Challenges for a Diamagnetic Measurement in NSTX

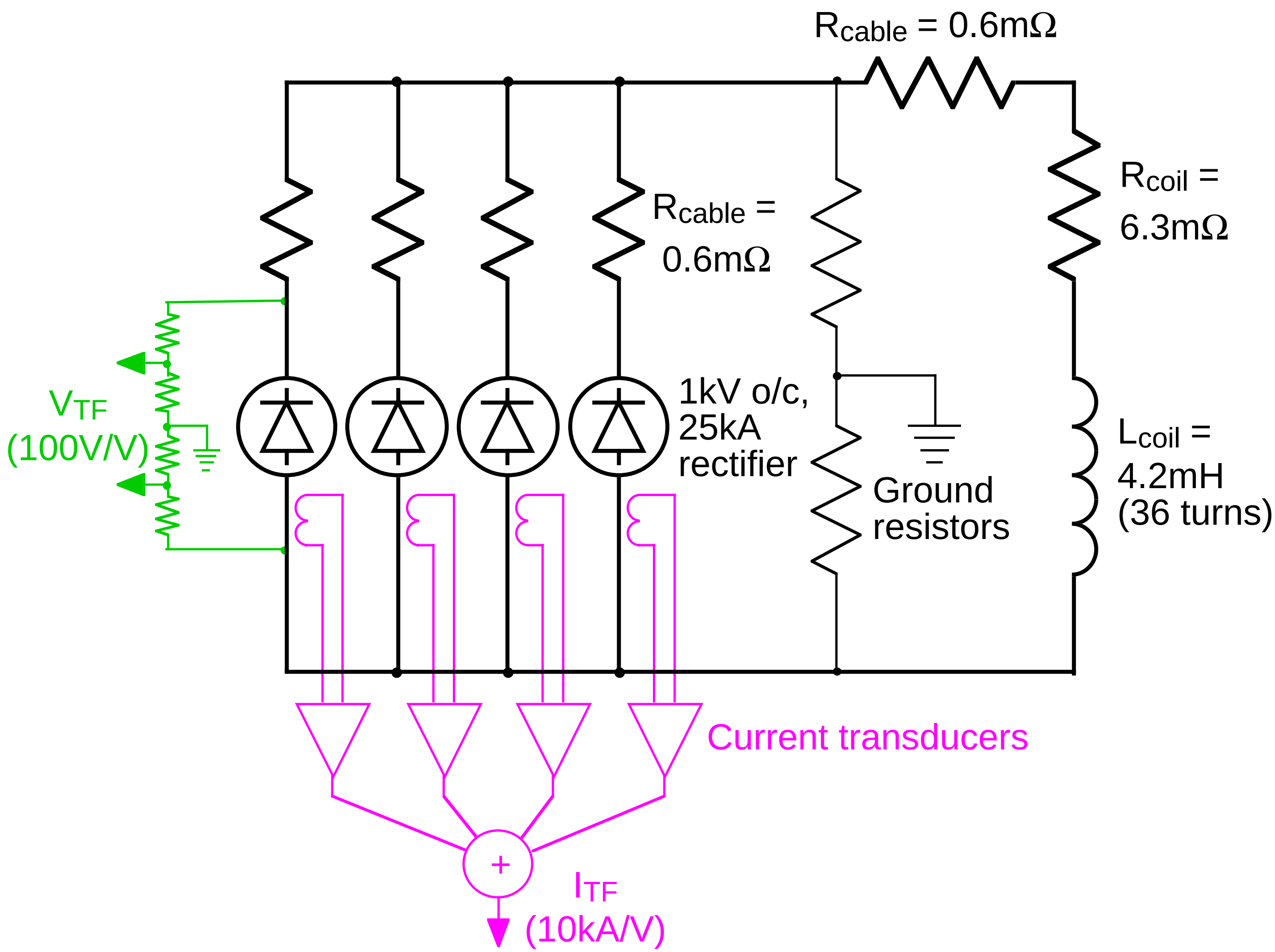
- Poloidal breaks for CHI prevent using internal loop for toroidal flux
  - Breaks allow rapid penetration of toroidal flux for external loop, *but*
- No room in center stack for loop with adequate isolation and stability
- Try using the TF coil itself to measure flux displaced by plasma
  - Method used on PDX [P. Thomas, report PPPL-1979 (1983)]

$$N_{TF}\phi_d = -\int_0^t V_{TF}\,dt' + L_{TF}I_{TF} + \int_0^t R_{TF}I_{TF}\,dt' + \sum_j M_{TF:j}I_j + \sum_{PF} M_{TF:PF}I_{PF}$$

N_{TF}:	number of turns in TF coil (36)
V_{TF}, I_{TF}:	coil terminal voltage and current
L_{TF}, R_{TF}:	coil inductance and resistance (as functions of time)
$I_{PF}, M_{TF:PF}$:	PF coil currents and their mutual inductances to the TF
$I_j, M_{TF:j}$:	Currents in structure driven by dI_{TF}/dt and mutual inductances

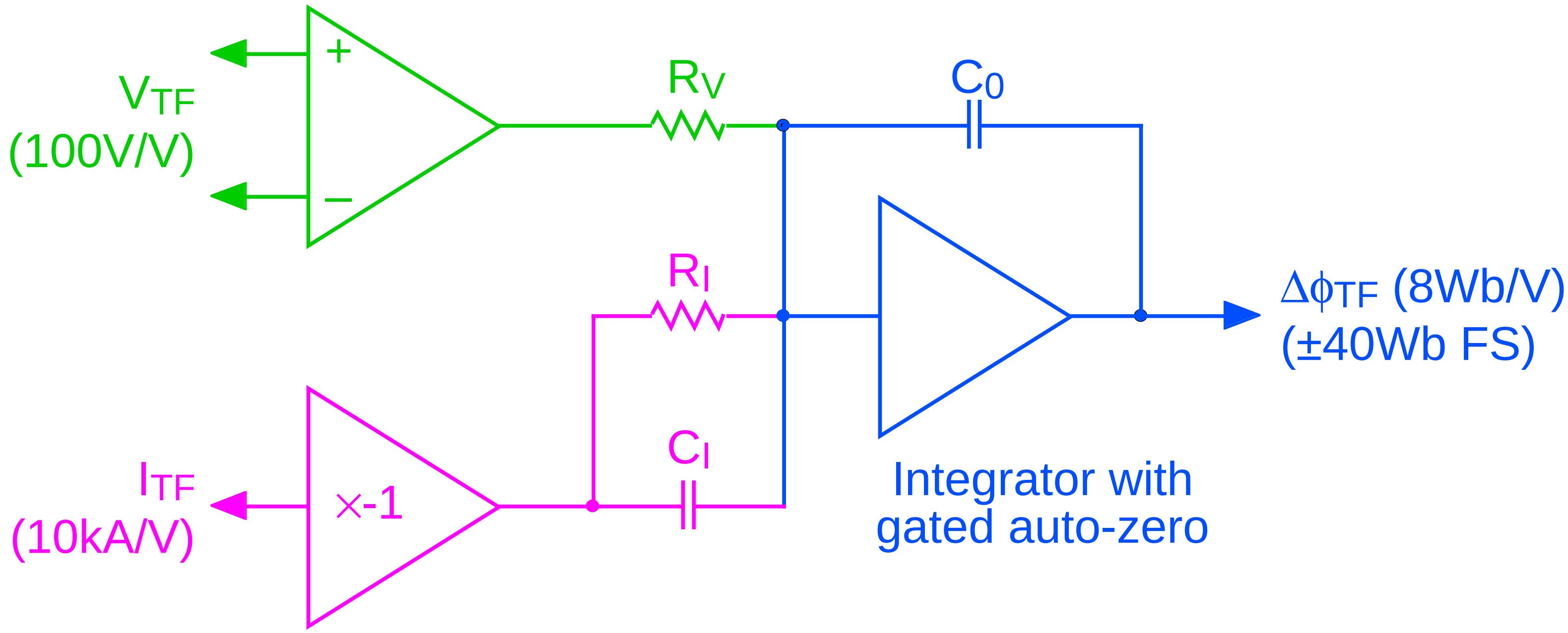
- ϕ_d ~ 0.1Wb while $L_{TF}I_{TF}$ ~ 200Wb and $\int R_{TF}I_{TF}dt'$ ~ 150Wb in a 0.4s pulse
  - Very accurate compensation and modelling of the TF is needed

NSTX Toroidal Field Coil Circuit and Diagnostics



- Precision DC current transducers make measurement possible

Analog Circuit Integrates Coil Voltage and Removes First-Order Self-Inductive and Resistive Flux Terms



1) $100[V/V]R_V C_0 = 8[s]$
2) $100[V/V]R_V C_I / 10^4[A/V] = L_{TF0}$
3) $R_I C_I = L_{TF0}/R_{TF0}$

- All input signals received differentially
- High stability components used throughout

Thermal Resistance Change of TF

- Adiabatic resistive heating of conductor carrying current $I(t)$ (A)

$$R(t) = R(0)\exp\left[\frac{\alpha}{SA^2}\int_0^t I^2(t')dt'\right]$$

$R(t)$: resistance; α (ΩmC^{-1}): temperature coefficient of resistivity;
S (Jm^{-3}C^{-1}): volume specific heat; A (m^2): cross-section area.

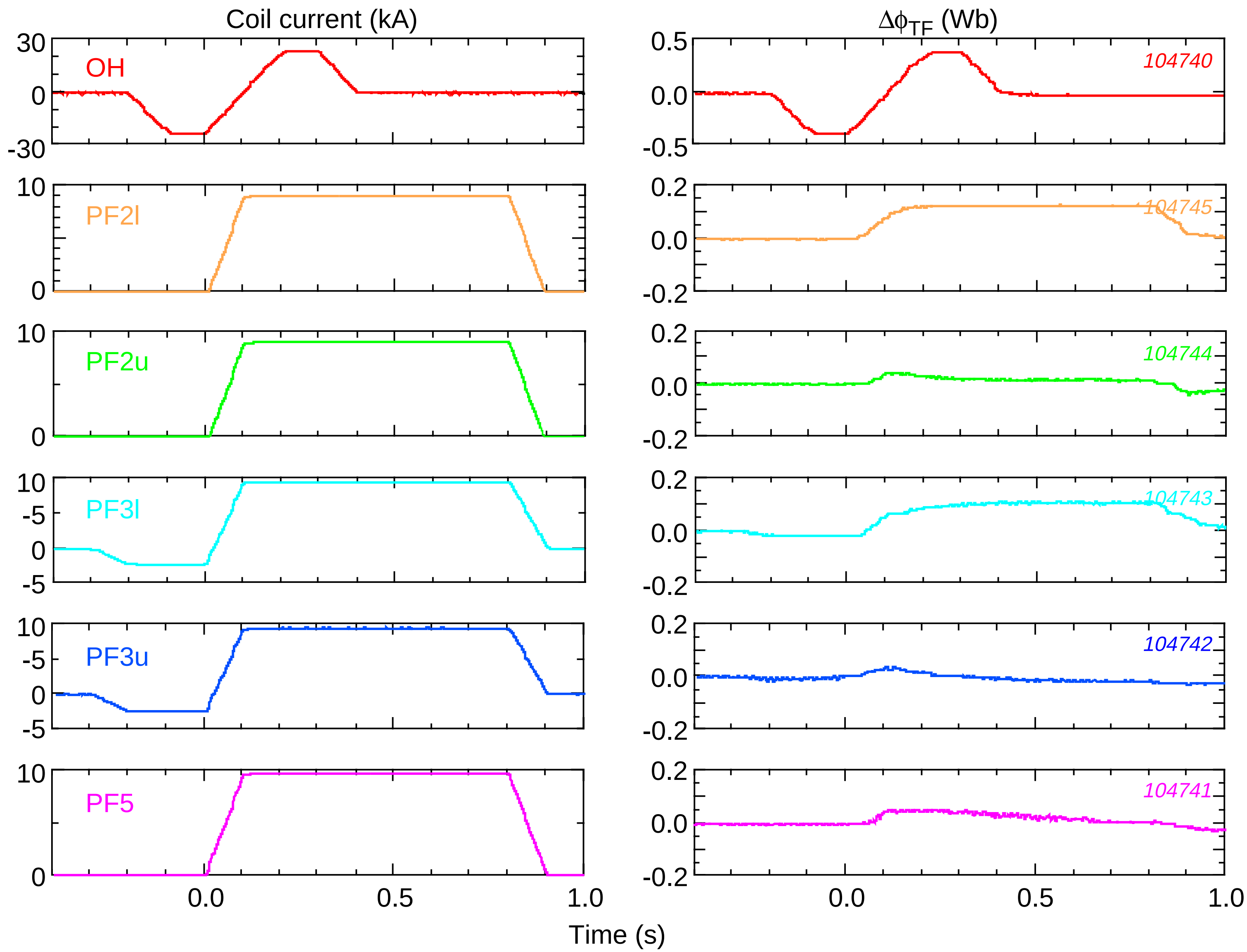
  - Inner legs of TF coil can rise from 10°C to 90°C during a TF pulse
  - Causes non-linear increase in resistive flux during TF flattop

$$\phi_{res}(t) = \int_0^t I_{TF}(t')\left\{R_{TF0} + R_{IL0}\left[\exp\left(4.5\times10^{-11}\int_0^{t'} I_{TF}^2(t'')\,dt''\right) - 1\right]\right\}dt'$$

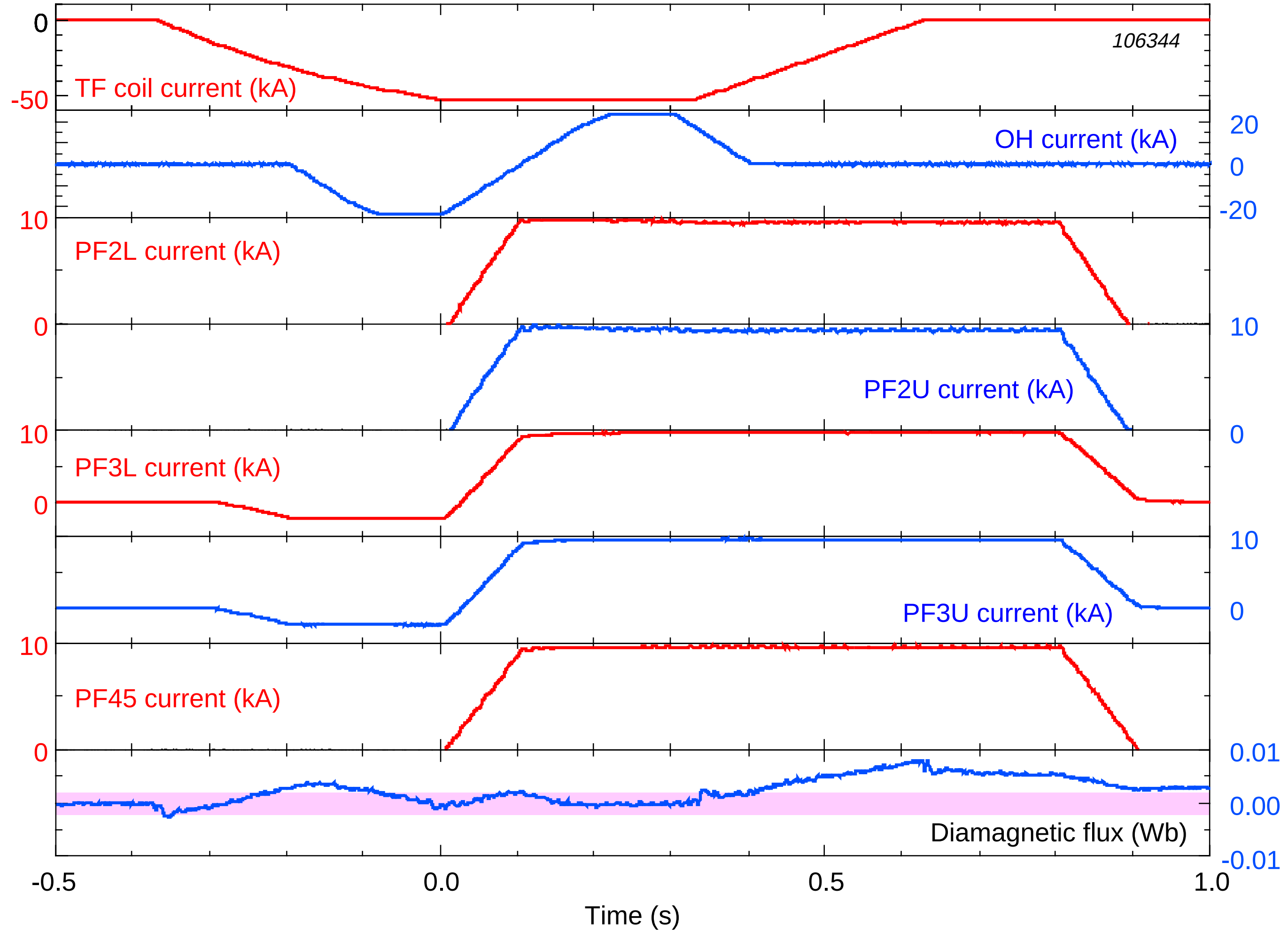
- Must also account for effects of:
  - Water already in the cooling channels (~6% decrease in ΔR_{TF})
  - Inflowing cooling water (~4% $\times$ t_{pulse}[s] decrease)
  - Diffusion of heat into insulation (~4% $\times$ $\sqrt{t_{pulse}}$[s] decrease)
- Fit to data implies ΔR is about 90% of adiabatic expectation

NSTX

PF Couplings Measured in Single-Field Test Shots

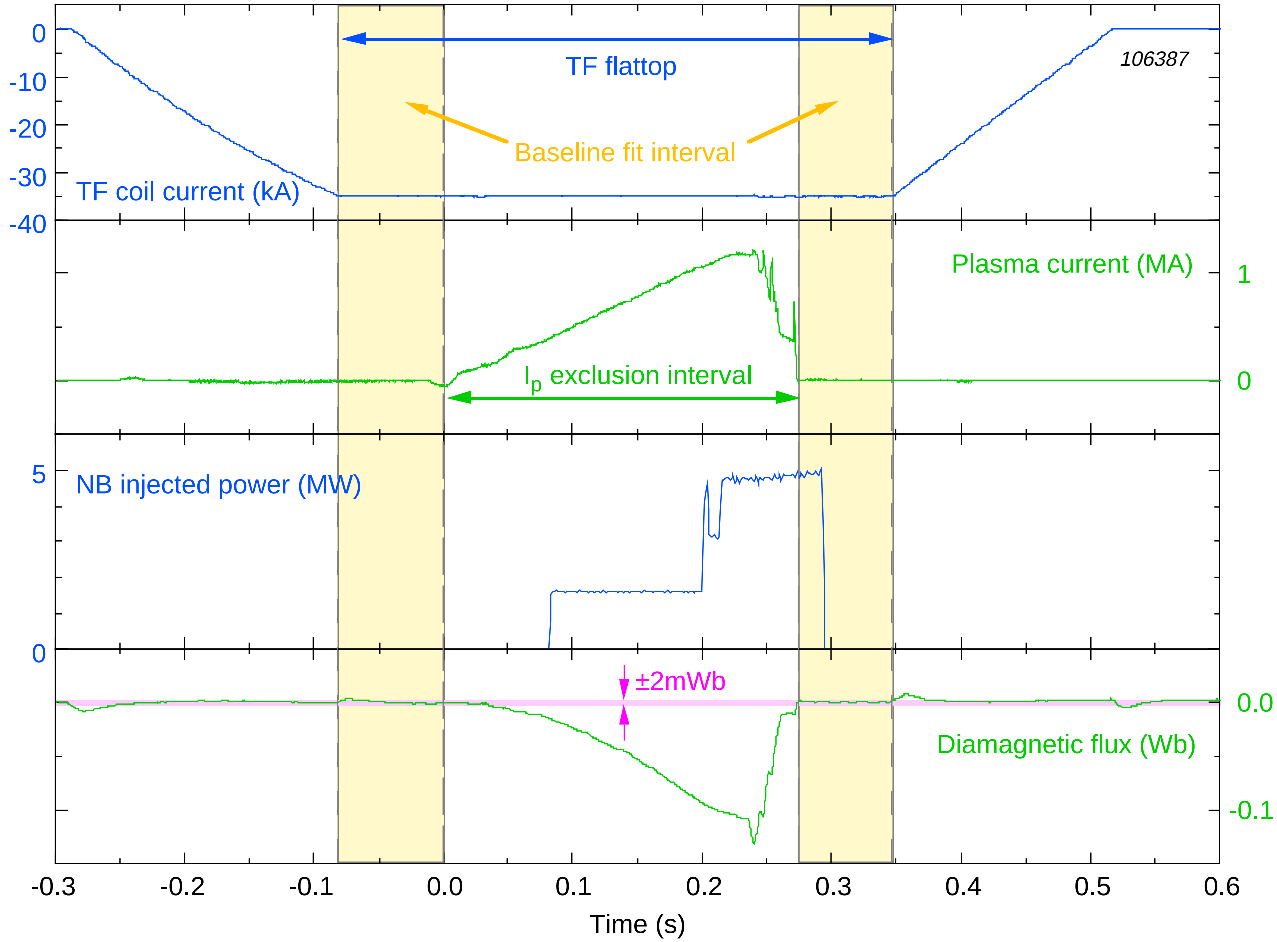


Uncertainty of 2mWb Achieved for Diamagnetic Flux in Combined TF/PF Shots During TF Flattop



- Drift during TF rampdown caused mainly by power supply imbalance

In Plasma Shots, Fit Residual Resistive TF Flux During TF Flattop When Plasma Current Absent



- Fit coefficient of resistive flux varies by about 1% with temperature of air-cooled buswork; coefficient of inductive flux varies by <0.1%