S2 Calibration

Calibration team

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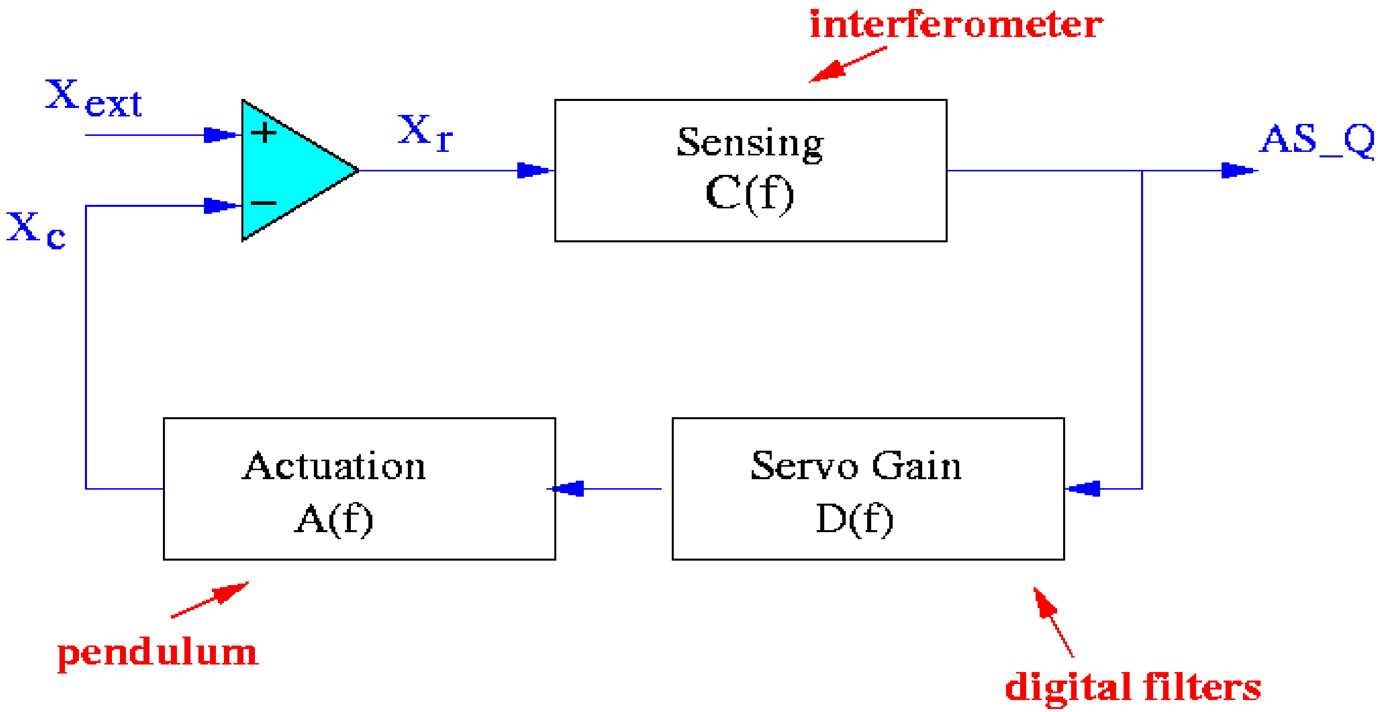
Calibration Basics



$$X_i = AS\_Q(f_i,t)R(f_i,t) = AS\_Q(f_i,t)\left[\frac{1+\alpha(t)\beta(t)G(f_i)}{\alpha(t)C(f_i)}\right]$$

R(f): Response Function   α: Scale Factor (from Calibration Line)

β: Tracks **DARM** gain   G(f): Open Loop Gain = C(f)•D(f)•A(f)

Calibration Basics

- We choose a time **t** and measure α,**A**,**D** and **G** and compute **R**.
- We do not measure **C** directly.
- This allows us to extrapolate to any time **t**.

$$R(f_i,t_0)=\frac{1+\alpha(t_0)G(f_i,t_0)}{\alpha(t_0)C(f_i,t_0)}=\frac{1+G_0}{C_0} \qquad R(f_i,t)=\frac{1+\alpha(t)G_0}{\alpha(t)C_0}$$

$$R(f_i,t)=\frac{1+\alpha(t)[C_0R_0-1]}{\alpha(t)C_0}$$

or

$$R(f_i,t)=\frac{R_0}{\alpha(t)}\left[\frac{1+\alpha(t)G_0}{1+G_0}\right]$$

The Loop Gain G

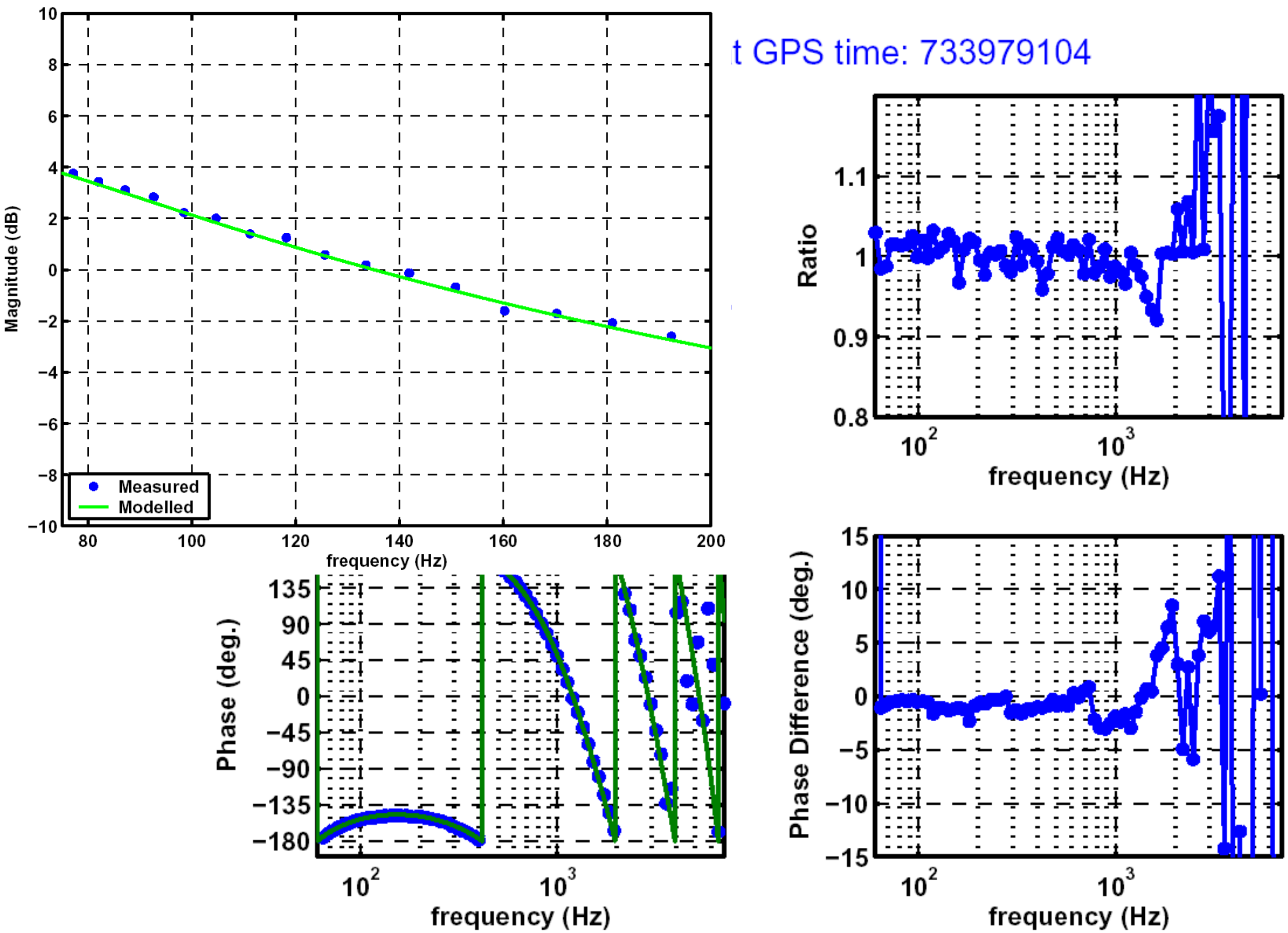
- We measure the loop gain by matching a swept-sine transfer function of the DARM loop to a MATLAB model.

- Good coherence reduces the error arising from the swept-sine measurement.

$$\Delta = \frac{\sqrt{\left(1-\gamma^{2}\right)}}{\gamma\sqrt{2\,N_{Avg}}}$$

- Main source of error lies in the match to the model.

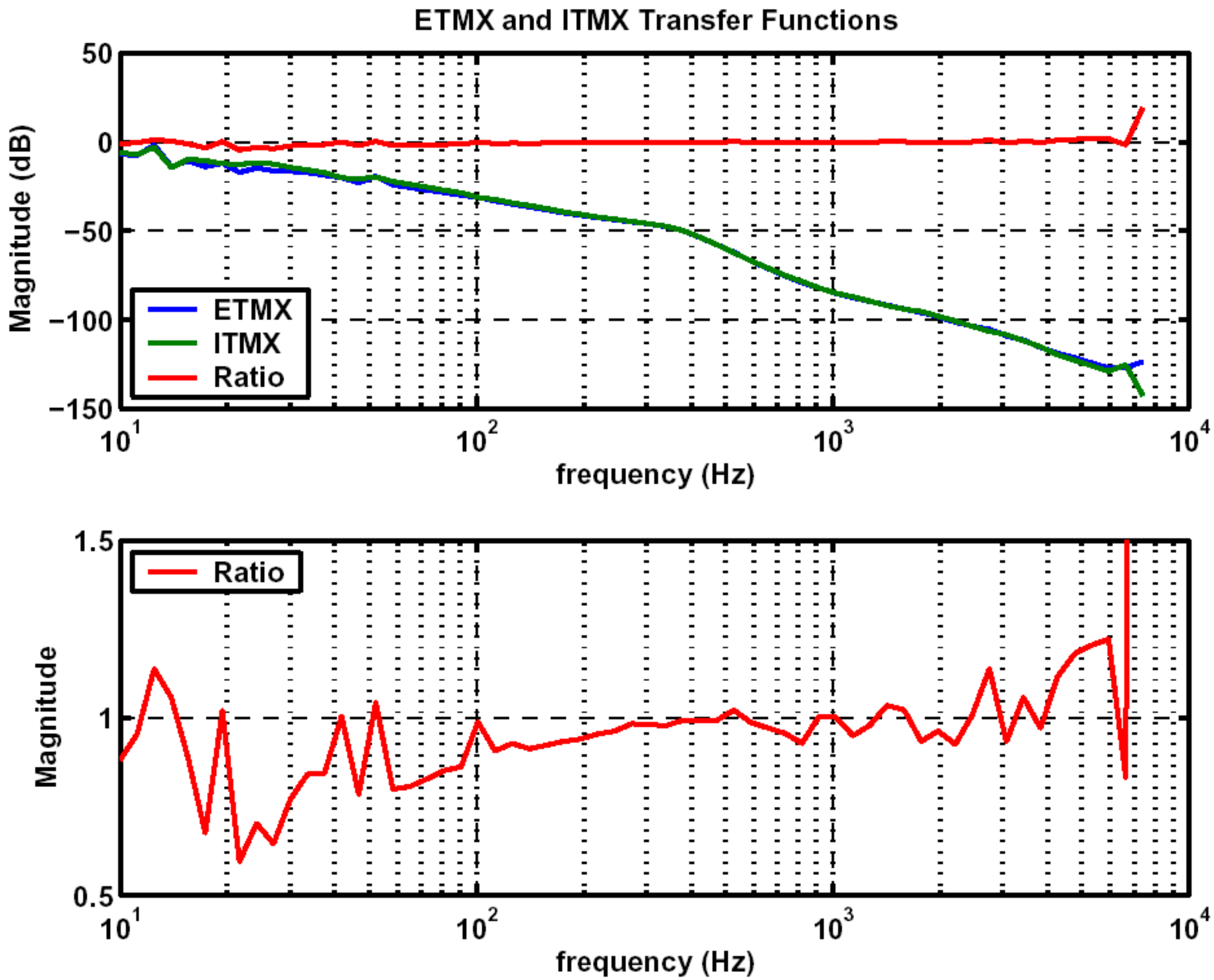
Loop Gain


t GPS time: 733979104
Magnitude (dB)
frequency (Hz)
Measured
Modelled
Ratio
frequency (Hz)
Phase (deg.)
frequency (Hz)
Phase Difference (deg.)
frequency (Hz)

Actuation Function

- Most difficult piece to measure accurately. Used many different approaches:
  - Free swinging Michelson.
  - Fringe fitting. (LHO)
  - Sign toggling.
  - Tidal Actuators. (LHO)
- Have to be careful to either make measurements at AC or know how to extrapolate.

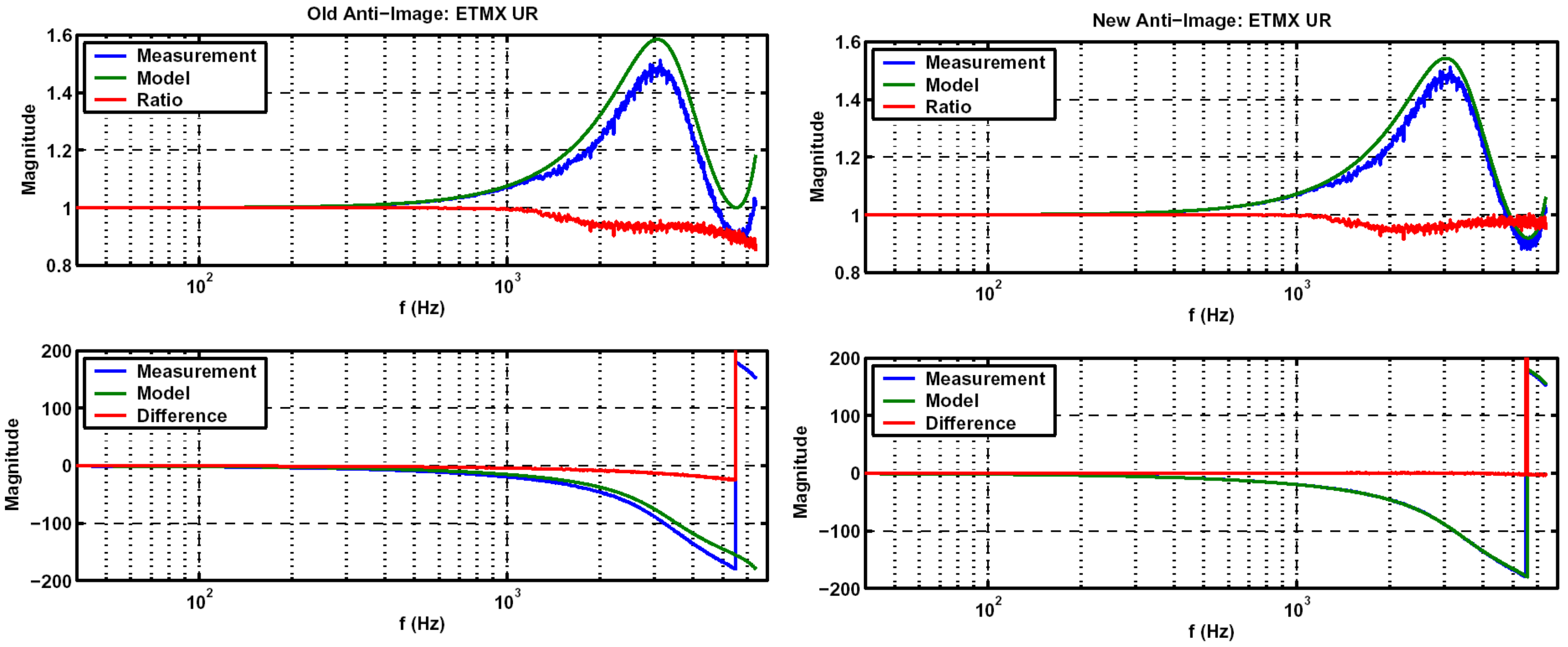
Actuation Function



Modelling of Filters

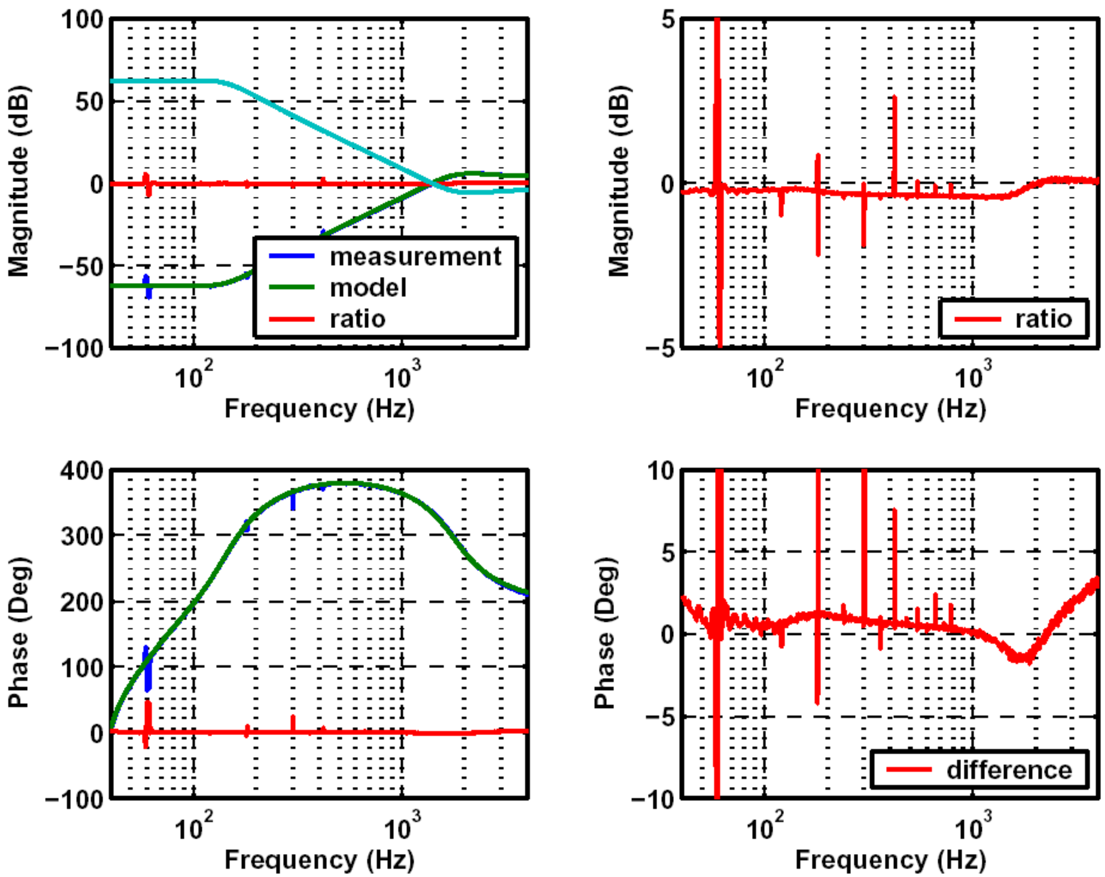
- Measurements of the electronics have been incorporated into the new model.
- Found deviations from expectations, but the individual pieces match better.

Anti-Image Filters



Dewhitening Filters

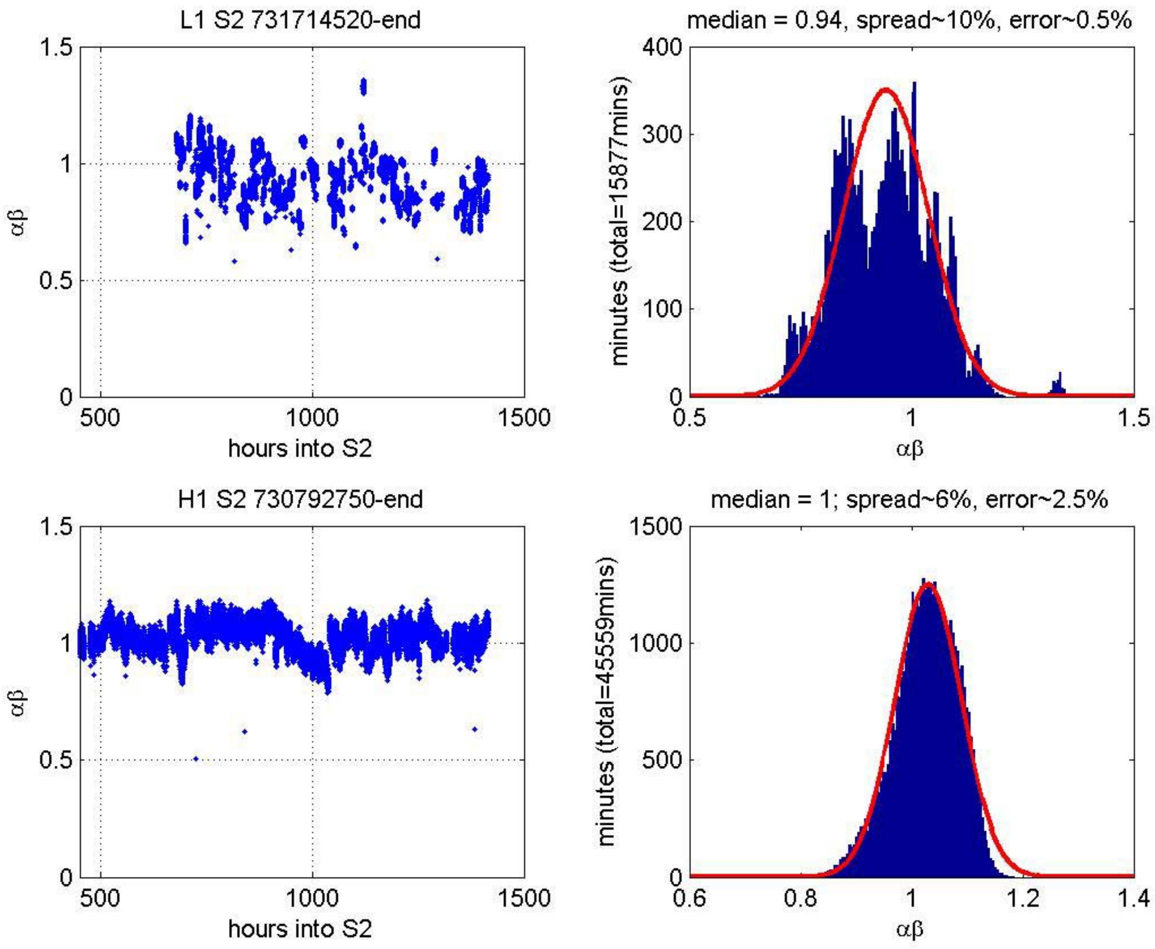
ETMY Dewhitening



α and β

- α is calculated from the amplitude of highest frequency calibration line (972.7 Hz at L1).
- For S2 β did not change at LLO, but did change at LHO.
- Stability of H1 alignment can be clearly seen in the stability of α.
- The higher the amplitude of the line the better.
- New Input Matrix code currently gives a dynamic β!
    - Track it dynamically… or
    - Change it?

$\alpha\beta$ in L1 and H1



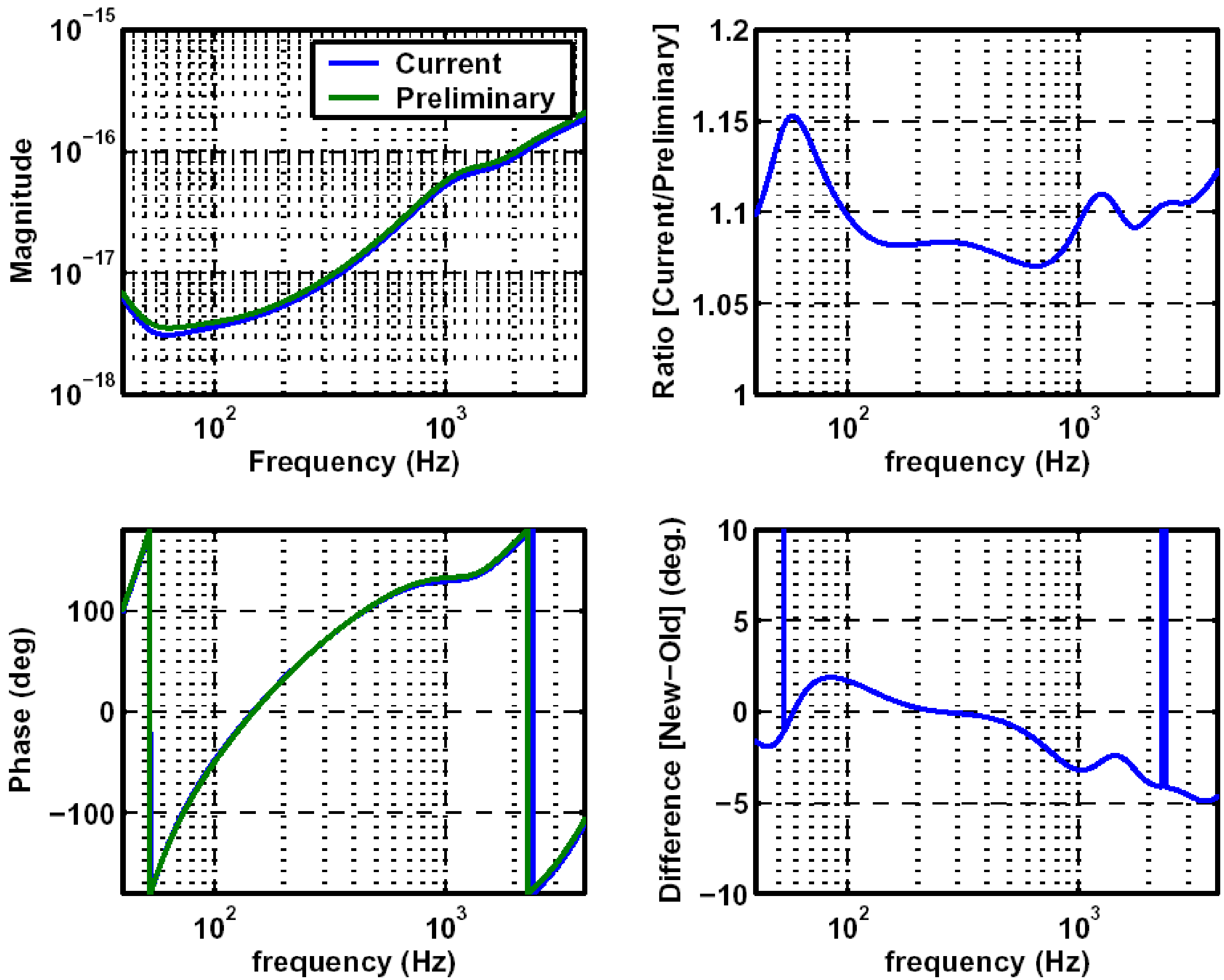
The Model

• Our model continues to evolve with contributions from many people.

• The current version is driven by IFO specific parameter files for gains and filters.

• With this infrastructure we anticipate being able to produce calibrations of S2 accuracy or better on the fly during S3.

Model Comparison



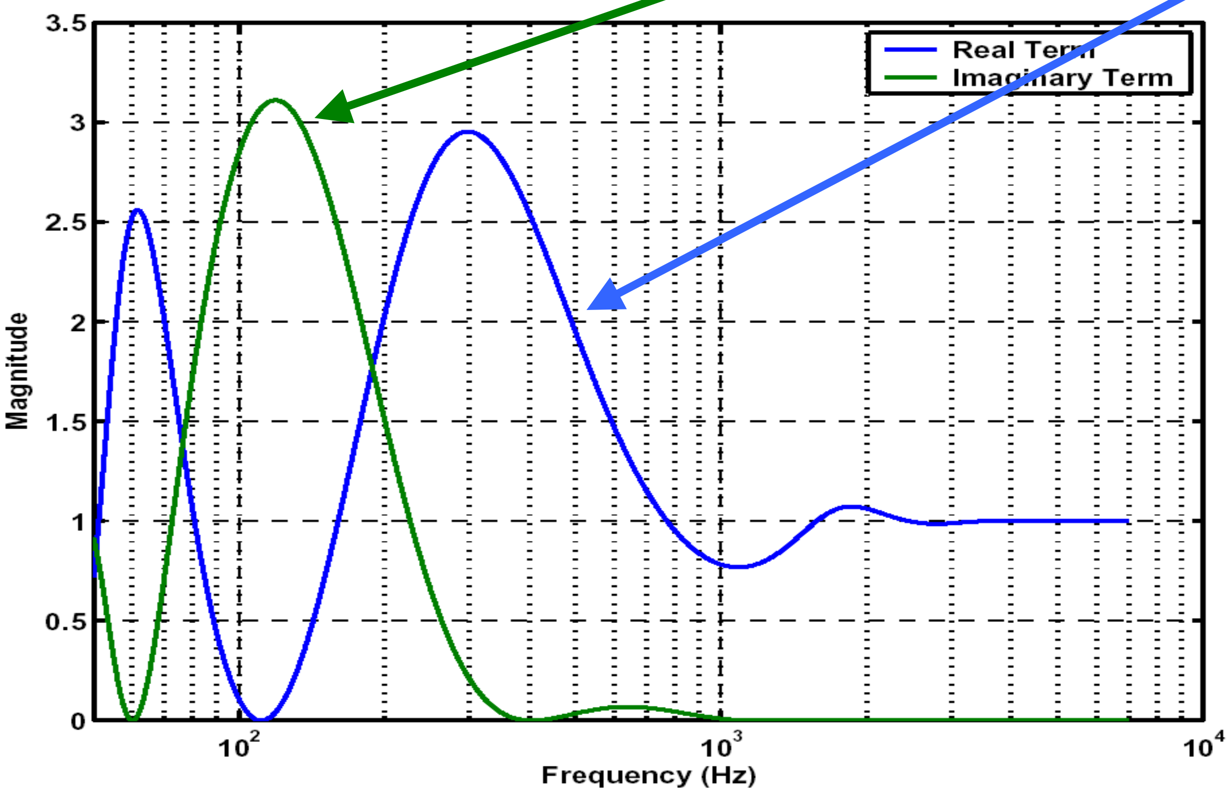
Error on R

Magnitude:

$$\left(\frac{\Delta|R|}{|R|}\right)^2 = \left(\frac{\Delta|A|}{|A|}\right)^2 + \left(\frac{\Delta|D|}{|D|}\right)^2 + \frac{\Re(1+\alpha G)^2}{|1+\alpha G|^4}\left(\frac{\Delta|G|}{|G|}\right)^2 + \frac{\Re(1+\alpha G)^2}{|1+\alpha G|^4}\left(\frac{\Delta\alpha}{\alpha}\right)^2 + \frac{\Im(1+\alpha G)^2}{|1+\alpha G|^4}\Delta\phi_G^{\,2}$$

Phase:

$$\Delta\phi_R^{\,2} = \Delta\phi_A^{\,2} + \Delta\phi_D^{\,2} + \frac{\Im(1+\alpha G)^2}{|1+\alpha G|^4}\left(\alpha^2\Delta|G|^2 + |G|^2\Delta\alpha^2\right) + \frac{\Re(1+\alpha G)^2}{|1+\alpha G|^4}\Delta\phi_G^{\,2}$$



$$R(f,t) = \frac{1+\alpha(t)G(f,t)}{\alpha(t)C(f,t)}$$

$$= A(f,t)D(f,t)\left[\frac{1+\alpha(t)G(f,t)}{\alpha(t)G(f,t)}\right]$$

LIGO

Magnitude Error

Magnitude: $$\left(\frac{\Delta|R|}{|R|}\right)^2 = \left(\frac{\Delta|A|}{|A|}\right)^2 + \left(\frac{\Delta|D|}{|D|}\right)^2 + \frac{\Re(1+\alpha G)^2}{|1+\alpha G|^4}\left(\frac{\Delta|G|}{|G|}\right)^2 + \frac{\Re(1+\alpha G)^2}{|1+\alpha G|^4}\left(\frac{\Delta\alpha}{\alpha}\right)^2 + \frac{\Im(1+\alpha G)^2}{|1+\alpha G|^4}\Delta\phi_G{}^2$$

Actuation: 5->10%.

Digital Filter: <5%.

Open Loop Gain: negligible errors < 2kHz

α: 0.5% –> 2.5% **in magnitude.**

Skirting the hairy edge of 10% errors in magnitude, driven mainly by Actuation function.

Phase Error

Phase: $$\Delta\phi_R^{\ 2} = \Delta\phi_A^{\ 2} + \Delta\phi_D^{\ 2} + \frac{\Im(1+\alpha G)^2}{|1+\alpha G|^4}\left(\alpha^2\Delta|G|^2 + |G|^2\Delta\alpha^2\right) + \frac{\Re(1+\alpha G)^2}{|1+\alpha G|^4}\Delta\phi_G^{\ 2}$$

Basically driven by the error in the phase of the Actuation.

With good measurements of the electronics we should easily have an error < 10 degrees.

A judicious choice of time delay can improve the match of model to measurement.

Final S2 Calibration

- We have all the machinery in place to produce the final S2 calibrations.

- Plan to have the final files for Response, Sensing and Open Loop Gain functions **and** α's and β's for propagation in time.

- Our "deadline" is next Monday, August 25th.

- We will continue to improve the model for S3.

Outlook for S3

- We will follow the same general methodology that has been and will continue to evolve.
  - Fast availability of calibrations at an accuracy comparable to that of S(n-1).
  - A "final" calibration soon (hopefully!) after S(n).
  - At some stage this will reduce to a one-step process but not yet.
- We intend to go into S3 with all the necessary measurements in place.
- Techniques, technology and accuracy are all still in flux.