Chapter 7

CONCLUSIONS

The high $T_c$ cuprate superconductors are highly anisotropic, layered type II superconductors with very short coherence lengths of the order of cell dimensions. This makes it possible for the ceramic samples to have a variety of inter- and intra grain defects which form weaklinks in these superconductors. The presence of such extrinsic but ubiquitous weaklinks makes the high frequency electromagnetic response of these materials very sensitive to the applied field and temperature. The loss that arises from such weaklinks is not fully understood yet. High frequency loss poses a serious hindrance to the technical applications of these materials. Interestingly, some of the intriguing, but unsolved, problems of HTSCs such as paramagnetic Meissner effect, order parameter symmetry, etc. could actually be understood by studying weaklinks as these properties are reflected in the unavoidable weaklinks in HTSCs. Therefore, a detailed study of weaklinks at high frequencies and vortex dynamics is essential both for scientific and technological points of view. In this thesis a detailed study of HTSCs is carried out at radio and microwave frequencies. The important conclusions that can be drawn from the work presented in chapters 2,3,4,5 and 6 are given here.

The construction of a marginal oscillator is described in chapter 2. Stable oscillations are obtained by feeding the output of the oscillator to a FET amplifier in common drain configuration, which also decouples the possible interdependence of power output and frequency. To accommodate samples of various sizes and densities a coil with varying pitch is designed. It is shown that the marginal oscillator can be
effectively used to study the radio frequency absorption, penetration depth and reactance as a function of temperature and magnetic field. The magnetically modulated radio frequency technique is developed in analogy with the MAMMA technique at microwave frequencies. This technique though more sensitive than the direct power absorption suffers from a few disadvantages and can be effectively used to detect the superconducting phase transitions.

In chapter 3 a detailed study of radio frequency (MHz) absorption in sintered BSCCO and GdBCO has been presented. It is found that London's two fluid equation for surface resistance fits very well to the experimental temperature dependent absorption in both BSCCO and GdBCO superconductors. The large effective penetration depth determined is explained in terms of reduced superelectron screening and contributions from both grain and Josephson penetration depths. The reduction factor of screening at MHz is found to be an order of magnitude larger than that at GHz frequency. The temperature variation of absorption has contributions from both inter- and intra grain regions. However, in the case of field induced absorption at low fields most of the response comes from the intergrain region.

The RSJ model presented has been shown to describe the magnetoabsorption data of BSCCO very well. In the case of BSCCO it is found that the magnetoabsorption originating from the decoupled junctions seems to be less appropriate. The higher values of the parameters of the RSJ model, $\alpha(t), \beta(t)$ and $H_0(t)$ at rf suggest that a much larger number of weaklinks participate at rf than that at microwave frequency. It is found that flux flow losses are absent at low fields in this sample. The present results when compared to the magnetoabsorption at microwave frequency suggest
that the weaklinks operative at rf are much different from that at 9.98 GHz. The junctions responsible for absorption at rf are found to be of SIS type. It is suggested that magnetoabsorption in BSCCO gives an indirect estimate of the critical Josephson current variation.

Field dependence of radio frequency absorption in sintered GdBCO sample at low fields shows a slightly different response when compared to the BSCCO and can best be described in terms of a combined response from both the RSJs and decoupled junctions. The loss arising from flux flow due to depinning of the vortices at high frequencies and temperatures is not seen in this sample. The high temperature linear magnetoabsorption is attributed to the strongly coupled weaklinks which might be operative in the intragranular region.

The field induced microwave absorption (GHz) study on both sintered and melt textured samples of GdBCO, and sintered and press sintered BSCCO is presented in chapter 4. At low fields, as in the case of rf absorption, microwave absorption in sintered samples is also found to be describable by the Josephson junction model. Melt textured samples are found to show no measurable change in absorption in low fields which suggests that intergranular weaklinks are greatly reduced in these samples due to melt processing. The high field absorption is explained using the flux flow model. Though the depinning frequency in HTSCs is higher than the present frequency used, 9.9 GHz, a fraction of the fluxons do get depinned due to proximity to the depinning frequency. However, thermally assisted flux flow seems to be a major source of loss compared to the depinning of the fluxons by the high frequency currents in the samples studied. At low temperatures since thermally assisted flux flow is absent no increase
in the field induced loss is observed. The phenomenological model described in the literature is used to simulate the high field loss and it is found to fit very well to the experimental observations.

In the case of melt textured GdBCO samples with varying 211 percentages, it is found that the change in loss with field decreases with the increase in the 211 percentage, at 77K. This is explained in terms of an increase in the number of flux pinning centres with an increase in the 211 percentage. The Pinning force constant and the $J_c$ are determined for all the HTSCs studied from the activation energy, which is obtained from the fit to the flux flow model. The values of these two parameters are found to match with those determined from the magnetization measurements.

While there have been very few reports on the paramagnetic Meissner effect there have been fewer reports on the anomalous microwave absorption which is associated with $\pi$ junctions and the paramagnetic Meissner effect (PME). In chapter 5 the results of field modulated microwave absorption (FMMWA) of GdBCO pellet and powder are presented. The signature of the $\pi$ junctions is observed in GdBCO powder as anomalous microwave absorption. The absence of anomalous in-phase signal (with reference to Gd$^{3+}$ EPR signal) of the FMMWA in GdBCO pellet is explained to be the result of overshadowing of the $\pi$ junction response by a very strong dissipation in the normal Josephson junctions. The phase change observed in the FMMWA of GdBCO powder as a function of temperature gives evidence for a change in the behavior of $\pi$ junctions from para to dia state. The intragrain weaklinks with high $J_c$ are likely to be forming $\pi$ junctions in the powder sample.
It has been suggested that high frequency absorption techniques make a better tool to investigate the \( \pi \) junctions in superconductors owing to their high sensitivity when compared to conventional magnetization measurements. The phenomena of thermally induced vortex-antivortex pair formation and flux compression due to inhomogeneous cooling may not be the right pictures to explain the origin of the PME as the flux trapping that is resulted by them does not give rise to anomalous microwave absorption. A cross check should be made, on samples that show the PME in magnetization measurements, using the FMMWA to say anything conclusive about the yet unsolved problem of the PME. In the wake of the on going controversy regarding the order parameter symmetry in HTSCs, whether it is the conventional s-wave or the unconventional \( d_{x^2-y^2} \), the origin of the PME need be understood fully. Whatever is the mechanism eventually proved to be it has tremendous importance in solving the long standing problems related to vortex dynamics or order parameter symmetry.

The changes in frequency of the oscillator as a function of temperature and magnetic field when the tank coil of the oscillator is loaded with different HTSCs are presented in chapter 6. From the frequency shift, it is shown that, one can determine penetration depth and rf reactance of HTSCs. The difficulties that arise when this technique is used to determine penetration depth of sintered HTSCs are discussed. It has been observed that for all the samples studied the frequency increases when the sample is cooled to below its transition temperature. A decrease in frequency is observed in the tail region of the transition in the case of BSCCO sintered sample which is explained to be the result of an interplay between grain and Josephson penetration depths, and fractions of inter and intragrain regions. The anomalous decrease in the
frequency observed in the case of sintered GdBCO pellet as the sample is cooled to below its transition temperature could be due to an interaction of $\text{Gd}^{3+}$ moments with the Josephson currents and needs further study since DyBCO does not exhibit such an anomaly. It is suggested that a detailed study is needed to comprehend all the features seen in the frequency variation as a function of temperature and magnetic field of the HTSCs studied.