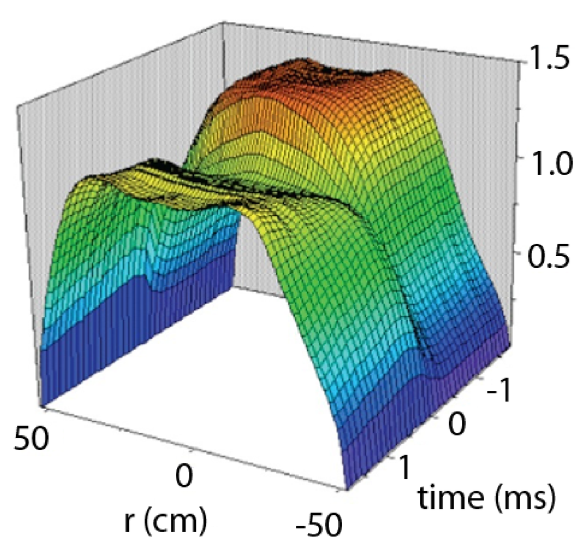
Abstract

An accurate temporally and spatially resolved measurement of the electron density profile is an important diagnostic for a confined plasma device. An understanding of particle transport during events like a sawtooth crash can be obtained from the changes in the density profile, and resolving density fluctuations can help in the understanding of plasma instabilities. Proposed here is a multi-frequency phase measuring reflectometer which measures the signal reflected from the cutoff layer in the plasma. Simultaneous measurements of phase change for four frequencies between 4-8 GHz are used to reconstruct the edge density profile. Each phase shift is measured via digital complex demodulation of a 455 kHz signal created by mixing each drive signal with an appropriately tuned local oscillator which can in principle deliver fluctuation information up to around 200 kHz. Included in this design in a phase and amplitude control to zero out the signal from the vacuum interface reflection.

Benefits of the diagnostic

•Provides information on evolution of the equilibrium edge density profile through sawtooth or transition to PPCD
•Unobtrusive nature and high temporal resolution allows for method to measure edge density fluctuations for high temperature and high current plasmas
•Can work in tandem with radiometer to get time-dependent coupling efficiency of ECE through vacuum layer



Previous work suggests analysis technique

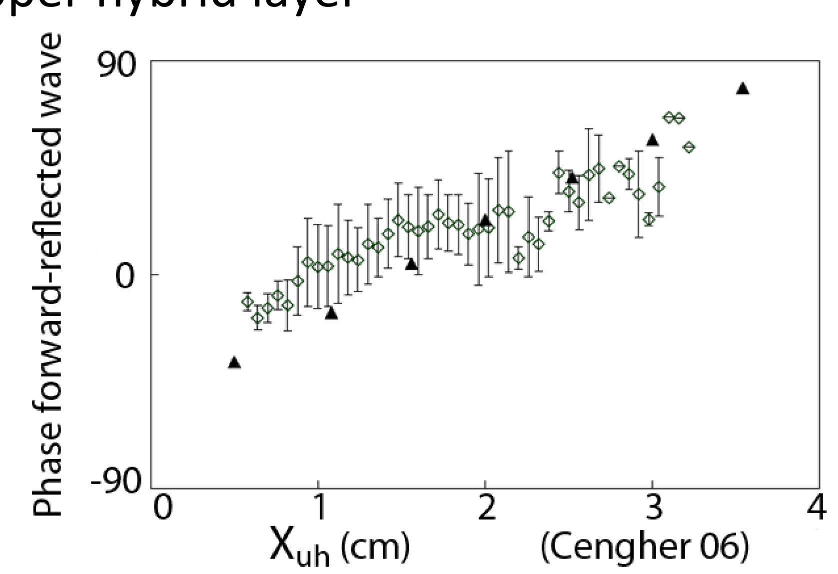
•Phased antenna array work on EBW coupling shows the expected correlation between the forward-reflected phase and distance to upper hybrid layer

Correct:

$$\Delta\theta = \int \frac{2\pi dx}{\lambda(x)}$$

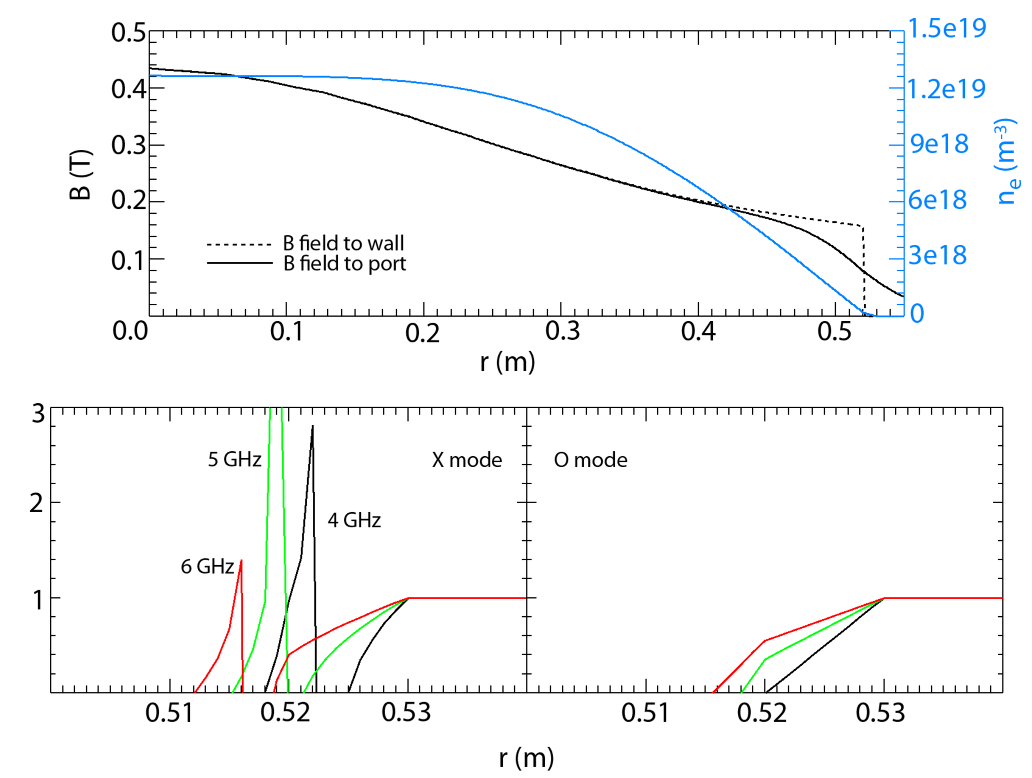
Good enough:

$$\Delta\theta = \frac{2\pi \Delta x}{\lambda_{vacc}}$$



Cold plasma dispersion relation describes wave behavior

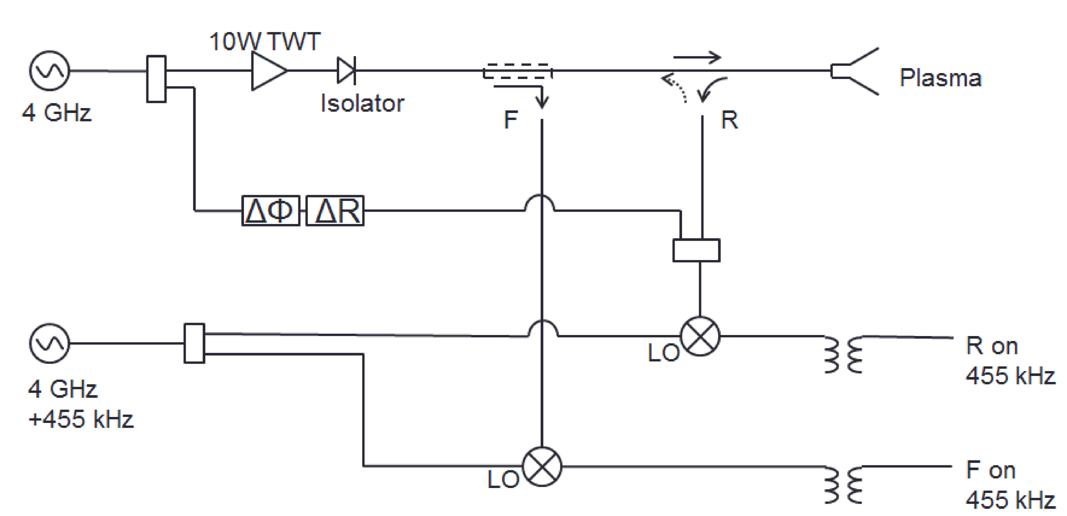
•B field modified to include port field error (solid line) and electron density given non-zero value (linear tail in blue) to show wave behavior of X-mode or O-mode launch
•Indicates the need for edge density correction: previous work (Cengher) shows X-mode penetration at 3.65 GHz



vertical dashed line marks transition to linear tail of electron density
B field and electron density from 400 kA standard plasma shot

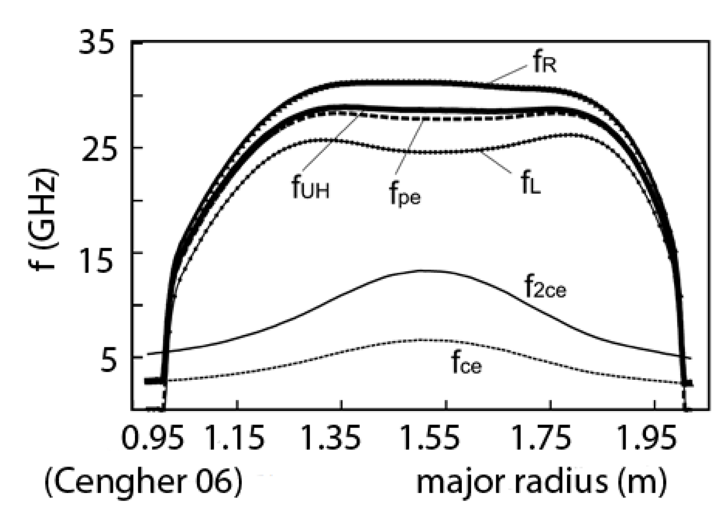
Reflectometer Design

•F and R signals digitized at 6 MHz
•4 channels (1 shown)



Limitations of Design

•Temporal resolution
  -Forward and reflected signals sampled at 6 MHz
  -Complex demodulation limits resolution to ~200 kHz
•Spatial resolution and restriction to edge
  -Changing pitch angle of B field with increased penetration of wave complicates wave behavior
  -Reliable profile construction requires small change in cutoff layer depth between probing frequencies



Signal Processing

•Take plasma (reflected) signal:

$$x(n) = A(n)\cos[w_0'n + \theta_r(n)]$$

$$n = 0,1,\ldots,N-1 \qquad w_0' = w_0\Delta t$$

•Take DFT

$$X(w_0') = \frac{1}{N}\sum_{n=0}^{N-1} x(n)e^{-iw_0'n}$$

•Remove terms above Nyquist frequency:

$$X(w_0') = 0, \qquad for\, \frac{N}{2} \le n \le N-1$$

•Taking inverse DFT gives:

$$x(n) \propto e^{i(w_0'n+\theta_r(n))}$$

•The same process applied to the forward signal gives:

$$y(n) \propto e^{i(w_0'n+\theta_f(n))}$$

•Then:

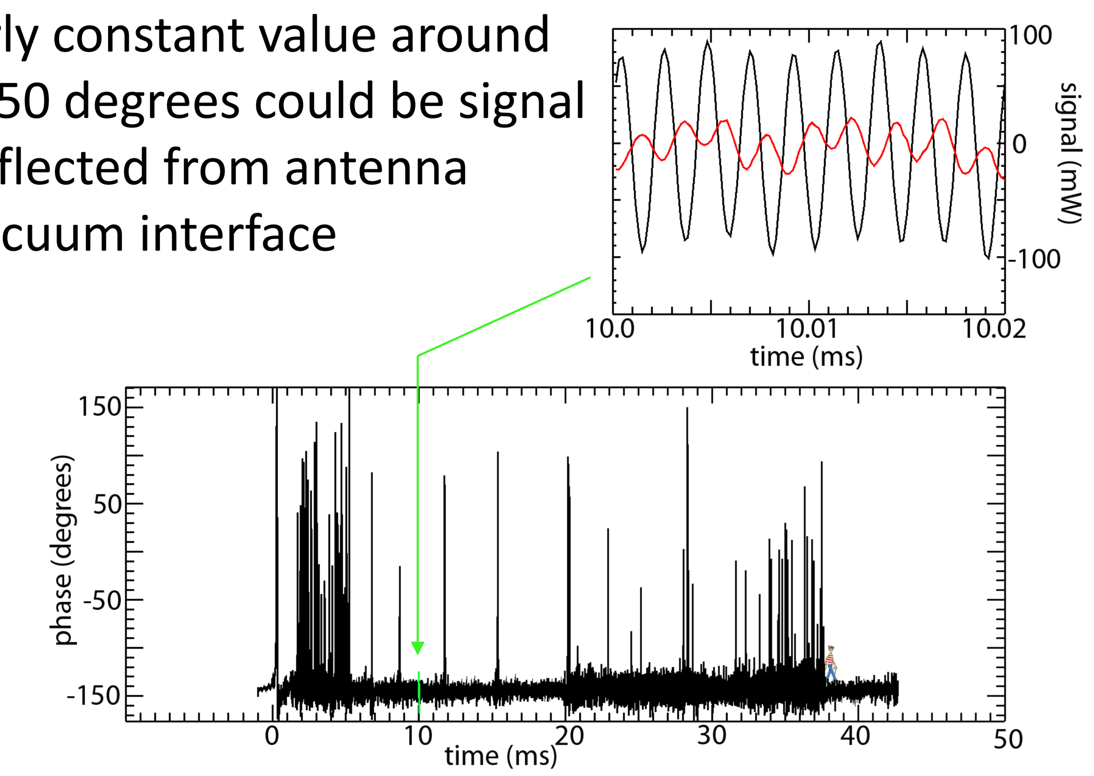
$$ϟ = x(n)y^*(n) = C(n)e^{i[\theta_r(n)-\theta_f(n)]}$$

•The phase is then:

$$\theta_{plasma} = tan^{-1}\left[\frac{Im(ϟ)}{Re(ϟ)}\right]$$

Initial phase data, antenna *retracted*

•Reflected signal shows low power
•Fairly constant value around
  -150 degrees could be signal reflected from antenna vacuum interface



top: forward (black) and reflected (red) signals are processed to give phase v. time
bottom: phase v. time for 6 GHz during 400 kA standard plasma

Future Work

•Upgrade antenna
•Calibrate diagnostic
  -Determine method to account for instrument phase
•Include instrument phase offset in signal analysis
•Assess best analysis procedure
  -Can we assume vacuum wavelength
  -Determine method to handle ambiguity in cutoff layer location

Creating edge density profile

•To correct for phase wrapping the signal is manipulated to satisfy the assumption $\Delta\theta < \pi$ between consecutive samples
•Correlate depth of cutoff layer for each frequency assuming vacuum wavelength, with correction to ensure larger wave penetration at higher frequencies
  -Previous work (Cengher) suggests assuming vacuum wavelength will give good agreement
  -Ambiguity: location of the cutoff layer for some frequency could vary by a multiple of $\lambda/2$
•Correlate cutoff layer to frequency

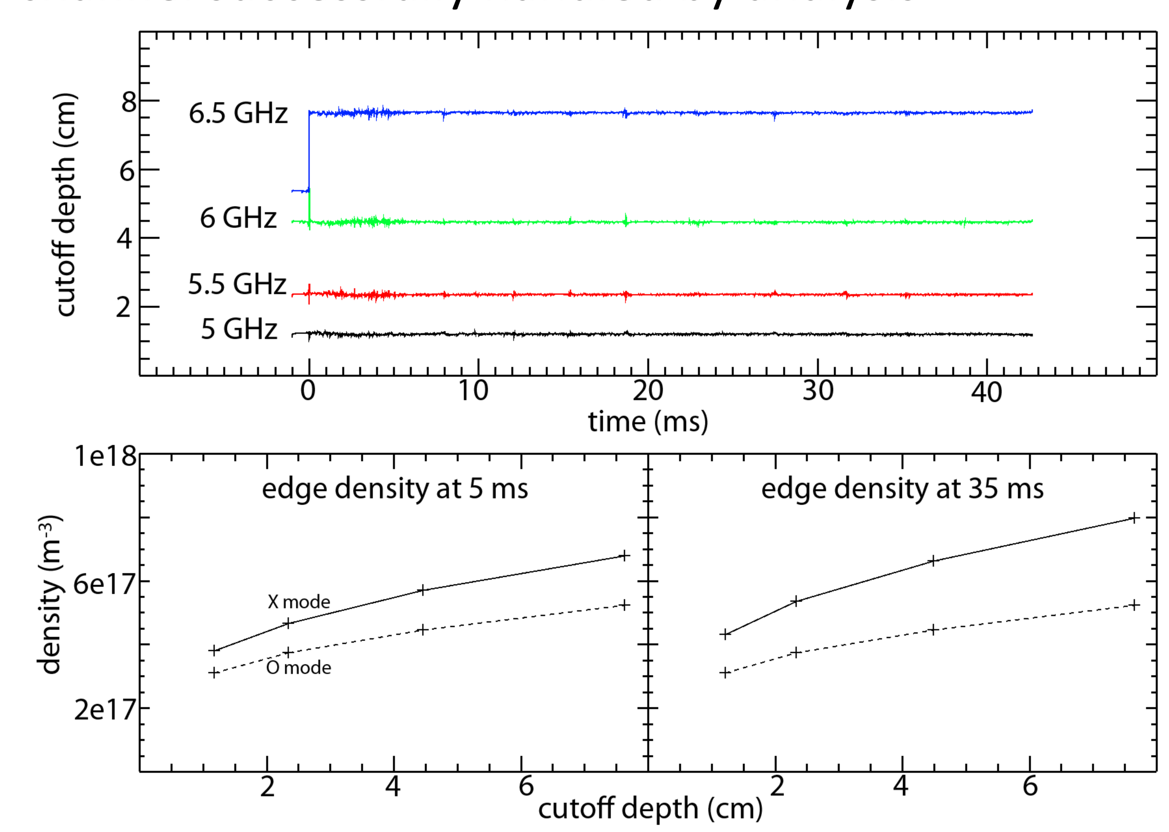
$$\omega = \omega_p = \sqrt{\frac{ne^2}{m\varepsilon_0}} \qquad O\ mode$$

$$\omega = \omega_R = \frac{1}{2}\left(\Omega + \sqrt{\Omega^2 + 4\omega_p^2}\right) \qquad X\ mode$$

•Combining these results gives a time dependent edge density profile
•Also available from this processing is the time dependent density fluctuation for each of the probe frequencies

Test data put through analysis code successfully returns edge density profile

•RF signal successfully launched and received from antenna on MST
  -Reconstruction of edge density profile successful
  -Phase offset (due to instrument) still present
  -High reflection from antenna, low signal information
•Using mock data from a realistic density profile, processing code reproduces edge density
  -Phase skip technique successful
  -Random phase added to each signal to simulate unknown electrical path length difference for each channel successfully handled by analysis



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