Results from Recent Tests of the JET ITER-Like High Power Prototype ICH antenna

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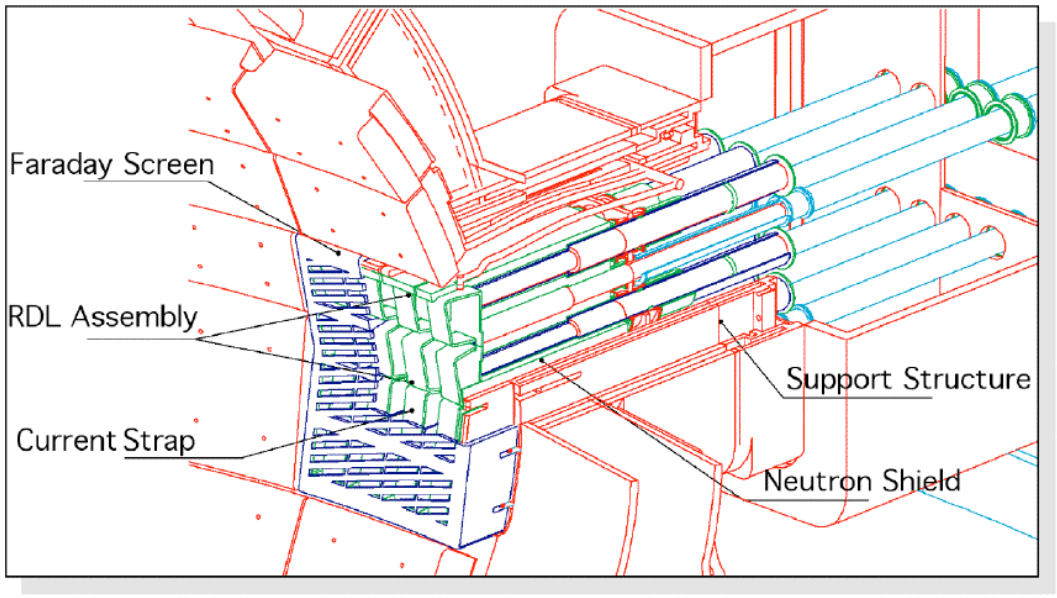
PPPL PRINCETON PLASMA PHYSICS LABORATORY

US and EU have collaborated to design and test an "ITER-like" high-power antenna

- For ITER, ICRH plasma coupling requirements are challenging:
  - Large antenna/separatrix gap
  - ELMs can produce order of magnitude variation in rf plasma load

ITER ICRF Launcher (Baseline Design)



- ITER design goals:
  - 20 MW through single port, 40-55 MHz
  - Produce launcher *insensitive* to changes in loading caused by ELMs
  - Minimize electric fields in antenna

- EU proposed to build an advanced antenna with ITER-relevant features for use on JET
- US collaborated in design and prototype testing

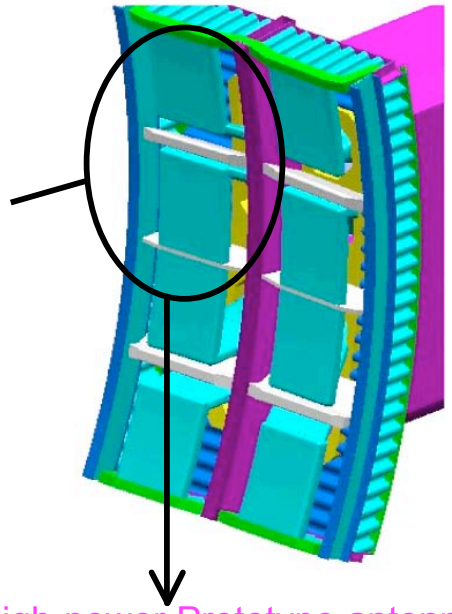
The High-Power Prototype (HPP) was built to test the JET-EP ICRF load-tolerant antenna concept

- JET-EP antenna is an advanced ion-cyclotron launcher
  - To be installed on JET in 2006.
  - Designed to couple ICRF power at high density (7.4 MW /m^2) into an ELMy H-mode plasma
  - New "load-tolerant" circuit design

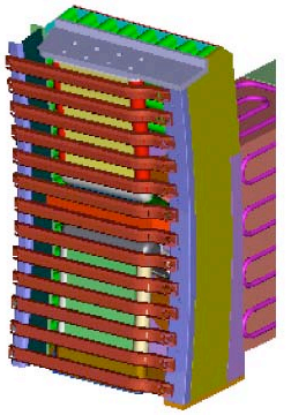
- It advances many aspects of ICH technology:
  - Use limited port space, with a high power density launcher
  - Run for 10-s long pulses
  - Work with rapidly varying plasma loads
  - Operate over a wide range of density and magnetic fields
  - Survive in a reactor environment

- ORNL and PPPL, in collaboration with the EU, fabricated a high-power prototype of one quadrant of the JET-EP antenna.
  - Complicated current strap shapes
  - Internal tuning and matching using two vacuum capacitors
  - *Large* vacuum transmission line
  - Component fabrication as close to JET-EP as possible

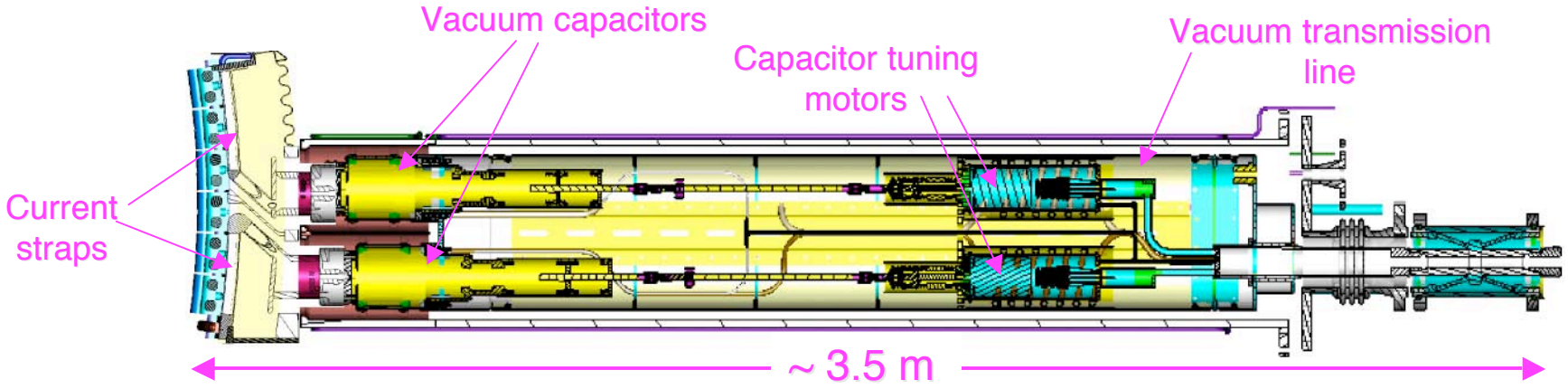
JET-EP ICRF antenna
(Faraday shield not shown)



High-power Prototype antenna



High-Power Prototype (HPP) Features Internal Capacitors and Large Vacuum Transmission Line



2001: Started design work, collaboration between US and EU

2003: Initial tests at ORNL
- Found significant problems
- JET EP antenna design modified

2005: Tests of improved antenna
- Worked significantly better
- Minor additional changes needed

HPP Antenna before installation in vacuum stand

Prototype tests were needed to answer several Critical Questions

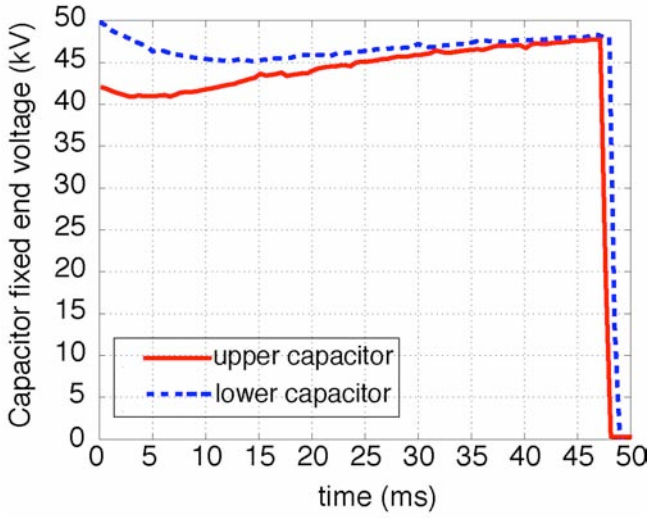
- What is the maximum antenna operating voltage:
  - For short-pulse operation?
  - For long-pulse operation?

- Are there thermal problems with long-pulse high-voltage, high-current operation:
  - Do metal surfaces heat up?
  - Do the capacitor ceramics heat up?
    - No way to directly cool ceramics, so have to rely on between-shot cooling.

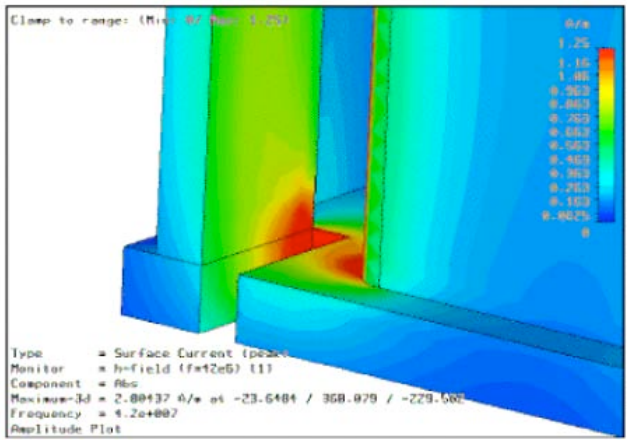
2003 tests found significant problems

- Arcing between C tiles on the side of the antenna to the Faraday shield limited max V to < 25 kV for short pulses
  - Removing tiles allowed V_{max} > 42 kV
- Long-pulse operation caused melting near base of current strap
  - High rf current density computed *post hoc*
- Regions of current strap cracked or lost plating (fabrication problems)

Voltage test after tile removal



Computed current concentration



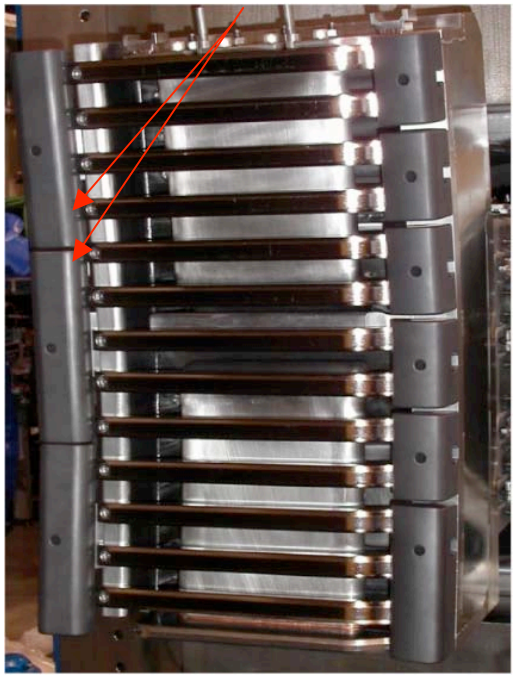
Arc damage on current strap

Revisions to JET-EP design were made to correct problems

Modified antenna showed much improved results in 2005

- Modified tiles with 10 mm gap to Faraday shield bars
  - eliminated arcing
  - allowed capacitor voltages > 50 kV to be achieved with tiles installed

Arc damage observed in 2003

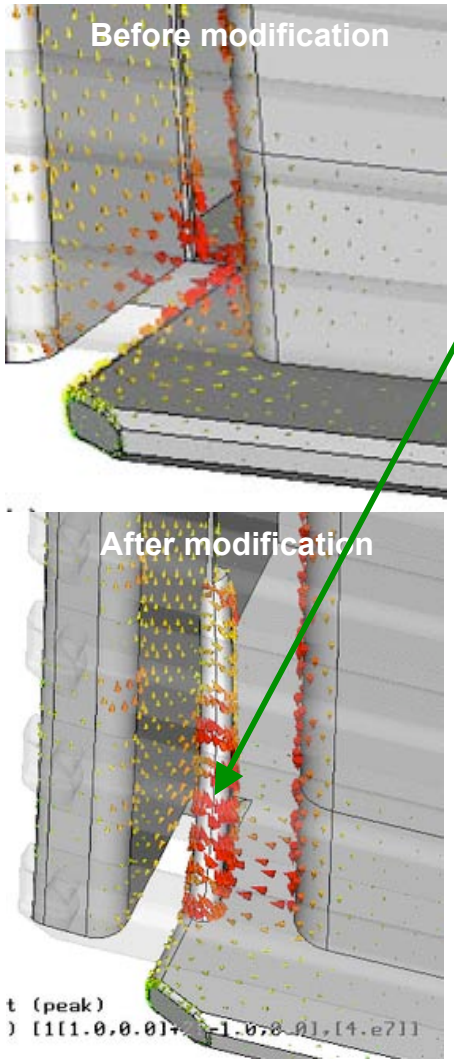


Closeup of damaged region

Same region after recent operation - no damage seen

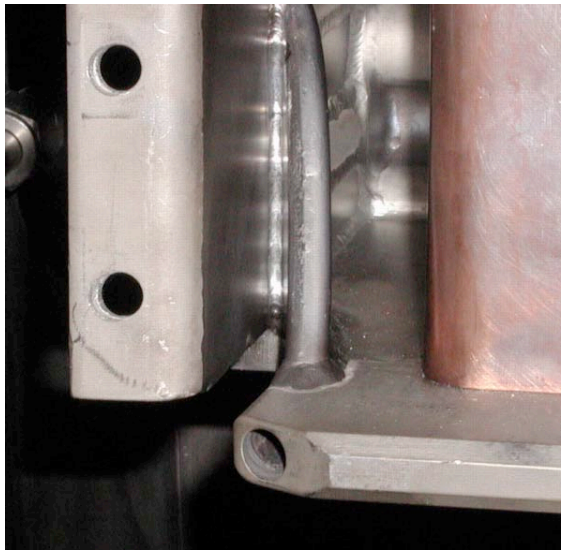
- Re-designed current straps showed no melting after long-pulse operation

Melted region near base of straps eliminated by installation of wedges to redistribute current



CST Microwave Studio calculations

- Localized melting observed after several 0.5 - 0.8 MJ pulses during 2003 operation

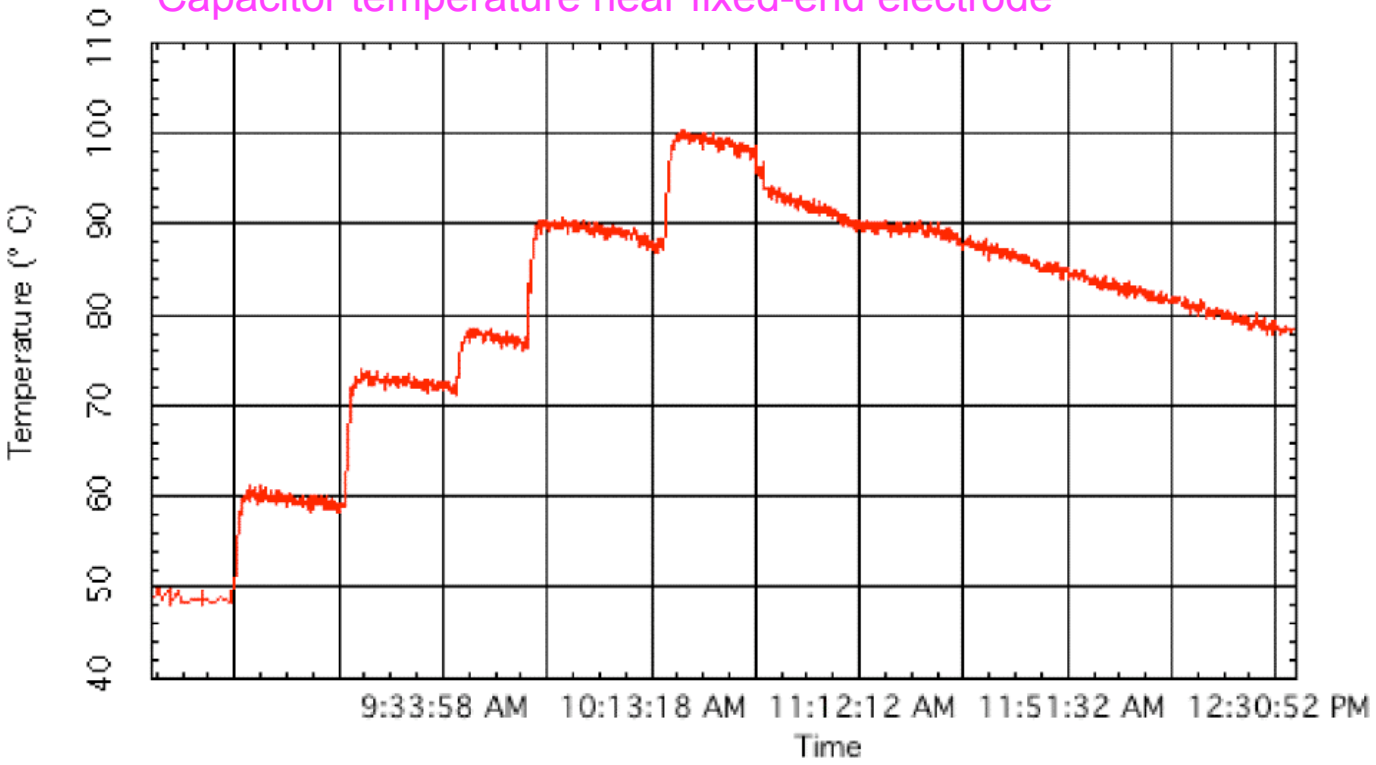


- No damage observed after many 0.8 - 1.8 MJ pulses during recent operation

Vacuum capacitor passed long-pulse thermal tests

- Ceramic capacitor can in vacuum, cooling slow through conduction only
- Results of series of 10-s pulses indicate
  - acceptable heating and cooling
  - ability to operate in vacuum at 50 kV

Capacitor temperature near fixed-end electrode



Temperature monitored here

Conclusions

- Construction and testing of antenna prototype *very* successful
  - Design problems identified
  - Construction pointed out fabrication and plating issues
  - JET-EP Antenna design revised to fix the problems
  - Saved lots of money *and time,* compared to repairing the actual antenna
- Revised version of antenna worked much better
  - Higher voltage, longer-pulse operation
  - Issue: Thermal glow seen on graphite tiles near Faraday shield bars
    - Antenna design revised
- Good preparation for collaborating with EU to build ITER antenna
  - Developed good working relationship with EU researchers
    [Note: ITER antenna split 50:50 between US and EU]
  - Found out realities of dealing with EU system
    - Good news: hard-working, dedicated, state-of-the-art researchers
    - Bad news: lots of red tape in their design and procurement system
- Looking forward to participation in experiments on JET with new antenna in 2006.