Overview of The University of Texas Research in US-PRC Collaboration: Fast Modulating ECE Diagnostic at EAST Tokamak

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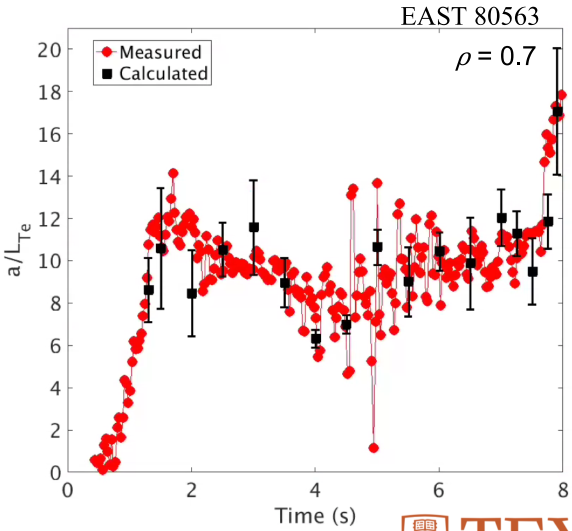
Motivation: Variable-Frequency ECE Channels can Measure ∇Te in Real-Time

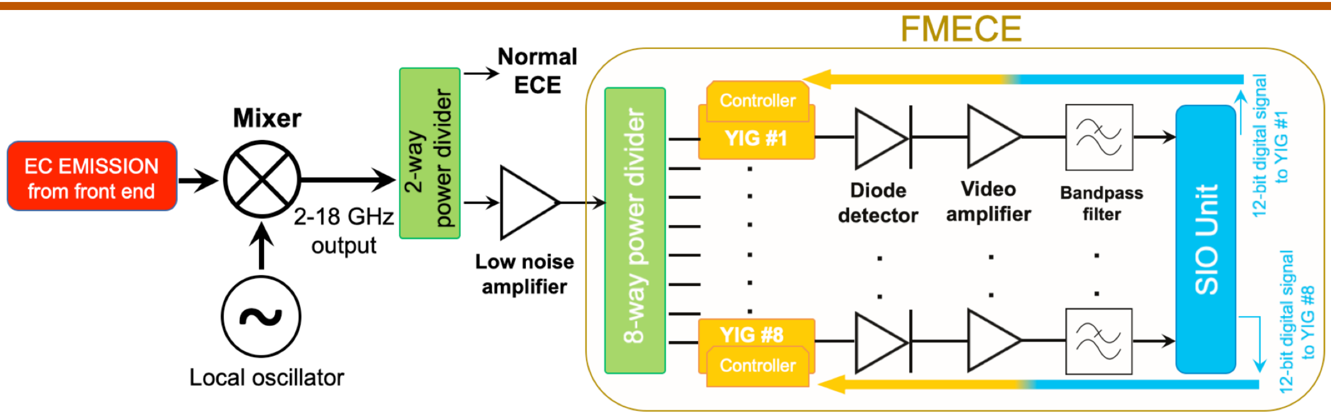
Here, we follow the idea of monitoring magnetic islands dynamics and locked mode detection via measuring the Te-profile flattening (i.e., reduced ∇T_e) in real-time.

- Utilizing variable-frequency channels, e.g., yttrium iron garnet (YIG) bandpass filters, in the intermediate frequency (IF) section of ECE radiometers has increased the spatial resolution of T_e and ∇T_e profiles.
- Fast frequency switching (slew) of the YIG filters facilitates real-time ∇T_e measurements with excellent temporal resolution.



- Two YIG channels were integrated into the EAST radiometer (summer 2018). The measured a/L_{Te} was found to be in good agreement with the one calculated from the T_e-profile.

INTRODUCTION

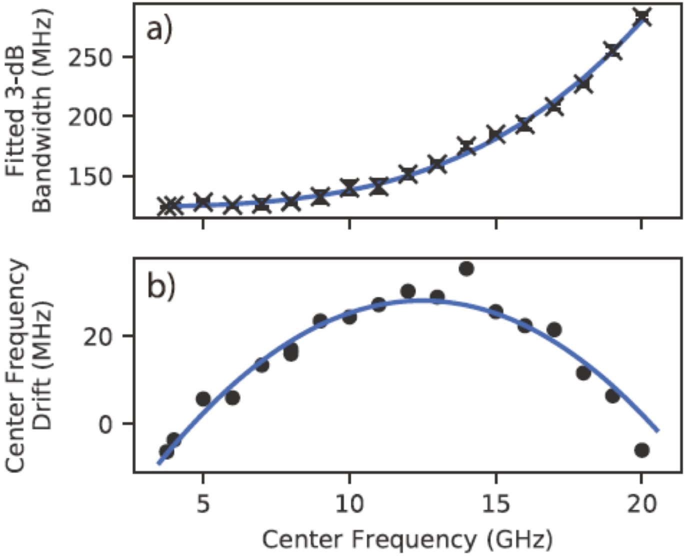


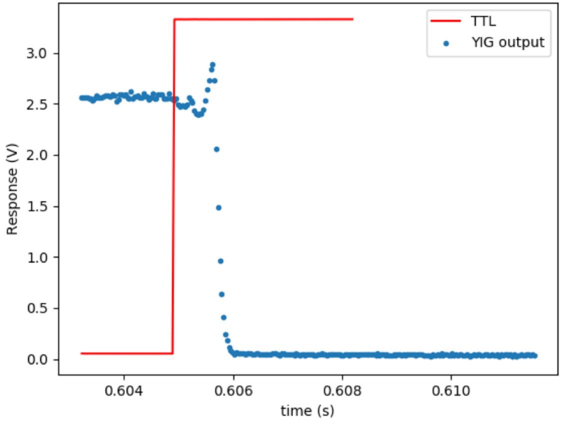
- Fast Modulating/Mobile Electron Cyclotron Emission (FMECE) diagnostic is designed to measure electron temperature gradient (∇T_e) and the gradient length scale ($L_{Te}^{-1} = \nabla T_e / T_e$) at eight radial location with 0.6 ms temporal resolution.
- FMECE can potentially be used as a sensor to the actuators and the control system by monitoring the island size and controlling tearing modes in tokamaks.
- FMECE is a stand-alone IF unit that utilizes fast response YIG filters; a fast (700 kHz) simultaneous input/output (SIO) data acquisition equipped with an FPGA card facilitates real-time ∇T_e measurements as well as real-time relocation of the ECE channels.
    - FMECE successfully measured L_{Te}^{-1} for a DIII-D discharge.
    - Using equilibria, FMECE was successfully simulated frequencies (i.e., ECE locations) to keep the channels on a specified flux surface. Research is underway to use real-time equilibria, for real-time relocation of the channels.

CHARACTERIZATION OF FMECE CHANNELS

Each FMECE's YIG filters was characterized for

- Frequency bandwidth at set (center) frequencies.
- Frequency shift when set at a center frequency.
- Time response to a frequency change (frequency slew).





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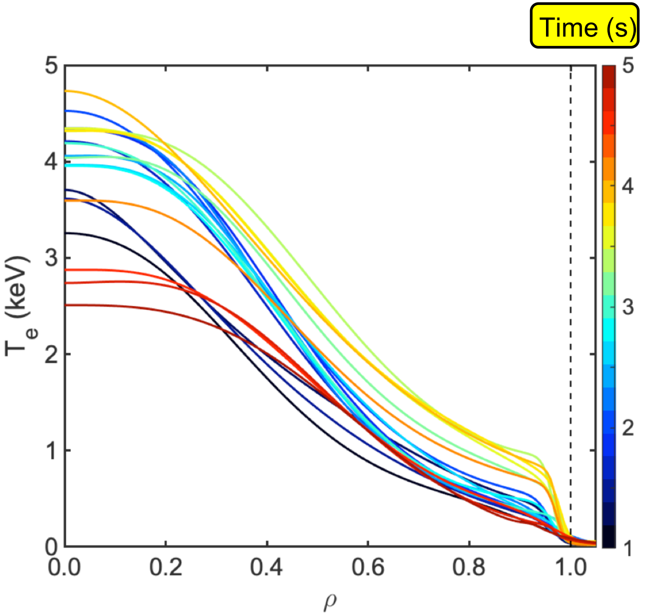
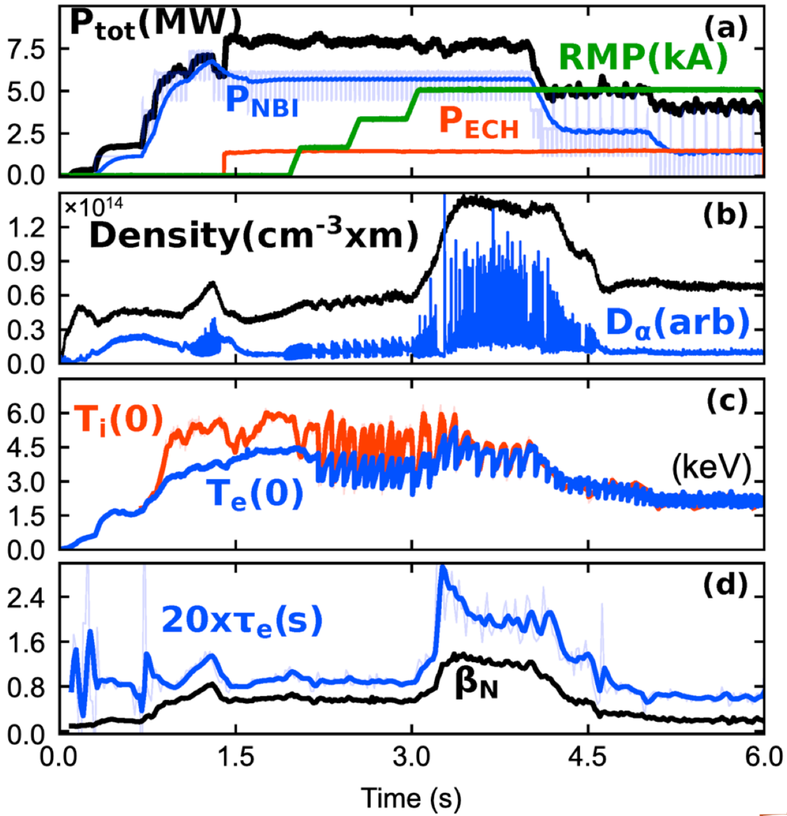
FMECE was Recently Tested with a DIII-D Discharge

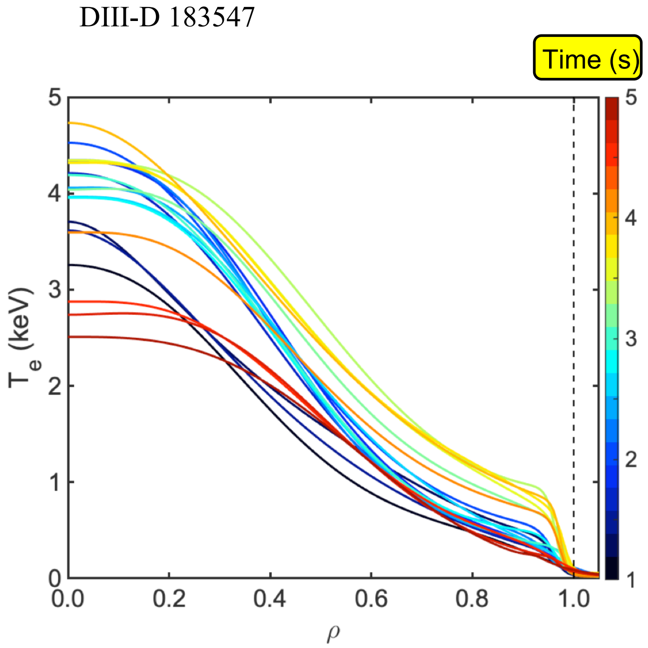


Fit to the T_e-profile from the Thomson Scattering diagnostics. Full H-mode observed at 3.0 s < t < 4.5 s. The discharge transitions back to L-mode at 4.5 s.

DIII-D 183547



Te-Profile from Thomson Scattering Diagnostic Shows Increase in the Gradient and Decrease in the Inverse Gradient Scale Length as the Discharge transitions to H-Mode



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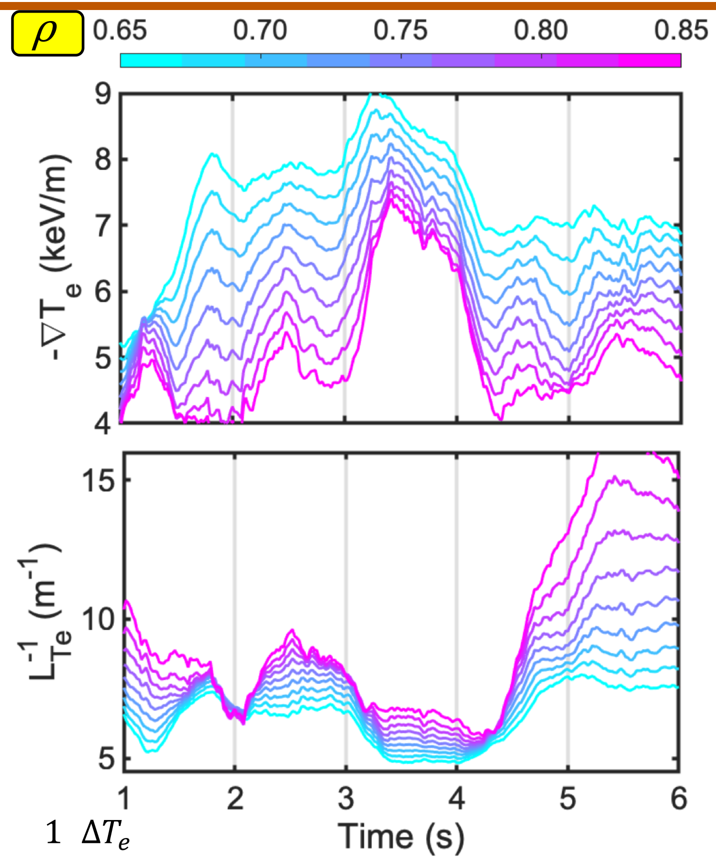
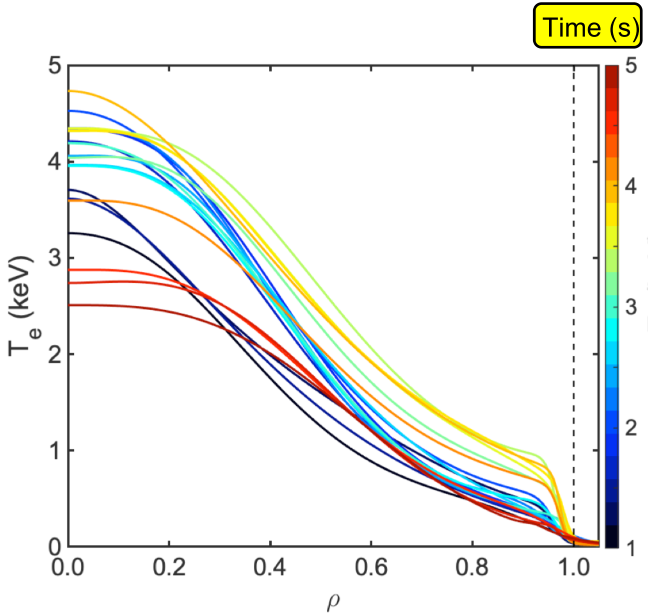
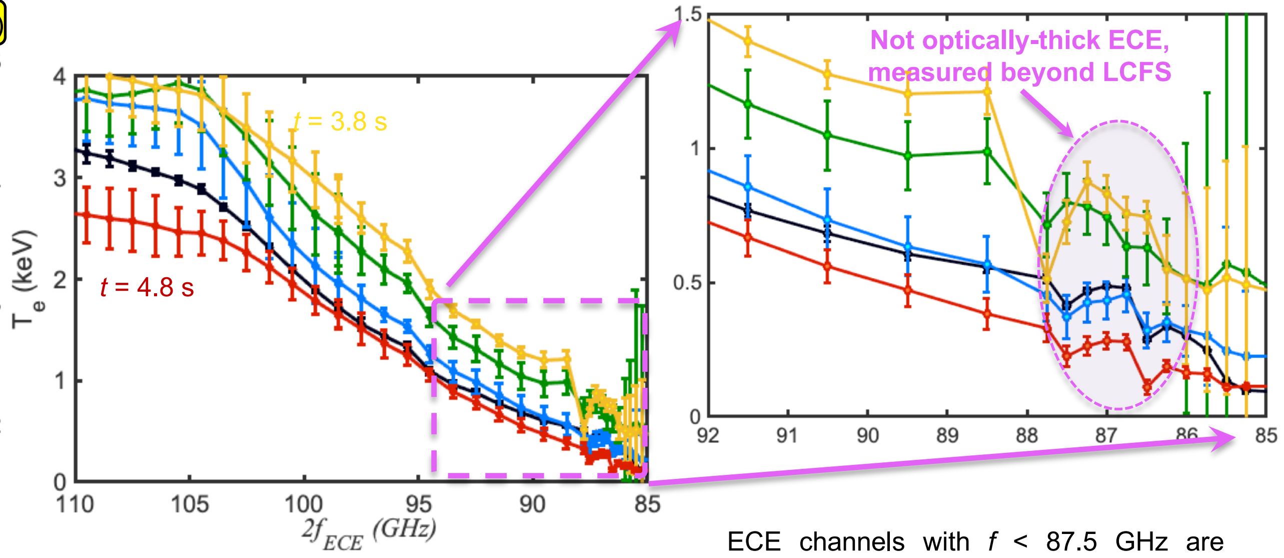


$$\frac{1}{L_{Te}} = -\frac{\nabla T_e}{T_e} \cong -\frac{1}{\Delta R}\frac{\Delta T_e}{\overline{T_e}}$$

ECE Measurements beyond Last Closed Flux Surface shows increase in Electron Temperature Due to Non-Thermal Electrons



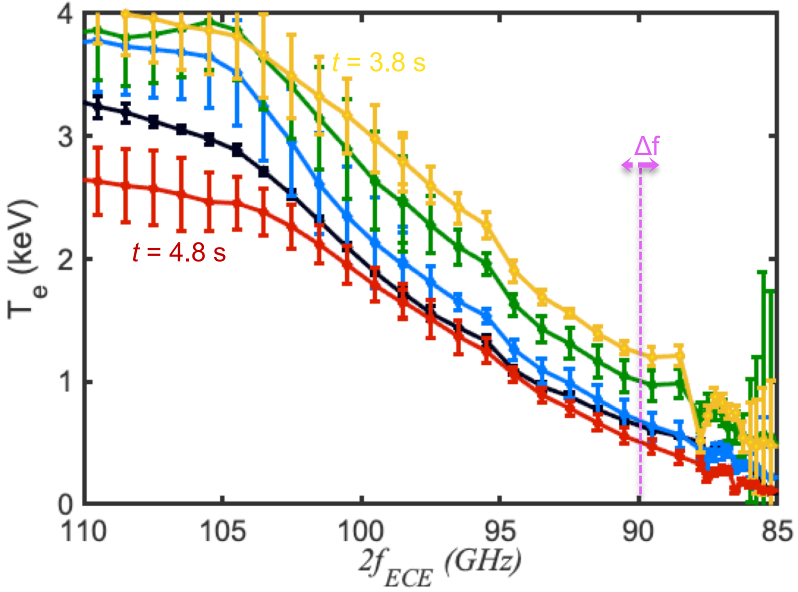


Fit to the T_e-profile from the Thomson Scattering diagnostics (left) is in good agreement with the one from ECE radiometer.

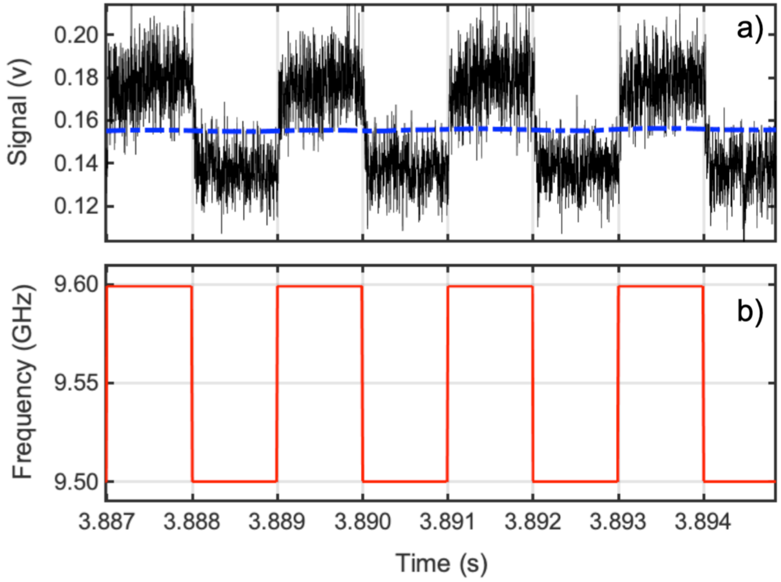
ECE channels with f < 87.5 GHz are collecting EC from sample volumes that are not optically-thick. In the full H-mode (e.g., t = 3.8 s), the normal ECE channel with f = 87.75 GHz is measuring beyond LCFS.

$$\frac{1}{L_{Te}} = -\frac{\nabla T_e}{T_e} \cong -\frac{1}{\Delta R}\frac{\Delta T_e}{\bar{T}_e}$$

∇T_E or L_{TE}^{-1} are Measured by Slewing of FMECE Channel



The vertical line shows the location of the FMECE channel 4 in within the profile and the horizontal arrows show the range of Δf.



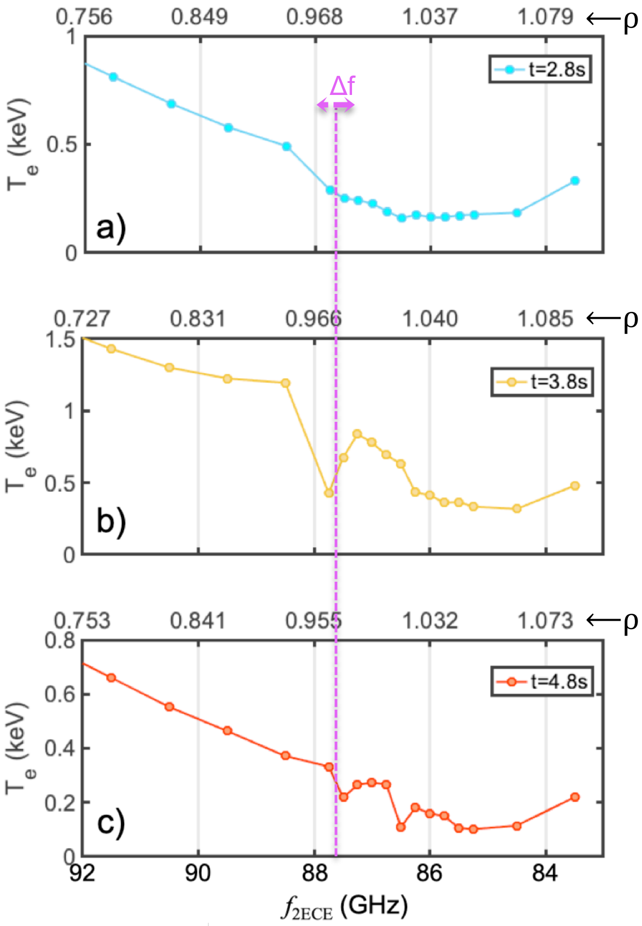
The signal from FMECE (top) channel 4, when it was slewed (bottom) between 9.5 and 9.6 GHz (equivalent to 90.5 and 90.6 GHz when mixed with a 81 GHz local oscillator). The blue trace in the average ECE signal. The fractional change is a calibration-free parameters and it is a proxy for L_{Te}^{-1}.

$$\frac{1}{L_{Te}} = -\frac{\nabla T_e}{T_e} \cong -\frac{1}{\Delta R}\frac{\Delta T_e}{\overline{T_e}}$$

Fractional Change $\frac{\Delta f}{|\Delta f|}\frac{\Delta ECE}{\overline{ECE}}$

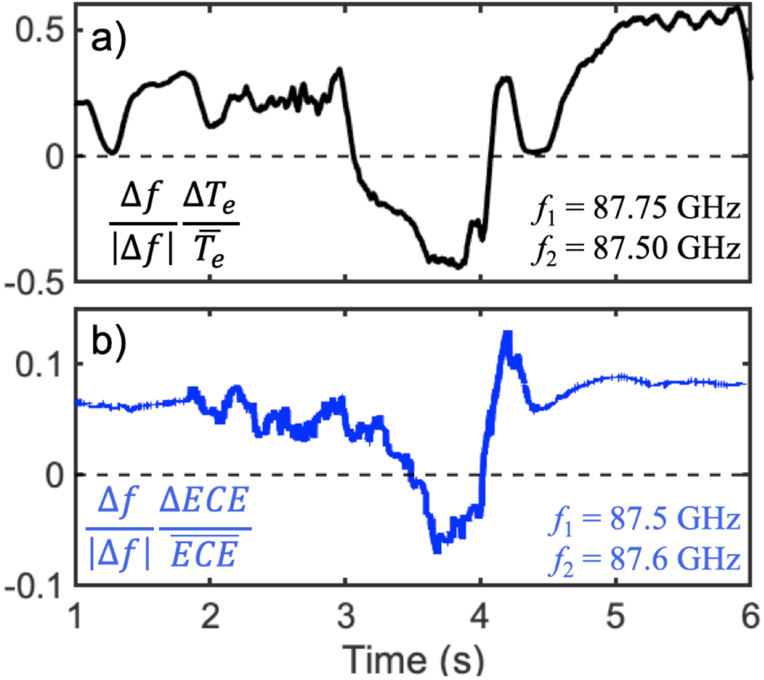
$$\Delta R \propto -\Delta f$$

The Fractional Change from FMECE Agrees with the one Calculated from the Te profile measured by ECE



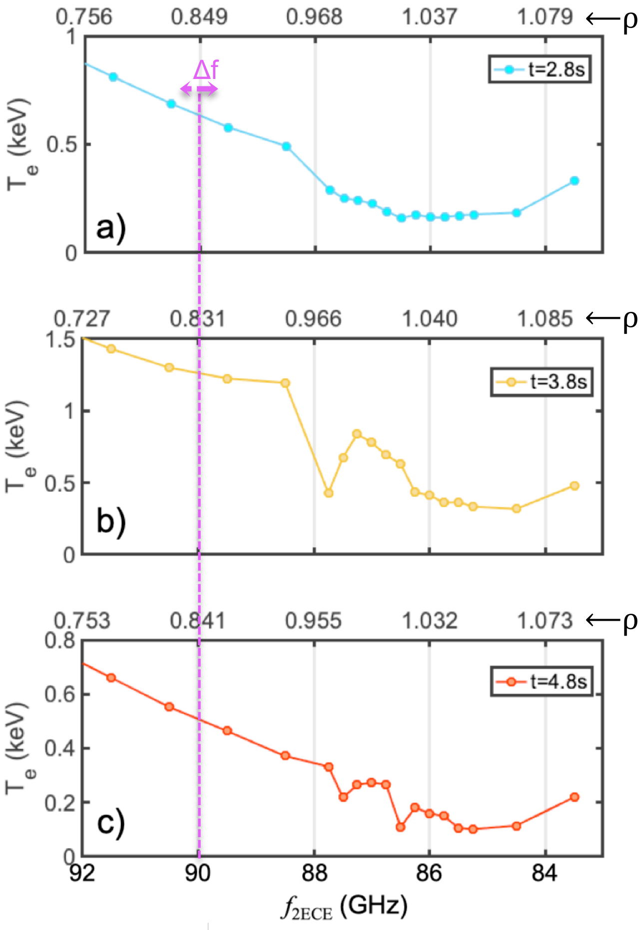
The vertical line shows the location of the FMECE channel 1 is within the profile and the horizontal arrows show the range of Δf = 0.1 GHz. The negative value for the fractional change (e.g., at *t* = 3.8 s) is due to the location of the channel, beyond LCFS.

a) Moving average (100 ms) of fractional change, measured from T_{ECE} profile, channels 48 and 5 (set at 87.75 and 87.5 GHz respectively).



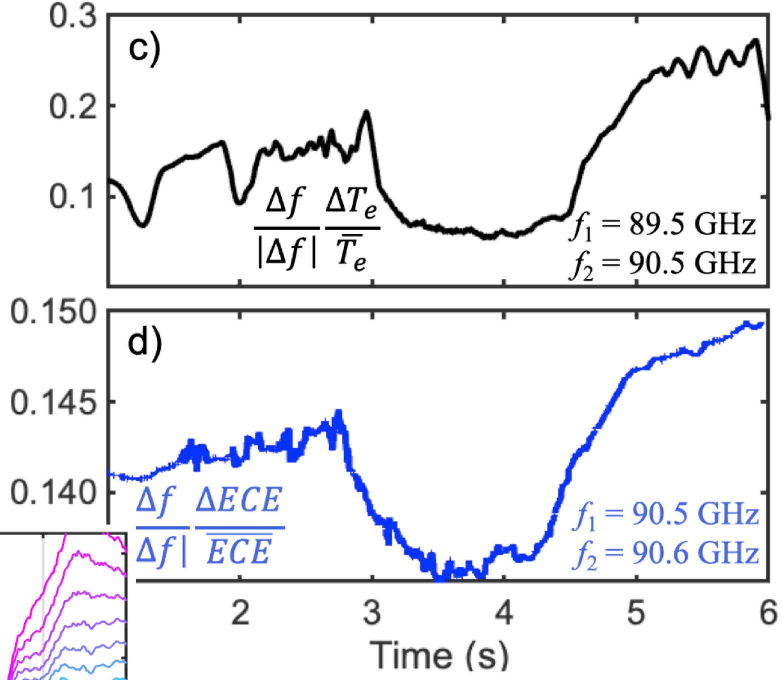
b) Moving average (750 ms) of the fractional change, measured by FMECE channels 1, slewed between 87.5 and 87.6 GHz

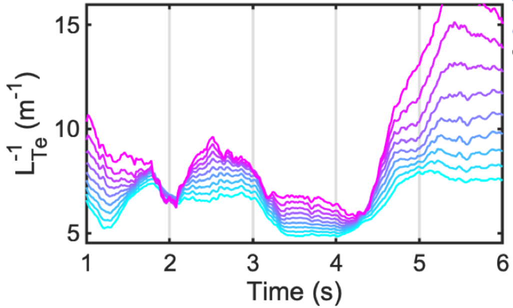
THE FRACTIONAL CHANGE FROM FMECE AGREES WITH THE ONE CALCULATED FROM THE TE PROFILE MEASURED BY ECE



The vertical line shows the location of the FMECE channel 4 in within the profile and the horizontal arrows show the range of **Δf = 0.1** GHz.

a) Moving average (100 ms) of fractional change, measured from T_{ECE} profile, channels 8 and 9 (set at 89.5 and 90.5 GHz respectively).





b) Moving average (750 ms) of the fractional change, measured by FMECE channels 4, slewed between 90.5 and 90.6 GHz

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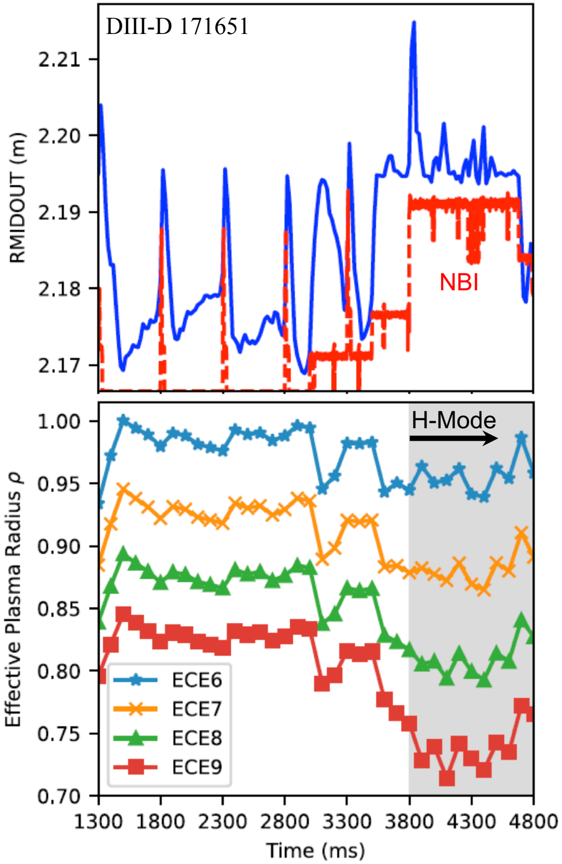
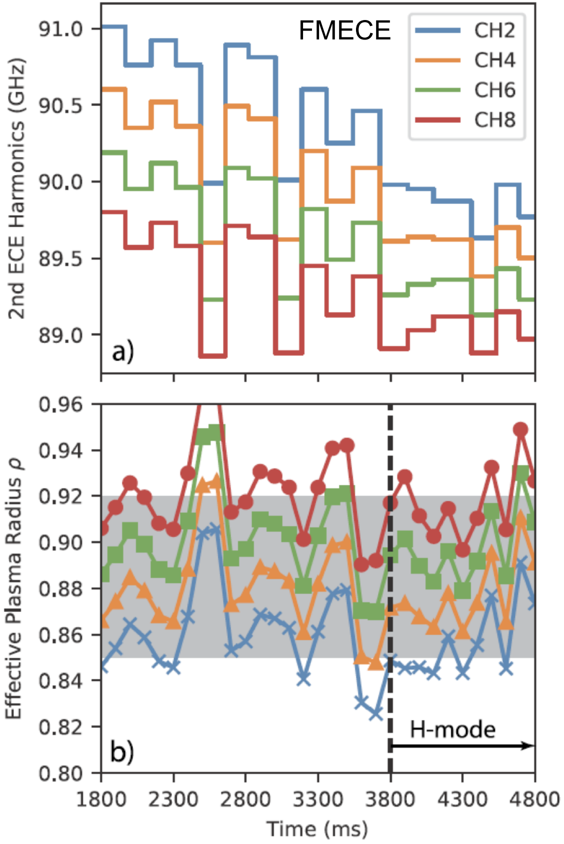
FMECE can be Used for Real-Time Relocation of ECE Channels





Frequency settings of even-numbered FMECE channels, using the latest reconstructed equilibria.

Research is underway to use the real-time equilibria to keep the FMECE channels in the region of interest.

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SUMMARY

- This work is a proof of principle for fast and real-time measurement of Te-gradient and gradient scale length, using FMECE. These measurements can be used as sensors for island size monitoring for the control purposes.
- FMECE is an IF module and an addition to any ECE radiometer. It utilizes eight fast-response yttrium iron garnet (YIG) bandpass filters.
- Short slew (Δf = 0.1 GHz) of the FMECE channel shows agreement in fractional change -a proxy to L_{Te}^{-1}- with the one calculated from regular ECE radiometer, as well as the profiles from Thomson Scattering diagnostic.
- FMECE is scheduled to be integrated into ECE radiometer at EAST tokamak for island detection and tearing mode studies.