LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

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LIGO DAC Tests

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1 Summary

1.1 General

Testing low noise converters is difficult since the device's non-linearity depends on the signal strength and requires signals with big swings to exposed noise in neighboring frequency bins. Both DACs and ADCs experience this type of noise. If one device is used to test the other, dedicated high quality analog circuits are required in-between to reduce the signal amplitude at the frequencies of the main signal and measure the distortion in close-by frequency bins.

A further difficulty is that the up- and down-converted noise heavily depends on the signal amplitude, the signal frequency distribution and the converter technology. A unified noise model may not be readily deducible, and a fixed noise curve, such as presented in E1800243, may not represent real world circumstances.

Most of our analog circuits such as AI, AA and whitening filters were built with converters in mind that had noise levels at and around 1µV/√Hz whereas newer devices may approach noise levels below 100nV/√Hz. As a consequence their contribution to the noise is no longer negligible in all circumstances.

We recommend to develop test procedures and setups that include dynamic signal testing for our electronics in critical places.

1.2 LIGO DAC

The LIGO DAC generally performs better than the previously tested 18-bit and 20-bit DACs from General Standards. In some tests the performance was significantly better. The channel to channel variation was also very small. We noticed a sensitivity to acoustic noise and 60 Hz line harmonics that was somewhat larger than anticipated with large amplitude signals. More investigation is needed here, but we don't see this as a showstopper. DC accuracy may also be worse than previous converters, but we have identified the issue and have a potential fix in the works.

Since all switching power supplies on the board are synchronized with GPS we see none of the intermodulation products of the previous boards.

2 Introduction

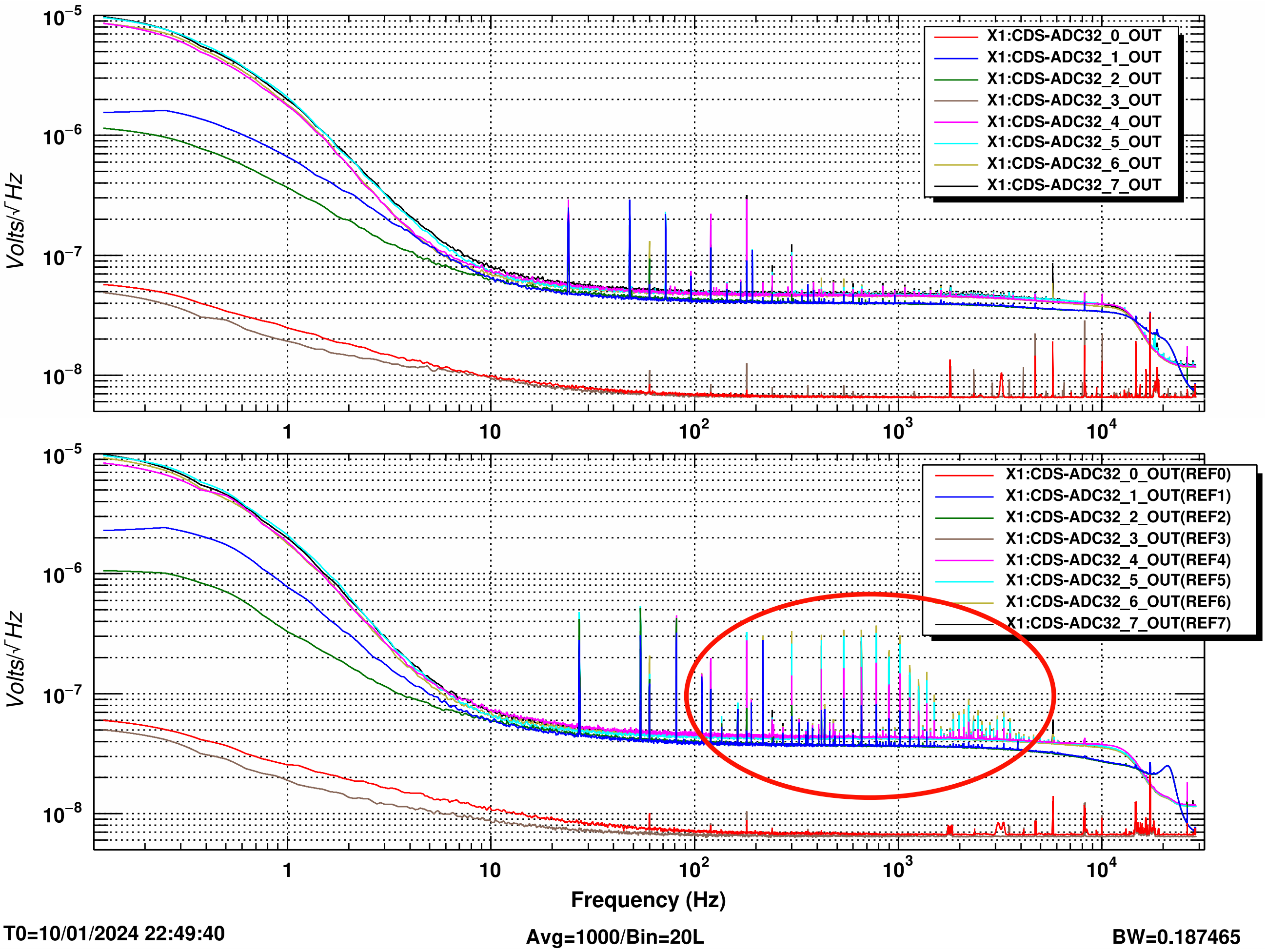
The DCC node for the LIGO DAC is E2200440.

The measurements for the 20-bit DAC can be found in the "20-bit DAC noise update" at G1500761.

The test setup is similar to the one described in the document above, but we are using a low noise ADC instead.

3 Intermodulation Products from Free Oscillators

When we first installed the LIGO DAC in the DAQ IO chassis it contains multiple GS 16-bit ADC cards. In the plot below the bottom panel shows the DAC noise with all the 16-bit ADC cards installed, whereas the top panel shows the same measurement with these cards removed. We can see a forest of lines between 100 Hz and a few kHz. These lines are generated by the intermodulation products of the free oscillators installed on these cards. The red/brown curves represent the noise floor of the setup. The DAC was running with 0V outputs. Features below 100 Hz are best ignored for now.



Plot 1: Noise from neighboring cards due to intermodulation products from their oscillators.

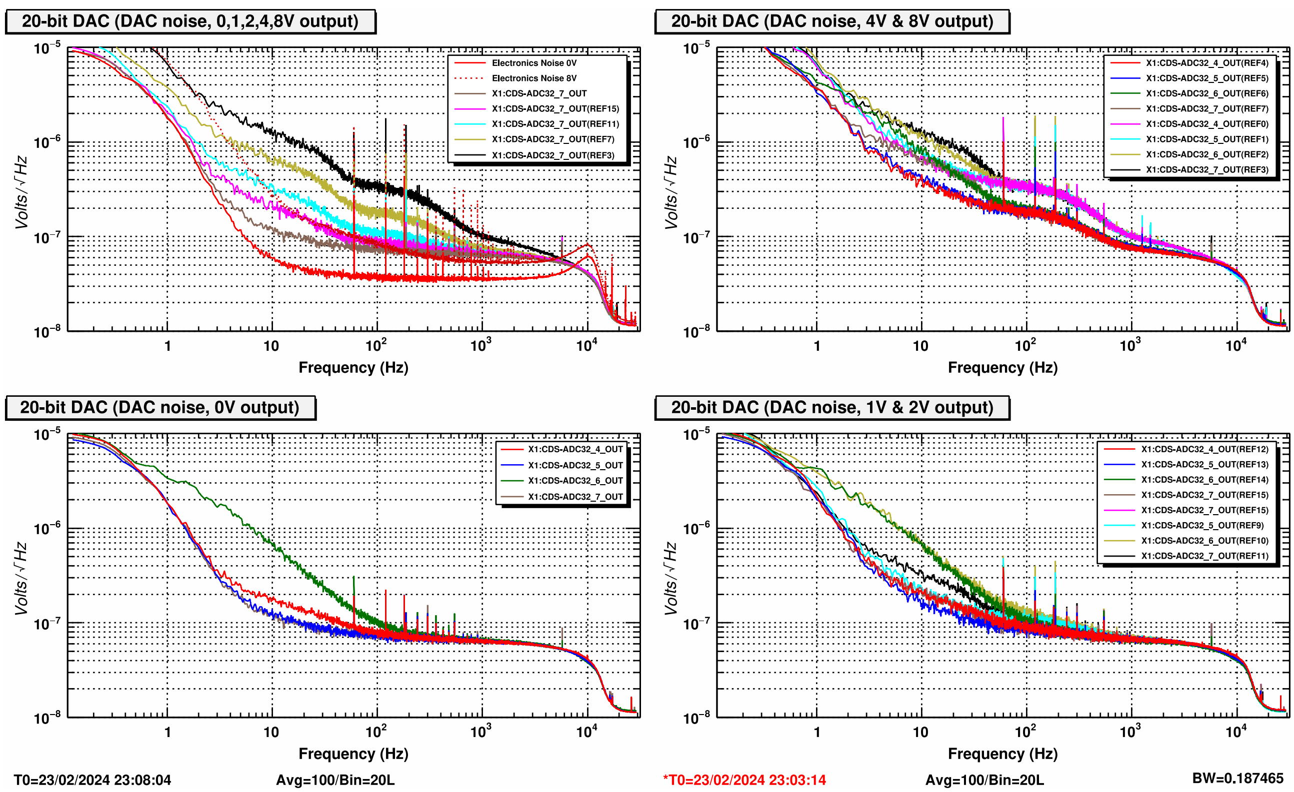
The LIGO converters do not implement free oscillators. This includes "hidden" oscillators such the ones used internally inside switching power supplies. The main oscillator is a 2^{26} Hz VCXO that is locked to the global timing distribution system. This clock is used to synchronize all switching power supplies on the board as well as drive the converter signals.

4 DC Tests

The DC test applies a fixed DC voltage to the output of the DAC and measures the noise after the signal has been whitened with a low noise ADC. The whitening filter is a standard LIGO whitening chassis with 2 stages of whitening (1 Hz/10 Hz zero/poles). This test represents the noise of a DAC that is mainly used to apply a bias such a suspension coil bias to steer the optics. One advantage of this test is that the noise of the analog setup can be measured using a 9V battery.

4.1 20-Bit DAC

The 20-bit DAC experiences quite a bit of excess noise with large offset voltages. Channel 6 of this board seems to have a much worse performance compared to the others.



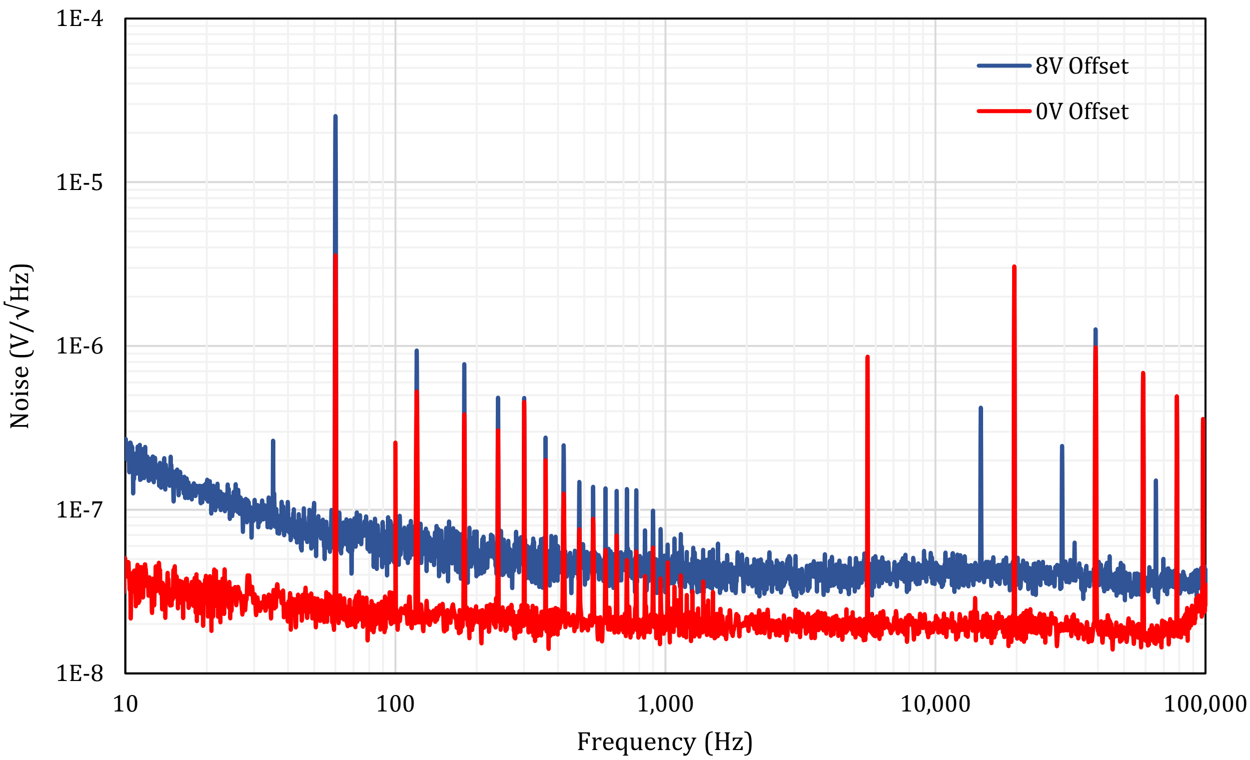
Plot 2: 20-bit DAC noise with constant output offsets. **Looks really bad. Needs to be retested!**

The top left plot shows the noise of the analog circuit driven by a 9V battery to be higher than the 0V DAC noise but lower than the noise of the analog circuit with shorted inputs. The peak and low pass at 10 kHz is due to the whitening chassis.

4.2 LIGO DAC

Plot 3 shows a preliminary plot of the noise of the LIGO DAC at fixed offset voltages of 0V and 8V. The measurement was done with an SR785 that has a noise level of ~3nV/√Hz. We can see elevated noise with the larger offset. At 10Hz the elevated noise may be limited by the noise of the DAC voltage supply and potentially can be improved further. In any case, the noise level stays below 100nV/√Hz for frequencies above 30 Hz which is significantly better than the 20-bit DAC. Most of the lines below 2 kHz are due to 60 Hz. There seems to be a higher susceptibility to 60 Hz noise at higher offsets, the actual line strengths also depend on the measurement setup.

When measured in the test stand additional noise is visible at the 8V offset around 500 Hz reaching 100nV/√Hz. This seems to be due to some acoustic sensitivity which we are still tracking down.

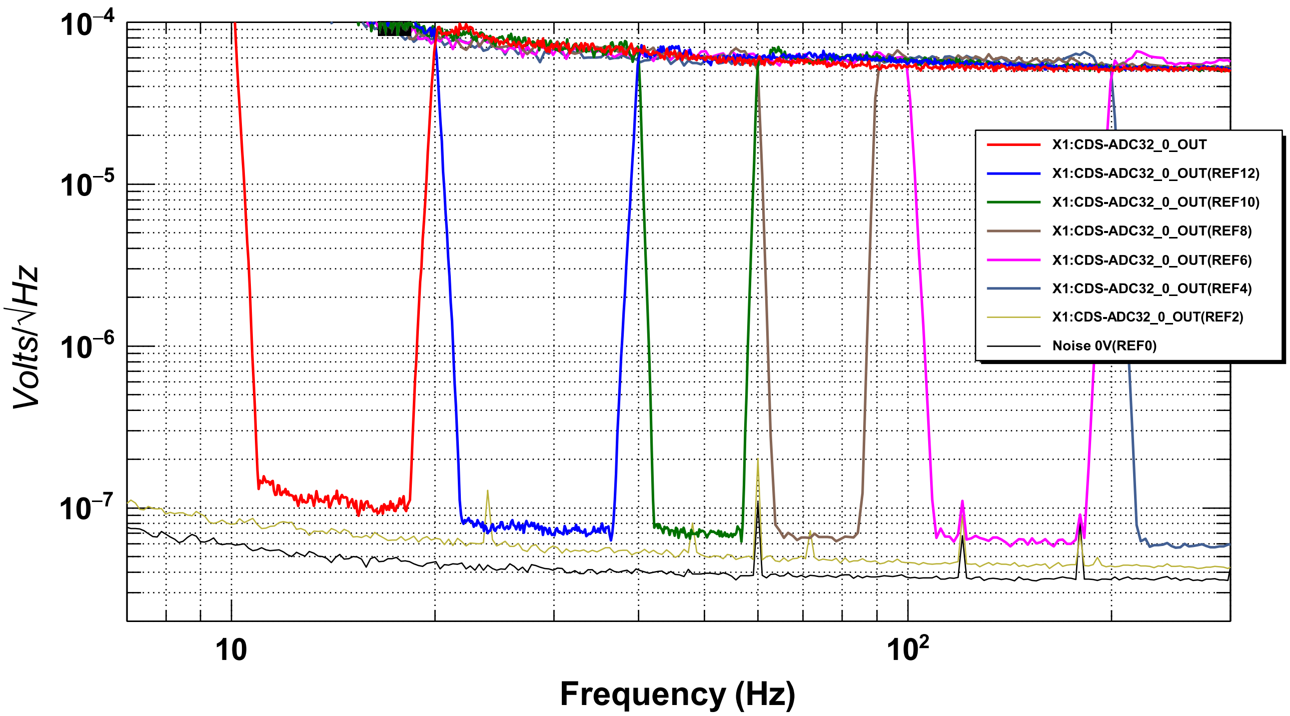


Plot 3: LIGO DAC noise at fixed offset voltages.

5 Dynamic Tests

5.1 Four Simple Poles/Zeroes at 1 Hz/10 Hz

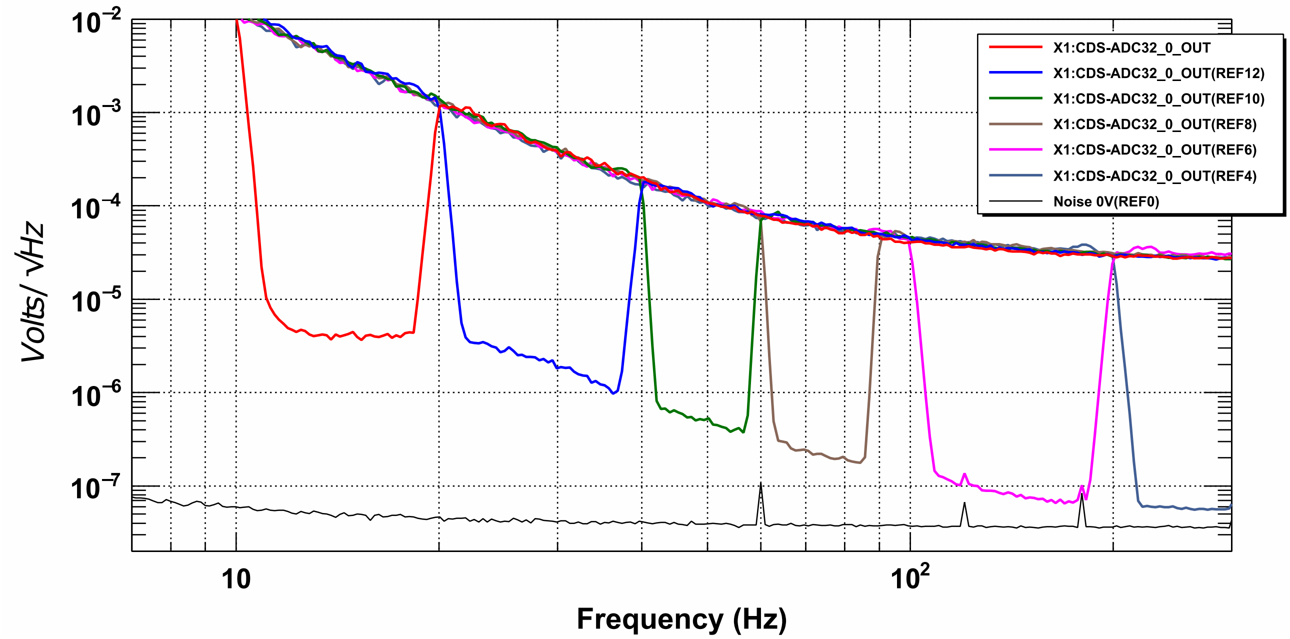
The test shown in Plot 4 was performed with white noise filtered by 4 simple poles at 1 Hz, 4 simple zeroes at 10 Hz, and varying elliptic bandstop band filters to reveal the DAC noise. The DAC signal had an amplitude of 1.4 Vpp. This plot should be directly compared to the one in G1500761 on page 5. In this test the LIGO DAC performs significantly better than the 20-bit DAC.



Plot 4: Dynamic test on channel 0 with differential output voltage of 1.4 Vpp, no offset, shaped noise with 4 poles at 1 Hz and 4 zeros at 10 Hz.

5.2 Four Simple Poles/Zeroes at 5 Hz/50 Hz

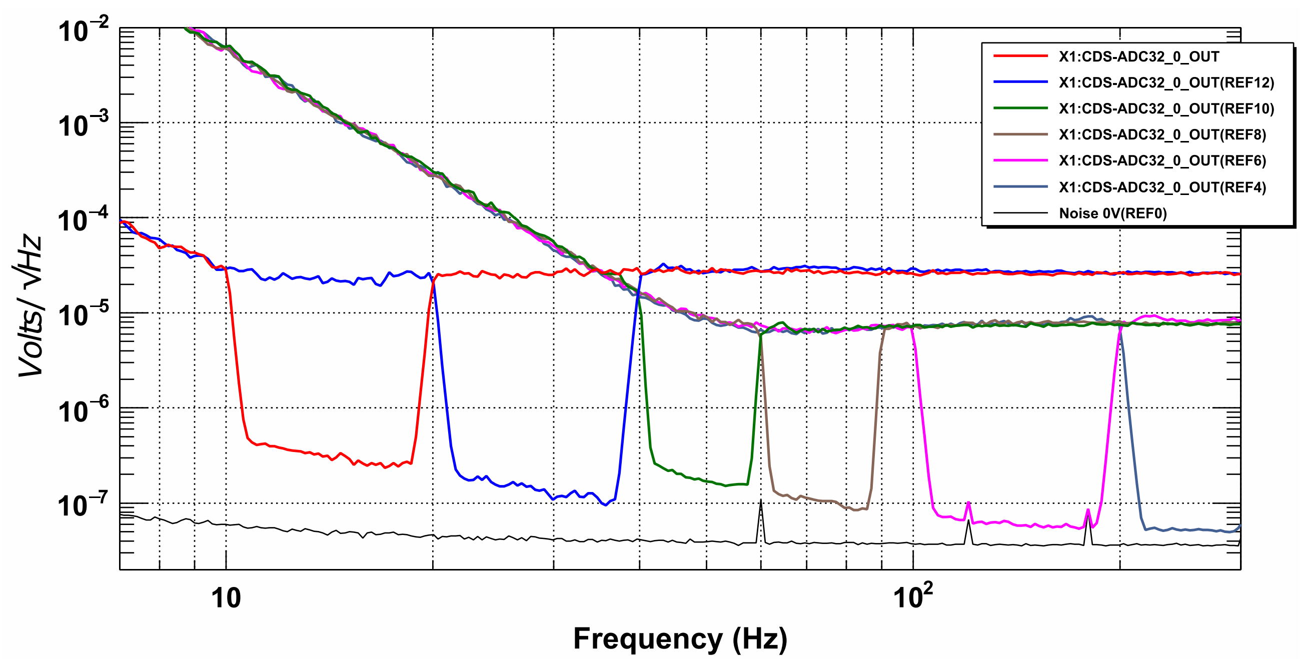
The next test shown in Plot 5 was performed with white noise filtered by 4 simple poles at 5 Hz, 4 simple zeroes at 50 Hz, and varying elliptic bandstop band filters to reveal the DAC noise. The DAC signal had an amplitude of 1.55 Vpp. This plot should be directly compared to the one in G1500761 on page 6. In this test the LIGO DAC performs about the same for frequencies below 30 and better at frequencies above.



Plot 5: Dynamic test on channel 0 with differential output voltage of 1.55 Vpp, no offset, shaped noise with 4 poles at 5 Hz and 4 zeros at 50 Hz.

5.3 Two Complex Poles/Zero Pairs at 5 Hz/50 Hz and 1 Hz/10 Hz

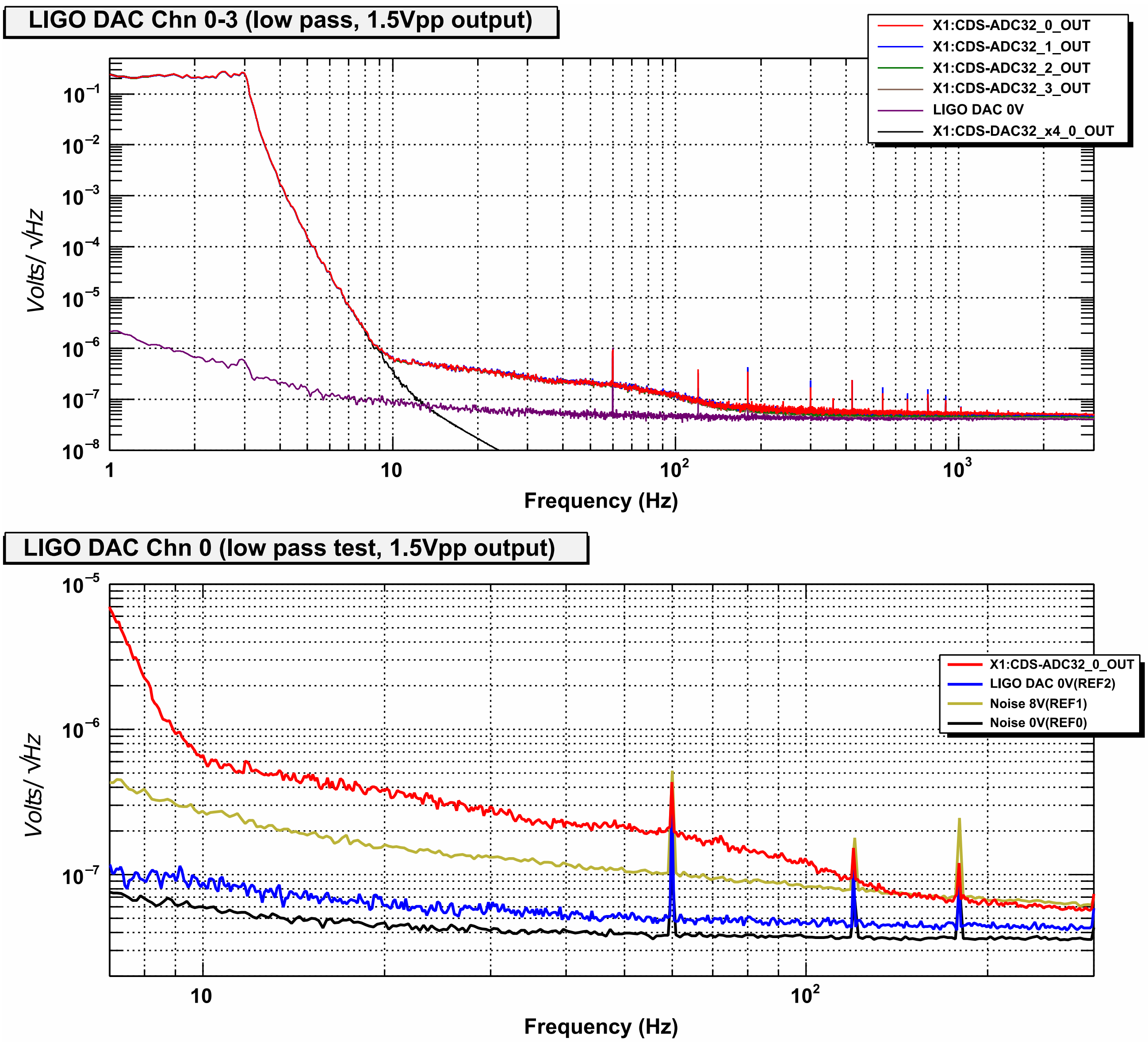
The next plot can be directly compared to G1401399 on page 6. This test uses complex poles and zeros. The LIGO DAC is significantly better than the 18-bit DAC used in G1401399.



Plot 6: Dynamic test on channel 0 with differential output voltage of 1.4 Vpp, no offset, shaped noise with 2 complex pole pairs at 5 Hz and 2 complex zero pairs at 50 Hz (Q = 1). For the 2 measurements below 40 Hz the noise shape was changed to push the rms to lower frequency: 2 complex pole pairs at 1 Hz and 2 complex zero pairs at 10 Hz.

5.4 Low Pass

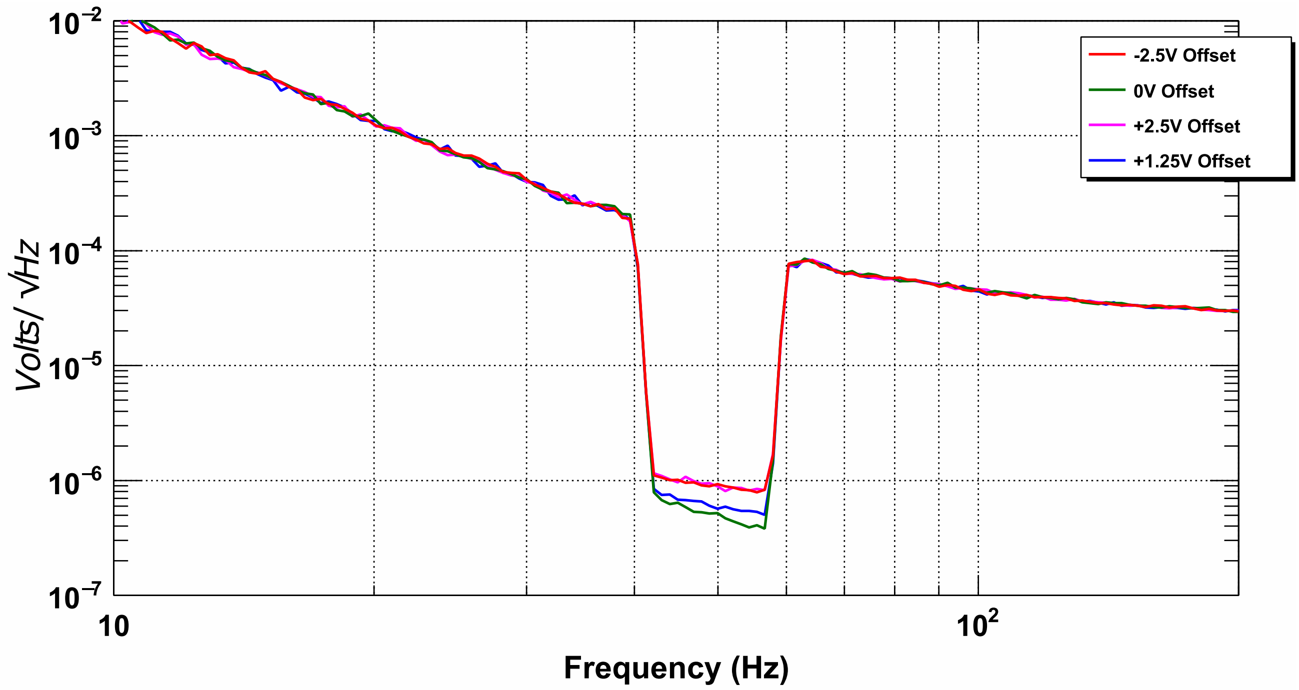
This test can be directly compared to the one in G1500761 on page 4. In this test the LIGO DAC performs mostly better than the 20-bit DAC.



Plot 7: Dynamic test on channel 0-3 with differential output voltage of 1.5 Vpp, no offset, shaped noise with 8-th order Chebyshev low pass filter at 3 Hz.

5.5 Varying Offsets

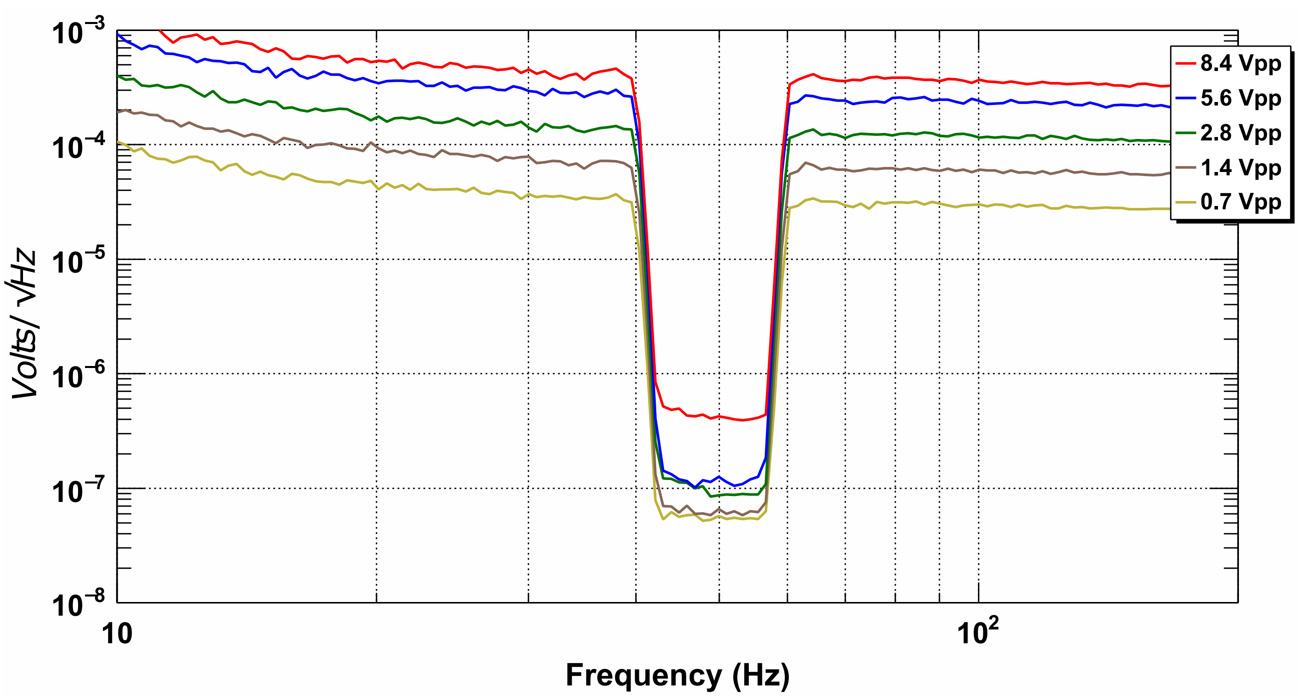
This test can be directly compared to the one in G1500761 on page 11. In this test the LIGO DAC performs better than the 20-bit DAC.



Plot 8: Dynamic test with varying offset on channel 0 with differential output voltage of 1.55 Vpp, shaped noise with 4 poles at 5 Hz and 4 zeros at 50 Hz.

5.6 Varying Amplitudes

This test can be directly compared to the one in G1500761 on page 12. In this test the LIGO DAC performs significantly better than the 20-bit DAC.



Plot 9: Dynamic test with varying amplitude on channel 0 with differential output voltage between 0.7 Vpp and 8.4 Vpp, no offset, shaped noise with 4 poles at 1 Hz and 4 zeros at 10 Hz.