introduction about DRAs, their merits over other conventional patch antennas and the major developments in this area of research have been discussed.
Chapter 2 illustrates the experimental method of conventional solid-state ceramic route for the synthesis of DRs. The information about instrumental techniques adopted for the structural, microstructural and microwave dielectric properties of DRs have also been summarised. The design and measurement methods employed for the fabrication of DRAs have been described in this chapter. Furthermore, a brief introduction about the theoretical modelling adopted for checking the validity of experimental results has been discussed. The experimental set up for measuring $Q_m$, $\varepsilon_r$ and DRA geometry was modelled using a complete software tool for 3D electromagnetic analysis (Micro - stripes 6.5). The time domain solver based on the Transmission Line Matrix (TLM) technique was adopted which allowed an efficient way of solving Maxwell's equations without suffering the drawbacks of other techniques such as FDTD and finite elements.

Chapter 3 presents the preparation, characterization and microwave dielectric properties of Ca$_5$B$_2$TiO$_{12}$ (B = Nb, Ta) [or Ca(Ca$_{1/4}$B$_{2/4}$Ti$_{1/4}$)O$_3$ in perovskite form] ceramics. The synthesizing conditions were optimised for best dielectric properties. Two novel DR materials were reported in which, Ca$_5$Nb$_2$TiO$_{12}$ has $\varepsilon_r = 48$, $Q_m x f >$ 26000 GHz and $\tau_f = +40$ ppm/$^\circ$C, whereas Ca$_5$Ta$_2$TiO$_{12}$ has $\varepsilon_r = 38$, $Q_m x f >$ 33000 GHz and $\tau_f = +10$ ppm/$^\circ$C. The effects of various dopants on the dielectric properties of these ceramics have been investigated. It is found that dopants such as MgO, ZnO, CuO, Co$_3$O$_4$, Sb$_2$O$_3$, Cr$_2$O$_3$, In$_2$O$_3$ and SnO$_2$ improve the microwave dielectric properties. A correlation between the microwave dielectric properties of the matrix and ionic radii of the dopant has been established.

The effect of glass additives on the sintering temperature, density and microwave dielectric properties of Ca$_5$B$_2$TiO$_{12}$ [B = Nb, Ta] ceramics have been described in Chapter 4. It is found that small amount (0.1 wt %) addition of glasses improved the density, dielectric constant and quality factor. Al$_2$O$_3$ and SiO$_2$ glasses are more effective in reducing $\tau_f$ whereas B$_2$O$_3$ based glasses better aids the lowering of sintering temperature. Higher wt % of all glasses deteriorated the density and microwave dielectric properties of these ceramics though they effectively reduced the sintering temperature.

Chapter 5 deals with tailoring the microwave dielectric properties of Ca$_5$Nb$_2$TiO$_{12}$ by partial substitution of Ca$^{2+}$ with Ba, Sr, Mg, Zn, Ni, and Co and Ti$^{4+}$ with Zr and Hf. Consequently, solid solutions such as Ca$_{5-x}$Ba$_x$Nb$_2$TiO$_{12}$, Ca$_{5-x}$Sr$_x$Nb$_2$TiO$_{12}$, Ca$_{5-x}$
Mg$_x$Nb$_2$TiO$_{12}$, Ca$_{5-x}$Zn$_x$Nb$_2$TiO$_{12}$, Ca$_{5-x}$Ni$_x$Nb$_2$TiO$_{12}$, Ca$_{5-x}$Co$_x$Nb$_2$TiO$_{12}$, Ca$_5$Nb$_2$Ti$_{1-x}$ZrO$_{12}$, Ca$_3$Nb$_2$Ti$_{1-x}$HfO$_{12}$ have been prepared and characterised. It is found that Ba and Sr substitution increased $\varepsilon_r$ and $\tau_f$ whereas all other compounds form temperature stable compositions for $0 < x \leq 1$. Moreover the quality factor increased and dielectric constant decreased with $x$. The experimental values were compared with that obtained by simulation. Excellent agreement between experiment and theory was observed.

Tuning of microwave dielectric properties of Ca$_5$Ta$_2$TiO$_{12}$ ceramics by solid solution formations like Ca$_{5-x}$Ba$_x$Ta$_2$TiO$_{12}$, Ca$_{5-x}$Sr$_x$Ta$_2$TiO$_{12}$, Ca$_{5-x}$Mg$_x$Ta$_2$TiO$_{12}$, Ca$_{5-x}$Zn$_x$Ta$_2$TiO$_{12}$, Ca$_{5-x}$Ni$_x$Ta$_2$TiO$_{12}$, Ca$_{5-x}$Co$_x$Ta$_2$TiO$_{12}$, Ca$_5$Ta$_2$Ti$_{1-x}$Zr$_x$O$_{12}$ and Ca$_5$Ta$_2$Ti$_{1-x}$Hf$_x$O$_{12}$ are illustrated in Chapter 6. As in the case of their niobium analogue Ba and Sr substitution increased the $\varepsilon_r$ and $\tau_f$ with gradual decrease in quality factor. Mg, Zn, Ni, Co, Ti and Zr substitution yielded temperature stable ceramics with slightly less $\varepsilon_r$ and high quality factor compared with the parent material. The experimental data is compared with simulated results and a very good agreement is observed between the two.

The results of experimental investigation made on DR loaded microstrip patch antennas are given in Chapter 7. The effect of $\varepsilon_r$ and resonant frequency of DR on the gain, bandwidth and radiation performance of microstrip patch antennas have been studied. Cylindrical DRs of $\varepsilon_r$ varying from 9 to 92 were loaded over the patch antenna. It was observed that $\varepsilon_r$ in the range 40 – 50 was best suited for bandwidth enhancement of antennas. When a dielectric resonator of $\varepsilon_r = 48$ and resonant frequency close to that of the microstrip antenna was loaded over the patch, a five fold increase in the percentage bandwidth of the antenna was observed without much affecting its gain and radiation performance. A much more improved bandwidth was obtained when the dielectric resonator was placed on the feed line close to the patch antenna.

Chapter 8 probes the fabrication of broadband dielectric resonator antennas with different geometries. A compromise between size, operating frequency and antenna performance can be made only if the $\varepsilon_r$ of the DR material is around 50. Hence cylindrical, elliptical and rectangular DRAs have been fabricated using Ca$_3$Nb$_2$TiO$_{12}$ ceramics ($\varepsilon_r = 48$) and excited with microstripline mechanisms. The experimental results were compared with simulated values and excellent agreement was observed. Cylindrical DRAs have higher gain and bandwidth compared with other two geometries. It was
observed that the antenna as well as feed line geometry plays a major role in controlling the gain, radiation performance and bandwidth. With this view the effects of feed line geometry on the antenna characteristics have also been investigated. The antenna makes a better performance with the branching of feed line.

The ninth chapter gives the conclusion of the thesis and scope for future work. It is proposed to synthesize Ca$_3$B$_2$TiO$_{12}$ (B = Nb, Ta) ceramics at low temperatures through chemical methods and development of single crystals with improved performance. Fabrication of DRA array using temperature stable DRs, miniaturized ceramic antennas employing LTCC technology and beam steerable DRAs using tunable dielectrics are proposed to improve antenna performance.
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