NSTX

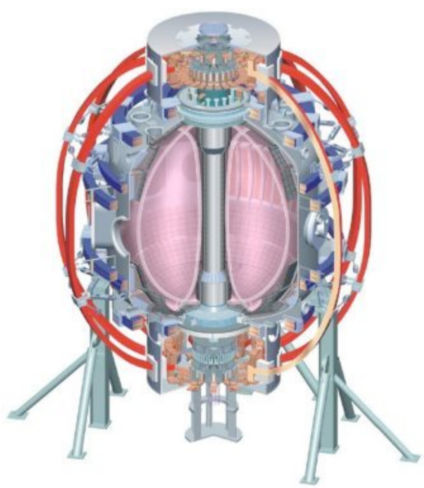
Supported by

U.S. DEPARTMENT OF ENERGY | Office of Science

Equilibrium Magnetics: Sensors, Locations, Uses,…

Stefan Gerhardt

College W&M
Colorado Sch Mines
Columbia U
CompX
General Atomics
INEL
Johns Hopkins U
LANL
LLNL
Lodestar
MIT
Nova Photonics
New York U
Old Dominion U
ORNL
PPPL
PSI
Princeton U
Purdue U
SNL
Think Tank, Inc.
UC Davis
UC Irvine
UCLA
UCSD
U Colorado
U Illinois
U Maryland
U Rochester
U Washington
U Wisconsin



Culham Sci Ctr
U St. Andrews
York U
Chubu U
Fukui U
Hiroshima U
Hyogo U
Kyoto U
Kyushu U
Kyushu Tokai U
NIFS
Niigata U
U Tokyo
JAEA
Hebrew U
Ioffe Inst
RRC Kurchatov Inst
TRINITI
KBSI
KAIST
POSTECH
ASIPP
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
ASCR, Czech Rep
U Quebec

Outline

- Uses of the equilibrium magnetics
- Locations and types of sensors
  - Mirnovs & flux loops & voltage loops & rogowskis
- Signal processing chain
  - Offline vs. online
- Oddball stuff
  - I_P calculator
  - Difference voltage for fast vertical position control.

Uses for the Equilibrium Magnetics

- Offline Equilibrium Reconstruction
  - EFIT, LRDFIT, GA Kinetic EFITs (BEFIT?)
    - Critical for physics analysis
  - Critical for appropriate operator decision making (EFIT)
- Online Equilibrium Reconstruction
  - rtEFIT
    - Provides the basis for shape control.
- Basic plasma position control
  - Early in the shot before switching to isoflux control
- Fast vertical position control
- Interlocks

Naming Convention For Sensors

Locations and Orientations

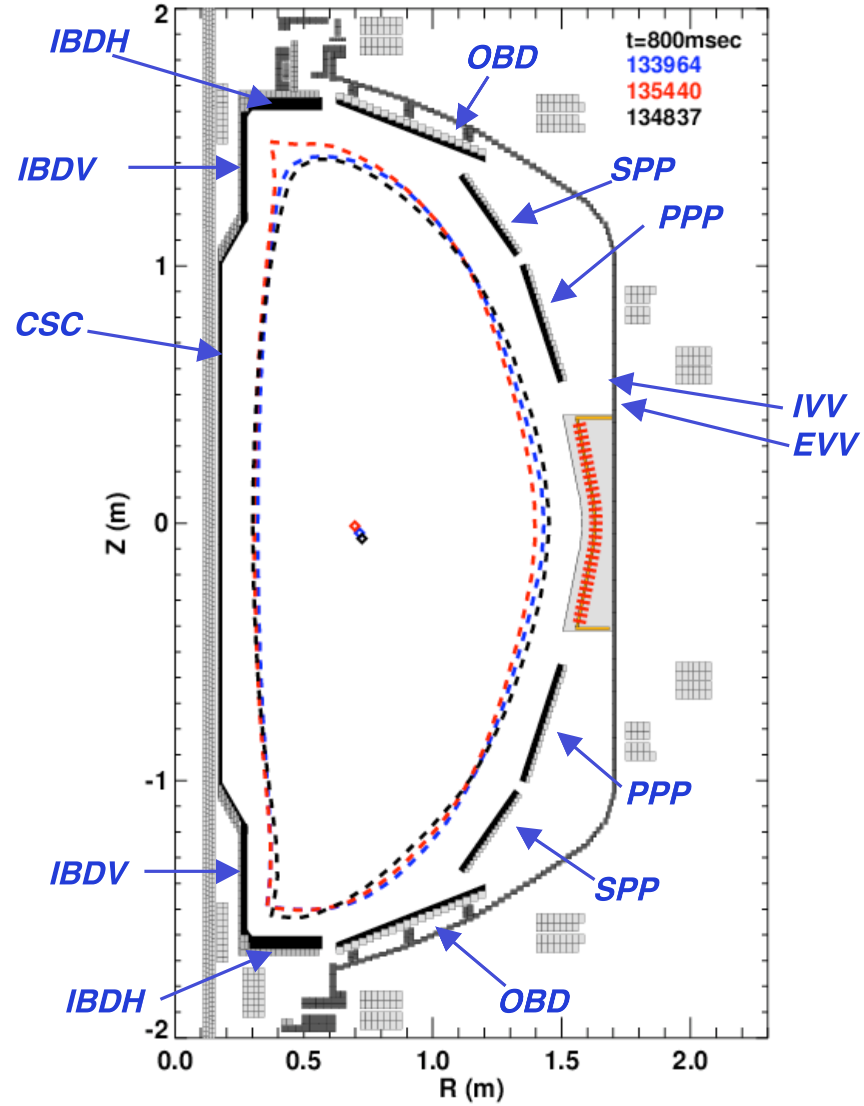
PPP = Primary Passive Plate
SPP = Secondary Passive Plate
IBDV = Inboard Divertor Vertical Part
IBDH = Inboard Divertor Horizontal part.
CSC = Center Stack Casing
OBD = Outboard Divertor
EVV = External to the (Outer) Vacuum Vessel
IVV = Internal to (Outer) Vacuum Vessel
OH = On the Solenoid
U = Upper
L = Lower
M = Midplane
N=Normal
T=Tangent

Sensor Types

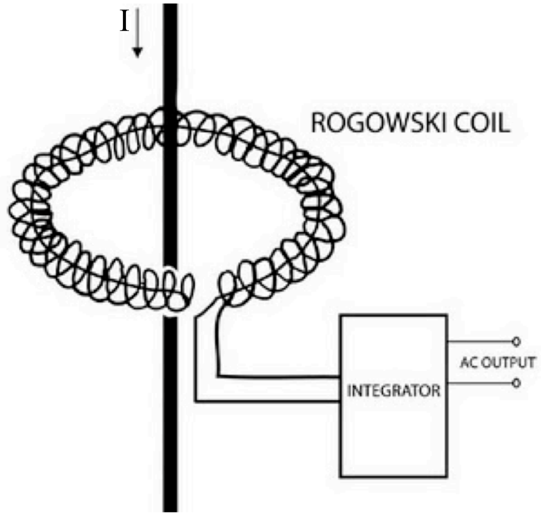
1DM = One Dimensional Mirnov
2DM = Two Dimensional Mirnov
FL = Flux Loop
Rog = Rogowski

Ground Classes

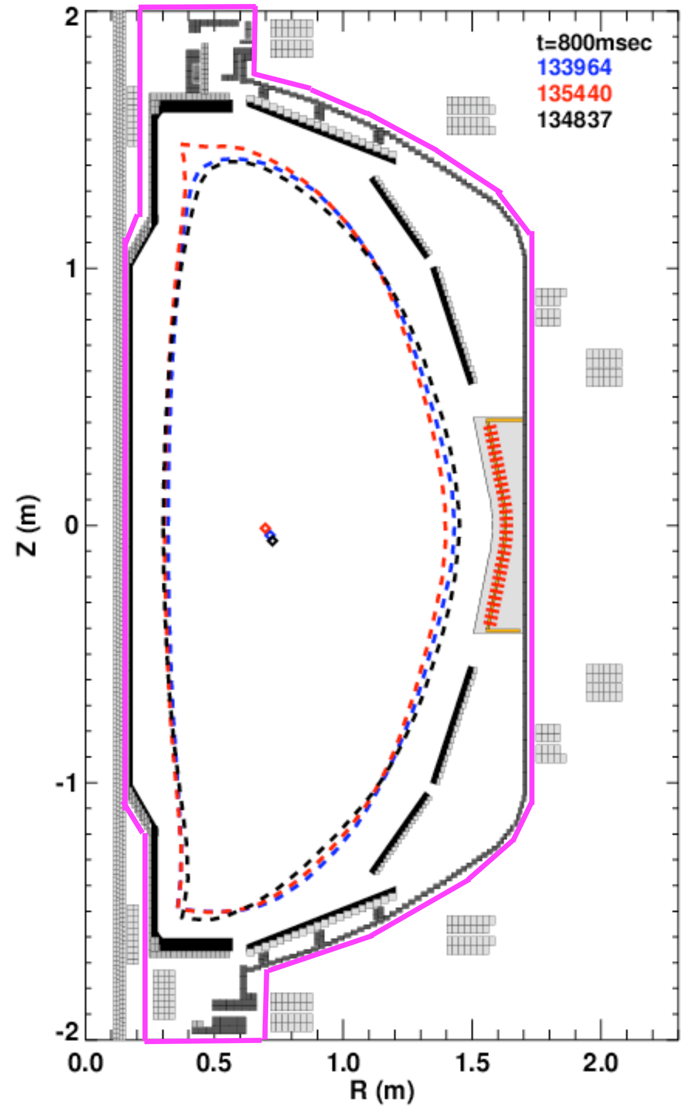
Category 3 = Inner Vessel
Category 4 = Outer Vessel



Plasma Current Rogowskis



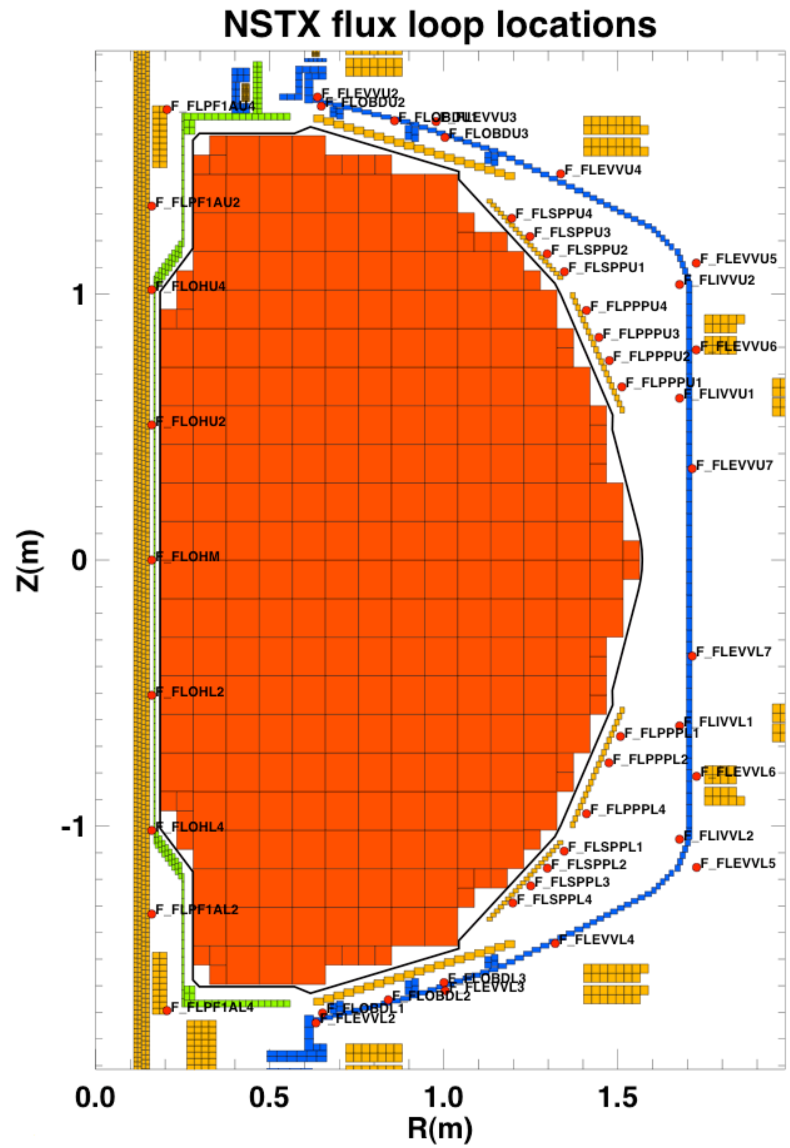
- Two plasma current rogowskis external to the vacuum vessel.
- They are references to inner vessel ground (Cat. 3).
- The link, and measure currents in:
  - The plasma
  - The PF-1B, the PF-AB1, and PF-AB2 coils
  - The chamber
- Necessary to remove the signal from PF-1B and the vacuum chamber in order to measure the plasma current.
  - Vessel currents exceed the plasma current during the breakdown and early current ramp.



Flux Loops

$$\psi = \iint B_Z dA = 2\pi \int_0^{R_{loop}} R B_Z dR$$

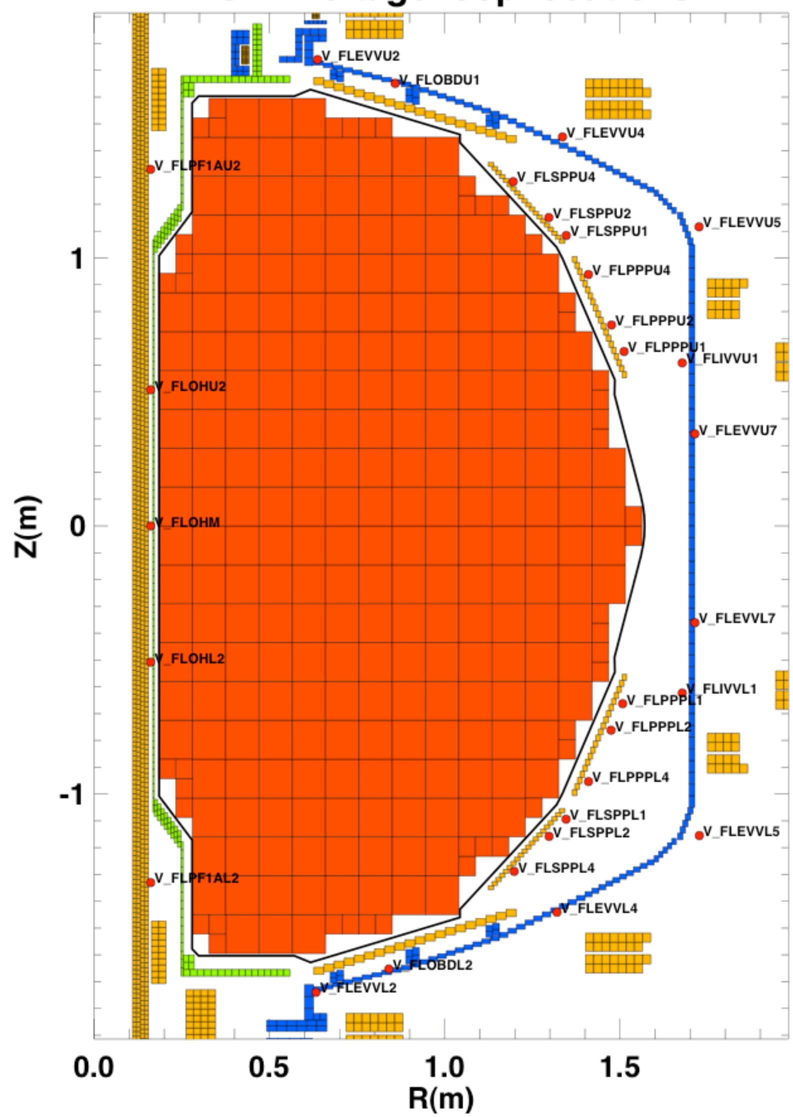
- 10 on the outside of the outer vessel (EVV).
- 10 on the inside of the outer vessel (IVV & OBD).
- 16 Behind the primary and secondary passive plates (PPP & SPP).
- 9 on the center column (OH & PF1A)



Voltage Loops

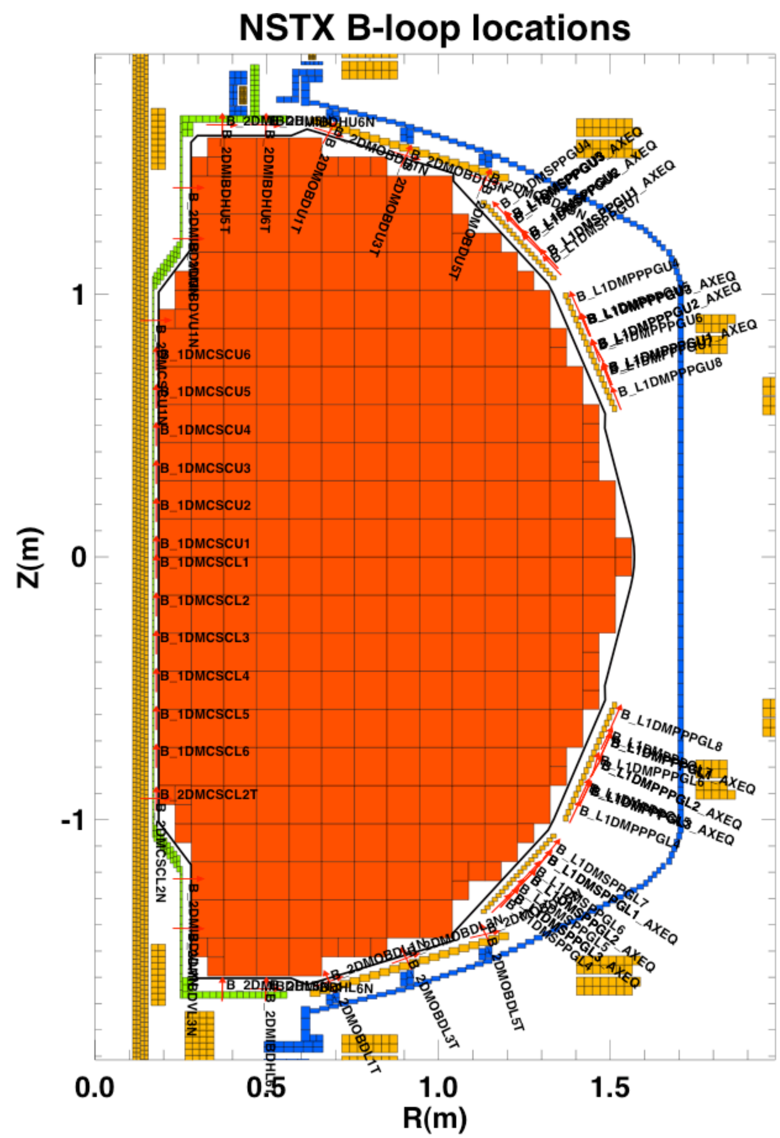
- Same as a "flux loop".
  - We just don't integrate the signal.
- 5 Measurements on the inner vessel
- 12 measurements on the outer vessel.
- 12 measurements on the plates themselves.

NSTX voltage loop locations

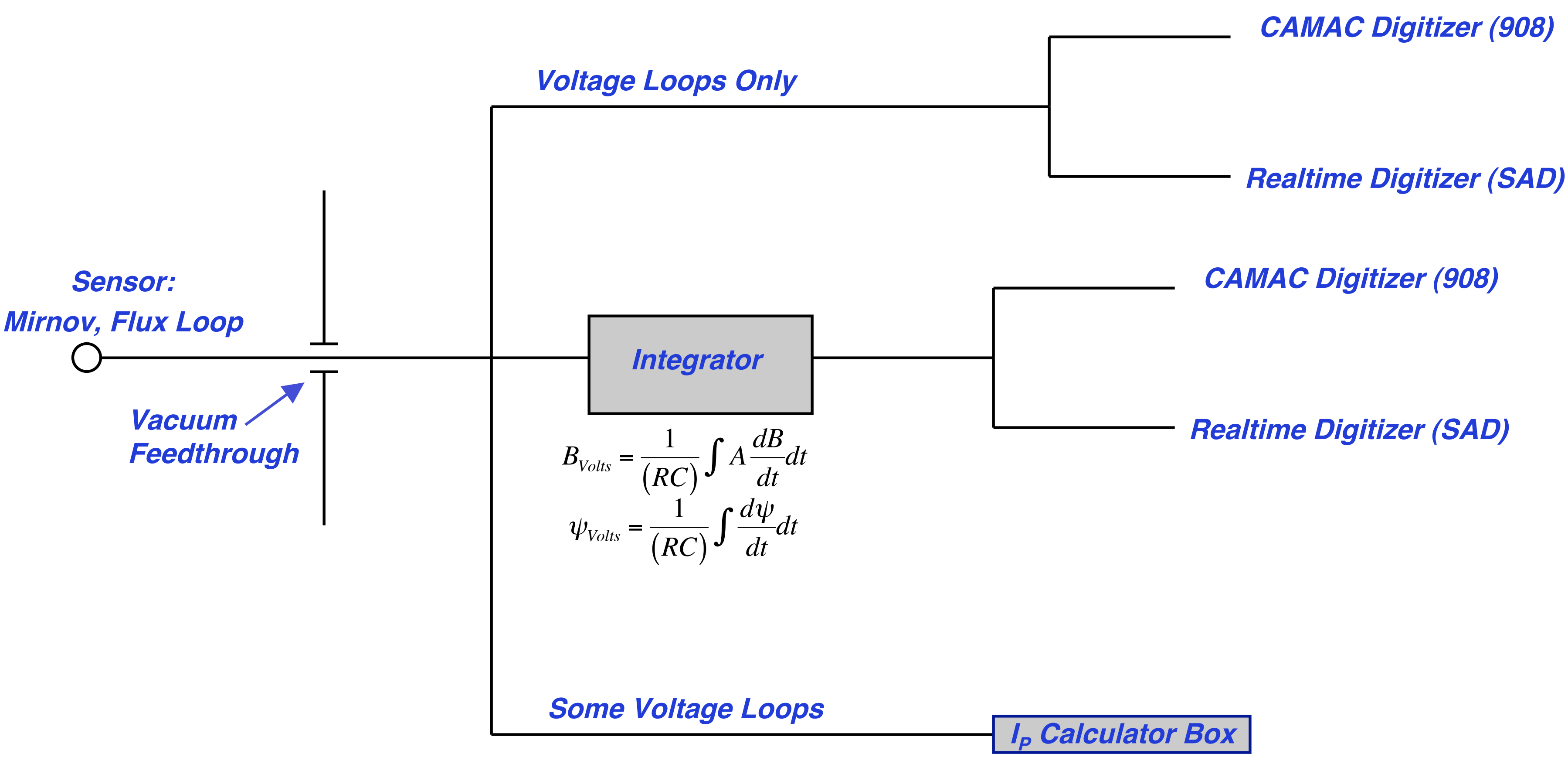


Mirnovs
(i.e small solenoids for local field measurements)

- Some have two sensors wound on the same mandrel.
  - 2D sensors mainly located in the divertor.
  - Normal to the PFC surface (N)
  - Tangent to the PFC surface (T)
- 2DMOBDL1 & 2DMOBDL3 were replaced this past opening as part of the LLD installation.
- Sensors mounted:
  - Between and behind the passive plates.
  - Inside tiles on the center stack casing.
  - Inside tiles in the divertor.
    - Outer
    - Horizontal Inner
    - Vertical Inner



Signal Processing Chain



$$B_{Volts} = \frac{1}{(RC)} \int A \frac{dB}{dt} dt$$

$$\psi_{Volts} = \frac{1}{(RC)} \int \frac{d\psi}{dt} dt$$

Signal Calibrations

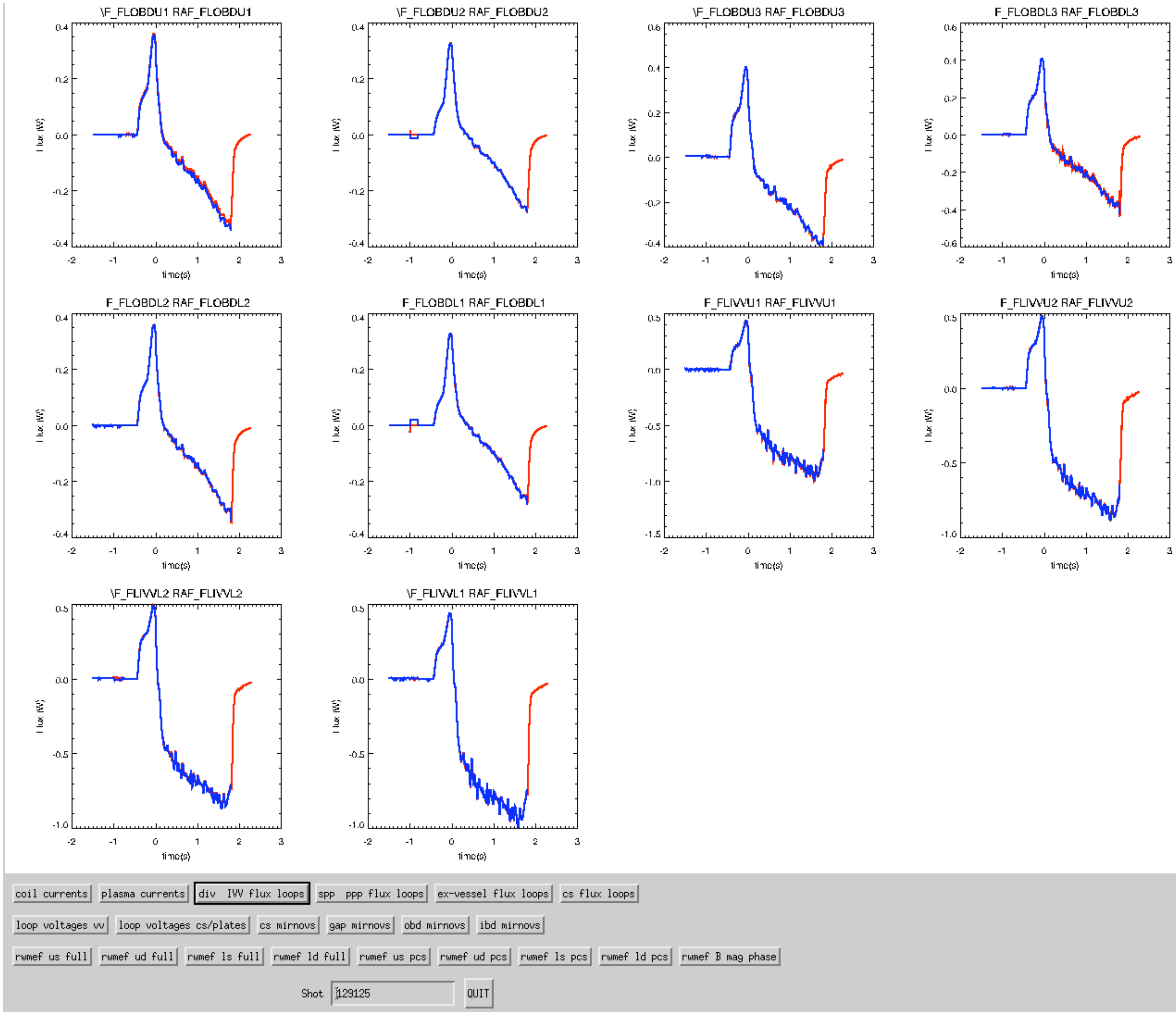
- Each sensor has many calibration coefficients.
  - Effective area
  - Integrator time constant RC (“Gain” = 1/RC)
  - Pickup coefficient for TF & other sources.

$$B = \frac{(RC)}{A} B_{Volts} - \sum_{i}^{i=NumCoils} p_i I_i$$

- Same calibration coefficients (with 1 exception) are used off- & on-line.
  - Offline: Used in tdi function calls.
  - Online: Done in ACQ.
- All of these coefficients are stored in the MDS+ model tree.
  - The “tree” is the database structure where all NSTX data is stored.
  - Some of the data in the tree is known before the shot starts.
    - Calibration coefficients, digitizer timing,…
  - Model tree contains all calibration data, places for shot-specific data.
  - Before each shot, the model tree is copied over to the shot-specific tree.
  - The coefficients are only read into ACQ from model tree when ACQ is started.
    - ***If the coefficients in the model tree are modified, ACQ must be restarted in order to get the most recent coefficients.***

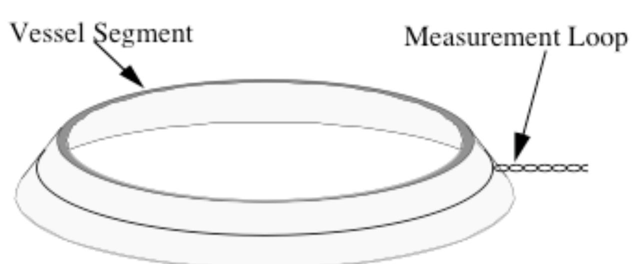
Comparison of Online and Offline Data: pecomp

- ***Procedure***
  - ***Open idl***
  - ***Type "pecomp"***
- ***Compare offline and online versions of most sensor data.***
- ***Note: not all sensors are "good" all the time.***
  - ***SPG repairs them as best possible when the break.***
- ***Important to have only good sensors in the constraint set for rtEFIT.***
  - ***Generally worked out between Steve Sabbagh, Dennis, and SPG…but sensors can break at any time.***
- ***rtEFIT sensor usage is part of the "snap setup", and it NOT restored with the shot.***

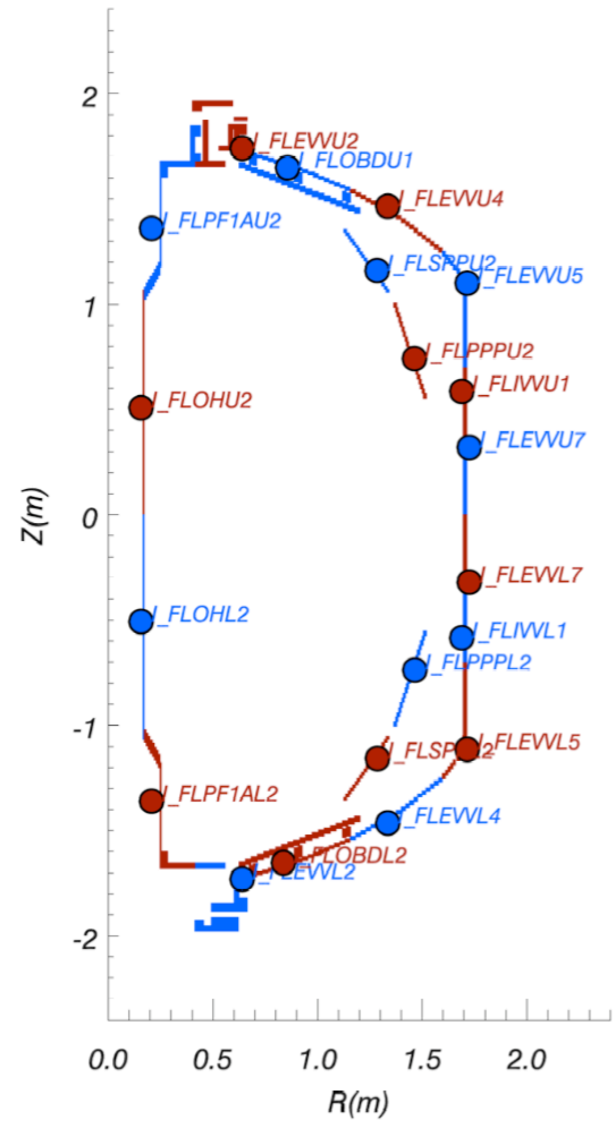


I_P Calculator (1)

- Rogowski links plasma, vessel, and PF-AB1, PF-AB2, & PF-1B coils.
- Need to know the plasma current in realtime for some interlock applications.
  - Interlock on neutral beams.
  - Interlock on HHFW.
- Need realtime subtraction of other currents from the rogowski signals.
  - Not “stray pickup”, but rather real current.
  - Easy to subtract off parts from coils…we have direct measurements of those.
  - Need to measure vessel currents in real-time.



$$V_{loop}=R_{segment}\times I_{Segment}$$



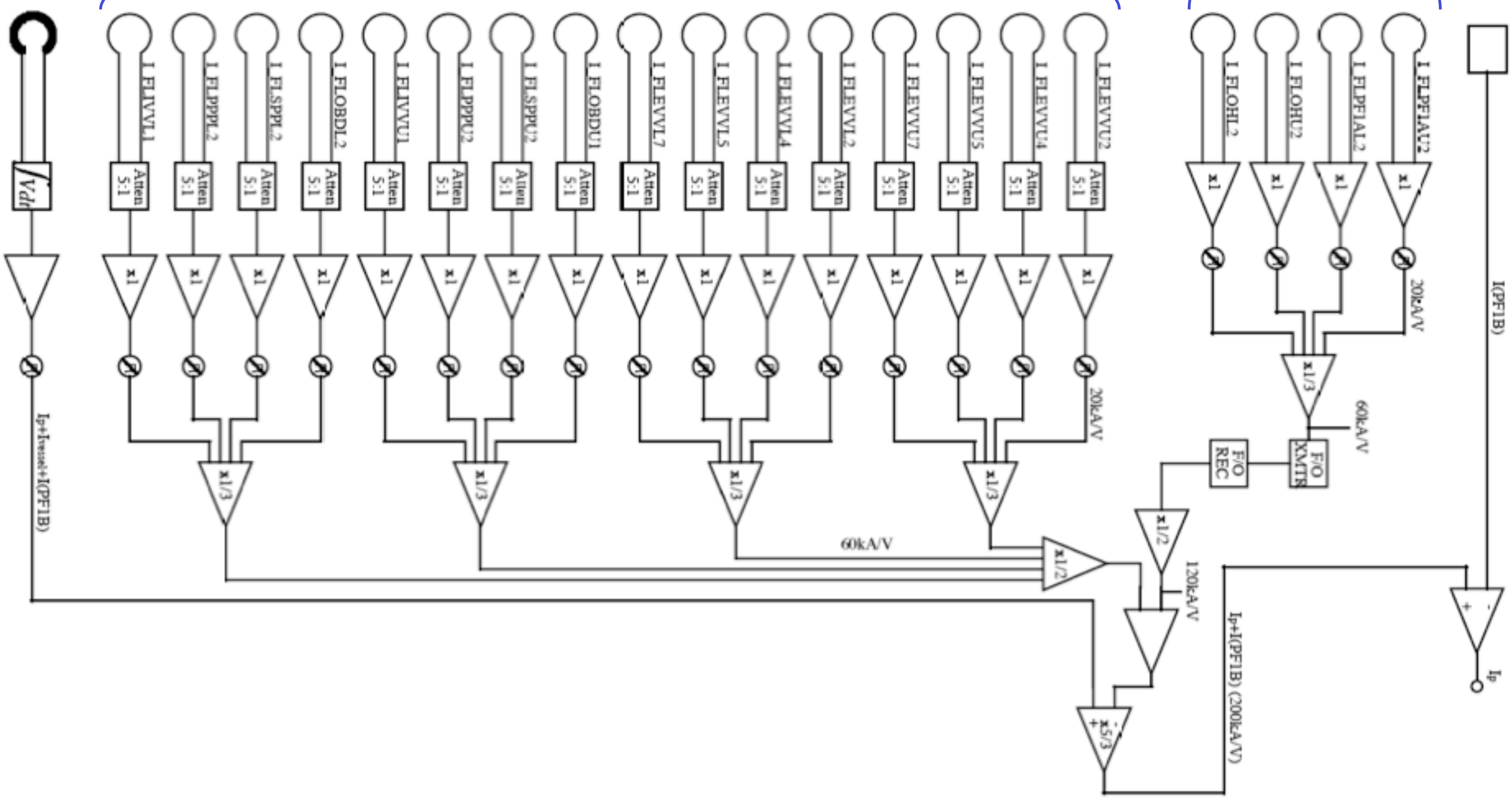
D. Gates et al., Rev. Sci. Instrum

I_P Calculator (2)

Rogowski

Flux Loops on the Outer Vessel (Cat. 4)

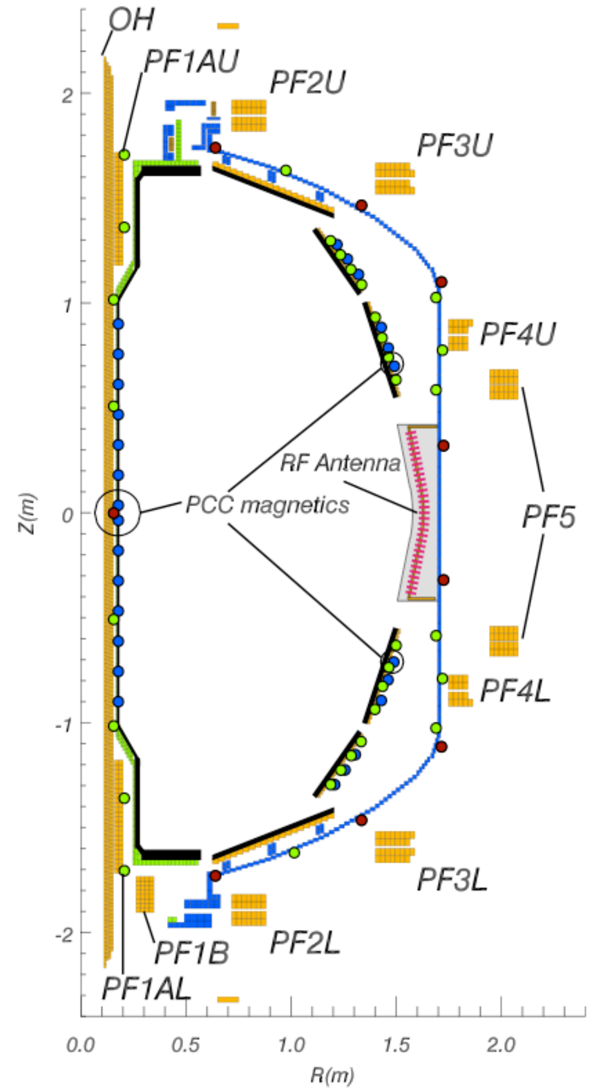
Flux Loops on the Inner Vessel (Cat. 4)



D. Gates et al., Rev. Sci. Instrum

Magnetics For Early Position Control

- Typical NSTX shape control sequence
  - 0-20 msec.: pre-programmed currents
  - 20-90 msec: gap-control
  - 90 msec-rampdown: Isoflux
- Gap-control phase ("pcc") relies on a limited number of magnetic sensors.
  - Flux and field at the midplane CSC.
  - Flux and field on the primary passive plates.
  - If these sensors fail, it is unlikely that the plasma will survive to the Isoflux phase.



See D. Gates et al, Nuclear Fusion 46, 17 (2006)

Fast Vertical Position Feedback

- Isoflux shape control is not fast enough to stabilize plasma against vertical instability.
- Extra feedback term in acqcategory_master.h.
  - Flux difference:

$$\partial\psi = \psi_{PPPU2} - \psi_{PPPL2}$$

  - Voltage difference:

$$\frac{d(\partial\psi)}{dt} = \frac{d\psi_{PPPU2}}{dt} - \frac{d\psi_{PPPL2}}{dt} = V_{PPPU2} - V_{PPPL2}$$

  - Extra term in control:

$$V_{PF-3U} = V_{PF-3U,Isoflux} + \boxed{D\frac{d(\partial\psi)}{dt} + P\partial\psi}$$

$$V_{PF-3L} = V_{PF-3L,Isoflux} - \boxed{D\frac{d(\partial\psi)}{dt} - P\partial\psi}$$

- The filtered voltage difference is calculated in analog in the test cell and digitized.
  - If that box doesn't work (unplugged, turned off,…), there is no fast vertical position control.