The initial Commissioning of the ITER-Like Ion Cyclotron Antenna on JET

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and the many participants in the JET ILA Program

VLT Conference Call

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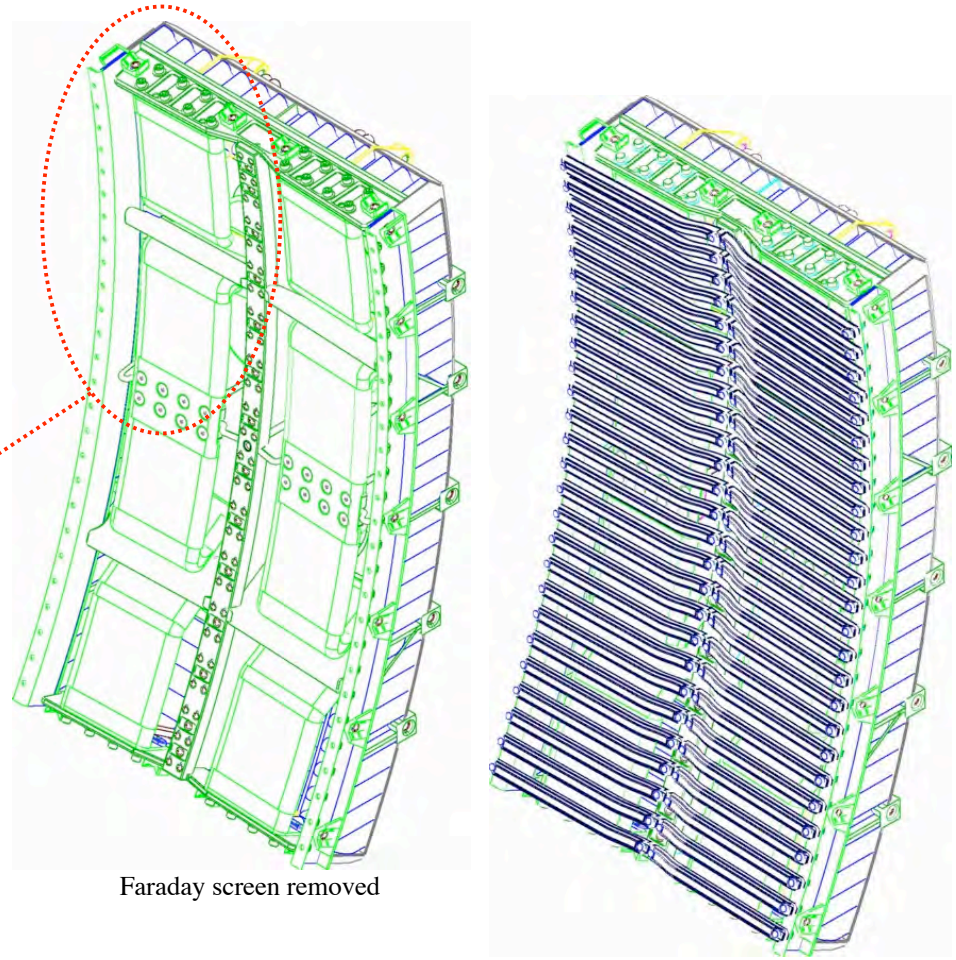
OAK RIDGE NATIONAL LABORATORY
U. S. DEPARTMENT OF ENERGY

Introduction

- The JET ITER-Like Antenna was installed on JET in December last year
- Commissioning activities on plasma began in May 2008
- To date the following has been accomplished
  - Automatic matching of upper and lower antenna halves including tracking during L-H transitions
  - Coupled power levels up to 1.5 MW into L-mode and 1.1 MW into H-mode plasmas for 5 s
  - Operating voltages up to 38 kV at capacitors in H-mode plasmas (5 s total pulse length)
  - Initial investigation of advanced arc protection systems for protecting against arcs in low voltage regions that do not produce large reflections in matched lines

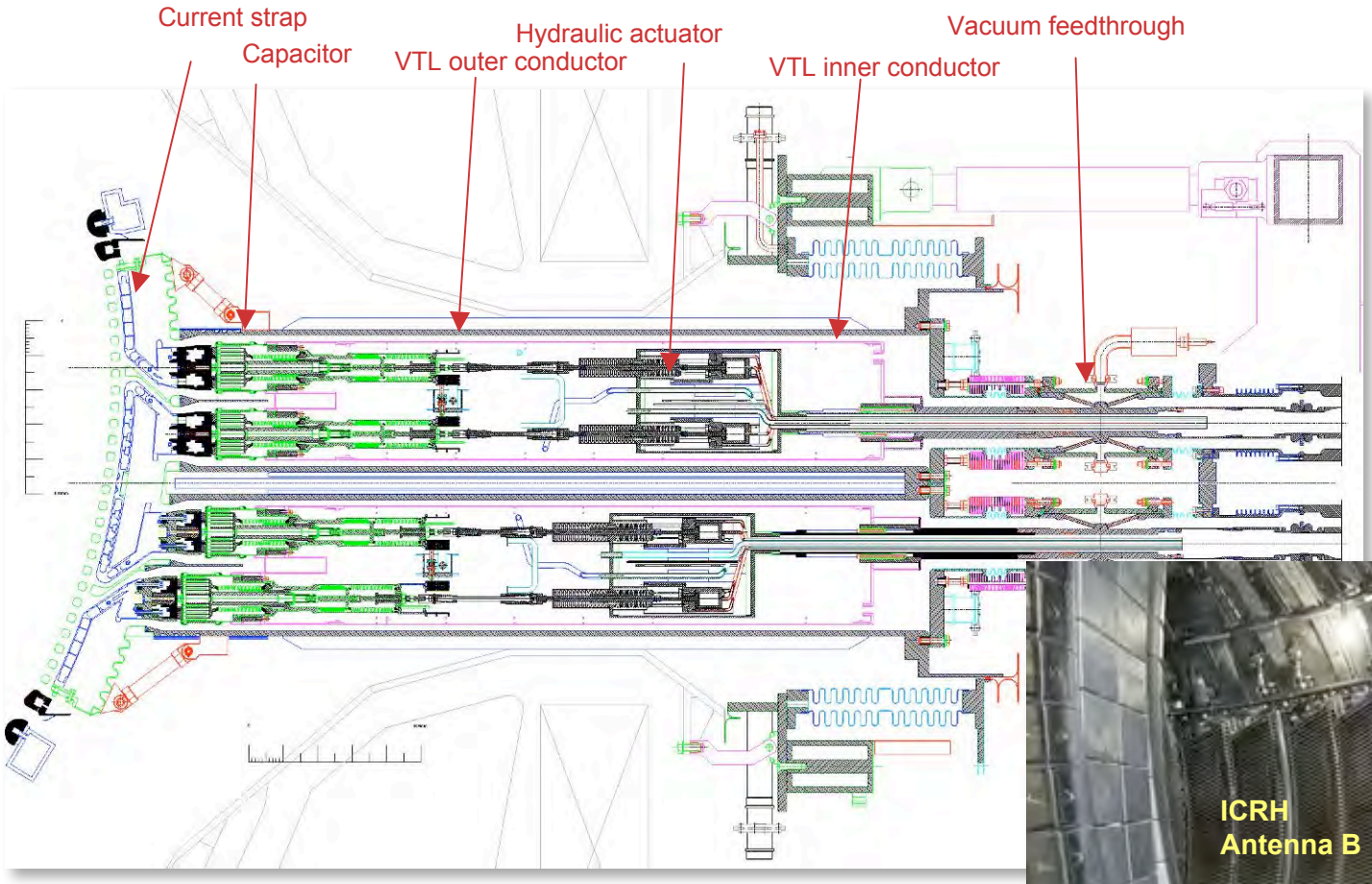
The JET ITER-Like Antenna (ILA)

- **Test design principles of ITER antenna on JET**
- **Goal to couple 7.1 MW (8 MW/m^2) of power in the frequency range 30-50 MHz into an ELMy H-mode plasma**
- **Designed to match during ELMs and other transients causing increases in resistive loading (VSWR < 1.5, allows rf generator to couple full power into antenna)**
- **ORNL designed, fabricated and tested prototype of 1 quadrant of antenna in collaboration with PPPL and JET (~ 75% funding provided by VLT)**

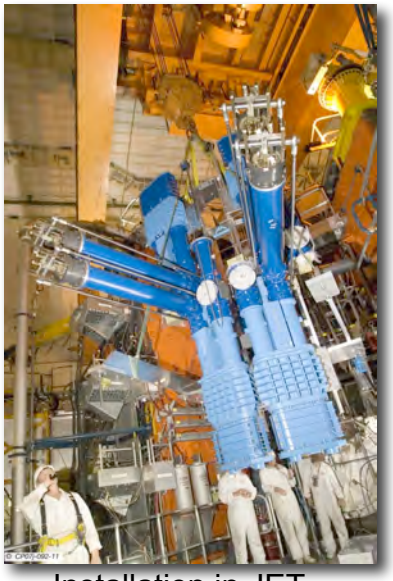


JET ITER-Like ICRF Antenna

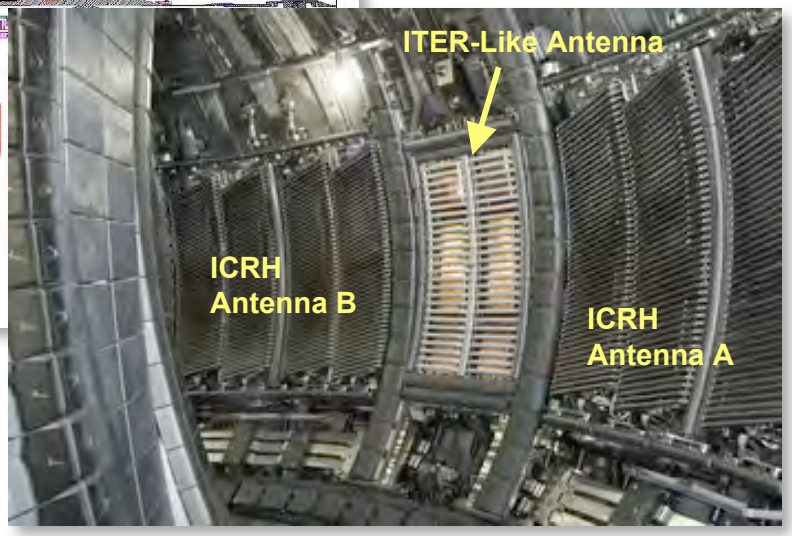
The JET ITER-Like Antenna



Elevation



Installation in JET

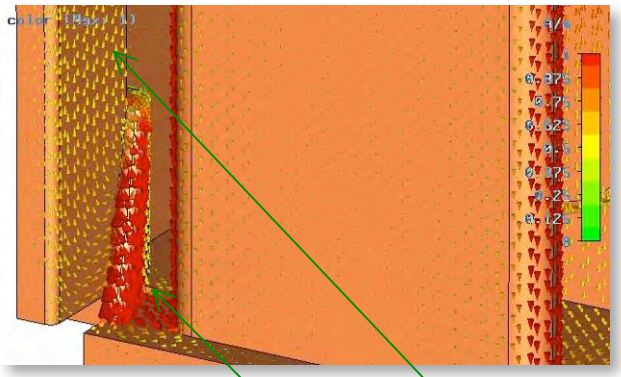


Antenna installed in tokamak

Summary of HPP collaboration results

- **Novel design features tested include:**
  - Custom built capacitors with modified braze joints and plug-in flanges
  - Low Z0 impedance transformer with internal capacitor actuators
  - Hollow current straps

- **Critical design changes and other recommendations resulted from tests**
  - Addition of wedges to reduce rf current in thin inconel “flexipivot”
  - Modification of protection tiles to prevent arcing
  - Replacement of center septum protection graphite tiles with beryllium tiles due to high rf dissipation and outgassing
  - More than 30 other design changes and recommendations



Rf currents in wedge and flexipivot modeled using Microwave Studio

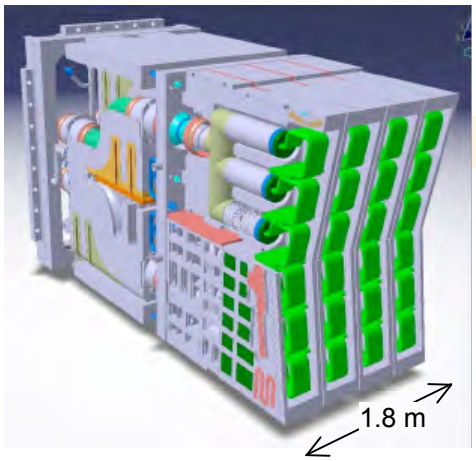
Wedge in antenna box

ILA tests are highly relevant to design and implementation of ICRH on ITER

- Determination of plasma loading and power handling for ITER-Like antenna geometry using multiple short poloidal straps similar to ITER design under ITER relevant conditions
  - H-mode ELMy plasmas with large gaps
  - Gas puffing to improve coupling
  - Both have been examined using A2 antennas, but ILA geometry closer to that of ITER antenna
- Investigation of ELM resilience of conjugate tee matching configuration and matching algorithm convergence
- Test of methods for detection of arcs in low voltage regions
- Investigation of physics with ICH replacing NBI heating (A. Loarte)
  - 10-20 MW level, would use both ILA and A2 antennas in ELM resilient configurations
  - Role of toroidal rotation on pedestal plasma and ELM characteristics
  - Achievement of high densities and good confinement without NBI fueling
  - Plasma performance with e-heating alone and good e-i coupling at high density

Some ITER relevant aspects of the ILA

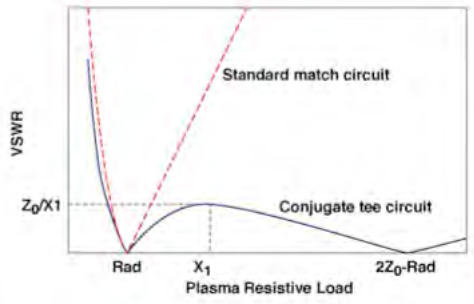
JET
8 straps 2 X 4



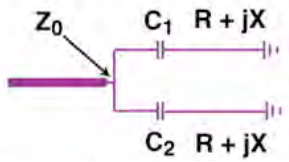
ITER
24 straps 4 X 6

- **Antennas have multiple short poloidal straps to minimize voltage and electric field close to plasma**

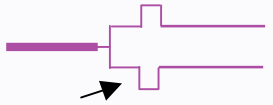
- **ILA serves as test of "conjugate-tee" matching network with large mutual inductance between poloidally adjacent current straps fed by circuit**



Conjugate tee maintains low VSWR at input to matching circuit as plasma resistive load increases during ELMs



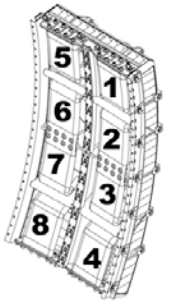
ILA Feed Circuit



Candidate ITER Circuit has internal capacitors replaced by external line stretchers, but principle is same

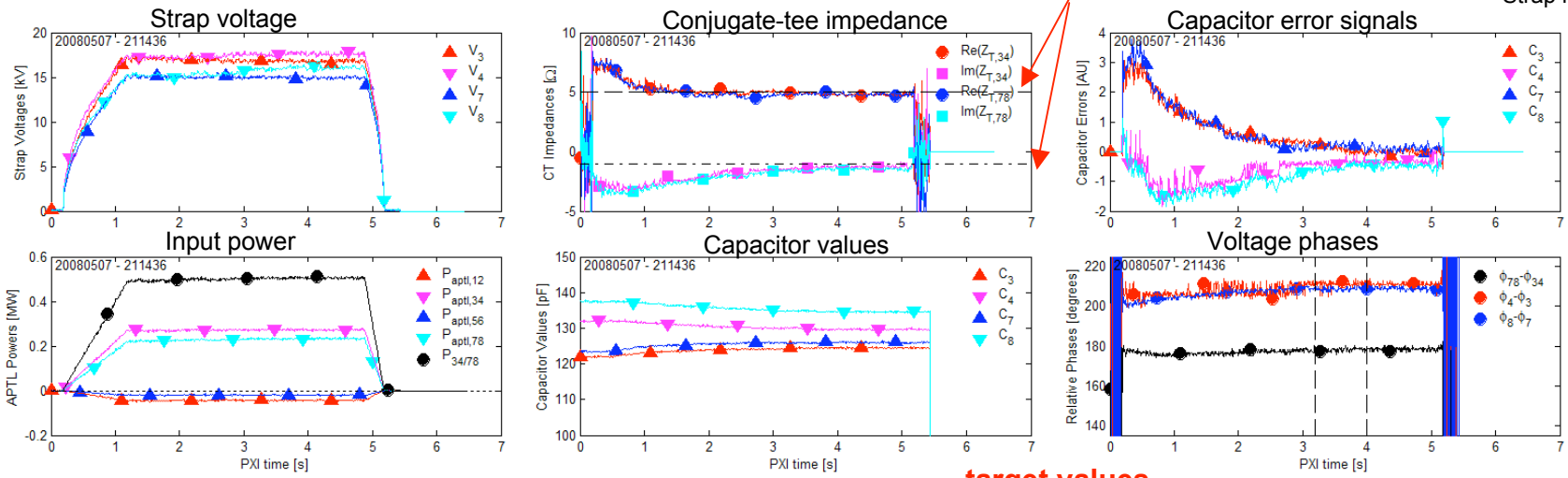
Antenna matching results

- **upper and lower antenna halves have matched well when operated separately**



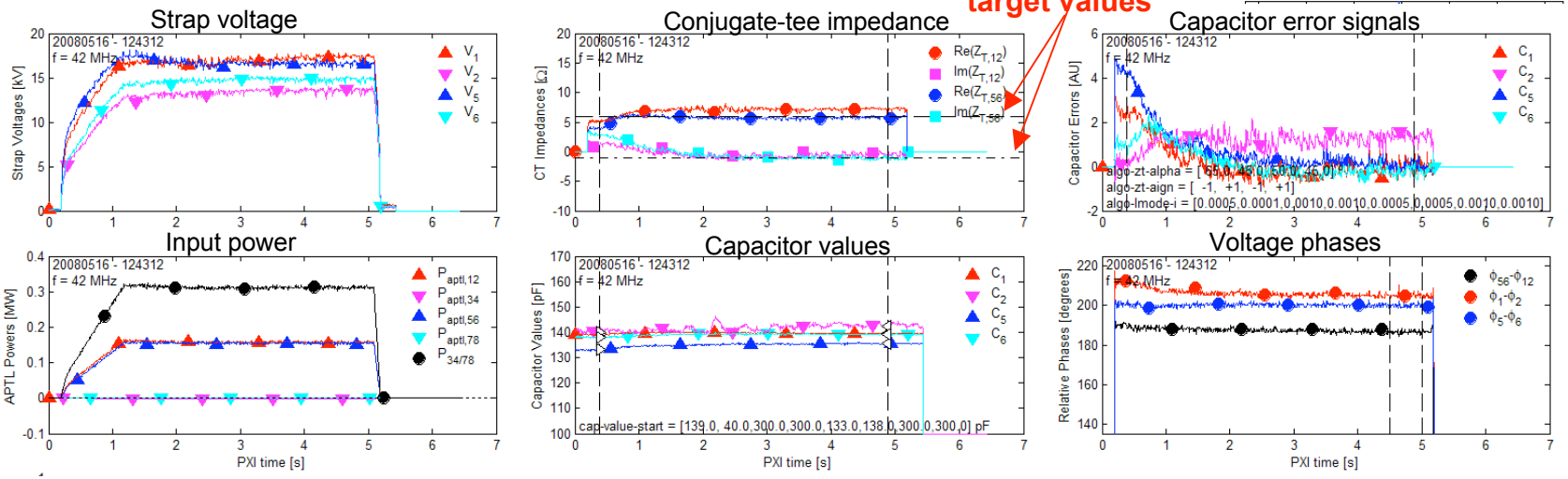
Strap numbering

target values



lower

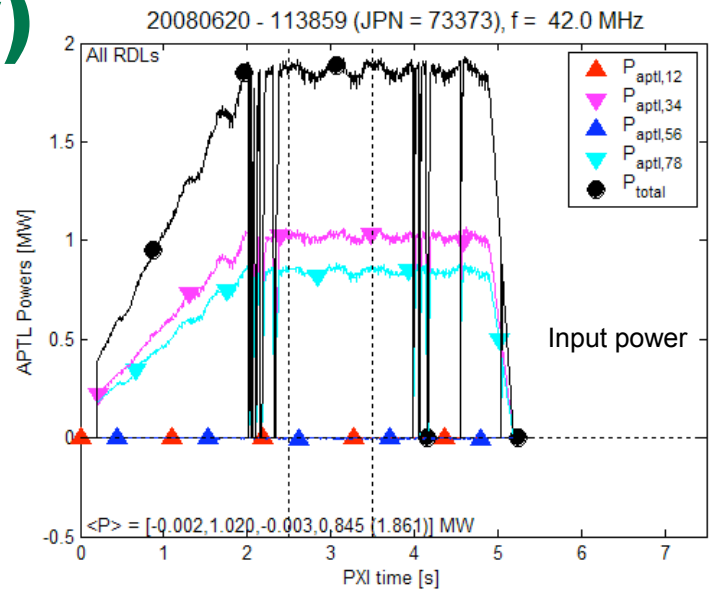
target values

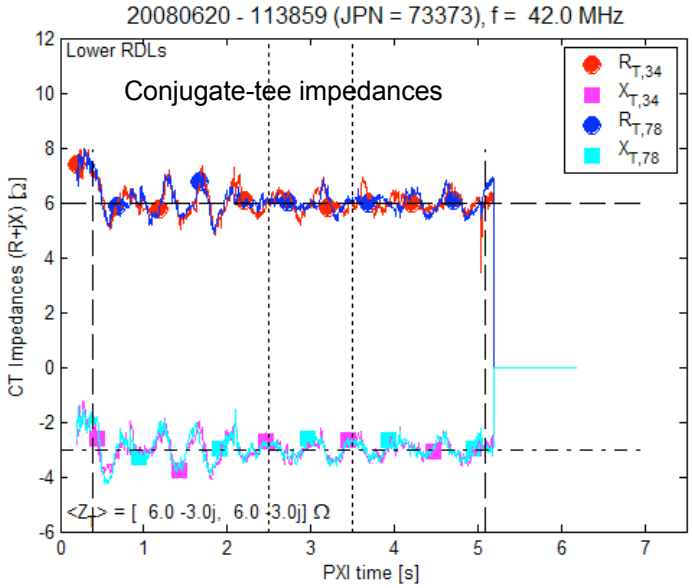


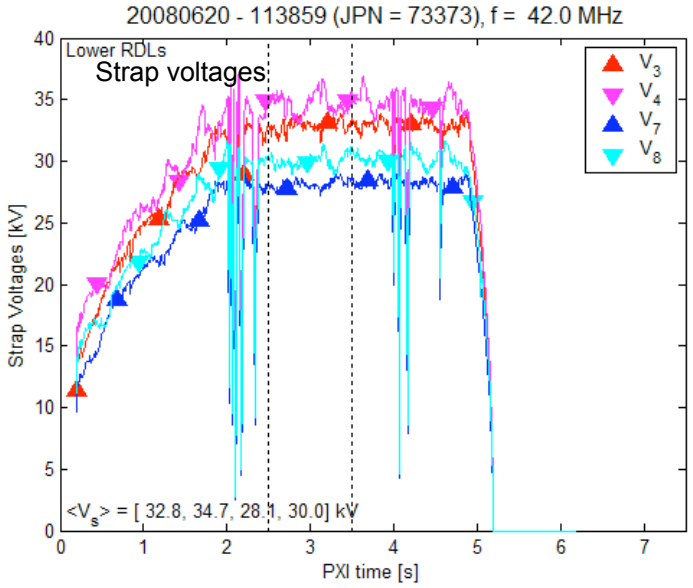
upper

1.5 MW coupled to date in L-Mode plasma (lower half only)

- **1.85 MW (APTL) - 0.35 MW (losses) = 1.50 MW coupled**
- **L-mode ROG (nominal midplane gap between separatrix and poloidal limiters) 4 cm**



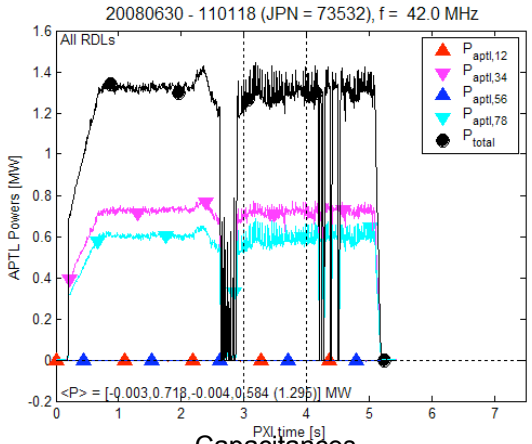




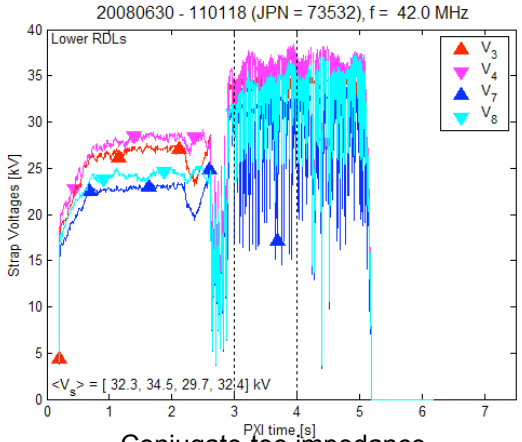
V ~ 38 kV achieved during H-mode operation

- **Coupled power ~ 1.05 MW (lower half only)**

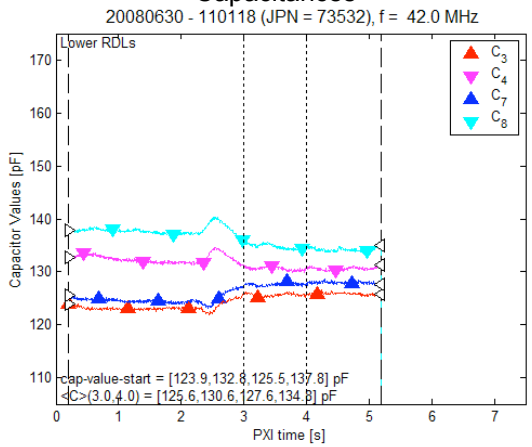
Input power



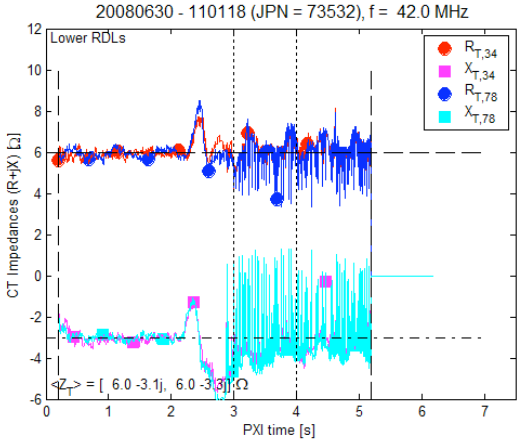
Strap voltage



Capacitances



Conjugate-tee impedance



Conclusions, Future Work

- **The JET ITER-Like Antenna has been operated successfully at power levels up to 1.5 MW, and the upper and lower halves of the antenna have been separately matched using feedback control in L and H mode plasmas**
- **Remaining commissioning work (through September) includes**
  - **Additional operation and conditioning to increase operating voltage**
  - **Operation of upper half of antenna with external potentiometer on C2 capacitor**
  - **Routine operation of full antenna with feedback matching**
  - **Commissioning of Scattering Matrix Arc Detection (SMAD) system (principle of operation confirmed by post-analysis of slow data)**
  - **Tests of ELM resilience with conjugate tee matching resistance lowered from 6Ω to 3Ω**
  - **Power maximization**
- **Other relevant work now underway includes**
  - **Modeling of antenna loading with TOPICA code, using edge plasma density profiles provided by edge reflectometer, multichannel FIR interferometer, and other diagnostics**