Study of Voltage Limits on Ion Cyclotron Antenna Power in Tokamaks

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Outline

High-voltage history -what's the problem?

Plan of basic research to attack the problem

Equipment description
- IPP-Garching
- ORNL

Initial Results

What limits power-handling capability of rf systems?

It's often the maximum voltage that antenna or vacuum transmission line can hold off before breaking down.

- Antennas can often withstand 50 kV in vacuum conditions
- Reductions of 30% to 50% are common when exposed to plasma

Why?

ORNL and IPP have started a collaborative program to study fundamental rf breakdown.

The goals of this study are to:

- Understand factors that limit rf voltage holdoff in the presence of plasmas
- Increase the voltage limits seen in present-day rf systems

What do we plan to do?

Plan:

- Develop a common geometry for tests - “High Voltage Tester” √ Done
  - Controlled geometry for well-known electric fields
  - Capability to easily alter test materials, geometry, and environment

- Carry out high-voltage breakdown tests at ORNL on mini-RFTF device
- Carry out similar tests at IPP on vacuum test stand
- Test the same electrode geometry exposed to the ASDEX-U plasma

Schedule:

- Carry out rf breakdown experiments in vacuum with and without magnetic field Fall 2000 (IPP and ORNL).
- Begin experiment on AUG summer 2001.
- Continue experiments on test stands and AUG into 2002.

What do we plan to study?

- Effects on RF breakdown voltage of
  - gas pressure
  - material, material preparation, material coating
  - plasma density
  - magnetic field
  - UV radiation level

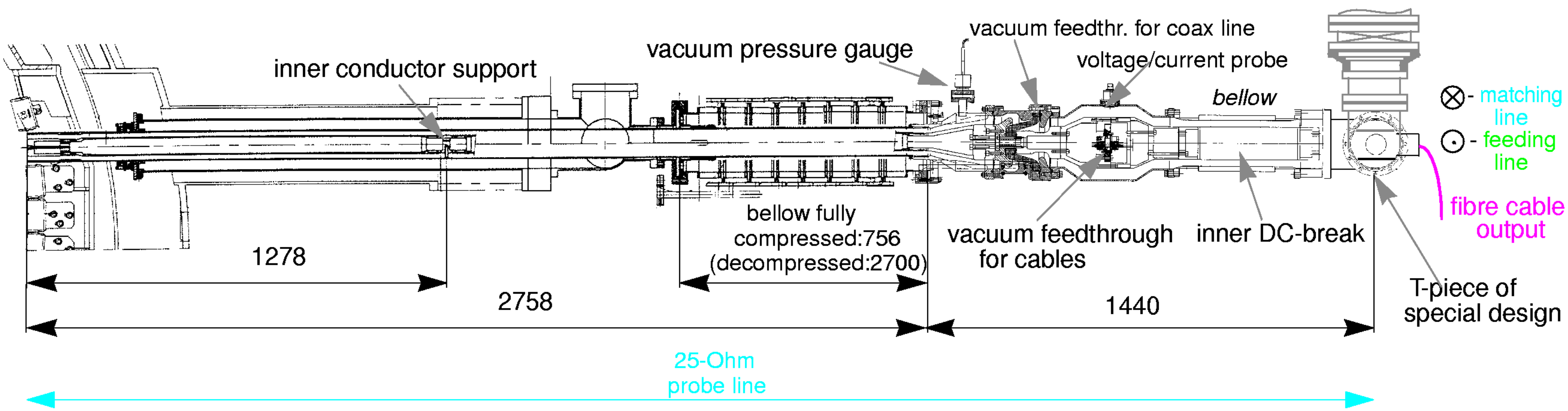
- Effect on breakdown voltage of gas adsorption and plasma exposure
- Breakdown voltage with and without conditioning
- Effects on conditioning speed of
  - turnoff delay
  - pulse length
  - rep rate

- Paschen (pd) dependence at high voltages?
- Optimum Z_0 for coaxial vacuum line (radius of curvature vs. gap)

- Effect on breakdown voltage of exposure to tokamak plasma environment

Ultimate test will be on ASDEX-U

- Test line uses modified fixture originally built for materials studies
- Breakdown voltage of simple electrode geometries will be tested in first wall environment
- Gate valve allows electrodes to be interchanged and baked without breaking vacuum in main vessel
- Can also be used for RF/edge plasma interaction studies



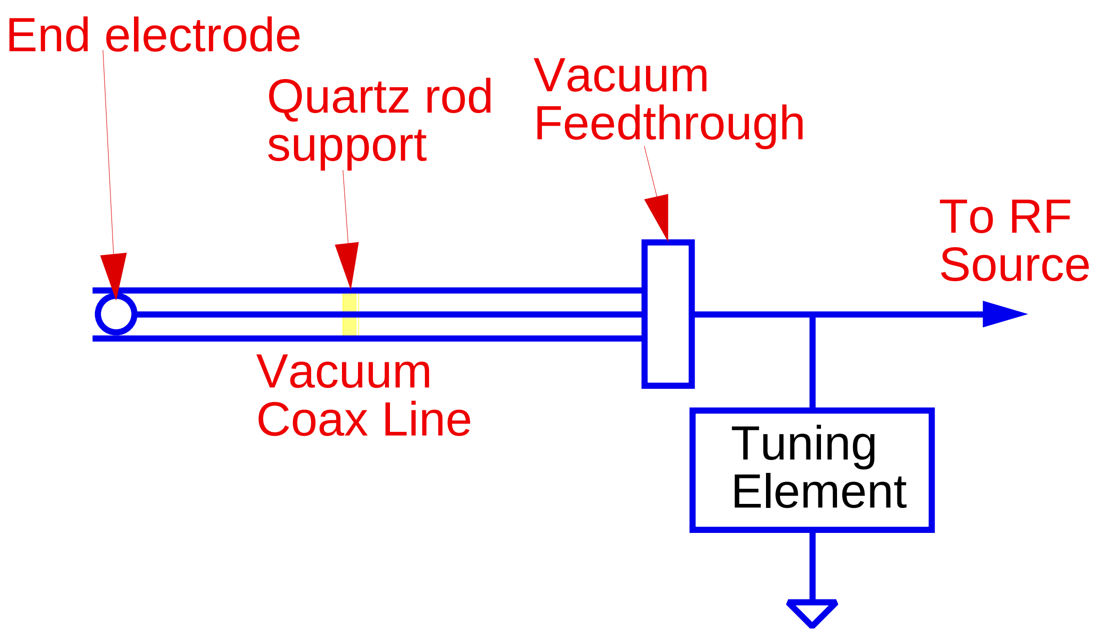
Overview of HV testers

Common features:

- Both use resonant length of transmission line open at one end to generate high voltages with modest amounts of power
- Testers can be matched to 50 Ω source by adjusting frequency and tuning element.
- Both have same outer diameter tube (fixed), with easily changed inner electrodes.

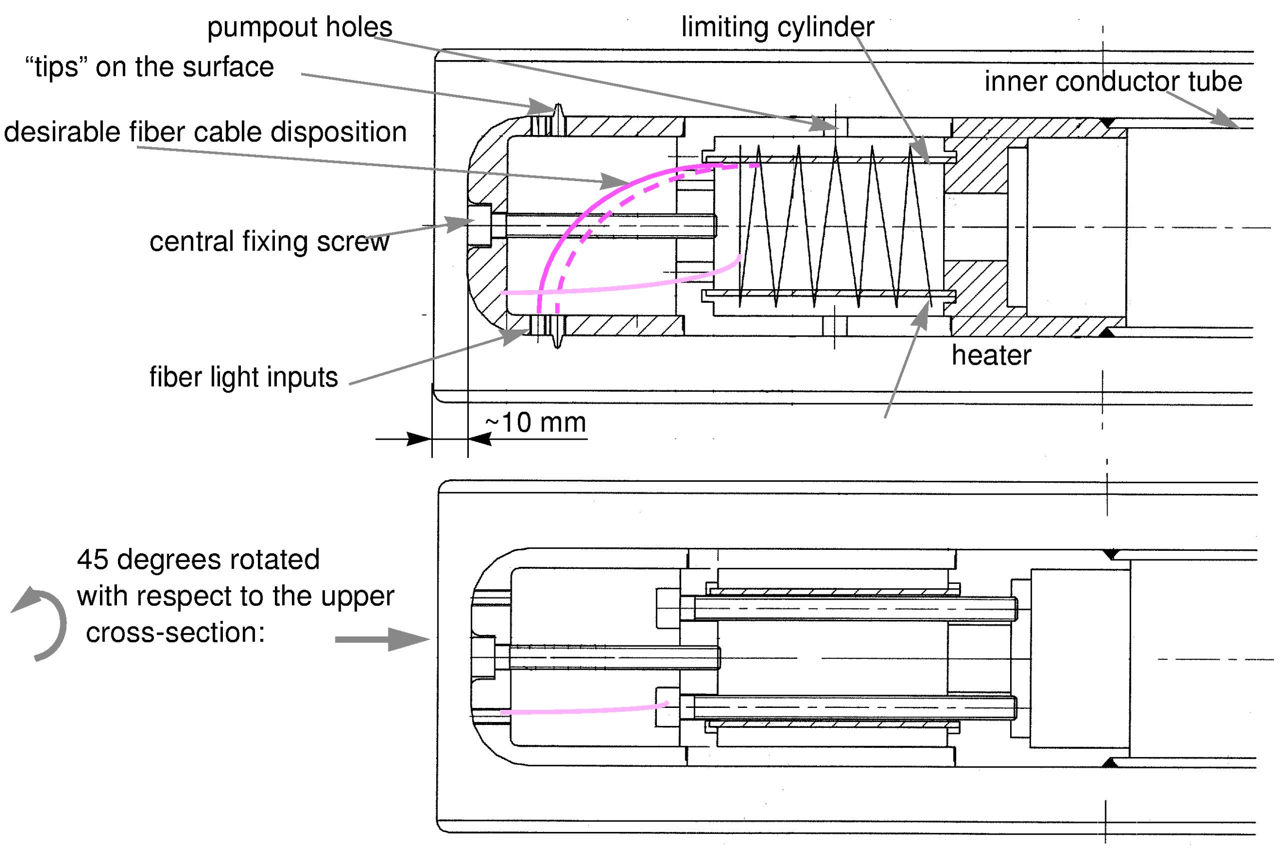
Differences:

- Tuning element
- Details of the vacuum line
- End electrode design details



The IPP end electrode

- Use uniform impedance transmission line (25 Ω) from vacuum feedthrough to end electrode.
- “Tips” at end electrode used to localize breakdown
- Has fiber light pipe from end of electrode to back, to look at light from breakdown



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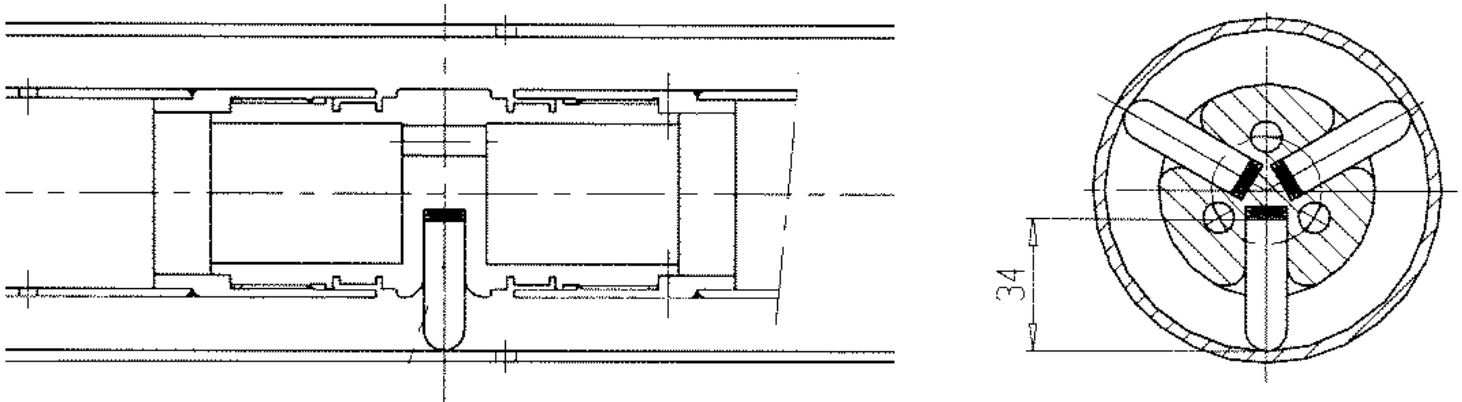
The IPP quartz rod support

Design:

- Designed into 25Ω vacuum transmission line
- Uses three 8-mm diam. quartz rods 34 mm long, rounded at ends, to support center conductor
- Similar to design used on DIII-D on pressurized side of line

Test results:

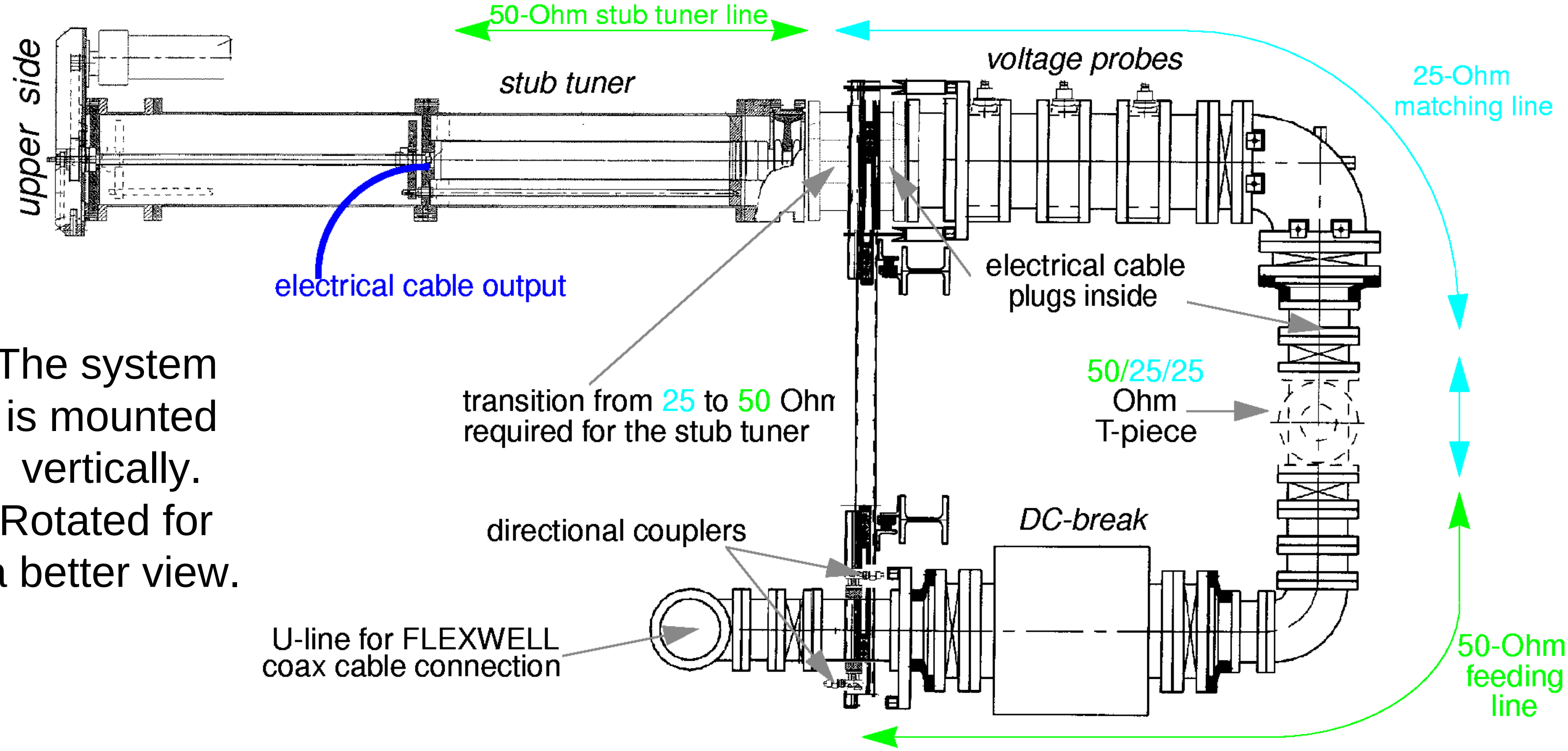
- Operated at 44 kV for 100 ms pulses in vacuum test stand @ 30 MHz
  Could probably be improved by more conditioning
- Mechanical shift from the electrode axis by bending < 1.5 mm.



For both systems, support is located at a relatively low voltage point in the vacuum line, so this holdoff voltage is sufficient.

IPP transmission line and matching system

- Uses adjustable stub tuner as matching element
- More diagnostics, suitable for operation on ASDEX-U



The system is mounted vertically. Rotated for a better view.

Experimental studies at IPP

Features:

- DC bias can be put on end electrode
- Temperature of end electrode can be controlled
- Fast RF measurements are used to get knowledge on breakdown characteristic times with plasma presence compared to that in vacuum
- For experiments on test stand, magnetic field of < 1 T at the end electrode and Hall thruster as stationary plasma source with densities $<10^{16}$ m^{-3} can be used

Status:

- All components are designed and manufactured
- Mechanical tests on ASDEX-U are in progress
- Set-up on test stand has been started

ORNL HV Tester-overview

The tester mounts vertically in mini-RFTF.

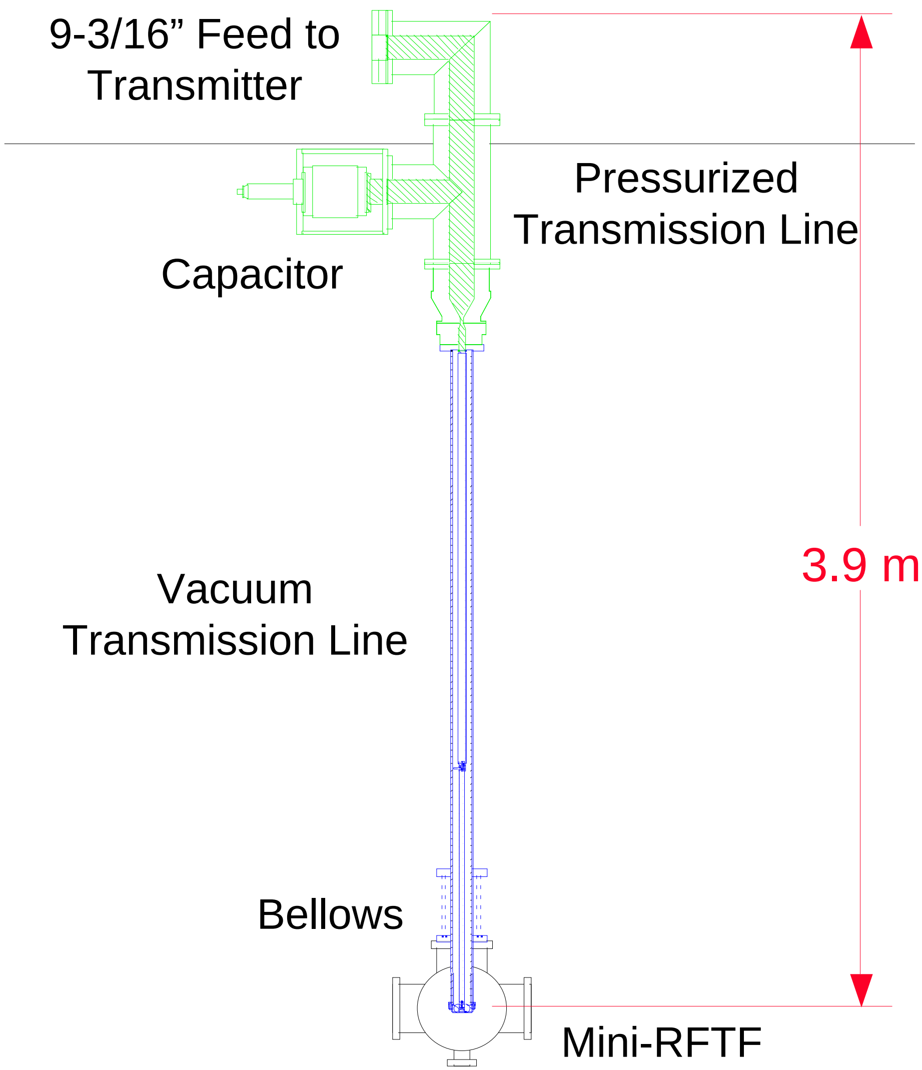
Uses variable vacuum capacitor as tuning element.

Operates around 60 MHz

Bellows allows radial motion of tester relative to plasma and magnetic field

Diagnostics will include

- Voltage and current probes
- Fast CCD camera



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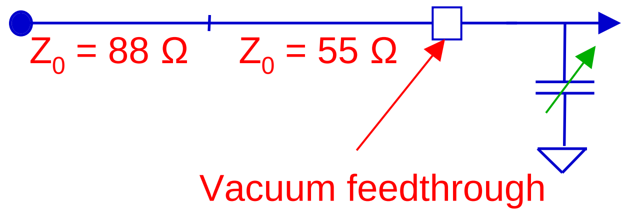
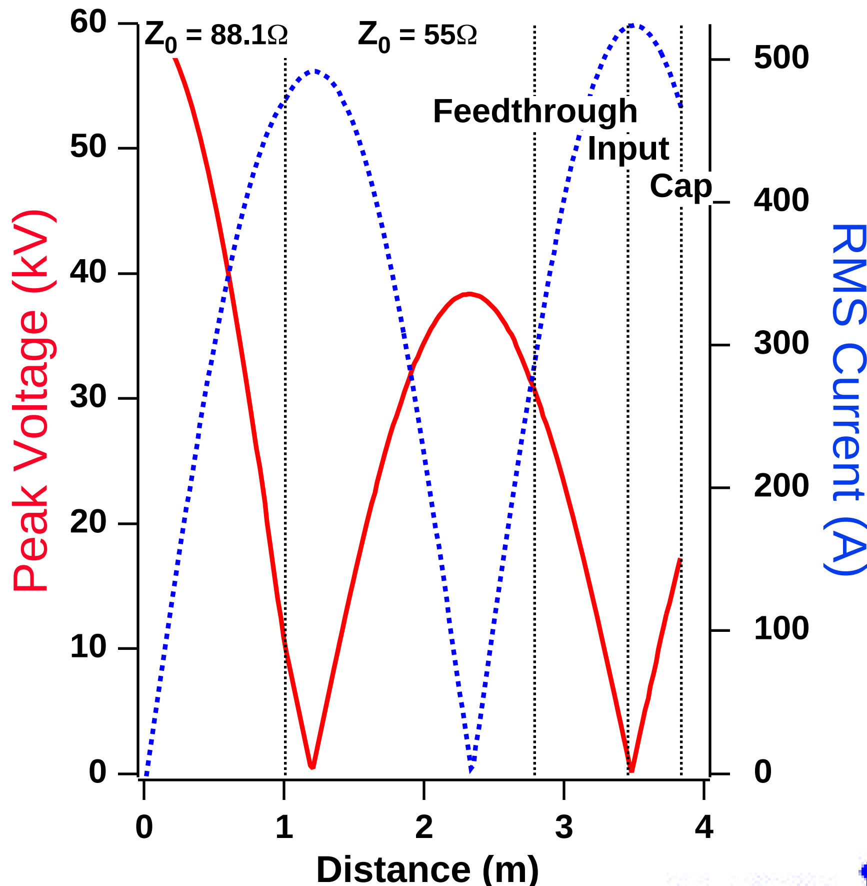
ORNL HV tester electrical properties

- 88 Ω line connected to open end electrode
- Transforms to 55 Ω line at quartz support, located at relatively low-voltage point.
- This allows feedthrough and quartz support to experience significantly lower voltages than peak voltage at end.
- Capacitor used as tuning element.
- 35kW input power required to reach 40 kV at open end (measured).

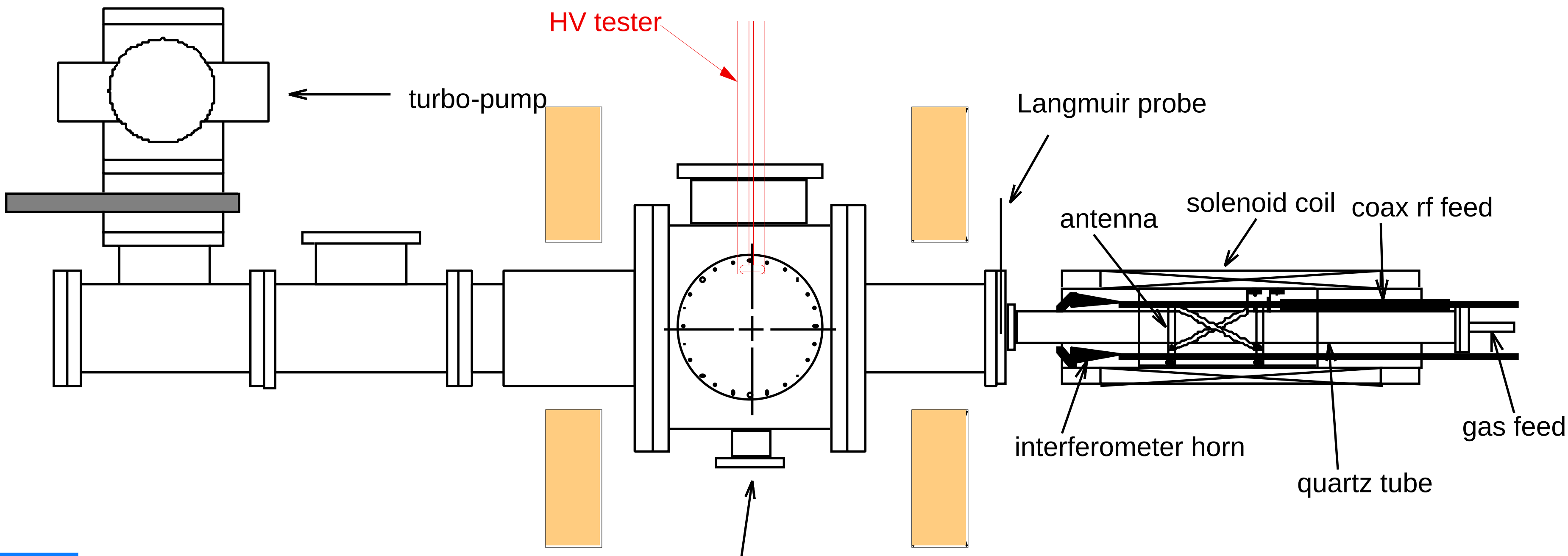




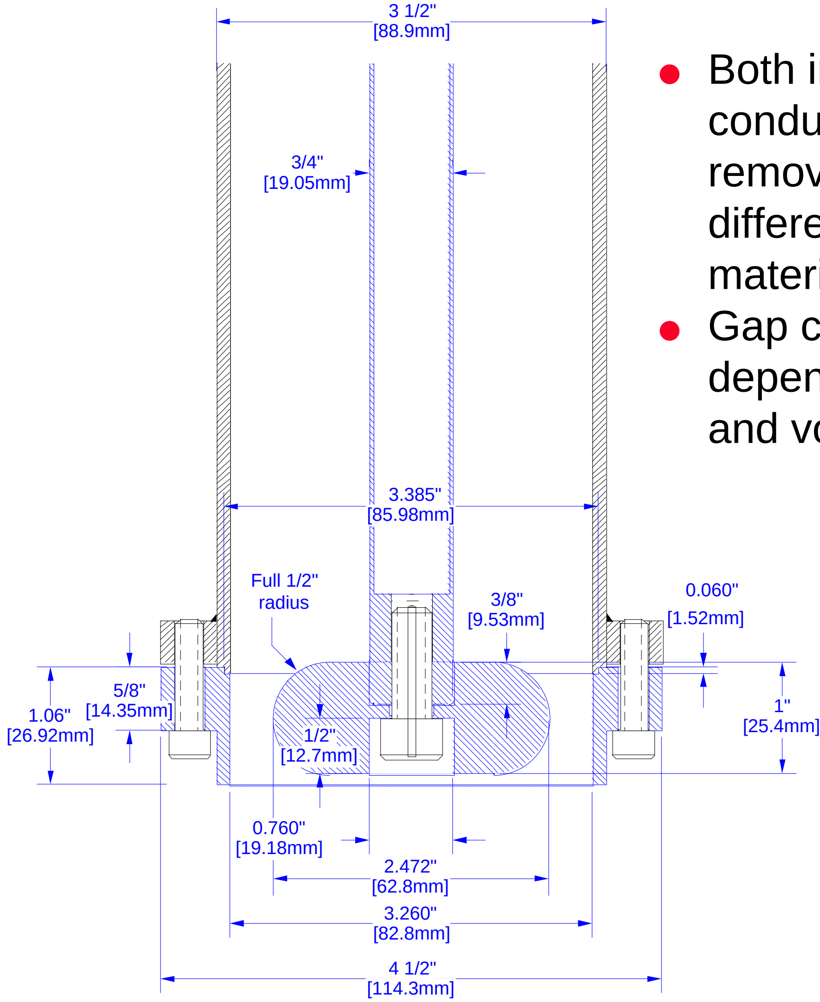
Mini-RFTF capabilities

Mini-RFTF is a versatile facility to use for the HV tester

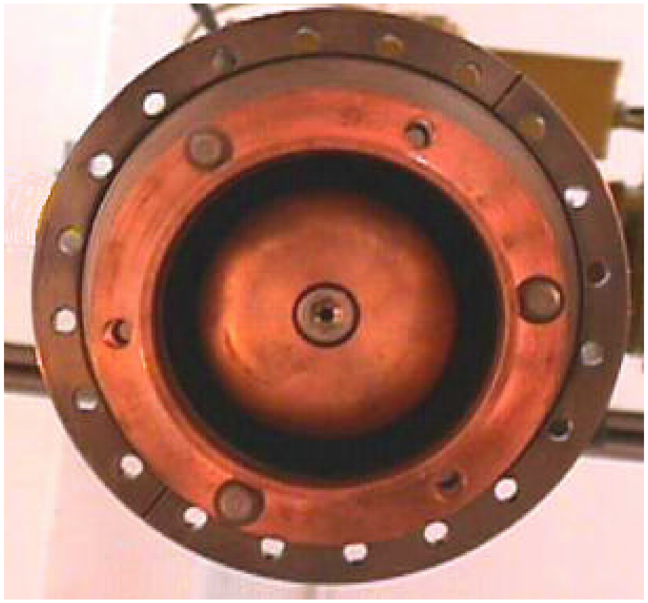
- Can put magnetic field up to ≈ 1 T at HV tester location
- Can generate plasma pulses (>100 ms, $n_e \approx 10^{19}$ m^{-3}) at HV tester
- HV tester radially moveable to change field and plasma configuration
- Easy access for observation and modification of the electrodes
- Diagnostics to characterize plasma



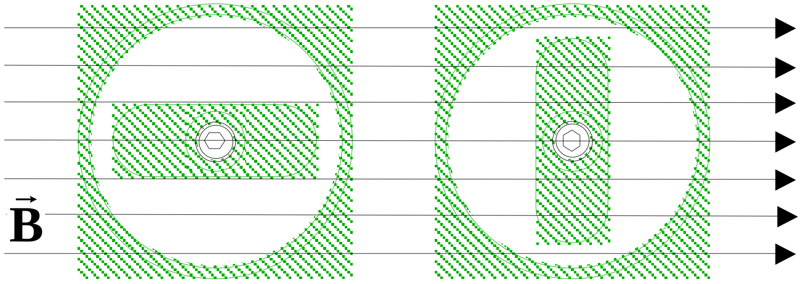
End electrode geometry is designed to produce high electric field



- Both inner and outer conductor end pieces can be removed easily to test different configurations or materials.
- Gap can be changed to study dependence on electric field and voltage



- Magnetic insulation can be investigated using asymmetric end electrode



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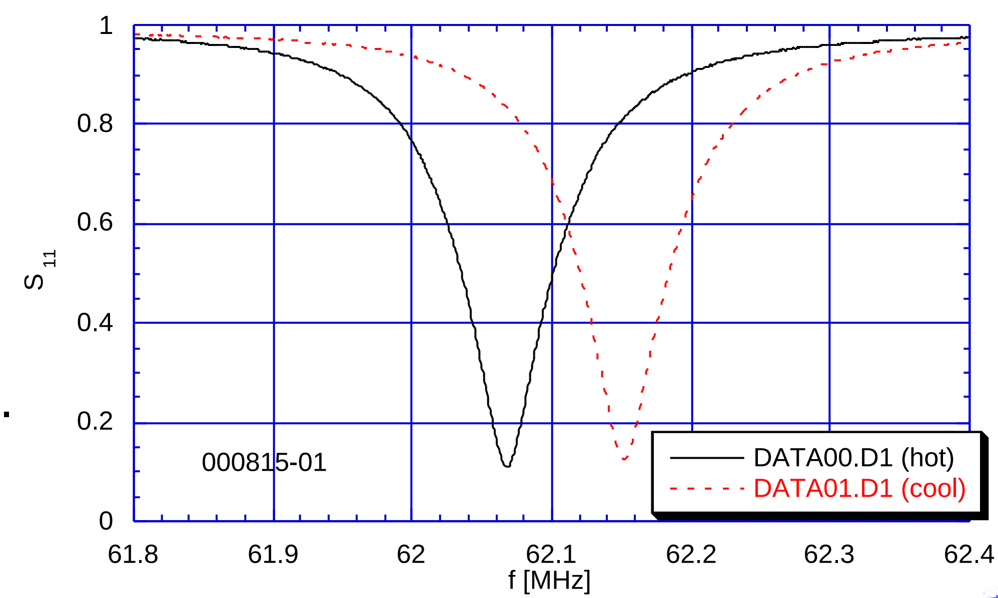
Experiments on ORNL HV Tester have begun

- Initial operation started in July 2000 with electrodes of unpolished copper.
- Initial outgassing of long vacuum transmission line during conditioning was a problem. Heating to > 200C got rid of most of outgassing with about 12 hr bakeout.
- Ran up to 35 kW input power for 40 kV voltage at end for short (< 1 ms) pulses.
- Could sustain ≈ 32 kV for 100 ms pulses; saw reproducible breakdown at end.
- End voltage measured by capacitive probe agreed with voltage calculations from circuit model using experimentally measured Q (≈ 500).
- Not enough data to evaluate day-to-day reproducibility of breakdown voltage
- Good match to 50 Ω line with proper capacitor setting and frequency.
- Heating of center conductor by about 100 C during repetitive pulsing changed resonant frequency ≈ 1 MHz.

Reflection coefficient of HV Tester Vs. frequency



Summary

IPP and ORNL have begun a collaborative program to study fundamental properties of rf breakdown in vacuum and fusion plasma environments.

Goal is to understand rf breakdown, and then improve voltage capabilities of rf launchers in fusion experiments.

First round of equipment has been fabricated, initial experiments have begun.

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