Generating time domain strain data ($h(t)$) for the ALLEGRO resonant detector

or

calibration of ALLEGRO data

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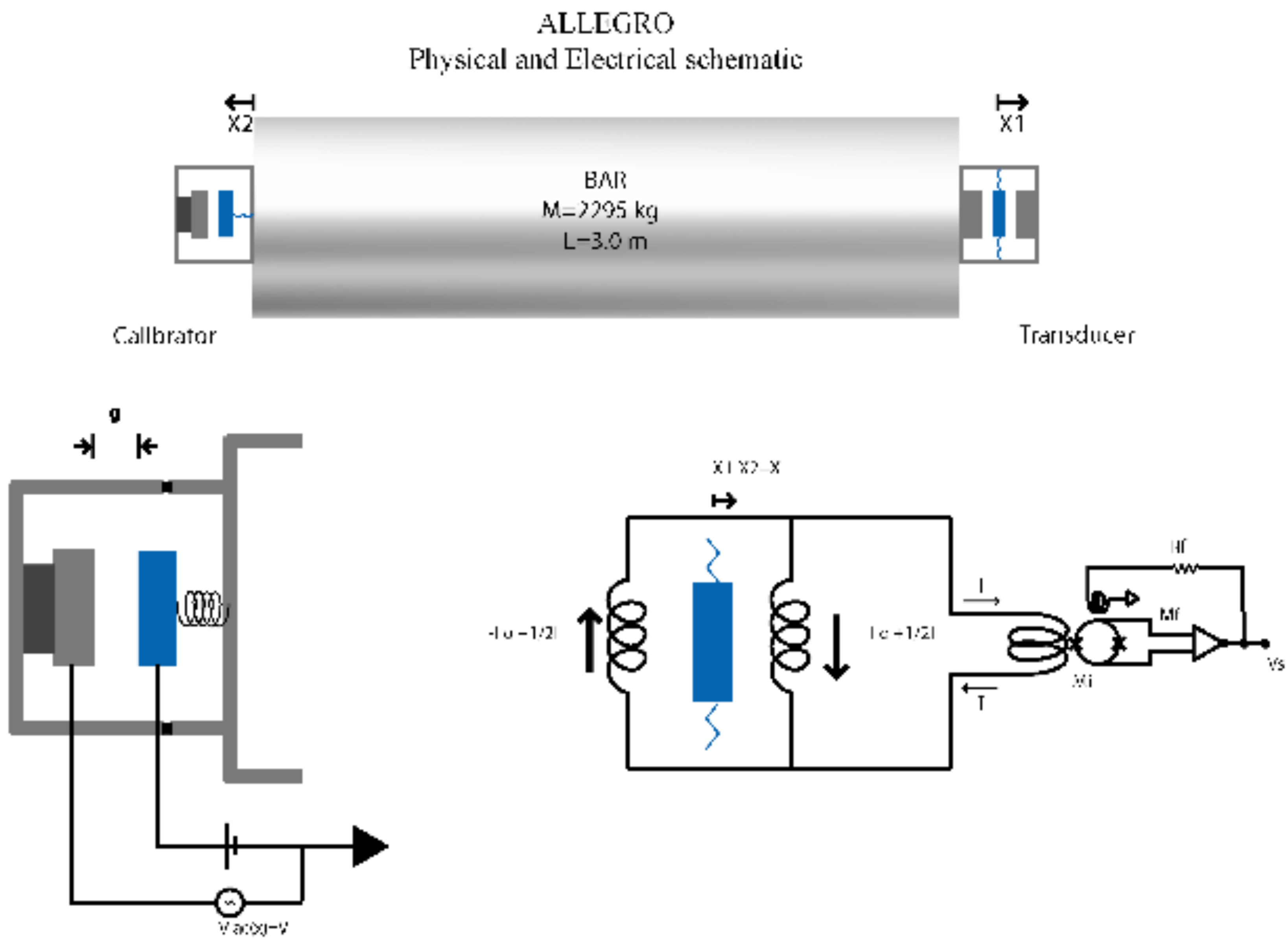
Outline

- Motivation
- Signal flow diagram, transfer function equations
- Discussion of calibration measurements
- Noise curves, stability
- future

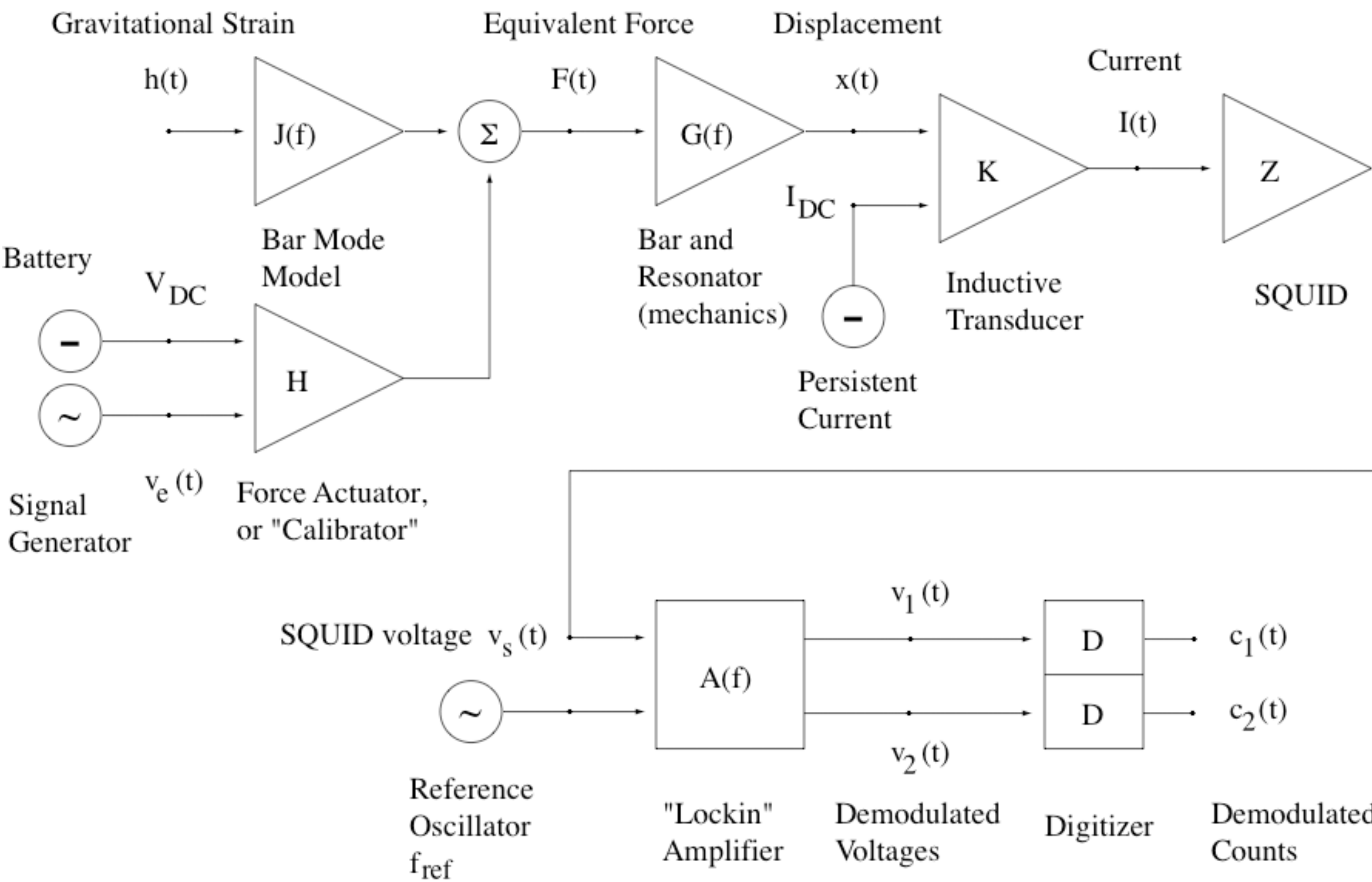
Motivation

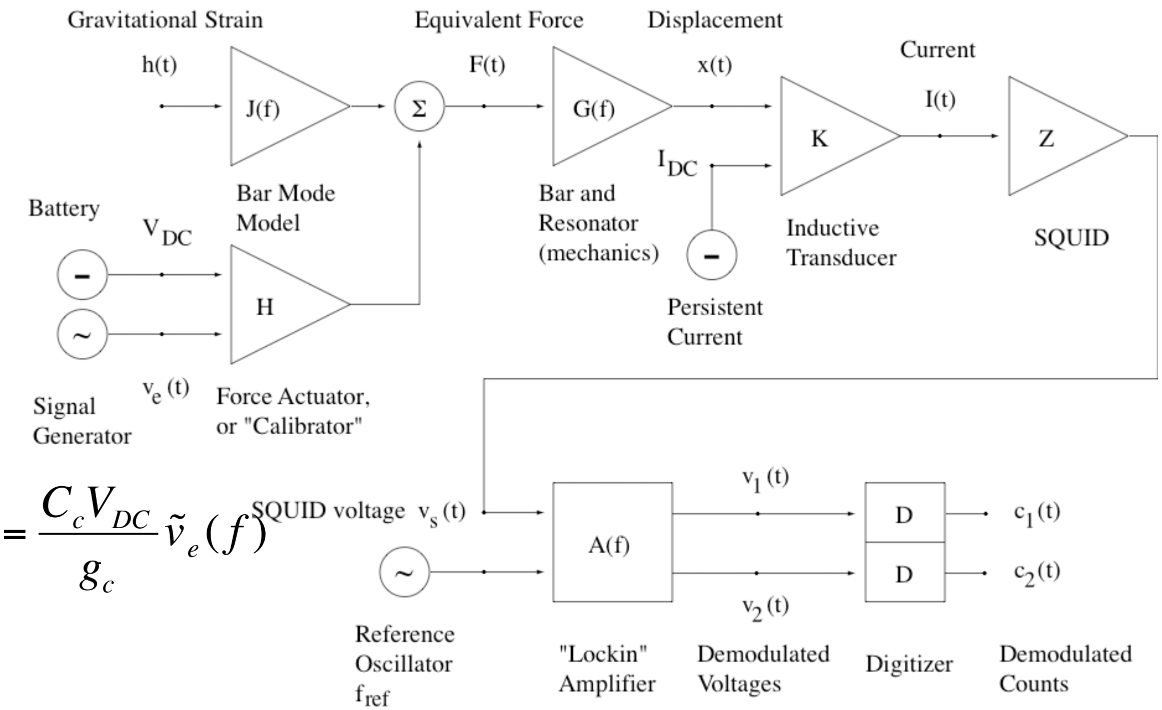
- LSC stochastic background analysis using S2 data from ALLEGRO and LIGO Livingston (see John Whelan's talk later today)
- Unlike an event list based search, a coherent search such as this requires a phase consistent response function for the detector signal path

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
Force Actuator, or "Calibrator"
Signal Generator
ve (t)
SQUID voltage vs (t)
Reference Oscillator fref
A(f)
"Lockin" Amplifier
v1 (t)
v2 (t)
Demodulated Voltages
D
D
Digitizer
c1 (t)
c2 (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 --

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

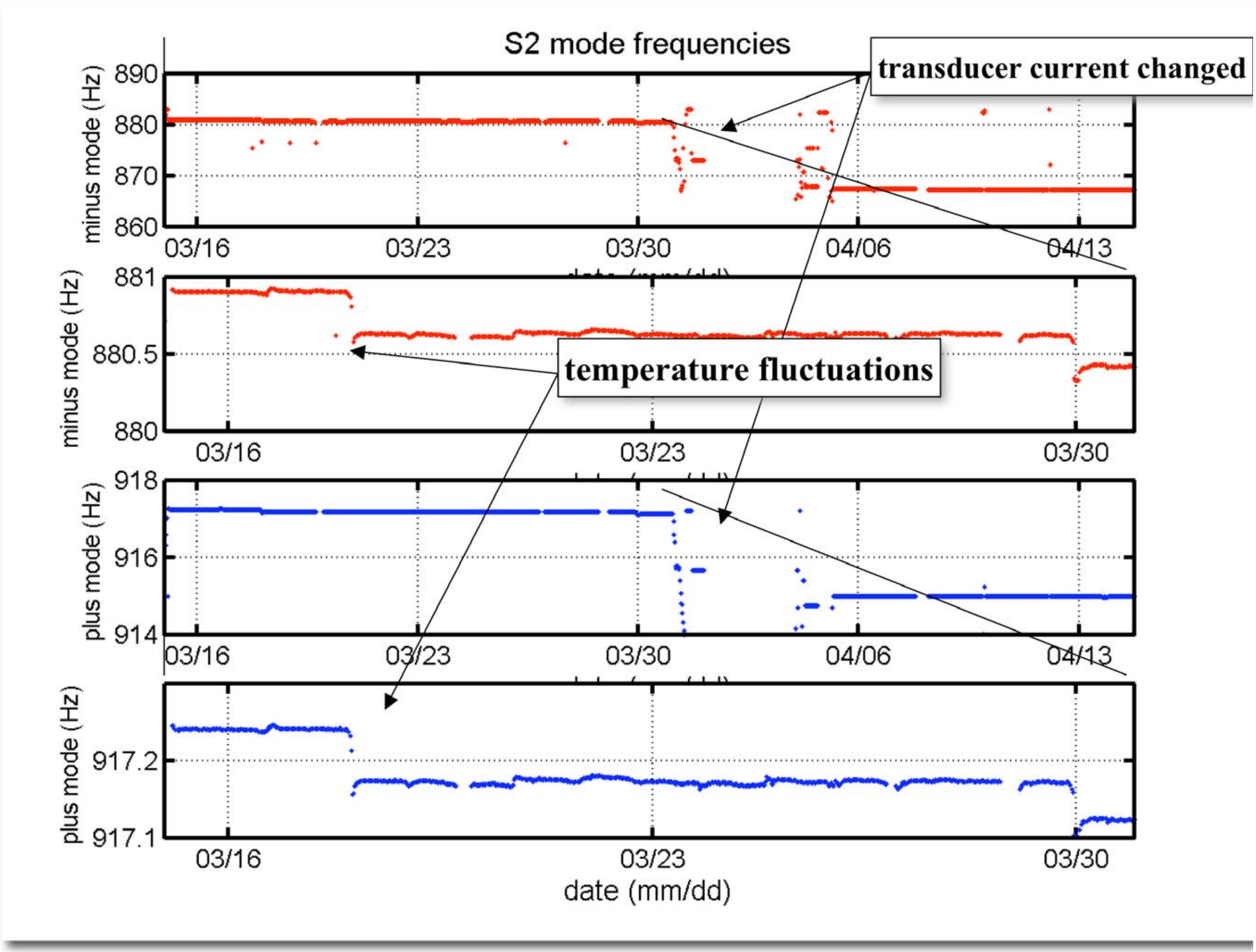
Inverse fft then gives

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

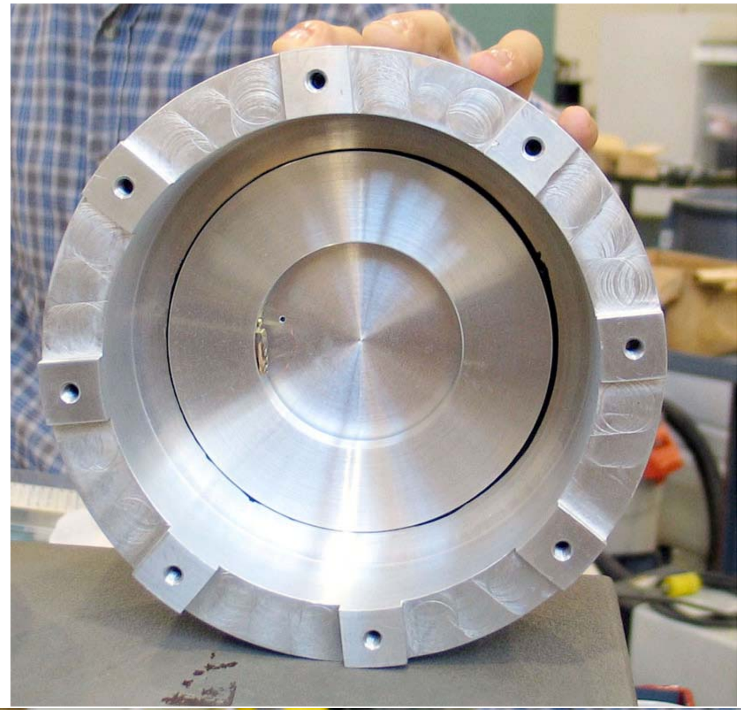
Need to determine --

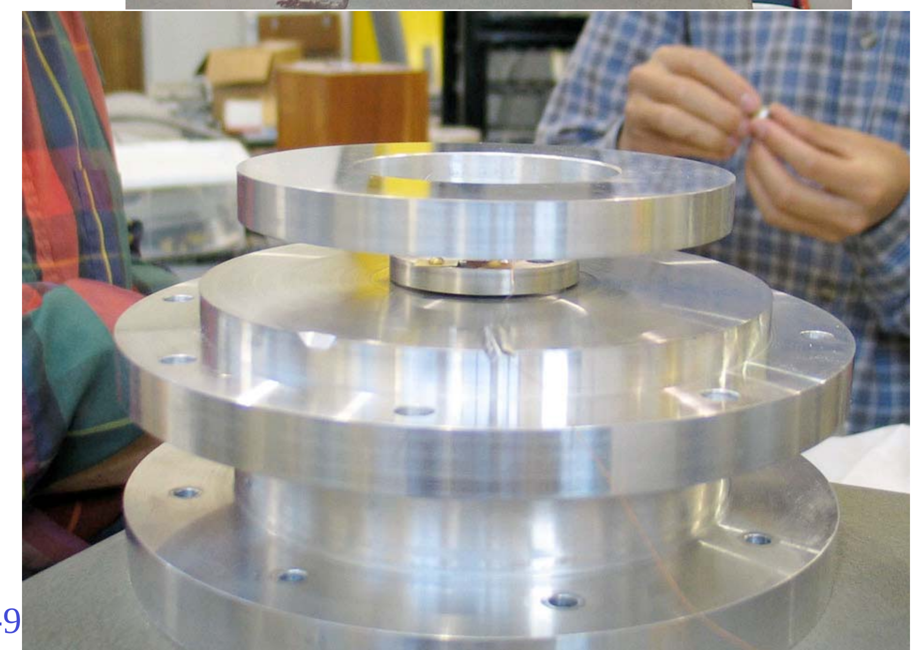
- Mode frequencies and Q's -- f_m, f_p, Q_m, Q_p
- overall scale -- in practice we measure $\alpha \cdot K \cdot Z$
  - α is mechanical gain -- includes 'tuning factor'
- Lock-in amplifier parameters -- gain, filter delay and phase shift
  - Also need to know the phase of the lock-in reference oscillator

S2 data -- 2003


S2 mode frequencies
transducer current changed
temperature fluctuations
minus mode (Hz)
890
880
870
860
03/16
03/23
03/30
04/06
04/13
minus mode (Hz)
881
880.5
880
03/16
03/23
03/30
plus mode (Hz)
918
916
914
03/16
03/23
03/30
04/06
04/13
plus mode (Hz)
917.2
917.1
03/16
03/23
03/30
date (mm/dd)

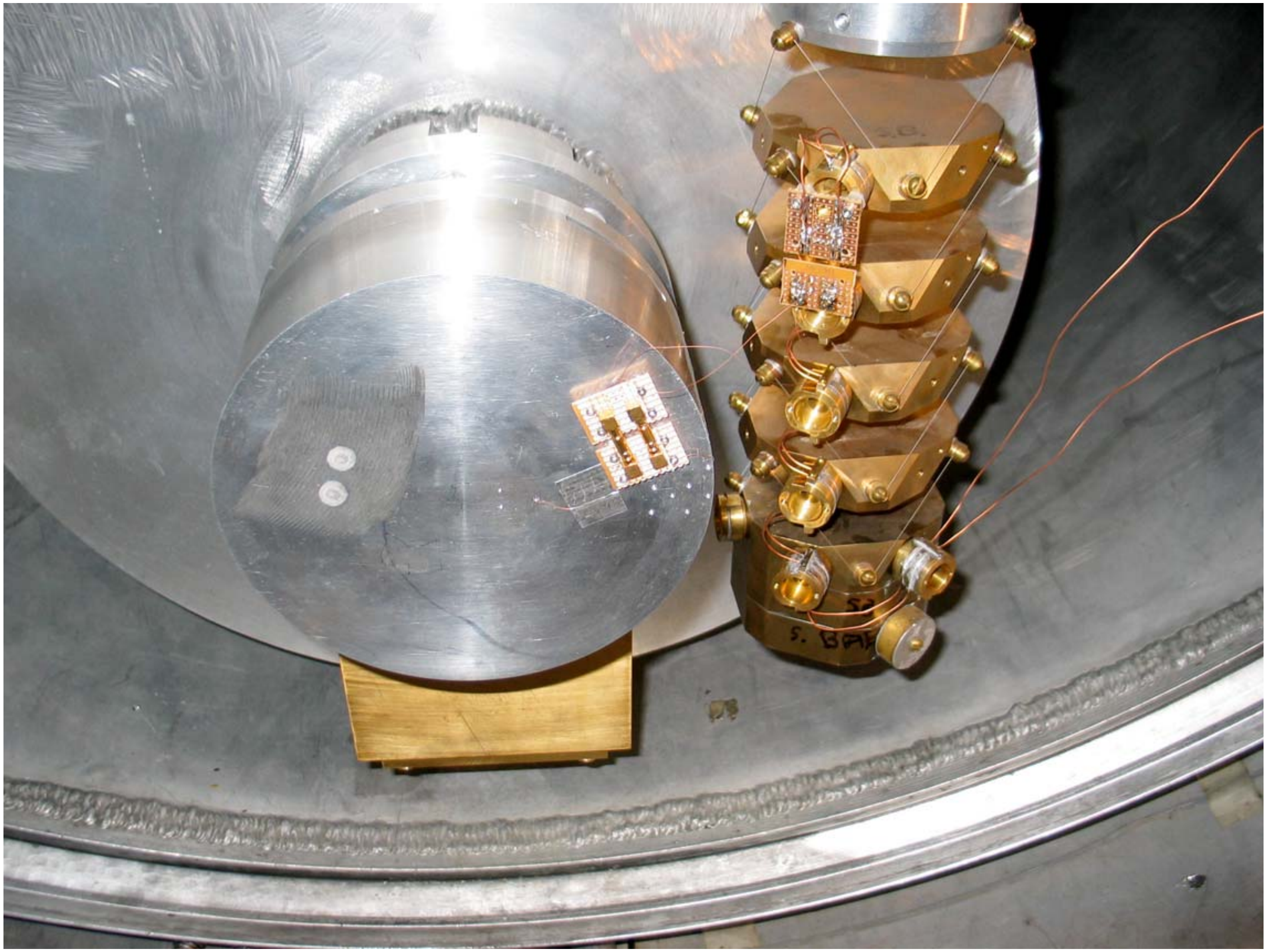
New calibrator





- 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.

The calibrator mounted on the bar

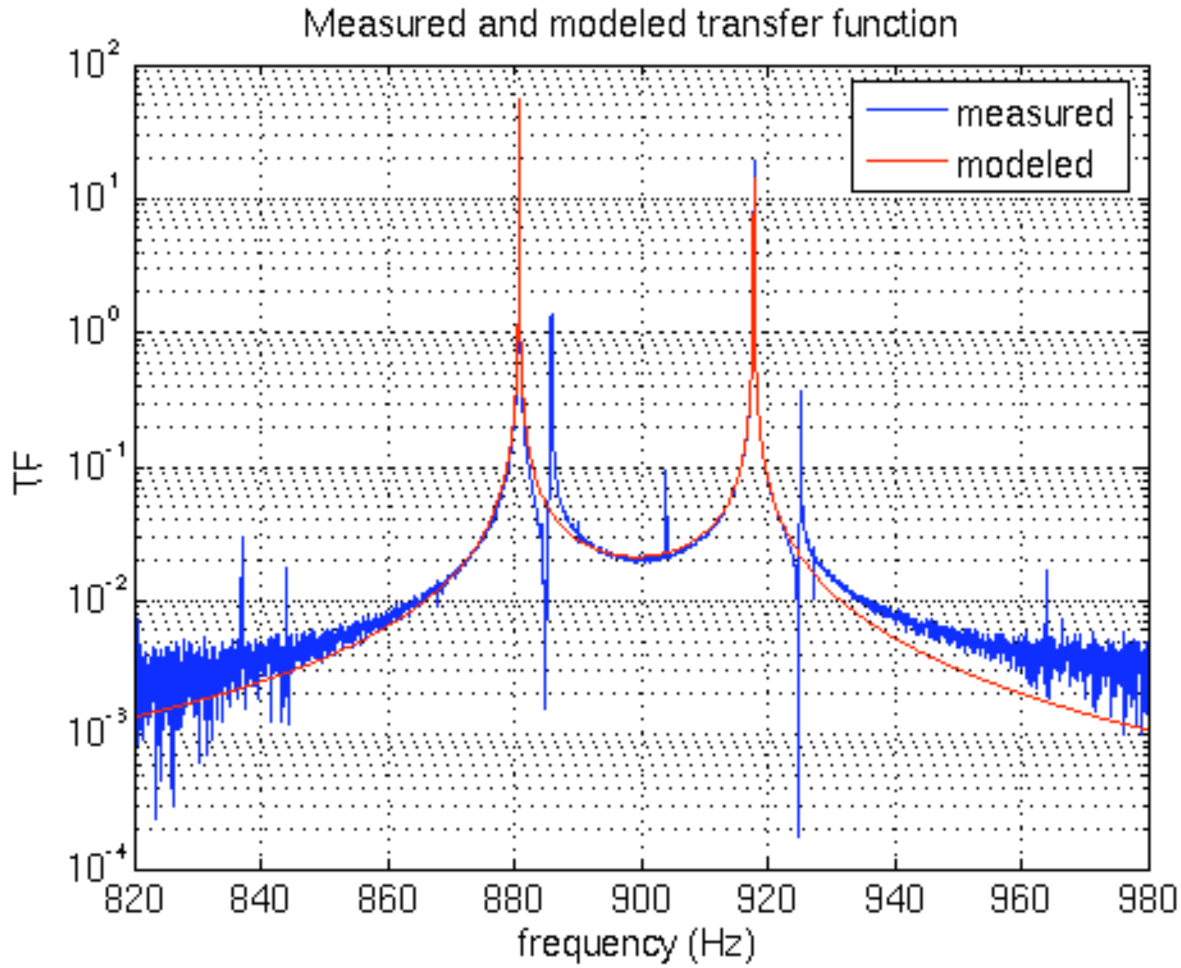


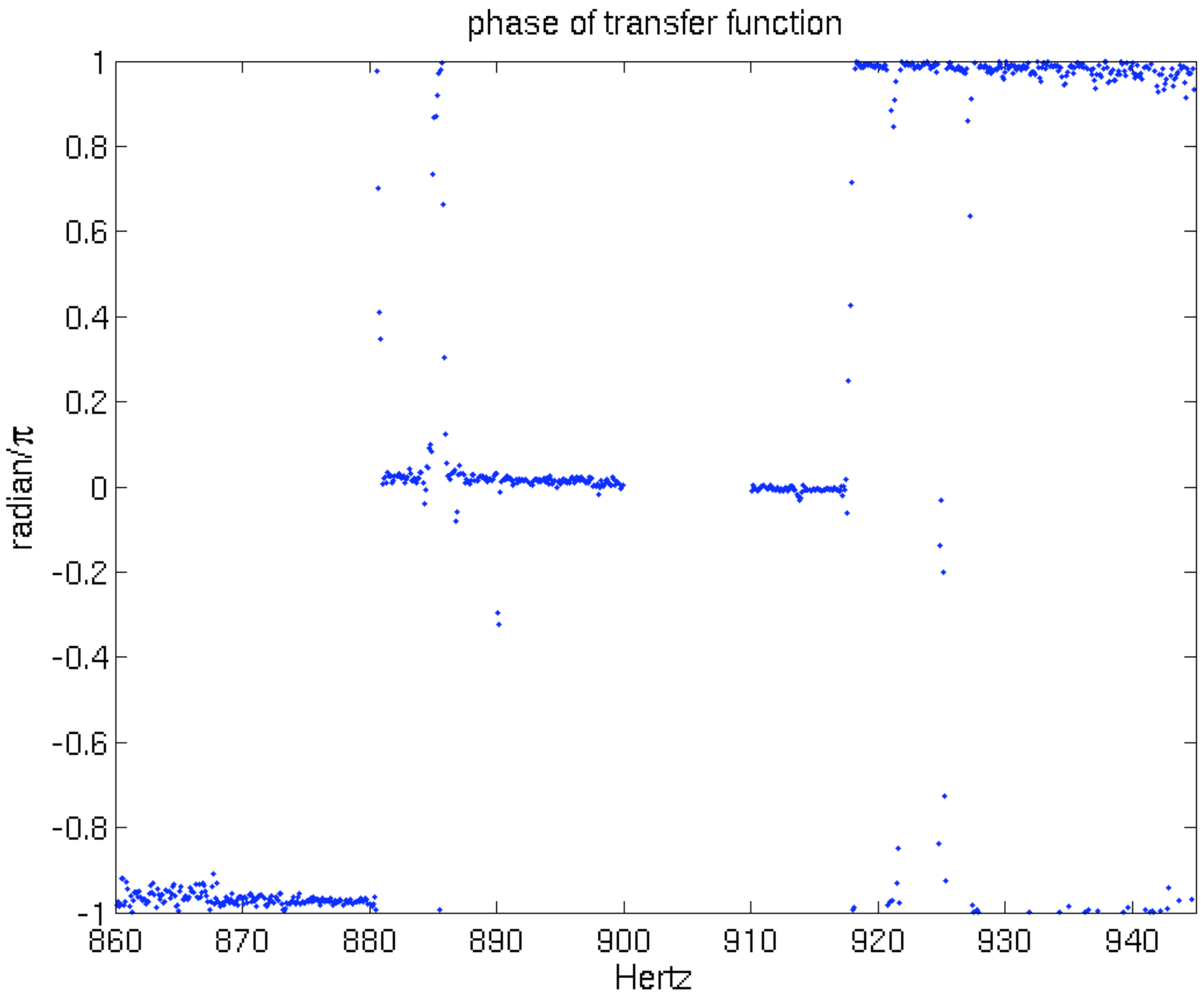
Transfer function - white noise excitation to measured output

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

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

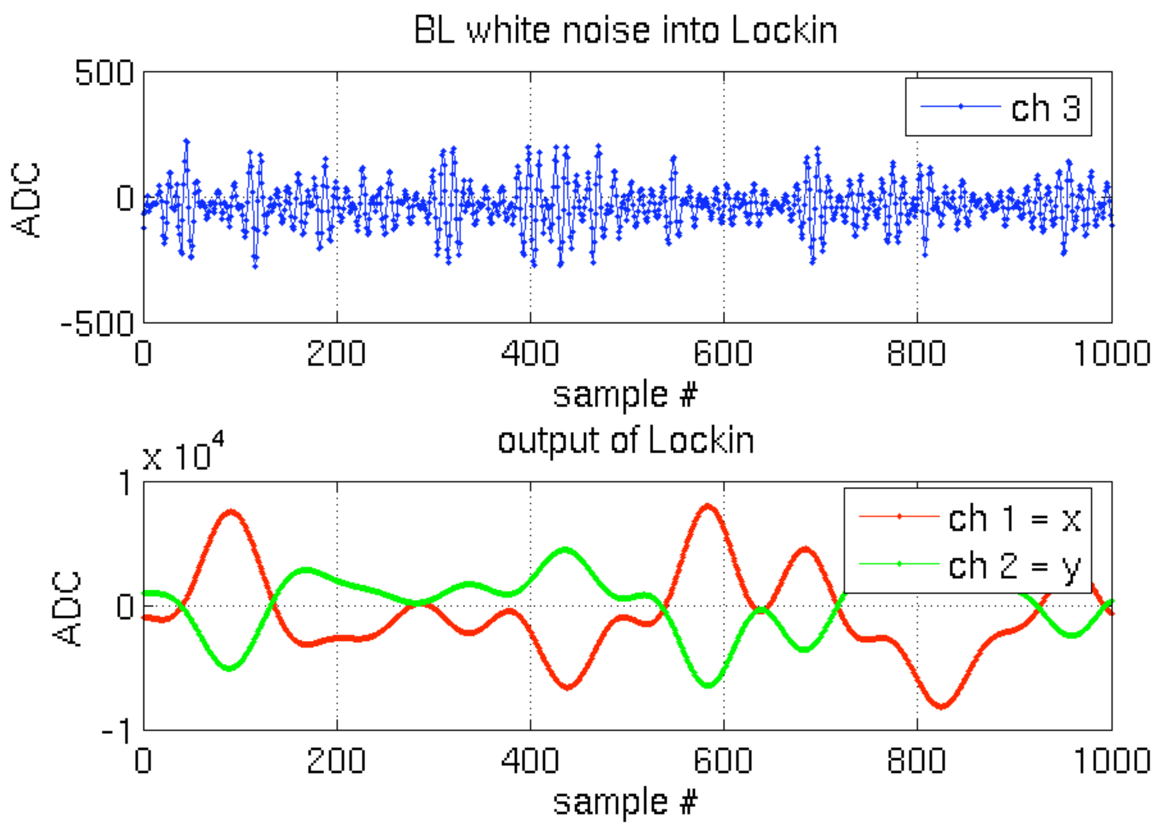
gives us the overall scale - α




phase of transfer function
radian/π
Hertz
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
860
870
880
890
900
910
920
930
940

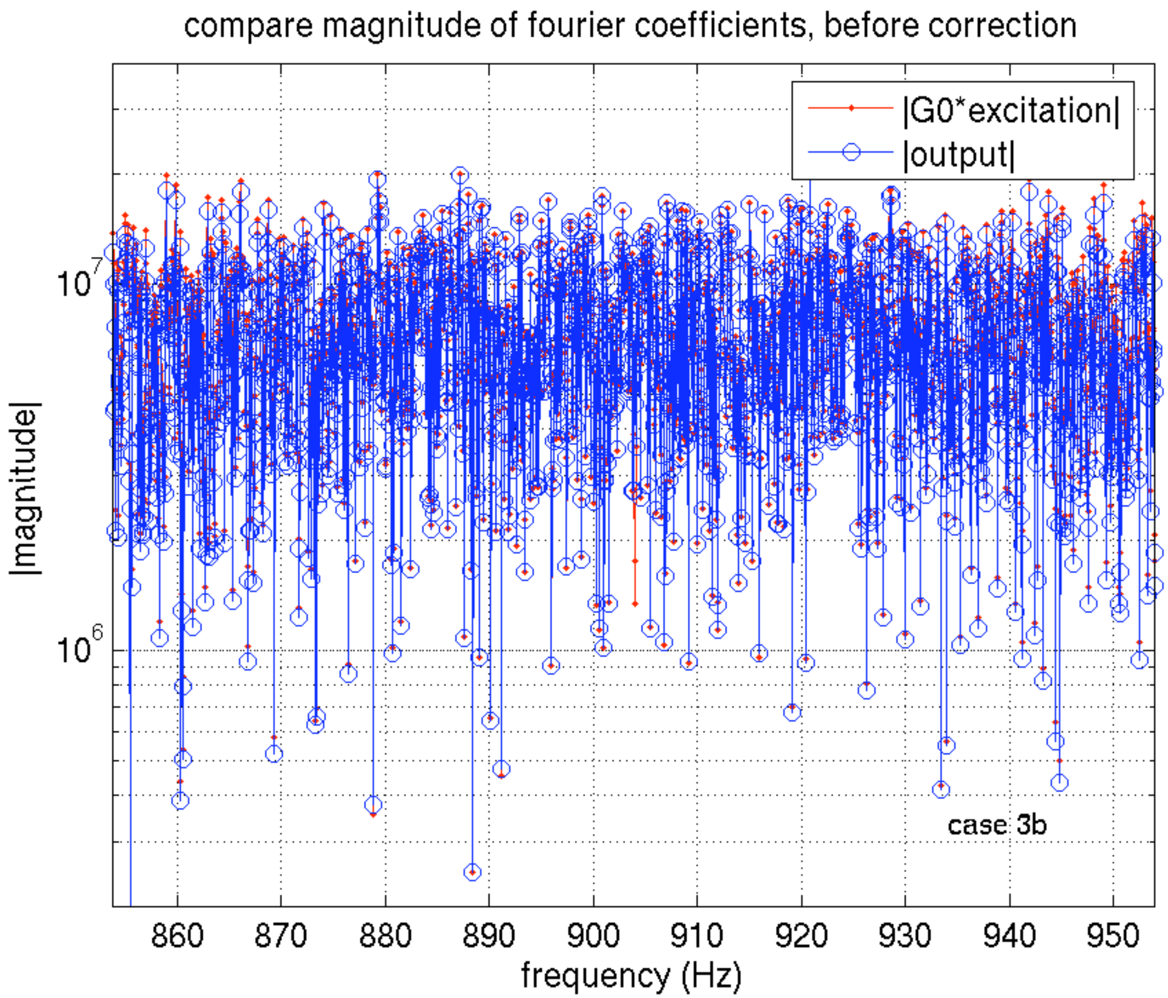
Lock-in measurements

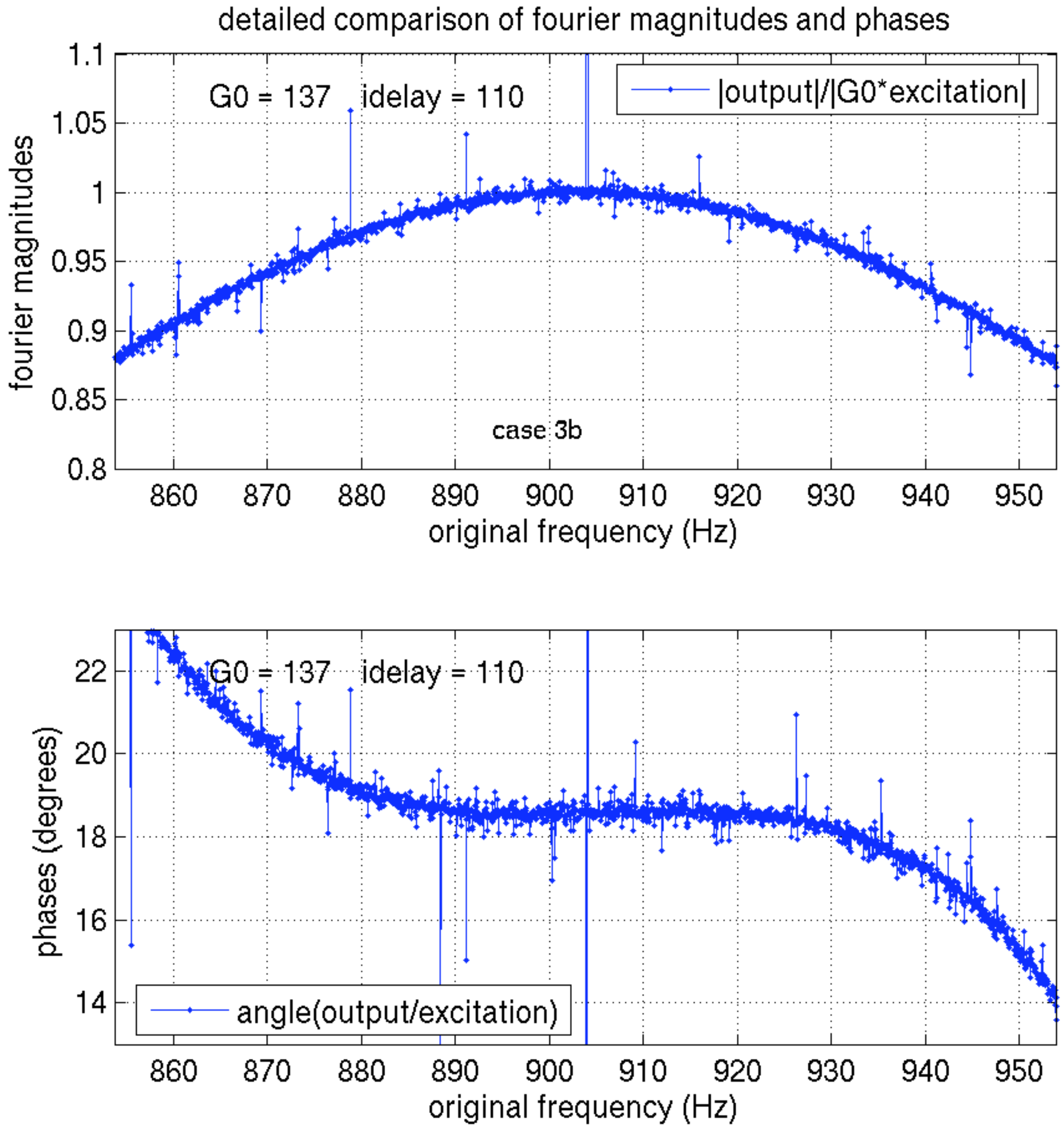
Band-limited white noise injection -- recorded directly and through lock-in/anti-aliasing filters

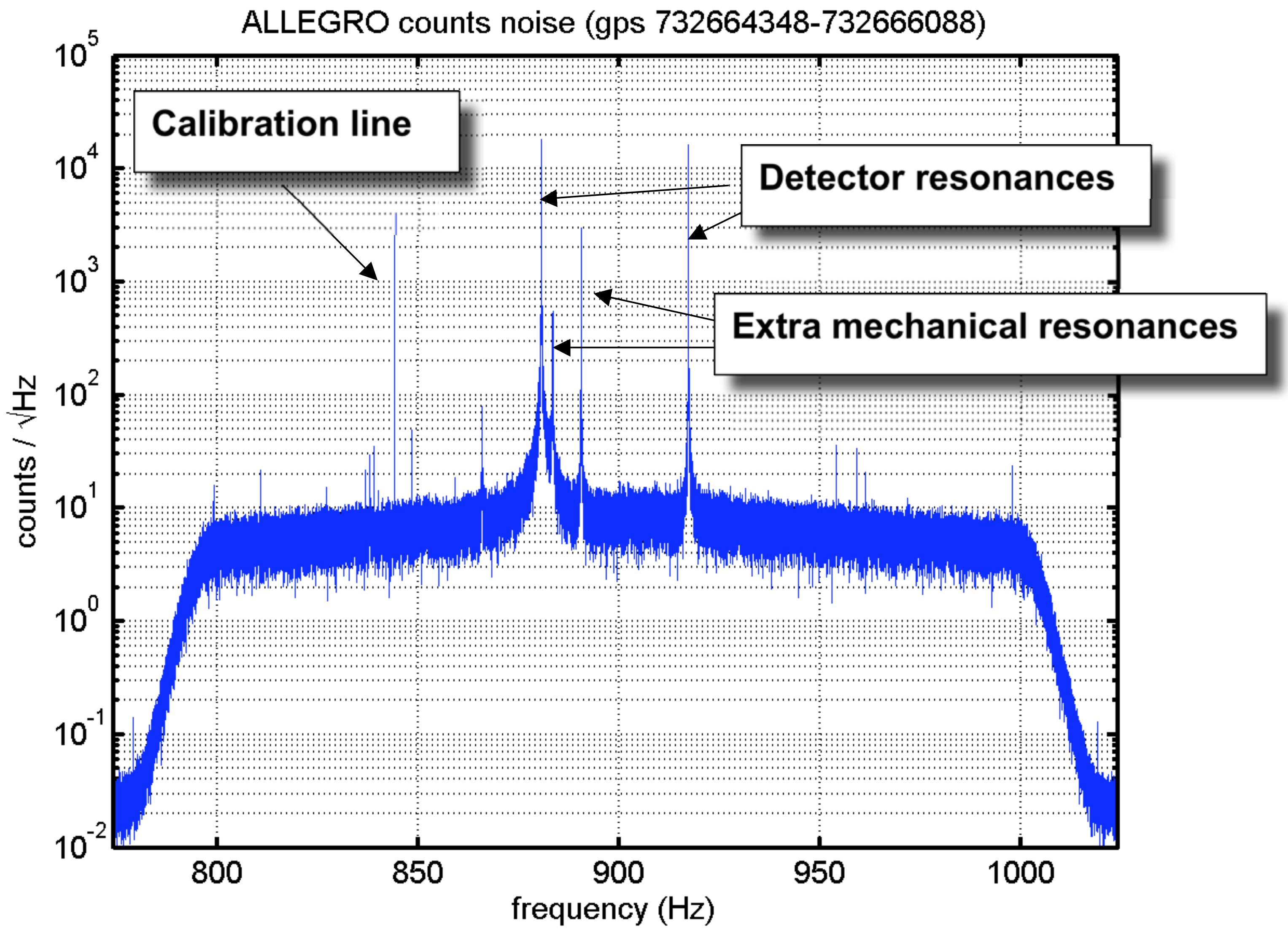


Compare fourier coefficients

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

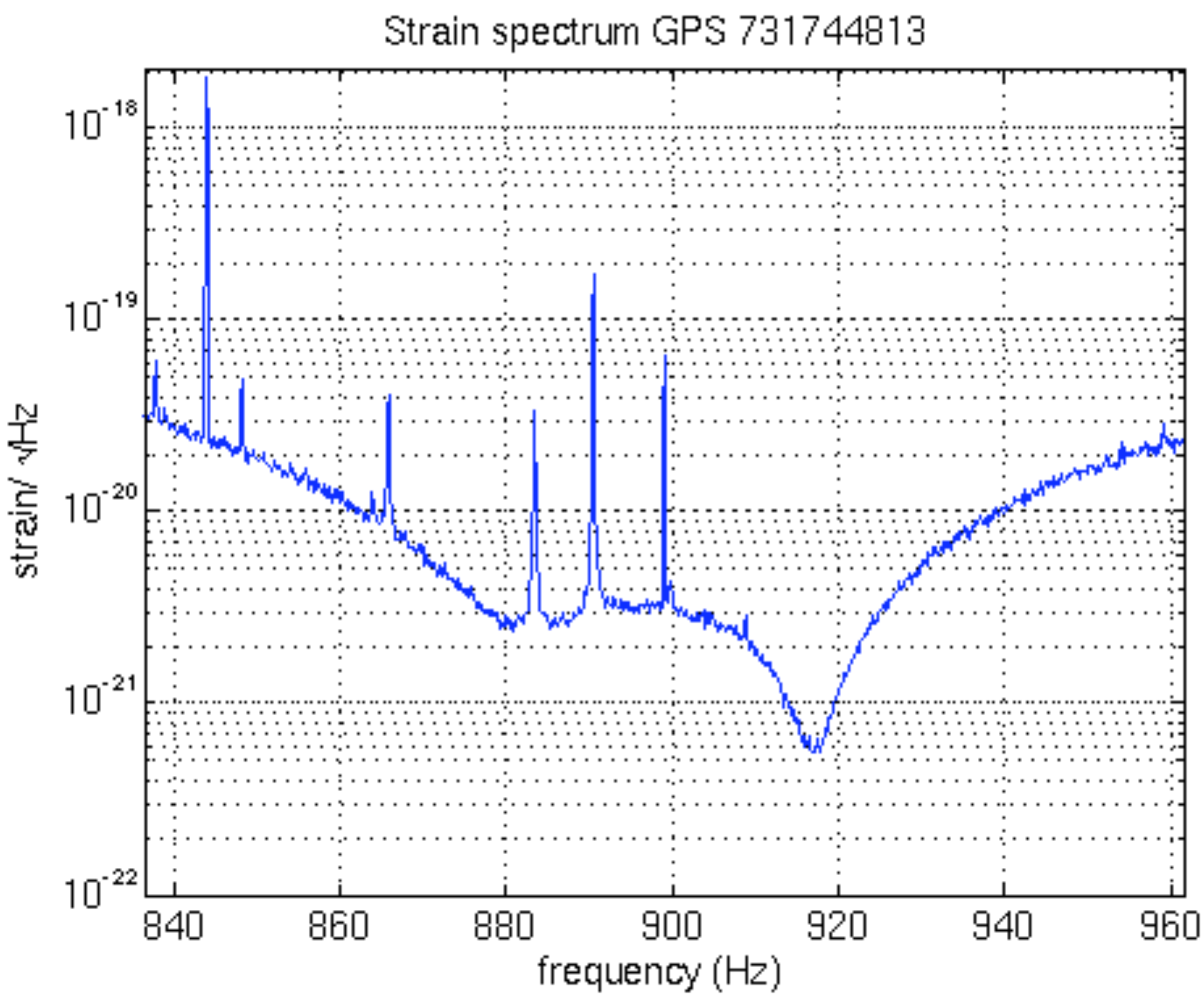



detailed comparison of fourier magnitudes and phases
G0 = 137 idelay = 110
|output|/|G0*excitation|
fourier magnitudes
case 3b
original frequency (Hz)
1.1
1.05
1
0.95
0.9
0.85
0.8
860
870
880
890
900
910
920
930
940
950
G0 = 137 idelay = 110
phases (degrees)
angle(output/excitation)
22
20
18
16
14
original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

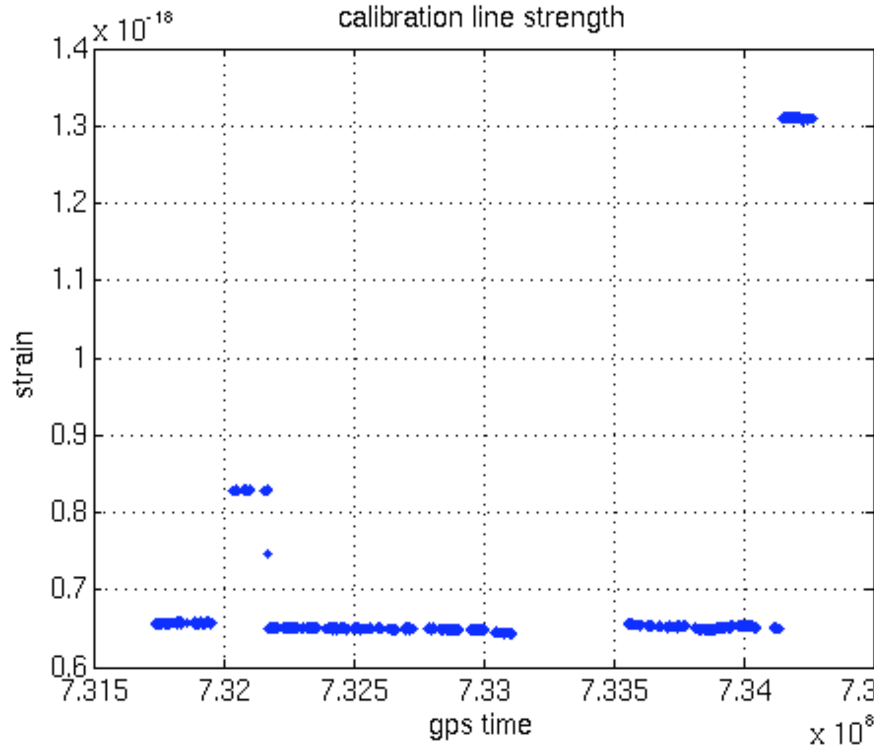


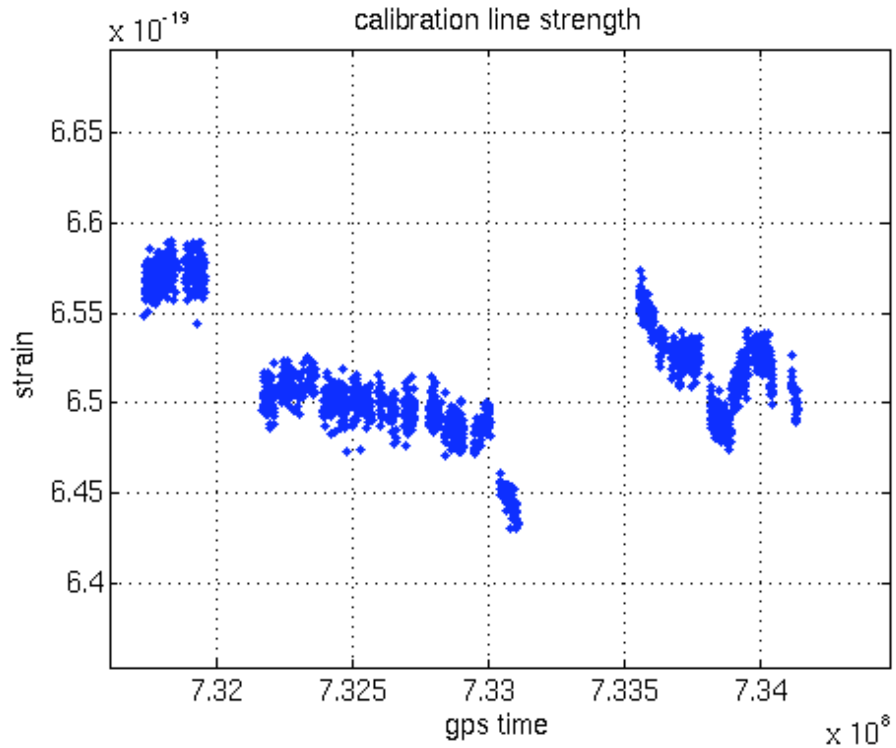
ALLEGRO counts noise (gps 732664348-732666088)
Calibration line
Detector resonances
Extra mechanical resonances
counts / √Hz
frequency (Hz)
10^5
10^4
10^3
10^2
10^1
10^0
10^-1
10^-2
800
850
900
950
1000

Calibrated strain spectrum from S2



Stability of calibration





Summary, future

- We have calibrated $h(t)$ for S2 data set at level $\leq 10\%$
- Currently stored in Matlab files, plan to put these data into frames
- detector much more stable now, should continue through S4
  - will determine overall sign
  - hardware injections are planned