LIGO Laboratory / LIGO Scientific Collaboration

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LOS Output Electronics Modifications

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1 Introduction

This document describes changes to the post-DAC electronics for the LIGO test masses. The purpose of the changes is to increase the headroom for the DAC signals by taking advantage of the lower noise in the new Frequency Devices Inc. (FDI) DACs and to achieve a lower coil current noise through increased filtering in the Coil Drivers.

1.1 Overview

The coil current noise for the IFO arm cavity mirrors is required to introduce a displacement noise spectral density less than SRD/10. In the course of commissioning it became necessary to compromise the noise performance of the output electronics chain in order to have sufficient dynamic range for running at the increased noise levels of the interferometer. With the recent reduction of other technical noise sources, the output electronics can now be re-designed to meet the noise spec and allow operation at the current noise levels.

Section 2 describes changes to the Rev B Universal Dewhitening boards and Section 3 describes changes to the LOS Coil Drivers. Sections 4 & 5 list the required component changes. Section 6 shows the effect on the DAC dynamic range. Section 7 shows the resulting displacement noise and the limiting noise sources in the coil driver.

1.2 Related documentation

- "LOS Coil Driver and Universal Dewhitening Filter Revisions," LIGO- T030094-01-D (P. Fritschel, 2003).
- "LOS Coil Driver (Rev C)," LIGO- D000325-C (J. Heefner, 2003)
- "LHO Electronics Schematics' Cabinet", LHO Control Room (markups of the installed electronics)
- "Universal Dewhitening Board (Rev. B5)," LIGO- D000183-B5 (J. Heefner, 2002)
- "LHO 4km Noise Budget", LHO e-Log, (8/16/04, S. Ballmer)

2 Dewhitening Filter

2.1 DAC Noise

Measurements of the new FDI DACs show a voltage noise level of 300 nV/rHz as measured by a Stanford SR785 Spectrum Analyzer with a half-scale (10 Vpp) signal being sent out of the DAC. By contrast, the old Pentek DACs had a voltage noise level of 3000-10000 nV/rHz. In addition, the FDI DACs have 2X the dynamic range of the Penteks (20 Vpp v. 10 Vpp). The result is a 20-60X increase in the output SNR.

2.2 Comparison of transfer functions

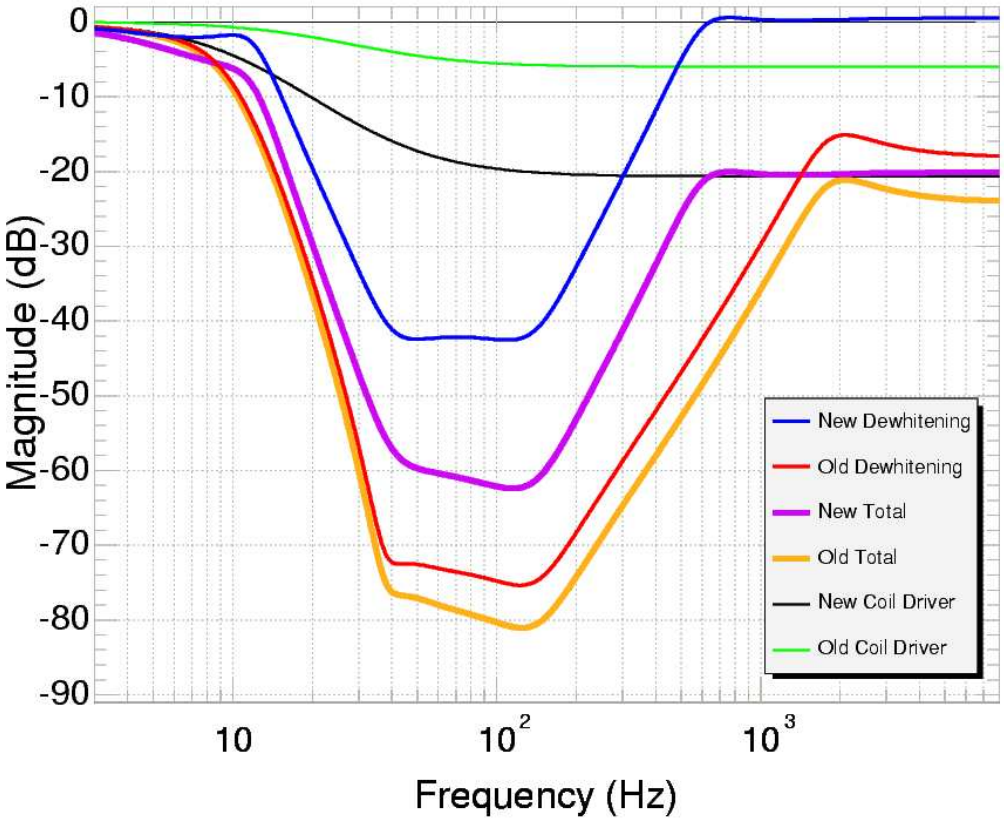

Figure 1 Modeled transfer functions of the analog ETM filters.

Figure 1 & 2 show only the shape of the filter; we are also proposing going from a DC gain of 3 in the dewhitening board to a DC gain of 1.

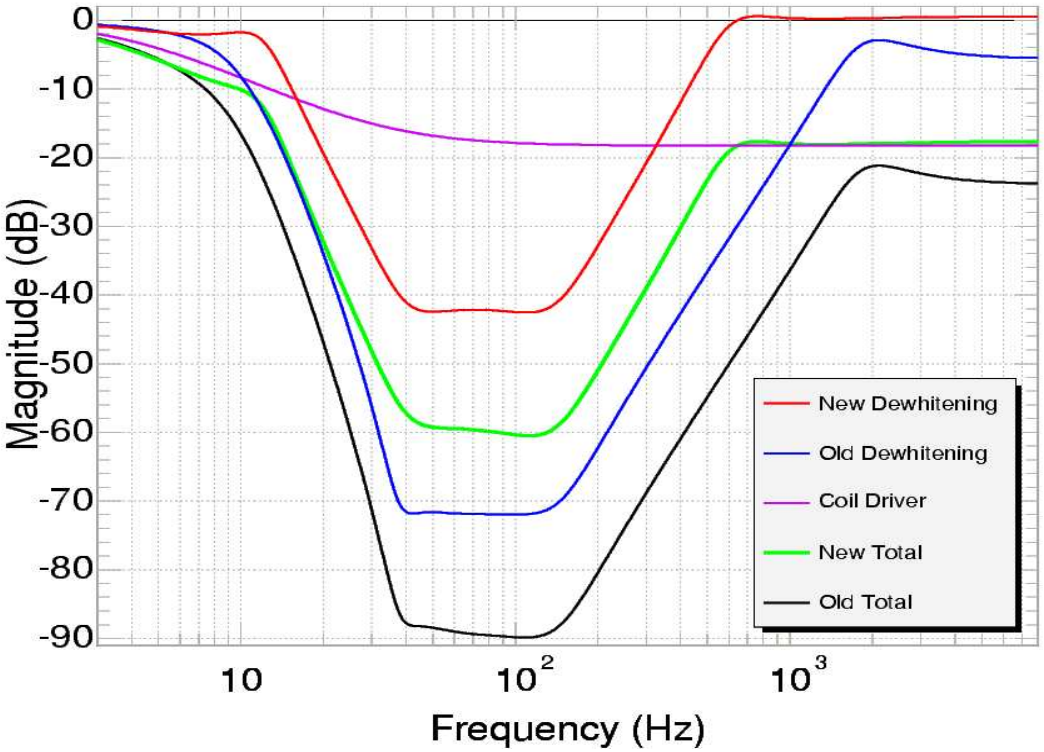

Figure 2 Modeled Transfer Function of the analog ITM filters. There is no proposed change to the ITM coil driver at this time.

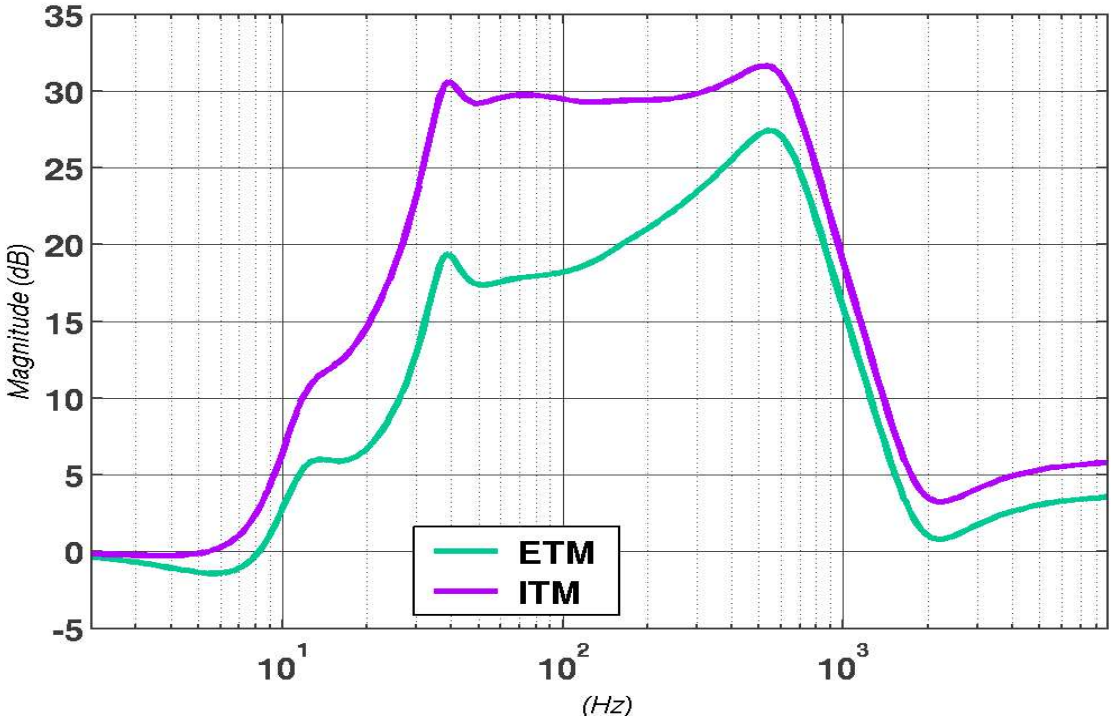

Figure 3 Increased dynamic range as a function of frequency: Ratio of the total attenuation of the new post-DAC filtering to the old.

3 Coil Driver

There are two pieces to the coil driver modification:

- 2X more GW band filtering in the feedback stage around the PA85; the 20:40 Hz pole:zero filter goes to a 10.6:42.5 Hz pole:zero.
- A new, passive R-C-R filter (11.7:31.8 pole:zero) after the PA85 to passively filter out noise without reducing the voltage swing required for lock acquisition.

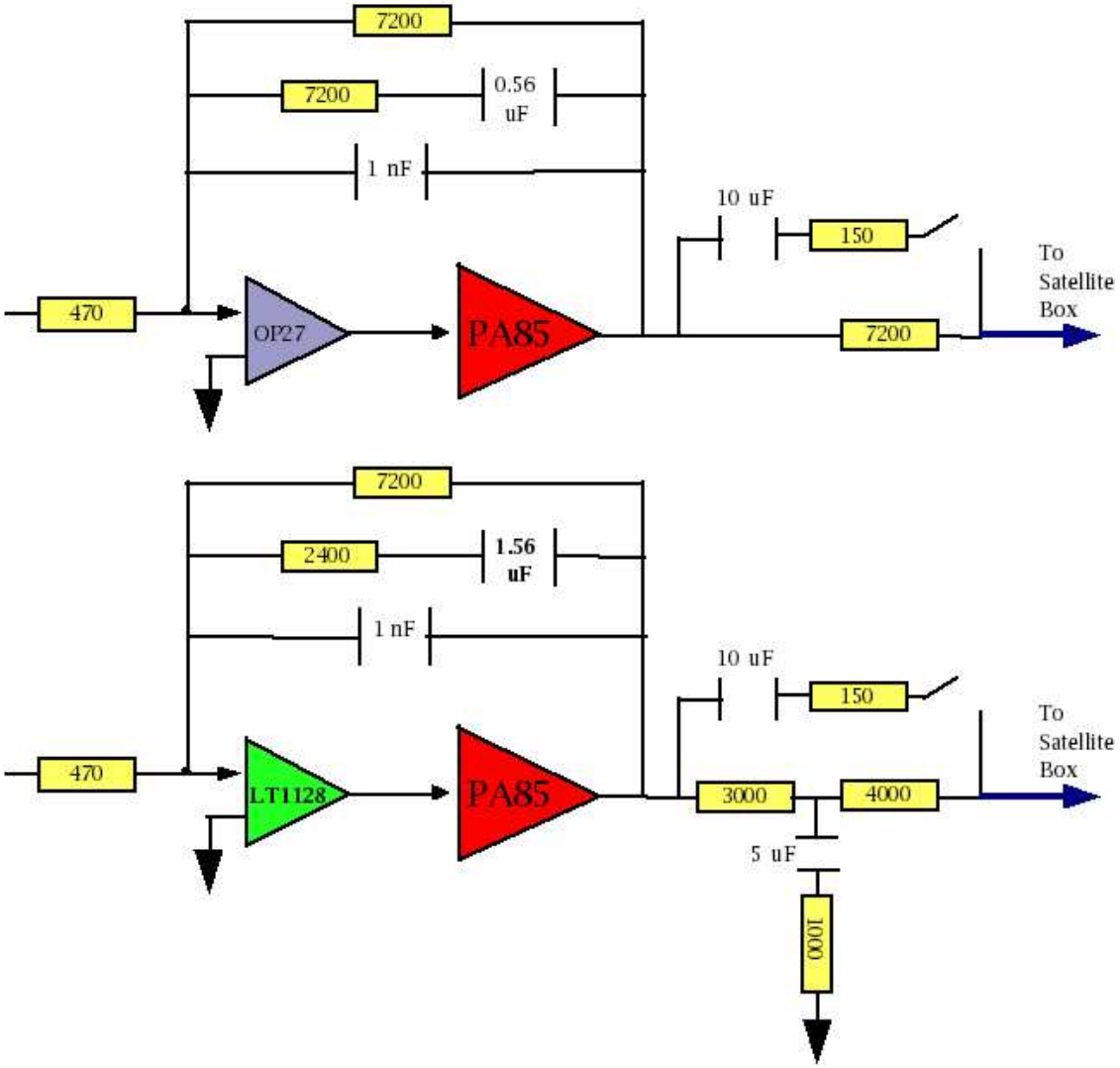

Figure 4 **Top:** H1 ETM Coil Driver (as installed)

Bottom: Proposed new configuration

The proposal is to change the ETM Coil Drivers only, since the ITM circuits are not used for lock acquisition and already have a 4:32 pole:zero filter in the feedback stage. As shown in Section 7, the noise from ITM Coil Driver will not dominate the noise.

4 Dewhitening Filter Comp. Changes (rev A1 -> D)

Components (ch. 1)	Value	Poles	Zeros
R	750	f = 12 Hz phi = 75 deg	f = 40 phi = 73
Rb	4000	f = 600 Hz phi = 72 deg	f = 140 phi = 70
Rc	4000	f = 5 Hz	f = 50 Hz
Rd	2865	f = 950 Hz	f = 150 Hz
Re	318		
Ca	0.22 uF		
Cb	10 uF		
C106	1 uF		
C108	0.22 uF		
C116	10 uF		
C127	1 uF		
C128	1 uF		
C129	not stuffed		
C132	1 uF		
R134	1 K		
R142	25.5 K		
R143	211		
R144	1 K		
R145	2 K		
R149	4.02 K		
R150	9.31 K		
R153	10 K		
R156	909		
R162	1 K		
R164	750		
R165	2.94 K		
R166	8.45 K		
R169	2.87 K		
R170	4.02 K		
R171	1 K		
R172	1 K		
R176	316		
R177	35.7 K		
R178	1 K		
R179	1 K		
R181	1 K		
R184	4.22 K		
U30	OP27		

5 Coil Driver Component Changes

Components	Old Value	New Value	Comments
R145, R147	470	470	
R126	7200	7200	
R123	7200	2400	
C52	0.56 uF	1.56 uF	1 uF || 0.56 uF
R132	7200	-	split into Ra-Rb
Ra	-	3 K	
Rb	-	4 K	
Rc	-	1 K	
Ca	-	5 uF	

6 Dynamic Range

Another motivation for these modifications is to recover some of dynamic range lost through overfiltering the DAC noise from 10-1000 Hz. As shown in figures 1 & 2, there is less overall post-DAC attenuation with the new filtering. The next plot shows the calculated effect of this on the ITM & ETM control signals for the Hanford 4km.

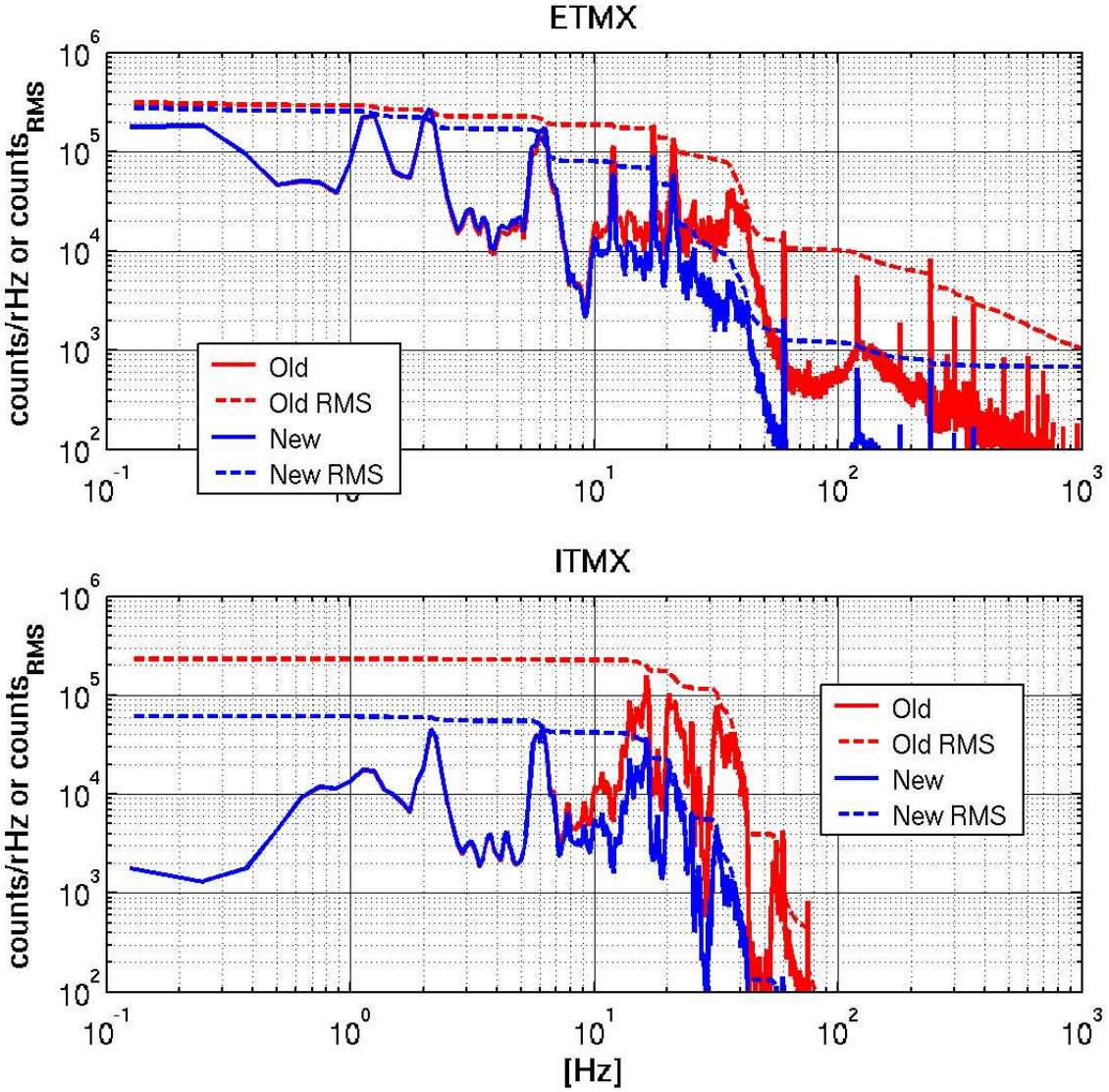

Figure 5. Shown are the DAC output signals for the UL coils of ETMX and ITMX (ETMY and ITMY are almost identical, respectively). The signals have been multiplied by 3 to account for the factor of 3 less gain in the new dewhitening board and so the actual DAC signal with the current setup is 3X less than shown. These data were taken with H1 in its "low noise" state as of 8/10/04.

7 Noise Performance

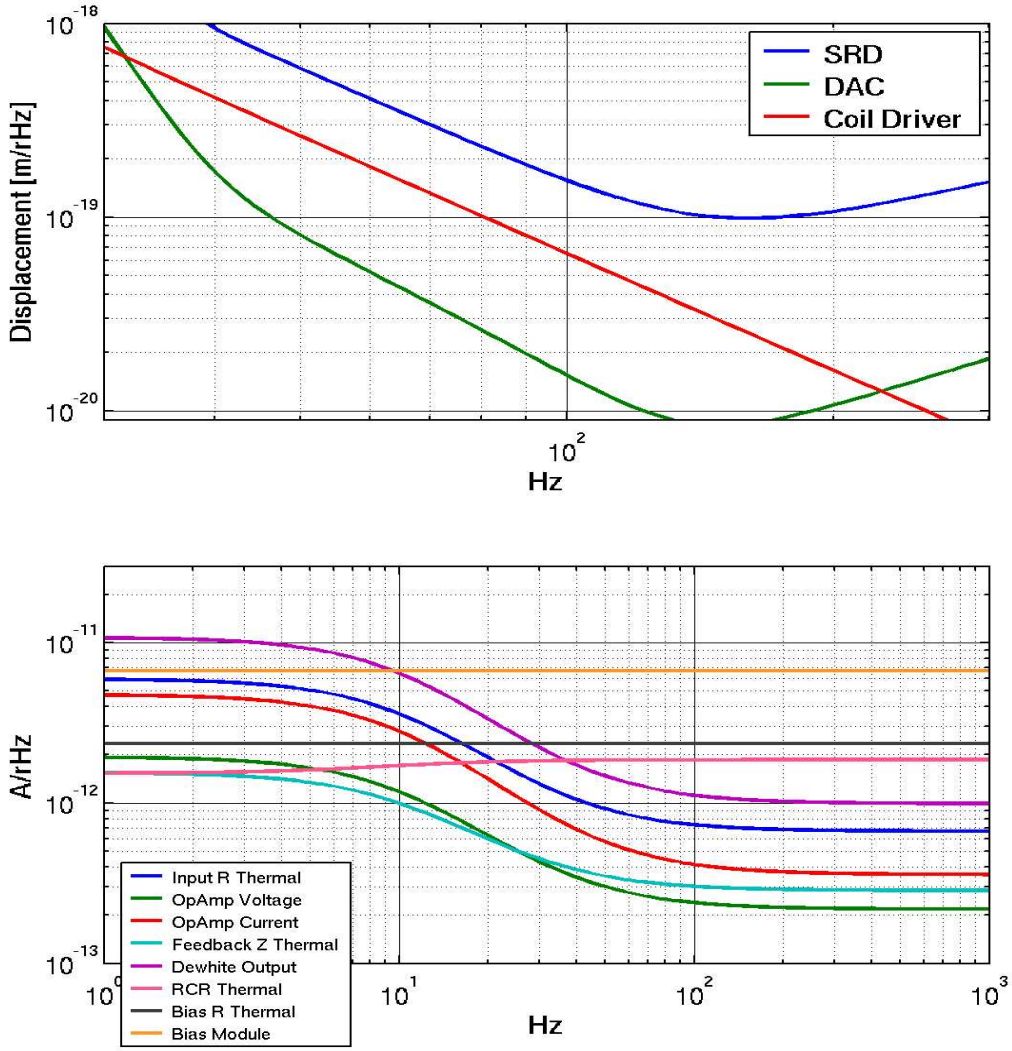

Figure 6 The top plot shows the displacement noise from the DAC noise and from the Coil Driver noise for just the ETMs. The bottom plot shows the current noise for a single coil in the ETM coil driver. The performance of this coil driver is limited by the excess voltage noise out of the LOS Bias Module (20 nV/rHz) and the thermal noise due to (chiefly) this low value resistor (3 K on the ETMY).

Some description of the traces:

- LT1128 as input op-amp (1 nV/rHz & 5 pA/rHz for input referred noise)
- Dewhitening board output noise = 6 nV/rHz (flat).
- Bias module - assumes 20 nV/rHz of output noise (based on measurements at LLO), 7K resistors on ETMX and 3K resistors on ETMY. It is assumed that there is no correlation between the four face channels.
- Bias Thermal is the thermal noise from the angular bias resistors.

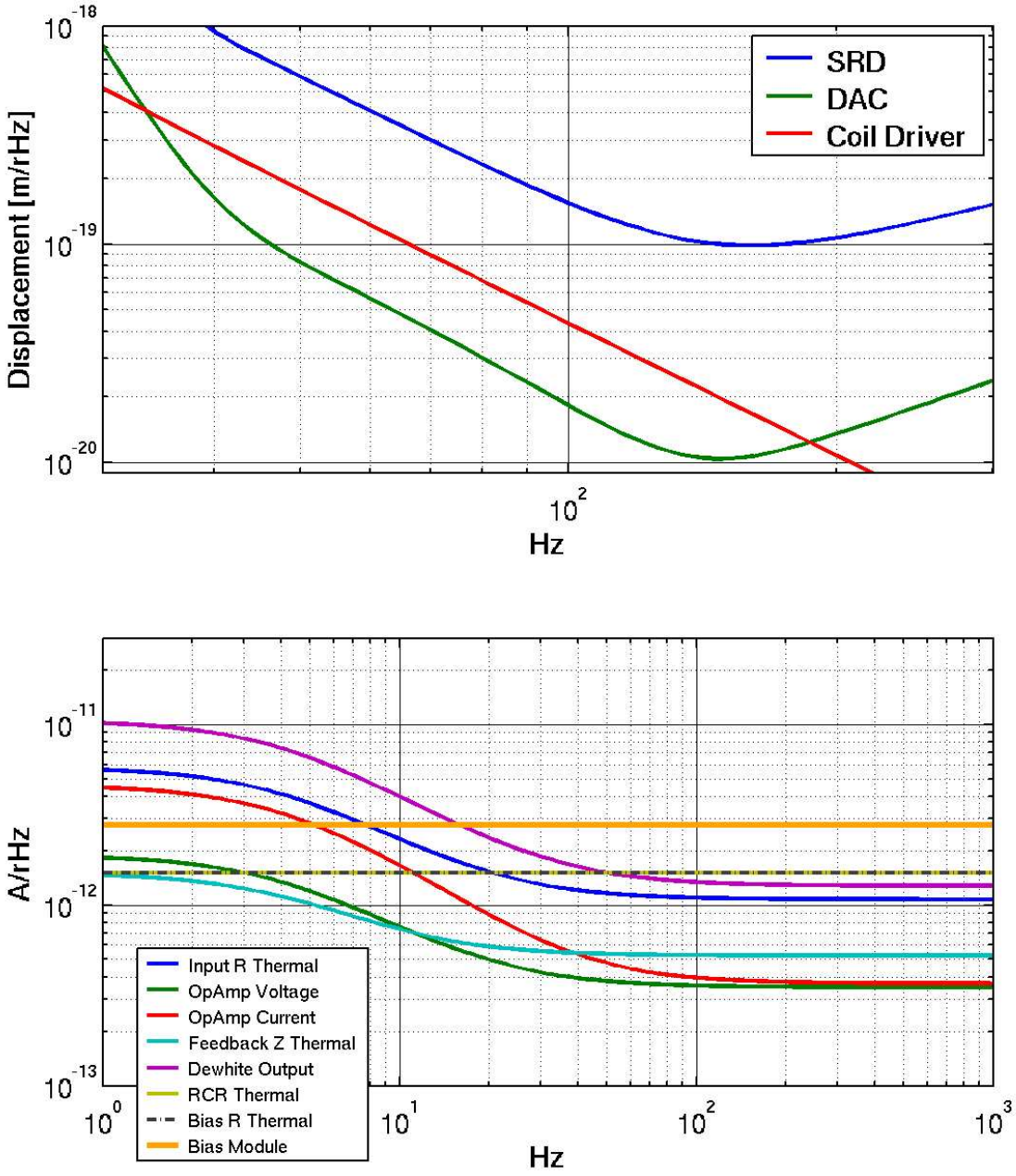

Figure 7 As Figure 6 above, but for the ITMs.

In both Figure 6 & 7, the number of 1000 nV/rHz has been used for the output noise of the DAC. This is a conservative number, assuming that there will be some units with less than optimal noise performance. However, even with this high estimate and the reduced filtering of the new configuration, DAC noise has essentially been removed from the interferometers' noise budget.

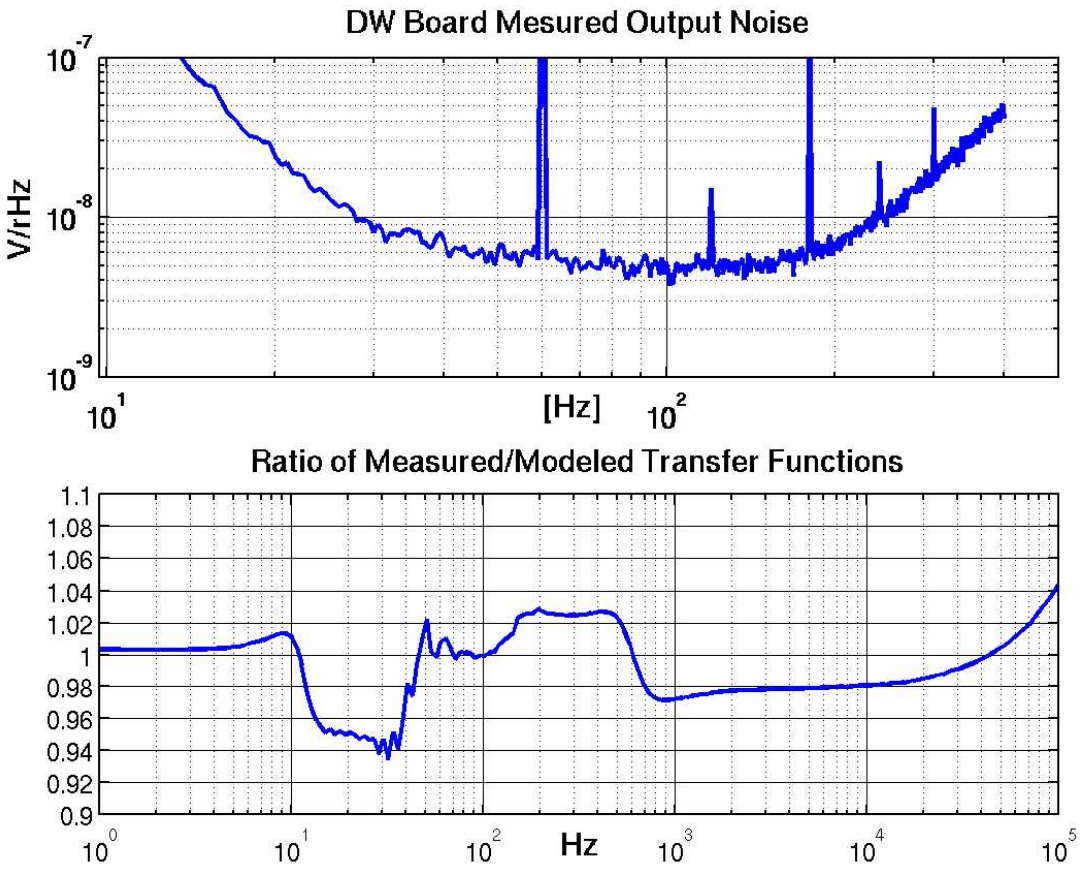

Figure 8 These measurements were made by J. Myers on a single channel of the new circuit. For the noise trace, the input noise of the pre-amp box has been subtracted in quadrature. The broadband noise level between 40 and 150 Hz is the same as on the A1 and C8 versions.

8 Bias Module Noise

Figures 6 & 7 show that current noise from the angular Bias Module would dominate the noise budget of the actuation electronics. There are two reasons for this; first,there is an excess voltage noise (~20 nV/rHz) measured on the bias module output and second, the bias resistor values have been reduced to supply the required torque to align the interferometer.

The following table lists the bias resistor values for the arm cavity masses in all three interferometers as of 8/30/04 :

	Hanford 4K	Livingston 4K	Hanford 2K
ETMX	7.2 K	**1.3 K**	7.2 K
ETMY	**3.0 K**	**1.3 K**	**3.0 K**
ITMX	7.2 K	7.2 K	**3.0 K**
ITMY	7.2 K	7.2 K	**3.0 K**

The excess voltage noise will be verified by measuring a few other units and/or investigated to reduce the levels. In addition, the severest case (on L1, where bias noise exceeds the SRD curve) is expected to be alleviated by angular control offload using the HEPI system (allowing the resistor values to be increased).

9 Conclusion

We propose to install this new dewhitening filter (Rev. D) for all the H1 test masses and make the listed changes to the H1 ETM Coil Drivers. If the test is successful (no problems in switching from ACQUIRE -> RUN mode) and the noise is as predicted, the changes should be propagated to H2.

For L1, the upgrade should only be made after there is a minimal isolation with HEPI and it has been established that lock acquisition is possible with these reduced currents (200 mA instead of 400 mA now).