HHFW System Studies - Progress report*

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Introduction

We have been looking at the rf data with emphasis on understanding the rf circuit and coupling to the plasma. There is a lot we don’t understand, so this is a report on work in progress.

- Improved reflectometer measurements give better density profile data at better time resolution
- Asymmetric loading seen in last year’s runs appear to still be there.
- Plasma loading is high (R’ ≥ 10 ohm/m), because density near antenna is high.
- Analysis of circuit model gives *pretty* good agreement, but there are some unknowns that we need to measure that are causing uncertainties. In particular, there is disagreement between two methods of calculating loading that we don’t understand.

Improved reflectometer

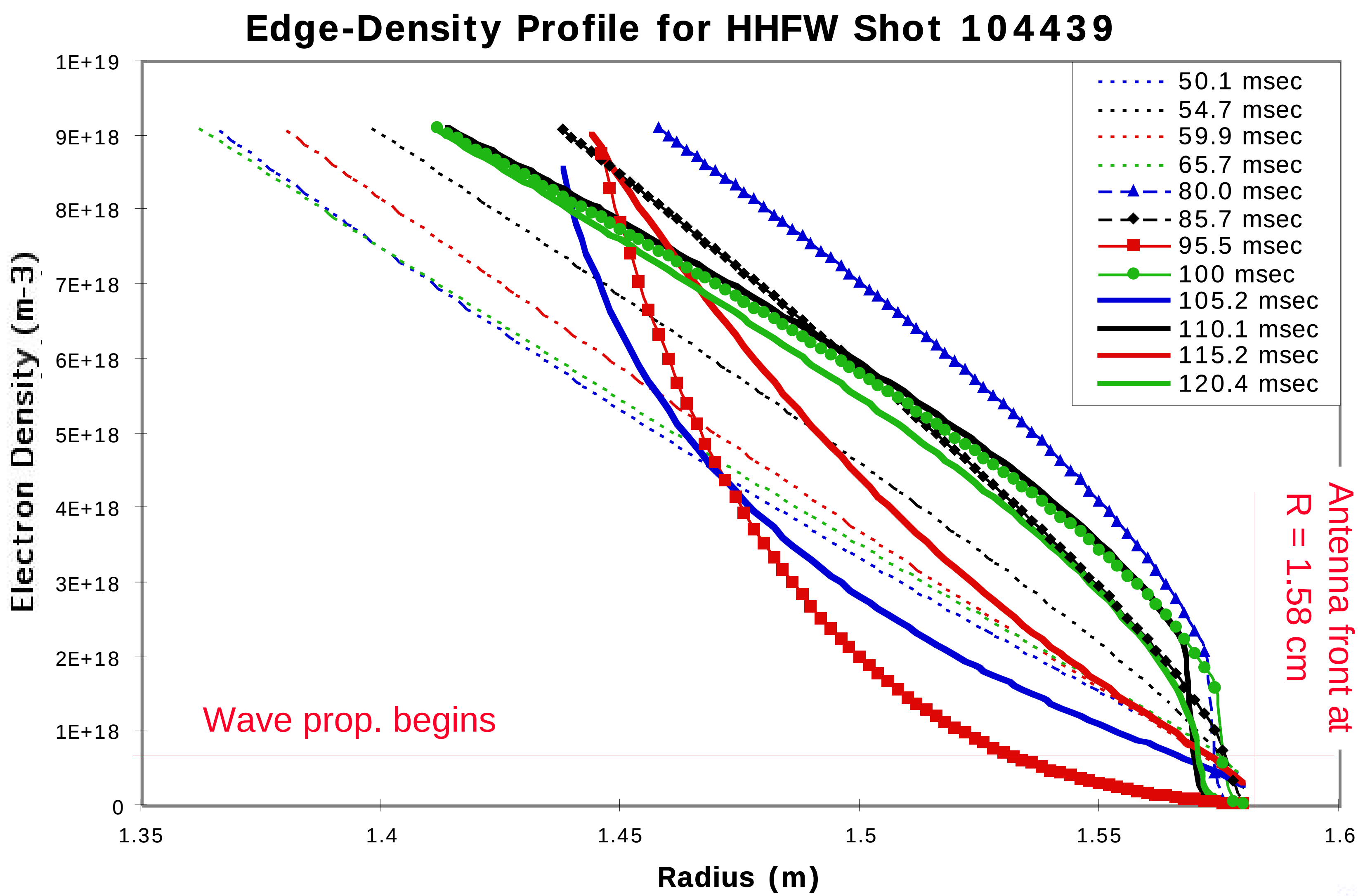
Switched to X-mode launch polarization, and retuned the frequency range to start at a lower frequency (5.7 GHz).

- This reduces the starting density by a factor of 10.
- Eliminates ambiguity in the starting location for the edge-profile reconstruction -- the profile location is effectively tied to the location of electron cyclotron resonance.
- Frequency sweep range of 6-30 GHz now provides a density range of 0.05 - 9.0×10^{12} cm^{-3}.

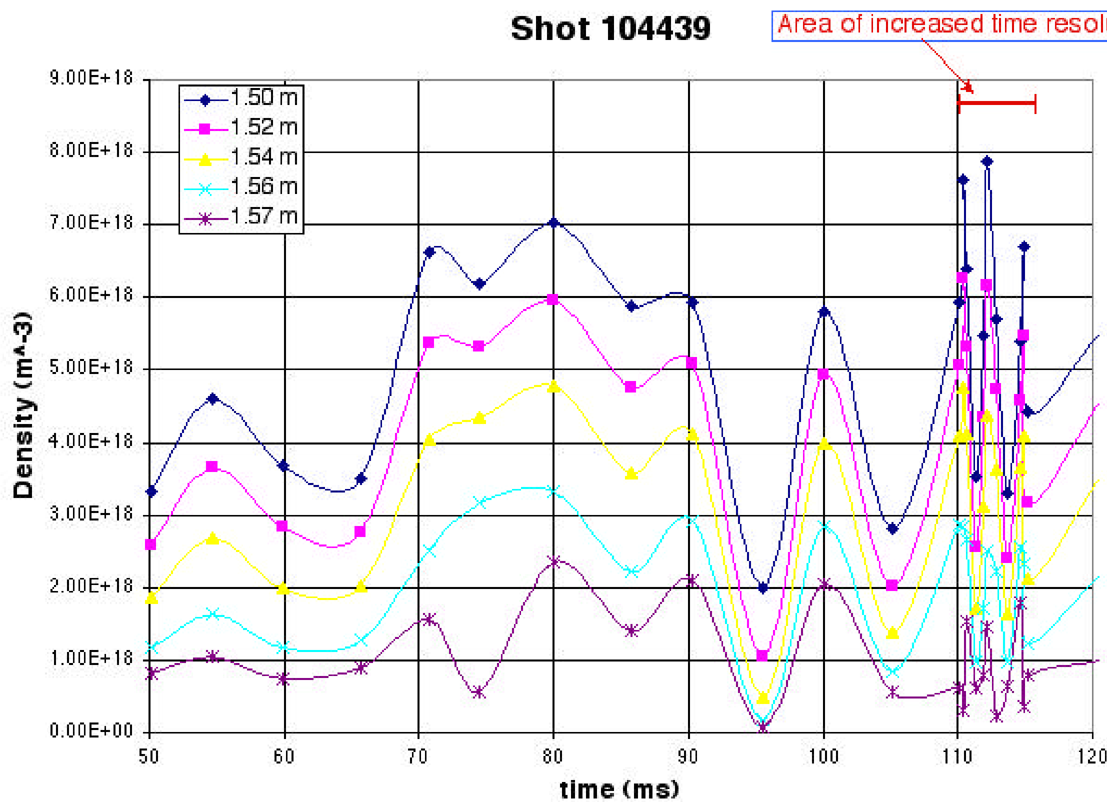
Reduced the sweep time from 800 µsec to 200 µsec. Improves the quality of the edge-profile data by reducing the effects of density fluctuations.

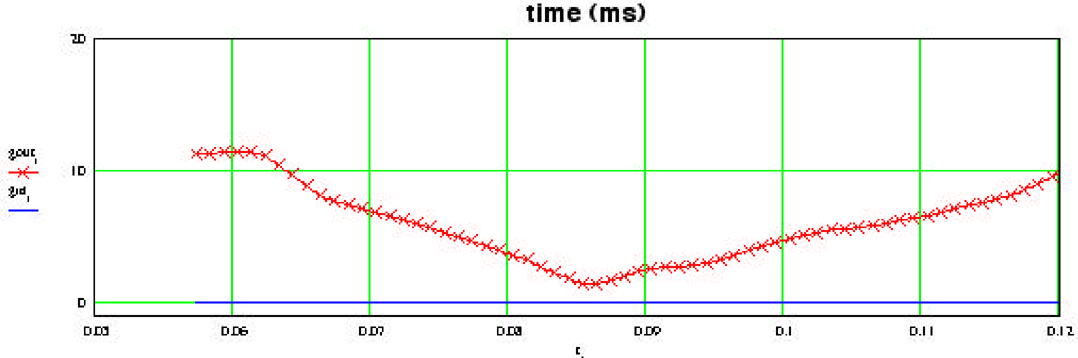
Significantly upgraded analysis code, including phase and frequency calibration. Modified the code to allow analysis of multiple sweeps.

Wave begins to propagate 1-2 cm from plasma edge



Large fluctuations in edge density are observed



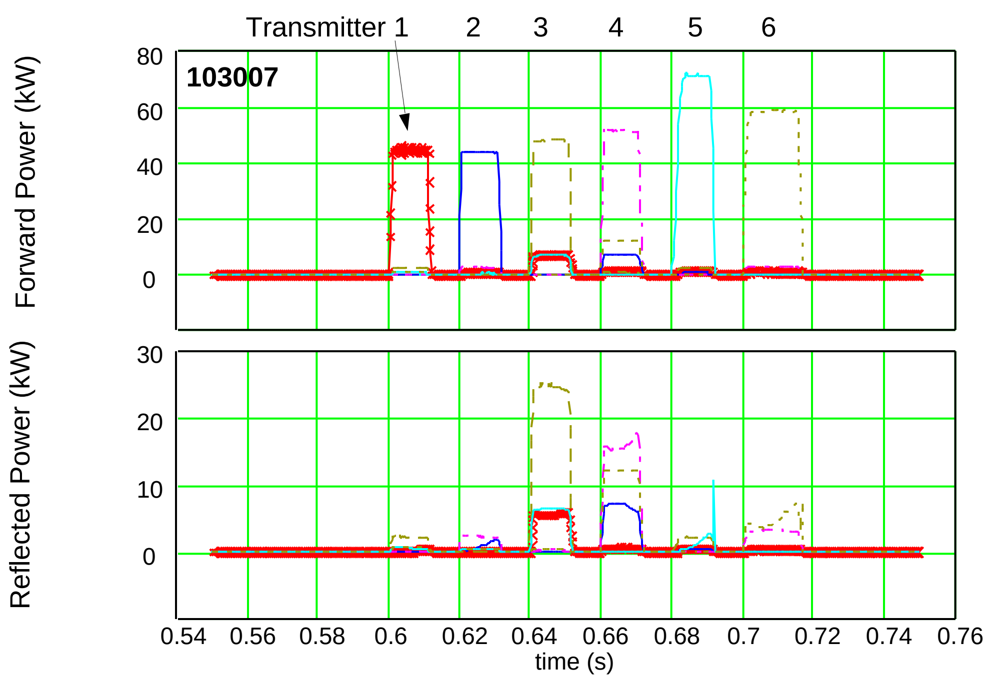


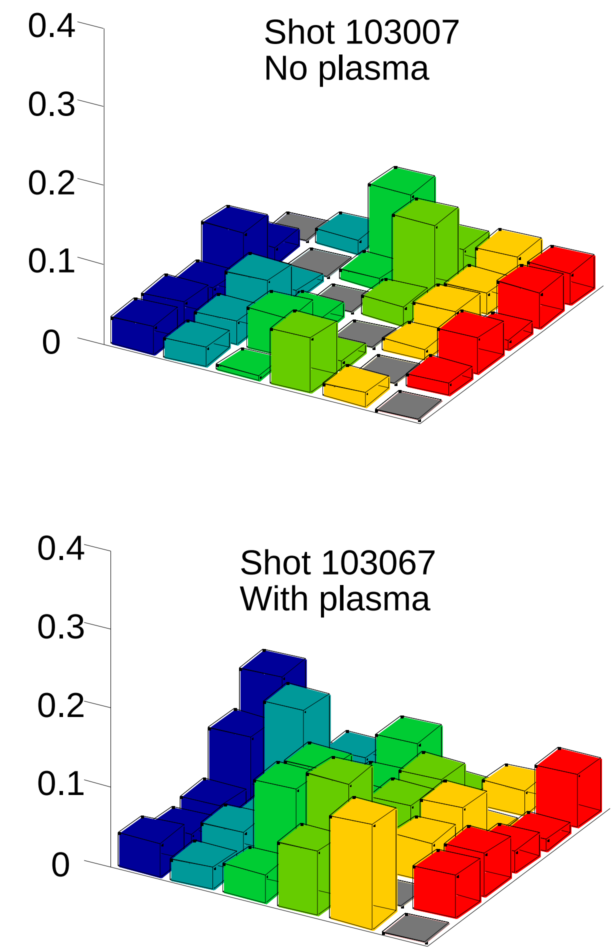
- Density profile shows general steepening as outer gap decreases.
- Fluctuations ≥50% occurring in edge
- Fluctuation time faster than can be observed by present sweeping mode of reflectometer
- Propagation density for wave still occurs within few cm of antenna surface

HHFW Reflectometer Plans for 2001

- Replace the sin(φ) detector with a broadband 6-26 GHz quadrature phase detector, so that phase detection is done electronically instead of computationally.
- Further reduce the sweep time to ≤ 100 μsec (in Feb) to meet the original design objective.
- Investigate use of faster methods for providing crude density profiles that are less computationally intensive.
- Upgrade the data analysis software to provide time-dependent edge density profiles.
- Monitor 30 MHz modulation of the plasma density in the gap between the antenna and the plasma by adding capability to look at the 30 MHz sideband on the reflected signal.

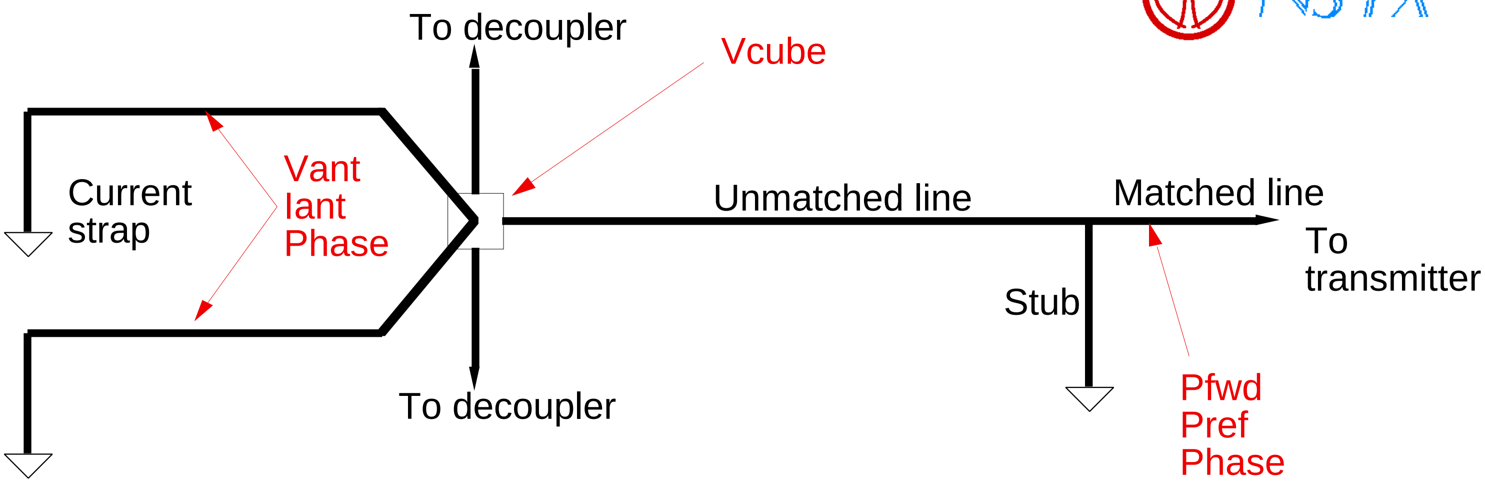
Measurements Indicate Asymmetrical Loading/Coupling With Plasma





Scattering matrices can be generated from forward/reflected power measurements at the match.

Circuit models are (sorta) working



Can calculate plasma loading (R') two ways:

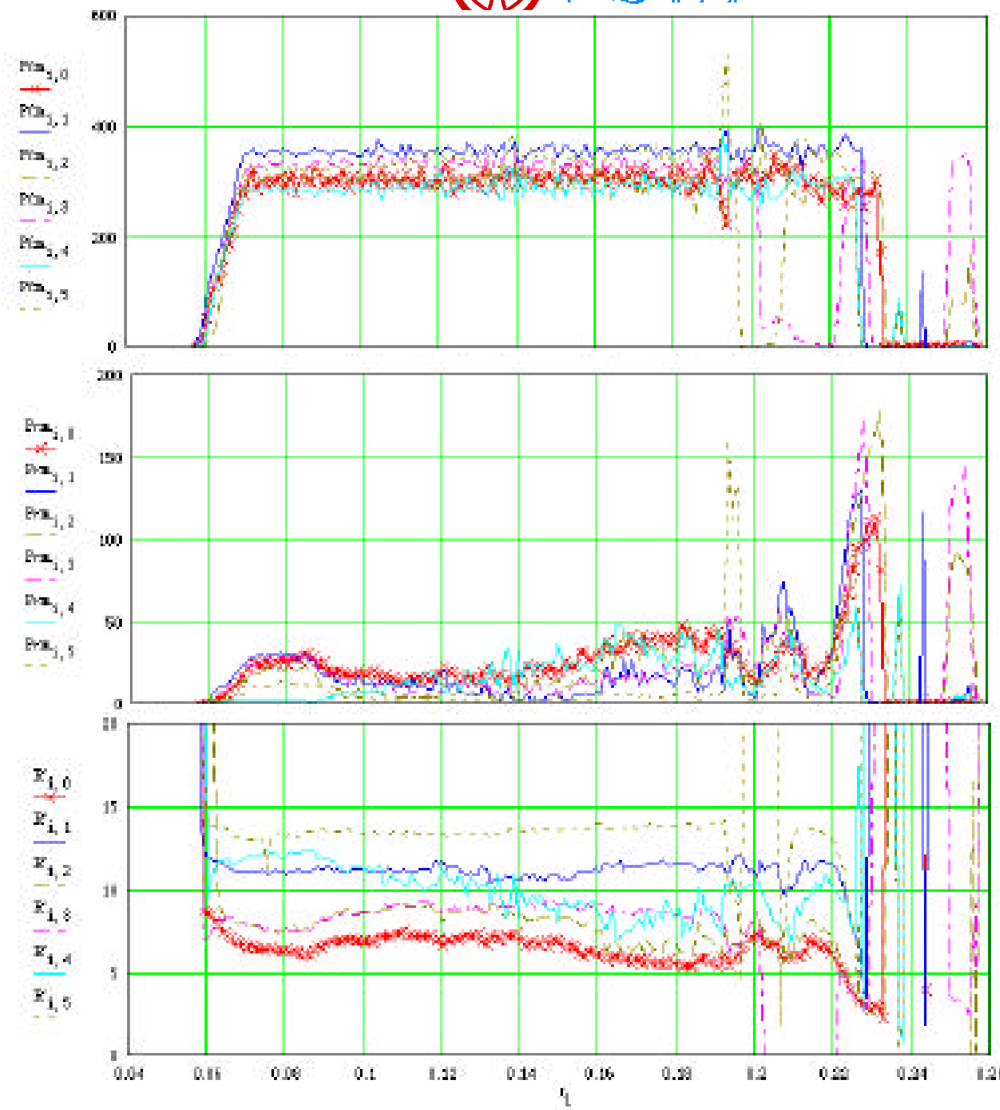
- From matched line measurements
  - Measure powers and phase on matched side of line (reliable meas)
  - Compute refl. coeff. (rho) on unmatched line (needs stub length)
  - Obtain R' from circuit model of loop that gives R'(rho)

- From net power and cube voltage measurements
  - Get net power from $P_{net} = P_{fwd} - P_{ref}$ on each line
  - $R' \sim P_{net}/(V_{cube})^2$

Analysis using power measurements

Shot 104439

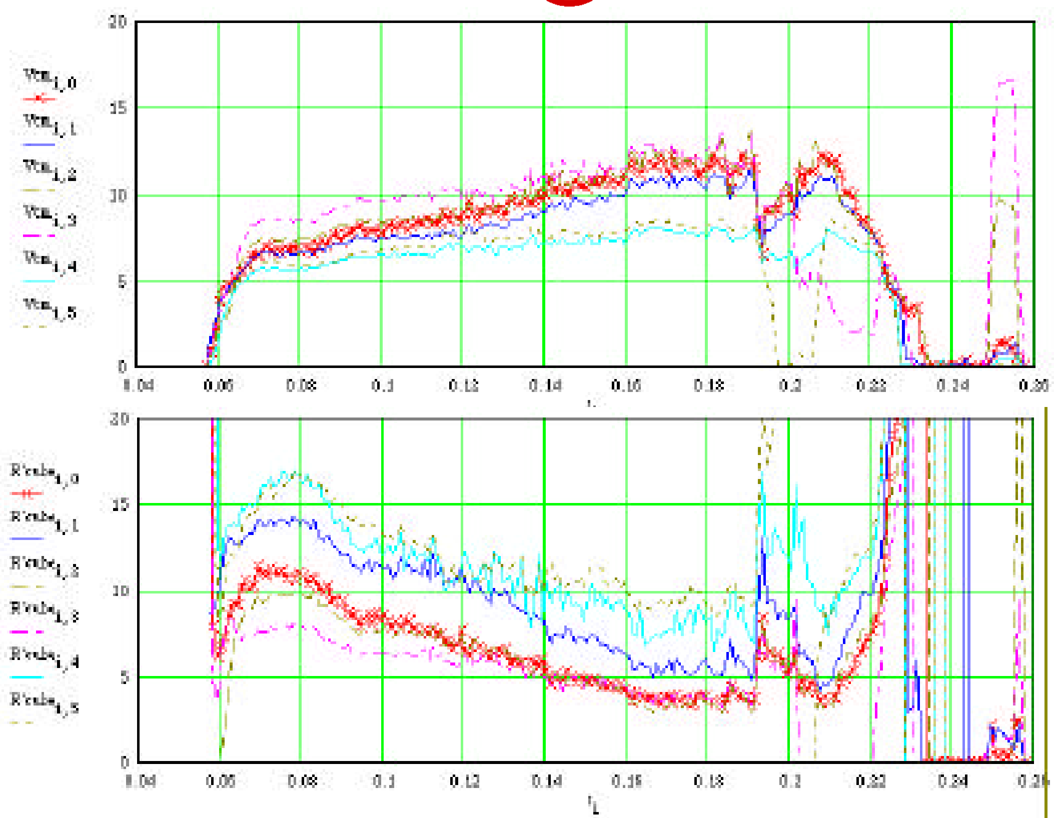
- 2 MW
- Flat forward power, pretty low reflected power
- Remember outer gap scan from 60 ms to 120 ms
- Result gives R’ pretty flat vs. time
- Values range from 7 to 14 ohm/m
- Loop 1 (red x) is lowest
- Loop 6 (brown dash) is highest



Analysis using cube voltages

Same shot

- Cube voltages all increase gradually during shot
- Resulting R' calculation changes by factor of ~ 2 during shot
- Loop 1 lowest
- Loop 6 highest (sometimes)
- Current and voltages in loops show same behavior (*quantitative* values are all over the map)



Figuring this out is going to take some work

- Better model?
- Better calibrations (stub and line lengths, sensors)

Carter has generalized RANT3D to calculate "impedance matrix*"

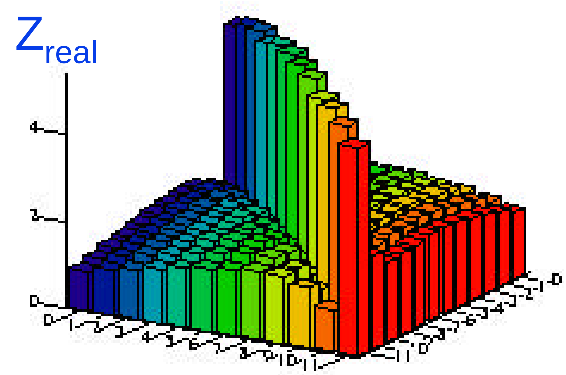
- 1. Set up coupled antenna structure in RANT3D, with multiple current straps.
- 2. Run GLOSI to compute the plasma input impedance in Fourier space at the plasma "boundary", given density profiles and magnetic field profiles and angles.
- 3. Specify the currents on each strap, and assume that they are UNIFORM poloidally, (v_{phase} infinite).
- 4. Run RANT3D to calculate the electric fields E everywhere, in particular at the strap locations.
- 5. Define the power from each strap to be $P_k = 0.5 \quad (E \quad J_k)$, where the integral is taken over the strap height. Because of the assumption that J is uniform poloidally, this can be written $P_k = 0.5 J_k \quad (\sum E_{kj}) = 0.5 J_k (\sum Z_{kj} J_j)$
- 6.By carrying out the calculation of P_k for special cases, the Z matrix can be evaluated:
  - Set only one current non-zero, so $P_k = 0.5 Z_{kk} J_k^2$ gives the diagonal terms of Z.
  - Set only two currents non-zero, so $P_k = 0.5 (Z_{kk} J_k^2 + Z_{kj} J_k J_j)$, use Z_{kk} from above to subtract and obtain Z_{kj} for $k \neq j$.
  - Repeat above for all pairs of currents.

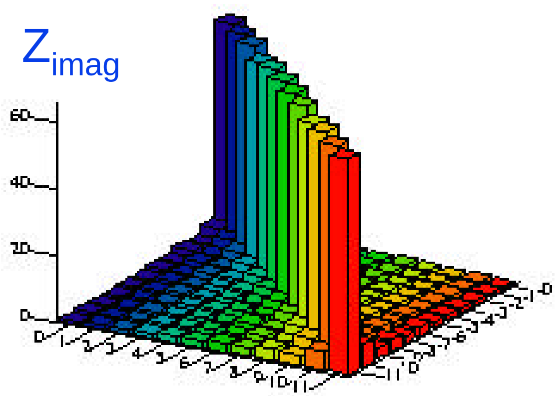
*Do not try this at home - professional driver on closed workstation!

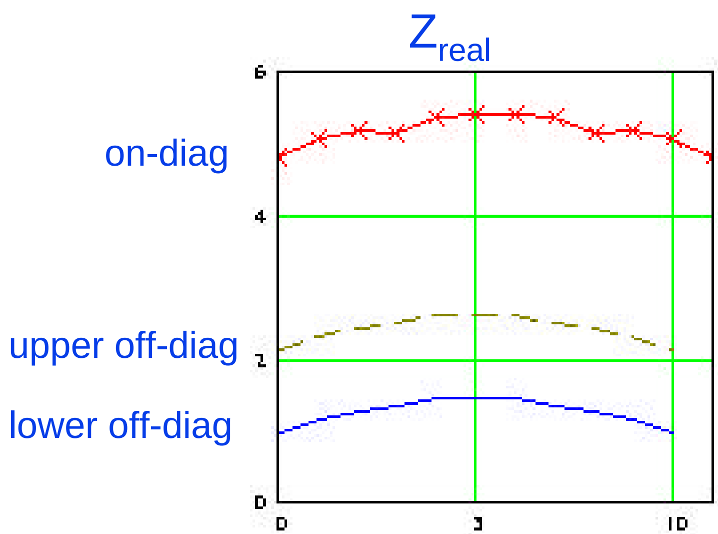
Calculated antenna matrix shows asymmetry for plasma operation

- Plasma calculations of Z (shown) show pronounced difference between antenna coupling, depending on direction.
- Same calculation with no poloidal field (angle of B = 0) gives symmetrical result
- Z matrix gives *all* info needed to compute circuit response for any antenna phasing
- These numbers can be used in a coupled circuit model to compare with circuit measurements

Antenna Z matrix (12x12)







Conclusions

Improved reflectometer data – lower density, better time resolution

- Can measure lower density by using X-mode
- Will enable dwell mode at one frequency to measure fast density fluctuations
- May observe 30 MHz coherent wave component (to meas. wave amplitude near antenna)

Asymmetric loading appears to exist – seen theoretically and experimentally

- Better quantitative measurements need better calibration of some lengths
- May still be unknown effects causing differences in different R' calculation methods – needs work, and maybe experiments

Loading is high, appears insensitive to gap

- Understandable since distance to density where wave prop. begins is ≈ 1 cm
- Need large-gap experiments w. profile data to see R' variations

Modeling of loading – becoming more sophisticated

- RANT3D can now calculate 12-antenna impedance matrix
  - Allows computation of changes in effective loading and asymmetry as rf source amplitude and phase are varied
  - Can replace earlier assumptions in model
  - Still need to understand what it all means