COMBLINE & INTERDIGITAL TRAVELING WAVE ANTENNAS

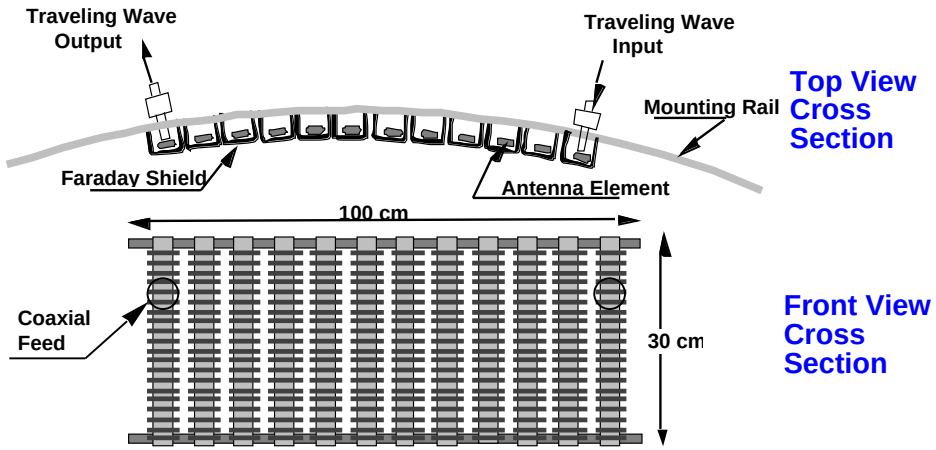
Concept and Applications

COMBLINE ANTENNA CONCEPT

- A Combline antenna is a traveling wave antenna, for launching magnetosonic waves, where the strap-to-strap mutual coupling is larger than [dominates] the strap-to-plasma coupling.

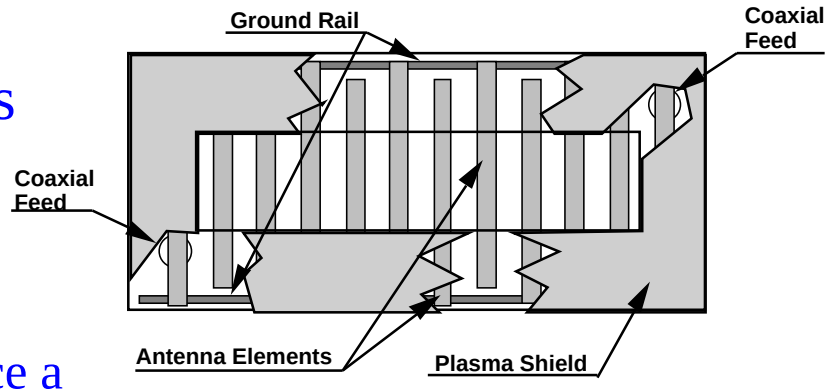
$$\omega M_c >> R_P$$

- Fed at upstream end only, power flow element to element by mutual reactive coupling
- Input impedance virtually independent of load conditions.



INTERDIGITAL ANTENNA CONCEPT

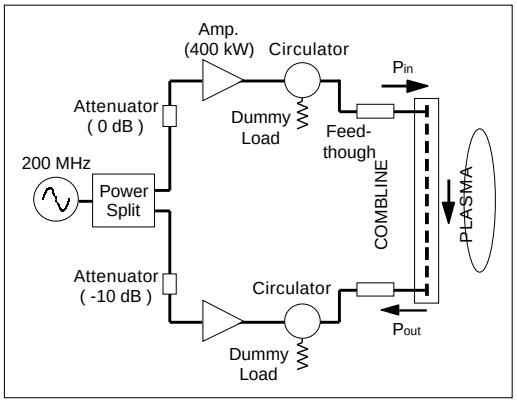
- An Interdigital antenna is a traveling wave, electrostatic wave, antenna, where the strap-to-strap mutual and capacitive coupling is larger than [dominates] the strap-to-plasma coupling.
  - Two bottom grounded comb antennas are interlaced to produce a $\pi/2$ electric field phasing between antenna elements



  - No Faraday Shields, masking plate used to expose only the element-to-element electric fields to the plasma

Traveling Wave "Combline & Interdigital" Antennas Have Several Advantages

- Two feedthroughs for arbitrary number of elements means a large number of elements is practical
  - (not limited by port space for feedthroughs)



1. Feeds are matched to transmission line impedance
   - Match is excellent for all operating scenarios
   - No matching network needed
   - Power-per-feedthrough can be much higher than conventional antenna because feed is in matched section (low VSWR)
   - Vacuum coax sees lower voltages (less likely to arc over)
- Large number of elements
  - Plasma load/element can be small
  - Large gaps acceptable
  - Dense Faraday shield allowable (Higher electric fields may be realized)
  - Directivity is high
    - Phase stability is high
  - Straps can be closer to groundplane, resulting in a more compact design

Combline Antennas in Use and Planned for Fusion Experiments

In Use

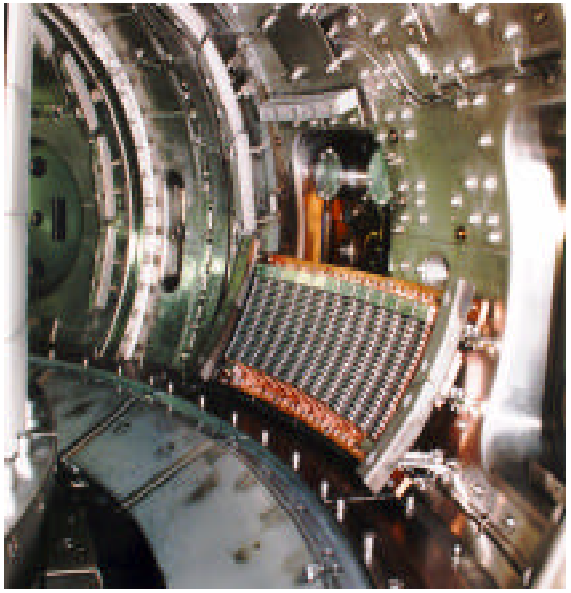
- JFT-2M Tokamak (JAERI)
- TST-2 Spherical Torus (Univ. of Tokyo)

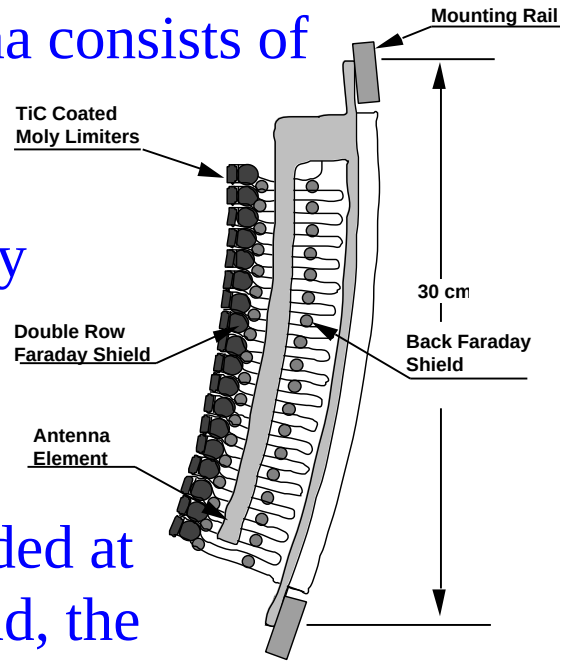
Planned

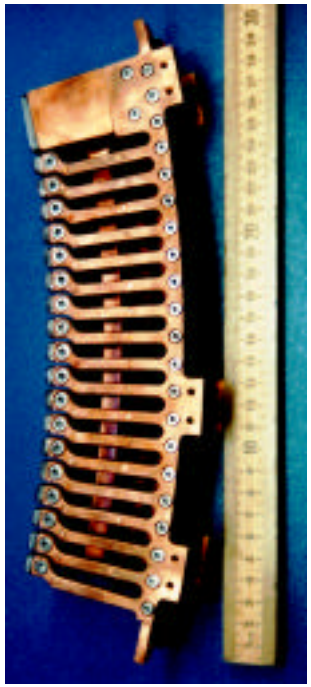
- LHD Stellerator (NIFS)

JFT-2M Combline Antenna

The JFT-2M Combline antenna consists of twelve modules, each with a single current strap, a back plate, and a three layer Faraday shield. The current strap is grounded at one end, the other end open.







JFT-2M Combline Antenna

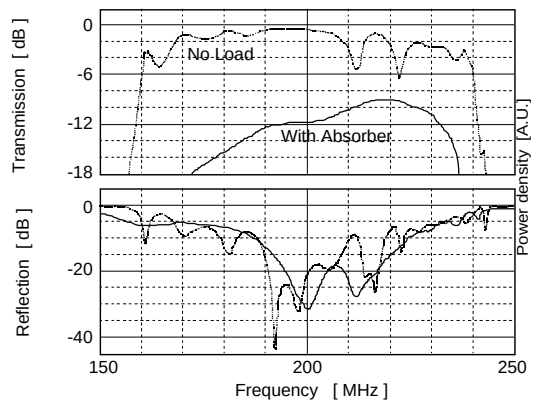
(continued)

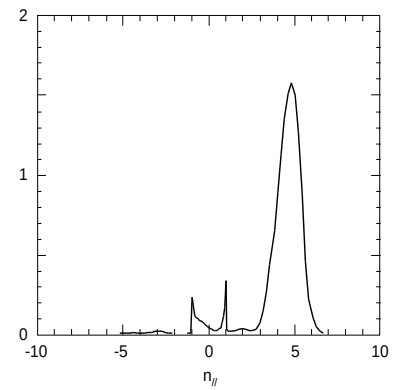
Antenna Characteristics

Frequency	**200 MHz**
Pulse length	**0.5 sec.**
RF power	**400 kW**
Coaxial feed	**50 Ω**
Module size Height **Width**	**20 cm** **5 cm**
Construction	**Copper plated SS**
Faraday shield Plasma facing side	**Molybdenum** **Titanium carbide**
$n_{\parallel}$	**≈5**
Power density	**3.3 MW/m^2**

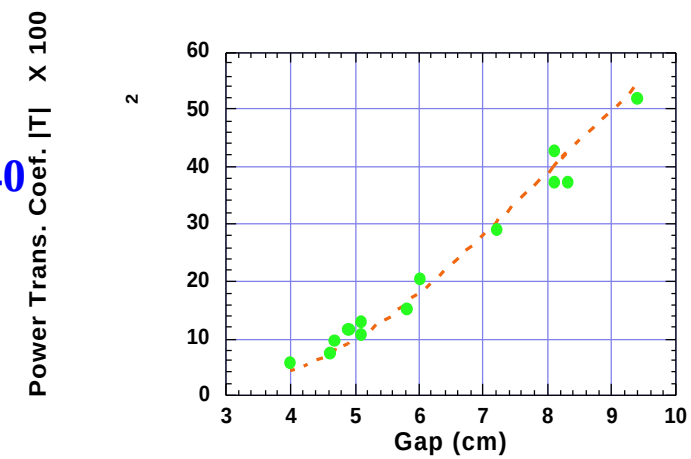
Experimental Results
JFT-2M Combline Antenna

- Testing with a network analyzer shows strong absorption (12 dB) at 200 MHz, the resulting reflection coefficient was less than 30 dB, under vacuum conditions the reflection coefficient was miniscule 20 dB. The wave is also highly directional with a parallel index of refraction $n_{||}=5$



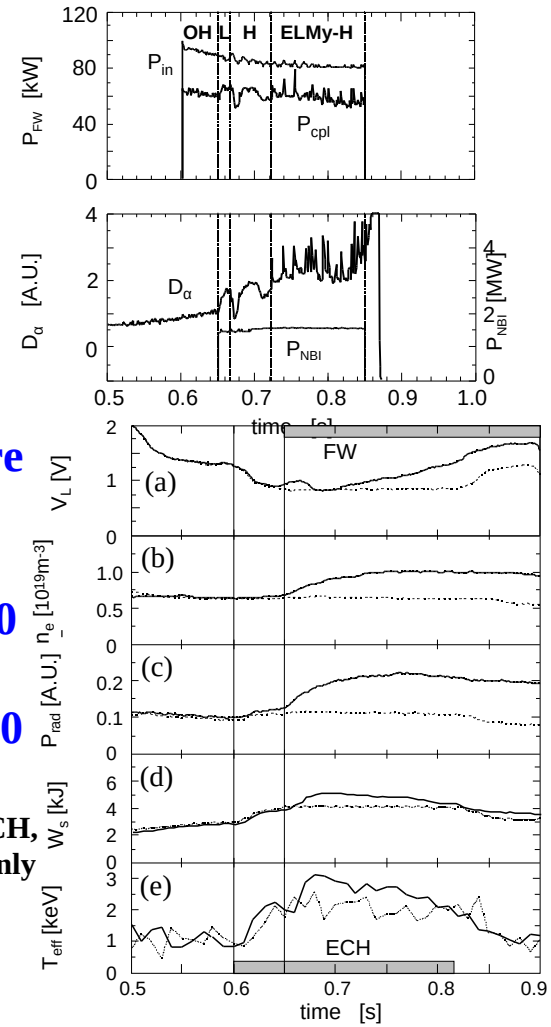


- A scan of the antenna/plasma gap with ohmic plasmas shows a slow decrease in the coupled power (95% to 48%) as the gap is increased (40 mm to 94 mm)



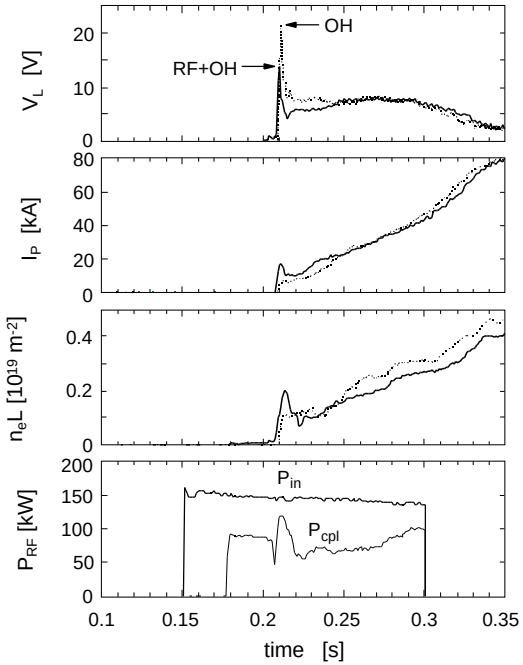
- **RF power injection into ELM y H-mode plasmas, show that the antenna/ plasma loading instantaneously adjusts to the changing conditions without any increase in the reflected power back to the transmitter.**

- **Fast wave (FW) heating and current drive experiments have been demonstrated in ECH preheated plasmas. The central electron temperature increased from 2 kV to 3 kV demonstrating that FW heat electrons. However, other than a measured increase in the soft x-ray distribution from 5 kV to 10 kV there is no other supporting measurement that true current drive was achieved (TORIC predicts ≈60 kA)**



Solid line FW+ECH, dashed line FW only

- **Using the property that the combline antenna does not need to retuned when going from vacuum loading to plasma loading, the combline antenna has been used for RF assisted start up, with the peak loop voltage at startup decreasing from 22V to 14 V using 150 kW of RF power.**



TST-2 Combline Antenna

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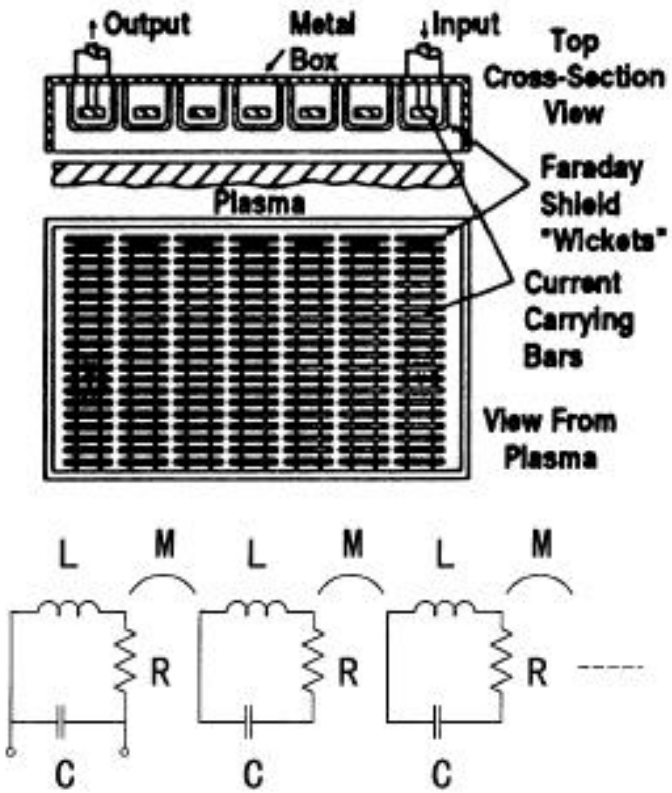
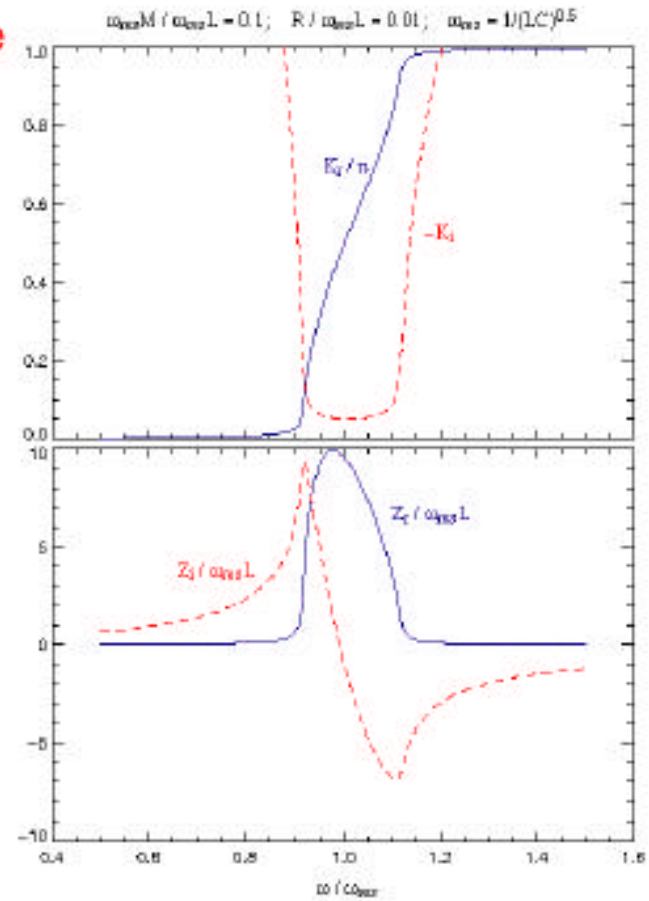
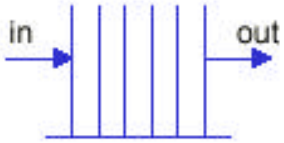
- Suitable for exciting a travelling wave

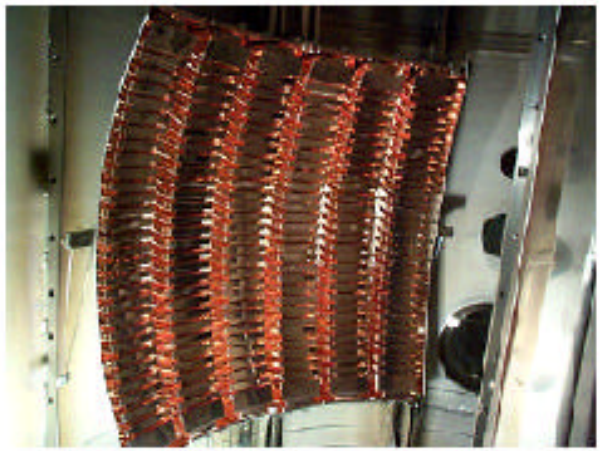


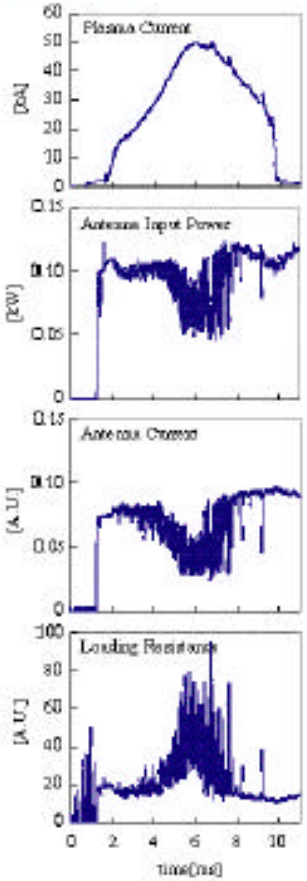


GENERAL ATOMICS

- Travelling wave antenna

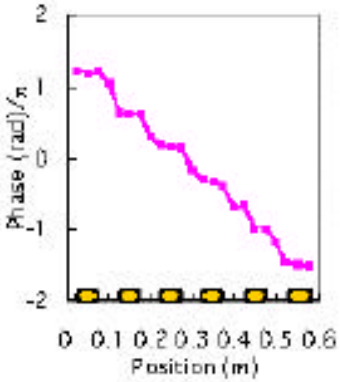


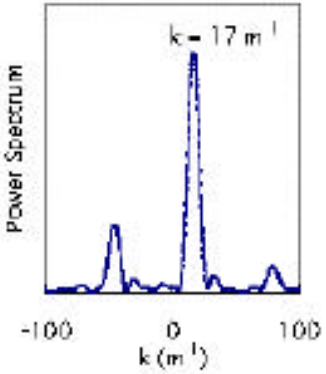




- Strong coupling to plasma

  → need to reduce loading for good CD spectrum





Development of a Combline Antenna for LHD

- **Development of a traveling wave antenna for LHD**
  - **Combline antenna with one input/one output**
    - **10 elements**
    - **2 rows stacked in the poloidal direction**
    - **Passband in the frequency range 70-80 MHz**
  - **Design optimization based on theory and experiment**
    - **Mock-up antenna measurements**
    - **TST-2 experiments (with plasma)**
    - **LHD prototype antenna (4 strap)**

Mock-up Antennas

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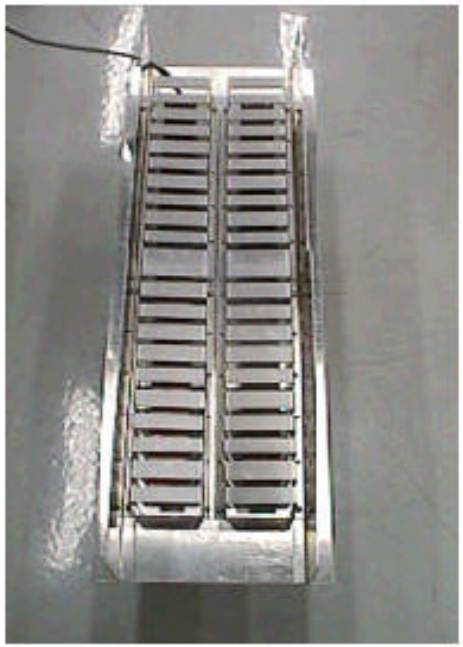
- MA1: Flexible geometry
  - Number of straps, spacing, length
  - Faraday shield type
  - Discrete capacitance
  - Strap to backplate distance

- MA2: 2×2 array
  - Center ground, top/bottom open
  - Coupling between straps



Combline Antenna in LHD V.V.

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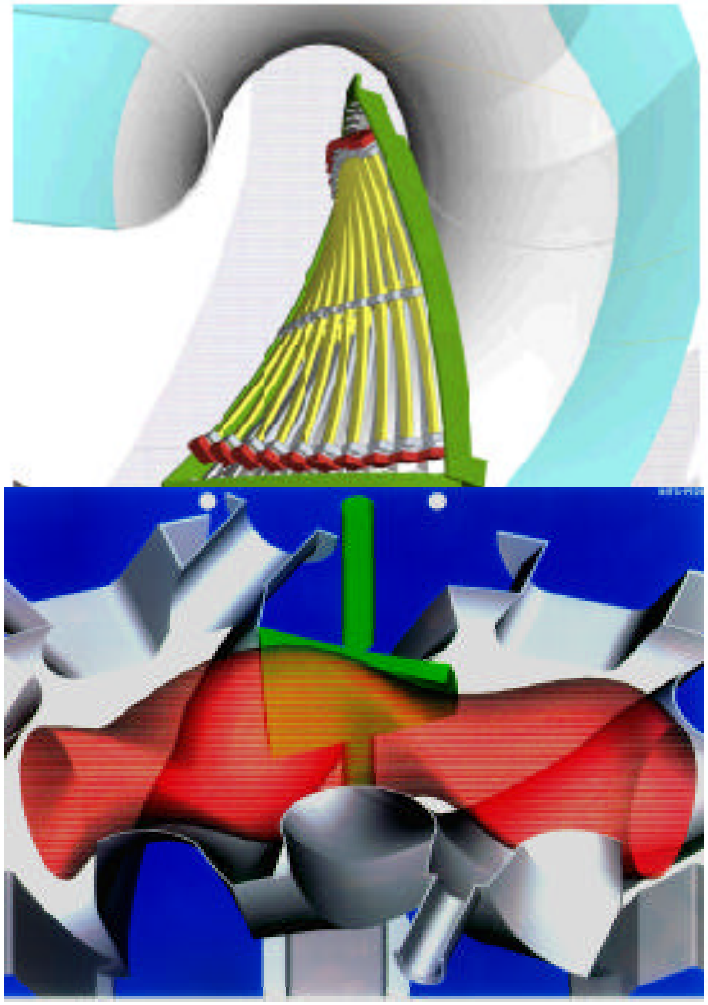

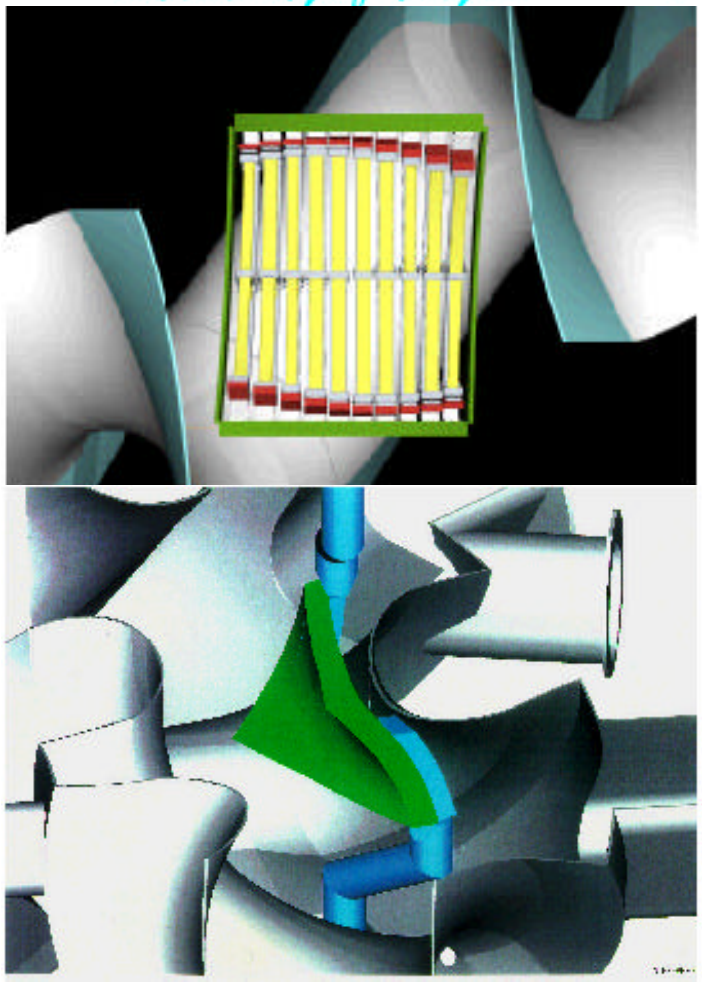

GENERAL ATOMICS

LHD Prototype Antenna

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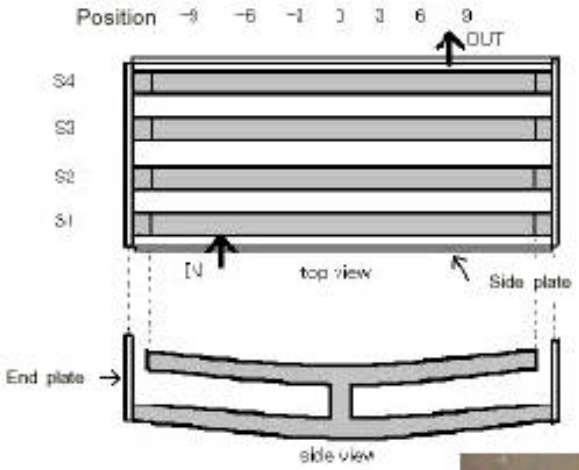
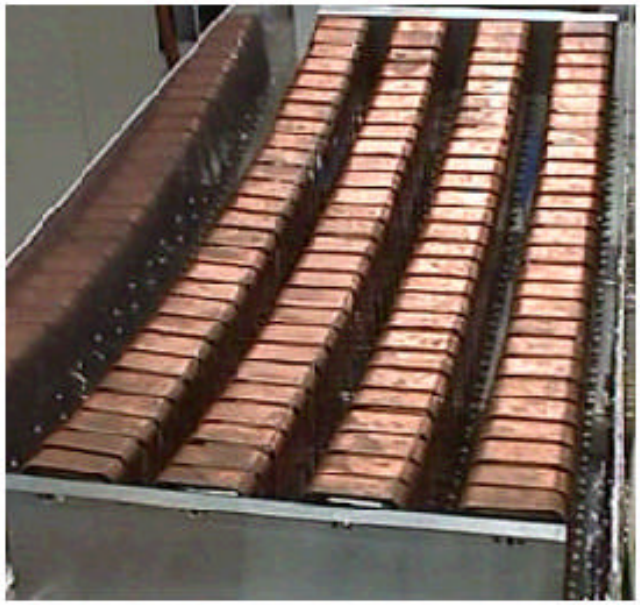
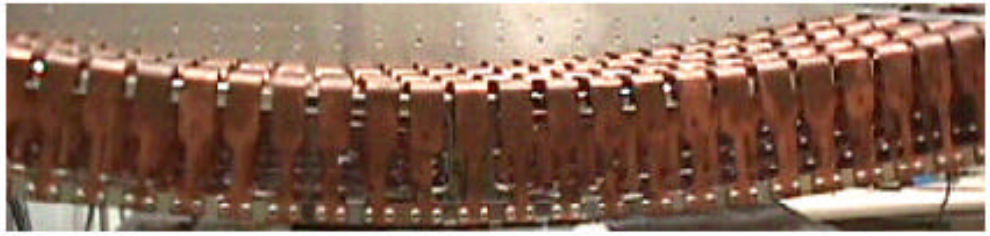
- Made of 4 modules of the LHD antenna

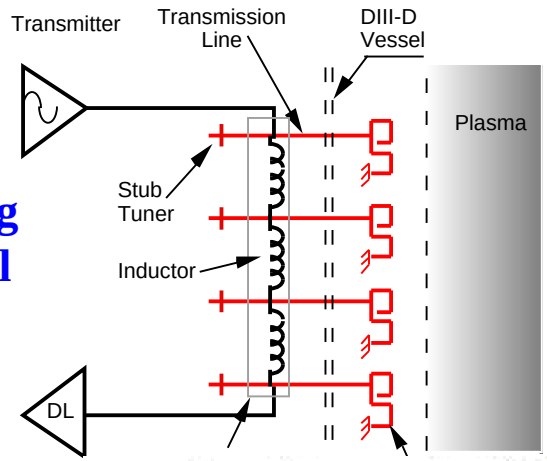


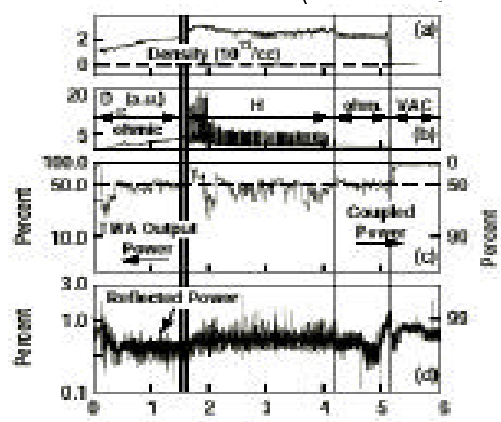




CONVERSION OF A FOUR STRAP ANTENNA TO A “COMBLINE LIKE” ANTENNA

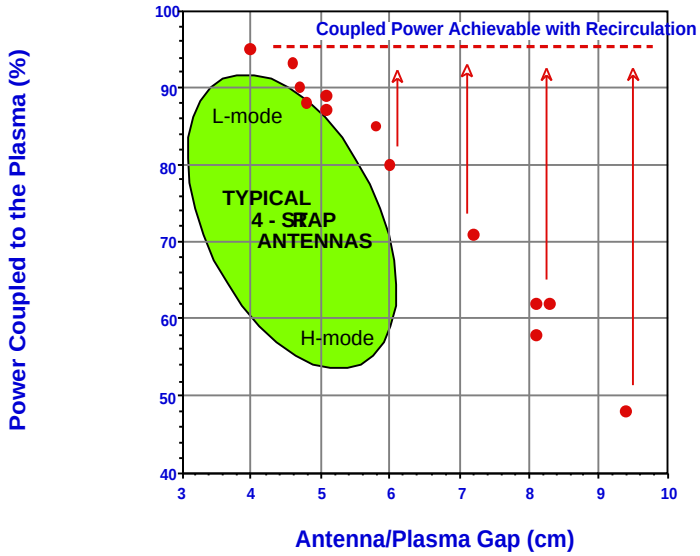
- **A standard four strap fast wave current drive antenna can be converted to a traveling wave “Combline like” antenna by using external coupling inductors to enhance the element to element mutual inductance.**
  - **Tested on DIII-D using low power, demonstrating <1% reflection over all ranges of plasma operation.**
  - **The 50% power coupling can be increased (≈90%) by using a 3 dB Hybrid as a recirculator**

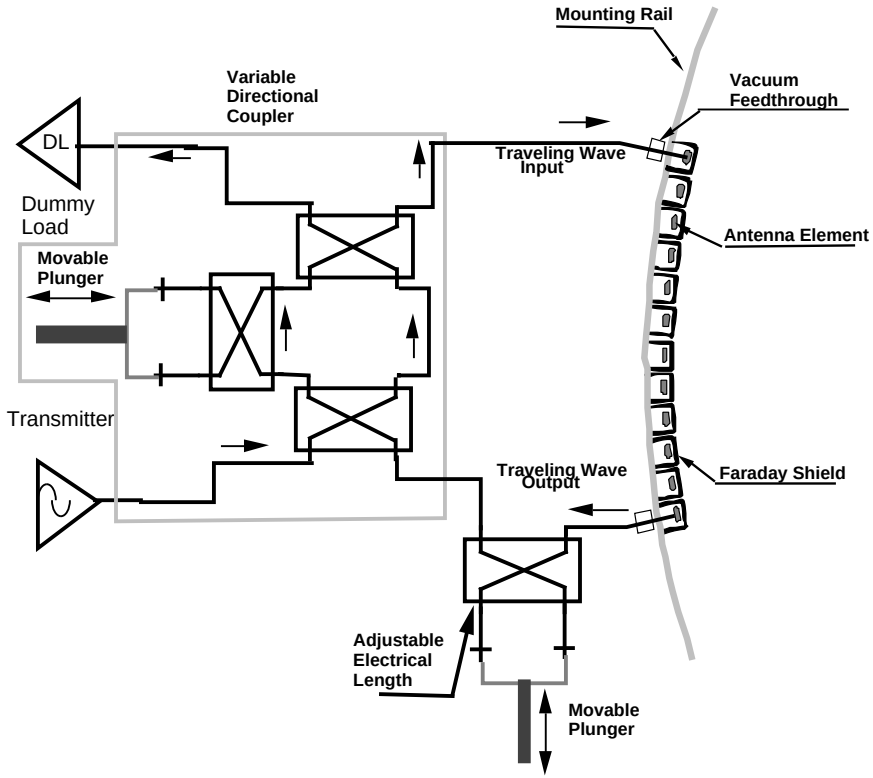




RECIRCULATION OF POWER

- **If the permissible length of the antenna is limited, it maybe necessary to recirculate the power unidirectionally**
- **This can be accomplished by making the antenna part of a resonant ring.**





GENERAL ATOMICS

SUMMARY OF TRAVELING WAVE COMBLINE ANTENNAS

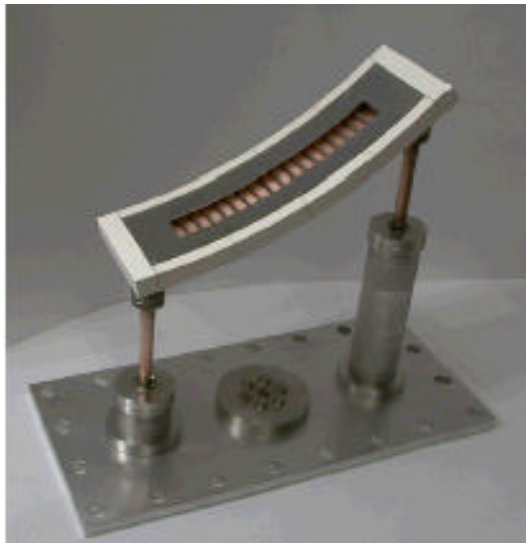
- **Combline antennas have been successfully used in plasma experiments and have validated that this type of antenna is robust to sudden plasma loading changes. This type of antenna may be very useful where its characteristics are favorable over the standard direct driven strap antenna.**
  - **One input/one output**
  - **Low profile**
  - **Narrow $n_{||}$ spectrum**
  - **Large plasma gaps**
  - **Robust to changes in plasma loading (can support plasma startup)**

Lower Hybrid Antenna Coupling and Power Handling Experiments on MST

- A system for launching slow lower hybrid waves into MST at 800 MHz and $n_{\|}$ =7.5 has been implemented. The antenna is an enclosed Interdigital line using 1/4 wave-length resonators with an opening in the cavity through which the wave is coupled to the plasma.
  - LHCD Antenna has been installed in MST
  - Up to 20 kW RF power applied at 800 MHz
  - Plasma loading of inboard and outboard antenna ports is asymmetric

LHCD ANTENNA CONSTRUCTION

The antenna consists of an interdigital slow wave structure, enclosed in a cavity, with an aperture for electrostatic coupling to the plasma. Phase between rods is p /2.



One port is powered and the other terminated. Interchanging driven and terminated ports reverses Wave launch direction.

LHCD Antenna installed in MST

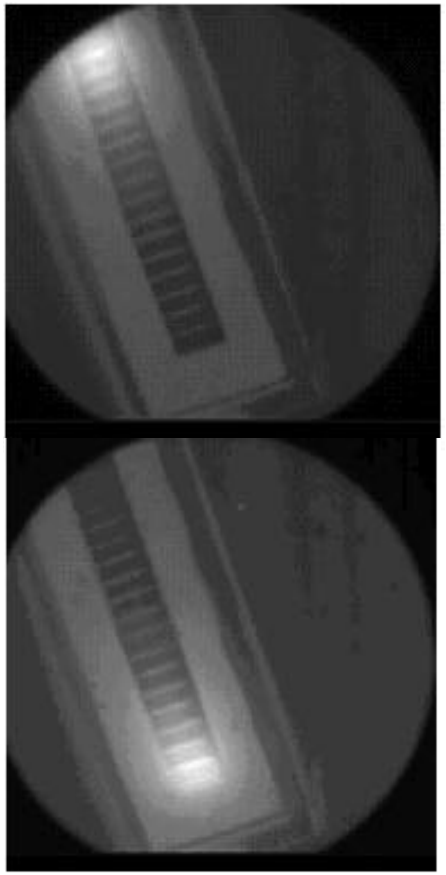
Plasma facing surface and rods are Molybdenum, edge limiter is Boron Nitride

(photo taken at installation 10/99)

Video Images

During initial high power operation, some localized antenna-plasma interaction was observed:

- After several shots the light emission decreased to zero, suggesting gas desorption
- Presently no light emission is seen for input power as high as 20 kW
- A CCD Spectrometer viewing the antenna directly shows no indication of Cu or Mo impurity lines

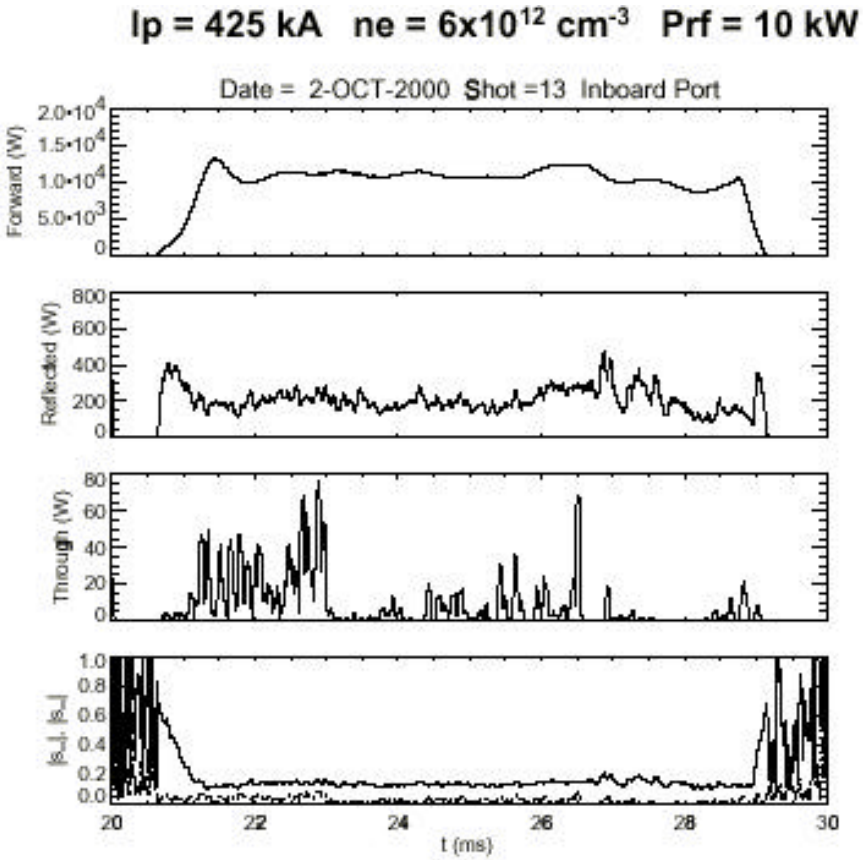


Outboard Port

Typical Inboard Port Data

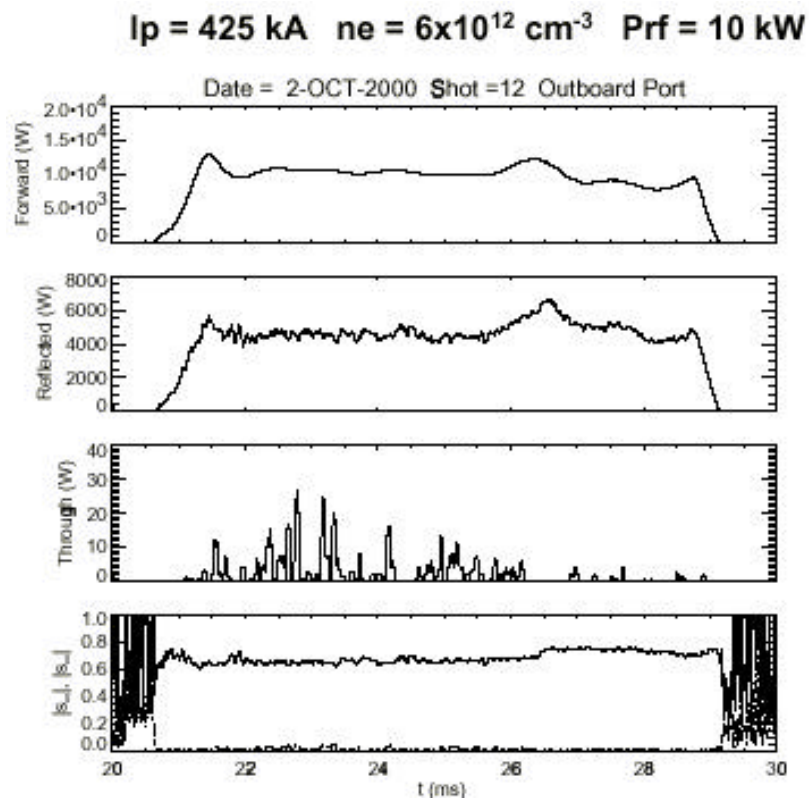
- Input reflection coefficient decreases smoothly as input power rises and impedance match improves

- Less than 0.5% of input power exits the outboard port to the load



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



SUMMARY OF TRAVELING WAVE INTERDIGITAL ANTENNAS

Initial results of an Interdigital antenna on MST for Lower Hybrid Current Drive is encouraging, however plasma loading problems are being addressed

- A limiter is being designed to control density along front of antenna
- 3D electromagnetic computer modeling of antenna coupled to plasma is ongoing
- Preliminary results are in good agreement with previous circuit simulation and measured fields of bench prototype, and also indicate desired plasma response