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Development of Electron Cyclotron/Bernstein Emission Radiometer for FIRST Spherical Tokamak

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Electron temperature, being one of the most important quantities to be measured in magnetized fusion plasma experiments, is conventionally diagnosed via electron cyclotron emission (ECE) for high-density and temperature plasmas that are optically thick [1]. Among the various diagnostic instruments adopted to ECE measurements, heterodyne radiometers are one of the most widely-adopted systems, where the collected radiation is down-converted to a lower frequency for easier manipulation. Such systems provide excellent time resolution along with high spatial resolution, which is suitable for not only basic steady state measurements, but also for the characterization of various MHD modes that could be excited in confined plasmas [2]. Here we report on the development of a heterodyne radiometer system that will be installed on the Formosa Integrated Research Spherical Tokamak (FIRST, major radius $R =$ 45 cm, minor radius $a = 32$ cm, maximum center magnetic field $B_0 \leq 0.5$ T) for the purpose of space- and time-resolved diagnostic of electron temperature.

As is typical in spherical tokamaks, FIRST is expected to produce overdense plasmas where the density is high enough such that the electromagnetic modes encounter cutoff regions where its propagation is prohibited. For this reason, the electron Bernstein wave (EBW) will instead be utilized, as its electrostatic nature allows it to propagate freely without cutoffs inside the plasma, while also easily satisfying the optically thickness condition required for temperature measurements. At the low-density region around the plasma boundary, EBW will mode-convert into conventional electromagnetic waves and tunnel outside to be detected. The overall conversion efficiency is determined by the edge density gradient [3], which together with the measured radiation temperature yields the actual electron temperature.

The 16-channel radiometer that will be installed on the midplane of FIRST for $T_e(R,t)$ measurements covers a frequency range of 32 GHz, where the central frequency is controllable in accordance with the magnetic field strength via the presence of a 33.5 GHz Gunn oscillator. Spatial resolution of ~ 5.5 cm at the plasma center is achieved via bandpass filter banks, each with a bandwidth of 1 GHz and ~ 70 dB suppression of neighboring channels. Optical lenses made from Teflon will focus the emission to increase the vertical spatial resolution to ~ 10 cm. A dual polarization horn antenna enables the selection of either X-mode or O-mode emission. Langmuir probe arrays will be utilized for the determination of the edge density profile required for the EBW measurements. Preliminary measurement results for a mirror-confined plasma will be presented.

References
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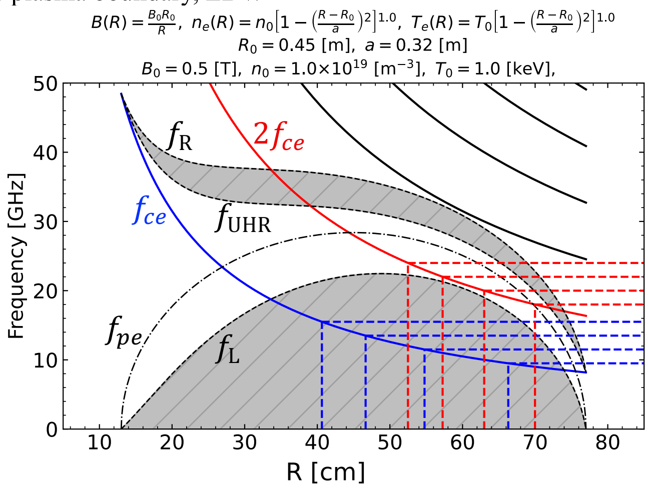

Figure 1. The radial profile for characteristic frequencies in overdense FIRST plasmas ($B_0 = 0.5$ T), along with 8 channels of the heterodyne radiometer corresponding to 1st and 2nd harmonics of ECE, covering the outboard side of the plasma.