Technologies for next generation RF plasma sources

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Radio Frequency Advisory Group Meeting

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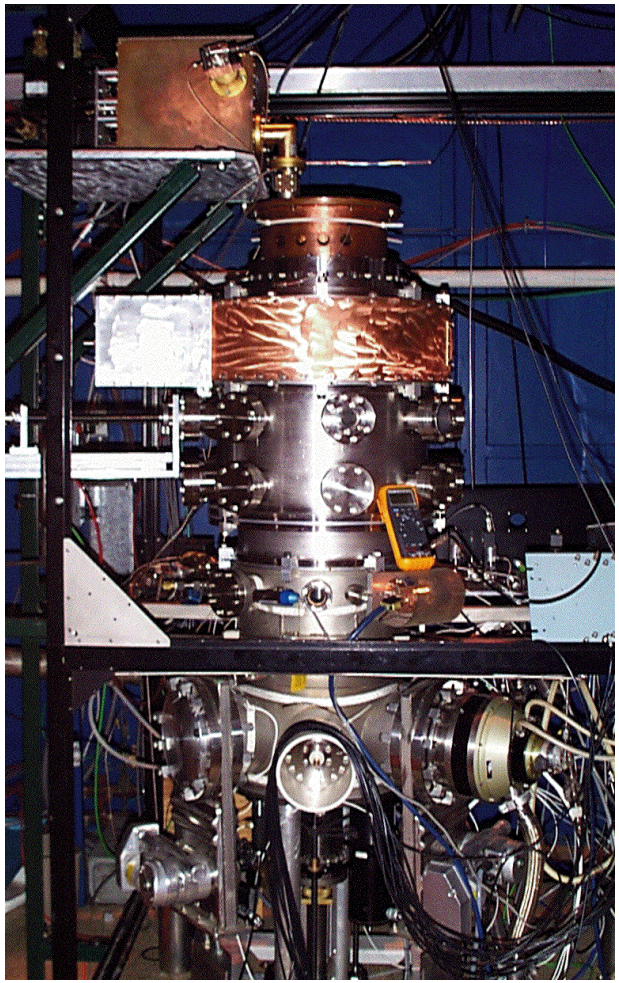
Topics:

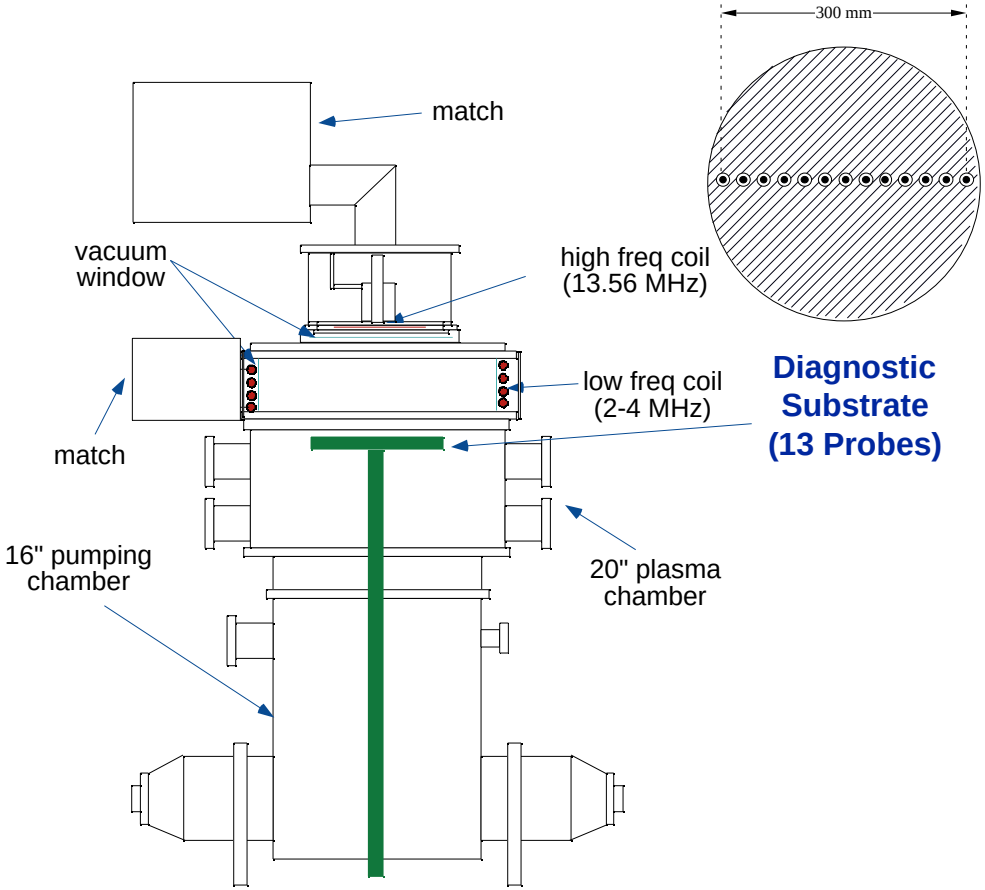
- Description of large area plasma source
- Control systems
- Plasma fluctuation measurement and suppression
- Match tester

DEVELOPMENT GOALS: LARGE AREA SOURCE

- **Maximize ion flux spatial uniformity**
  - **Coil design maximizes azimuthal uniformity**
  - **Power ratio between inner and outer coils maximizes radial uniformity**
- **Increase system reliability through robust matching and arc protection**
- **Increase process repeatability through net power control and suppression of plasma fluctuations**

Large area source chamber and system





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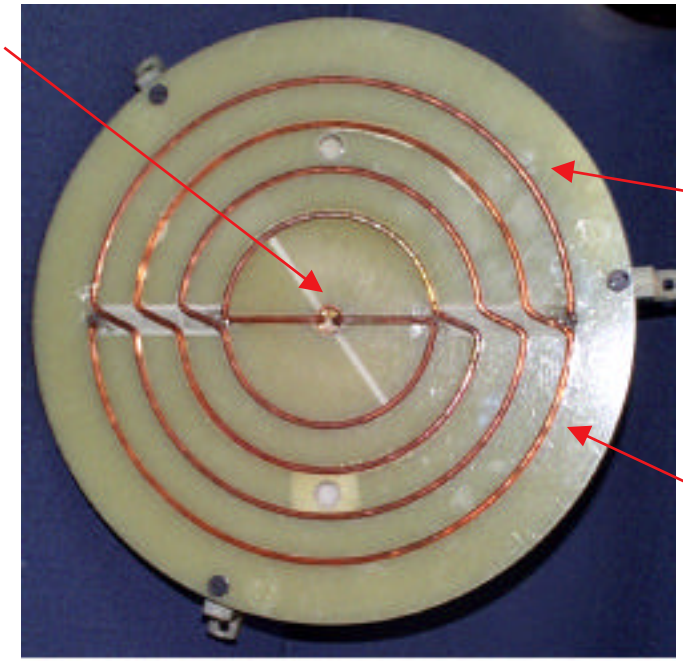
High symmetry multiple-coil system

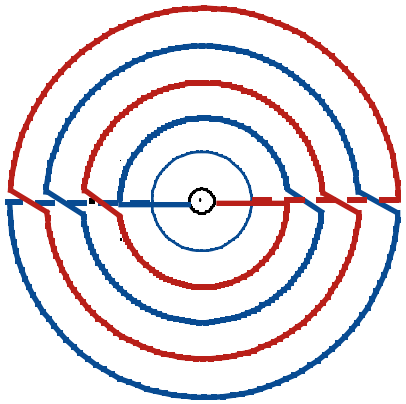
- Multiple parallel elements
- Short electrical length - constant current along conductor
- Low inductance, low voltage (cut by 50%)
- Scaleable to larger sizes by adding more coils

Coax feed

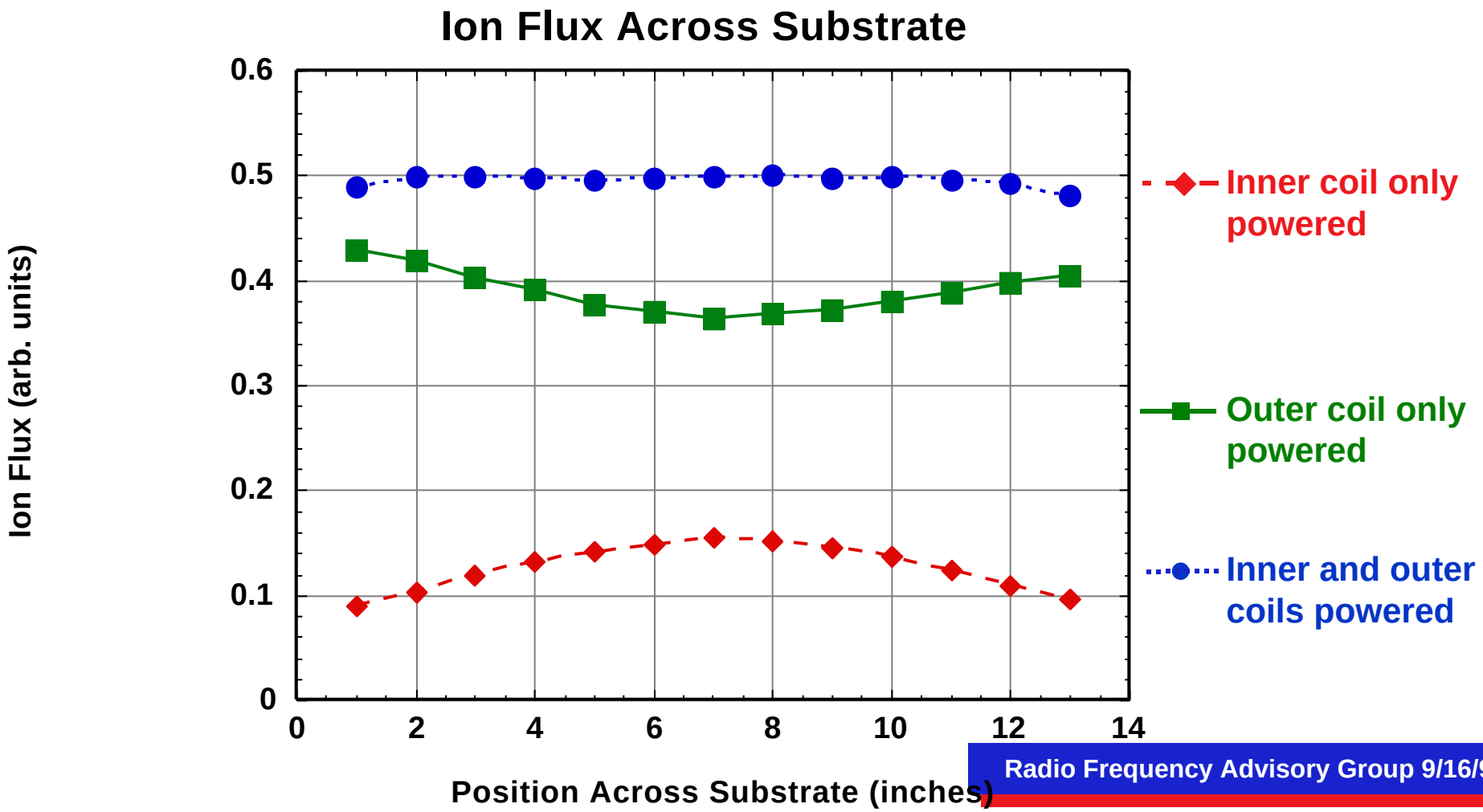


Two electrically short identical parallel coils rotated relatively by 180°

coil 1
coil 2



By use of 2 coils, uniform radial ion flux profiles can be achieved



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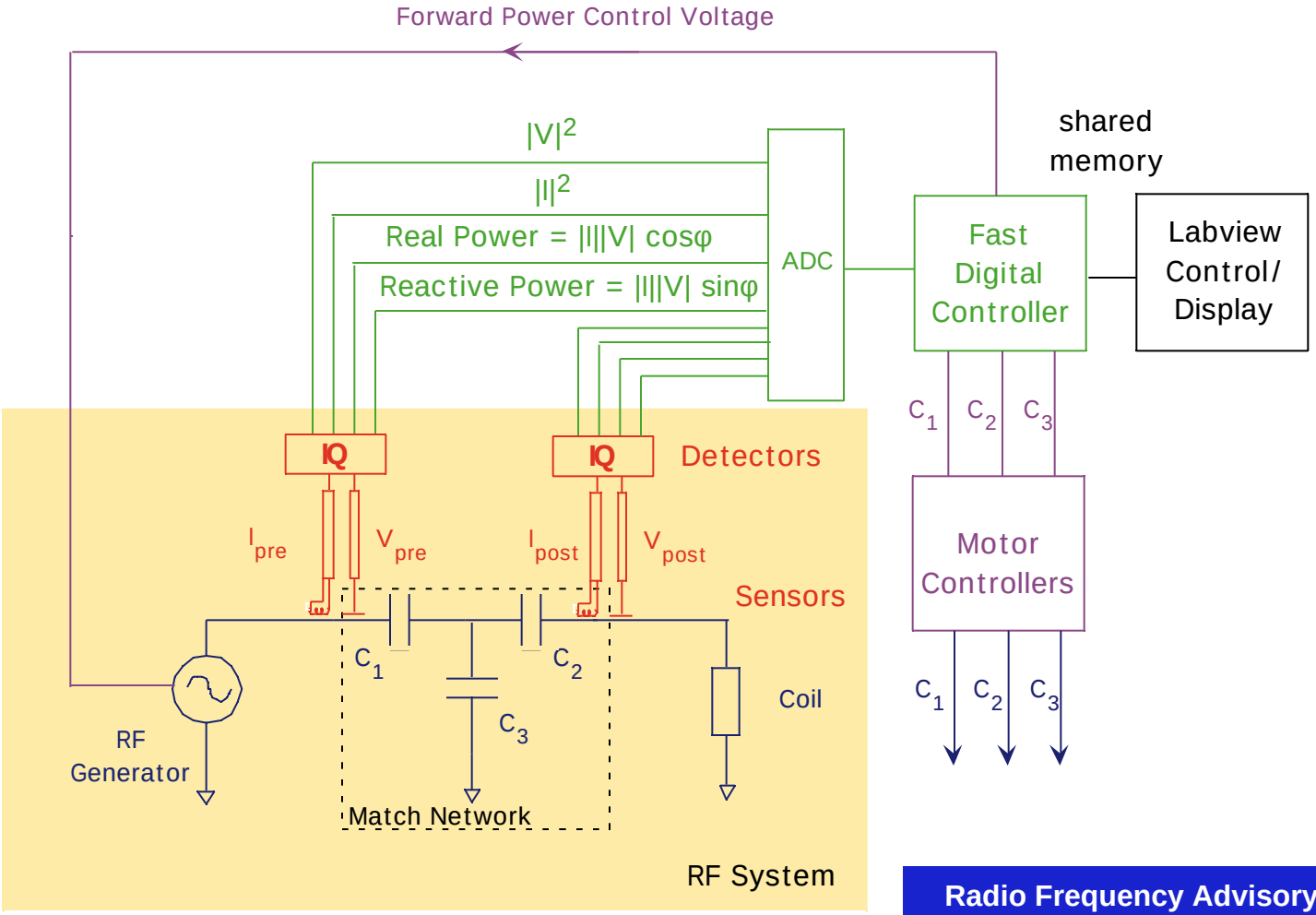
Combined match and net power control system



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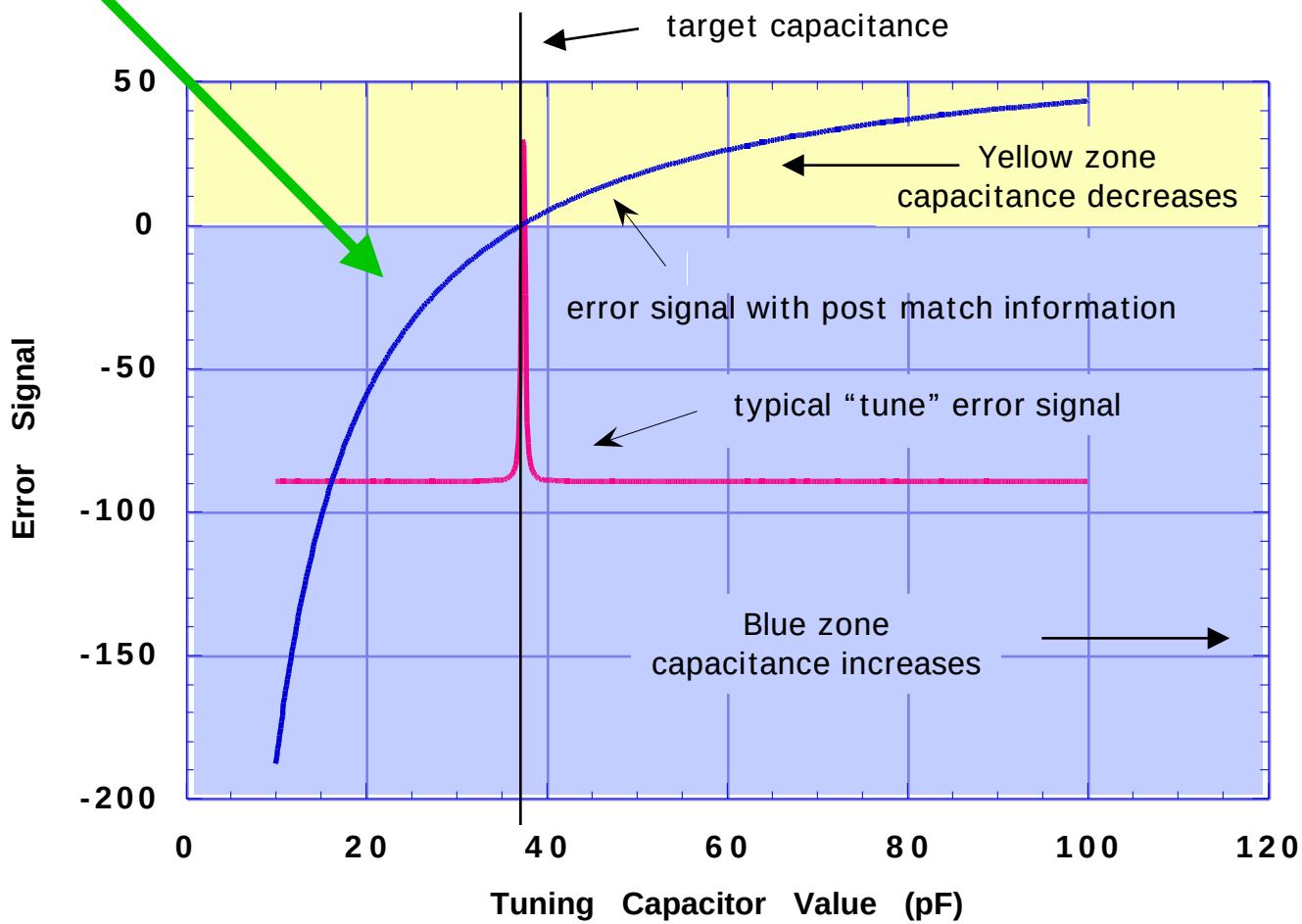
New algorithm features greatly improved analog control signal



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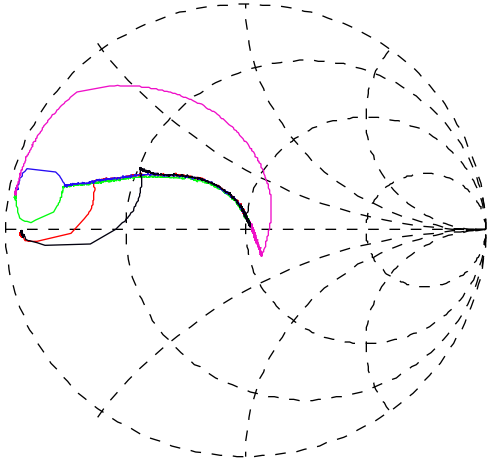
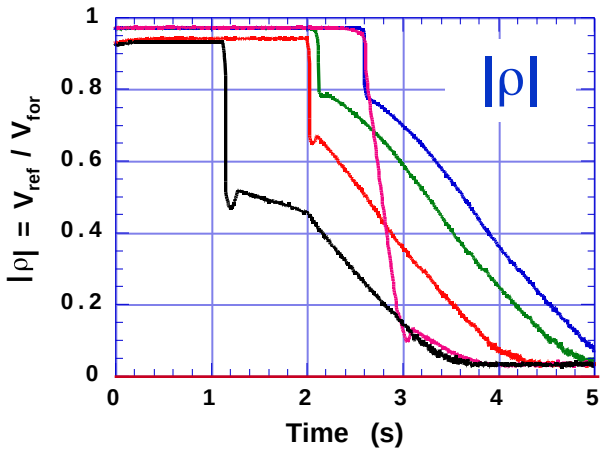
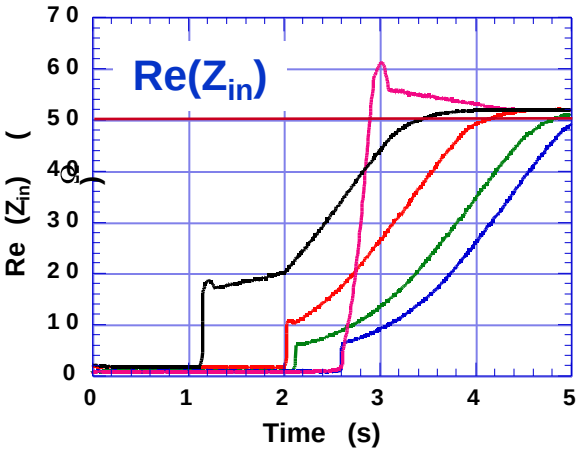
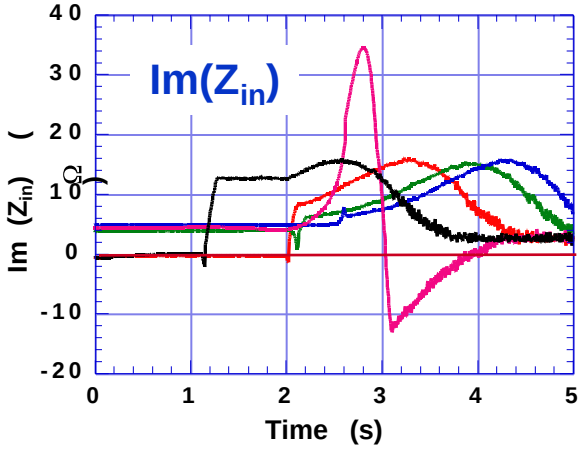
Robust match algorithm tested with TCP coil during Ar plasma operation



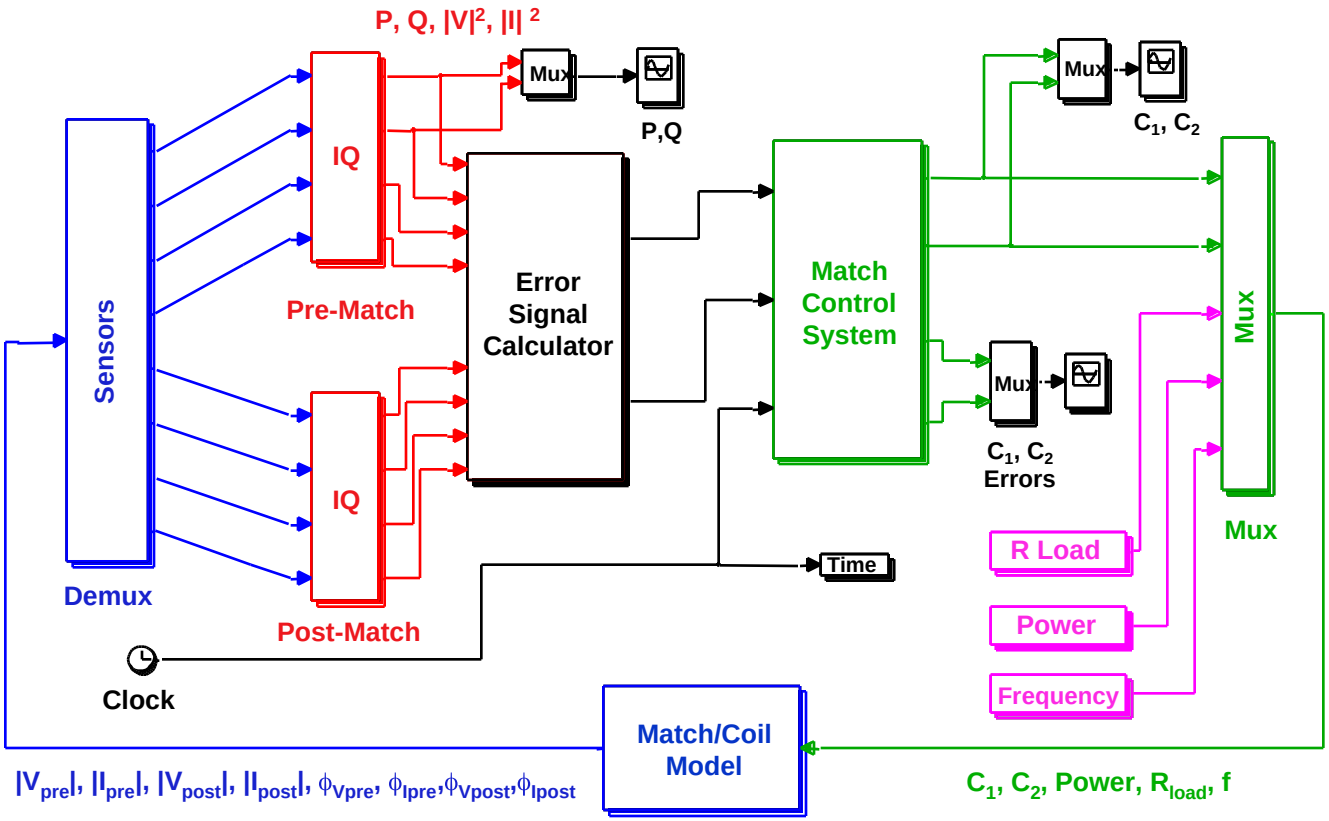


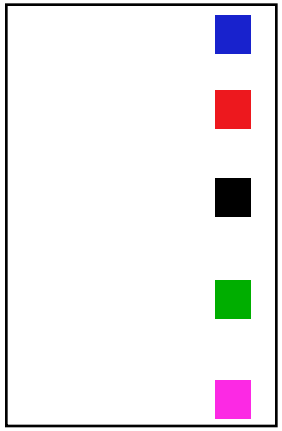




- Analog error signals: converges even with calibration errors, bad pre-sets.
- Single algorithm converges from perfect pre-strike to perfect post-strike match (red lines)
- System rapidly converges for errors of 400% in original setting (magenta lines)

Simulink Match System Model Top Layer





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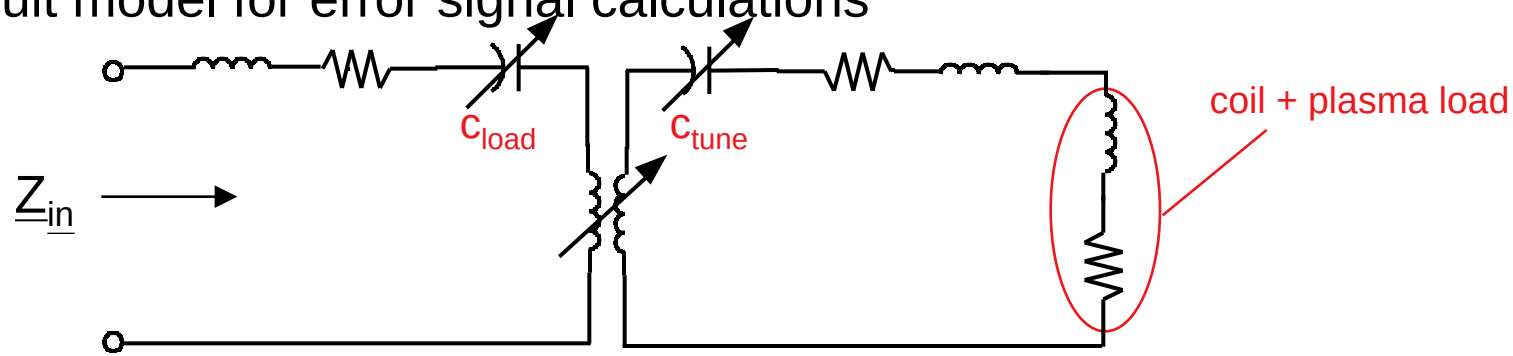
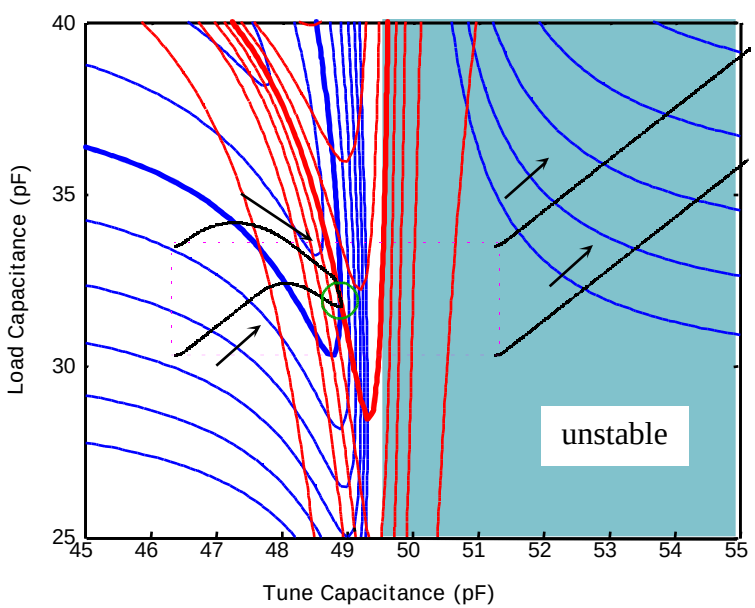
Robust match algorithm also predicted to work with other circuit configurations

- Circuit model for error signal calculations

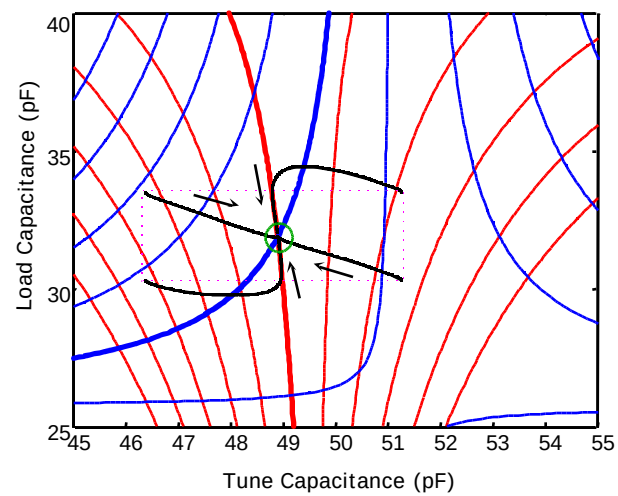


- Phase / Mag (Industry Standard)



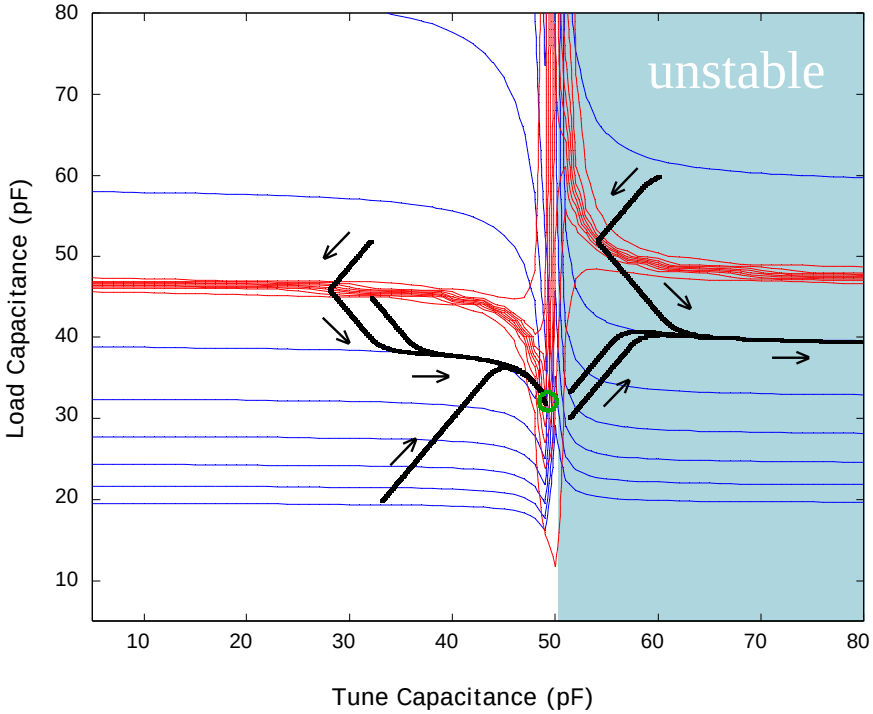
- New

O =match point

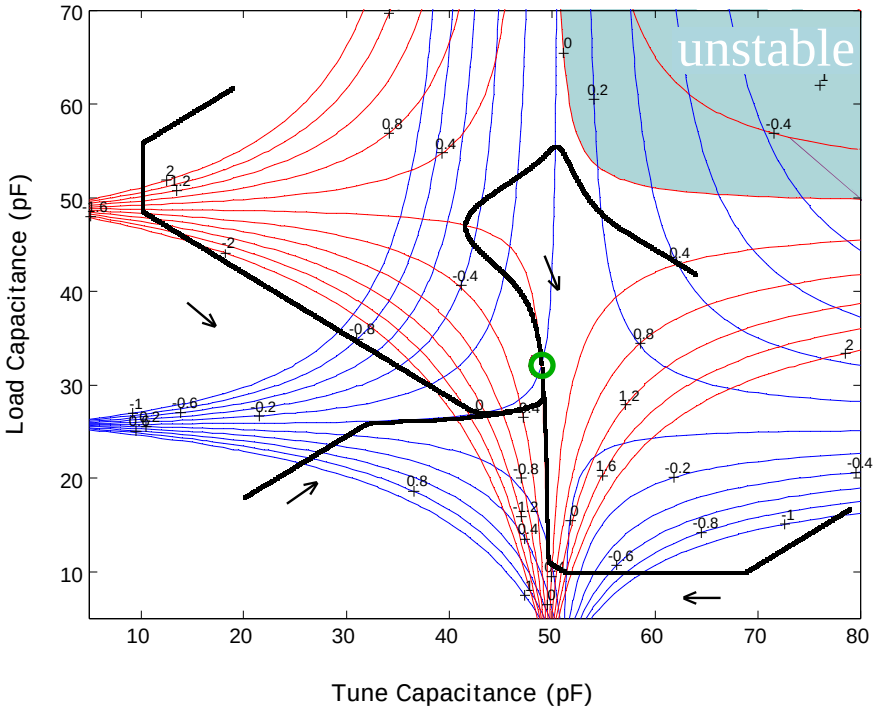


SIMULINK simulation of match compares standard and new algorithm

- Black lines: Simulink modeled tuning paths for auto-match
- Phase (Tune) / Mag (Load)



- New algorithm



○ = target region

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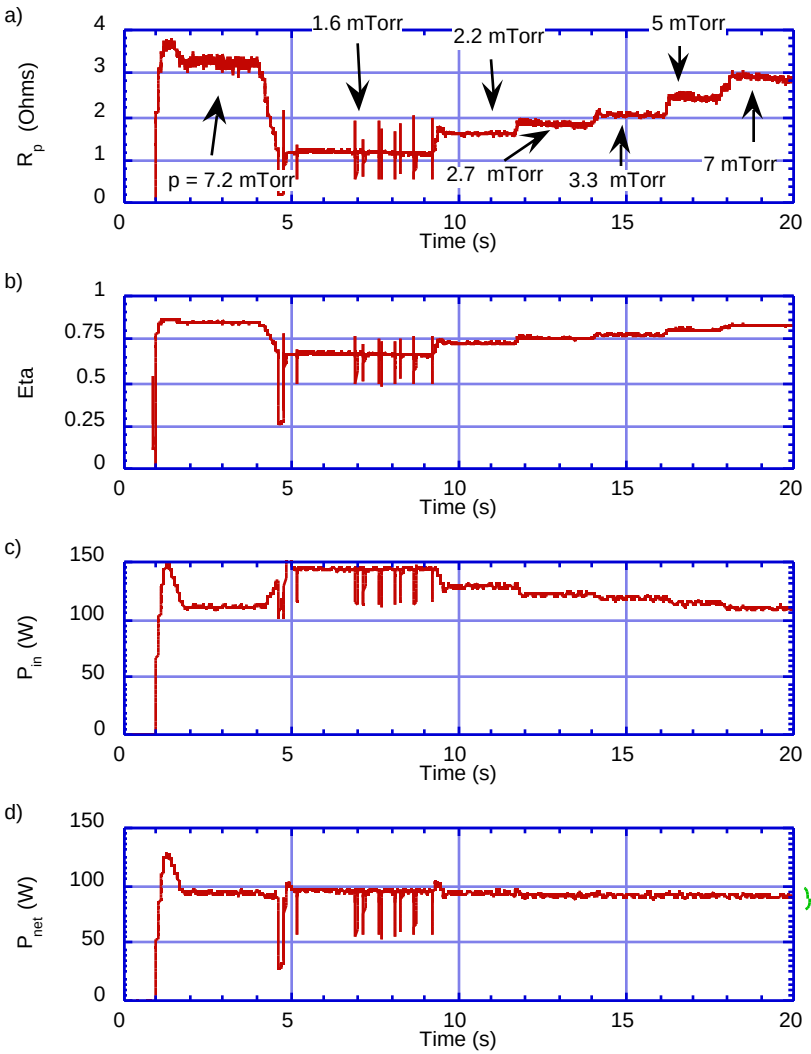
Robust match system has been tried on a Lam 9600 match

- Have implemented portable LabView based controller
- Have verified convergence from all four regions in vacuum and with plasma
- Pre-strike match to post-strike match with plasma, no presets required
- Will be tested at SEMATECH in near future

Net Power Control Test Results



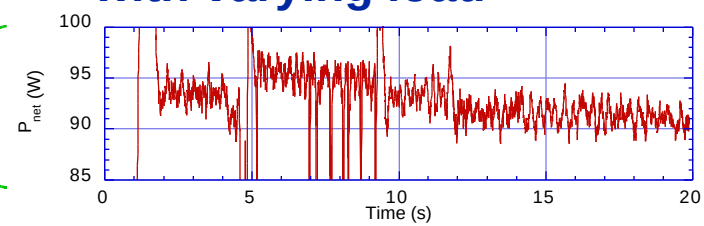
Plasma Resistance

Efficiency

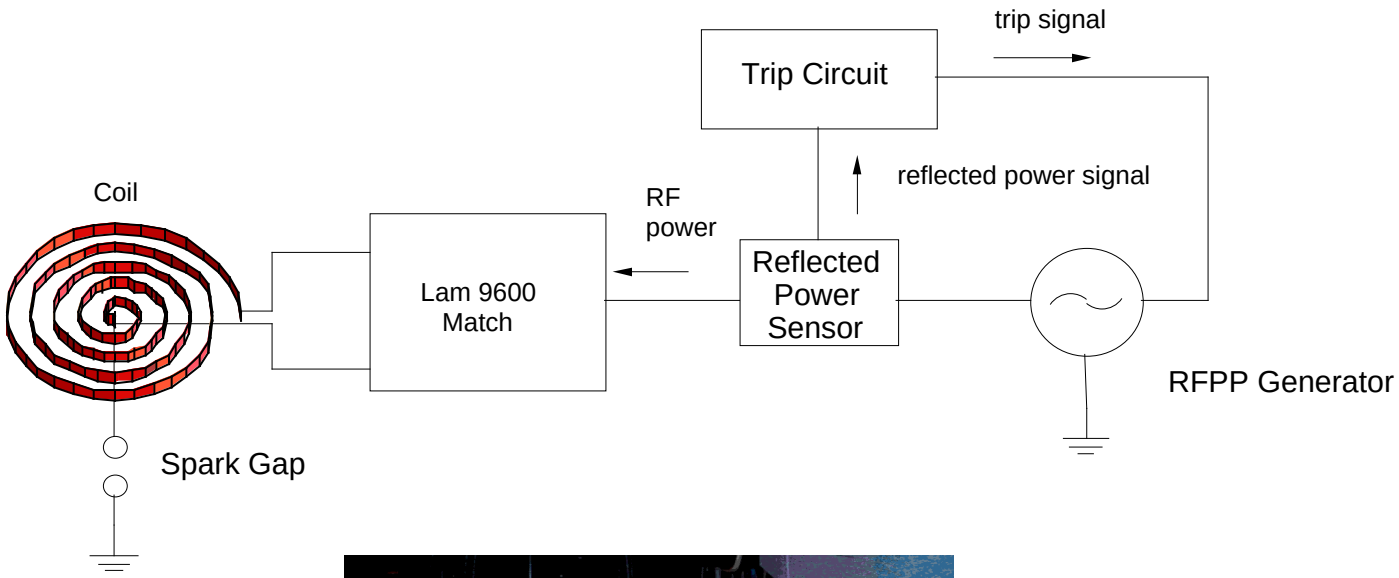
Input Power

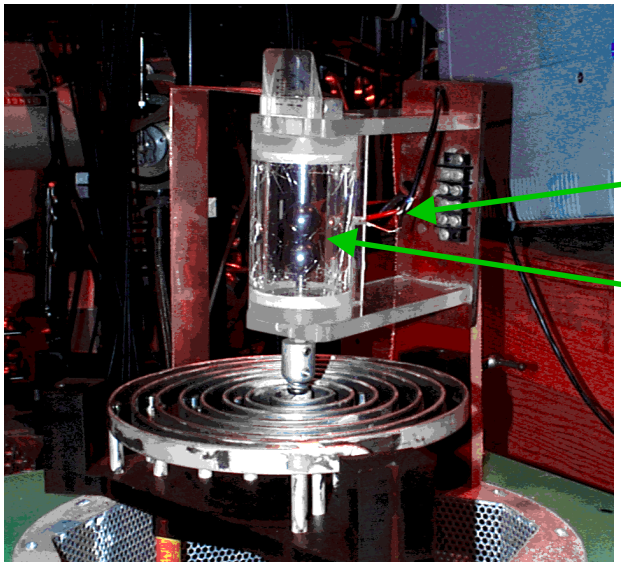
Net Power Control

- **Input power modulated to hold net power constant with varying load**



Arc Protection Circuit





light sensor

spark gap

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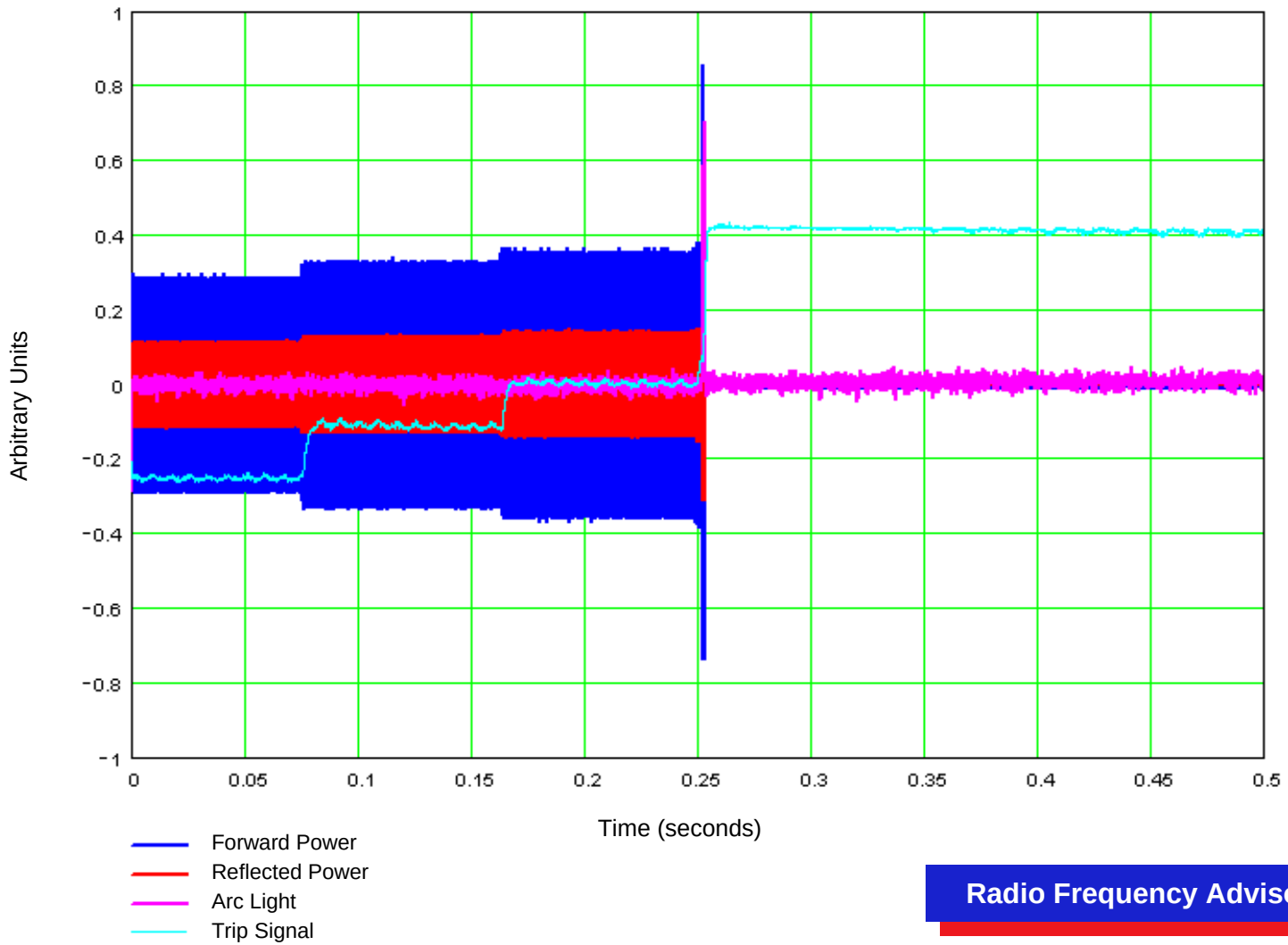
Arc Protection Using Reflected Power Detection



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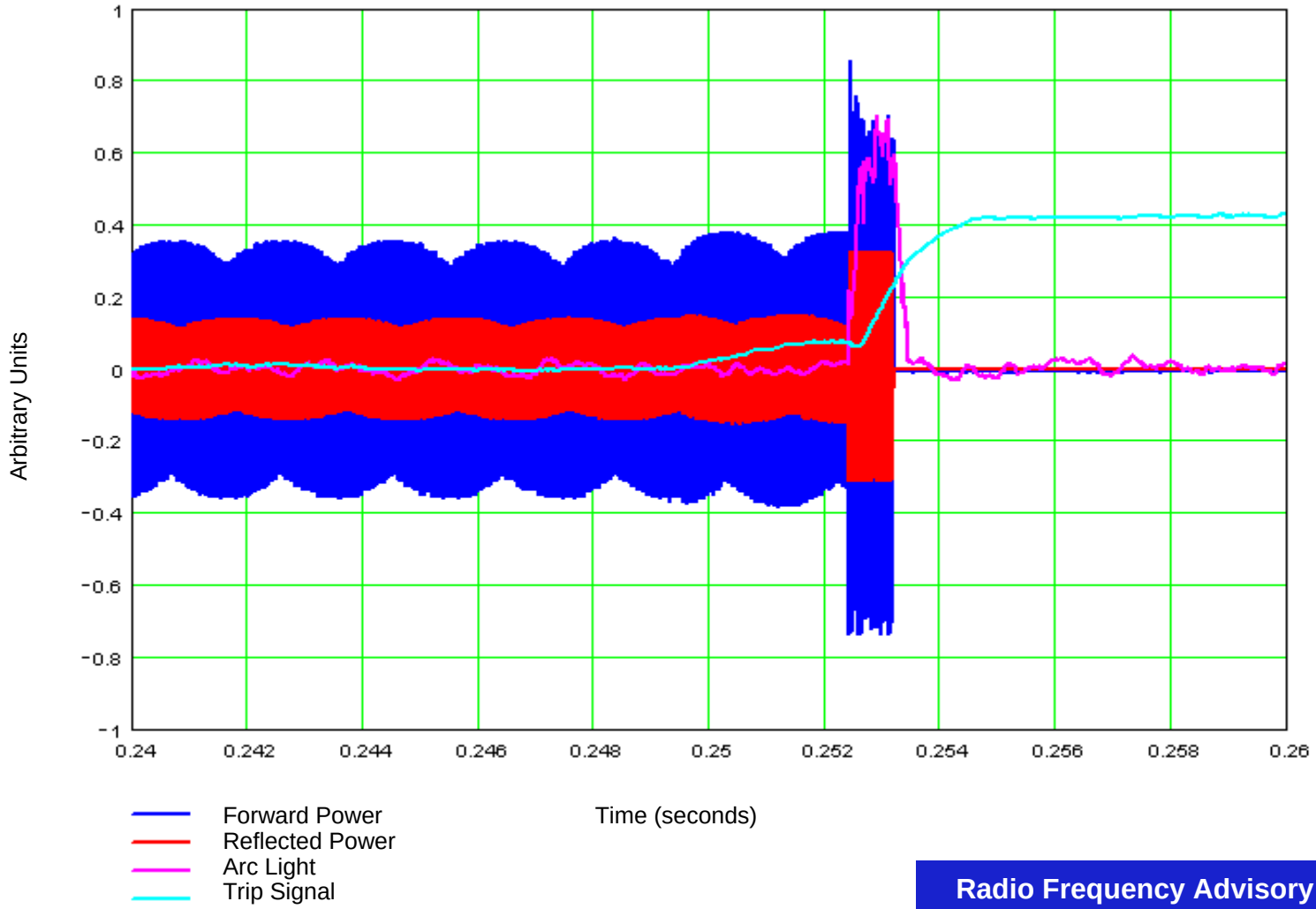
Arc Protection Using Reflected Power Detection (cont.)



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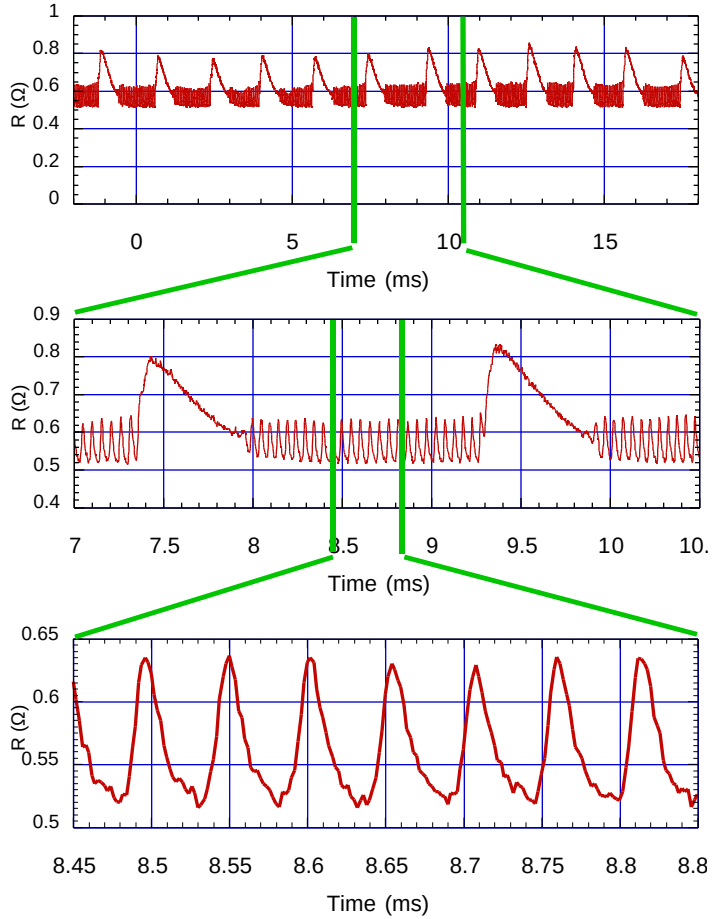
Plasma resistance fluctuations in an electronegative discharge



f ~ 500 Hz

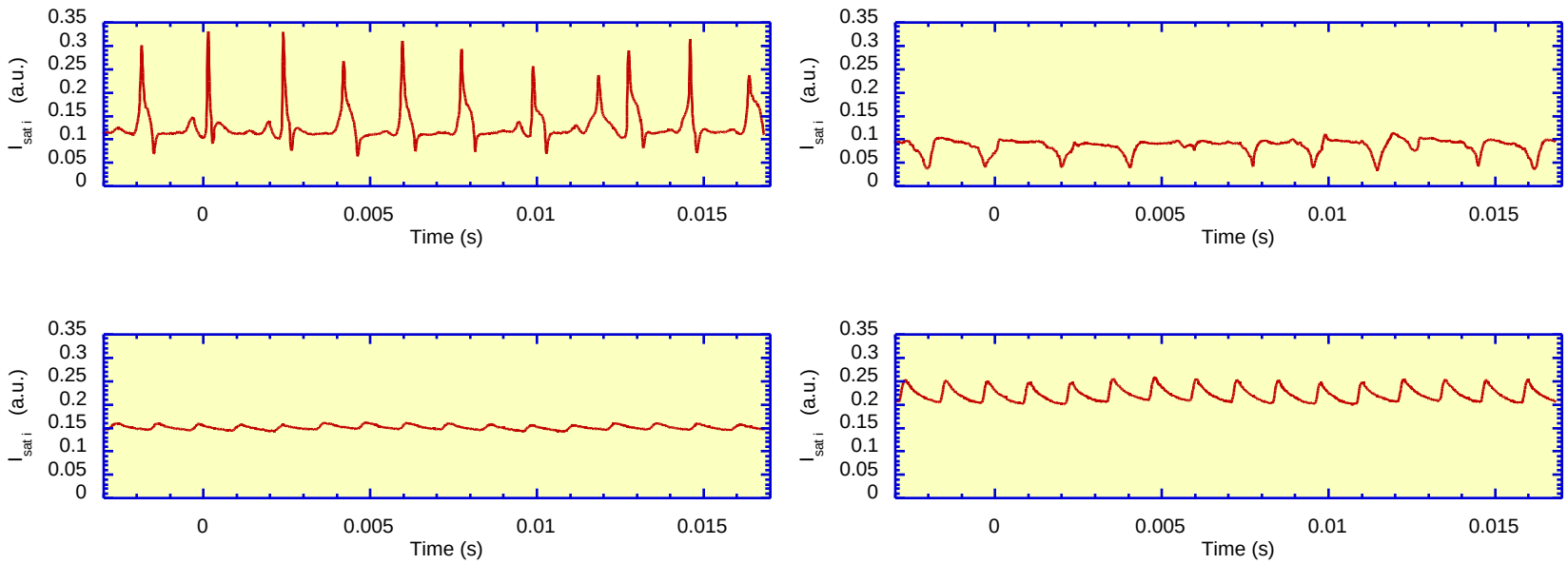
f ~ 20 kHz

- measured with pre-match VI sensor, post-match current probe, linear rf amplitude detector w/ 40dB dynamic range
- max increase in reflected power only 5%, but average density fluctuations much higher
- Normal pre-match sensors "blind" to this level of fluctuation - even though it causes ~30% density fluctuations

Fluctuations have clear radial non-uniformities

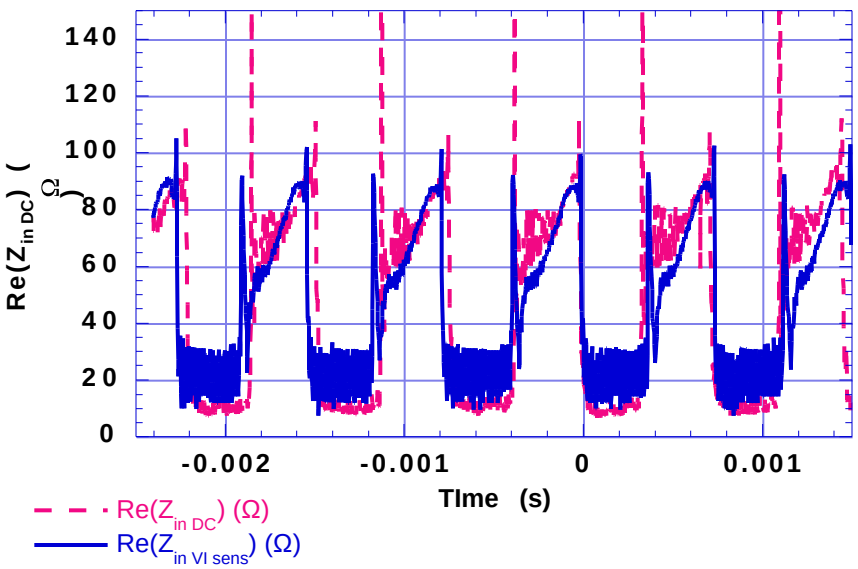
- **Pressure = const. = 6.9 mTorr**

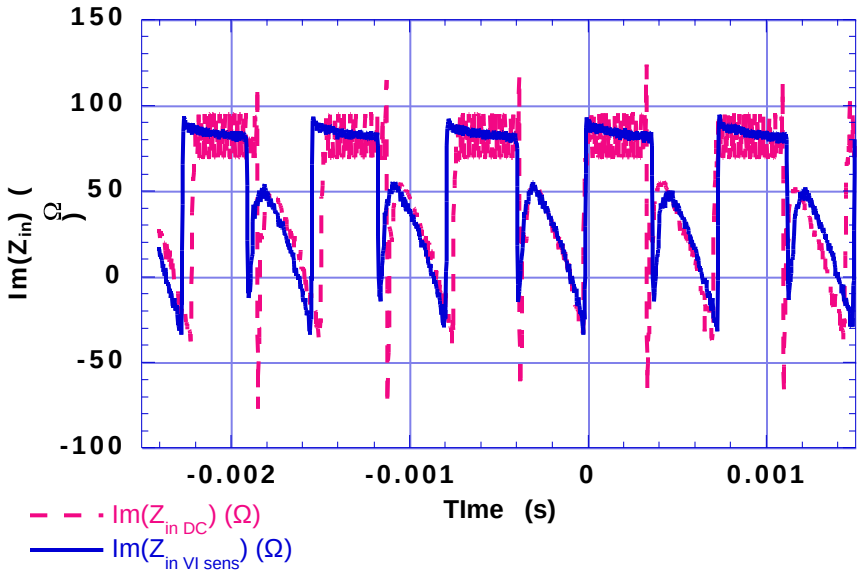
Ion saturation current at center | **Ion saturation current at edge**



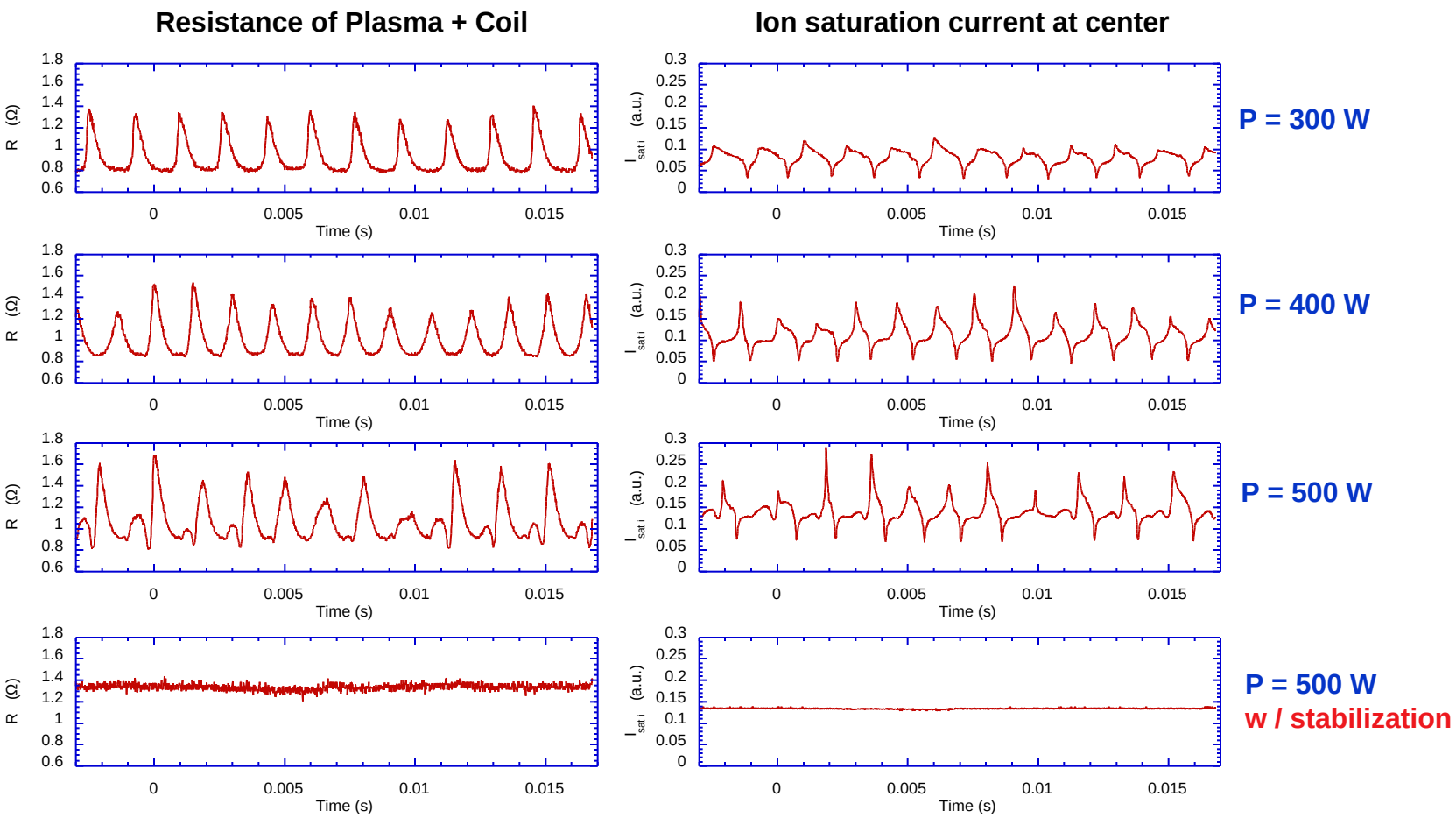
➢ **Top and bottom show 2 cases in different operating regimes**

Fast phase detectors (time resolution-2 µs) allow complex input impedances to be accurately measured during fluctuations





Plasma fluctuations can be detected non-invasively, and stabilized



• Pressure = const. = 8.0 mTorr

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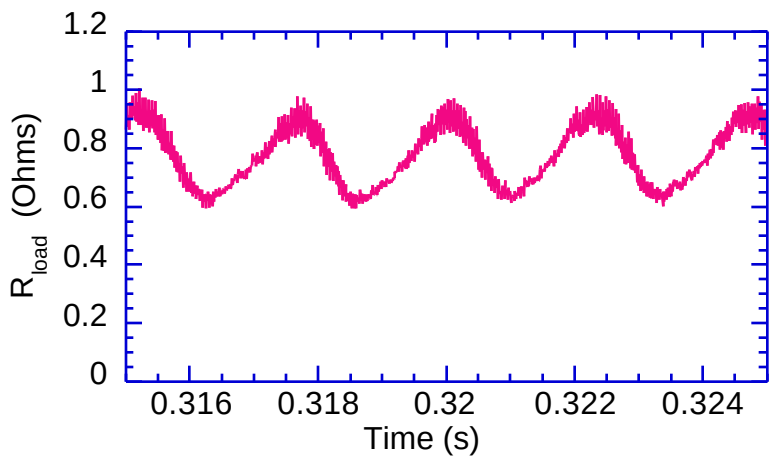
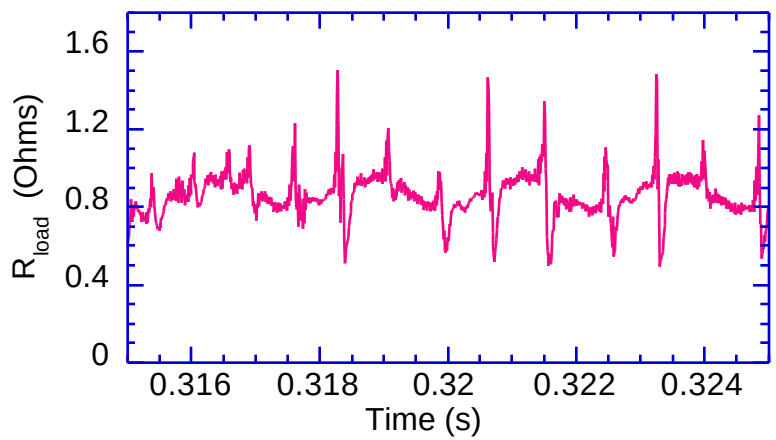
Fast fluctuation measurements on industrial etch tool

- "Noise" seen at low sampling rate can actually be plasma fluctuations
- Non-invasive fast measurement techniques developed at ORNL tried on industrial tool
- Initial fast loading measurements (HBr + Cl polysilicon etch)
- Fast changes in both resistance and reactance can be measured

Fluctuation at beat frequency



Fluctuation at ~ 2 x beat frequency + other components



RF power to chuck reduced slightly →

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Prototype RF manufacturing test hardware to improve match reliability

Plasma surrogate rf load

Water cooled for high power testing

- Low-power tests map tuning range / finds problems
- High-power stress tests reduce infant mortality
- Can be adapted to other match boxes / made portable
- Fixture greatly facilitates “field fixes”

Summary

New technology has been developed that can improve the performance of 300mm and other plasma processing systems:

- **multi-coil TCP sources**
- **net power control**
- **robust match algorithms**
- **arc protection**
- **noninvasive fluctuation measurement and suppression**
- **match testing techniques**