Reflectometer Measurement for the Levitated Dipole Experiment

Overview

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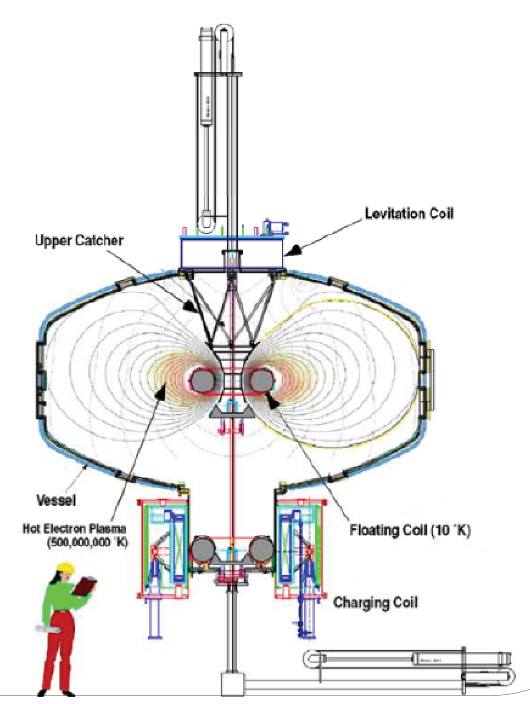
•Advantages
- Non-perturbative; power levels on the order of 1 Watt
- Easy access to interior of plasma
- Highly accurate measurements are possible, especially with high-speed digitization.

•Disadvantages
- Requires well-defined electromagnetic geometries
- Magnetic shear makes analysis more difficult (not a problem in LDX)
- Bandwidth competition with heating sources

The Levitated Dipole Experiment

INSERT brief LDX intro here



Existing LDX Density Diagnostic: 60 GHz Interferometer

Reflectometer Measurement Goals

1. Measure peak density in LDX
   - The innermost interferometer chord is outside the radius of the peak plasma density
   - The peak density is of significant general interest in determining confinement properties of the plasma.
   - The reflectometer will use the reflection from the floating coil to help determine the peak density of the plasma.
2. Measure the density profile.
   - It will also be possible to extract a detailed density profile from the reflectometer signal
3.
4.
   -
5.
6.
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Reflectometer Theory

Plasma Dispersion

The cold plasma approximation (wave phase velocities much faster than the thermal speed) yields the dispersion relation

$$N^2(N_\perp^2\kappa_\perp + N_\parallel^2\kappa_\parallel) + \kappa_R\kappa_L\kappa_\parallel - (N_\perp^2\kappa_R\kappa_L + (N^2 + N_\parallel^2)\kappa_\perp\kappa_\parallel) = 0$$

Choosing propagation perpendicular to the magnetic field

$$N_\perp^4 - N_\perp^2(\kappa_R\kappa_L/\kappa_\perp + \kappa_\parallel) + \kappa_R\kappa_L\kappa_\parallel/\kappa_\perp = 0$$

Solving:

$$N_\perp^2 = \begin{cases} 1 - \frac{\omega_p^2}{\omega^2} & \text{O-mode} \\ \frac{(\omega^2-\omega_L^2)(\omega^2-\omega_R^2)}{(\omega^2-\omega_{UH}^2)(\omega^2-\omega_{LH}^2)} & \text{X-mode} \end{cases}$$

$$\vec{N}(\omega) = N_\perp\hat{e}_\perp + N_\parallel\hat{e}_\parallel = c\vec{k}/\omega$$

Next steps

1. Increase frequency resolution with a delay line
   - A coaxial delay line inserted into the signal train will increase the signal time of flight, which will increase the mixer output frequency.
   - This will allow for greater frequency (and therefore density) resolution.
2. Add amplification stage for returning signal.
   - Since the return signal is very weak compared to the local oscillator signal it is mixed with, adding an amplification stage may improve the performance of the mixer
3. Fully calibrate oscillator in sweep mode
   - The calibration of the oscillator a steady frequencies is known, but the linearity of the sweep will be tested
4. Expand reflectometer capability
   - Measurement of full density profile
   - Measurement of density fluctuations at arbitrary radii
   - Purchase high-accuracy fully programmable signal generator to control oscillator.

Reflectometer Design and Operation

"Pseudo-heterodyne" Swept Reflectometer

The design of this reflectometer was motivated by the density and magnetic field of the plasma environment in LDX. The reflectometer has access to the plasma on the midplane of the experiment. The magnetic field is therefore almost entirely perpendicular to the signal path; the reflectometer is operated in O-mode to take advantage of the simple cutoff frequency dependence on density alone.

The plasma density peaks at approximately 10^12 cm^-3. Therefore, a frequency range of up to 8 GHz was required. In order to probe through most of the radius of the machine, a lower frequency limit of 4 GHz was chosen.

The oscillator at the heart of the reflectometer is a YIG (Yttrium Iron Garnet) oscillator, which is capable of very high frequency ranges, and is easily controllable via a DC voltage.

The reflectometer operates as follows:
1. The YIG oscillator produces a wave at a frequency which sweeps linearly between 4 GHz and 8 GHz.
2. The wave is launched into the plasma by a log-dipole-array antenna.
3. Depending on the current frequency, the wave is reflected from the plasma and returned to the receiving antenna.
4. The return signal is then mixed with the local sweeping frequency.
5. The returning frequency will be mixed with a frequency which depends on how long the wave was gone – the time of flight (i.e. the distance to the cutoff layer at the launched frequency).

Reflectometer Characteristics

Frequency range:	4 GHz – 8 GHz

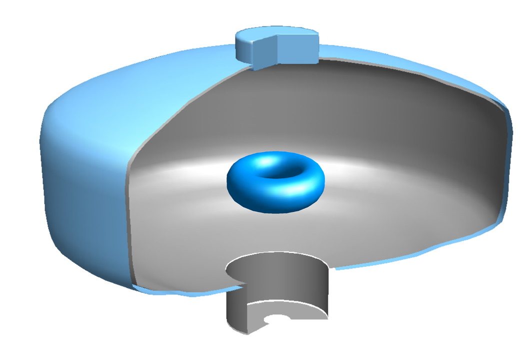
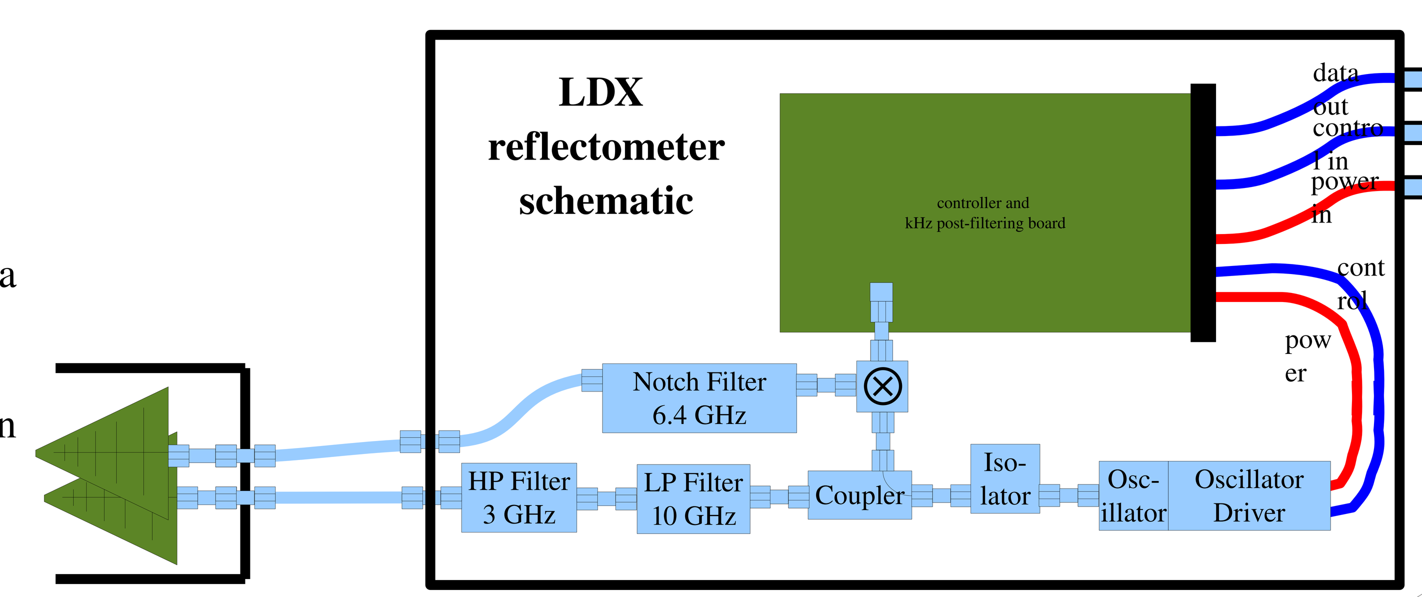


Photo of reflectometer's guts here?



Data Analysis

$$\omega_{probe}(t) = \alpha t + \omega_0$$

$$\begin{aligned}\omega_{reflect}(t) &= \omega_{probe}(t - 2\frac{r_c(n_c(\omega_{probe}(t)))}{c}) \\ &= \alpha t - \alpha\frac{2}{c}r_c(n_c(\omega_{probe}(t))) + \omega_0\end{aligned}$$

$$\begin{aligned}\omega_{mixer} &= \omega_{probe} - \omega_{reflect} \\ &= \frac{2\alpha}{c}r_c(n_c(\omega_{probe}(t)))\end{aligned}$$

$$\begin{aligned}n(r = \frac{c}{2\alpha}\omega_{mixer}(t)) &= n_c(\omega_{probe}(t)) \\ &= \frac{\epsilon_0 m_e}{e^2}(\omega_{probe})^2 \\ &= \frac{\epsilon_0 m_e}{e^2}(\alpha t + \omega_0)^2\end{aligned}$$

INSERT EXAMPLE DATA ANALYSIS HERE (working on it)