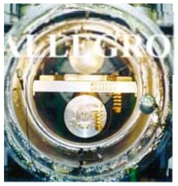

Calibration for the ALLEGRO resonant detector -- S2 and S4

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with the ALLEGRO group, Stochastic Sources Subgroup

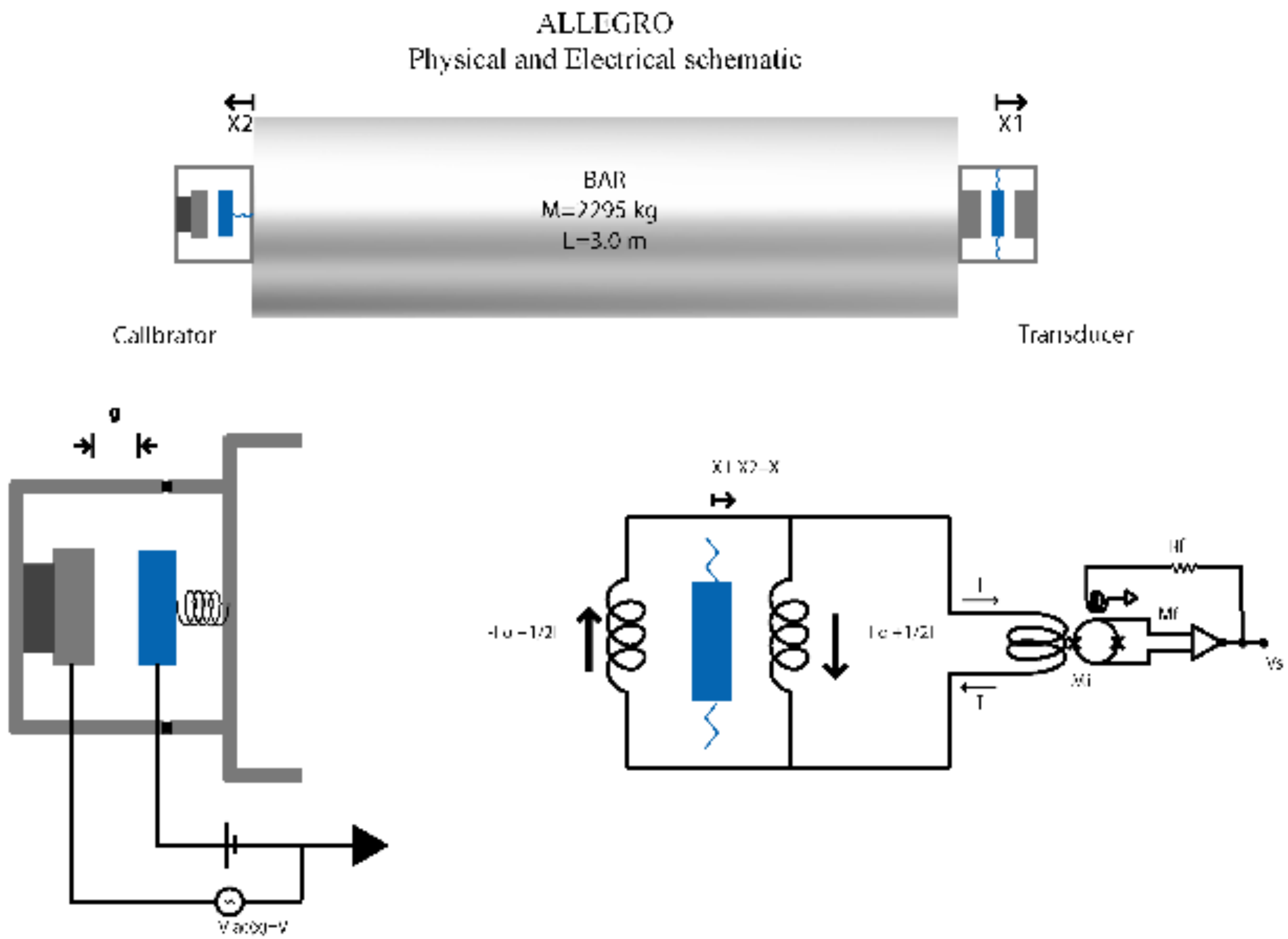
Outline

- Motivation, background
- Signal flow diagram, transfer function equations
- Discussion of calibration measurements
- Recent mysteries
- summary

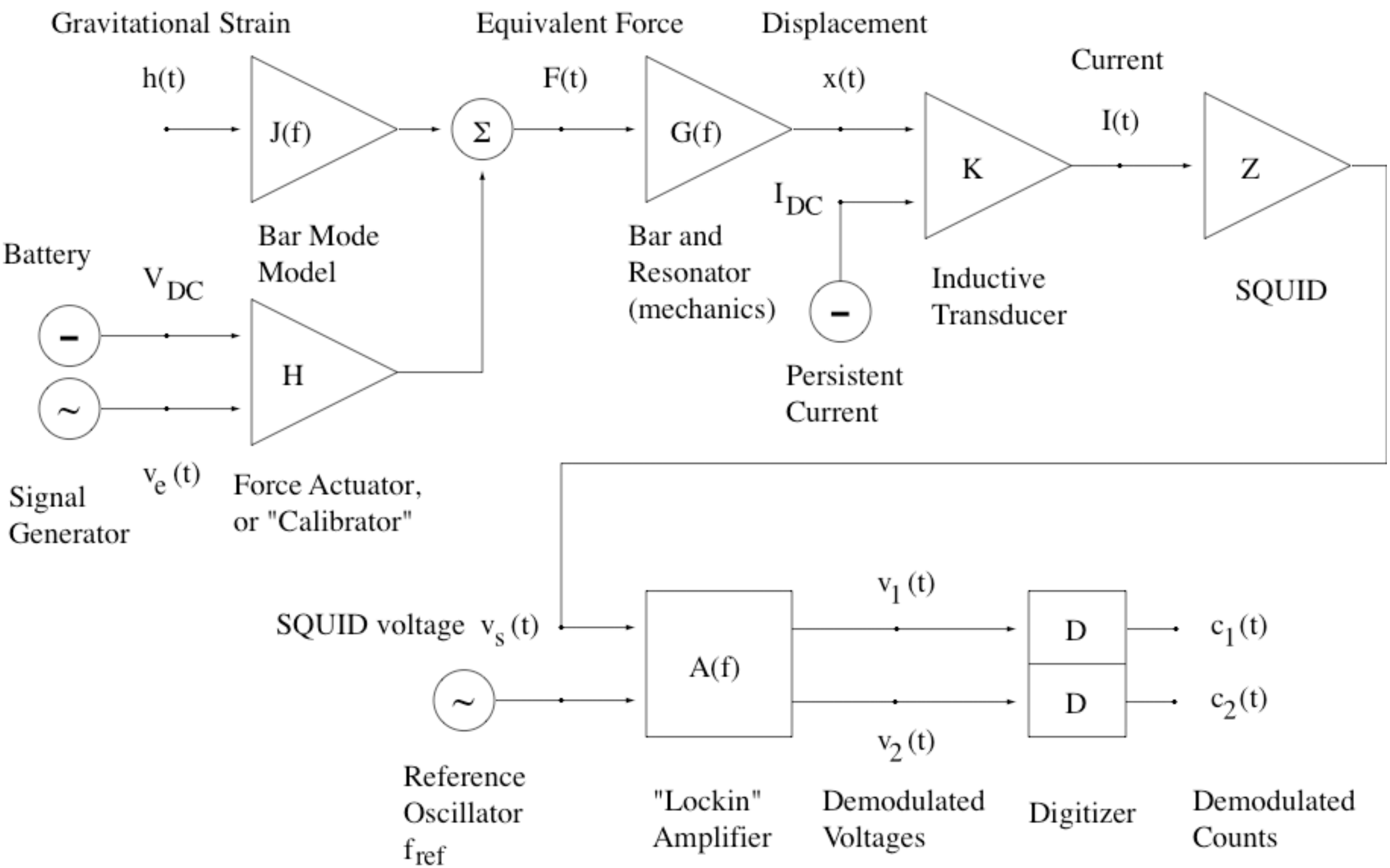
Motivation

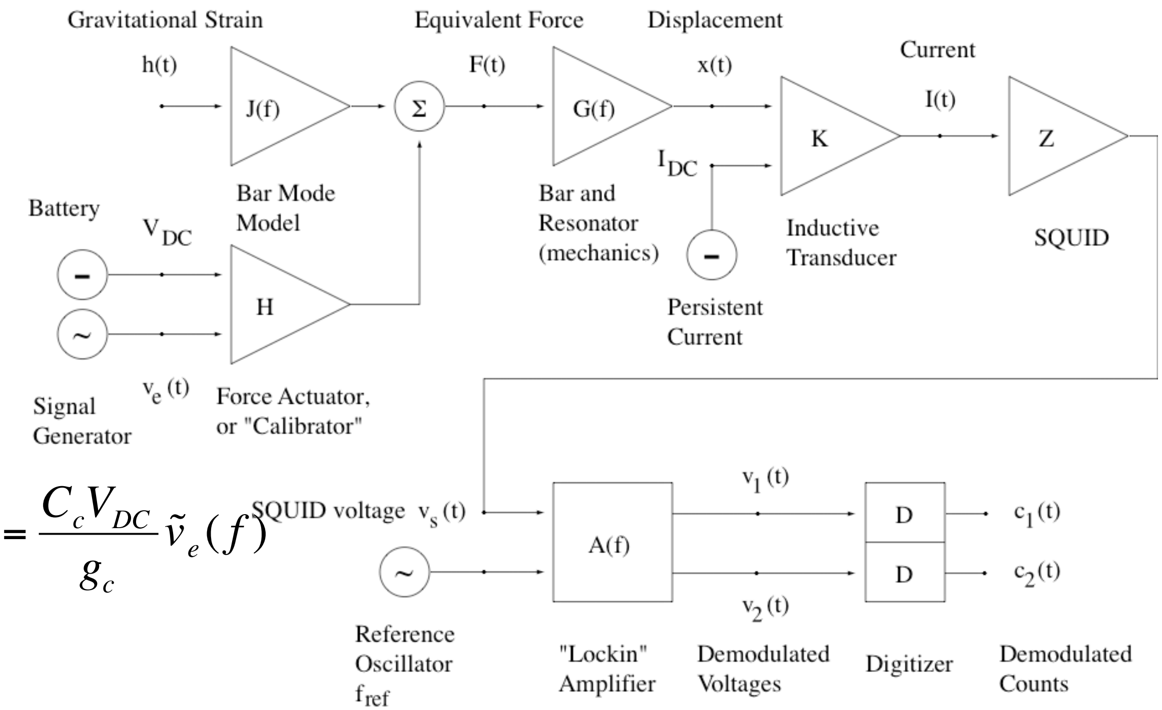
- Provide input to stochastic background analysis using ALLEGRO and LLO (John Whelan’s talk earlier this week)
- Unlike an event list based search, a coherent search such as this requires a phase consistent response function for the detector signal path

ALLEGRO schematic



Signal path


Gravitational Strain
h(t)
J(f)
Bar Mode Model
Σ
Equivalent Force
F(t)
G(f)
Bar and Resonator (mechanics)
Displacement
x(t)
I_{DC}
Persistent Current
K
Inductive Transducer
Current
I(t)
Z
SQUID
Battery
V_{DC}
H
Signal Generator
v_e (t)
Force Actuator, or "Calibrator"
SQUID voltage v_s (t)
Reference Oscillator f_{ref}
A(f)
"Lockin" Amplifier
v_1 (t)
v_2 (t)
Demodulated Voltages
D
D
Digitizer
c_1(t)
c_2(t)
Demodulated Counts



$$\tilde{F}_C(f) = H\tilde{v}_e(f) = \frac{C_c V_{DC}}{g_c}\tilde{v}_e(f)$$

Form of each Transfer Function

$$\tilde{F}(f) = J(f)\tilde{h}(f) = 4MLf^2\tilde{h}(f)$$

$$\tilde{x}(f) = G(f)\tilde{F}(f)$$

$$= \alpha\left(\frac{1}{\left(f_p^2 - f^2 + \frac{if_p f}{Q_p}\right)} - \frac{1}{\left(f_m^2 - f^2 + \frac{if_m f}{Q_m}\right)}\right)\tilde{F}(f)$$

$$\tilde{I}(f) = K\cdot\tilde{x}(f) = \left(\frac{I_{\mathrm{DC}}}{g}\right)\tilde{x}(f)$$

$$\tilde{v}_S(f) = Z\cdot\tilde{I}(f)$$

$$\tilde{z}_v(f - f_{\mathrm{r}}) = A(f)\tilde{v}_S(f) = a_{\mathrm{L}}e^{i(t_d 2\pi(f - f_{\mathrm{r}}))}e^{-i\phi}\tilde{v}_S(f)$$

$$\tilde{z}_c(f - f_{\mathrm{r}}) = D\cdot\tilde{z}_v(f - f_{\mathrm{r}})$$

So in practice the calibration amounts to --

$$\tilde{h}(f - f_r) = \frac{\tilde{z}_C(f - f_r)}{J(f)G(f)KZA(f - f_r)D}$$

Inverse fft then gives

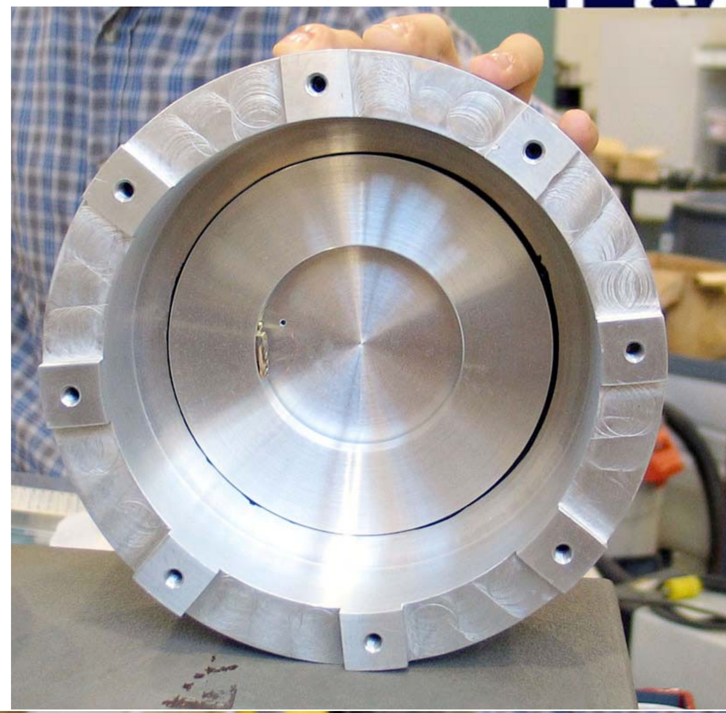
$h^H(t)$	complex heterodyned strain time series

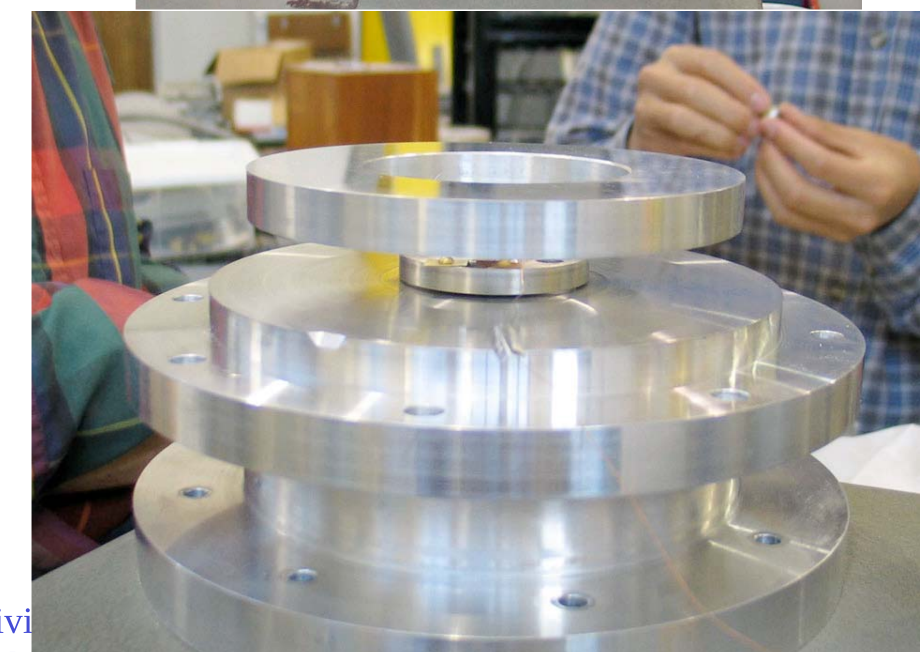
Need to determine --

- Mode frequencies and Q's -- f_m , f_p , Q_m , Q_p
- overall scale -- in practice we measure $\alpha \cdot K \cdot Z$
  - α is mechanical gain -- includes 'tuning factor'
- Lock-in amplifier parameters -- gain, filter delay and phase shift
  - Also need to know the phase of the lock-in reference oscillator

New calibrator installed between S2 and S4 -- known transfer function

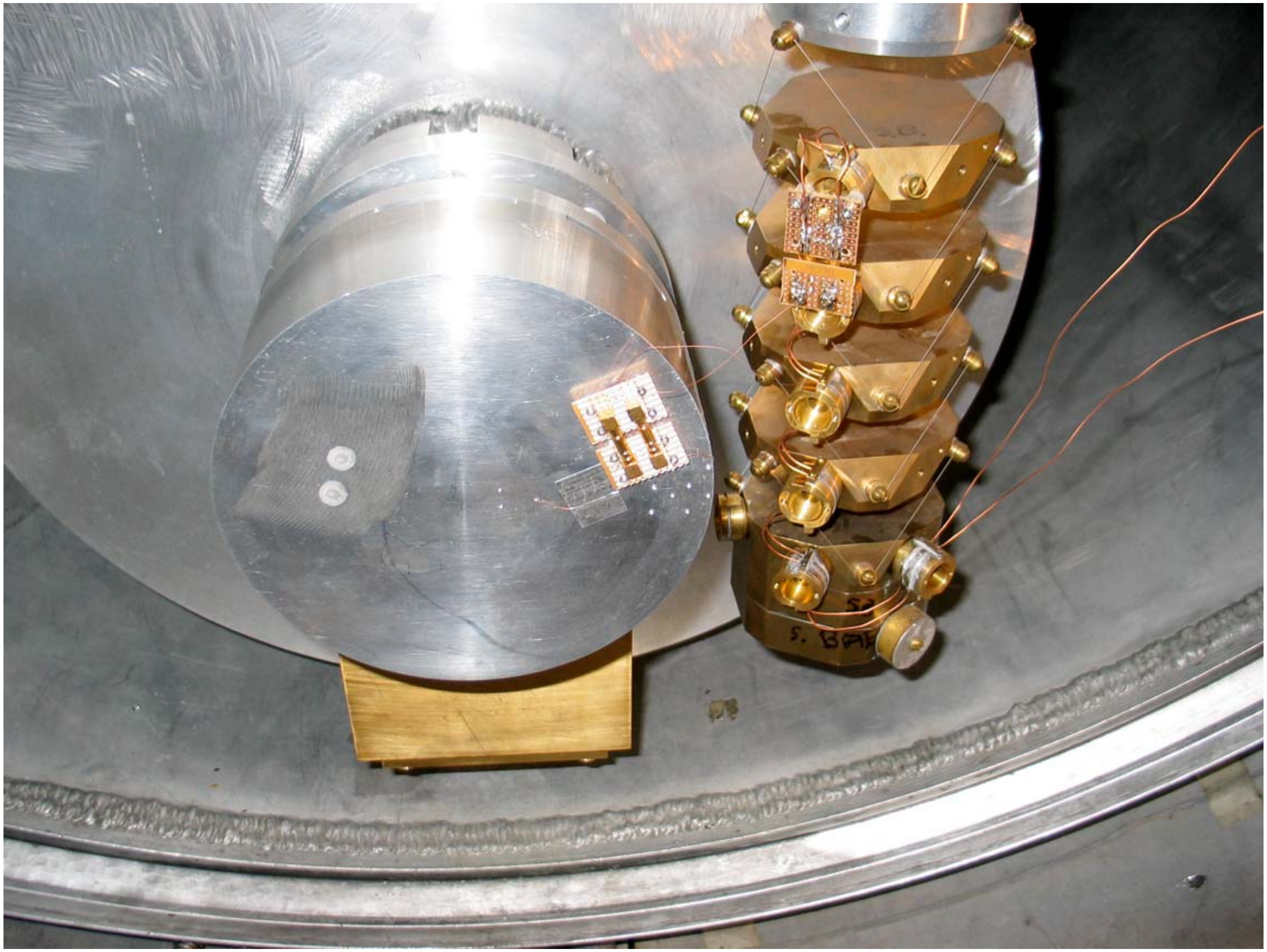
- One plate of capacitor is tightly coupled to bar.
- Other plate is weakly coupled to the bar, so acts like a free mass.
- Both plates electrically isolated.



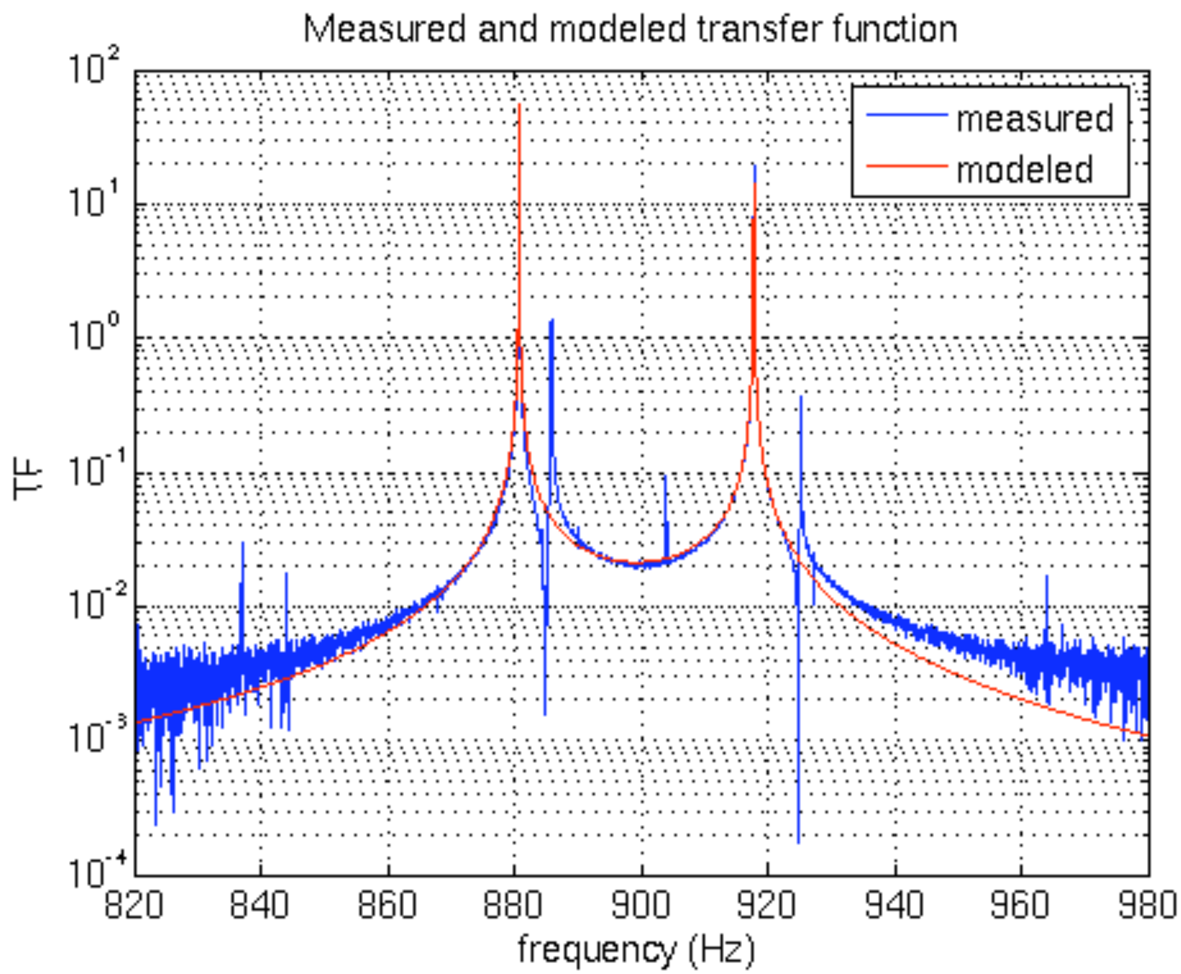


Rest of detector unchanged - Measurements will apply to S2

The calibrator mounted on the bar



Transfer function - white noise excitation to measured output



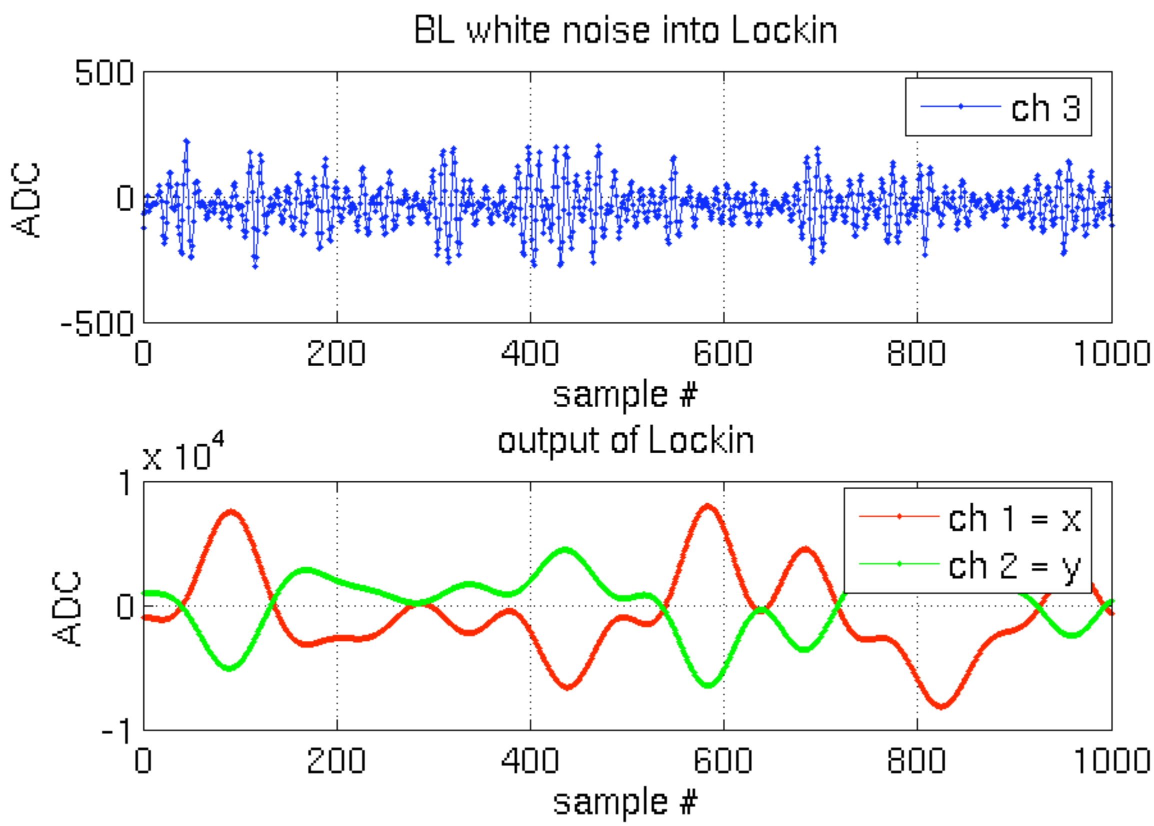
measurements from 20 March 2004 -- excitation measured through lock-in and A/D plotted here we have

$$\mathrm{TF} = H \cdot G(f) \cdot K \cdot Z$$

gives us the overall scale - α

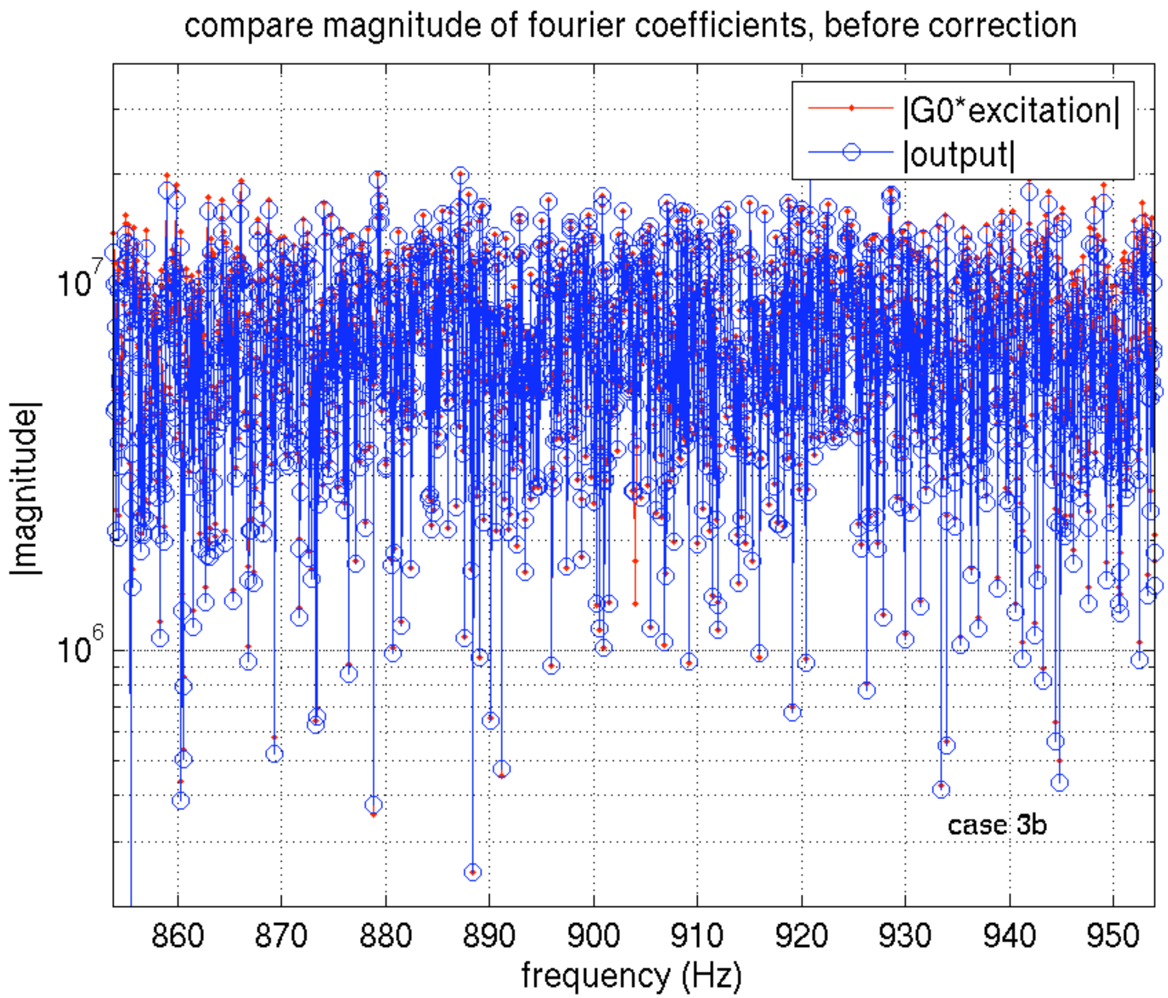
Lock-in/ filter measurements

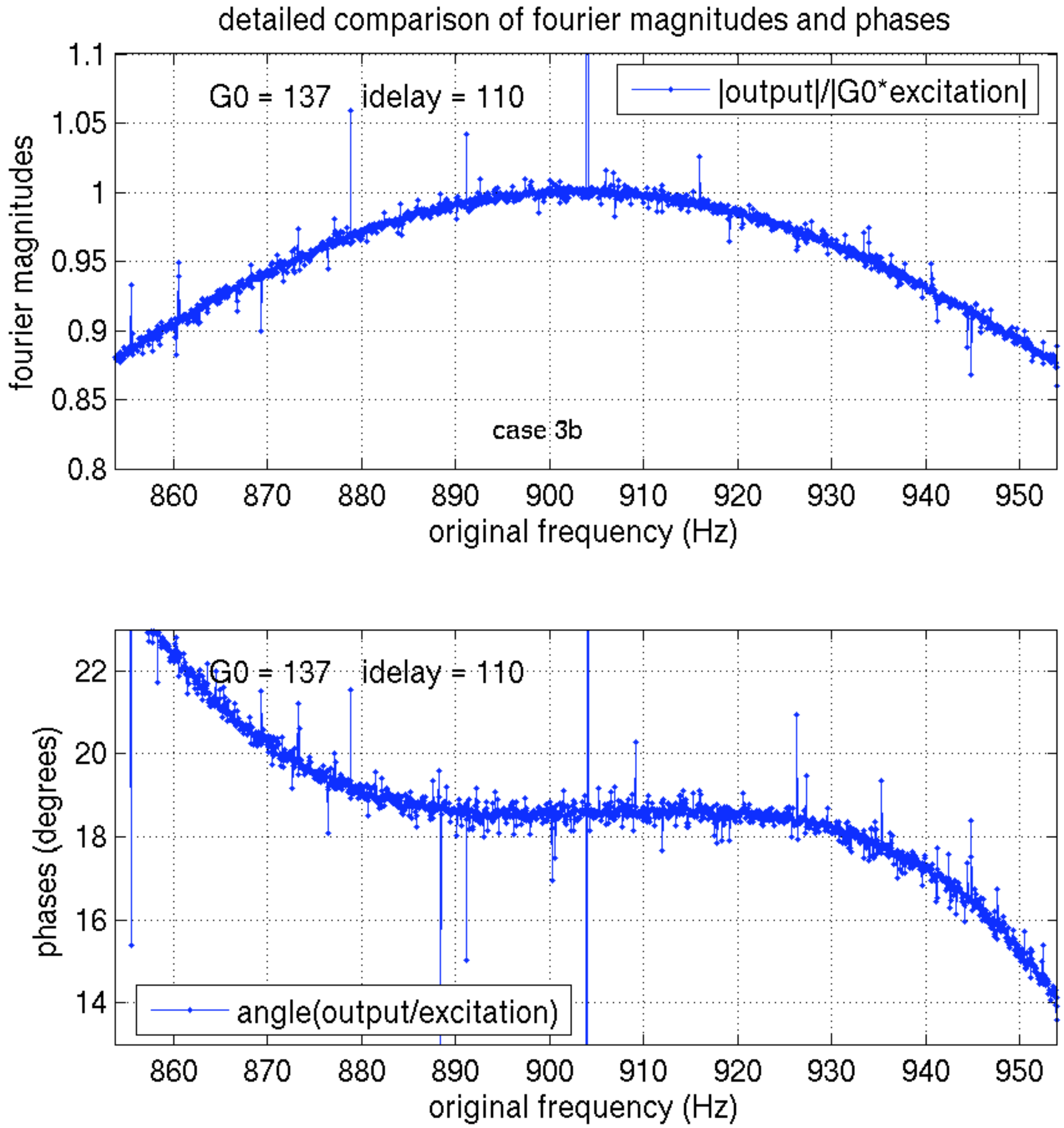
Band-limited white noise injection -- recorded directly and through lock-in/anti-aliasing filters



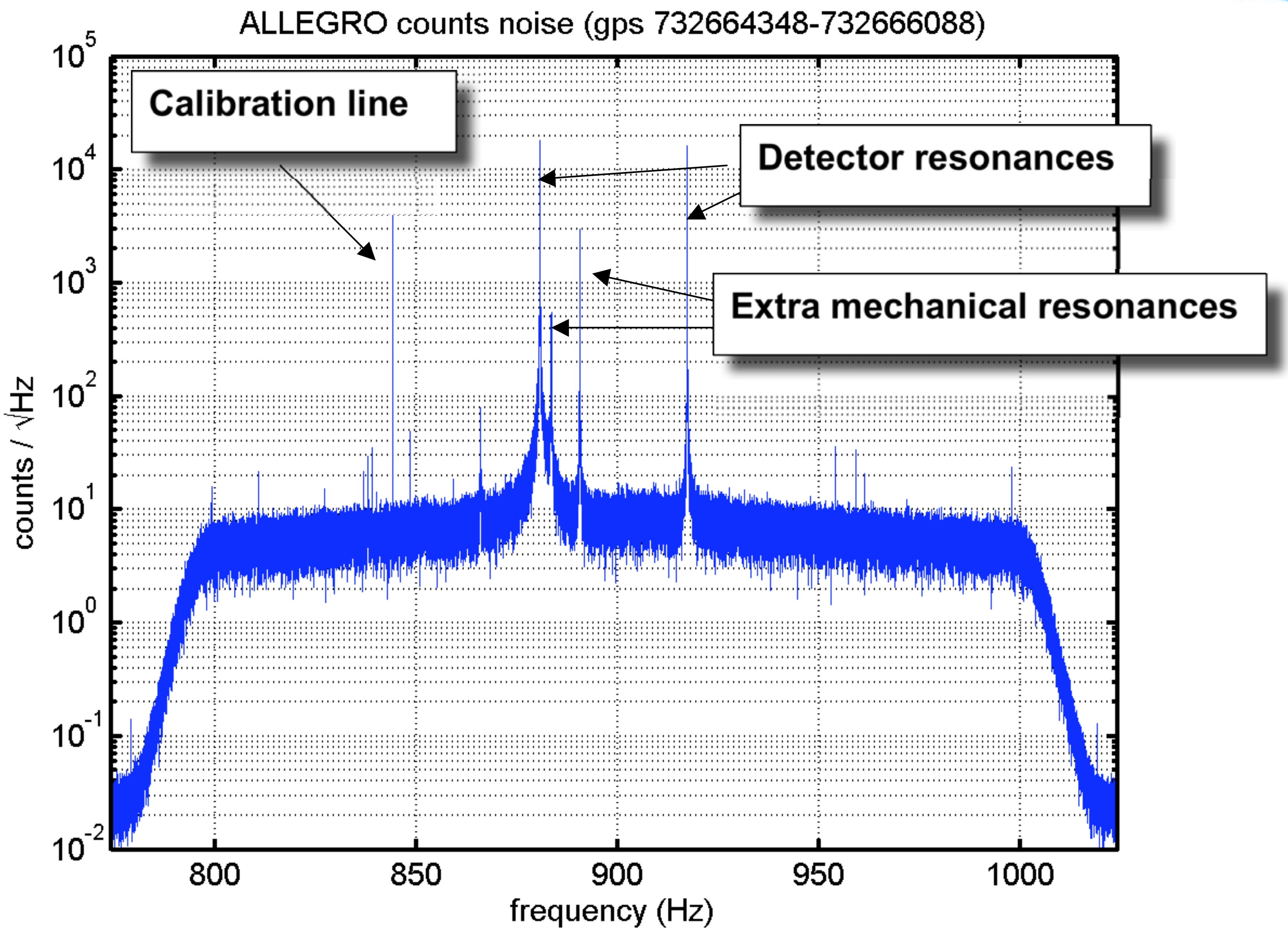
Compare fourier coefficients

Lock-in/filter introduces an 11ms delay and 18 degree phase shift

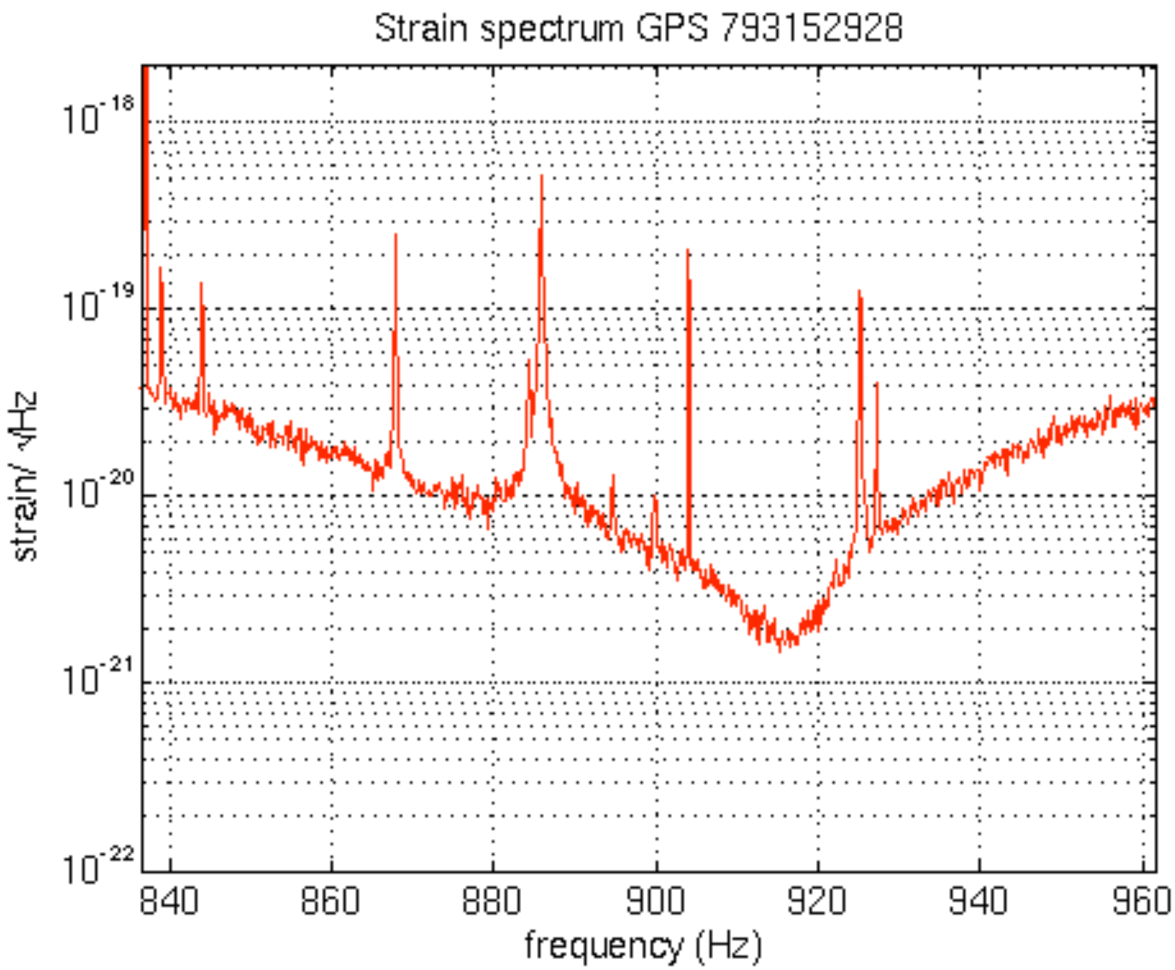



detailed comparison of fourier magnitudes and phases
G0 = 137 idelay = 110
|output|/|G0*excitation|
fourier magnitudes
1.1
1.05
1
0.95
0.9
0.85
0.8
case 3b
860 870 880 890 900 910 920 930 940 950
original frequency (Hz)
G0 = 137 idelay = 110
phases (degrees)
22
20
18
16
14
angle(output/excitation)
860 870 880 890 900 910 920 930 940 950
original frequency (Hz)

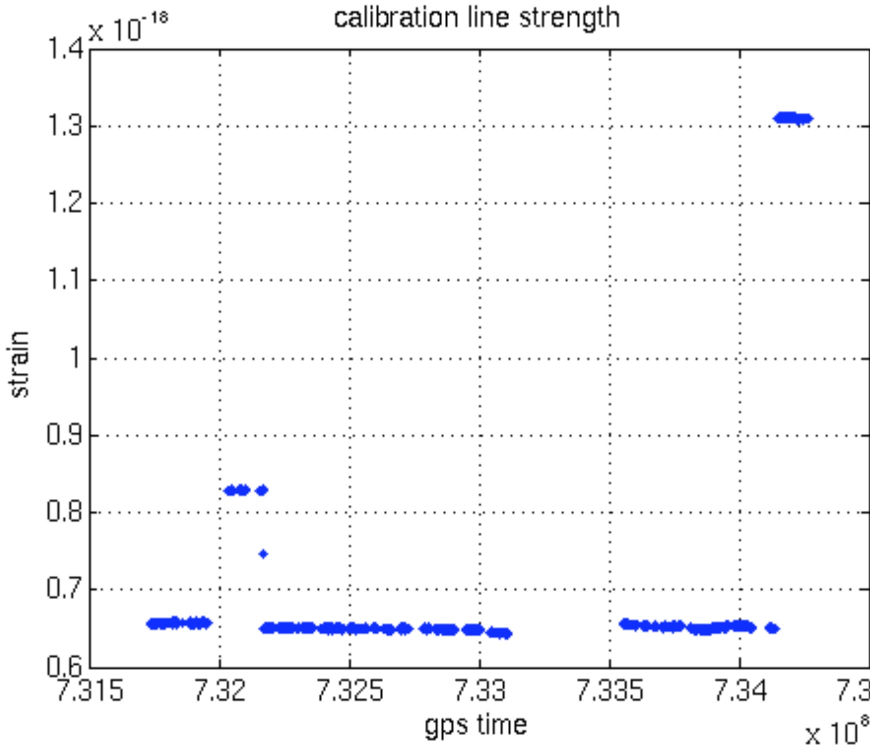
Raw data

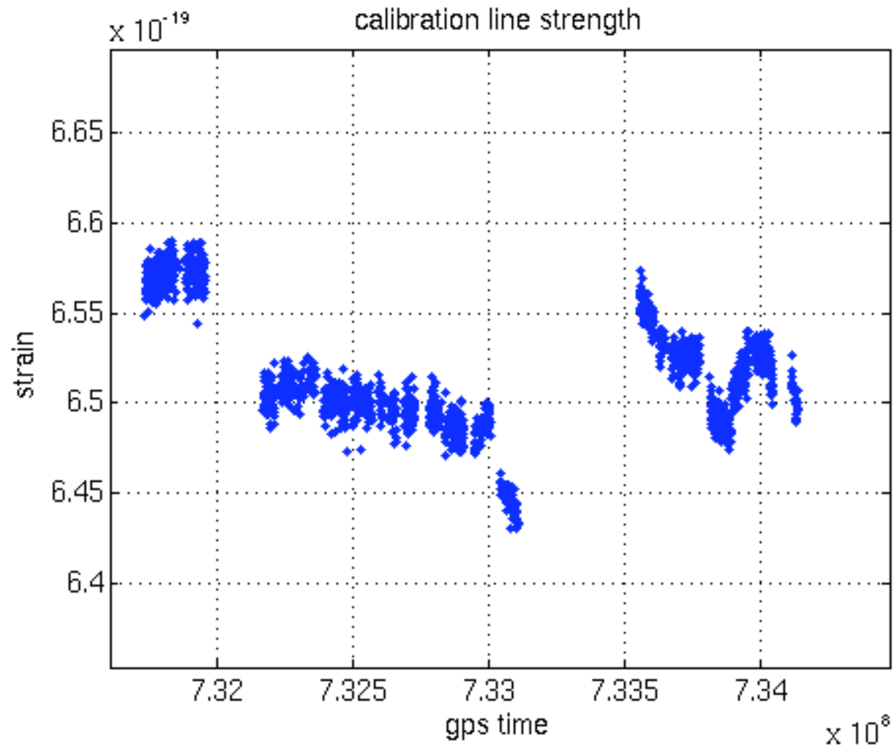

ALLEGRO counts noise (gps 732664348-732666088)
Calibration line
Detector resonances
Extra mechanical resonances
counts / √Hz
frequency (Hz)
10^5
10^4
10^3
10^2
10^1
10^0
10^-1
10^-2
800
850
900
950
1000

Calibrated strain spectrum from S4



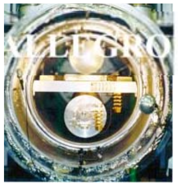
Stability of calibration -- calibration line tracked through S2

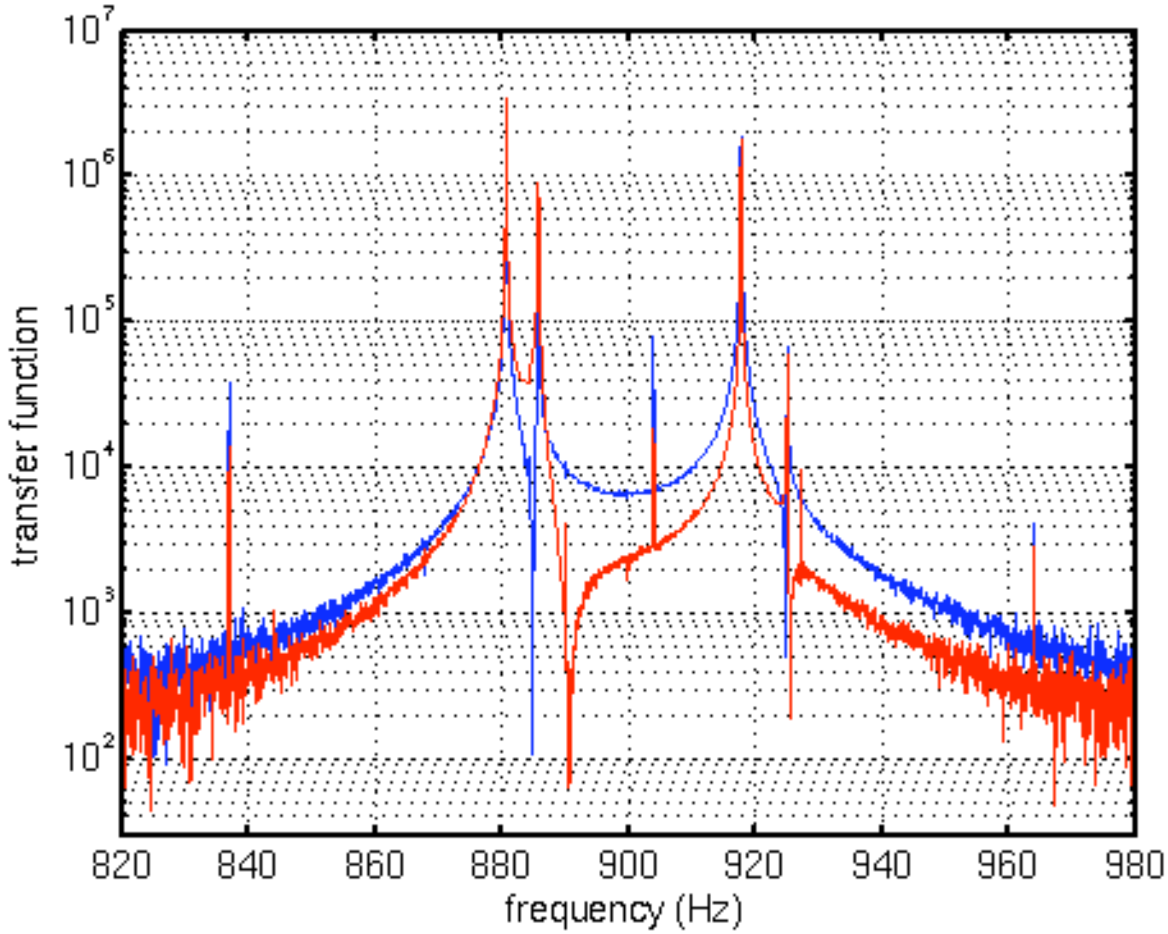




A Problem

- Discrepancy between white noise injection data sets
  - discovered to be due to change in polarity of DC bias applied to calibrator (?!)
- Two mysteries
  - Nuisance mode at 885 Hz -- relative phase changes with DC bias polarity
  - Apparent offset in DC bias voltage on calibrator

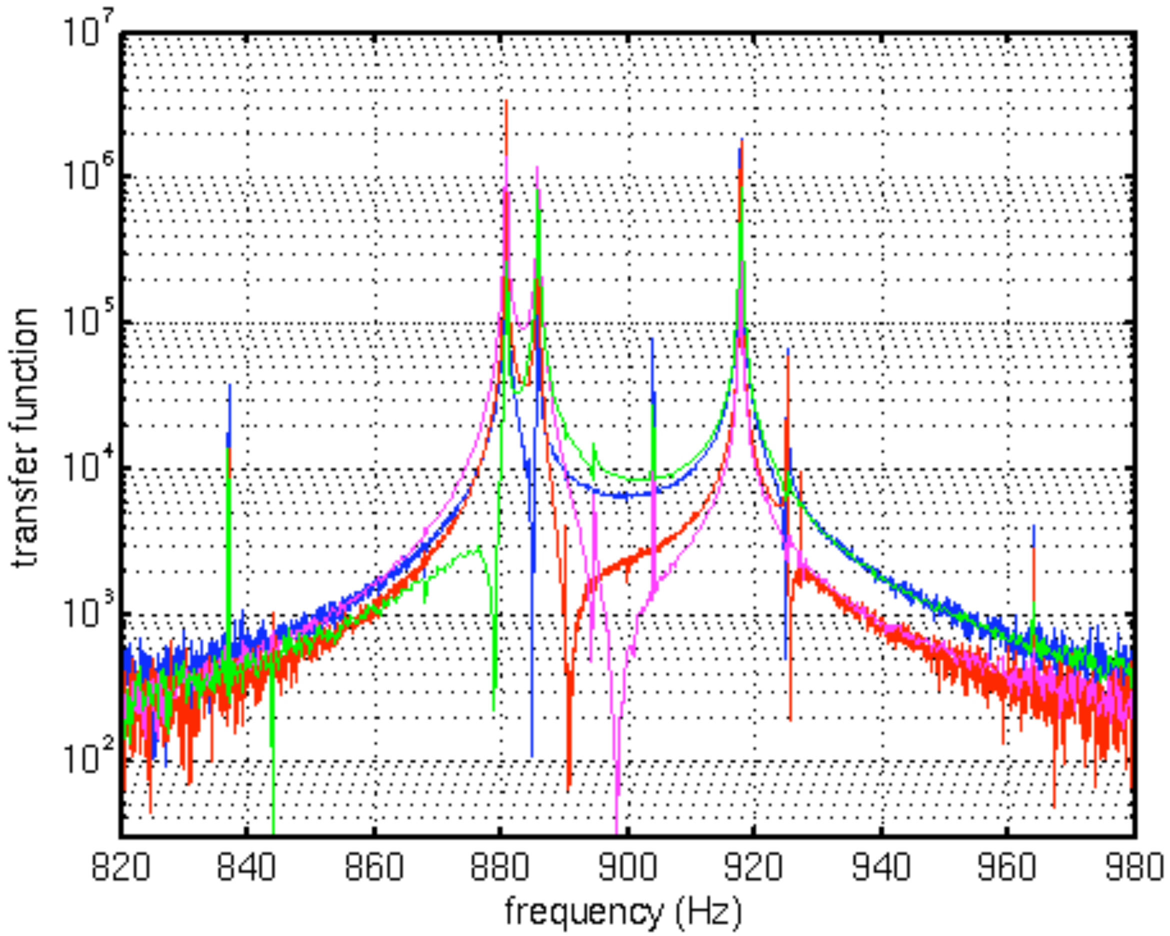




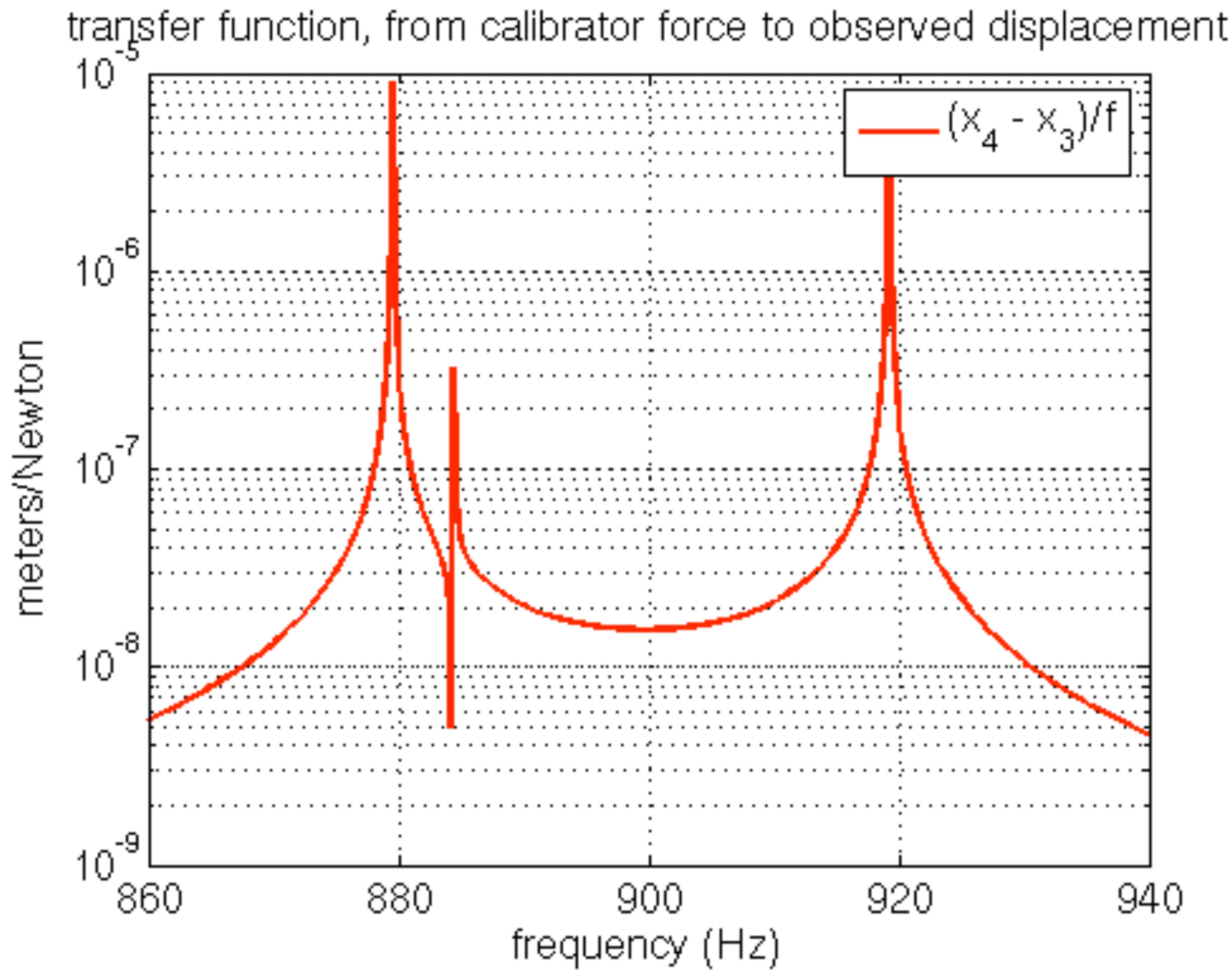
Transfer function magnitude, white noise injection --

blue curve   +3.99VDC nominal bias

red curve -3.99VDC nominal bias

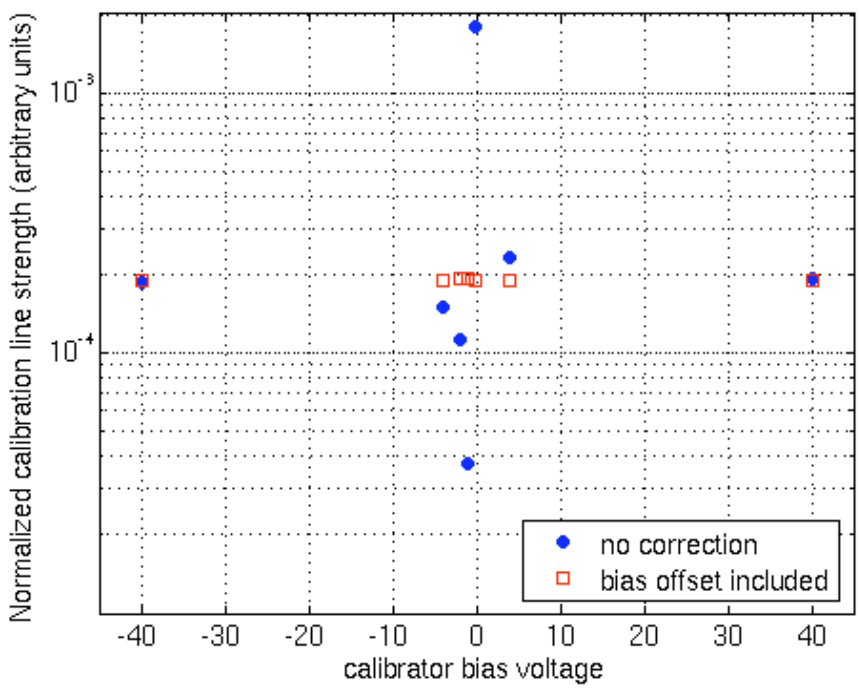


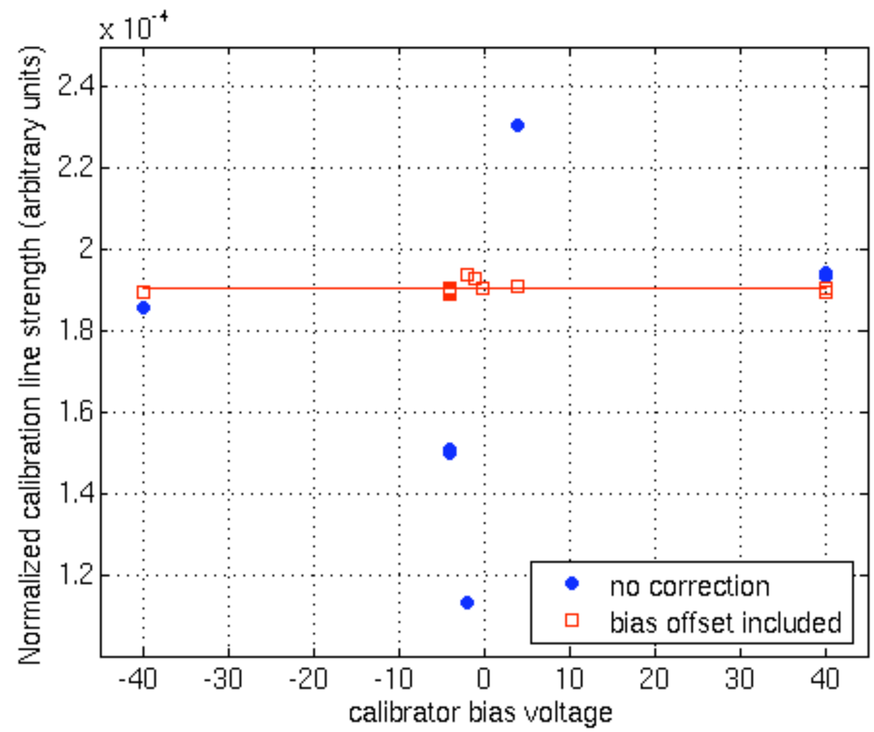
… now flip the plate to which the voltage is applied



we can certainly model extra mechanical modes
-- but the phase flip is a mystery

837Hz calibration line strength vs. calibrator bias





Summary

- We have calibrated *h*(*t*) for S2 data set
- Hardware injections done for E12, S4 -- good news we are able to extract coherent signal between L1 and A1 (see Sukanta's earlier talk)
- Analyze burst injections done to determine overall sign of the calibration
- Need to investigate calibrator behavior with post S4 measurements -- be sure there is no problem with overall scale determination