Tests of Interdigital Line Antennas for Launching LH Waves in MST

M.A. THOMAS, J.A. GOETZ, and S.P. OLIVA
University of Wisconsin-Madison

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Abstract

RF current drive has been proposed as a method for reducing the tearing fluctuations that are responsible for anomalous energy transport in the RFP. A system for launching lower hybrid slow waves at 800 MHz and $n_{||} = 7.5$ has been designed and implemented in MST. The antenna is an enclosed interdigital line using $\lambda/4$ resonators with an opening in the cavity through which the wave is coupled to the plasma. The power limit at which the first antenna reflects nearly all the input power is ~3 kW. A boron nitride limiter assembly was added to the face of the antenna and resulted in only a slight increase in the observed power limit. The antenna shows no signs of damage after 16 months of operation in MST. A new antenna with design improvements to the vacuum feedthroughs and better impedance matching is being implemented.

Introduction and Status

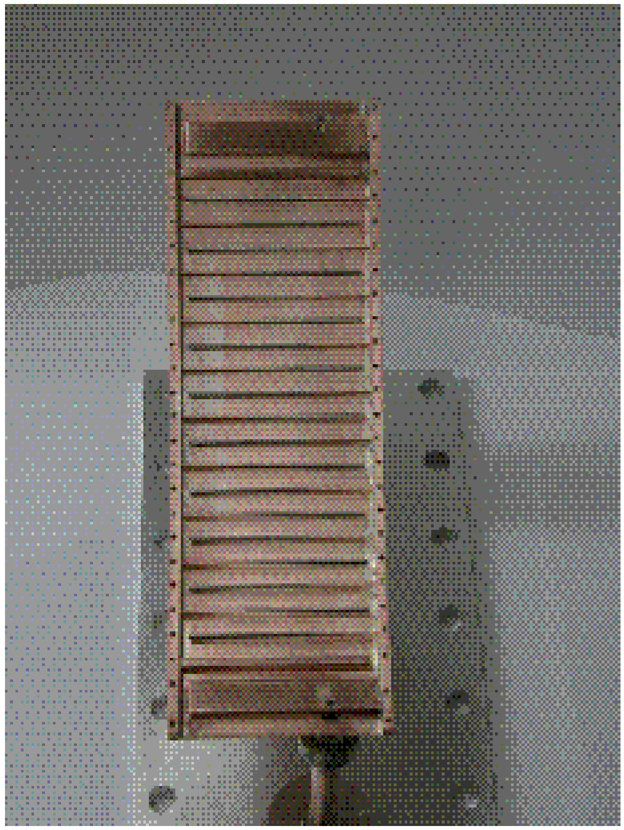
- LHCD antenna has been installed in MST; operated for 16 months without damage
- Plasma loading of inboard and outboard antenna ports is asymmetric
- Limiter installed over antenna face with no change in antenna behavior
- RF probes and diagnostics still under development
- Finite element analysis modelling of antenna proceeding
- Redesigned antenna being bench tested
- Next antenna being manufactured; incorporating results from testing

LHCD Antenna installed in MST

- 5 cm thick Al VCV has no portholes large enough for conventional waveguide grill
- Antenna conforms to wall; radial height is 2cm
- All plasma facing surfaces are Mo or BN; rods are Mo
- Travelling wave design uses only two 32mm diameter ports for end feeds; wave launch direction is reversed by interchanging feeds
- Radiating elements enclosed in cavity with aperture (~5$\lambda_{||}$ long) for electrostatic coupling to plasma
- Antenna still in good shape after 16 months in vessel (photo taken at installation 10/99)

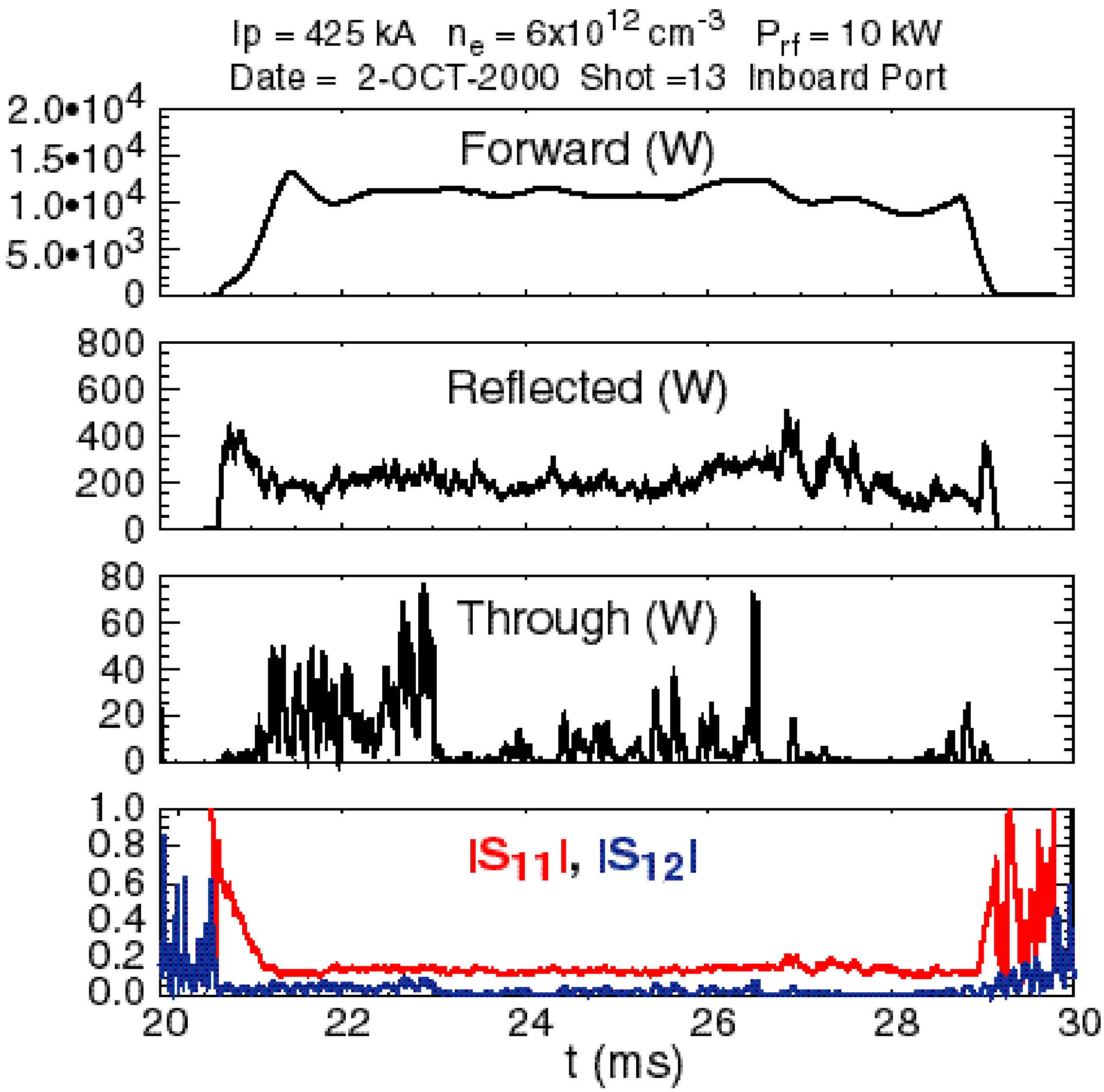
LHCD Antenna Detail

An interdigital line was chosen for the MST LH antenna design



- Combline would require a Faraday screen or reactive loading, neither of which favor an electrostatic wave
- Slow wave structure is an interdigital line, designed to have $n_{||} \approx 8$
- Phase between rods is $\pi/2$ at the center of the passband (800 MHz)
- Line impedance tapers at ends to match 50Ω coaxial feed
- No dielectric inside antenna except at coaxial vacuum feedthrough

Typical Inboard Port Data

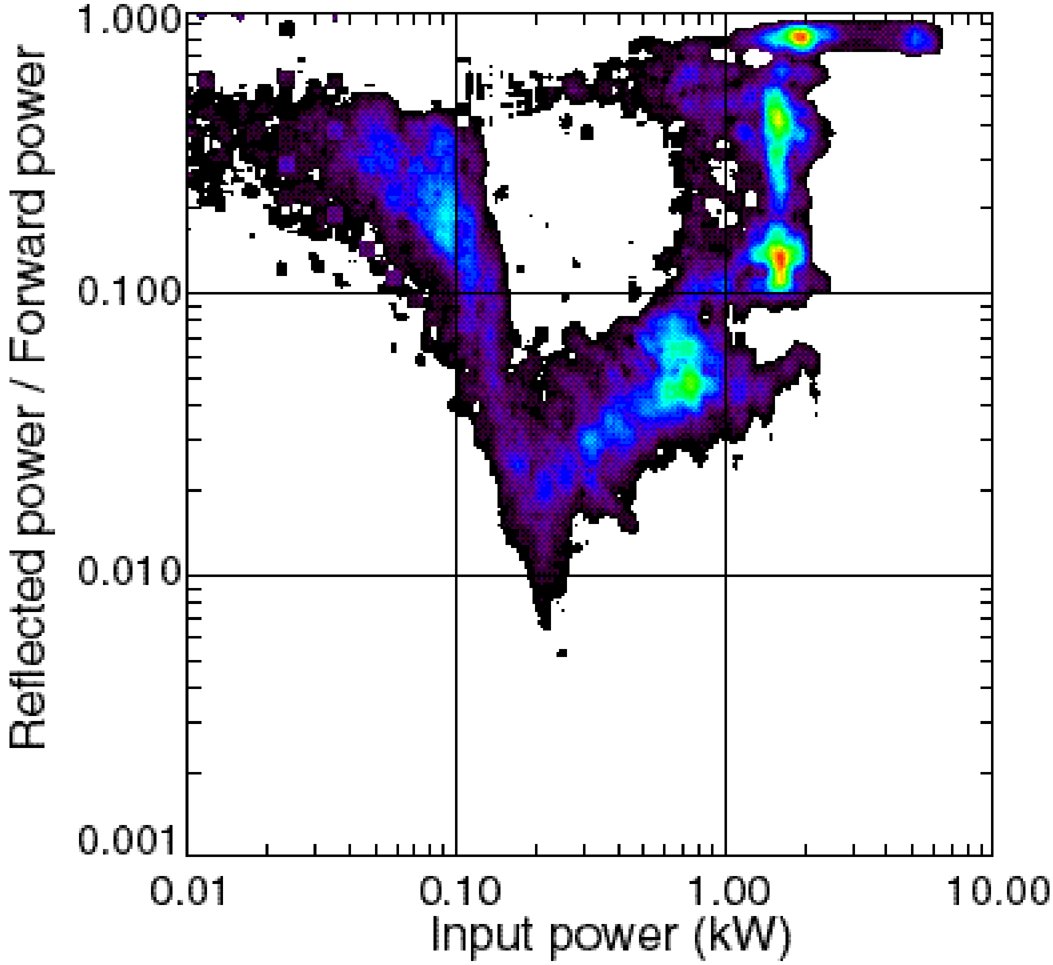


- Input reflection coefficient decreases smoothly as input power rises and impedance match improves

- Less than 0.5% of input power exits the outboard port to the load (see next slide)

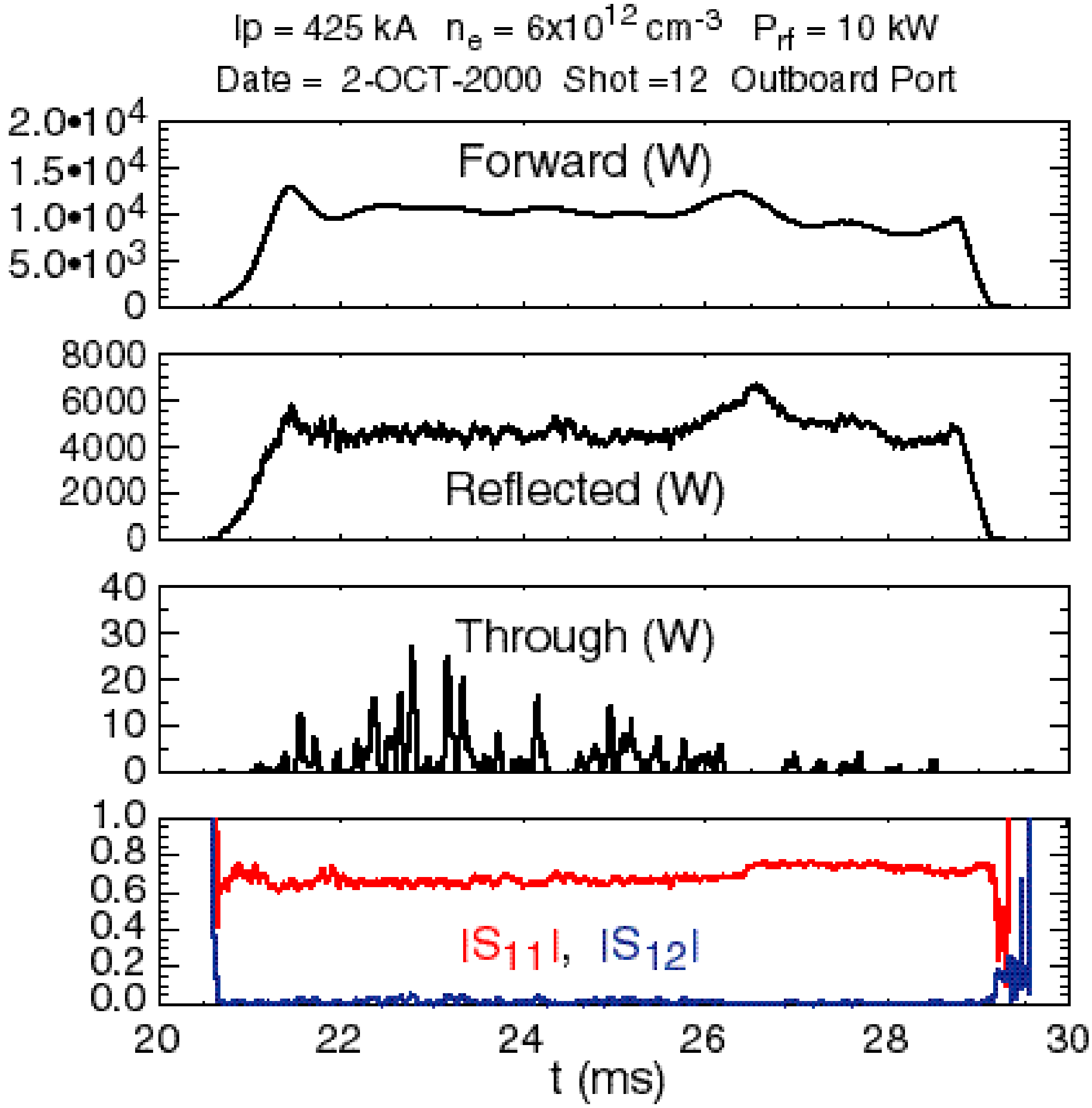
Inboard Port Operation Summary

The LH antenna is well behaved at <3 kW when fed from the inboard port



- **Multipactor discharge at low power?**
- **Good impedance match above 100 W**
- **Breakdown at 2-3 kW of input power**

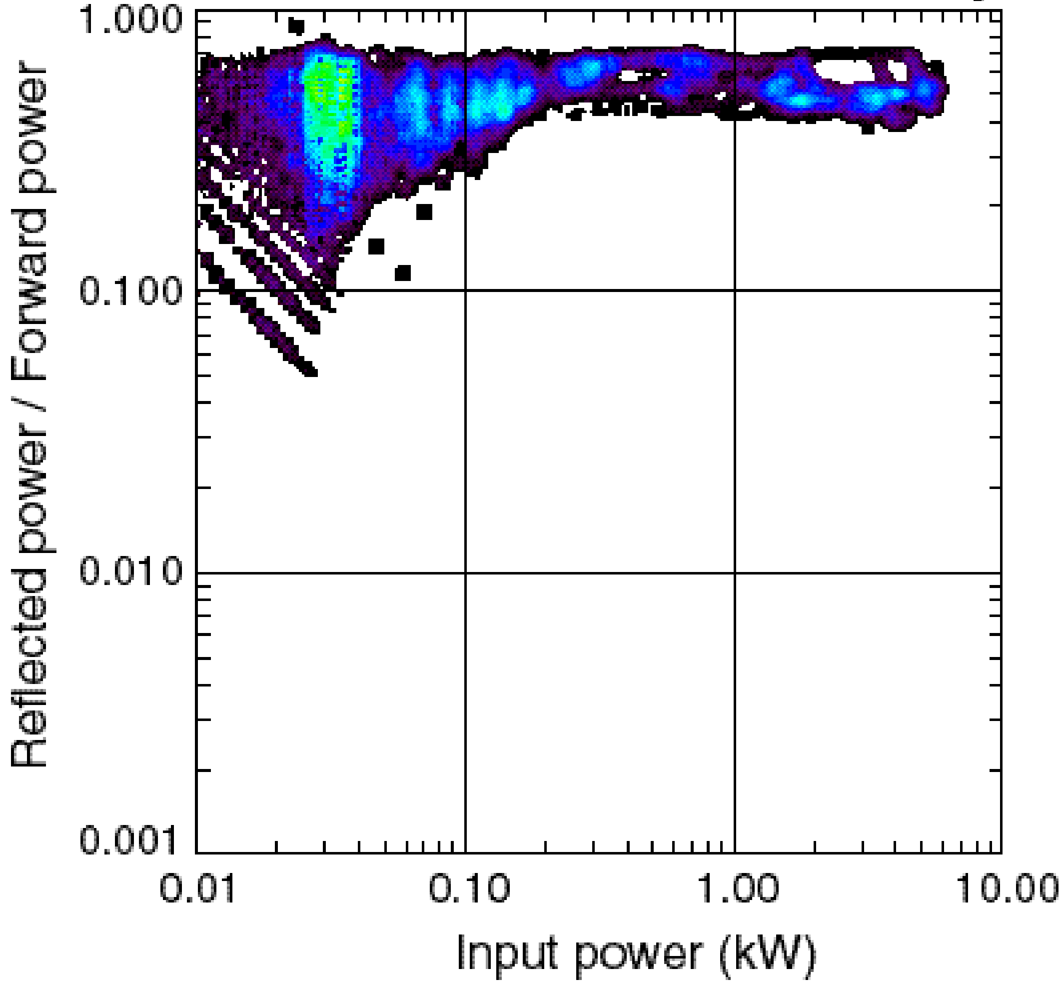
Typical Outboard Port Data



- **Input reflection coefficient remains high at all input power levels, impedance match is poor in the presence of plasma**
- **Outward equilibrium shift may contribute to asymmetry in plasma loading of antenna cavity; inboard BN limiter does not fully shadow outboard end of antenna aperture**

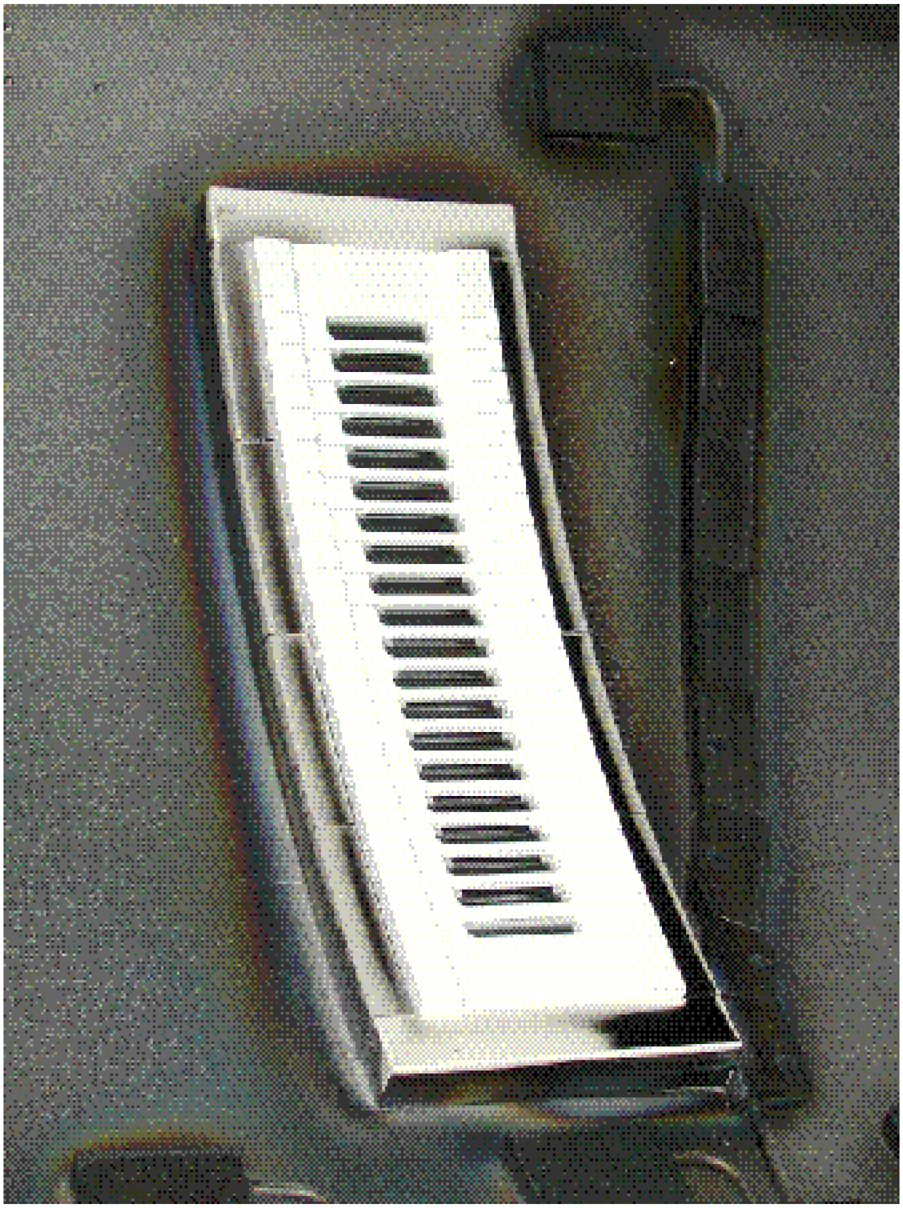
Outboard Port Operation Summary

The LH antenna does not perform well when fed from the outboard port



- Antenna is nearly 100% reflecting regardless of input power
- Post-run inspection shows no obvious damage at outboard port
- Vacuum test chamber measurements corroborate the observed feed asymmetry

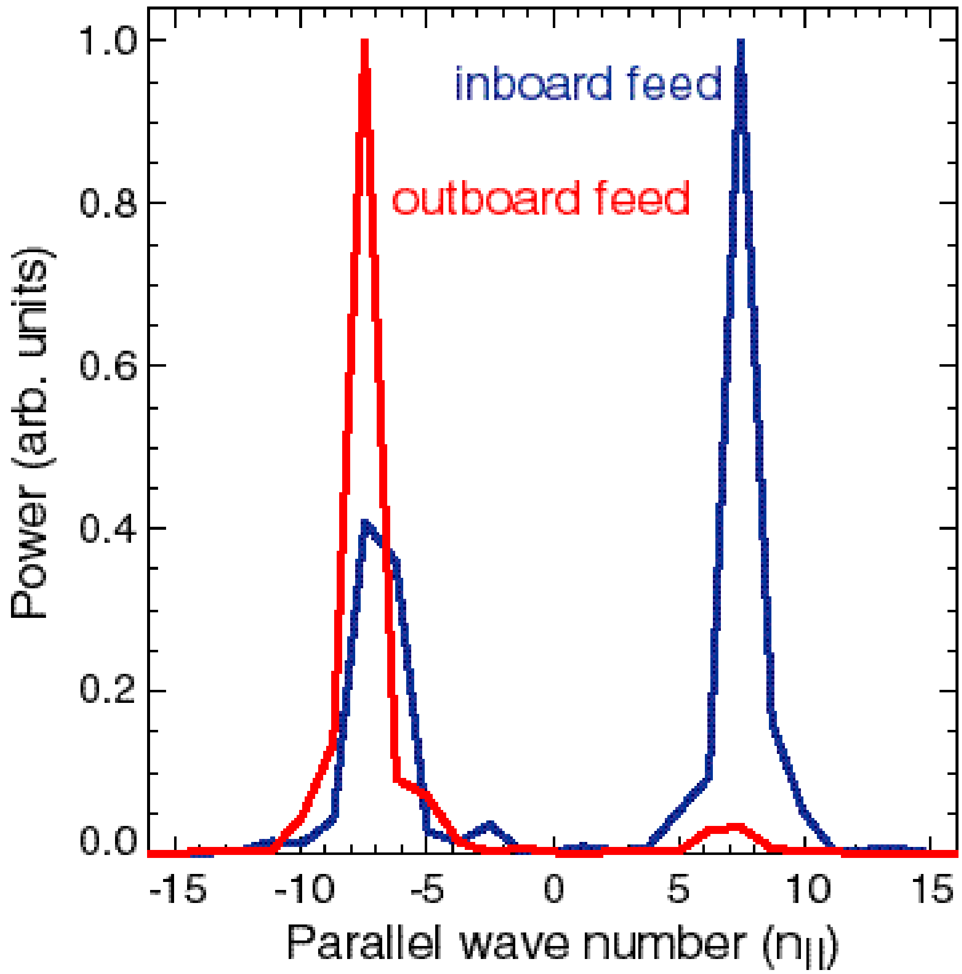
Antenna Limiter Installation



- Boron nitride limiter installed over antenna in Feb. 2001
- No discernible differences in antenna operational characteristics ⇒ plasma-antenna interaction not the cause of power feed asymmetry

Wave Spectrum Measurements

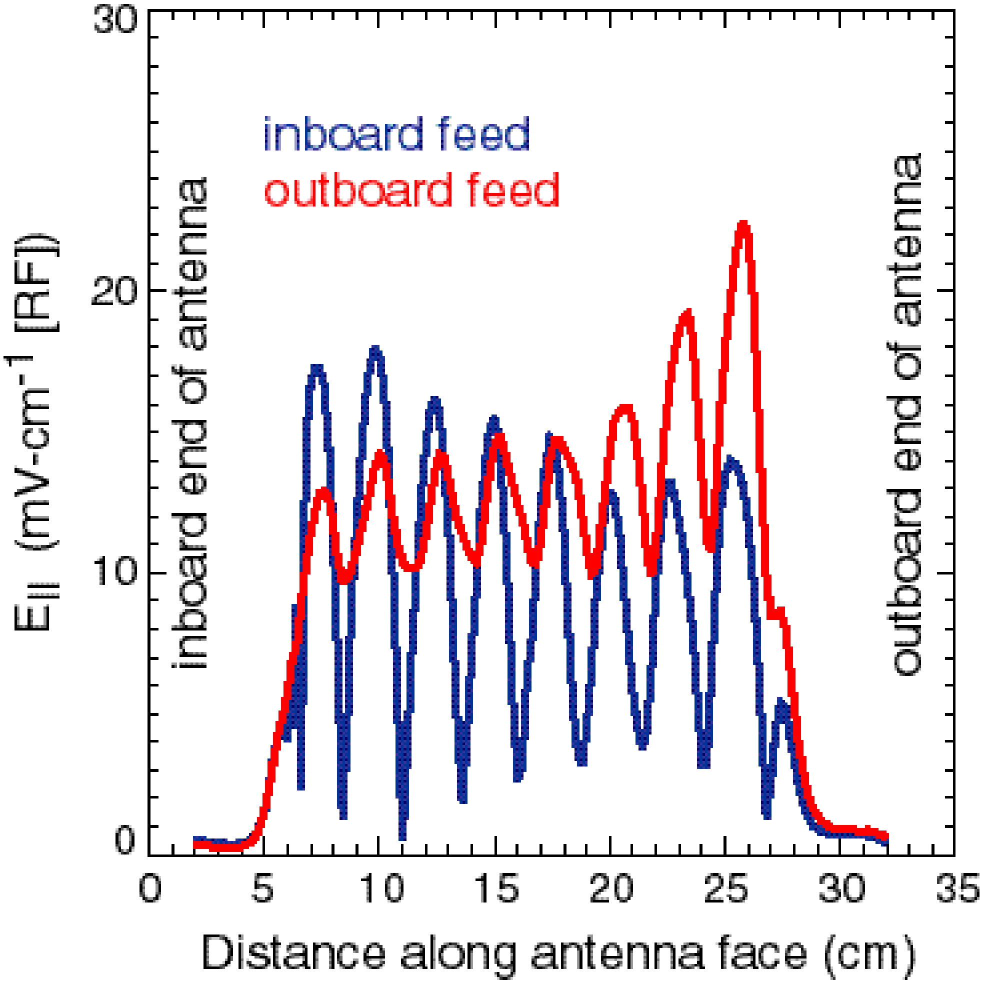
An RF wave with the desired $n_{||} = 7.5$ is produced



- **Antenna design produced the desired wave spectrum**
- **Large "backward" going wave when antenna is fed from inboard port implies reflection at outboard port**
- **Antenna spectrum is sensitive to external circuit tuning**

Wave Field Measurements

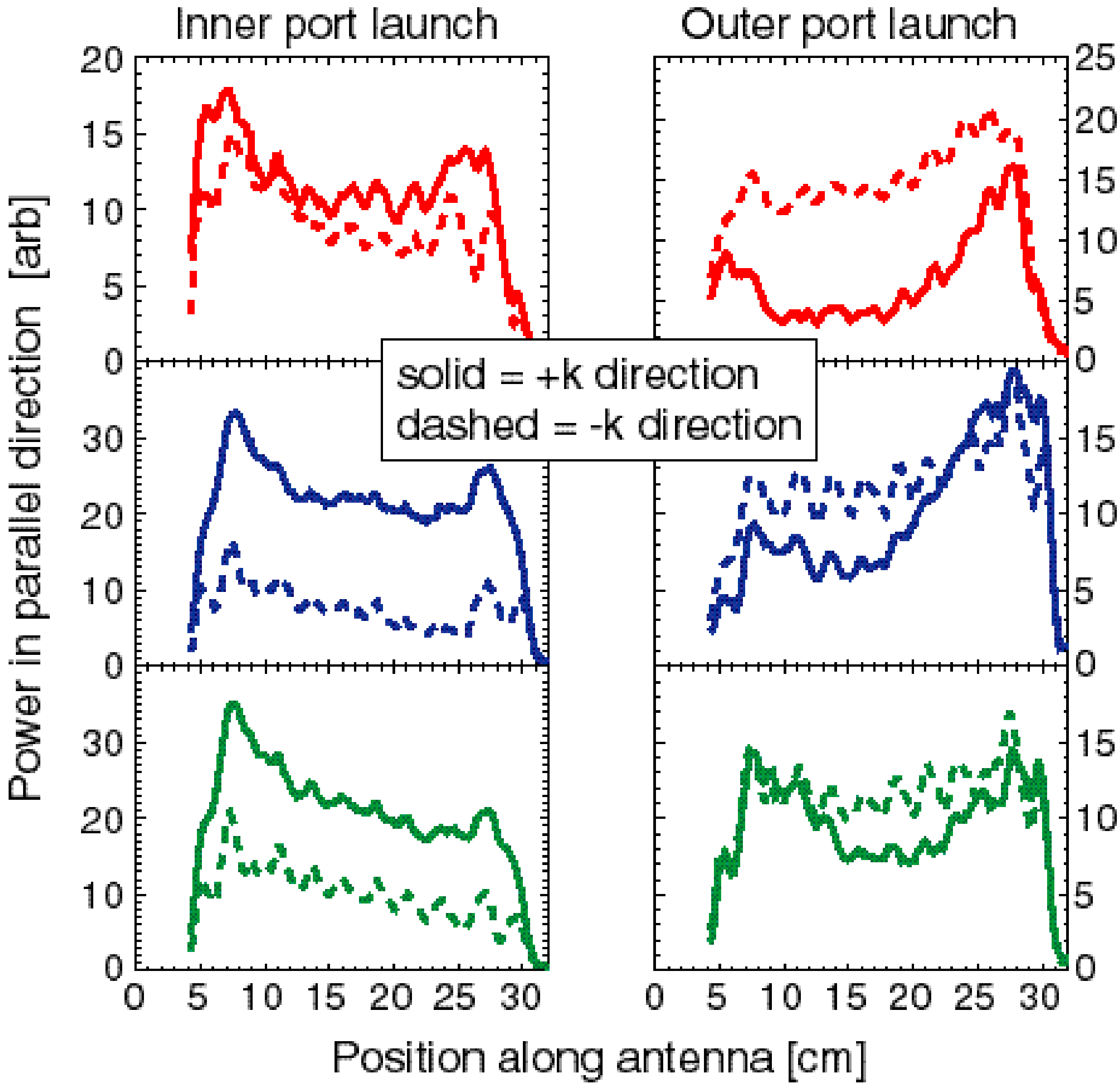
Bench measurements of the parallel electric field indicate that a standing wave exists



- **Large standing wave exists when the antenna is fed from the inboard port**
- **Smaller standing wave when fed from the outboard port**

External Tuning Measurements

Original MST antenna behavior is dependent on external circuit tuning

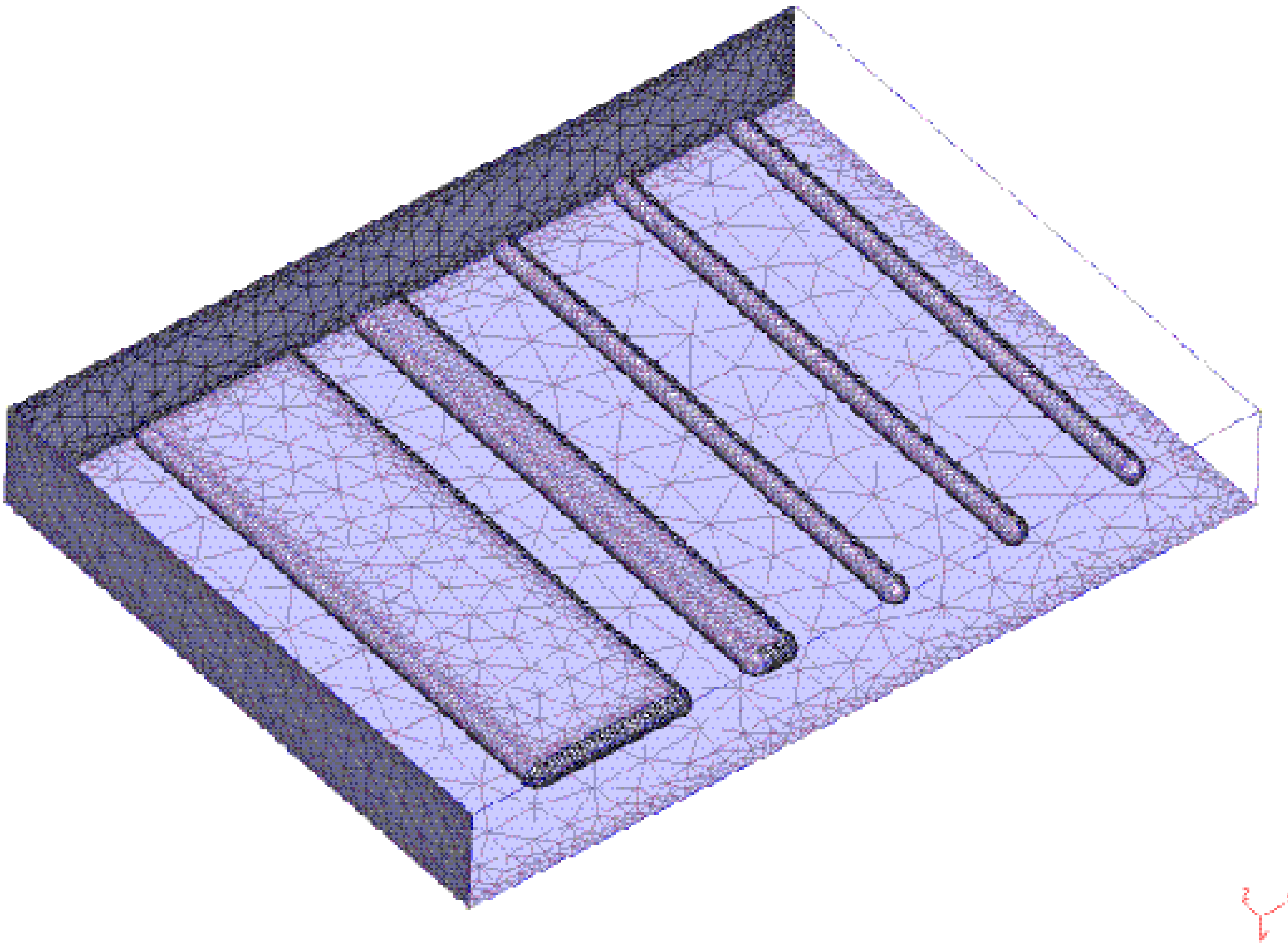


- External circuit is tuned to give best through/reflected power ratio for LH antenna on the bench
- Three different tunings; actual MST cabling and slug tuners (one solution and second solution)

Antenna Problems and Solutions

- Asymmetric loading of antenna in plasma
  - ⇒ Likely due to multipactor when standing waves present
  - ⇒ Improve wave directionality
- Wave directionality strongly influenced by external tuning
  - ⇒ Improve feed impedance match to eliminate need for external tuning
- Impedance mismatch at feeds
  - ⇒ Altered feed geometry based on better impedance calculations
- 2-D analytic impedance calculations insufficient
  - ⇒ 3-D finite element impedance calculations
- Antenna passband split by small periodic errors
  - ⇒ Improved fixturing during assembly
- Power handling limited by feedthrough?
  - ⇒ Implement larger diameter feedthrough

3-D Finite Element Modeling

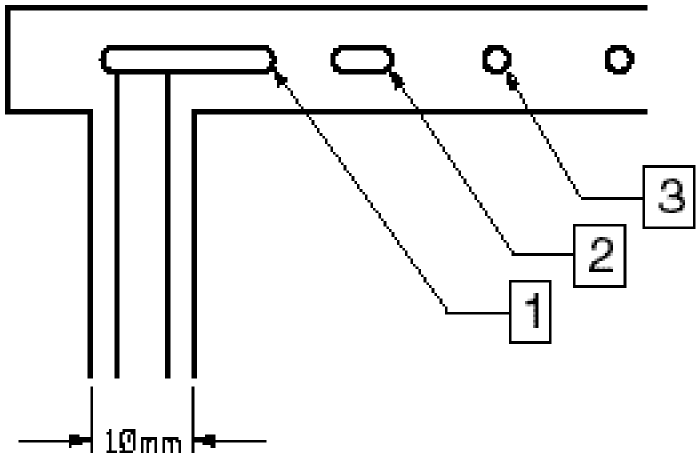


- **Antenna elements modeled using Gmsh**
- **Self and mutual capacitances computed using FastCap**
- **Least squares fit for different length elements yields capacitance per unit length and end capacitance**

Gmsh developed by J. Remacle (currently with Rensselaer Polytechnic Institute) and C. Geuzaine (currently with University of Liège)

FastCap developed by K. Nabors, J. White, *et al.* at the MIT Research Laboratory of Electronics

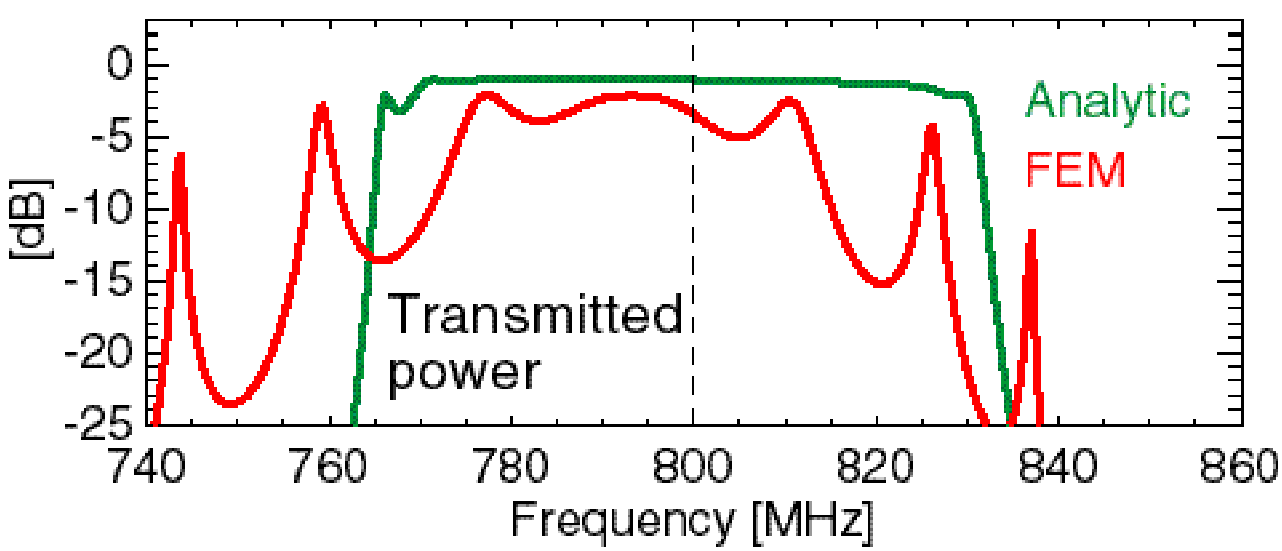
Original Feed Geometry



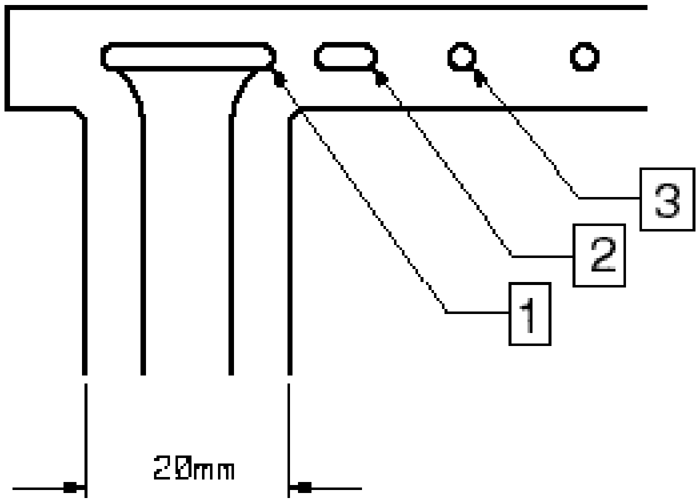
	Analytic	FEM
Z_1 =	30.0 Ω	34.5 Ω
Z_2 =	70.0 Ω	78.7 Ω
Z_3 =	104 Ω	108 Ω
Z_{12} =	1100 Ω	978 Ω
Z_{23} =	3100 Ω	2934 Ω

- 3-D finite element calculation of self and mutual capacitances show that analytic calculations had 10-20% error
- Radiating elements also more tightly coupled than originally calculated

SPICE calculated passband



Improved Feed Geometry



FEM

$Z_1 = 34.5\ \Omega$

$Z_2 = 78.7\ \Omega$

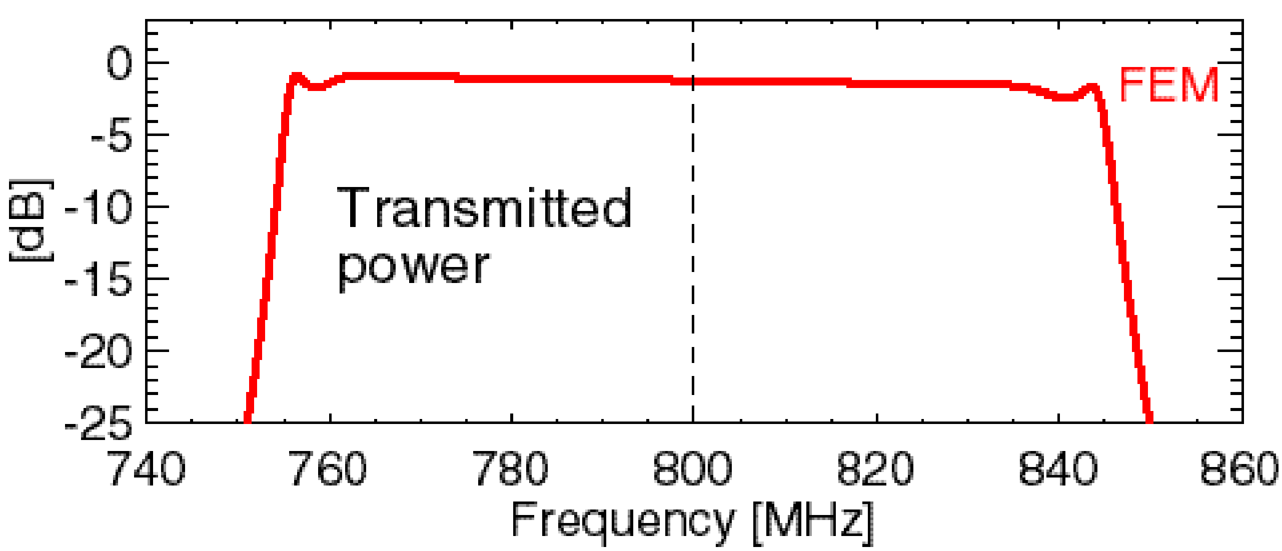
$Z_3 = 108\ \Omega$

$Z_{12} = 610\ \Omega$

$Z_{23} = 1730\ \Omega$

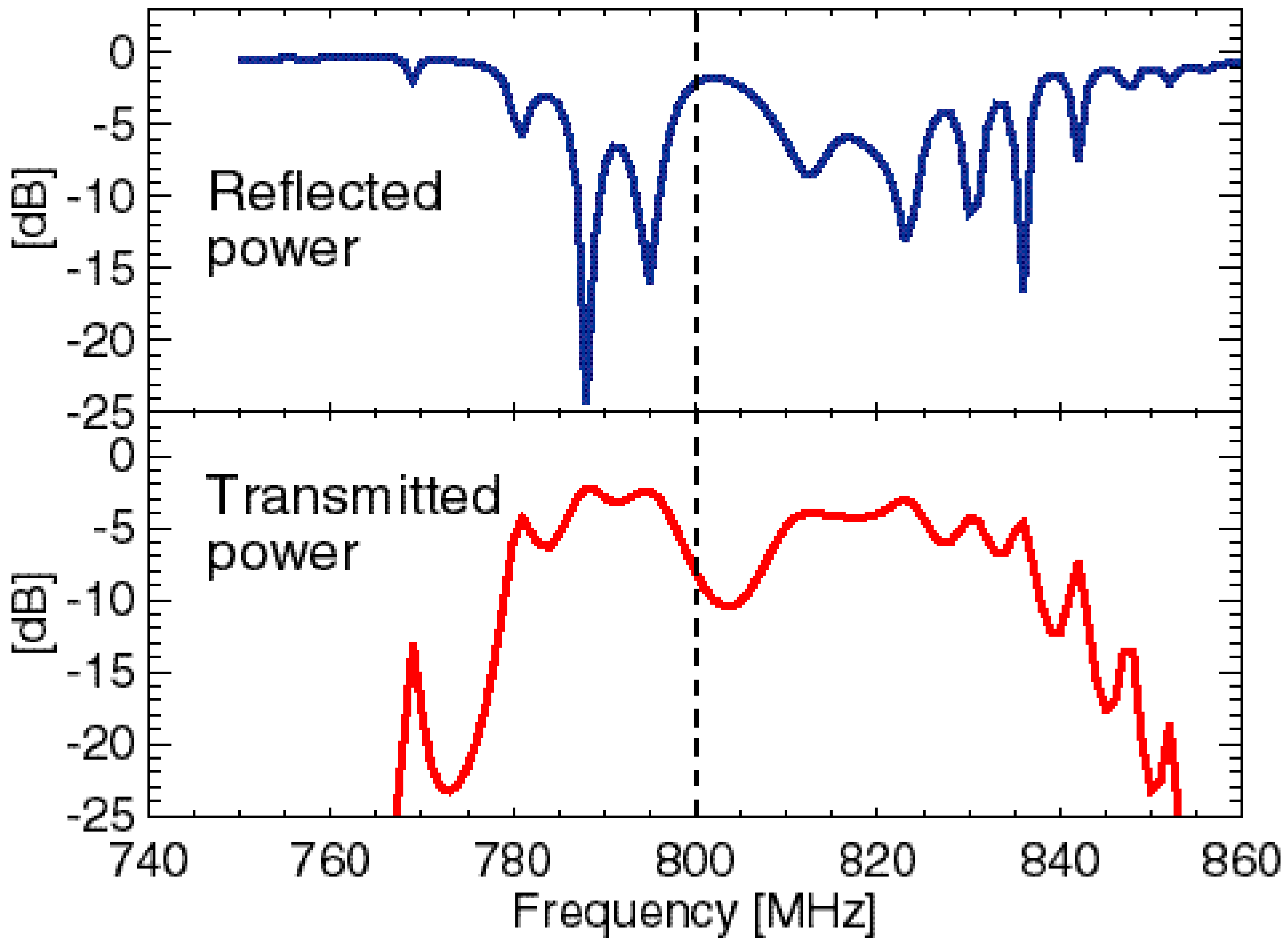
- End elements moved closer together to increase coupling
- Coaxial feed diameter increased to reduce power density
- Flared junction between coaxial feed and end resonator to reduce parasitic inductance

SPICE calculated passband



Antenna Passband Measurements

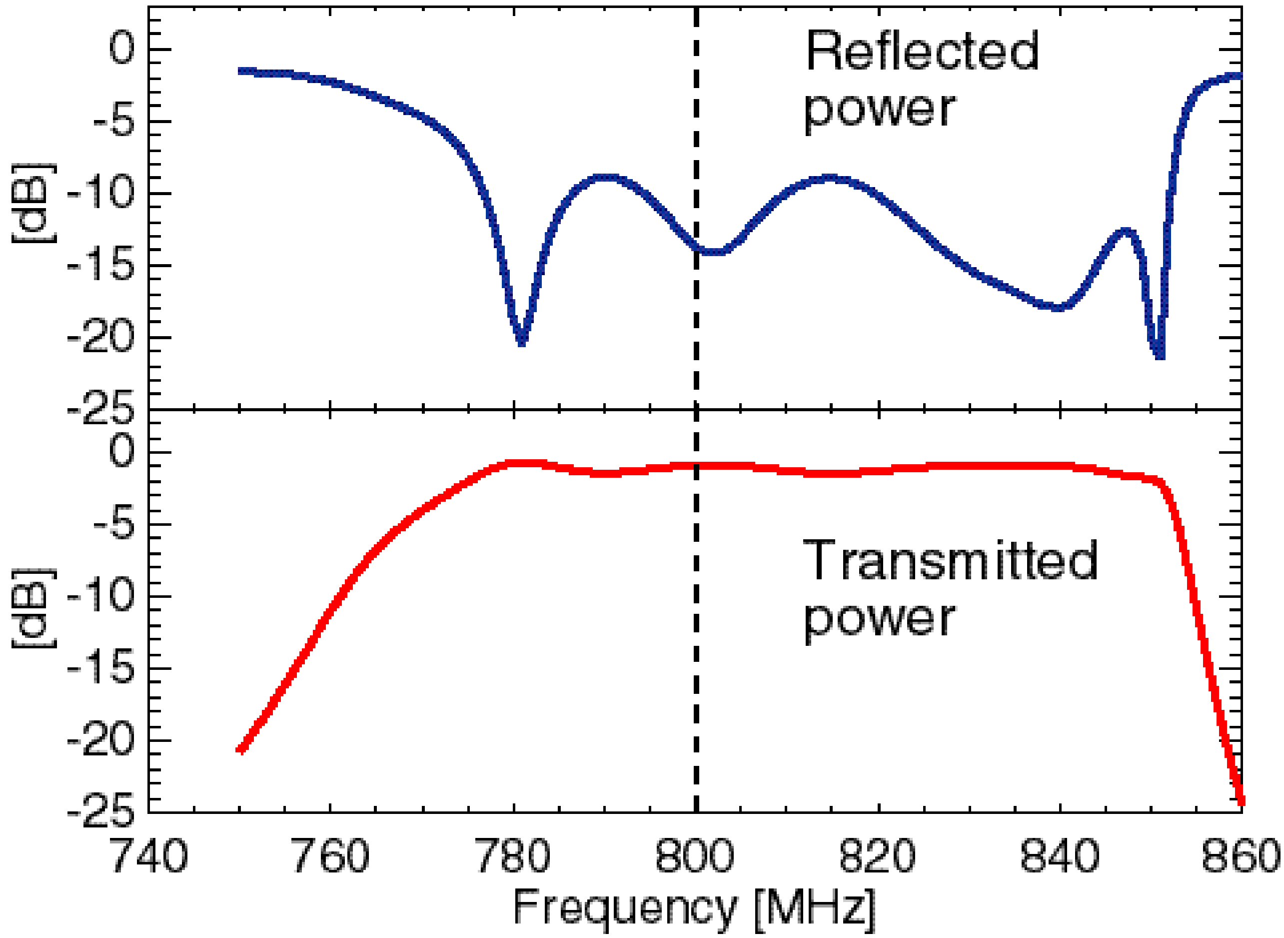
The passband of the original MST antenna is not very flat



- **No external circuit tuning used**
- **Large dip in the transmitted power around 800 MHz**
- **Reflected power is greater than 10% over most of the passband**
- **Transmitter frequency is 800 MHz**

Antenna Passband Measurements

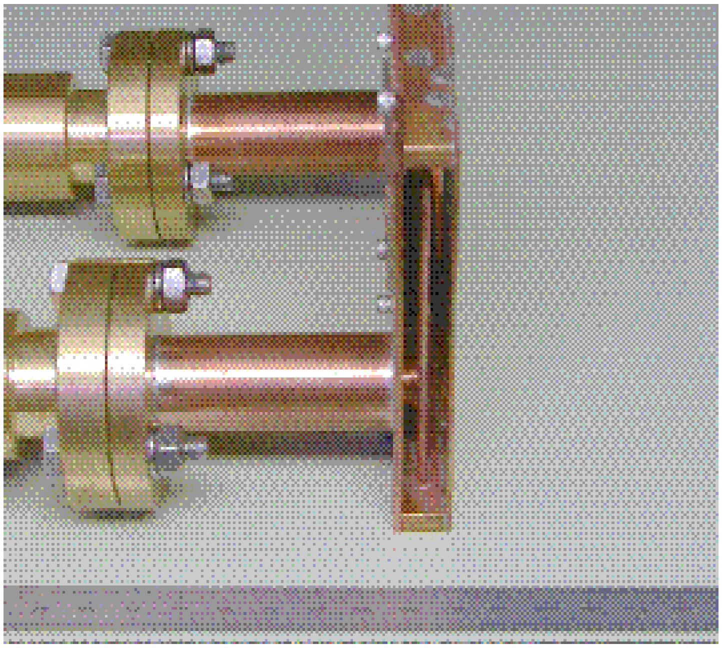
The redesigned antenna has a very flat passband



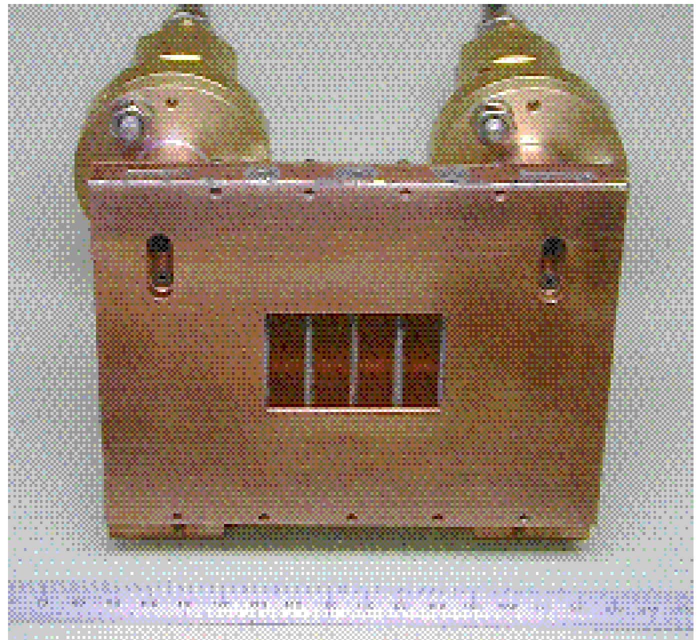
- **No external circuit tuning used**
- **Reflected power is less than 10% over most of the passband**
- **Larger diameter feed used together with adjustable feed location for better impedance matching**
- **Transmitter frequency is 800 MHz**

Redesigned Test Antenna

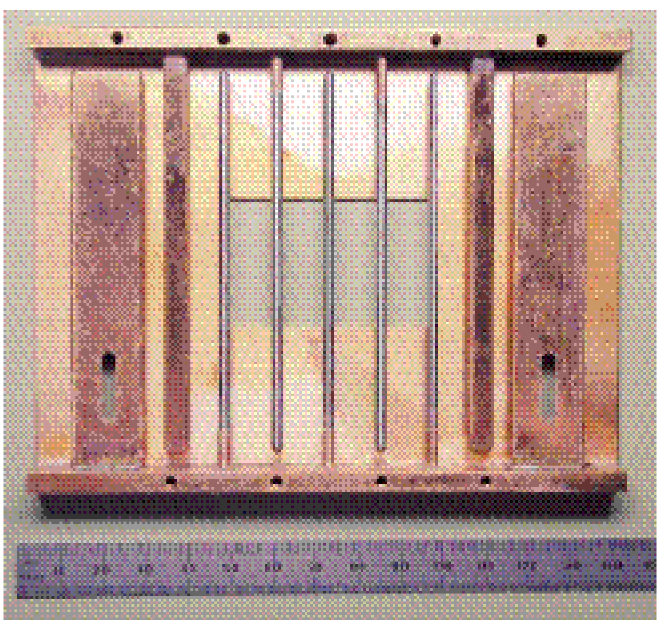
Side View



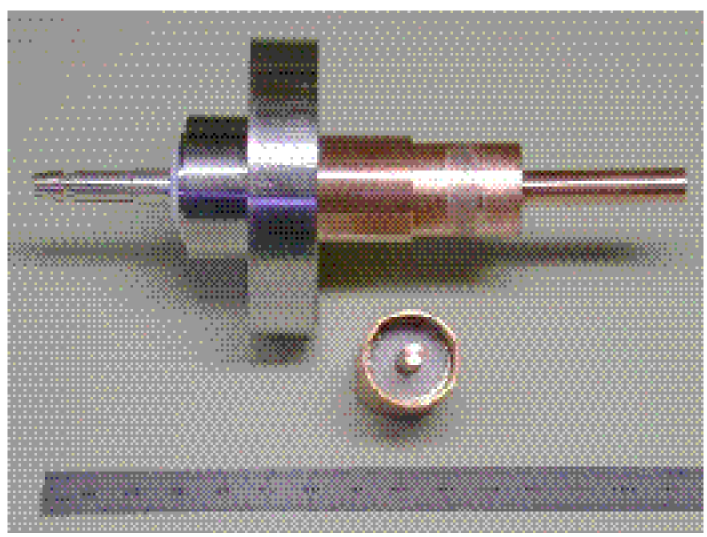
Front View



Feed and Rod Geometry



Vacuum Feedthrough



Timetable

- **FY2001 - 02**
  - ⇒ Next generation antenna with present 50 kW
    - ♦ improved power feeds
    - ♦ improved impedance matching
    - ♦ built-in RF probes
  - ⇒ 200 kW RF available with new power supply
  - ⇒ Damping length measurements
- **FY2003 - 04**
  - ⇒ 400 kW RF possible with another tube
  - ⇒ Maximize power handling
  - ⇒ Two antennas?
- **FY2004**
  - ⇒ Decision to pursue 1-2 MW experiment to reduce fluctuations and transport using LHCD

Summary

- **LHCD antenna was installed in MST for 16 months**
  - ⇒ asymmetry exists in loading
    - ♦ inboard port: reflection decreases with increasing power up to 2-3 kW
    - ♦ outboard port: reflection is always large
  - ⇒ limiter to control density at antenna face does not change behavior in plasma
  - ⇒ wave spectrum with $n_{||}$ = 7.5 produced but external circuit tuning affects directionality

- **Antenna improvements being made**
  - ⇒ improve impedance match at coaxial feeds
  - ⇒ implement larger diameter feedthrough
  - ⇒ better mechanical fixturing during assembly
  - ⇒ test antenna built with flat passband using no external circuit tuning
  - ⇒ second generation MST antenna being built