Response Function Compensation for DIII-D 3D Magnetics

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Response Function: Defining Input-Output Relationships for Linear Systems

A Response Function, through a convolution integral, defines a systems output (sensor voltage) from the time history of its input (B field coil driving voltage)

$$S(t)=\int_{t_0}^{t} d\tau R(t-\tau)V'(\tau)$$

- Like a transfer function, the applicability is to linear systems with zero initial conditions and zero-point equilibrium
  - V(0)=S(0)=0, no drive = no signal (no non-linear drifts please!)
- Straight grab from signal theory → Does not know about the geometry of DIII-D, or even that it is modeling eddy current decays

Think of this as a superposition of after effects

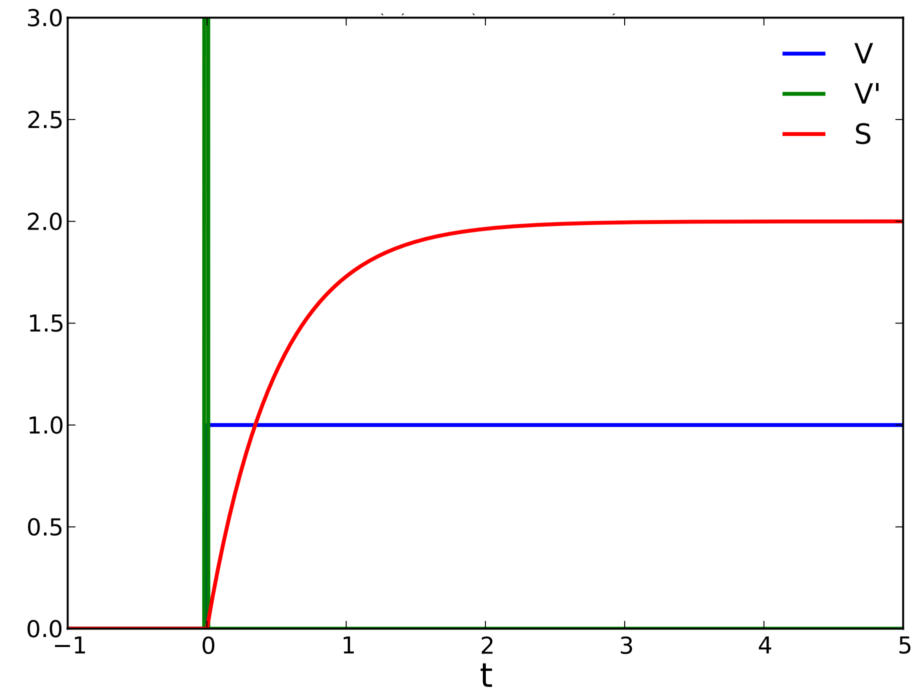
$$S(t)=\int_{t_0}^{t} d\tau R(t-\tau)V'(\tau)=R(0)V(t)+\int_{0}^{t-t_0} d\tau R'(\tau)V(t-\tau)$$

A Simple Example: Exponential Decay

Lets take a simple system defined by exponential (eddy current) decay as a (not at all) random example:

- If we want to do absolutely the least mathematics possible, for any system, we just apply a step function input

$$S(t) = \int_{t_0}^{t} d\tau R(t-\tau)\delta(\tau-t_s) = R(t-t_s)$$



Inspiration! This is exactly what we have in DIII-D "DC" calibration shots

DIII-D DC-Compensation Calibration shots yield Response Function Compensation

...With a little extra work

DC Vacuum shots had slow ramp rates → Used coil turn-off times

- Corresponded to between ~ 1ms (I-coils) and ~ 3ms (C-coils)

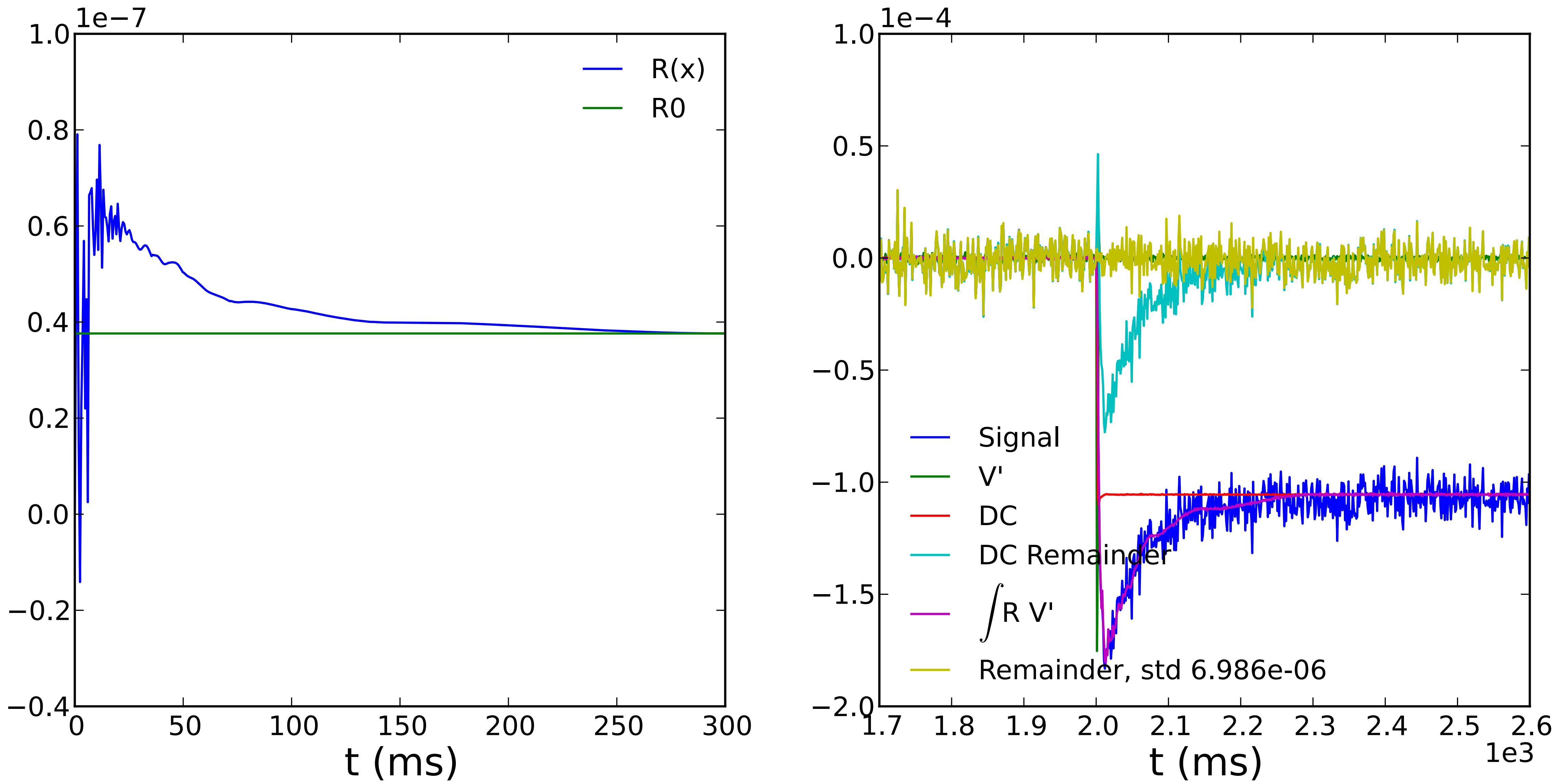
Simple response function matrix equation extremely sensitive to initial conditions (t_0)

$$\begin{bmatrix} S_0 \\ S_1 \\ \vdots \\ S_n \end{bmatrix} = dt \begin{bmatrix} V'_0 & 0 & 0 & \cdots \\ V'_1 & V'_0 & 0 & \cdots \\ \vdots & \vdots & \ddots & \\ V'_n & V'_{n-1} & \cdots & V'_0 \end{bmatrix} \begin{bmatrix} R_0 \\ R_1 \\ \vdots \\ R_n \end{bmatrix}$$

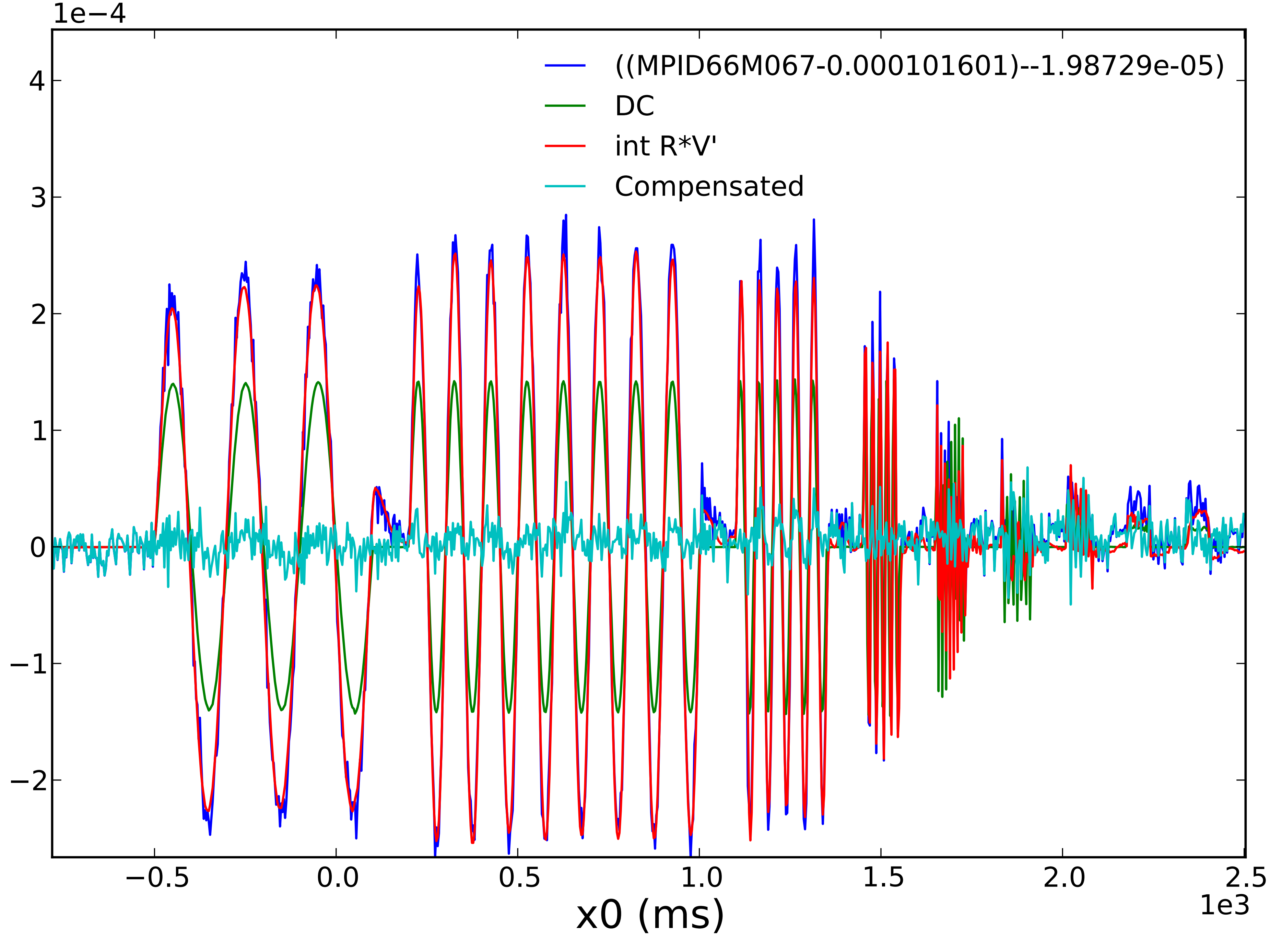
Used least-squares technique to minimize "Euclidean 2-norm" $||\mathbf{S}-\boldsymbol{V}\mathbf{R}||^2$ over ~ 900ms window around coil current drop

- Removed baseline prior to drop (did not account for drift term!)

Example Response Function From lstsq Fit
C79 - MPID66M067



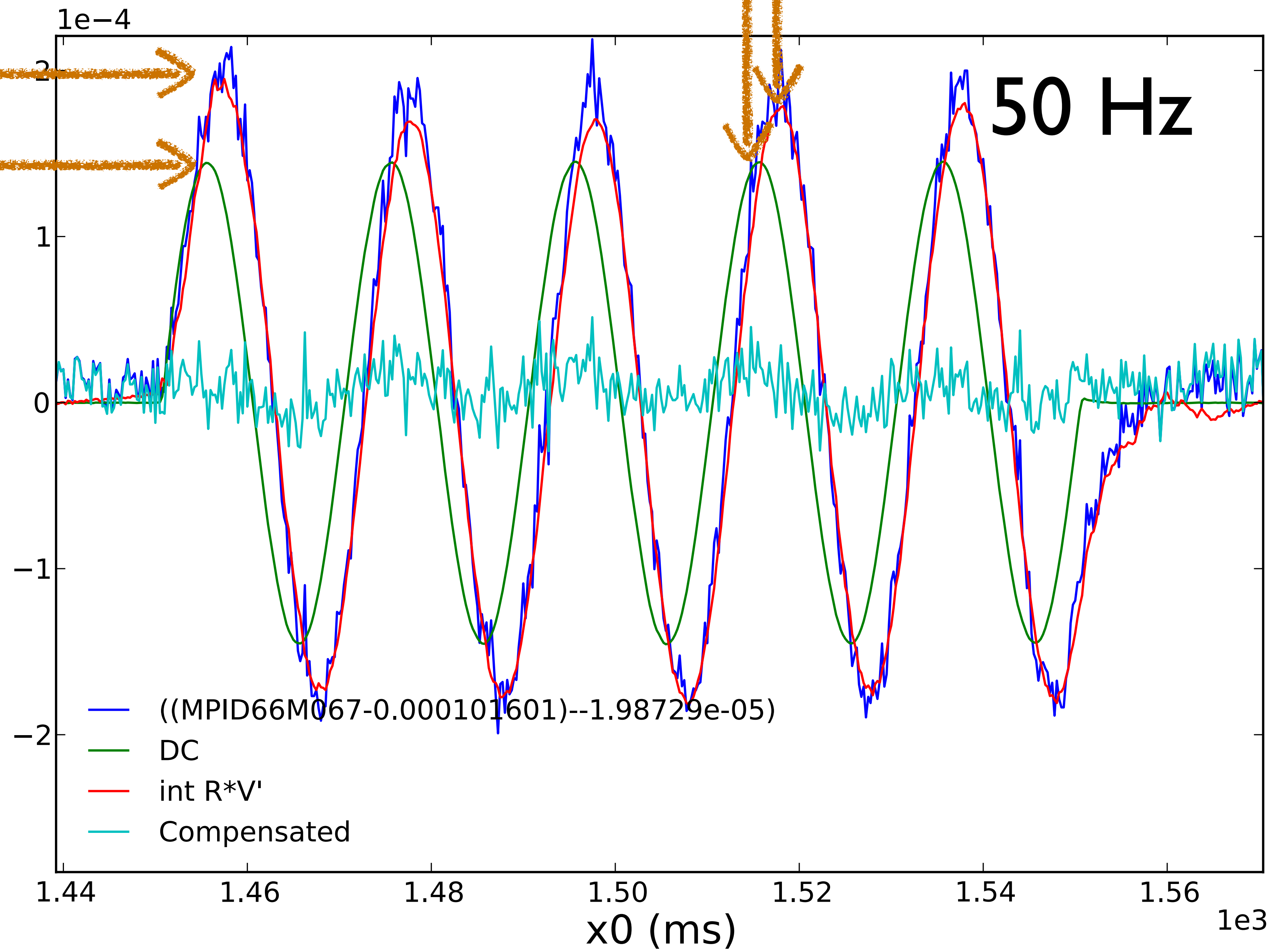
Example Application: Compensating AC Frequency Scan in Vacuum



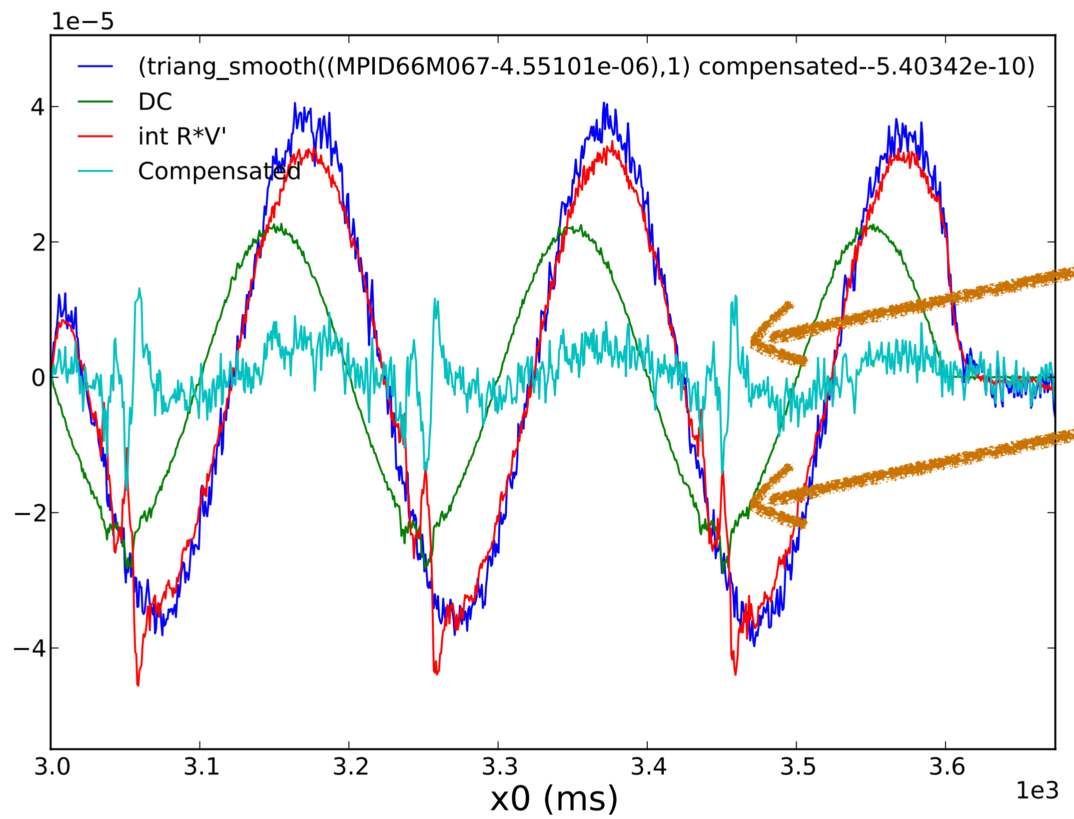
Seems to have Great Results for Low-Mid Frequencies

Automatically captures phase shift

DC Compensation can be $\mathcal{O}$(1G) short



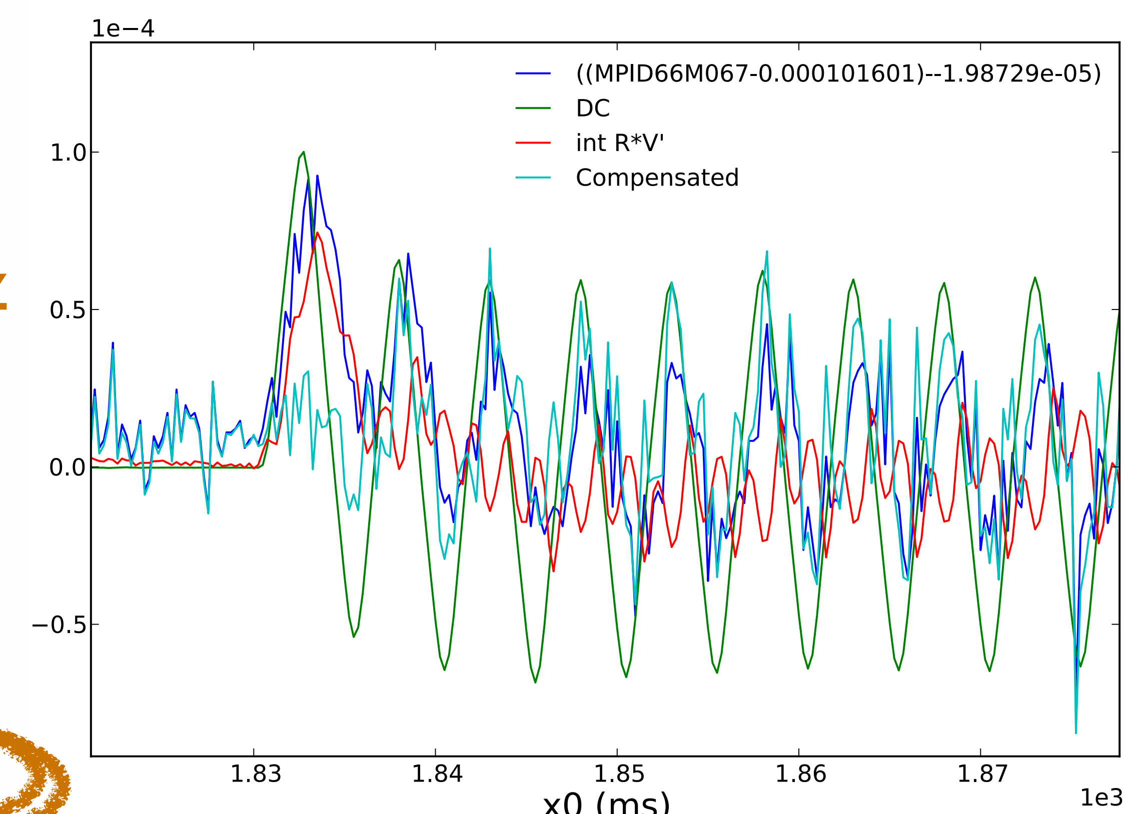
Deficiencies & Draw Backs (That I have Caught)



Looks like transients in coil's got amplified (large V')

Starts to break down above ~100Hz

- Effect of smoothing in fit?
- Is hard limit DC drop time?
  - Relevant??



C-Coil shots are **odd-pairs** only

Summary + Next Steps

Response Function compensation has been successfully implemented using DIII-D "DC" calibration shots

- Compensated signal reduced to $\mathcal{O}(10^{-1}\mathrm{G})$ for frequencies $\nu \lesssim 500\mathrm{Hz}$
- Currently dictionaries of coil-sensor couplings for all differenced pair mds pointnames can be found in /u/logannc/lib/python/magnetics
  - Built in to python magnetics module (still opportunities to increase efficiency)
  - Individual sensors and generalized formats will be added *if* there is interest

Response Function lstsq compatible with ~1s broadband vacuum shots needed for system identification technique (E. Olofsson, June 10)

- It would be great to have these (and individual C-Coils) in future vacuum compensation/calibration shots for 3-way comparison

All these techniques (Resp. Fun., Transfer Fun., Sys. ID) can be used to back out relevant eddy current decay times (interest??)