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

or

calibration of ALLEGRO data

Martin McHugh
Loyola University New Orleans

on behalf of the
ALLEGRO group

http://sam.phys.lsu.edu/

GWDAW-9, Annecy
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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

ALLEGRO
Physical and Electrical schematic

Callibrator

Transducer

BAR
M=2295 kg
L=3.0 m

\[ -I_0 - 1/2 \]

\[ I = 1/2 I \]

\[ T \]

\[ W_i \]

\[ V_s \]
Signal path

Gravitational Strain

h(t)

Bar Mode Model

Battery

V_{DC}

V_e(t)

Signal Generator

Force Actuator, or "Calibrator"

Gravitational Strain

J(f)

Gravitational Strain

Gravitational Strain

Equivalent Force

F(t)

Displacement

x(t)

Current

I(t)

Inductive Transducer

Persistent Current

K

SQUID

SQUID voltage v_s(t)

"Lockin" Amplifier

Demodulated Voltages

Digitizer

Demodulated Counts

Reference Oscillator f_{ref}

A(f)

D

c_1(t)

c_2(t)
\[ \tilde{F}_C(f) = H\tilde{v}_e(f) = \frac{C_v V_{DC}}{g_c} \tilde{v}_e(f) \]

Form of each Transfer Function

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

\[ \tilde{x}(f) = G(f)\tilde{F}(f) \]

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

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

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

\[ \tilde{z}_v(f - f_r) = A(f)\tilde{v}_S(f) = a_L e^{i(t_d 2\pi(f - f_r))} e^{-i\phi} \tilde{v}_S(f) \]

\[ \tilde{z}_c(f - f_r) = D \cdot \tilde{z}_v(f - f_r) \]
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

\[ h^H(t) \text{ complex heterodyned strain time series} \]

Need to determine --

- Mode frequencies and Q’s -- $f_m, f_p$, $Q_m, Q_p$
- Overall scale -- in practice we measure $\alpha \cdot K \cdot Z$
  - $\alpha$ 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

Graphs showing frequency data with notes on transducer current change and temperature fluctuations.
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 - \( \alpha \)
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
ALLEGRO counts noise (gps 732664348-732666088)

- Calibration line
- Detector resonances
- Extra mechanical resonances
Calibrated strain spectrum from S2
Stability of calibration

Stability of calibration

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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