Current Status of SOL Reflectometer

- Data has been taken since Aug. 27, 2010
  - Air-side waveguides were fully installed on Aug. 25, 2010
  - A total of 24 run days of data
- Many different plasma conditions have been observed
  - Effects of ICRF and LH
  - H-modes (ELM’s, EDA, ELM-free)
  - Helium, deuterium, and high hydrogen fraction (> 25%) deuterium plasmas
  - Ramp-up scenarios
  - Large range of densities and currents
  - Few different magnetic fields
- Full calibration will be done next in-vessel access
  - Currently, differential phase of in-vessel waveguides are calculated
  - Only differential phase is operational; full phase will be operational soon
  - Sweep speeds up to 50µs sweep speeds have been achieved
- All data, except for ICRF shots, has been cross calibrated to LH Langmuir probes
  - ICRF data has same initial conditions as ohmic phase
First Results from the SOL Reflectometer

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Motivation

At high power, ICRF and LHRF modify the edge density and density profile

- Nonlinear phenomena can modify the edge density and density profile
- High power can cause wave absorption on edge neutrals and consequently increased ionization
- Standard Langmuir probes measurements have difficulties with RF biasing.

Shaped plasmas and extended coupling structures could complicate efficient coupling

- Flux tube connection length influences plasma density on a particular flux tube
- RF biasing of flux tubes can cause convective cells
  - This could result in up-down asymmetries in the density profiles

Seek to measure the local density and density profile utilizing high temporal and spatial resolution reflectometry

- Reflectometer measures at three poloidal locations so that it can detect up-down asymmetry.
- Motorized switches will be used to change horn locations within a shot.
Reflectometry Basics

Full-phase reflectometry

\[ \phi(\omega) = 2 \frac{\omega}{c} \int_{r_0}^{r(\omega)} N(r, \omega) \, dr - \pi / 2 \]

\[ \Delta \phi(\omega) = \phi(\omega) - \phi(\omega - \Delta \omega) \]

where \( N \) is the index of refraction of the R cutoff and \( r(\omega) \) is distance of cutoff layer.
Our Reflectometer

Measurement Requirements

- Measure the density profile in the scrape-off-layer (SOL)
  - Density at last closed flux surface $\approx 5 \times 10^{19} \text{ m}^{-3}$
- Measure at different poloidal locations of the ICRF antenna and the LH antenna up to near SOL.
- Allow measurement of density fluctuations and parametric decay instabilities

Design Parameters based on Requirements

- Use X-mode with a frequency range of $100 - 146$ GHz
  - Yields density range of $10^{16}$ to $10^{20} \text{ m}^{-3}$ at $B_0 = 5.0 - 5.4$ T
- Use differential-phase measurement (500MHz difference frequency) to minimize effects of large density fluctuations in the SOL
- Also provide full-phase measurement for profiles and fluctuations
- Use sweep speeds of 10 $\mu$s to 1 ms

Unless otherwise indicated, all data in the rest of the talk will be from differential phase measurements at 100$\mu$s sweep speed and averaged over 100 sweeps
Reflectometer at Lower Hybrid Launcher

LH-SOL reflectometer horns

LH Langmuir Probes

Magnetic Field
Density Profile Measurements
Typical Ramp-Up

The calibrated phase is subtracted out from the raw phase to obtain the plasma phase.

Plasma phase can then be Abel inverted to get the density profiles.
Deuterium vs. Helium Ohmic Plasmas

Line averaged density = 1.2x10^{20}m^{-3}, B_0=5.4T, I_p=1MA for both discharges. Deuterium plasmas are noticeably steeper and higher in density in near SOL.
Differences during ELM’s

Difference in raw phase during ELM’s can be seen. This difference is prevalent during all ELM’s, and is most clear after the peak of the ELM’s. Careful analysis needs to be done to get density profiles.
Effects of LH on the SOL density profiles
Immediate Effects of LH

Effects of LH power is within hundreds of μs, as can be seen in the raw data of a typical LH shot. LH power is turned on after .8s.
Typical Effects due to LH

Before LH (0.79-0.80s)
After LH (0.80-0.81s)

Plasma Phase (fringes)

Frequency (GHz)

Density (m⁻³)

Thomson scattering
Separatrix
LH Langmuir Probes
Plasma Limiter
LH Limiter
LH Launcher
Inner gap scan shows strong differences in density profile. This further hints that the SOL density profile is correlated with the LH power not penetrating into the plasma at high densities (see Wallace TP9.0082, same session)
LH increases density in the profile at SOL even in low line averaged densities. LH power ramp does not seem to have a large effect. Other factors, such as neutral pressure may also play a role. It should be noted that at high line averaged densities (>10^{20} \text{ m}^{-3}), the increase in the SOL density profile due to LH is much more prominent.
Summary of effects due to LH

Density profiles show strong increase in the SOL density profile when lower hybrid is turned on.

- The LH-SOL reflectometer is beside the LH launcher, so there is no issues with magnetic field line mapping. The time resolution of the reflectometer also allows us to observe the immediate effects of LH. Since the effects are immediate, transport effects, do not play a major role in this process.
- SOL ionization and ponderomotive forces are the most likely reason for the observed density profile increase.
- Decrease of density near the LH launcher (within a mm) is likely

Density Limit Problem

- Inner gap scan shows strong influence of the inner gap on the SOL density profiles, which correlates with hard x-ray signals. The SOL density profiles definitely play a major role in this issue (Wallace, TP9.0082, same session)

Lower Hybrid Coupling

- Density profiles during LH is much steeper than without LH. It is hypothesized that this may better match lower hybrid coupling simulations. (Meneghini, PO4.00004, Wednesday afternoon)
Effects of ICRF on the SOL density profile
ICRF Power Ramps

ICRF power ramp from 200 kW to 1 MW. Density profile changes accordingly.

$B_0 = 5.4\, T$

$I = 1\, MA$

$n_{e\text{bar}} = 1.4 \times 10^{20} \, m^{-3}$
Different Density
$B_0 = 5.4\, \text{T}$
$I = 1\, \text{MA}$
$n_{\text{ebar}} = 2 \times 10^{20} \, \text{m}^{-3}$

Different Current
$B_0 = 5.4\, \text{T}$
$I = 0.8\, \text{MA}$
$n_{\text{ebar}} = 1.4 \times 10^{20} \, \text{m}^{-3}$

Note: change in density profiles due to ICRF occur within a few ms. Reflectometer is magnetically connected, but $80^\circ$ toroidally away from ICRF antenna.
As both ICRF and LH raises the density, it is expected that the combination of the two will do so too. This has been observed, as shown above.
Summary of effects due to ICRF

ICRF seems to increase the density in the near SOL and decrease the density in the far SOL.
- This effect seems to be strongly dependent on the estimate of the first radial cutoff layer location.
- This result have been seen in many experiments such as TFTR (Hanson PPCF 1994), DIIID (Hanson 1998).

ICRF Coupling
- SOL density profiles greatly influence antenna-plasma coupling. Reflectometer measurements in conjunction with modelling should clarify this issue.
- The density profiles in deuterium plasmas are much steeper than the density profiles in helium plasmas. This may explain differences in coupling due to different gas species, as seen in Alcator C-mod and other tokamaks.

ICRF sheath/convective cell
- Reflectometer has not seen substantial up/down asymmetries. This was thought to be possible since reflectometer is magnetically connected to the bottom of J-port ICRF antenna and the top of D/E port ICRF antenna. A future ICRF-SOL reflectometer will examine this issue.
Summary of Initial Results

- Data has been taken since Aug. 27, 2010
  - A total of 24 run days

- Many different plasma conditions have been observed
  - Effects of ICRF and LH
  - H-modes (ELM’s, EDA, ELM-free)
  - Helium, deuterium, and high hydrogen fraction (> 25%) deuterium plasmas
  - Ramp-up scenarios
  - Large range of densities and currents
  - Few different magnetic fields

- Near SOL density increases when ICRF and LH is turned on
  - Physical process such as convective cells (ICRF), pondermotive force (ICRF/LH), and SOL ionization (LH) are probably the main driving force
  - Far SOL density near the ICRF/LH seems to decrease, but this is not conclusive due to the inaccurate knowledge of the first radial cutoff layer location
Extra Slides
(Online Reference of Future Plans)
Density profiles have been measured in the SOL

Full phase will be ready soon
  • Density fluctuation measurements will be possible
  • Density profile comparison with differential phase will be possible
  • Different sweep speeds (up to 10μs) are planned.
    • Differential and full phase behave differently at different sweep speeds
    • Raw data for differential phase looks very clean at multiple sweep speeds
      • Effect of density fluctuations is greatly reduced

Switches will be motorized early 2011
  • Measure at the top, middle, and bottom horn locations during the same shot

ICRF-SOL reflectometer will be ready mid-2011
  • Reflectometer horns will be mapped to the top, middle, and bottom of the new J-port ICRF antenna
  • Design of the waveguide layout ongoing
  • Electronics is ready (same as LH-SOL reflectometer)

Electronics upgrade (future plans)
  • Log amplifiers will give better measurement of received signal
  • Fast digitizer and electronic components will be needed for PDI
Reflectometer Electronics

CMOD Reflectometer 100–146 GHz

Proposed Log amplifiers and PDI measurement will be added here
Similar waveguide components will be used for ICRF-SOL reflectometer.
H-Port ICRF-SOL Reflectometer

Reflectometer Horns: mapped to top, middle and bottom of ICRF antenna

RF Limiter

New J-port ICRF antenna (Garrett, TP9.00088 and Wukitch, TP9.00089, same session).