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OMC DCPD characterization for aLIGO transition

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1 Introduction

The eLIGO OMC DCPD preamps (D060572-v1) and photodiodes (EG&G/Perkin-Elmer C30665, 3-mm InGaAs) will be reused on the Advanced LIGO OMCs. This document describes the characterization of the preamps and diodes at the time of their removal from the eLIGO assemblies so that this information is available during aLIGO.

2 Analysis

2.1 Livingston – L1

During the H1 squeezing experiment, the eLIGO-L1 OMC was shipped to Hanford due to its lower loss, and the eLIGO-H1 OMC was sent to Livingston. Therefore, the photodiodes and preamps (S/N 006 and 008) from the eLIGO-H1 OMC will be on the *aLIGO*-L1 OMC.

2.1.1 DCPD preamp transimpedance

The transimpedances of the preamprifiers were measured in High-Z and Low-Z mode:

- Preamp S/N 006

  - $Z_{\rm HI} = 399.63\Omega$
  - $Z_{\rm LO} = 100.48\Omega$

- Preamp S/N 008
  - $Z_{\rm HI} = 399.88\Omega$
  - $Z_{\rm LO} = 100.69\Omega$

These were stable to below 0.01Ω on the display, though systematics particularly from cables probably make these numbers less accurate than that.

(LLO ALOG 7323)

2.1.2 DCPD dark noise

The DCPD dark noise was measured using a spare eLIGO whitening amplifier. The voltage signal was picked off at the output of the in-vacuum preamp, and the external whitening amplifier was only used as a power supply and to provide the transimpedance switching function. The photodiodes and preamps were still installed in the eLIGO assembly.

Figures 1 and 2 show the photocurrent-referred noise level of the DCPD and preamp chains in both the 100- and 400-Ω configurations, compared with a LISO simulation for each circuit. The shot-noise level for a 35-mA photocurrent is plotted for reference. Also plotted is the measurement noise level in each case.

2.1.3 DCPD preamp voltage transfer function

After removal of the photodiodes, the preamp voltage transfer functions were measured by injecting an excitation at the photodiode socket between the anode and ground pins. This means the excitation is applied across the transimpedance resistor, but this is negligible given the low source impedance of the spectrum analyzer.

The transfer function measurements are shown in Figs. 3 and 4. Each preamp plotted alongside the LISO prediction, and the variation from the model is shown magnified against the right axis.

Further, a LISO vector fit was applied to the measured transfer functions for the purpose of empirically constructing the appropriate digital compensation filters (since the true transfer functions deviate significantly from the design). These fit results are shown in Figs. 5 and 6.

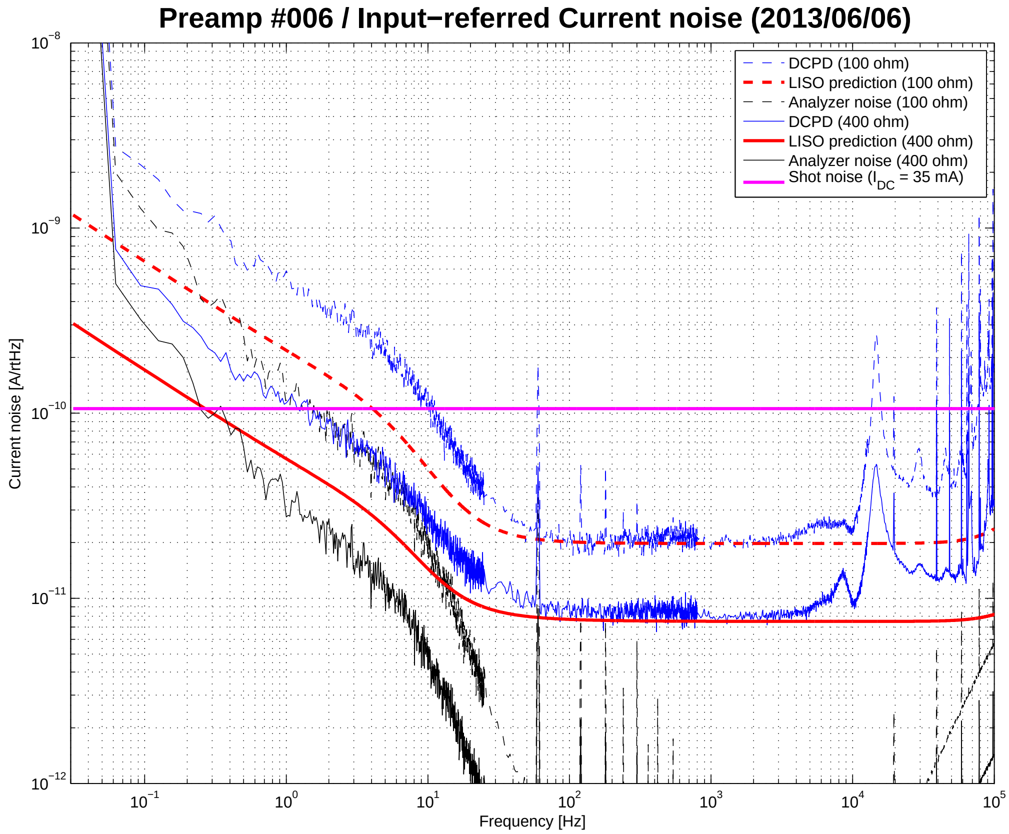

Figure 1: L1 DCPD A (S/N 006) photodiode and preamp chain noise for Z = 100 Ω and Z = 400 Ω.

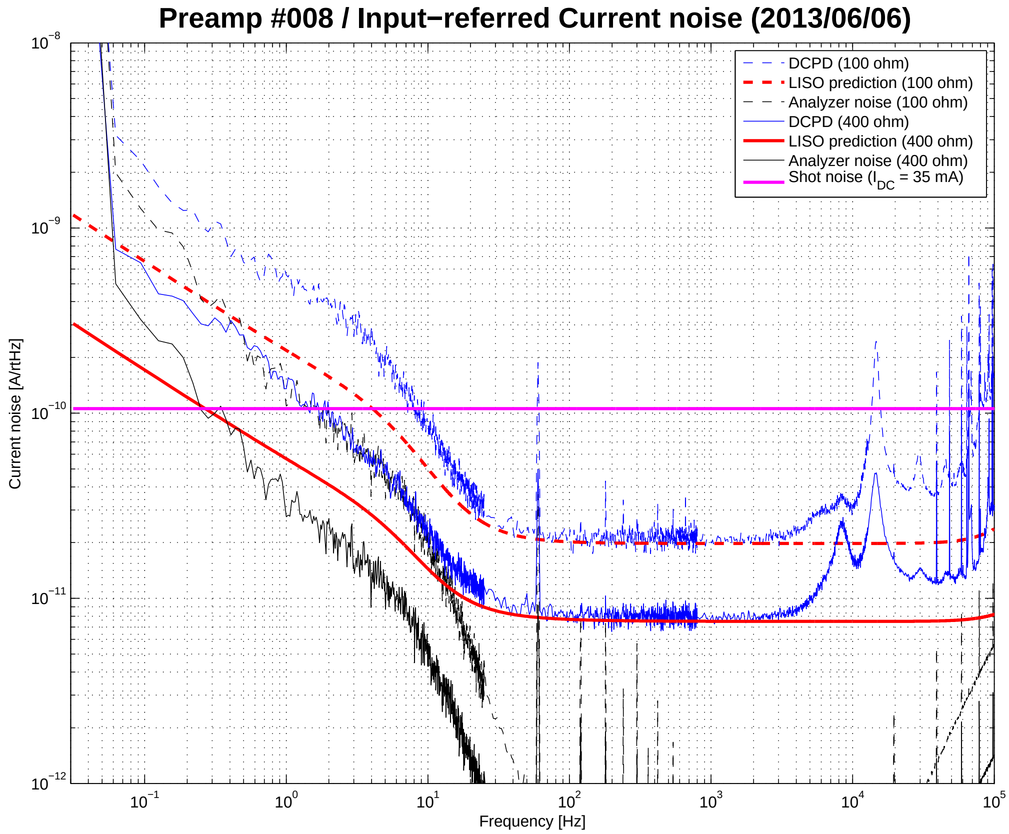

Figure 2: L1 DCPD B (S/N 008) photodiode and preamp chain noise for Z = 100 Ω and Z = 400 Ω.

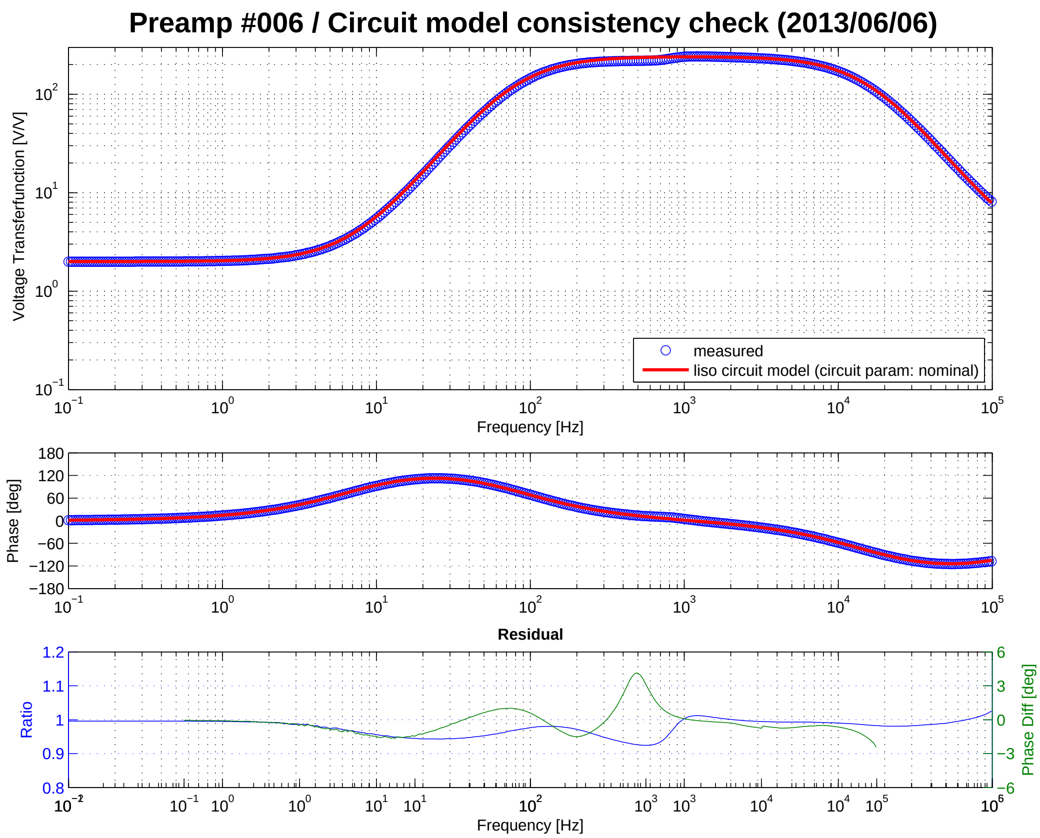

Figure 3: L1 DCPD A (S/N 006) measured transfer function compared with a LISO simulation of the design.

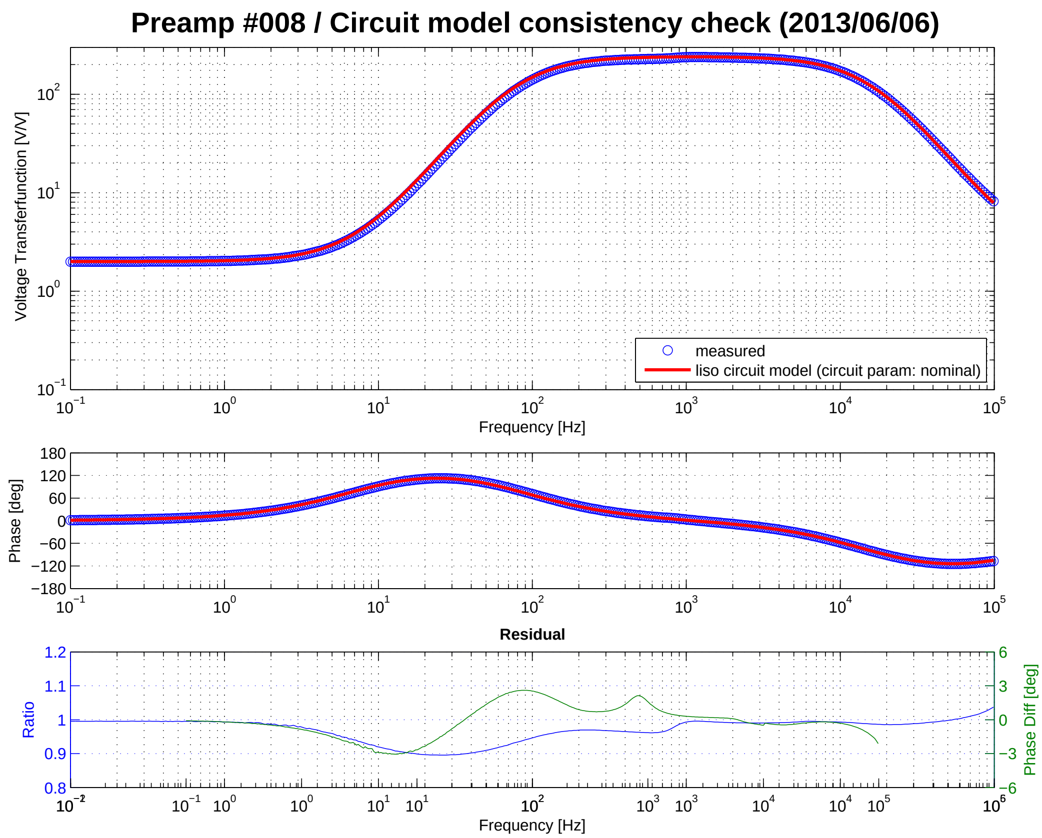

Figure 4: L1 DCPD B (S/N 008) measured transfer function compared with a LISO simulation of the design.

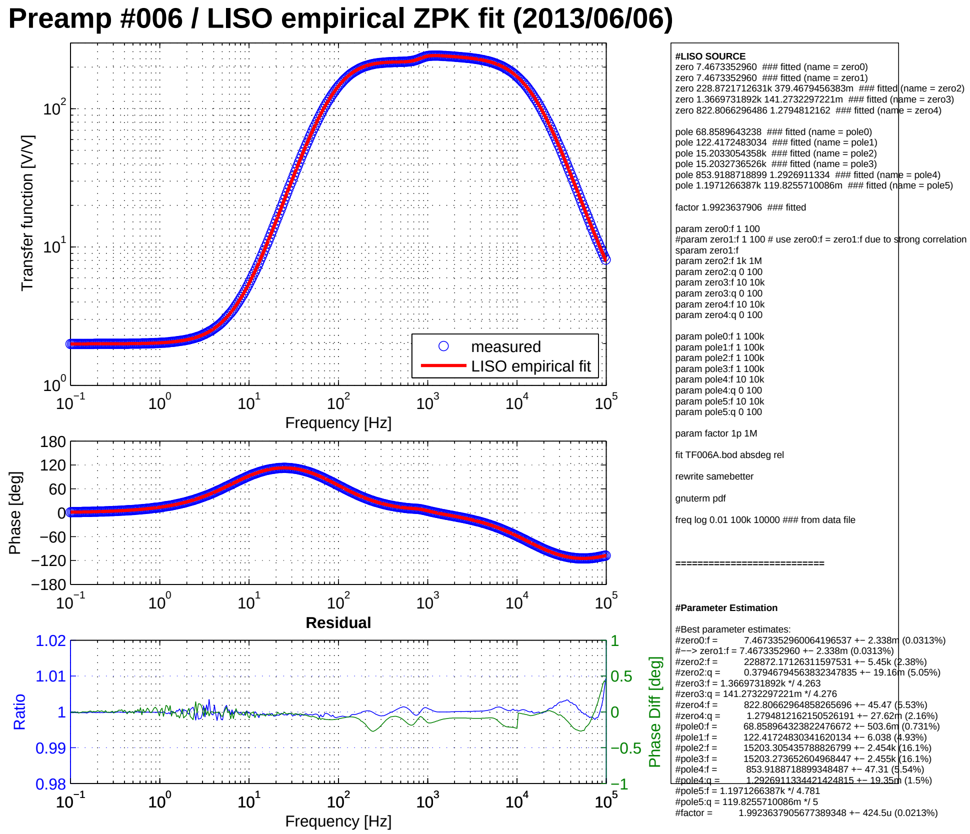

Figure 5: L1 DCPD A (S/N 006) empirical LISO ZPK vector fit.

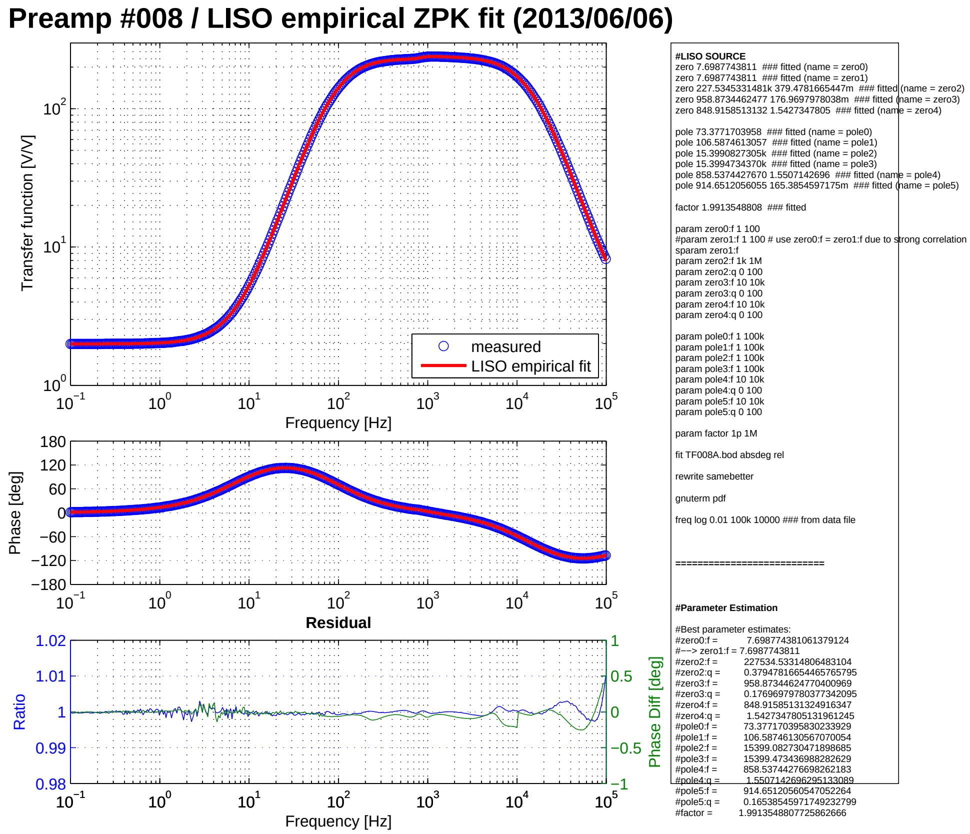

Figure 6: L1 DCPD B (S/N 008) empirical LISO ZPK vector fit.

2.1.4 Revised preamp voltage transfer function

When the balance of the OMC DCPD outputs were checked at LLO, it was discovered that the current model of the DCPD preamplifiers couldn't explain the relative misbalance of the DCPDs.

It turned out that the features at around 1kHz in the measured transfer functions on the bench were measurement artifact. These features can be seen in Figures 3∼6. They don't exist in the actual eletronics chain. These bumps in the transfer function were, in fact, precisely reproduced by the transfer function models, and caused mis-compensation of the DCPD responses.

In order to mitigate this issue, the calibration measurements in eLIGO era were revisited. D. Yeaton-Massey measured the transfer functions of the in-vacuum preamplifiers at Hanford in 2009, as found in this iLog entry[1]. The data files can be found in this link[2]. In his

[1] http://ilog.ligo-wa.caltech.edu/ilog/pub/ilog.cgi?group=detector&date_to_view=02/24/2009&anchor_to_scroll_to=2009:02:24:00:58:44-dmass

[2] https://svn.ligo.caltech.edu/svn/calibration/trunk/calibration/frequencydomain/runs/S6/H1/measurements/OMCwhiteners/2009FebMar_DMass/

measurement DCPD1 and 2 correspond to the preamp #006 and #008, respectively.

The measured transfer functions found in the links do not exhibit the bump feature at 1kHz. And indeed they explains the imbalance of the DCPDs better than the models in the previous section.

However, these eLIGO measurements have few points below 10Hz and not precise enough to model the tranfer function below 10Hz. And the models in the previous section shows better agreement with the measured DCPD imbalance.

Therefore, we have to stitch eLIGO and aLIGO measurements. Figures 7 and 8 shows how the data were stiched. In Figure 7, top two shows the bode plot of the aLIGO and eLIGO measurements. The aLIGO measurements (blue) have wider bandwidth and higher resolution, but have "dent" at 1kHz. The eLIGO (red) measurement does have flat response at 1kHz, but the resolution is low. The absolute magnitude of the eLIGO measurement is not calibrated. Therefore, the eLIGO measurement had to scaled such that it matches with the aLIGO measurement. The bottom plot shows the relative difference of these two data in magnitude and phase. The aLIGO data was linearly interporated with the frequency spacing of the eLIGO data. As one can see, They are well matched below 100Hz and above 3kHz. **The two data were stiched at 30Hz;** Below 30Hz, the aLIGO data was used. Above 30Hz, the eLIGO data was used.

Figure 7 shows the same plots for the preamp #008. Based on this plot, **the two data were stiched at 30Hz** in the same way.

Now, the stiched data sets are fitted by LISO to obtain ZPK model. Here the revised modeling results are shown.

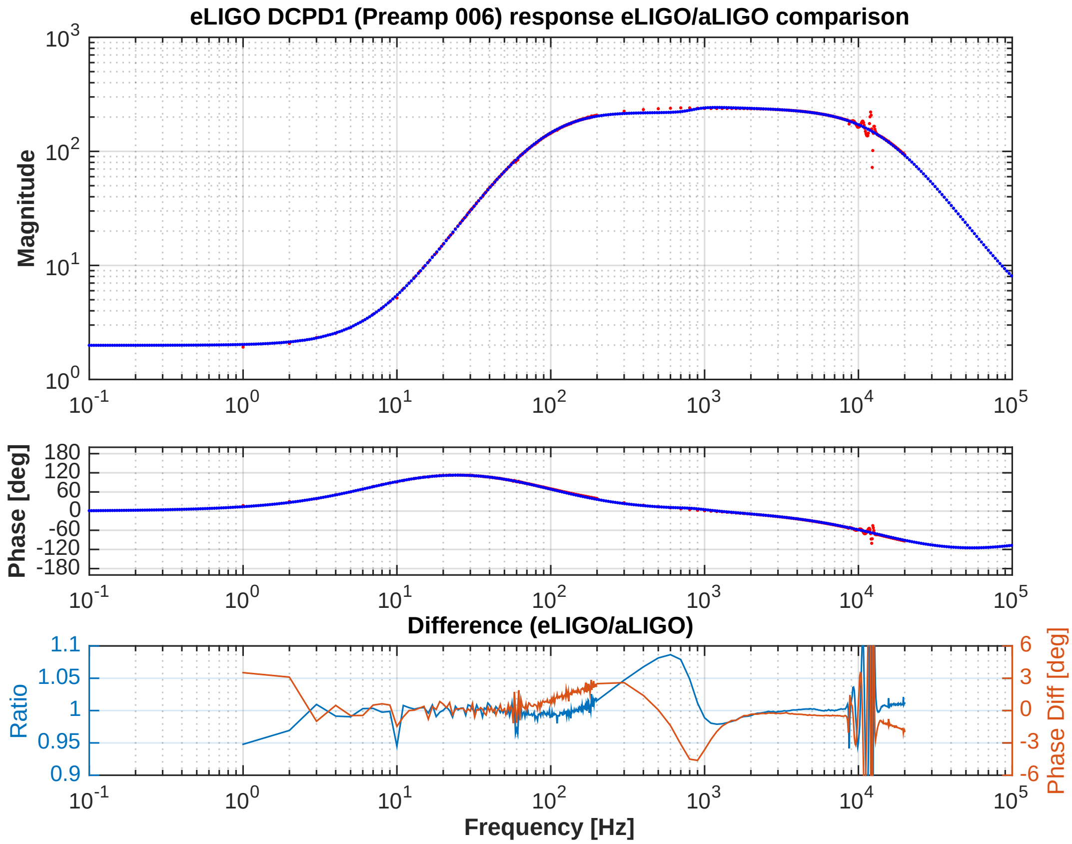

Figure 7: Comparison of the eLIGO and aLIGO measurements for the preamp #006. The eLIGO data is scaled by a factor of 8.0 so that it can match with the aLIGO measurement in magnitude.

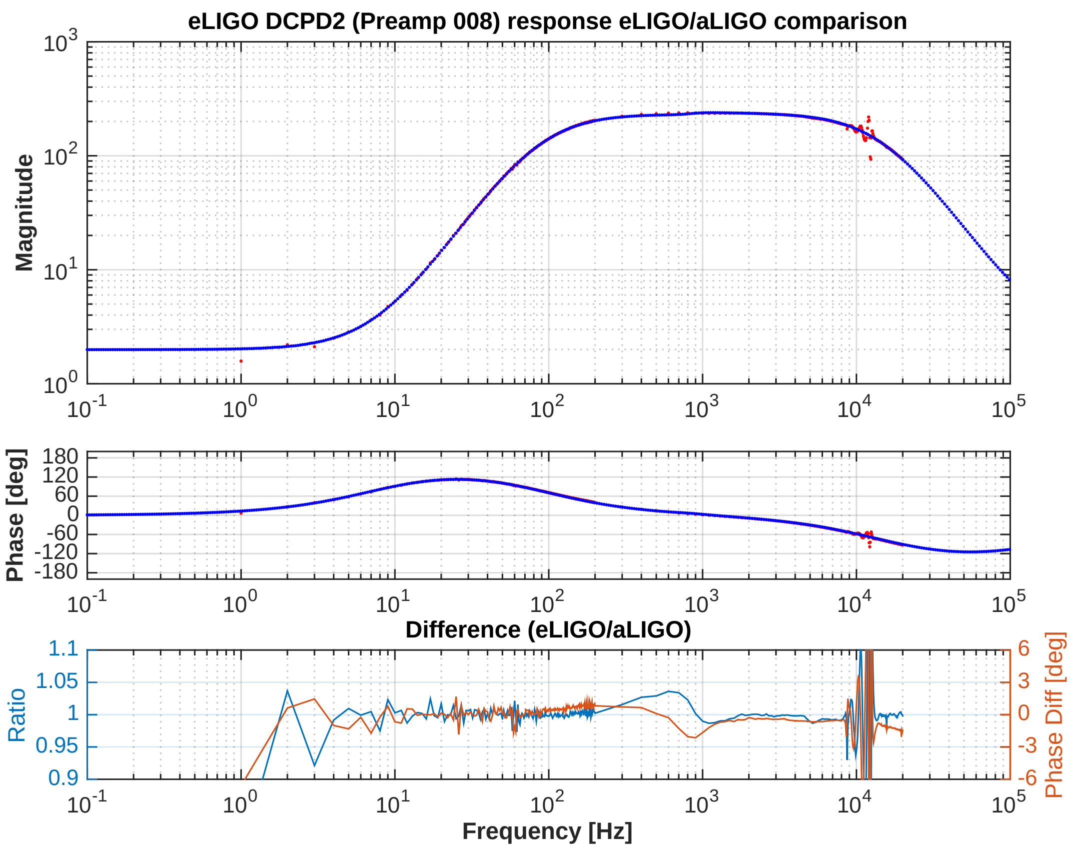

Figure 8: Comparison of the eLIGO and aLIGO measurements for the preamp #006. The eLIGO data is scaled by a factor of 6.95 so that it can match with the aLIGO measurement in magnitude.

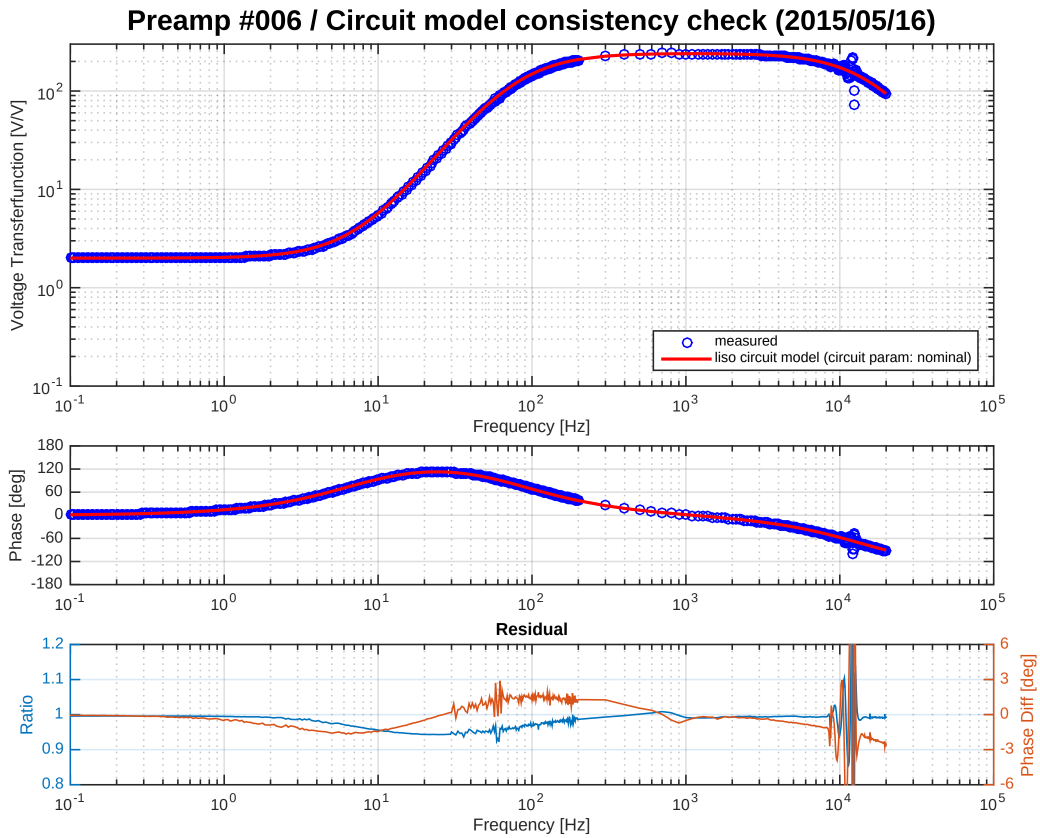

Figure 9: L1 DCPD A (S/N 006) revised measured transfer function compared with a LISO simulation of the design.

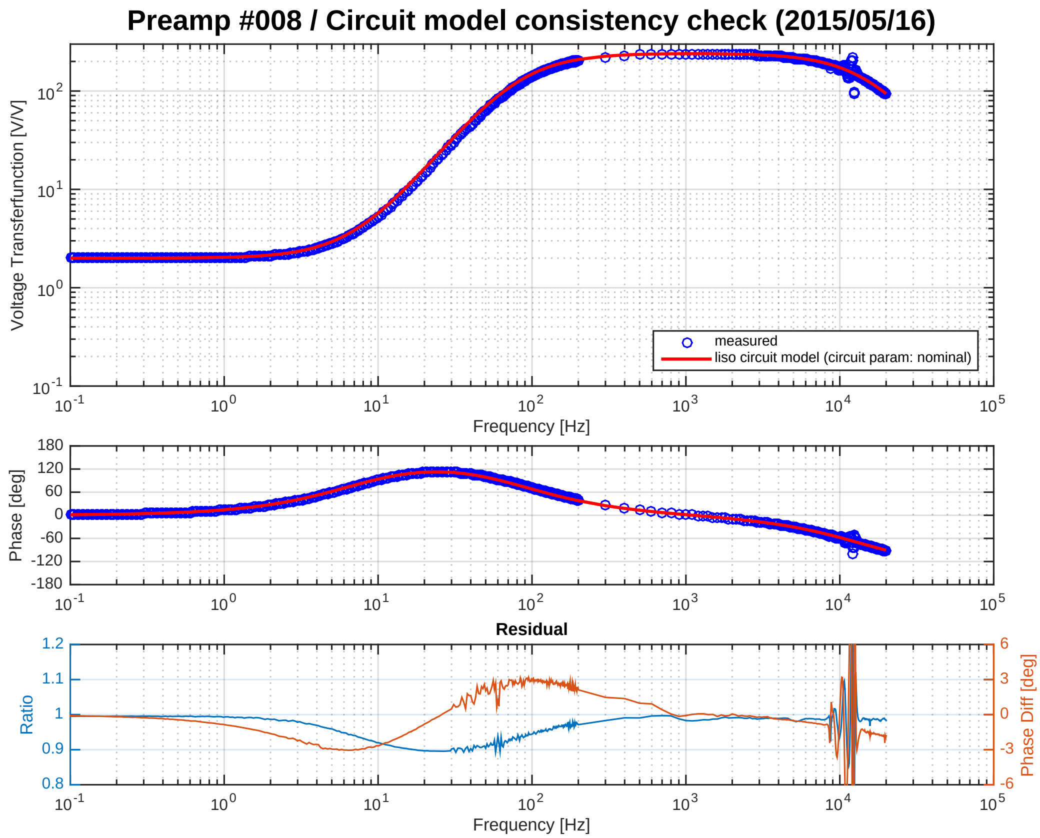

Figure 10: L1 DCPD B (S/N 008) revised measured transfer function compared with a LISO simulation of the design.

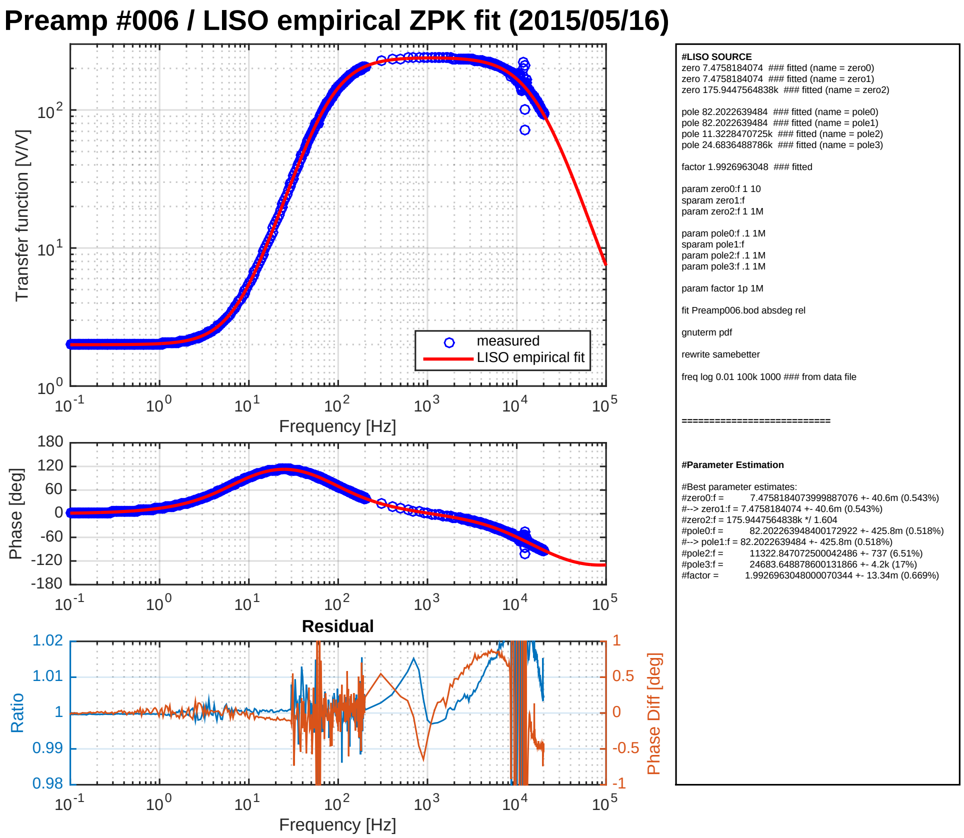

Figure 11: L1 DCPD A (S/N 006) revised empirical LISO ZPK vector fit.

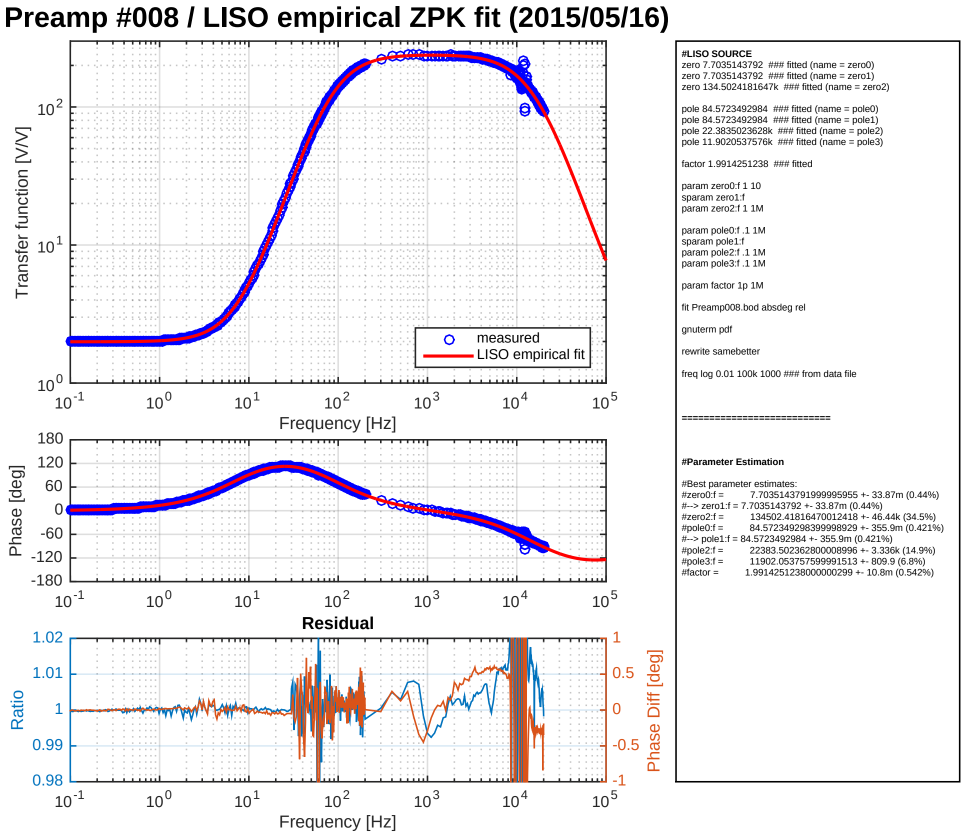

Figure 12: L1 DCPD B (S/N 008) revised empirical LISO ZPK vector fit.

2.2 Hanford - H1

As described in Sec. 2.1, the OMC assembly at Hanford during the eLIGO-to-aLIGO transition was actually the original L1 OMC. Therefore, the aLIGO H1 preamps (S/Ns 004 and 005) are the L1 preamps from enhanced LIGO.

The H1 preamp testing was performed by K. A. some months after W. Z. K. did the L1 testing, but the methods used were the same as those described in Sec. 2.1.

2.2.1 DCPD dark noise

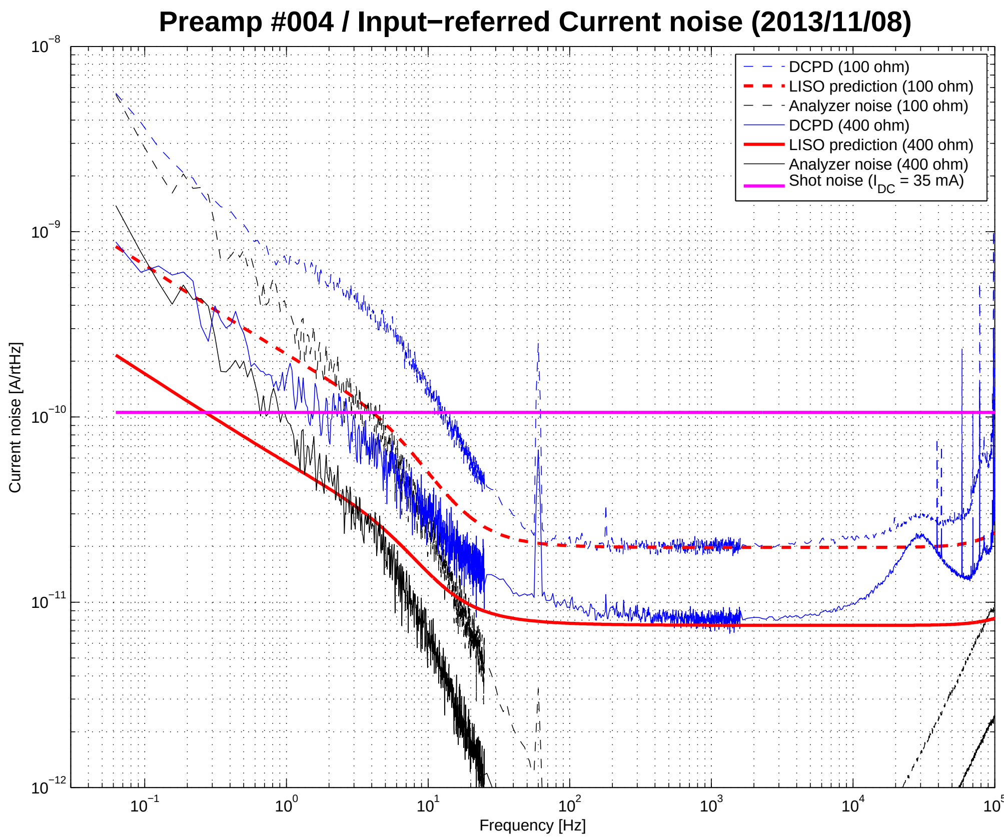

Figure 13: H1 DCPD A (S/N 004) photodiode and preamp chain noise for Z = 100 Ω and Z = 400 Ω.

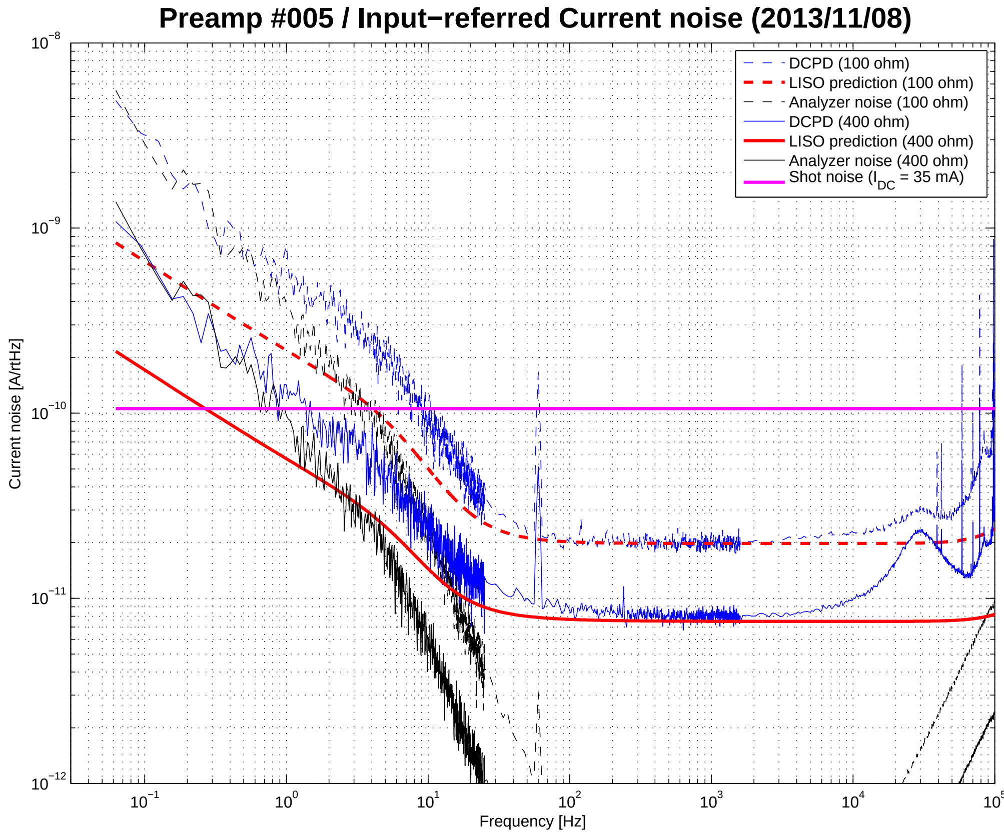

Figure 14: H1 DCPD B (S/N 005) photodiode and preamp chain noise for Z = 100 Ω and Z = 400 Ω.

2.2.2 DCPD preamp transimpedance

x

The transimpedances of the preamprifiers were measured in High-Z and Low-Z mode:

- Preamp S/N 004
  - $Z_{\mathrm{HI}} = 400.9\Omega$
  - $Z_{\mathrm{LO}} = 100.8\Omega$
- Preamp S/N 005
  - $Z_{\mathrm{HI}} = 400.0\Omega$
  - $Z_{\mathrm{LO}} = 100.2\Omega$

The meter cable resistance was subtracted. The error is $\pm 0.1\Omega$.

(Based on the note by KA on Nov 09, 2013)

2.2.3 DCPD preamp voltage transfer function

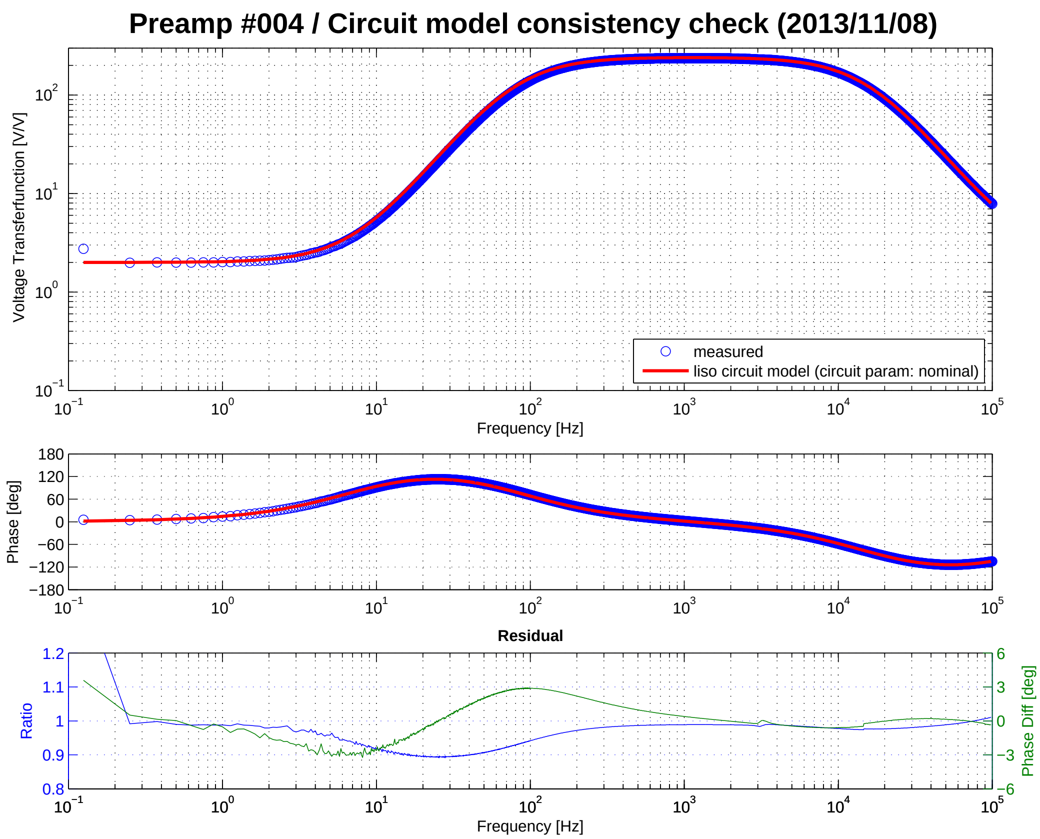

Figure 15: H1 DCPD A (S/N 004) measured transfer function compared with a LISO simulation of the design.

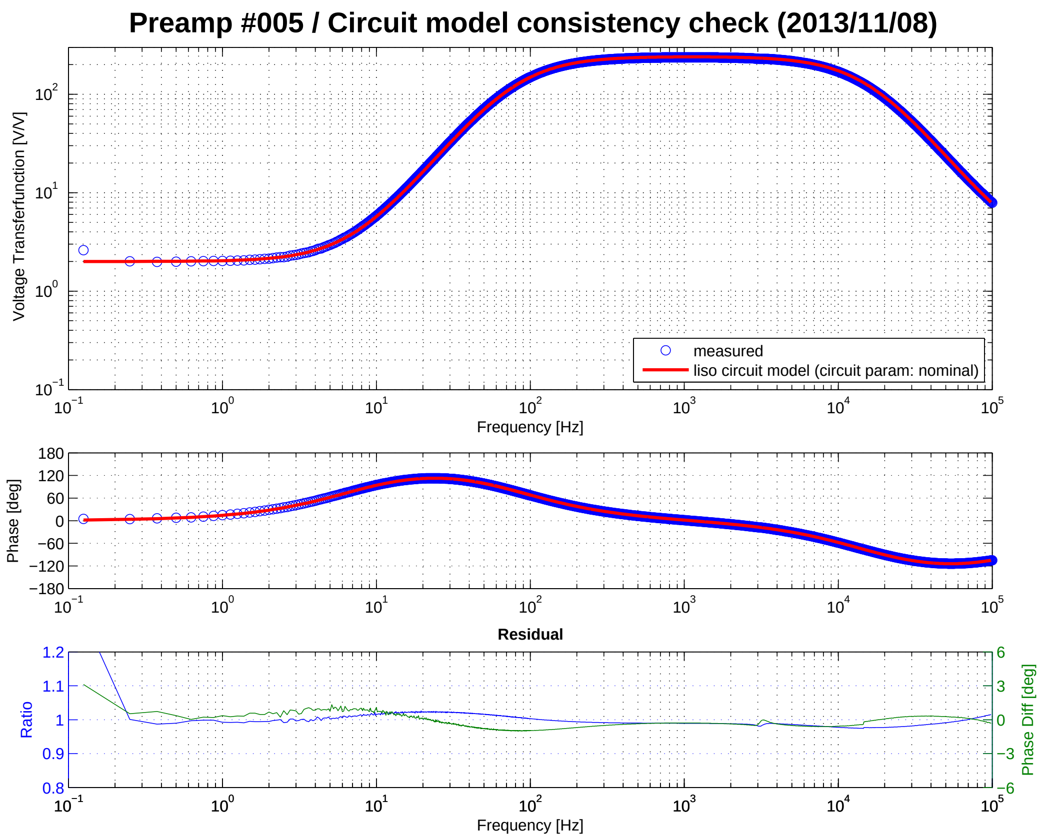

Figure 16: H1 DCPD B (S/N 005) measured transfer function compared with a LISO simulation of the design.

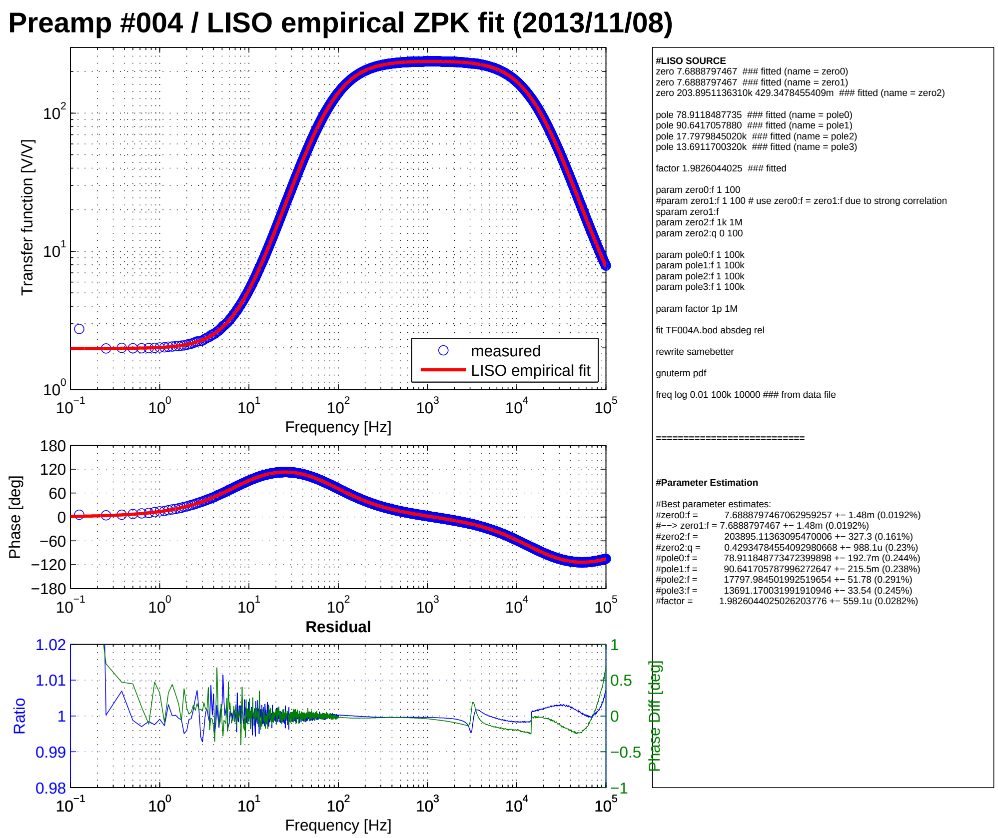

Figure 17: H1 DCPD A (S/N 004) empirical LISO ZPK vector fit.

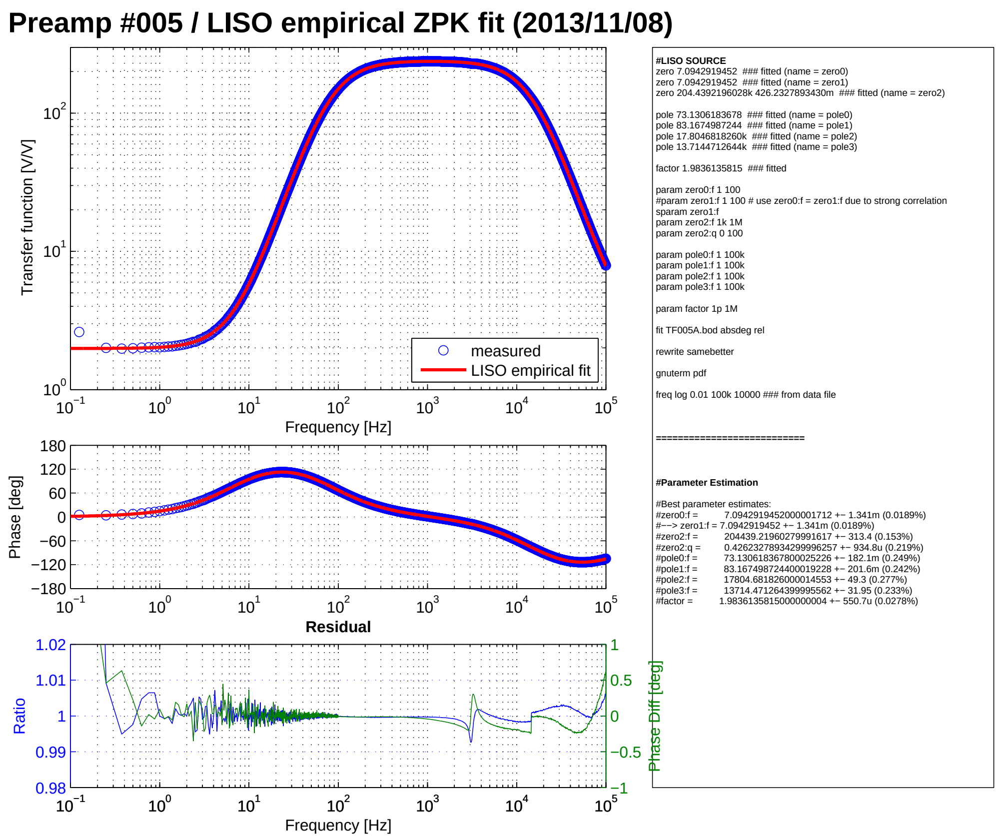

Figure 18: H1 DCPD B (S/N 005) empirical LISO ZPK vector fit.

2.2.4 DCPD preamp linearity check

In addition to the noise and transfer function verification that was done at L1, the H1 preamps were also subject to a linearity test: the amplifiers were swept with excitations of two different amplitudes (10 mV and 20 mV) and it was verified that this made no difference in the measured transfer functions.

The results of these tests are shown in Figs. 19 and 20.

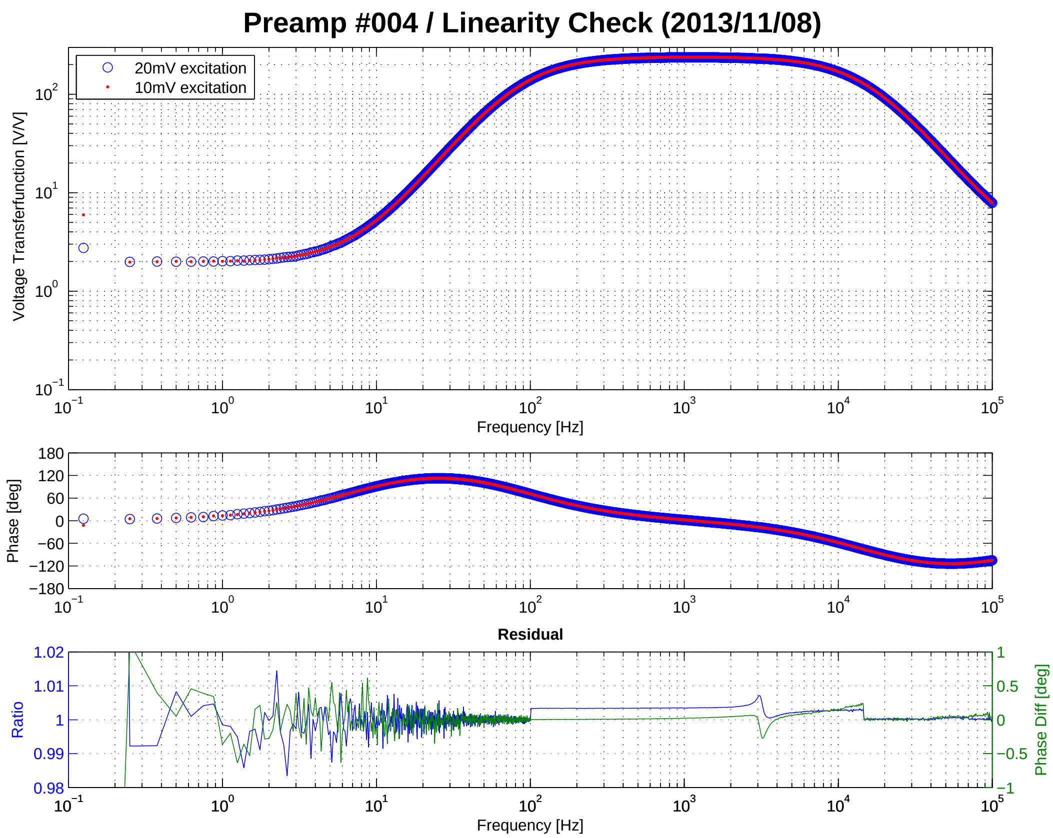

Figure 19: H1 DCPD A (S/N 004) linearity verification.

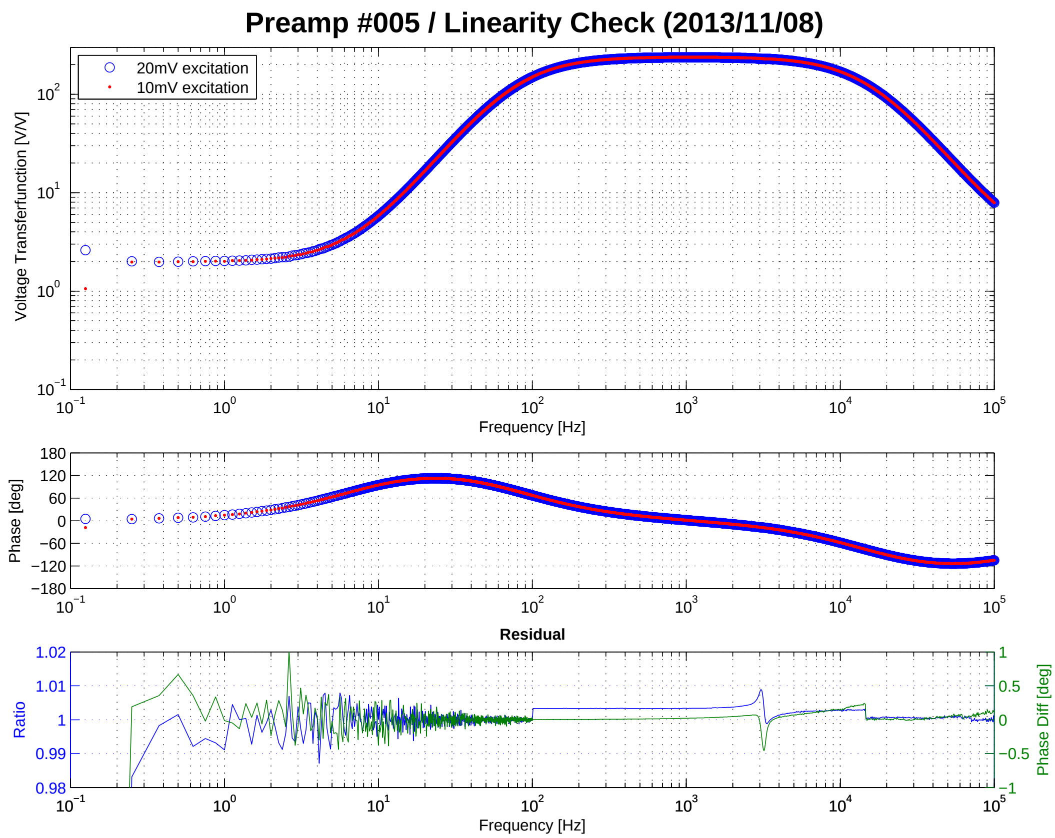

Figure 20: H1 DCPD B (S/N 005) linearity verification.

2.3 3rd IFO

This section will be completed once the corresponding analysis is done on the I1 DCPDs. Note that these will not have previously been integrated in an eLIGO OMC.