Calibration of LIGO data in the time domain

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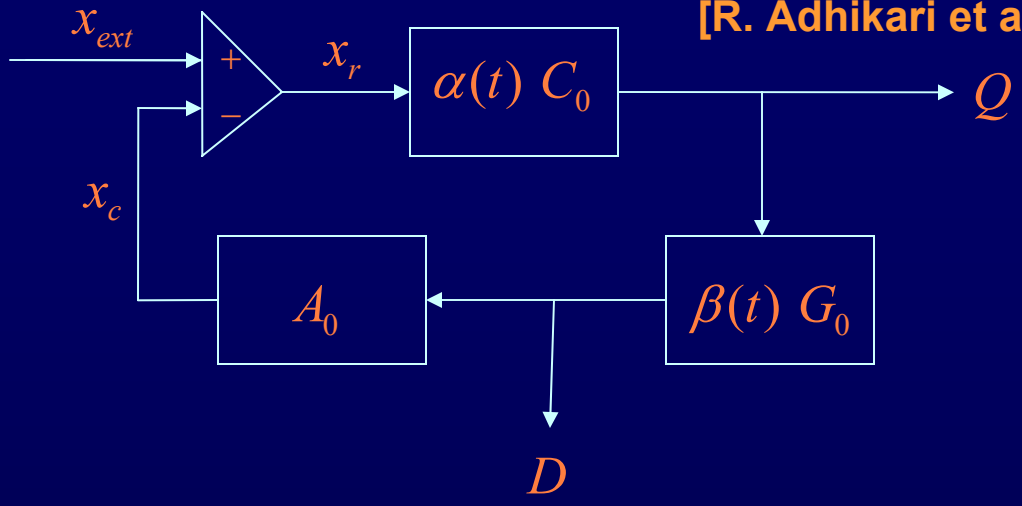
-So far LIGO data has been calibrated in the frequency domain.

-For the S1 analysis 60s Fourier transforms were used. The change in the response of the instrument was computed every minute.

-For the S2 analysis the pulsar working group decided to use 1800s long Fourier transforms to take advantage of the speed of FFT.

-GEO has been producing h(t) and we can adapt their method to calibrate our data.

[R. Adhikari et al. LIGO-T030097-00-D]



We reconstruct the strain from the residual and control motions:

[Mohanty and Rakhmanov, August 2003 LSC Meeting]

$$x_r(f_c) = x_{ext}(f_c) - x_c(f_c)$$

$$\Rightarrow x_{ext}(f_c) = x_r(f_c) + x_c(f_c)$$

$$x_{ext} = \frac{1}{\alpha(t)\,C_0}\,Q + A_0\beta(t)G_0\ \ Q$$

$$D$$

High frequency

Low frequency

Need to construct digital filters for the inverse sensing function $\left(\alpha(t)C_0\right)^{-1}$, the servo $\beta(t)\ G_0$, and the actuation function A_0

Have implemented time domain calibration for S2/H1.

Sensing function

-cavity pole at 84.8 Hz
[Inverse of pole is unstable: Stabilise it by adding a zero at 100 kHz and filter up-sampled (by a factor of 16) Q through it]

-anti-aliasing 8th order elliptic filter at 7.5KHz
[Has zeros on imaginary axis which need to be moved off; Inverse rises sharply at 7.5 kHz: low-pass at 6kHz with high order BW filter]

-a pole at 100kHz
[We ignore it]

-electronics gain

Have digitised the modified sensing function using a bi-linear transformation at 16384*16Hz

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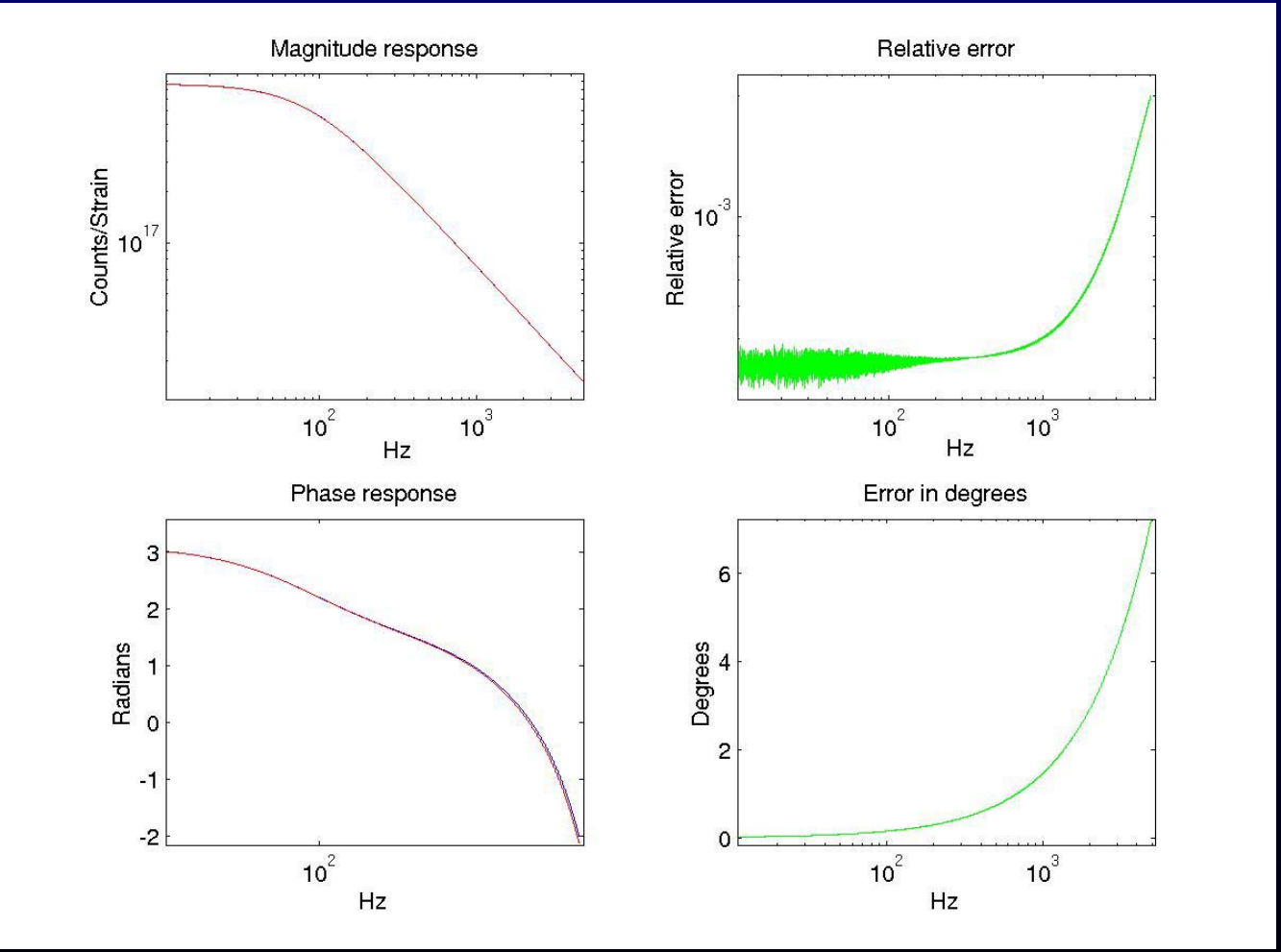
Response of digital filter (blue) vs. official sensing function (red):

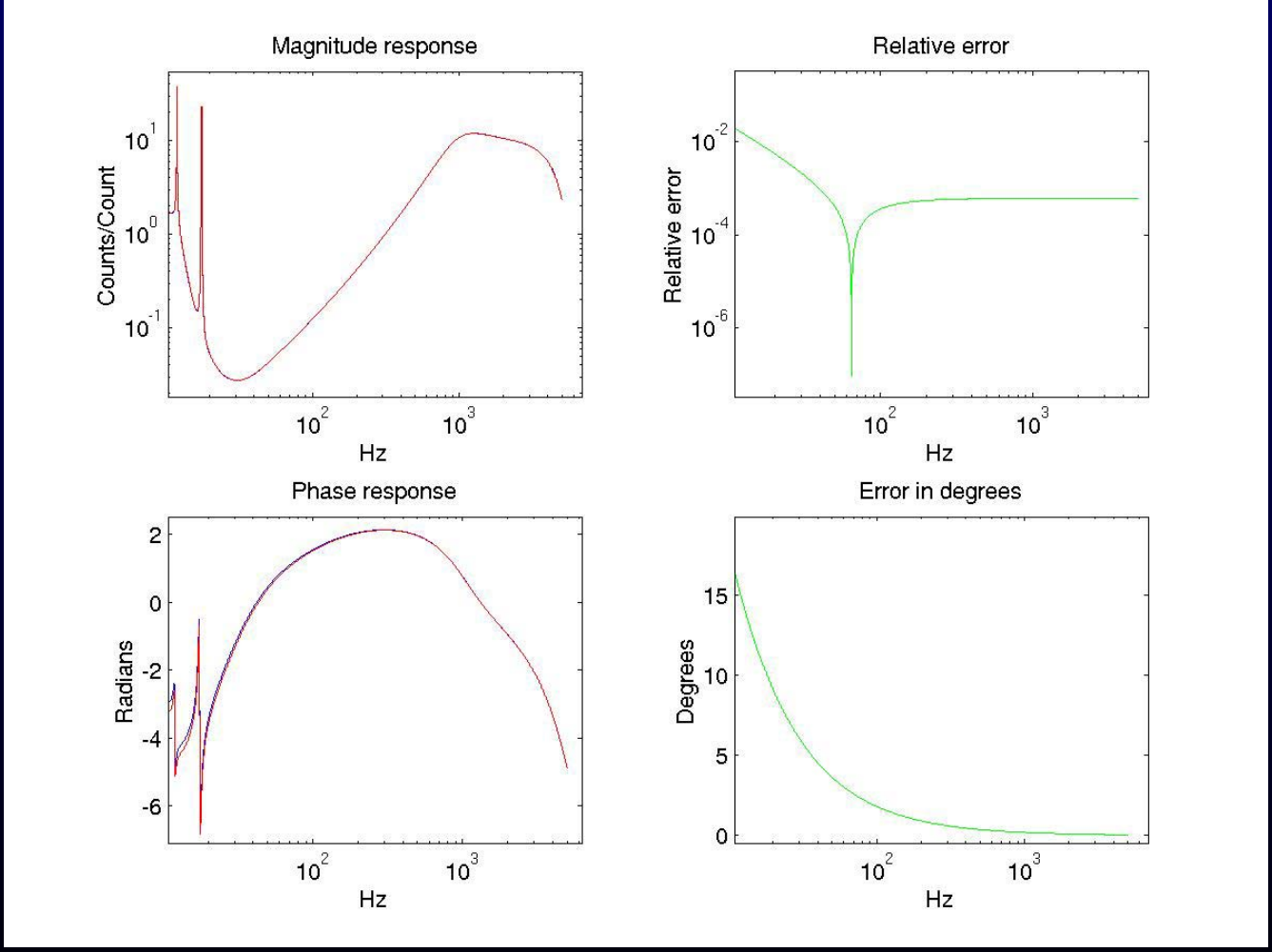


Servo

-11 2nd order digital filters

[problems with first filter: a double pole at 0Hz which we moved to 1.6Hz]

Response of modified servo (blue) vs. actual servo (red):

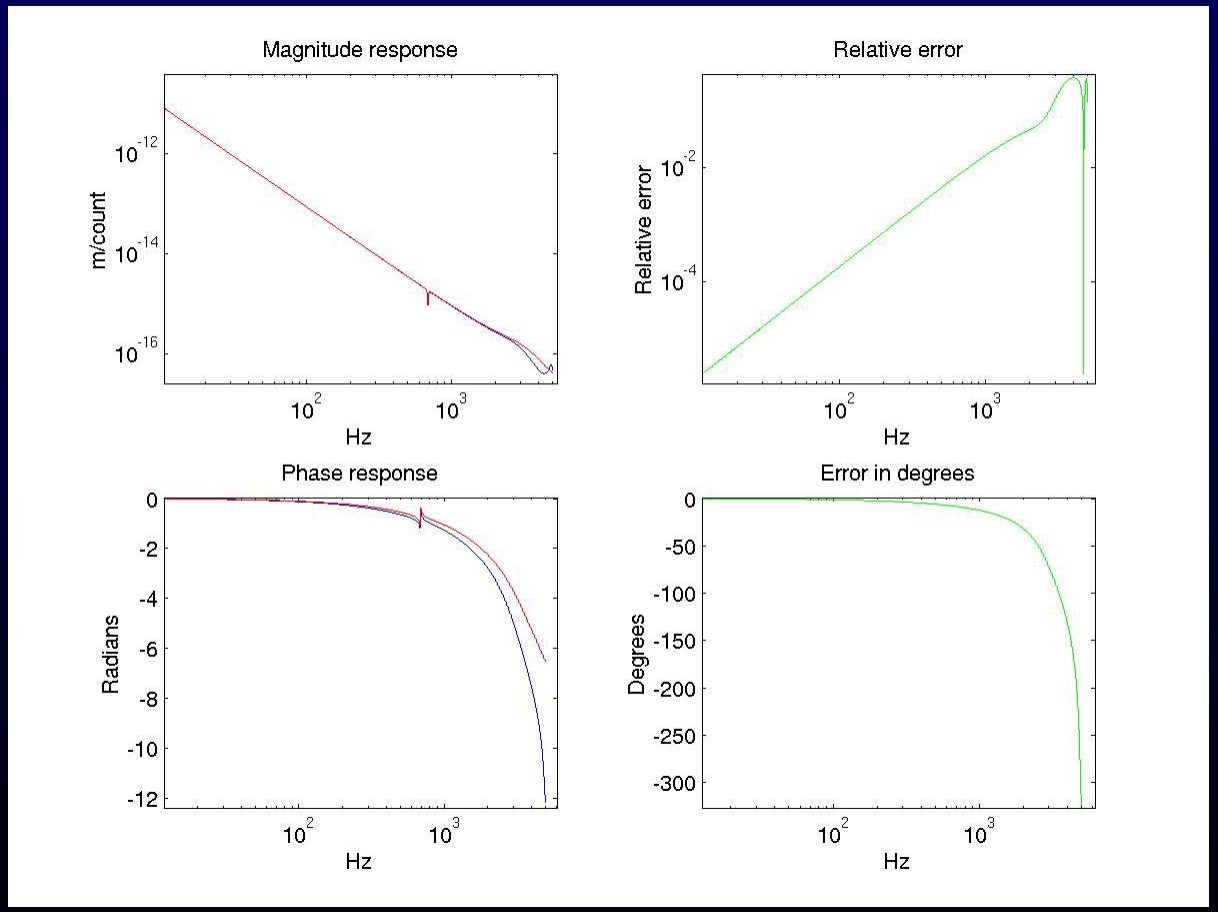


Actuation function

-13 2nd order digital filters (7 for x-arm, 6 for y-arm), pendulum transfer function, anti-imaging 4th order elliptic filter at 7.5kHz, time delay Pade filter, snubber

Analog part of this filter was digitised using a bilinear transformation at 16384Hz

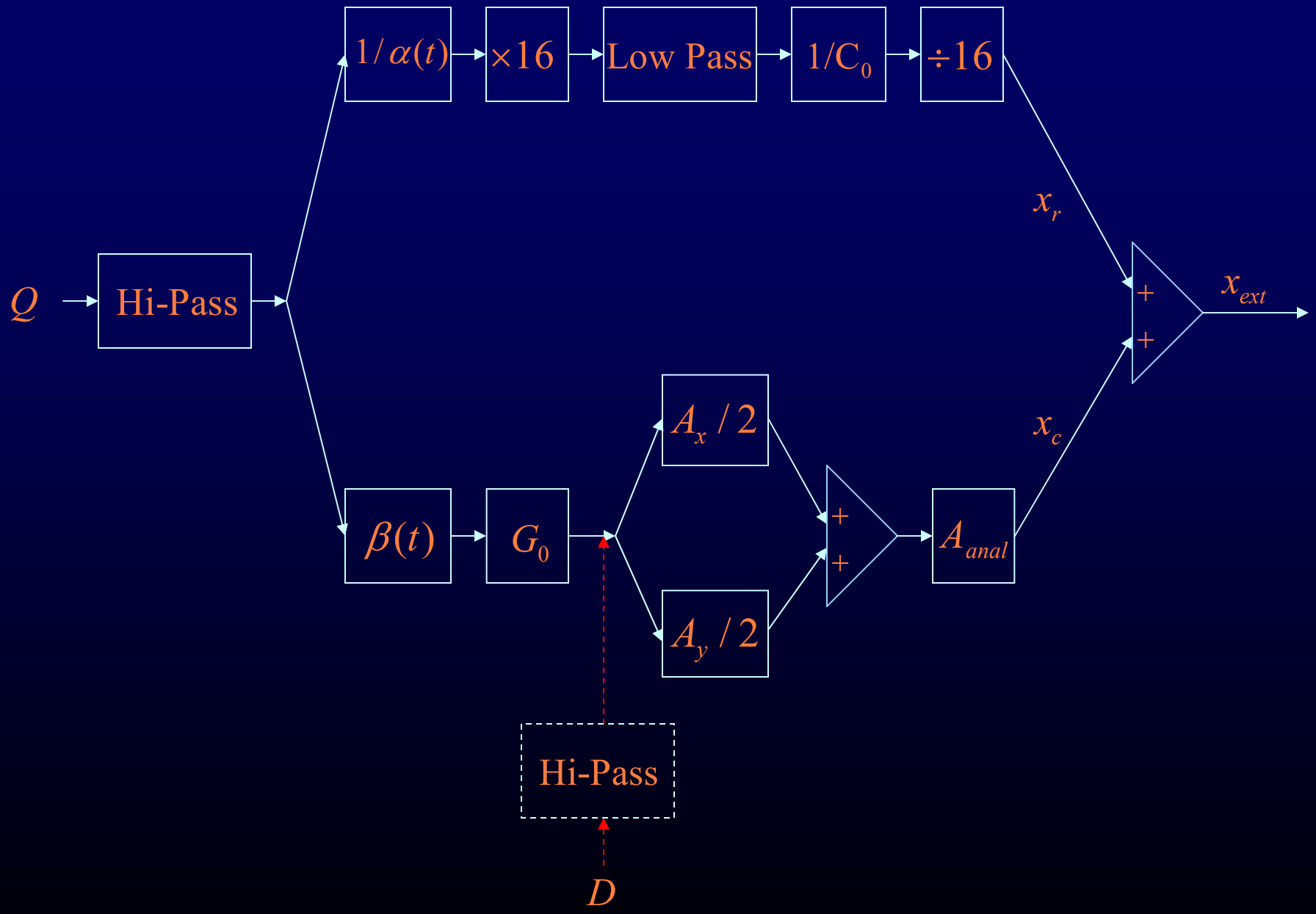
Response of digitised actuation (blue) vs. official actuation (red):



m/count

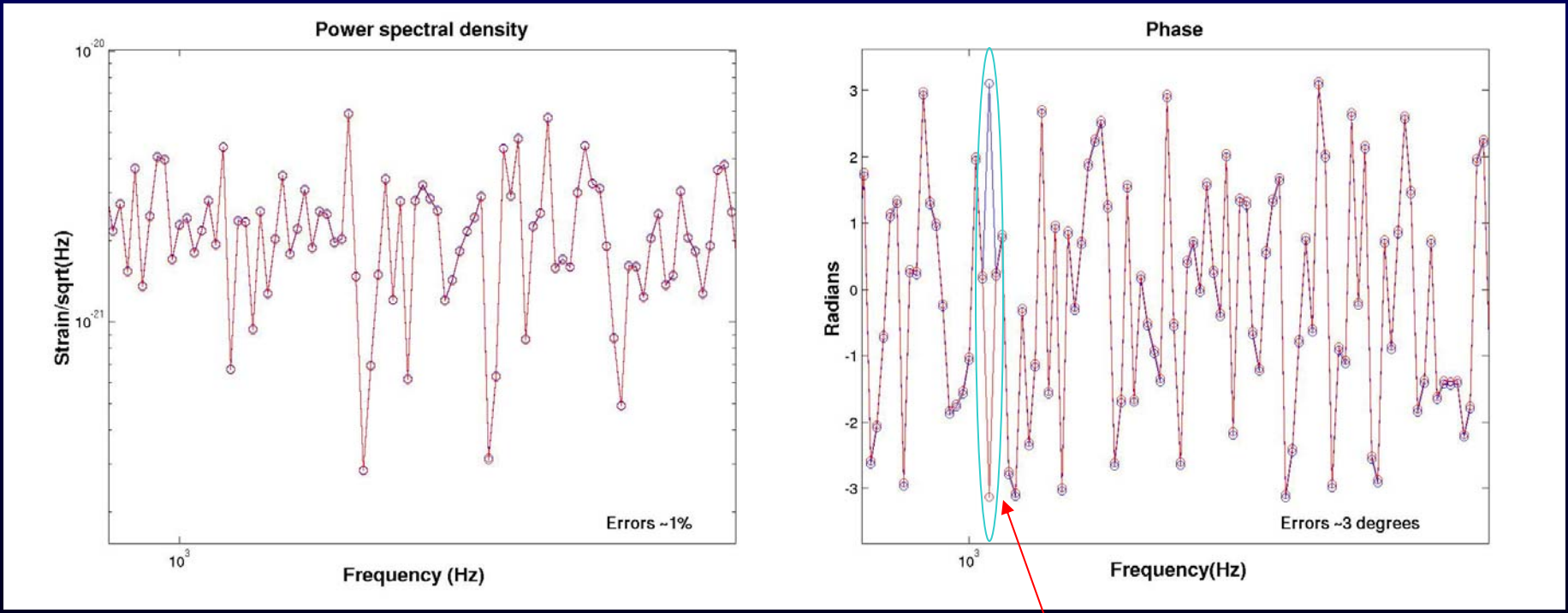
Actuation makes no difference at high frequencies!

Signal Processing Pipeline:



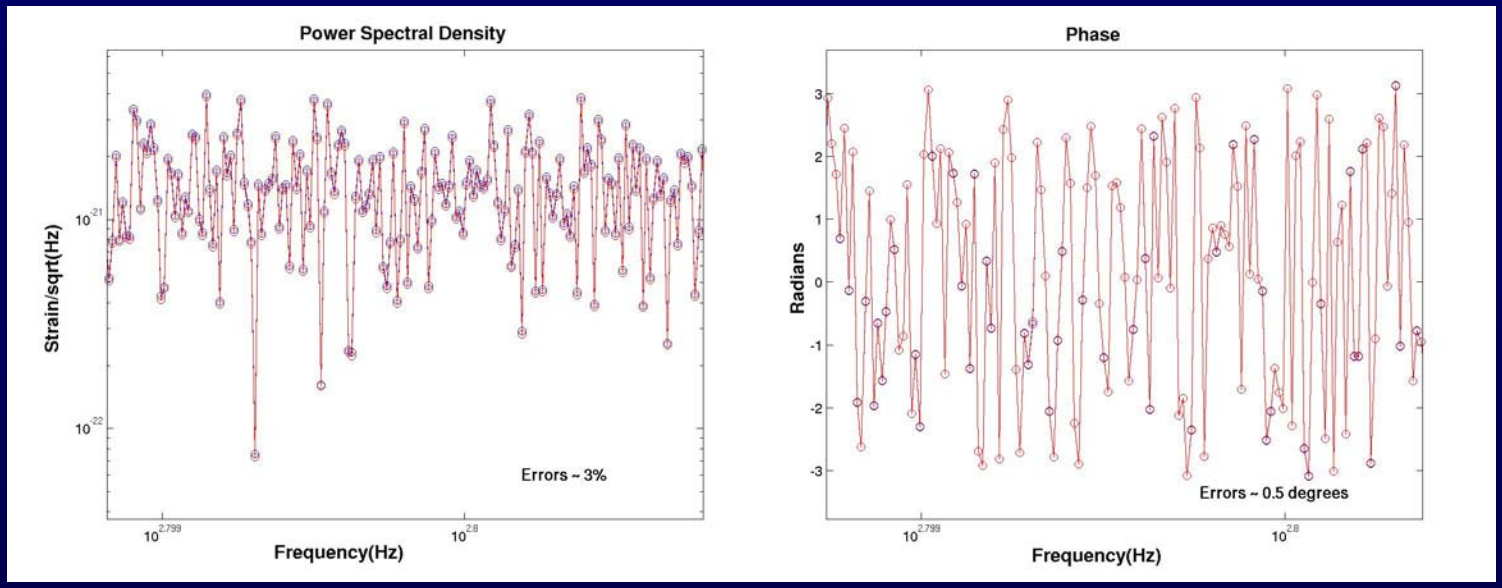
Comparison of Fourier transform of time domain calibrated data (blue) with data calibrated in the frequency domain (red).

~1Hz band around 1000Hz at 1/60 Hz:

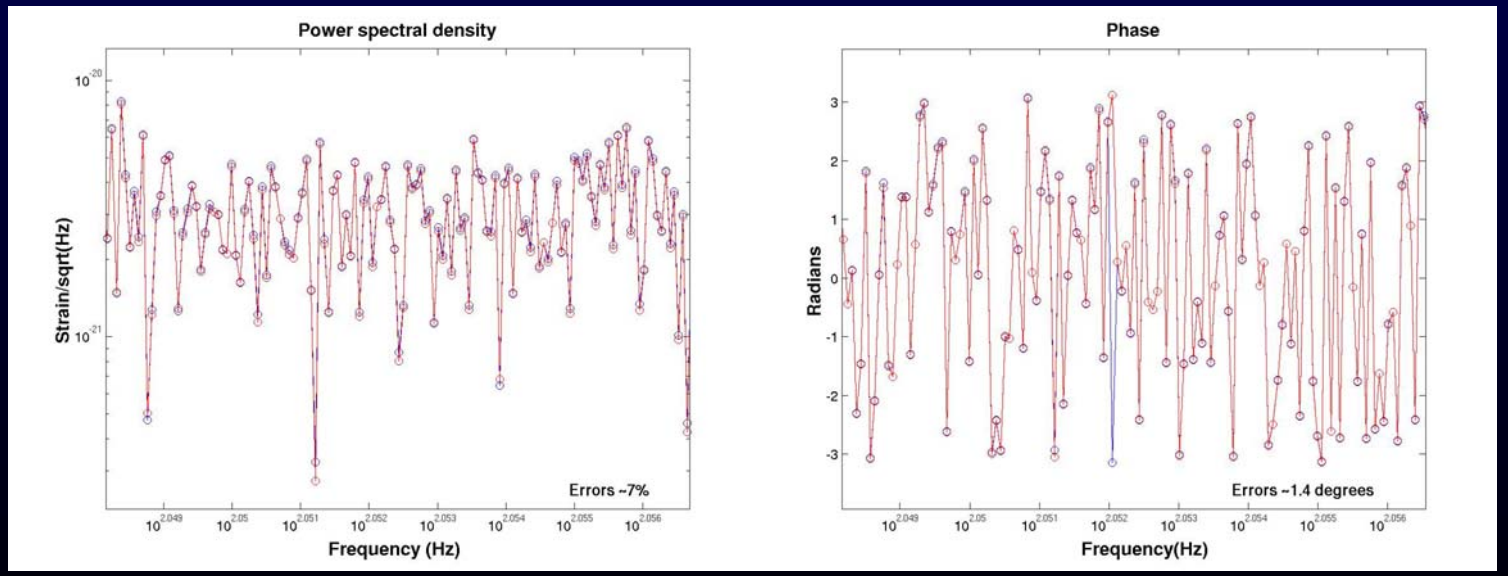


Wrap-around

Around 630Hz:



Around 112Hz:



Conclusions

-All elements of pipeline are in place

-Code has been parallelized (under condor) and full S2/H1 dataset is calibrated on Medusa (UWM) in a few hours. The output is 16s frames.

-Still need filters for H2 and L1.

-Will keep working on filter and pipeline optimization.