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Diagnostic of the Spatial and Velocity Distribution of Alpha particles in
Tokamak Fusion Reactor using Beat-wave generated Lower Hybrid
Wave
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Theory Collaboration (zero cost)

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I. Introduction:

The alpha particles in a fusion reactor play a key role in the sustaining the fusion reaction. It is the heating provided by the alpha particles that help a fusion reactor operating in the ignition regime. It is, therefore, essential to understand the behavior of the alpha population both in real space and velocity space in order to design the optimal confinement device for fusion application. Moreover, the alphas represent a strong source of free energy that may generate plasma instabilities. Theoretical studies has identified the Toroidal Alfvén Eigenmode (TAE) as an instability that can be excited by the alpha population in a toroidal device. Since the alpha has an energy of 3.5 MeV, a good confinement device will retain it in the interior of the plasma. Therefore, alpha measurement system need to probe the interior of a high density plasma. Due to the conducting nature of a plasma, wave with frequencies below the plasma frequency can not penetrate into the interior of the plasma where the alphas reside. This project uses a wave that can interact with the perpendicular motion of the alphas to probe its characteristics. However, this wave (the lower hybrid wave) is below the plasma frequency and can not be directly launched from the plasma edge. This project was designed to non-linearly excite the lower hybrid in the interior of a magnetized plasma and measure its interaction with a fast ion population.

II. Summary of Experimental Progress:

This project was funded to explore the interaction of beat wave excited lower hybrid wave which can interact with a fast ion population (alpha particles in a fusion reactor). The original project schedule was I) preparation of the longitudinal beat-wave system to launch perpendicular lower hybrid waves. This work was completed in year one, and the modified launching system is shown in figure 1. The fields were detected using a computer controlled probe and its layout on the DDT port is given in figure 2. The beat-wave generators consisted of two magnetrons with frequency between 8 and 10 GHz, and with output power > 100 kwatts each. The frequency difference to excite beat wave in the ion plasma frequency range of $1 \text{ Mhz} \ll f_{pi} \ll 100 \text{ Mhz}$. The measured beat-wave and pump field and wave phase are shown in Figure 3 and 4.

Year 2 was originally devoted to optimize the microwave beam quality and beam steering (see progress report). However due to the reduce in scope, the tasks were reduce to particle probe measurements and characterization of the

excited beat-wave. Figure 5 illustrates the geometry of the probe system for ion saturation measurement. From the particle probe data, the lower hybrid wave intensity was obtained. The ion saturation current as a function of the lower hybrid resonance cone angle is plotted in figure 7 and there is general agreement with theory. The temporal measurement of the lower hybrid beat-wave was confirmed using field probes and the data is given in figure 8. The interaction of the lower hybrid wave with a fast ion population was the main task of year 3. However, due to the cancellation of the third year funding, this work was not performed. The project tasks are summarized in table I

Table I:

Tasks	Original	Reduced Scope	Final
Beat-wave excitation of LH wave	year 1	year 1	year 1
field probe detection of wave	year 1	year 1	year 1
wave dispersion	year 1	year 1	year 1
wave scattering	year 1	year 3	deleted
non-linear wave loss	year 2	year 3	deleted
3-D effects	year 2	year 3	deleted
theory comparison	years 1-3	year 3	deleted
particle probe measurement of LH wave	year 2	year 2	year 2
LH resonance cone	year 2	year 2	year 2
beat-wave antenna modification	year 2	year 3	deleted

beam steering effects	year 2	year 3	deleted
SS effects	year 2	year 3	deleted
Installation of fast ion source	year 3	year 3	deleted
Installation of particle energy analyzer	year 3	year 3	deleted
Ion source improvements	year 3	year 3	deleted
Wave-fast ion interaction	year 3	year 3	deleted
new modulator circuitry	year 3	year 3	deleted

Fields and signals

Figure 1. Experimental arrangement of the LH beat-wave excitation experiment. The orientation of the fields are

Figure 2: LabView controlled 3-axis probe scanning system on DDT. It can manipulate both field and particle probes.

Antenna and probe geometry

Figure 3: Beat wave and pump wave signals in plasma afterglow. Note beat-wave resonance at .0025-.0030 sec, not associated with pump-wave vessel resonance

Figure 4: Radial phase profile of pump and beat waves.

Figure 5: Separation of beat-wave, pump-wave, and ion-saturation measurements from single probe

Figure 6: Transverse profiles of lower-hybrid wave intensity versus time; Cone angle is used to measure plasma density.

calibration curve from 98 MHz resonance cone $\rightarrow$ 15 microamp/ 10^9 cm^{-3}

Figure 7: Calibration of ion saturation current probe using lower-hybrid resonance cone angle.

Figure 8: Beat wave signal measured directly with fast oscilloscope