NSTX

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RFA Suppression With Different Sensors and Time Scales in NSTX

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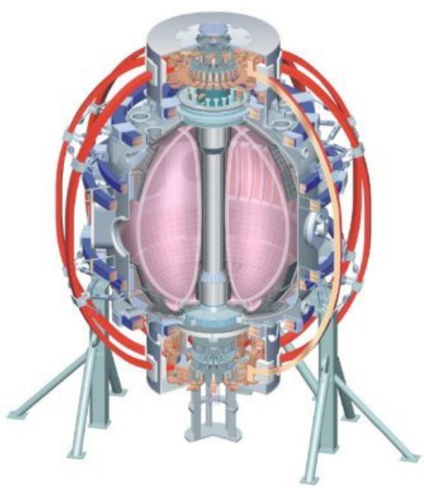
S. P. Gerhardt, J. E. Menard, S. A. Sabbagh

MHD TSG Group Review
Feb. 12th, 2010



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Overview

- Background:
  - RFA is the amplification of “error fields” by a stable RWM
  - The resulting rotation damping can destabilize the RWM.
  - In 2007, JEM utilized RFA to develop a DEFC scheme.
    - XP-701 used B_P sensors only.
  - New compensations have been implemented in real-time, allowing better mode identification using B_R sensors.
- Goals of proposed XP:
  - Determine B_R sensor compensations and FB parameters which are optimal for error field correction.
    - Examine system response to applied n=1 fields.
    - Examine system response to the intrinsic time-varying error field.
    - Attempt to minimize rotation damping and pulse length using B_R feedback.
  - Compare results to DEFC with B_P sensors.
    - Filtering from the PPPs slows the B_R response (filters noise), which can be beneficial for DEFC.
  - Note: Fast feedback is out of scope.
- Contributes to:
  - MDC-2: Joint experiments on resistive wall mode physics
  - MS Milestone R(10-1): Assess sustainable beta and disruptivity near and above the ideal no-wall limit.

Outline

- New sensor compensations
- Results from previous XPs
- Considerations and shot list for this XP

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New Realtime Sensor Compensations For Improved Mode Identification

- Sensors should measure the n=1 field from the plasma only.
  - Need to "compensate" the i^th sensor B_i for other sources of field
  - With proper compensations, vacuum shots produce no signal
- Three compensations now in realtime system

Static
Present From Beginning

$$C_{i,static} = \sum_{j=0}^{NumCoils-1} p_j I_j$$

816 Coefficients

OHxTF
New For 2010

$$f_i = LPF\left(I_{OH} \times I_{TF};\tau_{OHxTF,i}\right)$$

$$f_i = \frac{f_i}{1+\beta_i f_i}$$

$$\textbf{if } f_i > 0 \textbf{ then } C_{OH\times TF,i} = r_{p,i} f_i$$

$$\textbf{if } f_i < 0 \textbf{ then } C_{OH\times TF,i_i} = r_{n,i} f_i$$

96 Coefficients

AC Compensation For Fluctuating RWM Coil Currents
New For 2010

$$C_{AC,i}(t) = \sum_{j=0}^{5} \sum_{k=0}^{k_{max}} p_{i,j,k} LPF\left(\frac{dI_{RWM,j}(t)}{dt};\tau_{AC,i,k}\right)$$

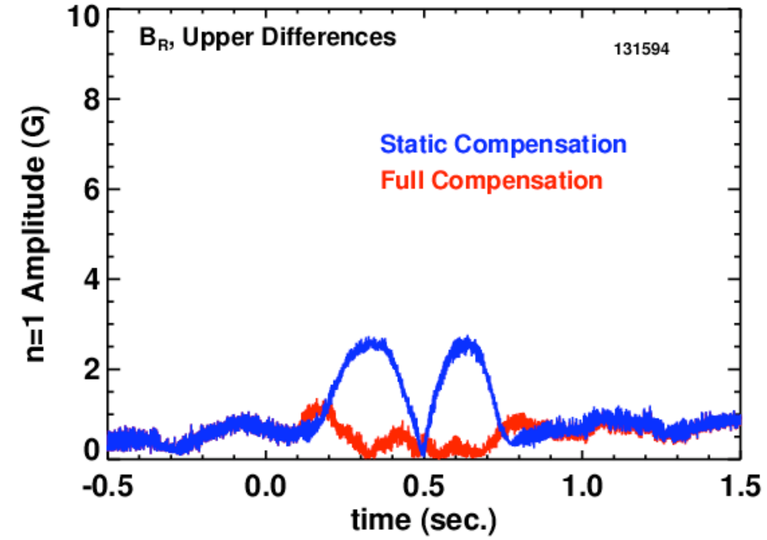
504 Coefficients

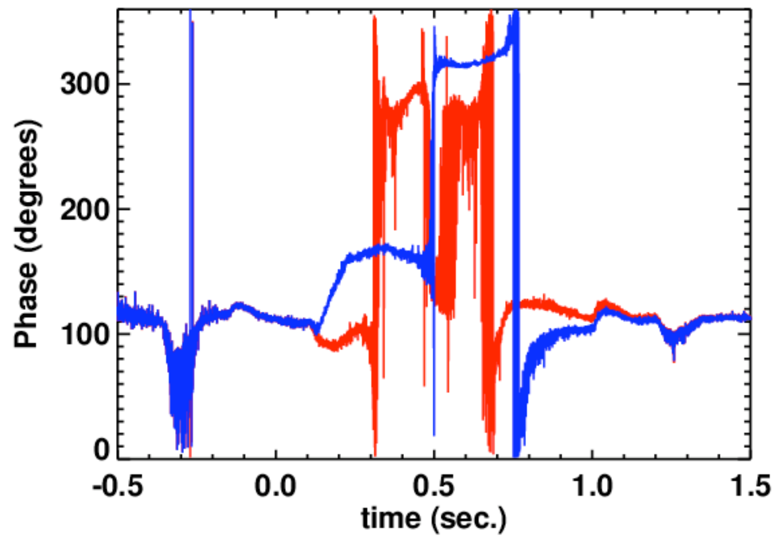
Final Field For Plasma Mode Identification

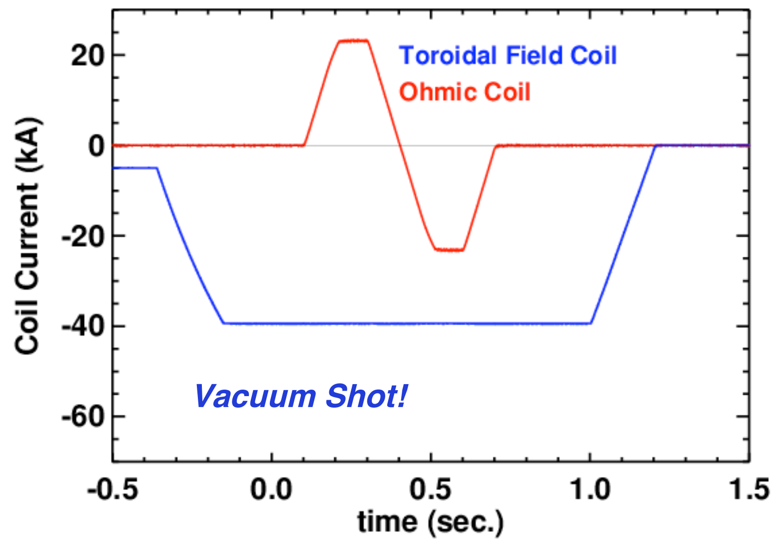
$$B_{i,plasma} = B_i - C_{i,static} - C_{i,OH\times TF} - C_{i,AC}$$

remaining compensation: vessel eddy currents via loop voltages

OH x TF Compensations Important For The B_R Sensors (I)







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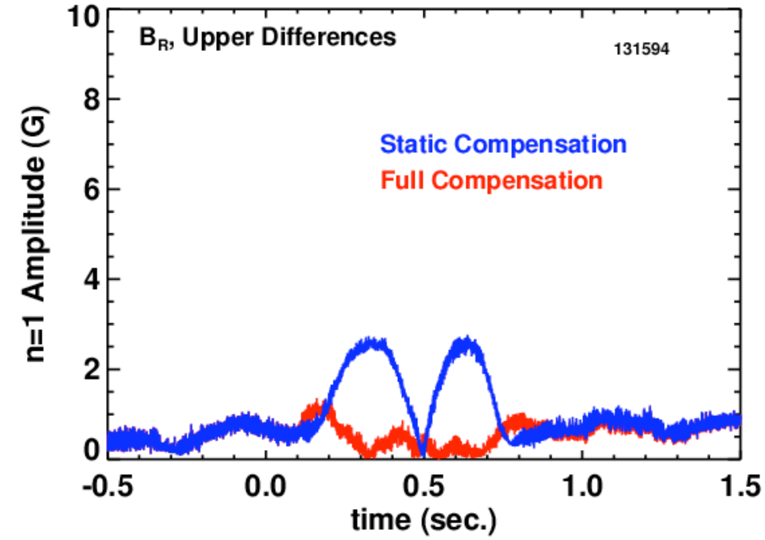
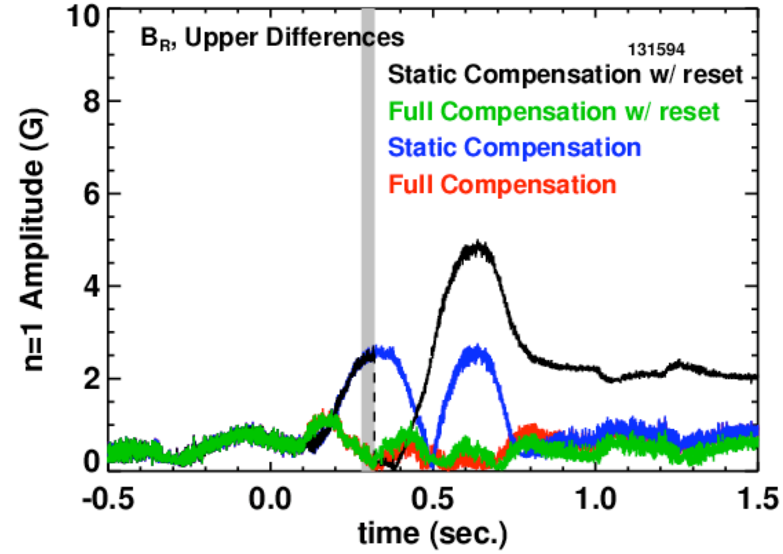
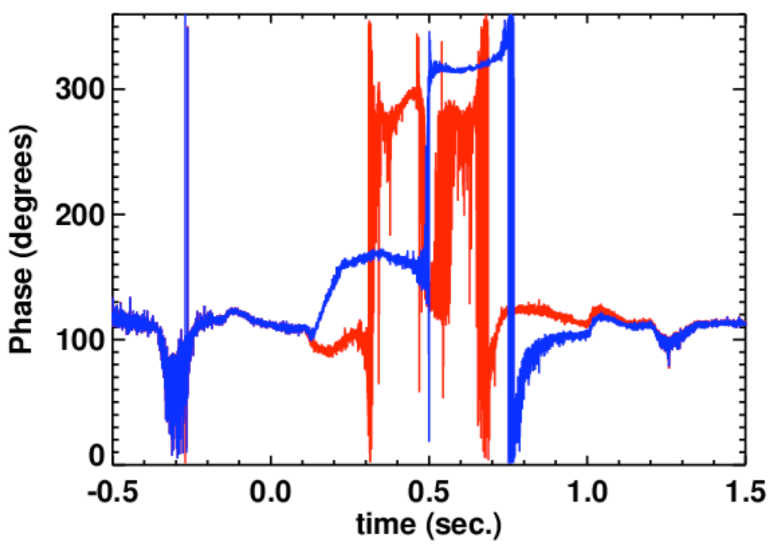
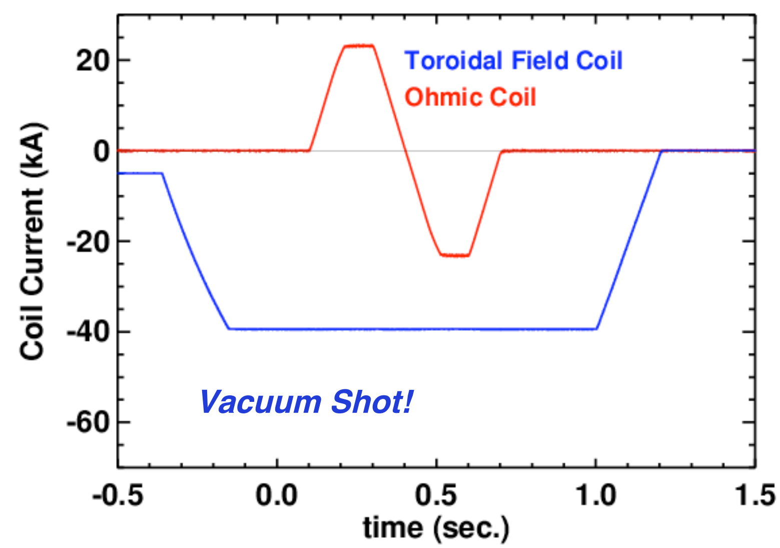
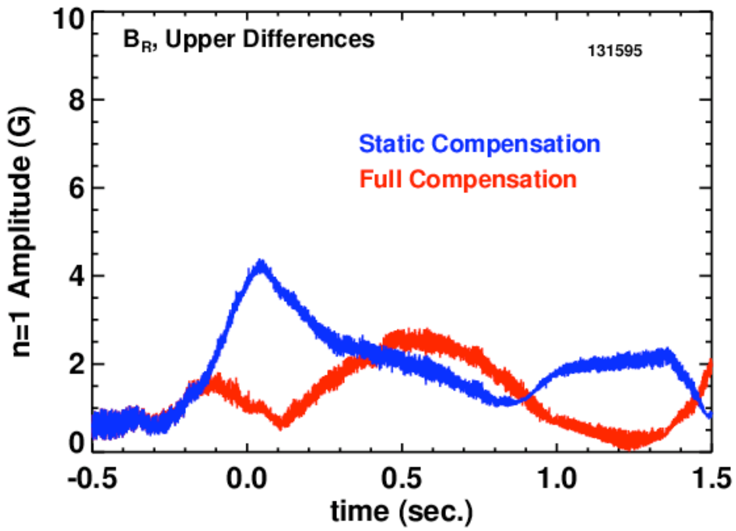


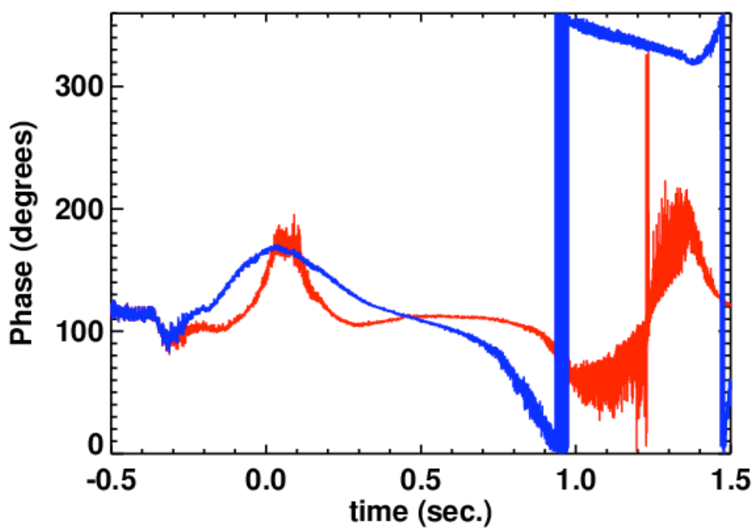


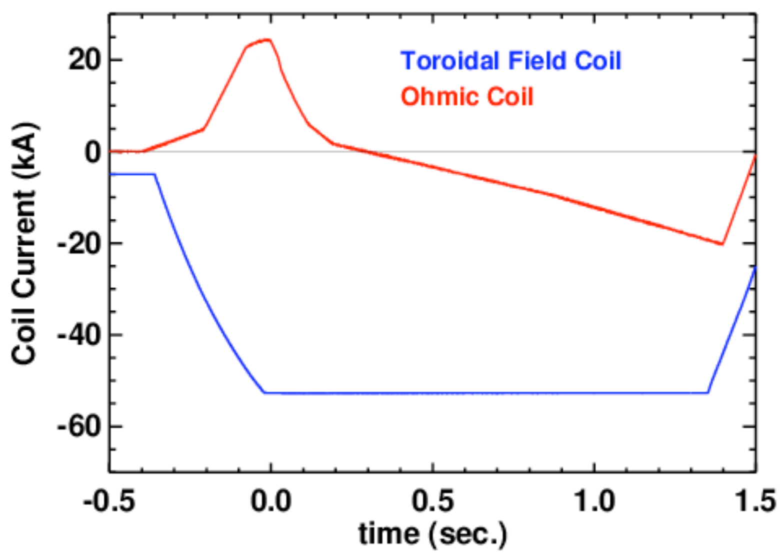




OH x TF Compensations Important For The B_R Sensors (II)







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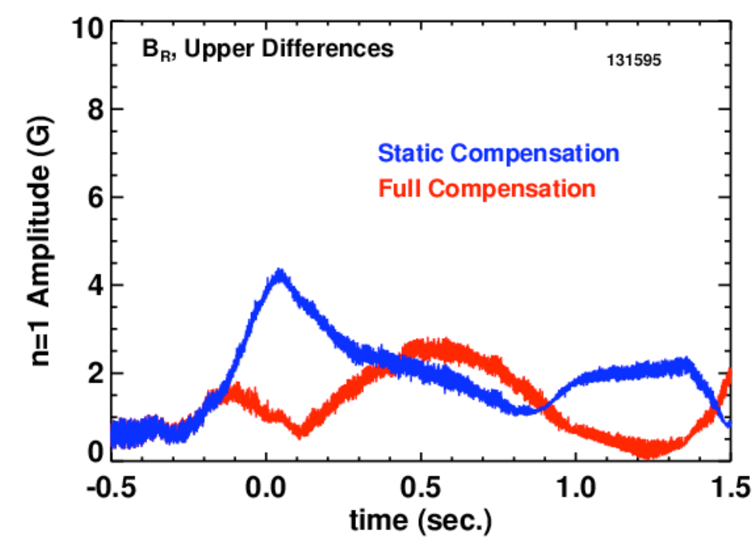
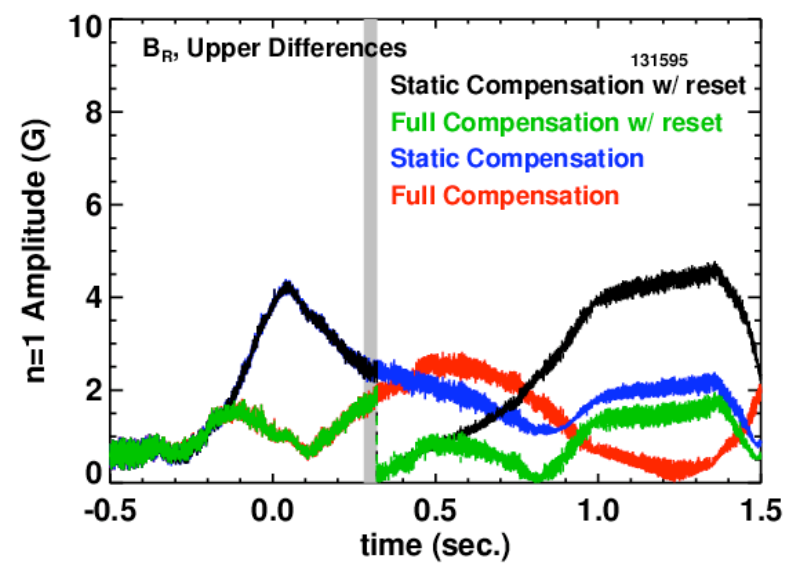
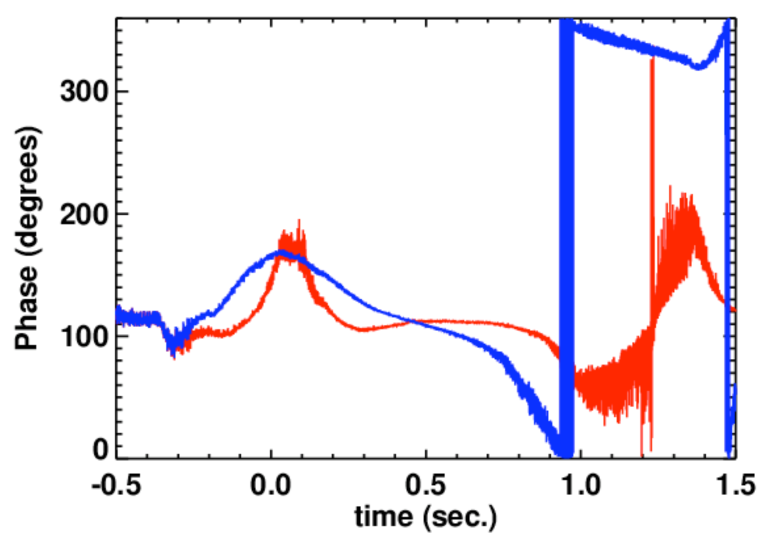
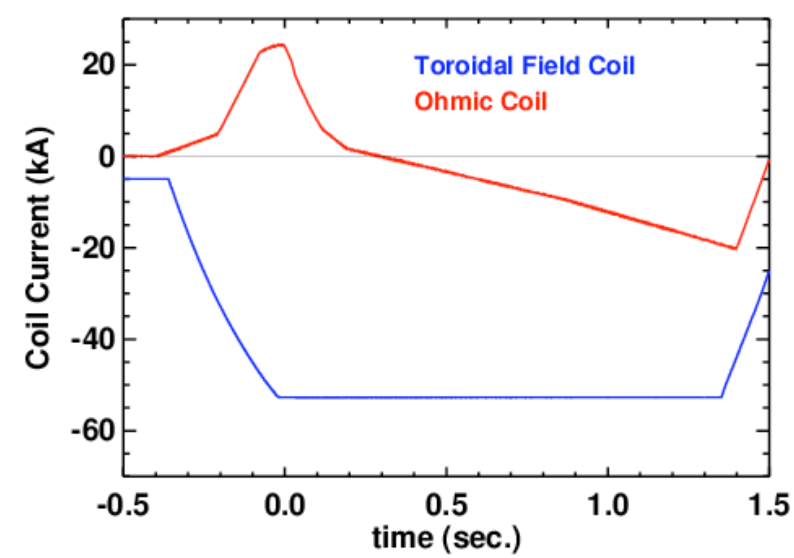


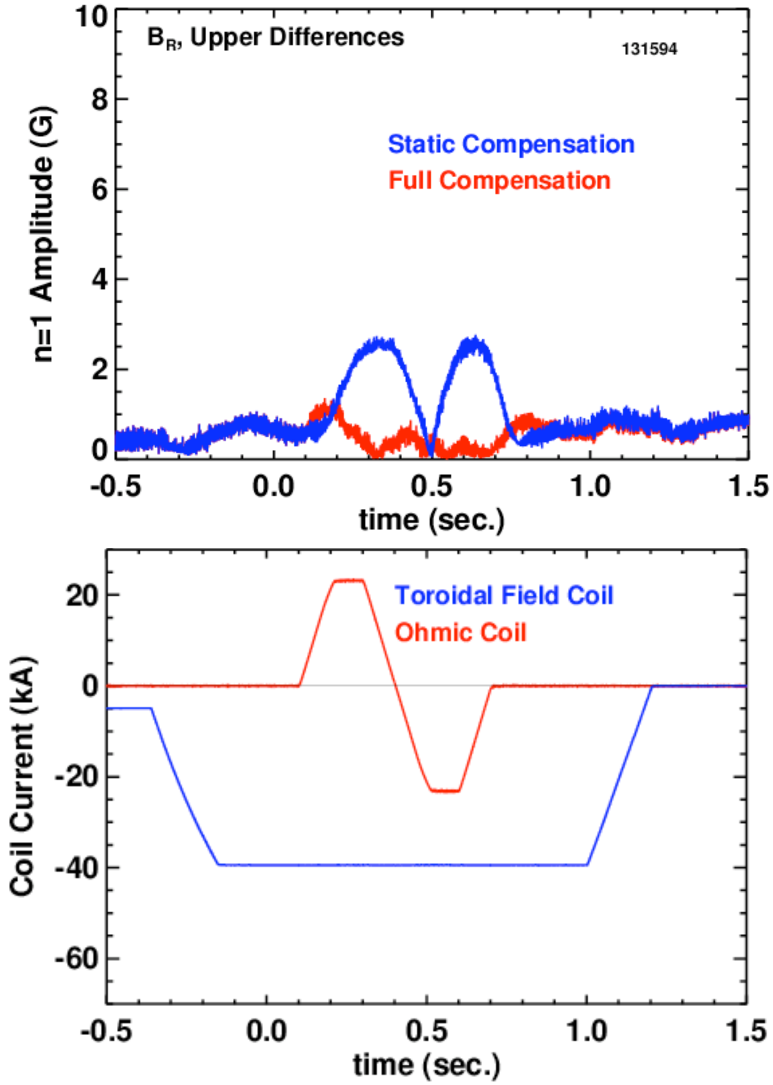




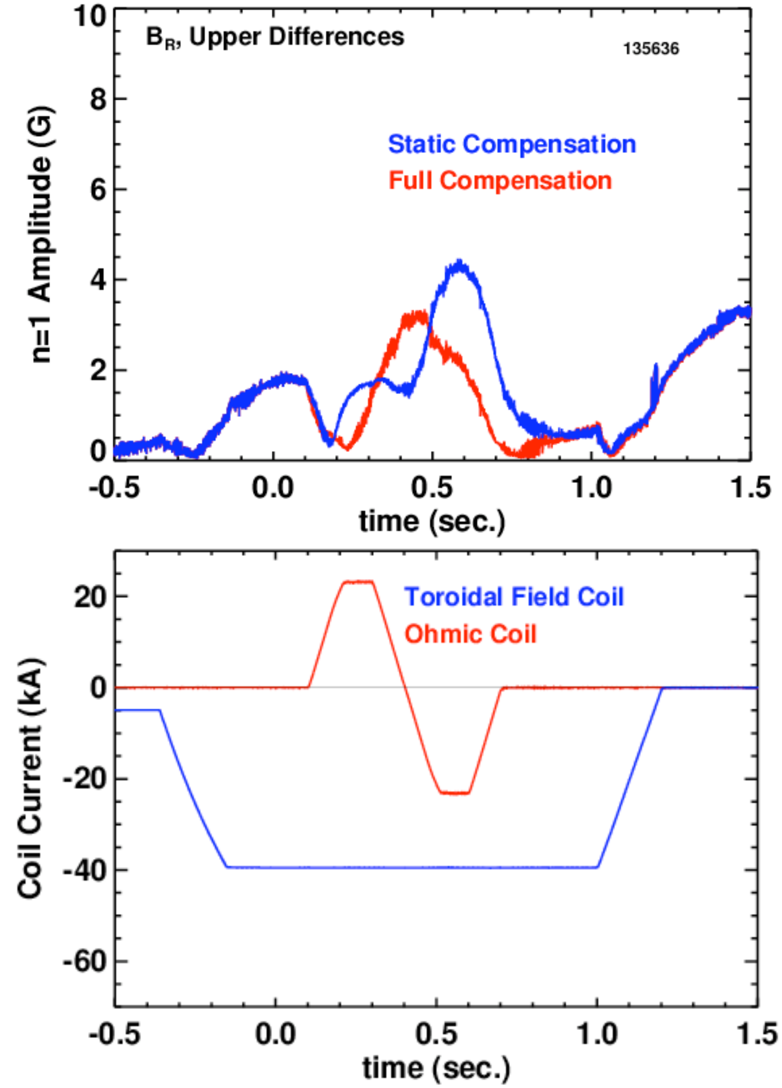


Need to Keep a Careful Eye on Compensations Through the Run

Beginning of Run



End of Run



AC Compensations Remove dI_{RWM}/dt Driven Eddy-Current Pickup

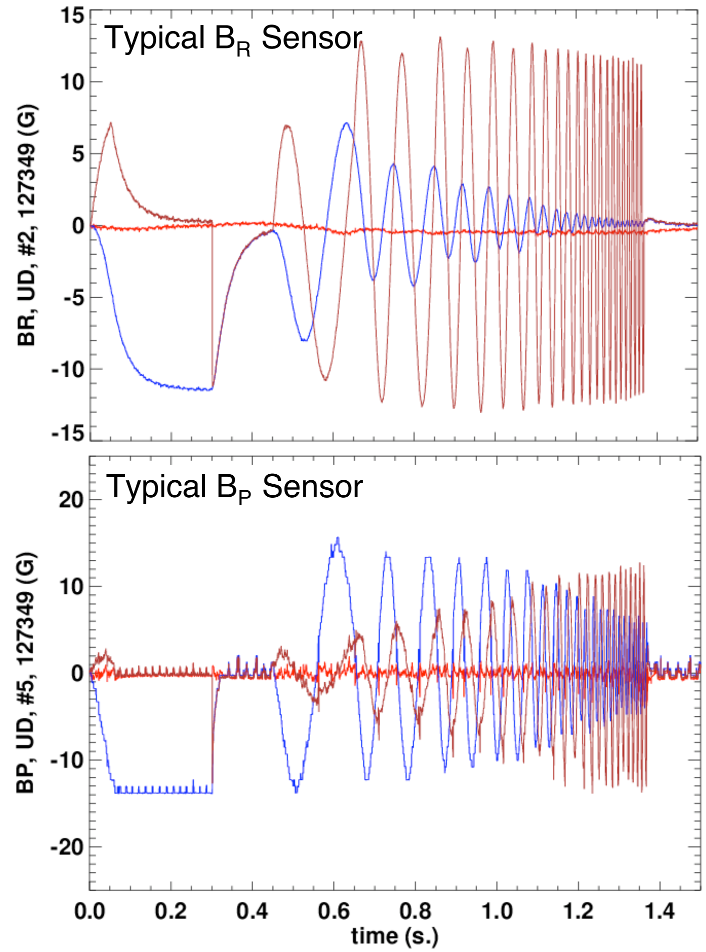
$$C_{AC,i}(t) = \sum_{j}^{NumRWMCoils} \sum_{k=0}^{k_{max}} p_{i,j,k} LPF\left(\frac{dI_{RWM,j}(t)}{dt};\tau_k\right)$$

- Sensors should measure the n=1 field from the plasma only.
  - Direct mutual coupling of RWM coil to sensors has always been subtracted off in PCS.
  - Eddy currents due to dI_{RWM}/dt leads to pickup without plasma.
    - *Eddy currents are out of phase with the coil currents.*
- Realtime AC compensations may be useful for:
  - Mode identification during fast feedback.
    - SAS proposal on fast feedback.
  - Mode identification with rapidly changing preprogrammed currents.
    - ELM triggering experiments.
  - Future realtime RFA measurements.

Blue: Full Pickup

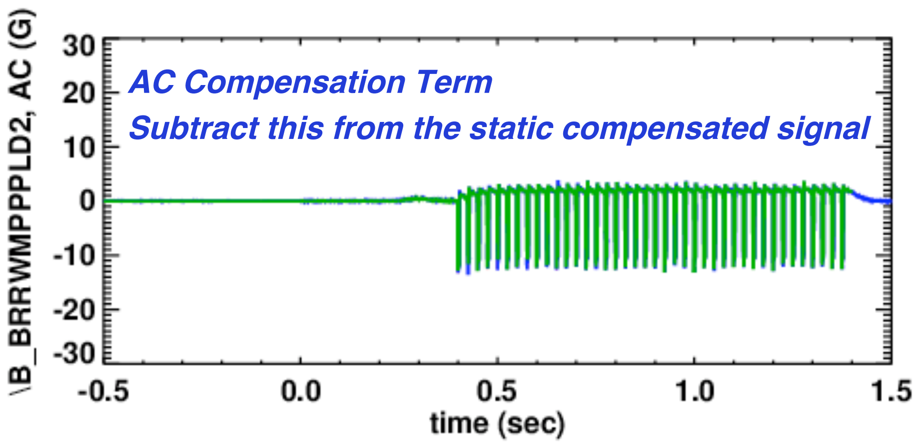
Brown: Direct Pickup Only Subtracted (Previously in PCS)

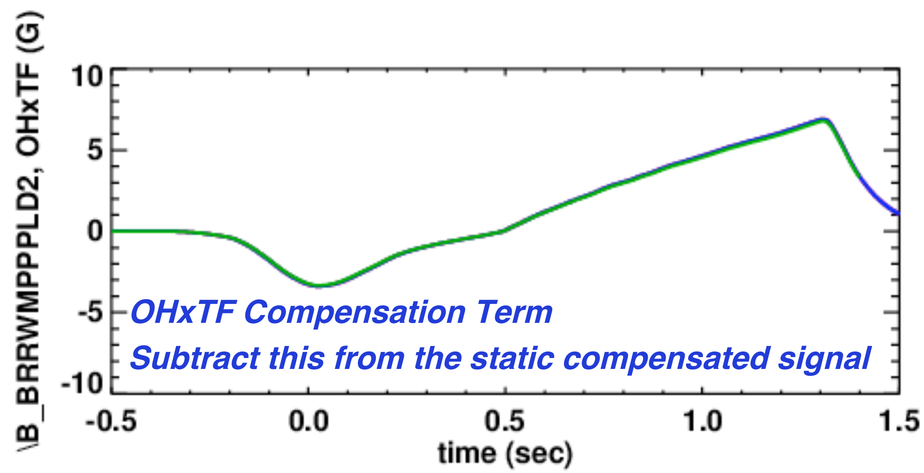
Red: Fully Compensated (Now in PCS)

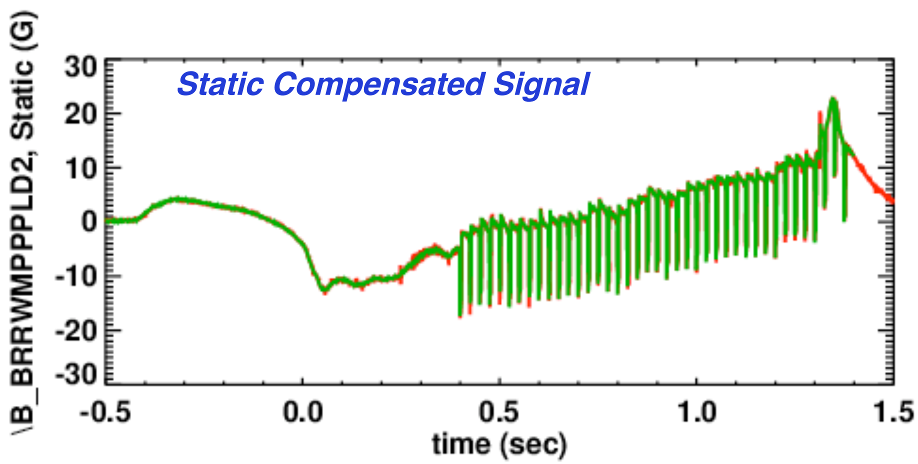


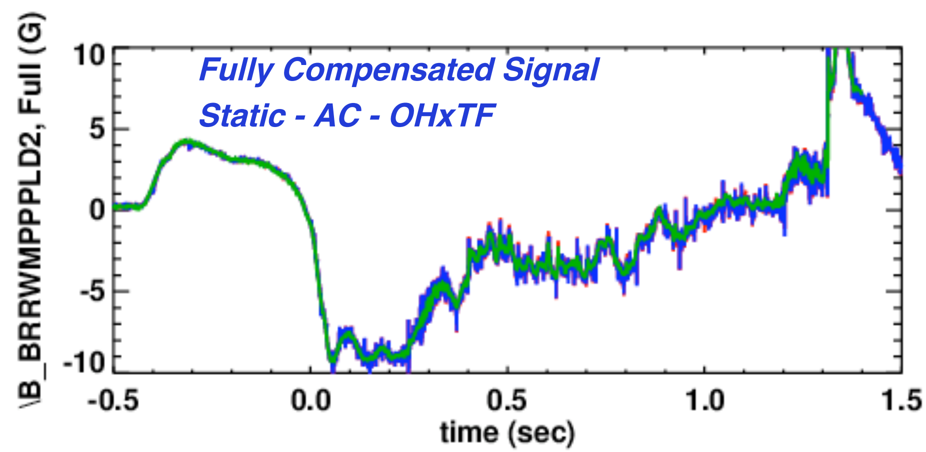
New Sensor Compensation Fully Implemented in PCS "miu" Algorithm (I)

Red: Calculations in idl, from Jon's routines
Blue: Calculations in idl, in a form appropriate for PCS (streamlining a bunch of loops)
Green: Archived PCS Calculations







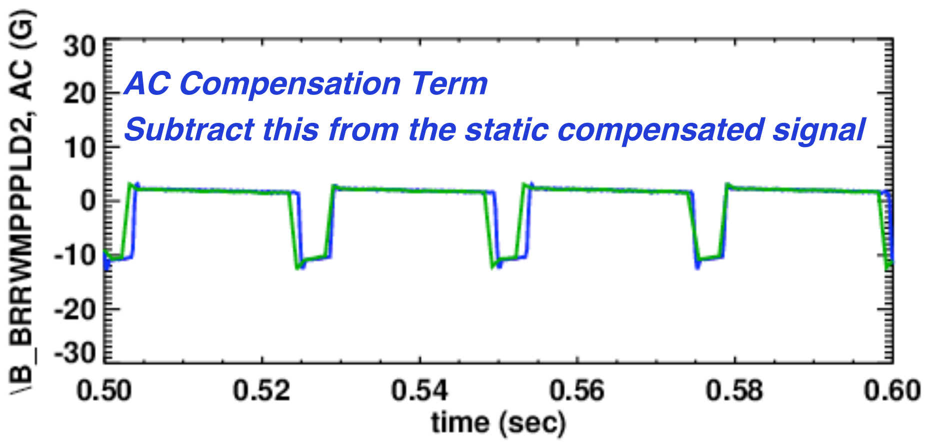


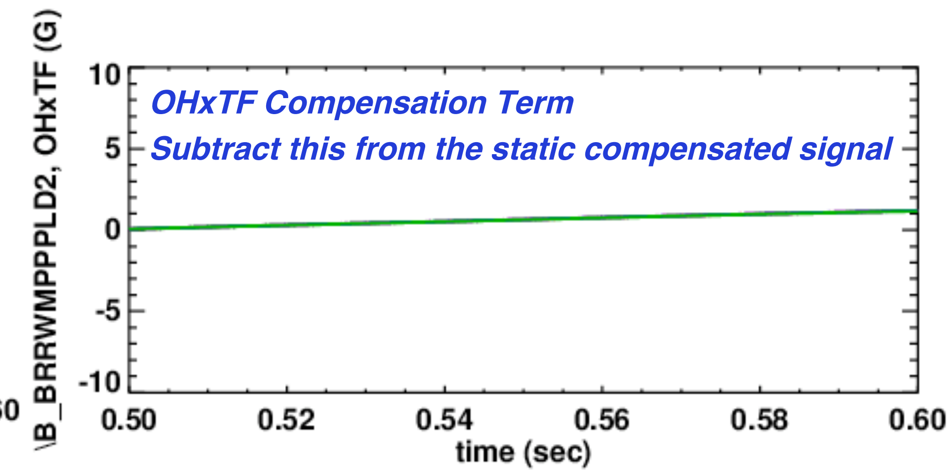
New Sensor Compensation Fully Implemented in PCS "miu" Algorithm (II)

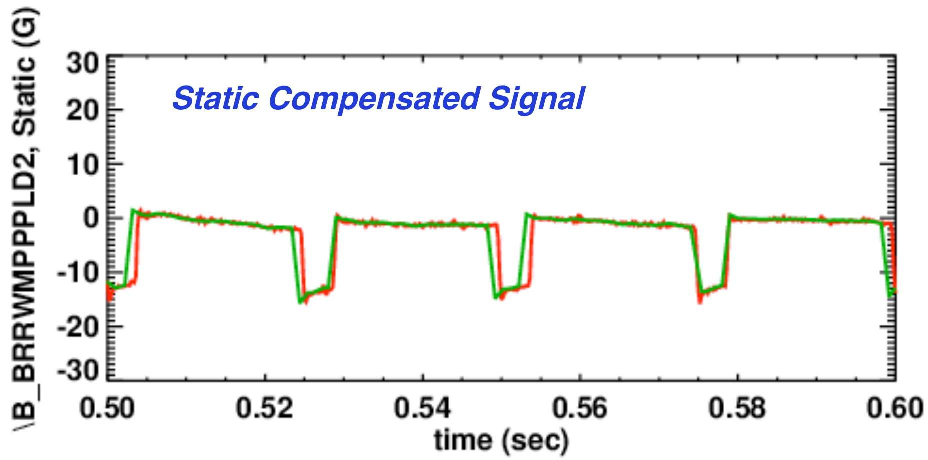
Red: Calculations in idl from Jon's routines

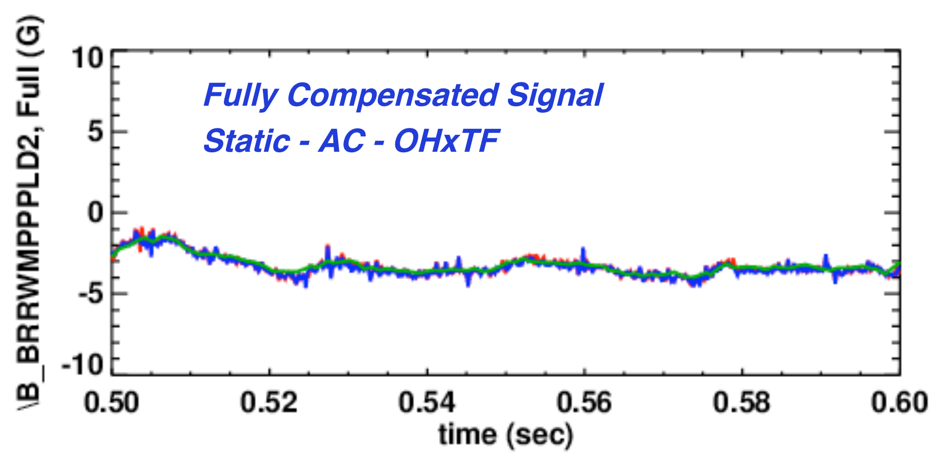
Blue: Calculations in idl in a form appropriate for PCS (streamlining a bunch of loops)

Green: Archived PCS Calculations









More About the New “miu” Algorithm

- Provides identical “outputs” as the present mid algorithm
  - Mode amplitude and phase from B_P, B_R, & B_P+B_R sensors.
  - Fully interchangeable with the mid algorithm for RWM control.
- Allows separate re-zeroing times for B_R and B_P sensors.
  - Old mid algorithm had a single common re-zeroing time.
- Has switches to turn off the new compensations.
  - “static only”
  - “static +AC”
  - “static+OH×TF”
  - “static+AC+OH×TF
- All compensation coefficients are read from the model tree.
  - Many new nodes open in the model tree in September.
- Archives many many internal calculations for comparison to off-line.
- Prepares sensor data for the state-space controller.

Outline

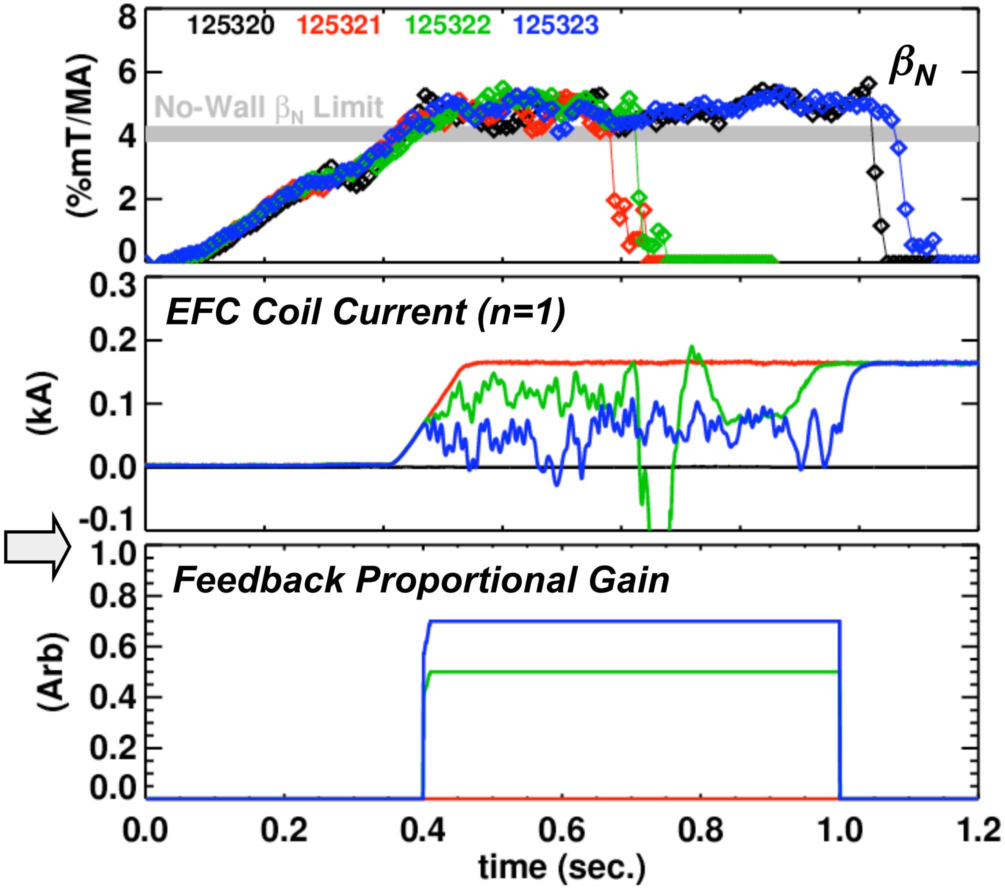
- New sensor compensations
- Results from previous XPs
- Considerations and shot list for this XP

2007 Experiment Had a Phase Scan…
…and a Gain Scan

- **Pre-programmed n=1 EF correction requires a priori estimate of intrinsic EF**
- Detect plasma response → **EF correction using *only feedback on RFA***

RFA Suppression Algorithm

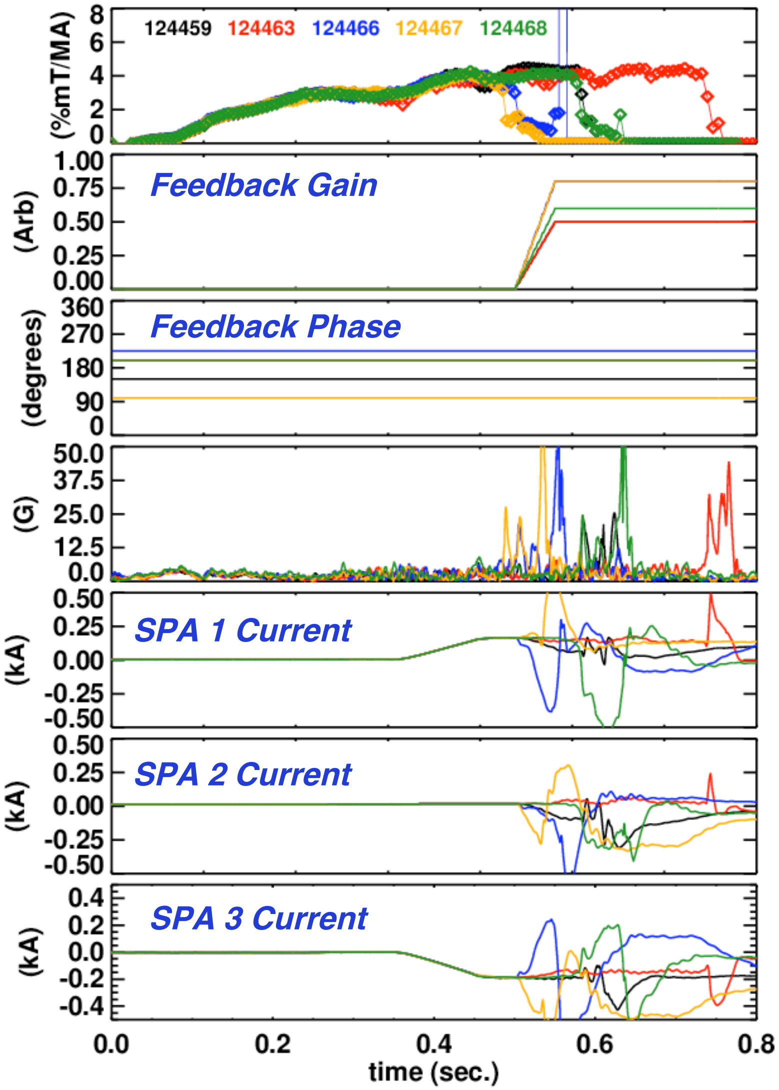
- **Use discharge with rotationally stabilized RWM.**
- **Deliberately apply n=1 EF in order to reduce rotation, destabilize an RWM.**
- **Find feedback phase that reduces the applied n=1 currents (B_P sensors).**
  - **Direct coil-sensor pickup is removed.**
- **Increase the gain until currents are nearly nulled and plasma stability is restored.**



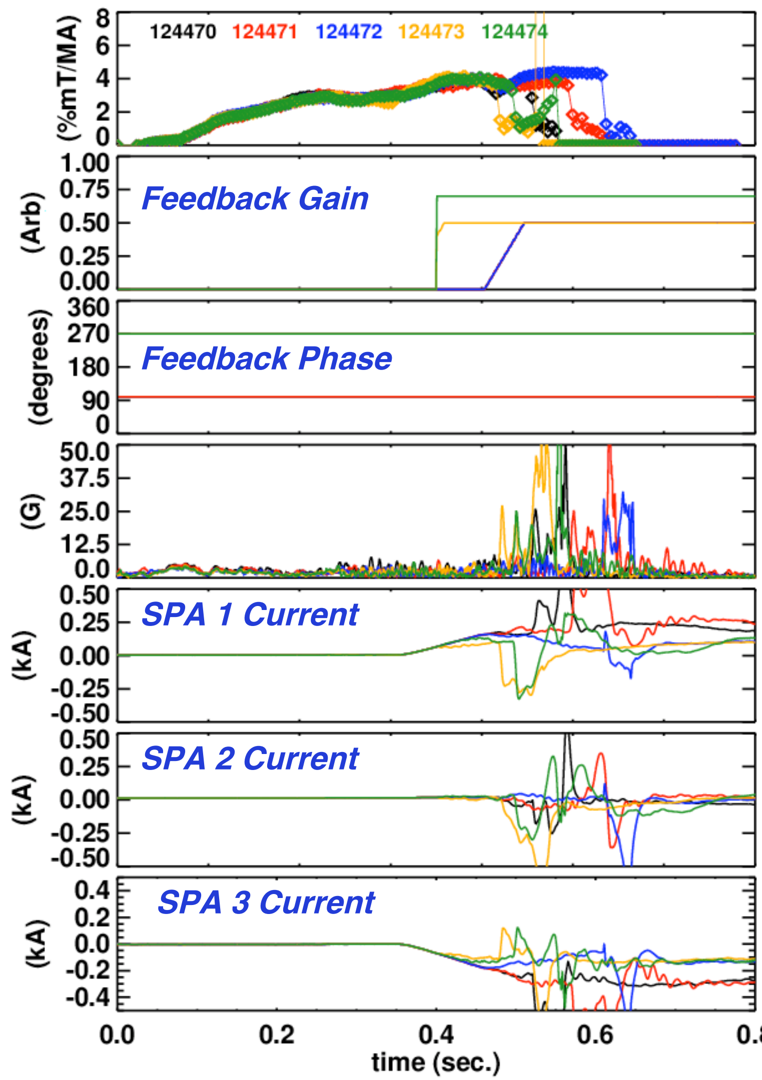
→ *Use same gain/phase settings to suppress RFA from intrinsic EF **and** any unstable RWMs*

2007 Experiment Had a Phase Scan…
…and a Gain Scan

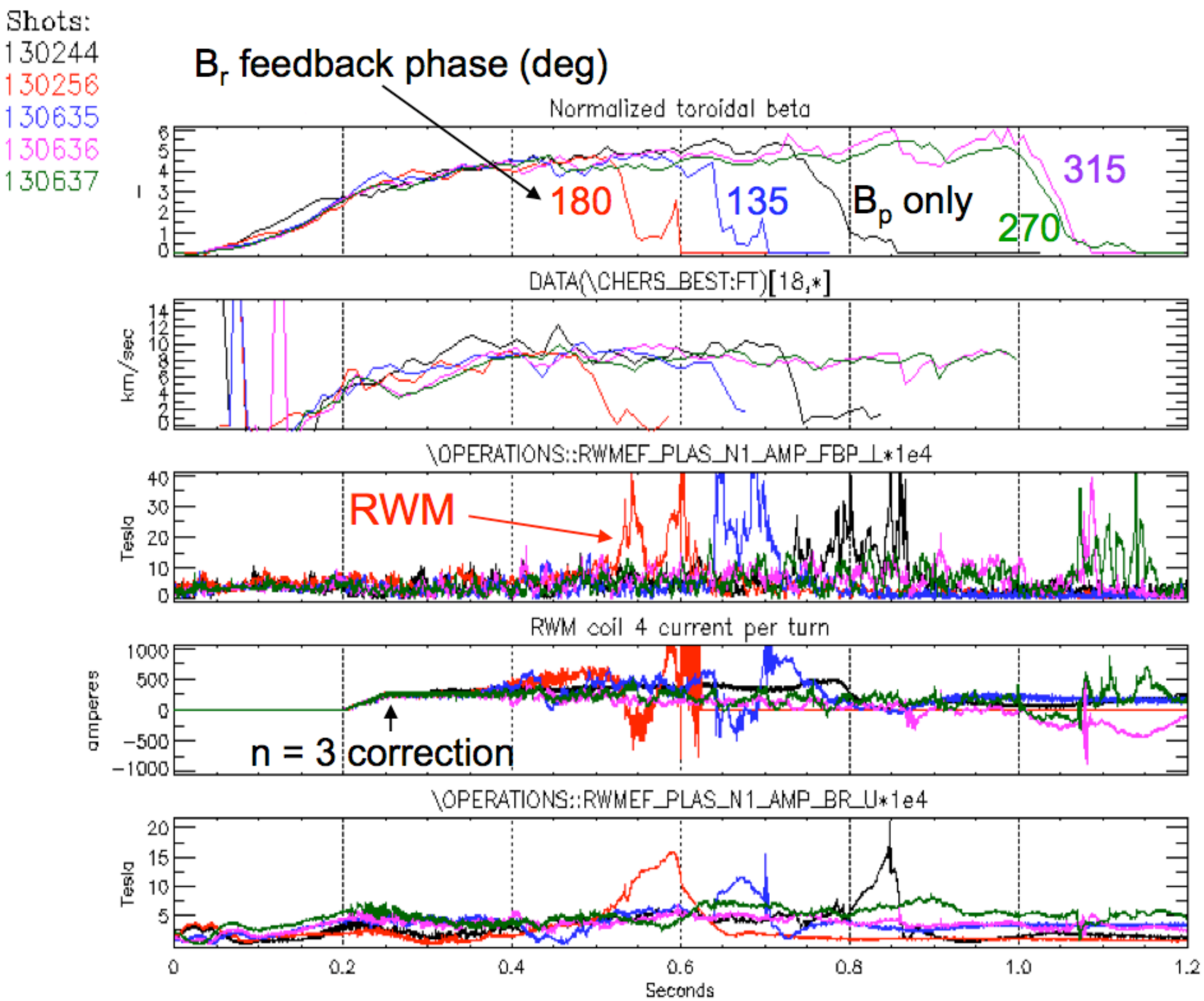
Upper B_P Sensors



"Combined" B_P Sensors



2008 Also Had Feedback Attempt With B_R Sensors



- Combined $B_P + B_R$
- B_R feedback phases around ~290 appear to be useful.
- B_R feedback gains of 0.7 appeared stable.
- Use these parameters as starting points for the XP.

XP-802, Sabbagh et al.

Outline

- New sensor compensations
- Results from previous XPs
- Plan for this XP

Experimental Plan (I)

- Background Testing
  - Algorithm tested already, but not as built into the present PCS.
  - Run some cases on the 2nd computer when the run starts, using shot data.
    - Compare to outputs of the "identical" idl code.
  - Introduce the miu algorithm as the primary mode-ID algorithm for standard RWM feedback.
  - Use 50% test shots to check for stability of OHxTF compensations.

- Qualify the reference discharge. (4 shots)
  - High-β discharge with n=3 correction, but no fast feedback.
    - 800 kA SAS and JB shots with high β_N from 2009 (like 133775)?
    - Lasted 1.15 seconds using only (-)10 kA of OH current.
  - Should suffer a rotation collapse and RWM
    - Induce with n=1 applied field as necessary (as in XP-701).
    - Phase relationship with OHxTF field?

Experimental Plan (II)

- Apply (only) B_R n=1 feedback with varying phases and gains. (10 shots)
  - Low-pass filter the feedback request in order to eliminate fast feedback.
  - Gain and phase optimization
    - Start with gain and phase from XP-802.
    - Scan both, starting with the phase, then optimizing the gain.
    - Try to achieve cancellation of the EF effect as in XP-701.
  - Repeat best test with OHxTF compensations turned off.
  - Particular emphasis on the edge rotation sustainment.
- Apply B_P n=1 feedback on the same situation. (6 shots)
  - Recreate phase scan in XP-701 for comparison.
  - Test FB noise level, rotation evolution in similar situations…can B_R cancel better?
- Repeat with intrinsic EF. (4 shots)
  - Raise I_P to ~1MA in order to get to larger OH currents.
  - Shots with both "optimal" B_R and B_P feedback separately, then combined.
- Test compensation of time varying error fields. (6 shots)
  - Choose "best" sensor polarity, phase and gain.
  - Apply n=1 TWs with 10, 20, 30, 40 Hz.
  - Determine frequency above which the TW is not fully cancelled by FB.
  - Repeat without AC compensations

Total: 30 Shots

Backup

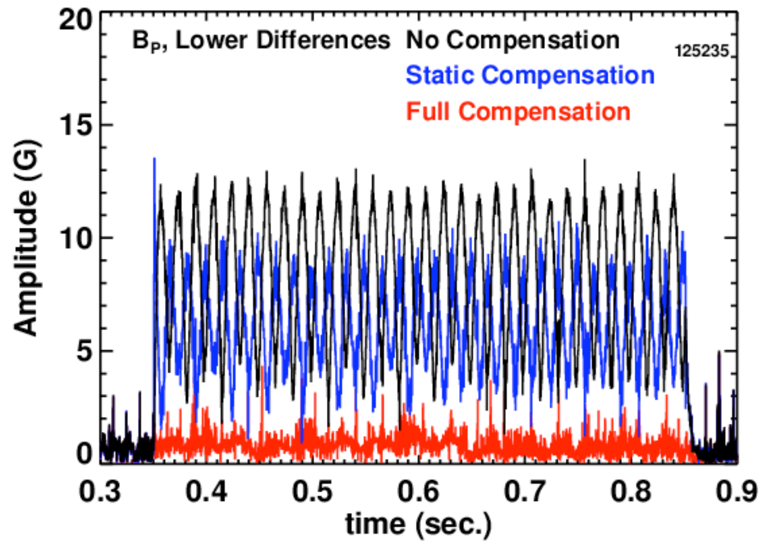
Goals For Proposed Experiment

- Qualify B_R sensors for error field correction.
  - Determine the optimal phase shift and gain for DEFC.
    - Can start with results from Steve's XP in 2008
  - Determine if OHxTF sensor compensation is necessary…or beneficial…or irrelevant.
  - Fast feedback is out of scope

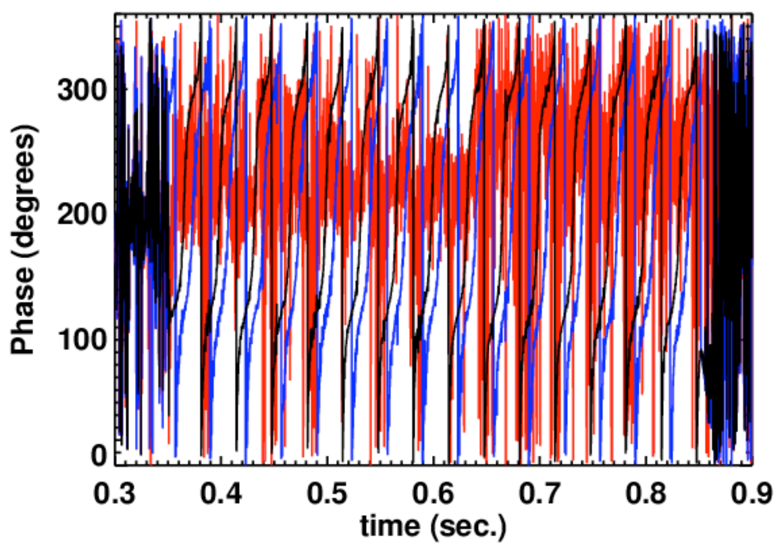
- Determine if one or the other sensor type is better for correction:
  - Reduced fluctuations in the FB coil current?
  - Improved rotation sustainment?
  - Higher gain?

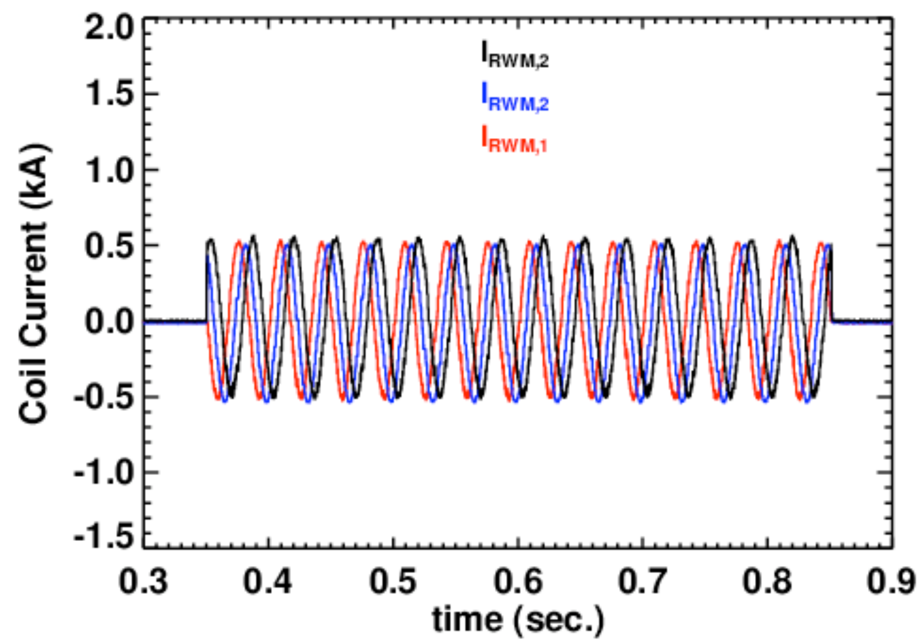
- Examine β-dependence of FB response.

AC Compensations Can Be Important For



- Large amplitude modulation in signal with static compensation





Other Stuff

- Lithium
  - LITER at ~200 mg/shot
  - No LLD
- Diagnostics
  - Profile diagnostics
  - RWM detection
- Analysis
  - MSE reconstructions.
  - DCON for proximity to ideal stability limits.
  - Intrinsic EF and detailed RWM sensor analysis.