NSTX

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Preliminary study of HHFW driven plasma fluctuation measurement using FIReTIP in NSTX

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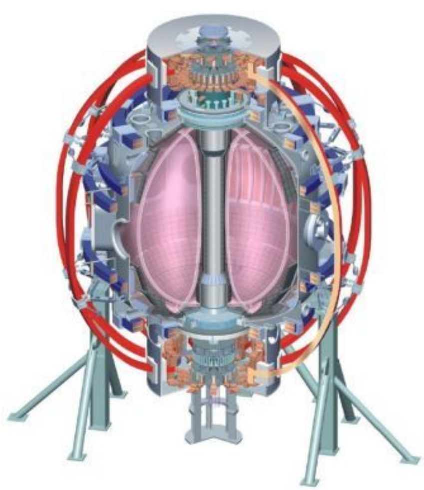

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ABSTRACT

NSTX is equipped with an FIR interferometry (FIReTIP) and high k scattering system, which can monitor high frequency density fluctuations driven by RF waves. High Harmonic Fast Wave (HHFW) fields drive localized density fluctuations at 30 MHz that may be detectable by this system. The electronics for 30 MHz signal observations were designed and are being upgraded for FIReTIP, which can observe path-averaged density fluctuations with localization information obtained using a multi-channel system. The location of the observed fluctuations will be compared to predictions from the HHFW version of the TORIC code, which solves the Maxwell equations in toroidal geometry, using a quasi-local approximation that retains large $k_{perp}\rho_i$ effects but assumes that only the HHFW fields are excited. The RF induced density perturbation in NSTX discharges heated by the 30 MHz HHFWs will be localized within the field distribution predicted by the TORIC code. In this presentation, the conceptual design including experimental development and the preliminary results of simulation will be presented.

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Overview

- Description of FIReTIP system for RF fluctuation measurement
  - Status of experiment
  - Preliminary results
- Brief description of TORIC, full wave code
  - HHFW simulation with quasi-local approximation
- Summary and Future work

Experimental Measurement of RF Fluctuation

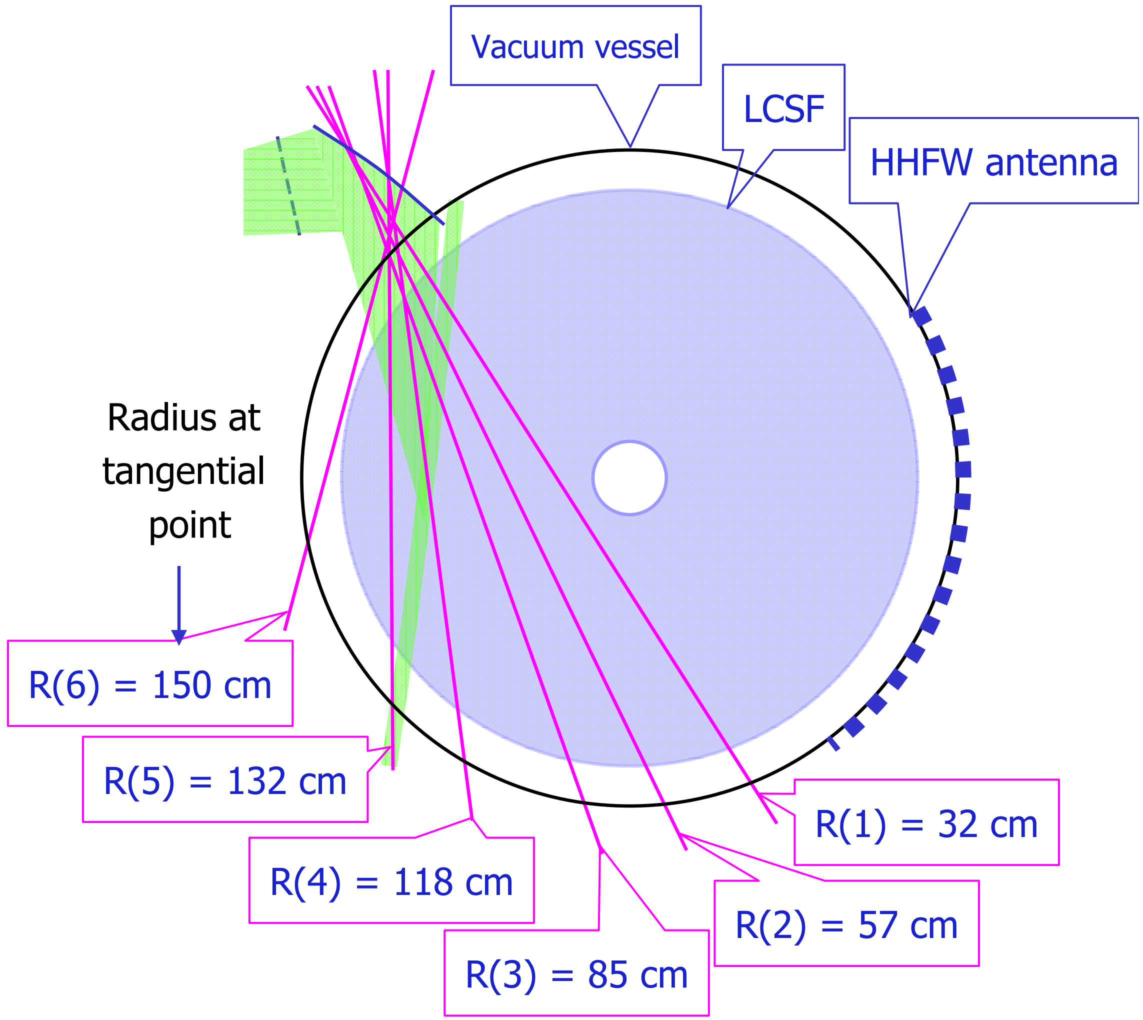
- Diagnostics for RF wave induced density fluctuation measurement
  - Reflectometers in many devices
  - Phase Contrast Imaging (PCI) in C-mod

- NSTX has two more candidates for RF density fluctuation measurement
  - High k scattering system.
    - Local monitoring of RF driven waves
  - FIReTIP
    - Global monitoring system

  ➔Separate outputs with additional mixers at RF frequency

FIReTIP Chords in NSTX Midplane

- The RF mixing circuit was installed for R(1) = 32 cm chord of FIReTIP in 2009.
- RF mixing circuits can be installed on any of these chords.
- The measured fluctuations at various radial chords and antenna phase angles will be compared to the calculated levels from TORIC results.



Separation of RF Fluctuation Signal

- Signals from RF induced density fluctuation
  - Scattering from electron fluctuation
  - Macroscopic fluctuation in dielectric constant
- Perturbed electric field by refractive index fluctuation

$$E(t) = E_o \exp i(\omega_i t + \Delta\phi_e) = \exp i(\omega_i t + \overline{\phi_e} + \tilde{\phi}_e)$$

$$= \exp i(\omega_i t + \overline{\phi_e}) \boxed{\exp i(\tilde{\phi}_{eo} \cos\omega_{RF} t)}$$

$$n_e = \overline{n}_e + \tilde{n}_e \Rightarrow \Delta\phi_e = \overline{\phi_e} + \tilde{\phi}_e$$

$$\tilde{n}_e \sim \tilde{n}_{eo} \cos\omega_{RF} t \Rightarrow \tilde{\phi}_e = \tilde{\phi}_{eo} \cos\omega_{RF} t << 1$$

$\overline{n}_e$: Unperturbed density

$\tilde{n}_e$: RF induced density fluctuation

Taking a Fourier transform of an integral representation of a Bessel function

$$\exp(iz\cos\theta) = \sum_{n=-\infty}^{\infty} i^n J_n(z) \exp(in\theta)$$

- Fourier component

$$E(\omega) = E_o \exp[i\,\overline{\phi_e}] \sum_{n=-\infty}^{\infty} i^n J_n(\tilde{\phi}_{eo}) \exp i[\omega_i t + n\omega_{RF} t]$$

Separation of RF Fluctuation Signal (cont'd)

- Taking the real part..

$$E(\omega) = E_o \cos \overline{\phi_e}$$

Equivalent to several Hz.

$$\times [J_o(\tilde{\phi}_{eo}) \cos \omega_i t$$

→ Unperturbed density signal

$$- J_1(\tilde{\phi}_{eo}) \{ \sin(\omega_i + \omega_{RF}) t + \sin(\omega_i - \omega_{RF}) t \}$$

→ Signal be monitored

$$+ J_2(\tilde{\phi}_{eo}) \{ \cos(\omega_i + 2\omega_{RF}) t + \cos(\omega_i - 2\omega_{RF}) t \}$$

→ Small amplitude (higher frequency)

$$+ \text{higher order of } \omega_{RF} \cdots]$$

- After sequential mixing with Stark laser and the second LO with $\omega_{LO,2} \sim \omega_{RF} - \omega_\Delta$, unperturbed density signal and higher frequency signal ($>2\omega_{RF}$) would be filtered.

$$E(\omega) = E_o \cos \overline{\phi_e} \times J_1(\tilde{\phi}_{eo}) [\sin(\omega_{RF} - \omega_\Delta - \omega_{LO,2}) t - \sin(\omega_{RF} + \omega_\Delta - \omega_{LO,2}) t]$$

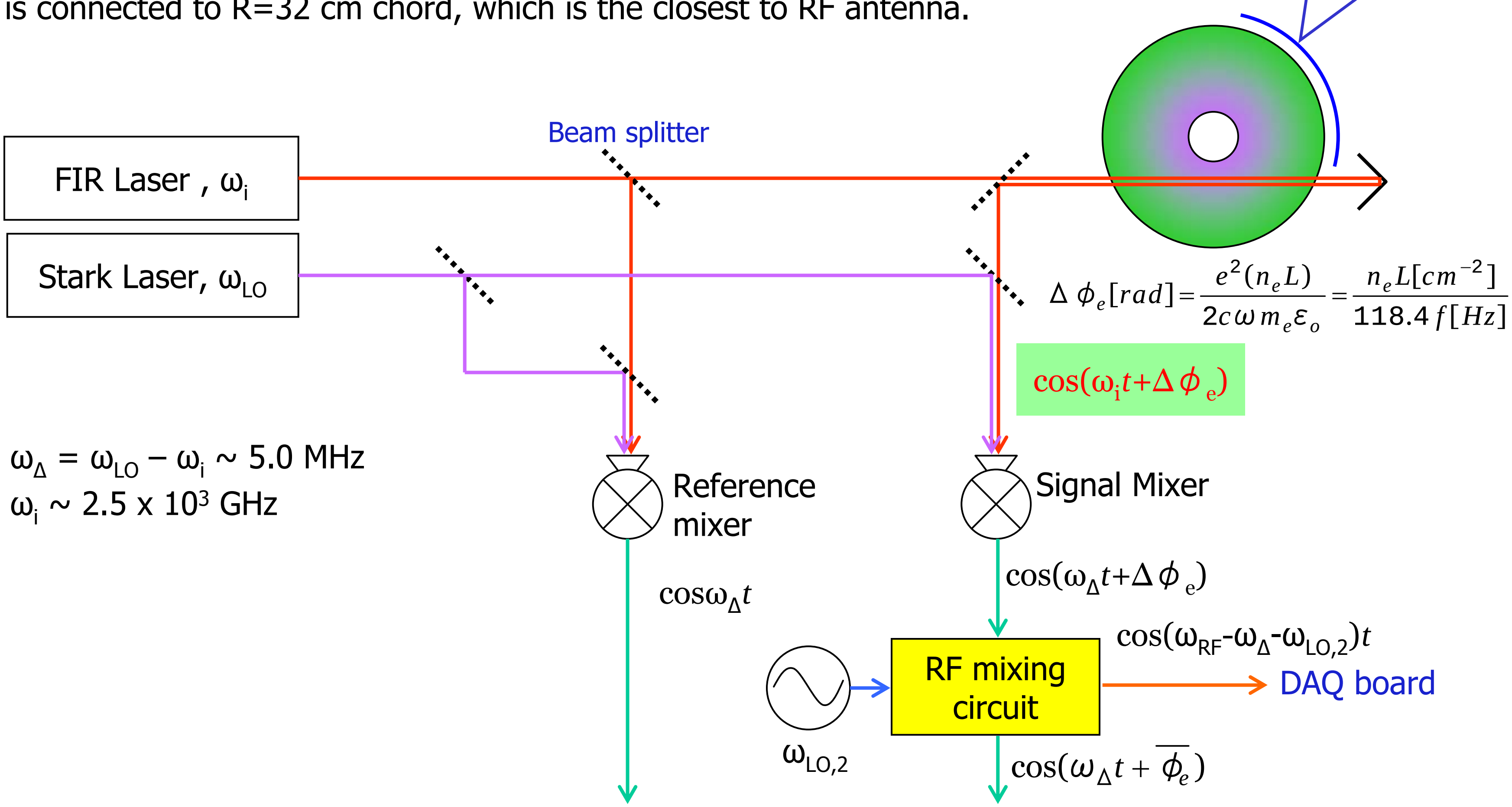
$\omega_{RF} \sim 30$ MHz
$\omega_\Delta \sim 5$ MHz
$\omega_{LO,2} \sim 25$ MHz

⇒ ~ 0 MHz ; ~ 10 MHz (filtered)

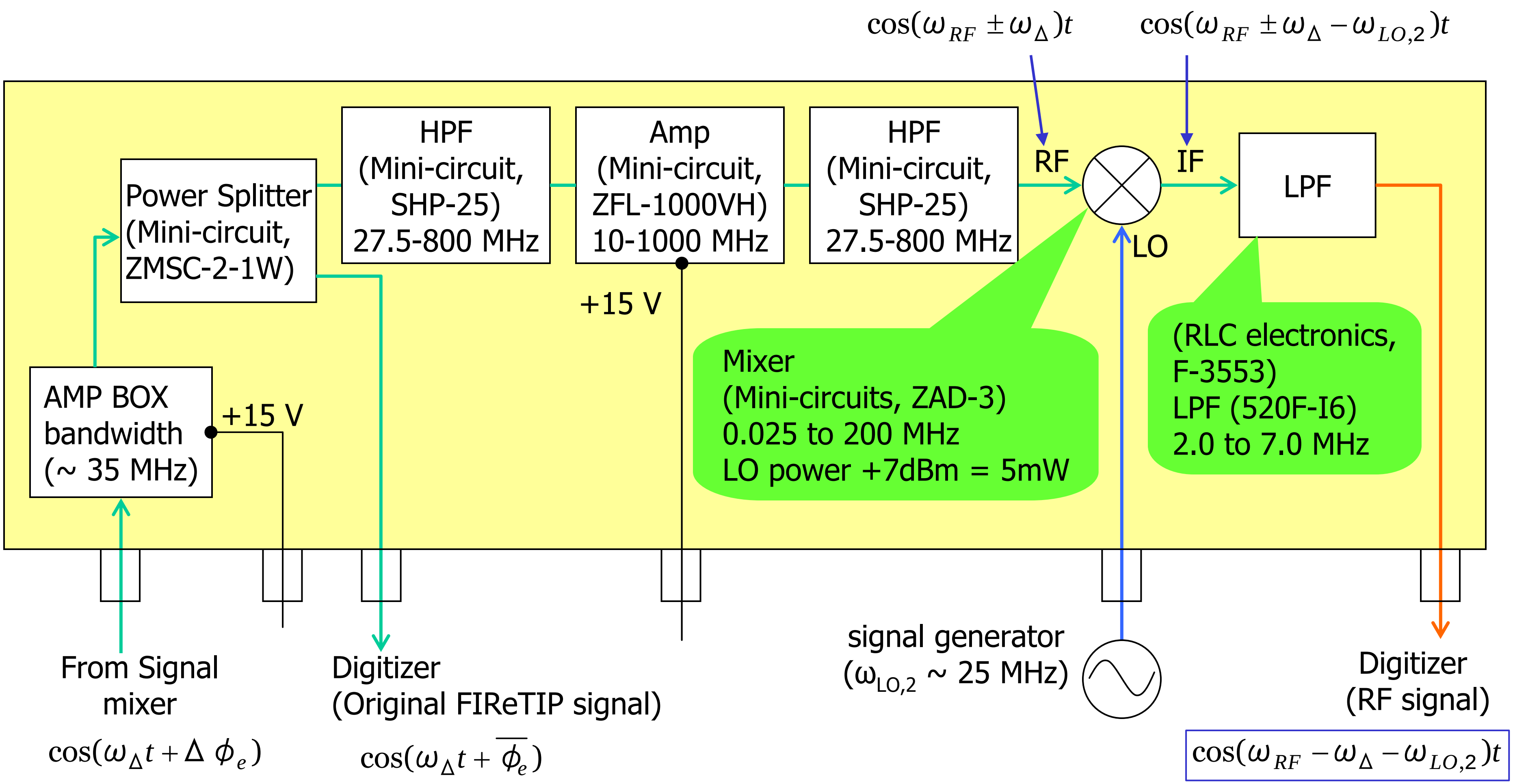
⇓ Signals sent to DAQ board and then FFT

Current Interferometric Set-up of FIReTIP

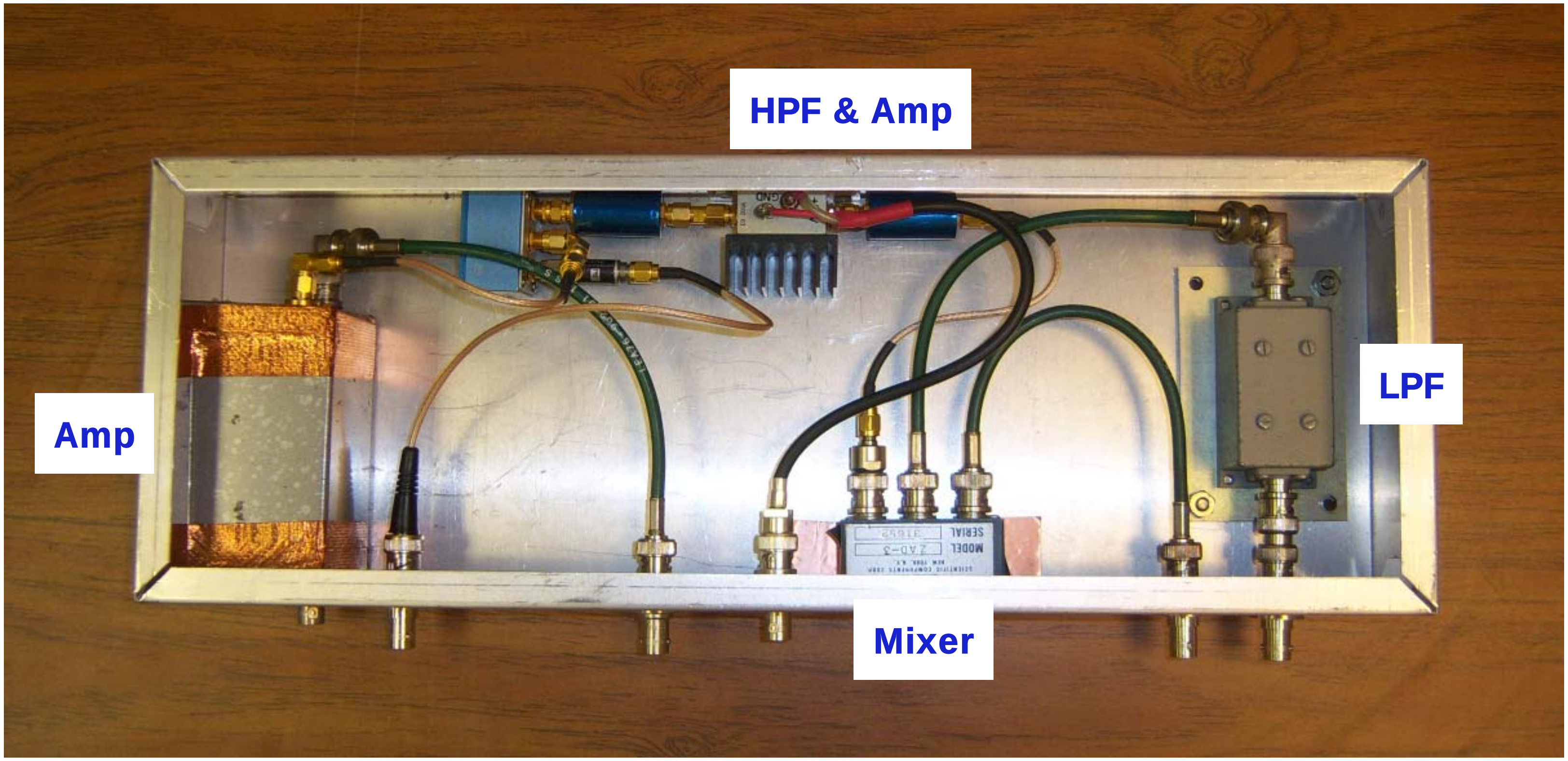
- FIReTIP has six chords each with different radius at tangential point.
- The RF circuit for observing the RF signal by HHFW driven density fluctuation is connected to R=32 cm chord, which is the closest to RF antenna.



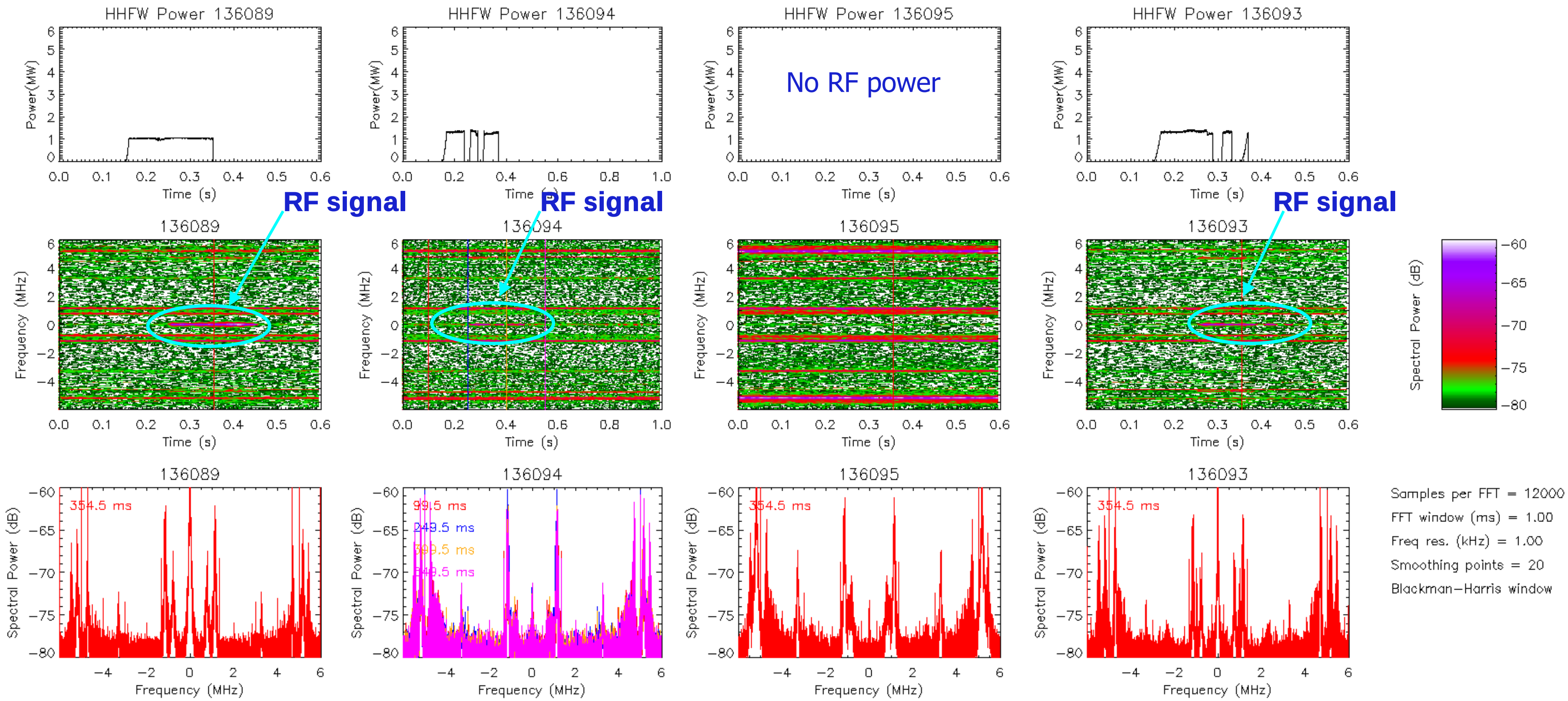
RF Amp and Mixing Circuit



Picture of RF Amp/Mixing circuit



Preliminary Results of RF Measurement - FFT Spectrum



- FIReTIP signal was delayed 0.1 sec due to DAQ board.
- RF signals exactly coincided with the HHFW power and was detected even without laser.

No FIReTIP laser
(Laser was blocked)

Preliminary Results of RF Measurement (cont'd)

- The RF mixing circuit was installed for R(1)=32 cm chord this year
  - It can be moved to any other chords.
- Frequency ~ (ω-30 MHz)
  i.e. 0 Hz corresponds to 30 MHz.
- 30 MHz signal was detected even without FIReTIP laser
  - The RF signal was not from plasma.
  - The circuits can be RF-shielded by:
    - Using Triaxial cables and connectors.
    - Adding simple LC filter to eliminate 30 MHz noise from ground.
- Signal discrimination from noise needs improvement.

Measured Fluctuation will be compared to predictions from TORIC Code

- Finite Larmor Radius (FLR) full wave simulation
  - Solves the Maxwell-Vlasov equations in toroidal geometry

$$\nabla \times \nabla \times \mathbf{E} = \frac{\omega^2}{c^2}[\mathbf{E} + \frac{i}{\omega\, \varepsilon_o}(\mathbf{J}_{HF} + \mathbf{J}_A)]$$

$\mathbf{J}_{HF}$: HF plasma current,
$\mathbf{J}_A$: Antenna current

$$\mathbf{J}_{HF}(\mathbf{r},t) = \int_{-\infty}^{t} dt' \int d\mathbf{r}' \underline{\underline{\boldsymbol{\sigma}}}(\mathbf{r},t;\mathbf{r}',t') \cdot \mathbf{E}(\mathbf{r}',t')$$

: constitutive relation (from linearized Vlasov equation)

➔ The wave equation is an "integro-differential equation" in a hot non-homogeneous plasma.

[REF: M. Brambilla, *Plasma Phys. Control. Fusion* **41,** p1 (1999)]

- Quasi-local approximation
  - Assumes the range of spatial dispersion to be small compared to the linear dimensions of the plasma.
  - Valid to all orders in the Larmor radius.

[REF: M. Brambilla, *Plasma Phys. Control. Fusion* **44,** p2423 (2002)]

Predictions of Density Perturbations by TORIC

- TORIC output → *Electric field* in Stix Frame
  - E^+ (LHCP), E^-(RHCP), $E^{//}$(parallel to local $\mathbf{B}_o$)
  - The wave field is expanded in toroidal and poloidal Fourier components.

$$\mathbf{E}(\mathbf{r},t) = \sum_{m,n} \mathbf{E}^{m,n}(\psi) e^{i(m\theta + n\varphi - \omega t)}$$

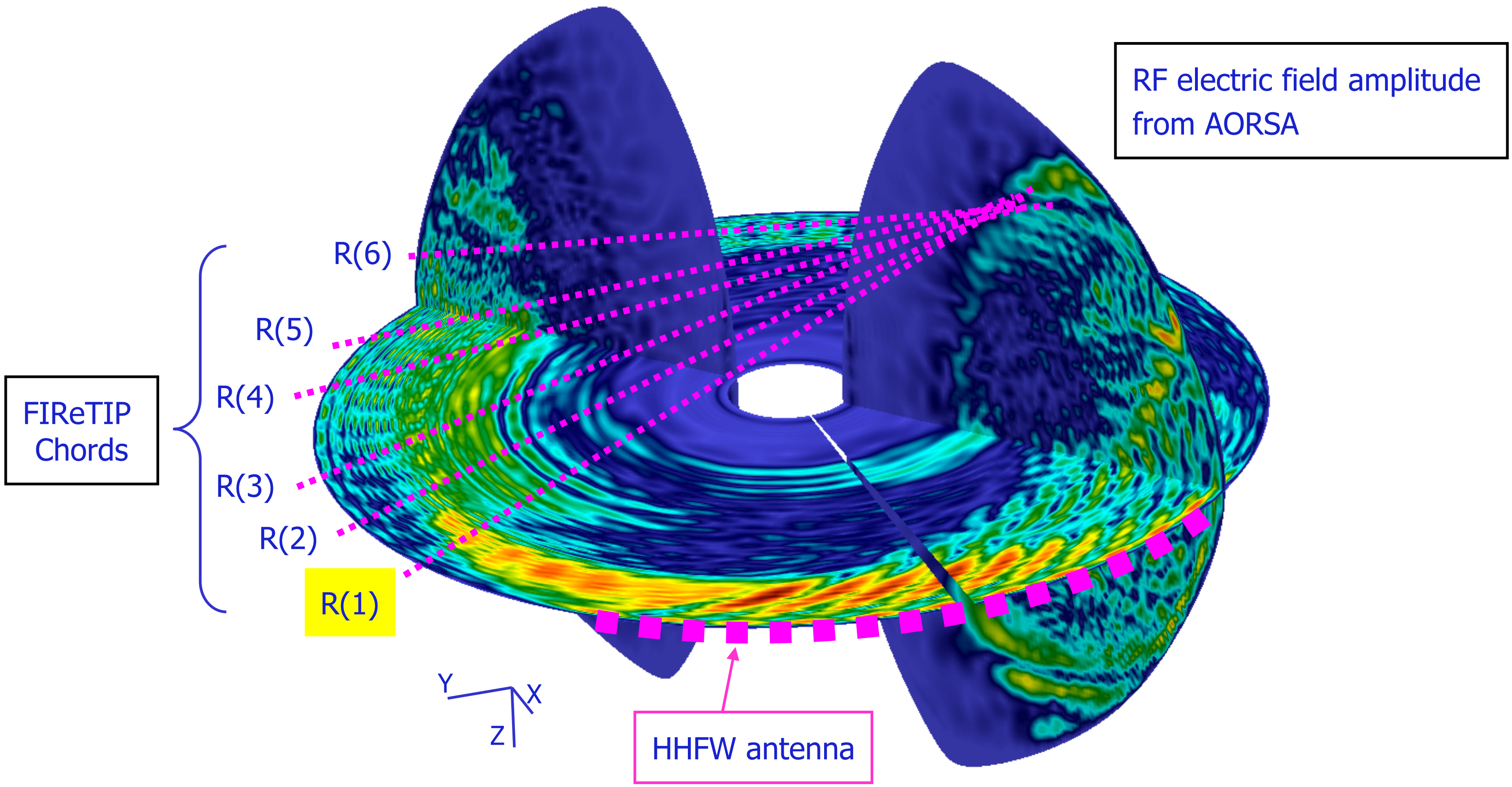
- FIReTIP → *Line integrated density*.

- Perturbed density vs. Electric field?
  - Perform approximate calculations from TORIC results using linearized continuity equation and cold plasma approximation.

$$n_{HF,e} = \frac{i}{\omega e} \nabla \cdot \mathbf{J}_{HF,e} \qquad \mathbf{J}_{HF,e} = -i\omega\, \varepsilon_o \overline{\overline{\chi}}_{e,cold} \cdot \mathbf{E}$$

    - Local susceptibility (χ_e) from EFIT ($\mathbf{B}_o$) and MPTS (n_e) with cold plasma approximation in Stix coordinate system
  - Improved model: Modify the TORIC code to extract the high frequency electron current density information ($\mathbf{J}_{HF,e}$) and calculate the density fluctuation.

Fluctuations Predicted for FIReTIP Chords



- Fluctuations for each chord depending on the antenna phase angle can be evaluated from TORIC results and compared with the experiments.

Summary and Future Work

- RF mixing circuits were installed on FIReTIP to measure the density fluctuation induced by 30 MHz HHFW.
  - RF circuit picked up 30 MHz signal directly from HHFW system (capacitively or inductively).
  - Signal discrimination from noise has to be done by filtering the noise
    - Improve shielding using Triaxial cables and connectors
    - Ground isolation though simple LC compensation circuit at 30 MHz
    - Using local oscillator with stable RF frequency (~25 MHz)
- Density fluctuations will be calculated from electric field given by TORIC and compared with the experimental measurement.
  - Modification of the TORIC code is needed to extract the information we need.