Diagnostic setup for spatial and temporal measurements of plasma fluctuations using electric probes in LDX

E. Ortiz, M. Mauel, D. Garnier, A. Hansen
- Columbia University -

O. Grulke, J. Kesner
- MIT PSFC -

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Introduction

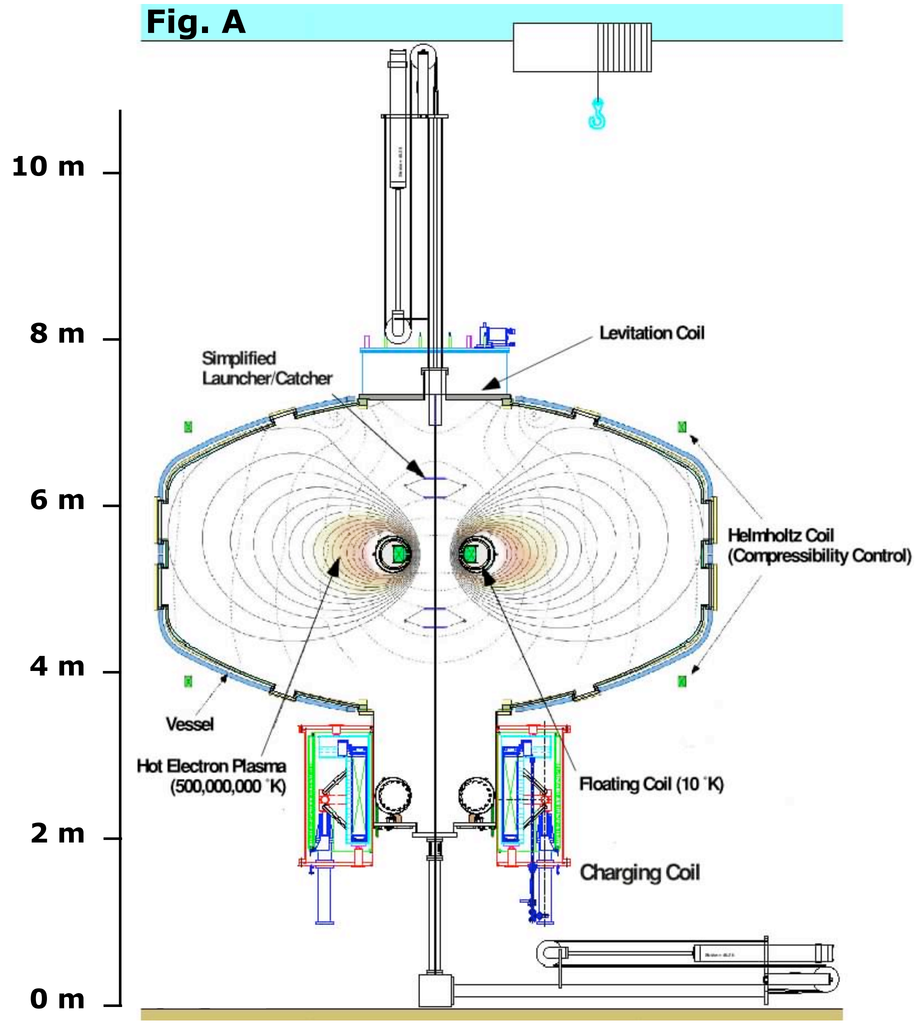
LDX will investigate the equilibrium and stability of a high-beta plasma confined in a dipolar magnetic field. As theorized and observed for planetary dipole configurations, electrostatic fluctuations play an important role in the dynamics behind degradation of confinement properties (in the lab) and, because no experiment before has been able to duplicate such fields, a poor understanding exists. Electrostatic fluctuation measurements in dipole confinement have been limited to space crafts zipping planetary size masses or experiments (ex: CTX) that attempt to replicate these fields. LDX, with its novel levitation magnetic, promises to provide an optimal environment to explore more thoroughly the physics behind these fluctuations.

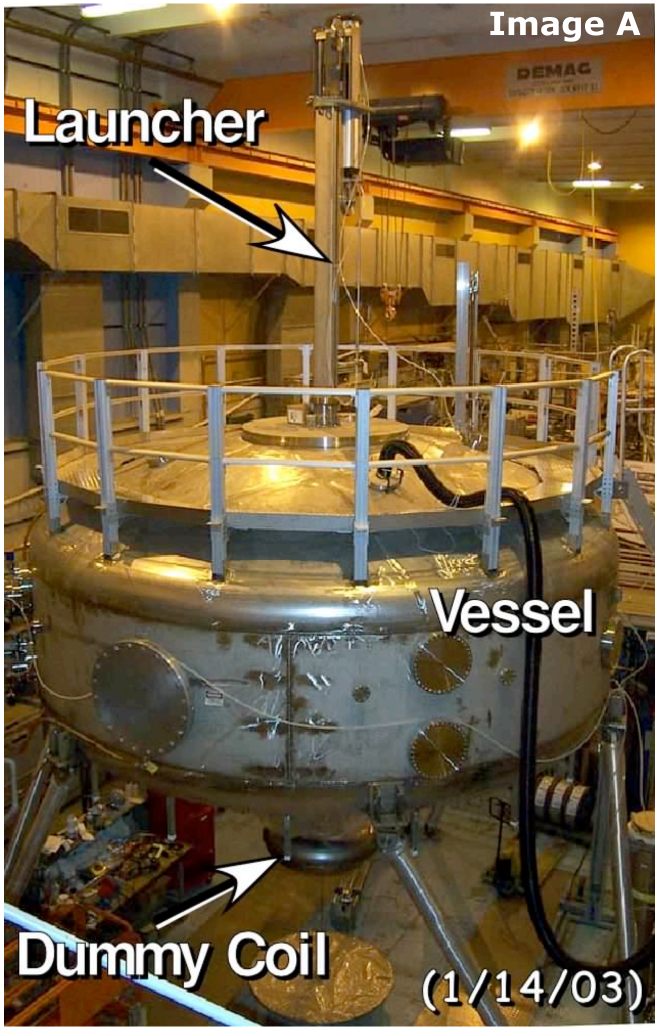
LDX, much like a bag of jelly beans, promises to serve these fluctuations in assorted flavors and, depending on the bag, quantities and quality, too. Our first sampling will look at the time average of basic plasma parameters to identify behavior such as ion velocity changes, large scale flow phenomena, and specific properties expected of dipole configuration plasma containment machines. In addition, the cross check with the magnetic equilibrium reconstruction code represents our first order attempt at building a physical picture behind plasma fluctuations in a true dipole field. To this end emissive, triple, and mach probes as well as two multi-probe arrays have been designed and built as the tools for our electrostatic fluctuations investigation.

Outline

- Time averaged measurements
  - Expected key parameters
- Large scale fluctuations
  - Interchange instabilities
  - Convective cells
- Planned probe setup
  - Single probe
    - Emissive probe & electron source
    - Triple & Mach probe
  - Multi-probe array
    - Low field array
    - High field array
- Status of probes
  - Expected schedule of operation

The Big Picture





* Image and Fig. by D. Garnier [6]. Updated by E. Ortiz. October 2003.

Expected LDX Parameters

Parameter	Hot Electron
Levitated coil current (MA)	1.19
Major radius of coil (m)	0.34
Total usable flux (V·s)	0.43
Total plasma volume (m^3)	26
Core volume (m^3)	0.5
Minimum, Maximum B at core (T)	0.088, 3.3
B at edge (G)	30
Core hot electron density (m^{-3})	3.6×10^{16}
Core total electron density (m^{-3})	7.6×10^{16}
Core hot electron temperature (keV)	≈ 250
Core thermal electron temperature (keV)	5
Core thermal ion temperature (keV)	0.05-0.1
Peak core β (%)	~ 55
Edge density (m^{-3})	7×10^{14}
Edge thermal temperature (eV)	5

Table 1: Plasma equilibria parameters. (A) diverted, no shaping, (B) diverted, shaped for maximum beta, (C) diverted, shaped for minimum beta, (D) limited plasma.

	A	B	C	D
S-Coil Currents; I_{s1}, I_{s2} (kA)	0,0	1,12	50,50	3,12
Plasma Volume (m^3)	14	27	1.7	24
SOL Pressure (Pa)	0.25	0.25	0.25	0.1
Max Pressure (Pa)	136	1530	45	472
Plasma Current (kA)	3.2	16.4	0.39	5.78
Stored Energy (J)	316	1450	27	516
R(P_{max}) (m)	0.76	0.76	0.77	0.79
B(P_{max}) (T)	0.088	0.088	0.088	0.088
$\beta(P_{max})$	0.08	0.55	0.015	0.15

* Tables by D. Garnier [6]. Updated by E. Ortiz. October 2003.

Fluctuations

- First year steady state conditions
  - Supported coil operation
  - Initial plasma testing with hydrogen based plasmas
  - Obtain baseline characterization of basic parameters
- Measurements of time average basic parameters
  - Obtained using computer controlled, motor-driven probes
  - Measurement confidence gained by various types of probes
- ECRH injection of negative charge at pressure peak leads to (we expect)
  - Plasma temperature peak also near pressure peak, due to electron source centered about pressure peak [6]
  - Density profile may be similar to temperature profile, maximum shifted inwards as a result of curvature drift [6]

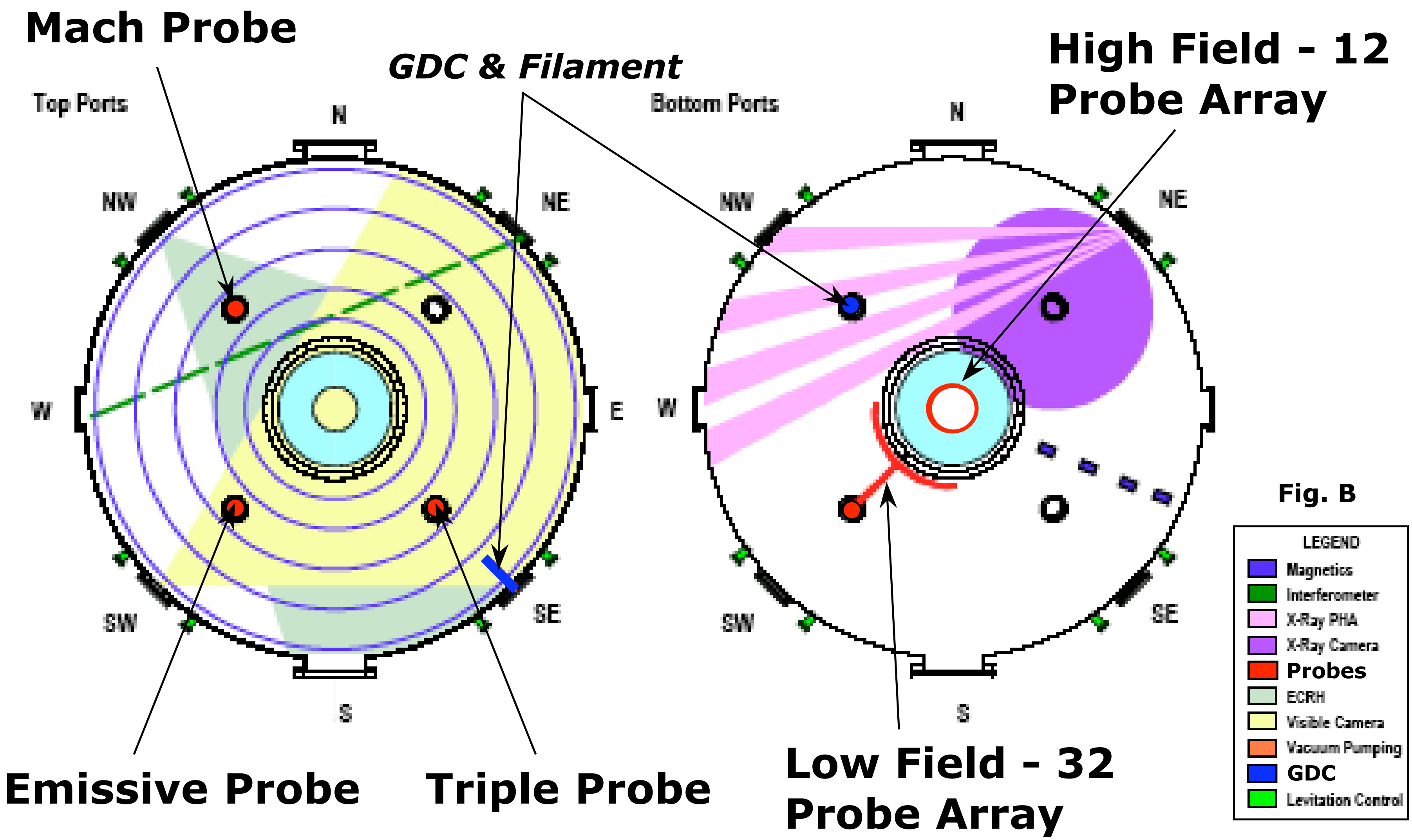
Large Scale Fluctuations

- Electrostatic Fluctuations are integral to understanding confinement of plasma
  - Several different types of instabilities are responsible for fluctuation levels
- Identification and characterization of fluctuation type (wave or coherent structure) important to compare to theory
  - LDX (MHD predicts-no shear) should not see ballooning or Alfven modes [6]
  - Experimentally (similar) dipole experiments to date have witnessed interchange, or ‘fluting’ instabilities [6]
- Interchange motion of plasma confined in dipole-field can be driven or ‘spontaneous’
  - In plasma with no magnetic shear, large scale equipotential contours propagate slowly as coherent E x B vortices, or ‘Convective Cells’ [6]

Convective Cell Questions

- Will convective cells exist in LDX and are they the nonlinear saturation of interchange modes?
  - Both theory and experiments agree: we expect to see these modes and they can provide a dominant source of cross field transport in a shear-free environment [6]
  - Expected to grow as a nonlinear consequence of interchange instabilities [6]
- What will they do to energy confinement?
  - MHD suggests they generate non-local energy transport of required to prevent the pressure profile from exceeding the critical gradient [6]
- Where would they form?
  - Attempts to exceed the critical pressure gradient in the outer bad curvature region between the pressure peak and vacuum chamber wall may lead to CC formation [6]
  - Not energetically favored in the inner, good curvature region-plasma stable to interchange modes [6]

Electrostatic Probe Setup



* Fig. by D. Garnier [6]. Update by E. Ortiz. October 2003.

Electric Probe Overview

- Conditional sampling and averaging method
  - Describe the average time evolution of structures related to a triggering condition [8]
  - Linear motion capable probes allow for increase sample space in surface plots
- Emissive probe
  - Measure plasma potential
  - Inject electrons -> induce fluctuations -> convective cells
- Triple probe
  - Obtain instantaneously T_e and n_e
  - No voltage and/or frequency sweeping required
- Multi-probe array
  - Low field array made of 36 Langmuir probes on 1/4 arc
  - High field array mounted on center fixture made of 6 equally spaced probes covering entire circumference

Electric Probe Overview cont.

- Simultaneous measurement of plasma parameters at fixed distance from floating coil
- Detect plasma rotation about z-axis (cross field)

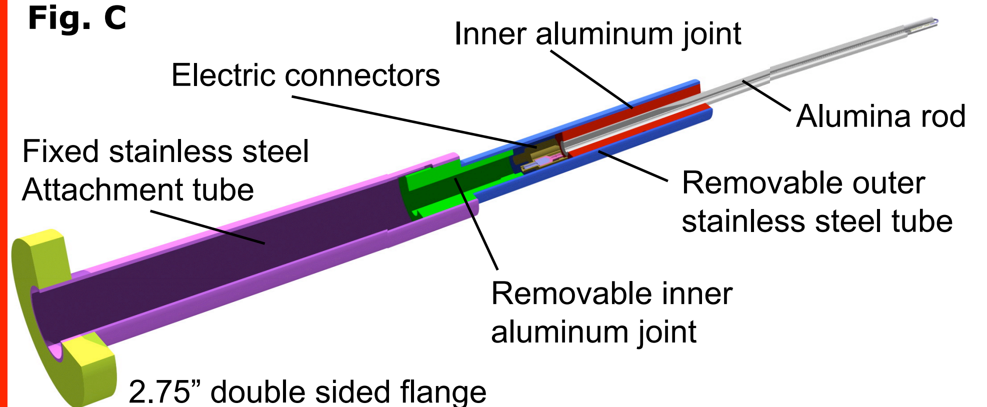
§ Mach probe

- Measure plasma flow velocity
- Track plasma flow along B-field

§ Electric probes measure edge plasma parameters

- Universal mount allows interchange of probes without breaking vacuum and probe exchange between shots

Fig. C



* Fig. by Eugenio Ortiz. November 10, 2002.

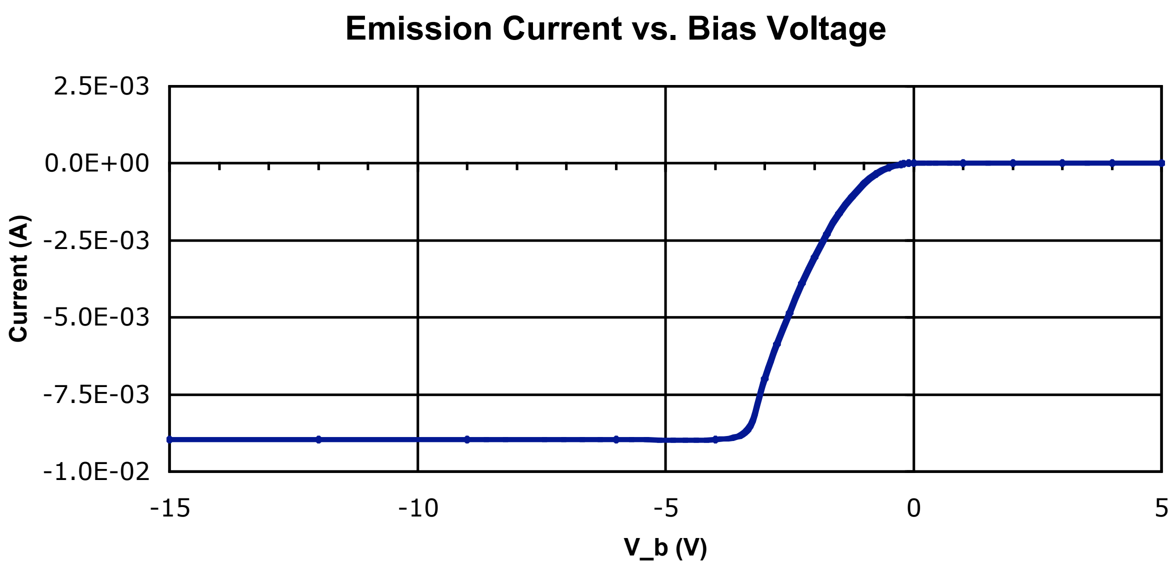
Probe Interface Mounting

* Image by E. Ortiz. November 10, 2002.

- Easy access via platform
  - Actual height ~ 4.5′ (137 cm) from base flange
  - Four ports available
- Bellow stroke ~ 32.5″ (83 cm)
  - Max length ~ 42.25″ (108 cm)
  - Min length ~ 9.75″ (25 cm)
- Probe incursion depth in to chamber ~ 60 cm
- Removal of probe without breaking main vacuum
- Motorized version allows remotely controllable motion
- Glow discharge plasma to be used to characterize probe behavior

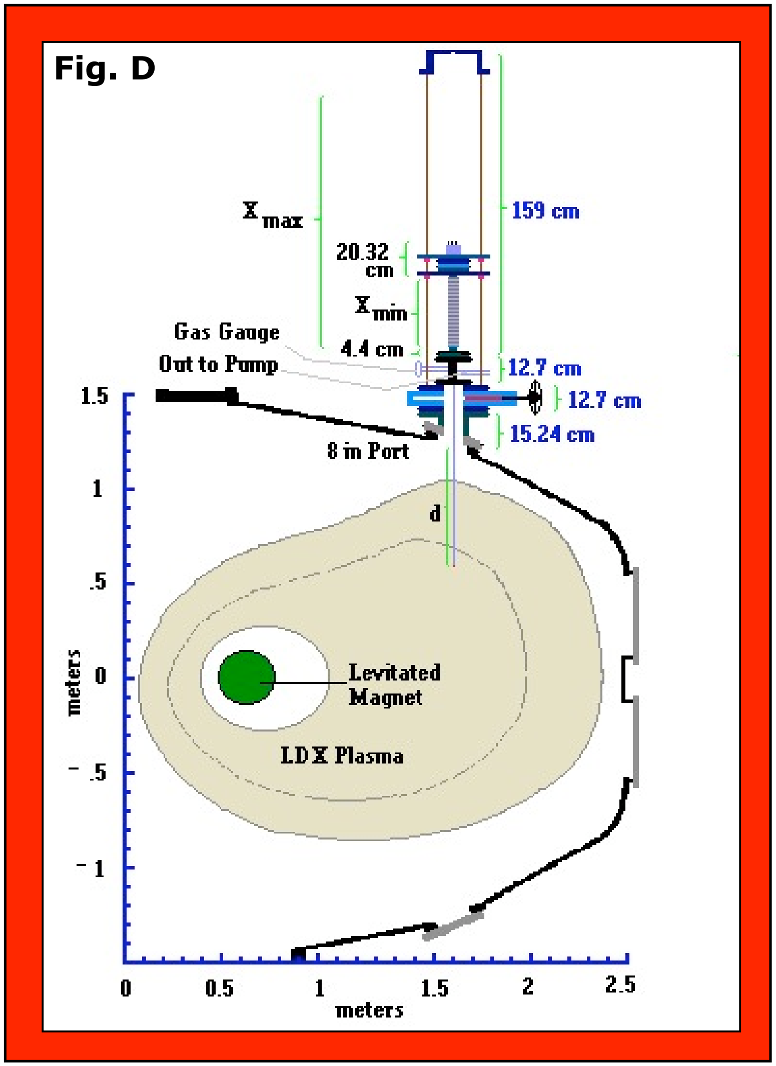
Expected Edge Plasma Values

Electron Temperature	5	eV
Electron Density	7×10^{14}	m^-3
Ion Saturation Current	0.1	mAmps
Ion Acoustic Velocity	21.9	km/s
Debye Length	6.3×10^{-4}	m
Edge Plasma Pressure	0.5	Pascal



* Chart based on model derived by M. Y. Ye and S. Takamura. August 2000.

Emissive Probe Goals



* Fig. by E. Ortiz. May 15, 2001.

- Measure edge plasma phenomena
  - Fluctuations in local potential, ie. **E**-field
- Switch application to emitting filament and bias single magnetic field line
  - Pin point injection of hot electrons
  - Attempt to 'stir' plasma and create vortex motion
  - Expect density profile evolution (local flattening) - product of particle transport by convective cells [8]

Driving Convective Cells

- Emissive probe design
  - Bias field lines & charge flux tubes
  - Create small **E**-field fluctuations
- Explore emissive probe ability to control cells
  - Attempt to drive new convective cells or suppress existing cells
- Study dynamics with probe array and emissive probe combination
  - Track large scale vortices
  - Time dependent polarity
  - Plasma flow dominated by vortices
  - Convective cell structure seen by probe arrays
  - Conditional sampling

Emissive Probes

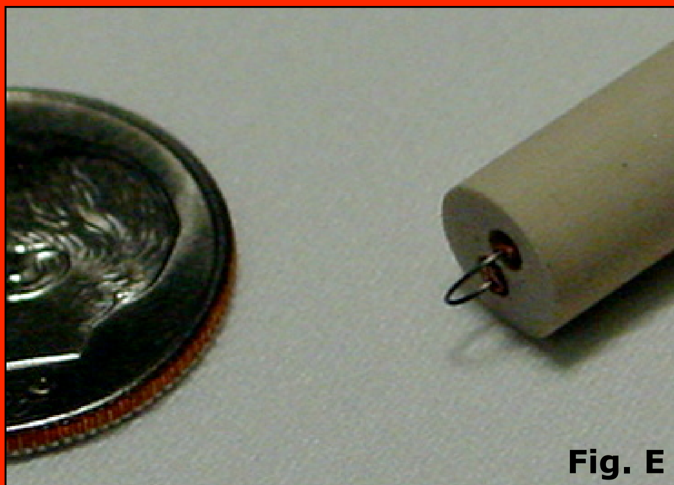


Fig. E

Fig. F

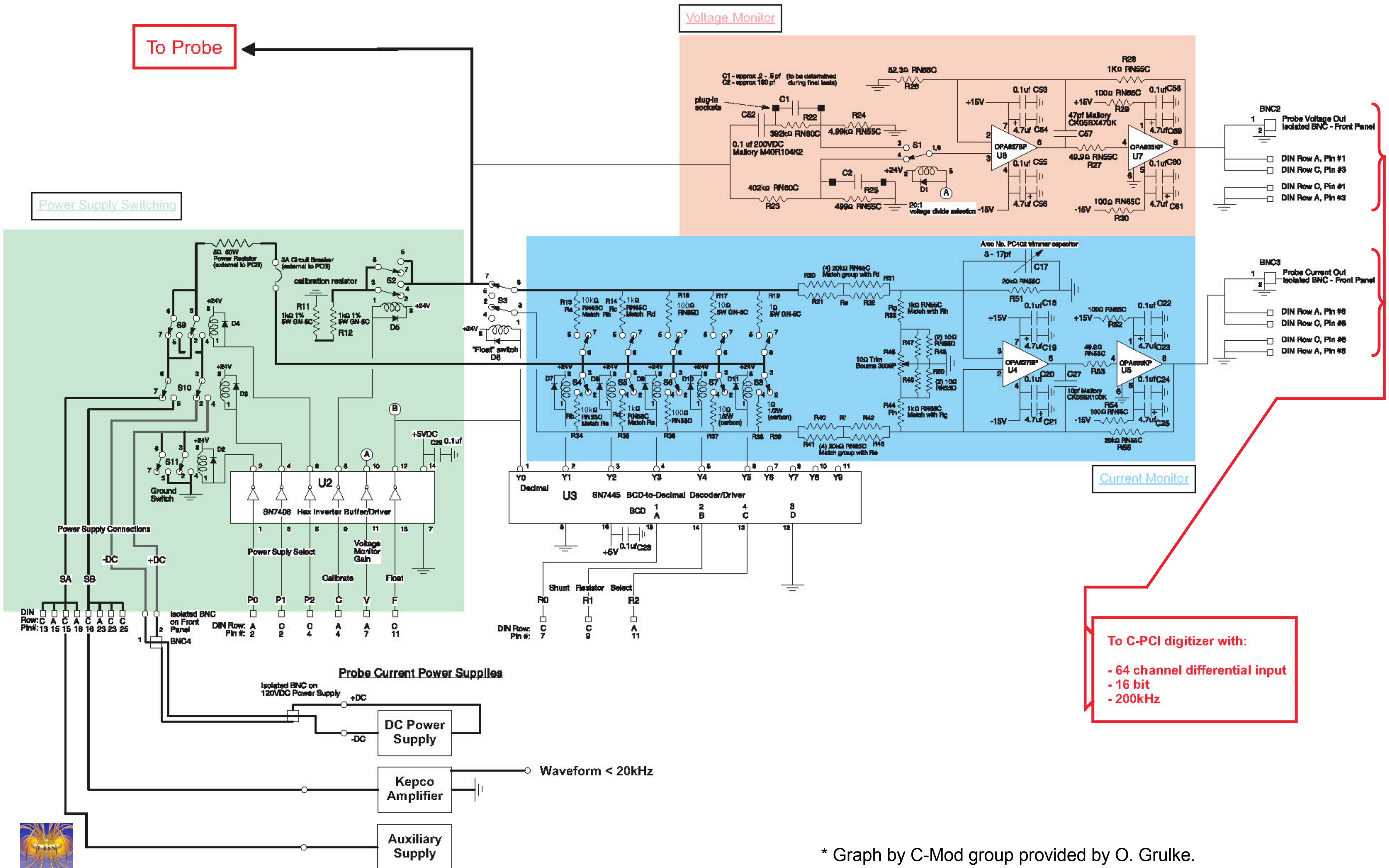
- Emissive probe (Fig. E)
  - Tungsten filament length ~ 5 mm, diameter ~ .2 mm
  - Signal wire is 21 AWG magnet wire, copper end connectors with filament
  - Enclosed in Al_2O_3 tubes, diameter ~ 6 mm
- Plasma 'Stirrer' probe (Fig. F)
  - Tungsten filament length ~ 6 mm, diameter ~ .5 mm
  - Signal wire is 18 AWG magnet wire, copper end connectors with filament
  - Enclosed in Al_2O_3 tubes, diameter ~ 9.5 mm

* Images by E. Ortiz. October 2003.

Multi-Probe Array Goals

- Low field array
  - Detect large scale fluctuations in low field region
  - Describe scale and structure of instabilities
  - Identify convective cells
- High field array
  - Detect large scale fluctuations in low field region
  - Describe scale and structure of instabilities
  - Identify convective cells
- Data measured via computer controlled 50 probe boards
  - Data stored into MDS-Plus database
- Based on B. LaBombard’s design and currently on C-Mod for their Langmuir probes
- Ability to handle sweep or fixed biased probes

Probe Board Circuit



* Graph by C-Mod group provided by O. Grulke.

EO_APS_DPP_10-03

Triple and Mach Probe Goals

- Triple probe
  - Allows for the instantaneous measurement of electron temperature and density
  - Three exposed wires aligned with plasma flow
  - Essential to make three probes as identical as possible and free of contamination
- Mach probe
  - Measure pressure and velocity perturbations
  - Measure the ratio of ion velocity to plasma sound speed
  - Langmuir electrode split in half, separated by insulator and aligned orthogonal to flow
  - Upstream and downstream comparison allows determination of plasma velocity

Triple & Mach Probes

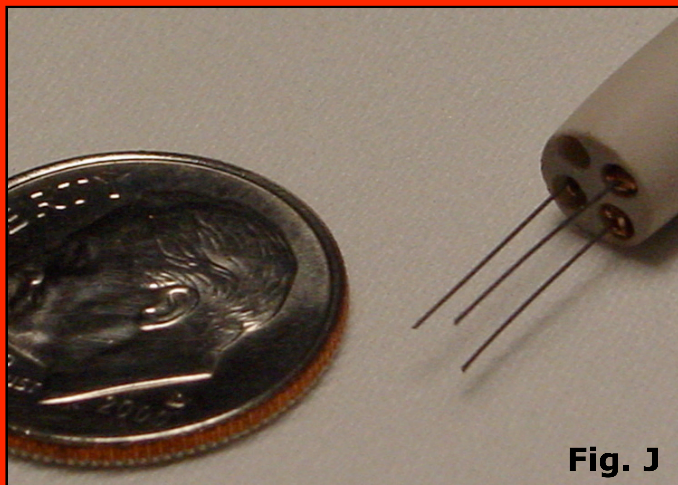


Fig. J

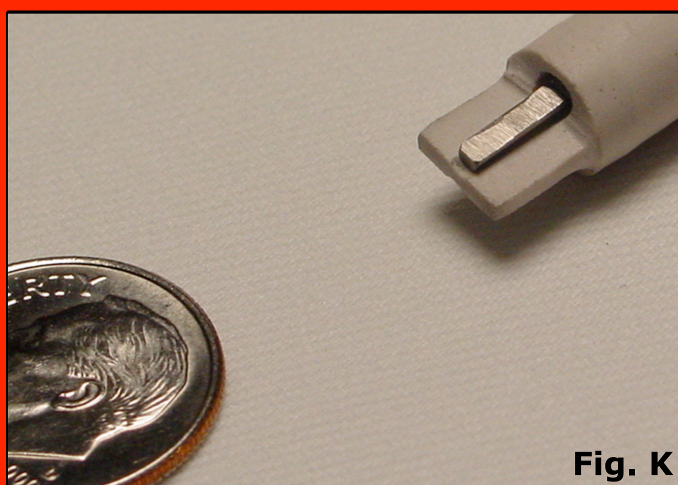


Fig. K

* Images by E. Ortiz. October 2003.

- Triple probe [1] (Fig. J)
  - Filament length ~ 10 mm, diameter ~ .2 mm
  - Signal wire is 21 AWG magnet wire, copper end connectors with filament
  - Enclosed in Al_2O_3 tubes, diameter ~ 6 mm
- Mach probe [12] (Fig. K)
  - Thoriated Tungsten filament length ~ 6 mm, diameter ~ 2 mm, depth ~ .8 mm
  - Signal wire is 21 AWG magnet wire, Stainless Steel end connector to filament
  - Enclosed in machined Al_2O_3 tubes, diameter ~ 9.5 mm

Summary

- The LDX electrostatic diagnostic layout, purpose and progress have been reported
  - Several common probes have been built and will be used to determine basic plasma characteristics
  - Probe arrays and emissive probes primarily used to explore the nature of convective cells
- Probes have been built with the three main goals:
  - First identify electrostatic fluctuations
  - Attempt to control and/or suppress convective cells
  - Help to develop theory to gain insight on the behavior convective cells for dipole B-field confinement
- Finally -> ALL three magnets have arrived!
  - Supported mode to follow shortly after glow plasmas
  - All probes will be ready in time for magnetized plasmas

LDX Research Team

M. Mauel	Columbia	Co-PI
J. Kesner	MIT	Co-PI
Engineering and Superconducting Magnets		
J. Minervini	MIT	Head
A. Zhukovsky	MIT	Cryogenics
P. Michael	MIT	Magnets
Experimental Operations		
D. Garnier	Columbia	Head
A. Hansen	Columbia	ECRH, Diagnostics
Dipole Physics		
J. Kesner	MIT	Head
Technical Support		
R. Lations	MIT	Cryogenics, Electromechanical
D. Shahan	MIT	Mechanical, Welding
Graduate Students		
I. Karim	MIT	Magnetics, Equilibrium
E. Ortiz	Columbia	Edge Probes, Edge Potential Control
J. Ellsworth	MIT	X-ray Imaging, Pulse-Height
A. Boxer	MIT	Interferometry, Profiles
Visiting Scientists		
Y. Ogawa	U. Tokyo	Magnets, Dipole Physics
O. Grulke	IPP	Edge Arrays, Convective Cells

* Table by D. Garnier [6]. Edited by E. Ortiz. October 2003.

ABSTRACT

LDX will investigate the equilibrium and stability of a high-beta plasma confined to a dipolar magnetic field. A crucial area of focus is the response of the edge plasma pressure profile to MHD fluctuations. Large-scale convective cells may form if the plasma pressure exceeds a critical gradient and we would like to understand the relationship between convective cell formation to plasma equilibrium and stability. The nature and role of convective cells will be explored using emissive probes that function not only as an electrostatic potential diagnostic but also as a low-impedance electrode for charging field lines and exciting or controlling the cells.

ABSTRACT cont.

By biasing a given field line, we expect to interact with convective cells in a controlled manner and thereby amplify or suppress the level of electrostatic perturbation. In addition, electric probe arrays will be used to characterize the dynamics of plasma fluctuations with high spatial and temporal resolution. A 32-probe array will be installed to measure fluctuations in the plasma edge covering 1/4 of the toroidal plasma circumference on the outer (low field) side. Another 12-probe array covering the entire plasma circumference will be installed on the high field side. The conceptual electric probe diagnostic setup and its relation to the expected plasma fluctuations will be presented.

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