# LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

# -LIGO-

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**Preliminary Noise Measurements of the General Standards PCI66-16AI64SSA-64-50M ADCs**

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# 1 Introduction

## 1.1 Purpose

The purpose of this document is to present the results of the preliminary noise tests recently conducted on the General Standards model PCI66-16AI64SSA-64-50M Analog to Digital converter (ADC) boards. These boards are 32 channels differential or 64 channels single-ended in a PCIX form factor. Detailed documentation of the module can be found on the General Standards web site at: http://www.generalstandards.com/. A more complete set of tests is planned for the very near future.

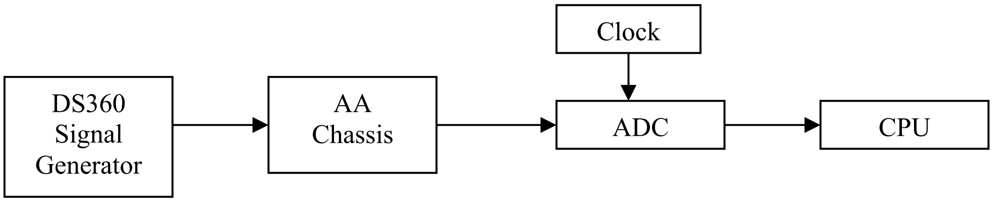
The ADC modules are presently being used in the AdL Suspension Quad Controls prototype and the BSC and HAM HEPI systems at LASTI. They are also scheduled for use in the AdL SEI Internal Seismic Isolation System (ISI) and the Squeezing Experiment at LASTI, and the DC Detection Experiment at the 40 Meter Interferometer. It is envisioned that these modules will eventually be replaced by a custom ADC module being developed within LIGO.

## 1.2 Test Setup

All tests were conducted using the test stand installed at Caltech and used LIGO front end software, timing system components, framebuilder and data analysis tools. The signal generator was a Stanford Research model DS360 and the signal analyzer was a Stanford Research model SR785. The Anti-Alias chassis was a LIGO-developed 32 channel 750Hz low pass filter chassis similar to those installed on the LASTI suspension and HEPI systems. Future testing will use an AA chassis with a cutoff frequency more appropriate to the 16384Hz sample rate. These chassis should be available later in the summer.

### 1.2.1 Single Tone Test Setup

The first tests conducted were the standard single tone tests typically used to measure the THD (Total Harmonic Distortion) and SFDR (Spurious Free Dynamic Range) of a particular ADC. In these tests a single tone, 100Hz in this case, is injected into the ADC and an FFT is performed on the sampled data. A block diagram of the test setup is shown in the figure below.

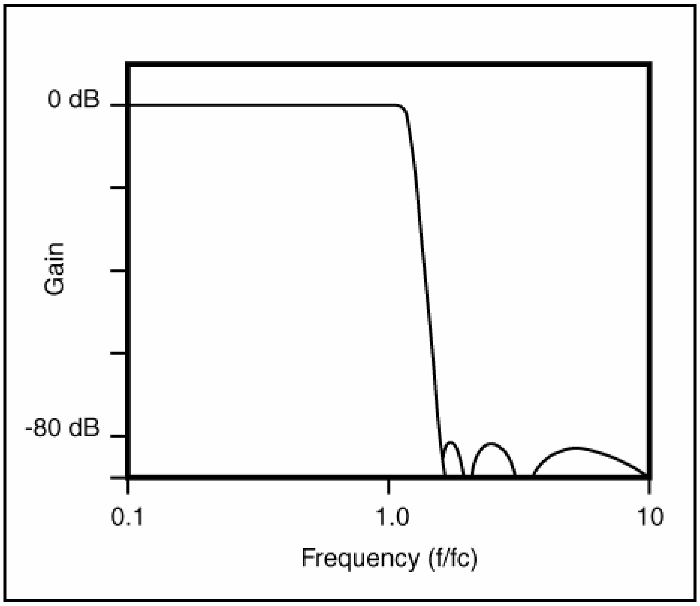


One problem in this type of test is making sure that measurement of the harmonics is actually a measure of the ADC and not a measure of the quality of the tone generator or a measure of the THD of the AA filter amplifiers. As a check a Stanford Research SR785 signal analyzer was used to independently measure the output power spectrum of the AA filter prior to the ADC input. This data is then compared to ADC data to make sure that the harmonic peaks are well below the measured peaks in the ADC power spectrum. Results are documented in the sections below.

### 1.2.2 Shaped Noise Test Setup

The second set of tests conducted used shaped noise to characterize the ADC. In these tests white noise is passed through various filters that simulate the power spectrum that a typical ADC may see in LIGO. In this case the filter is a very sharp cutoff low pass filter at 75Hz. The object of the test is to measure the noise floor beyond the filter cutoff and look for any non-linear up-conversion of the low frequency signal. The filter used for the tests was obtained using a Stanford Research model SR650 programmable filter.

Specifications for this module can be found at http://www.thinksrs.com/products/SR600.htm. The figure below is a plot (taken from the SRS website) of the low pass response of the filter.

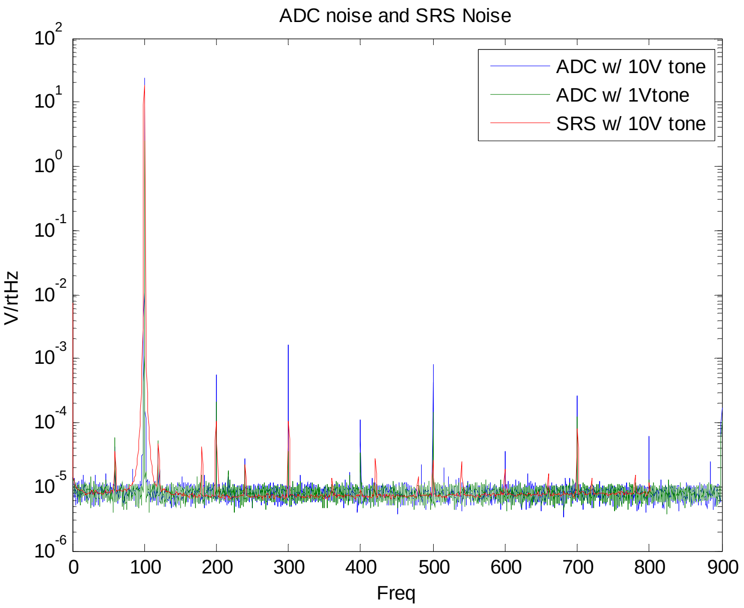


The block diagram for the test setup is similar to that used for the single tone tests described above with the exception that the SR650 filter is inserted between the DS360 signal source and the Anti-Alias filter.

# 2 Results

## 2.1 Single Tone Test Results

For this test a single tone frequency of 100Hz was chosen. Measurements were taken using 10Vrms (blue) and 1Vrms (green) signal levels. The sample frequency used was 16384 samples per second. Data was collected and analyzed using LIGO front end software and data analysis tools. The figure below shows the power spectra for the collected data. The third (red) trace on the plot was collected using the SR785 signal analyzer.

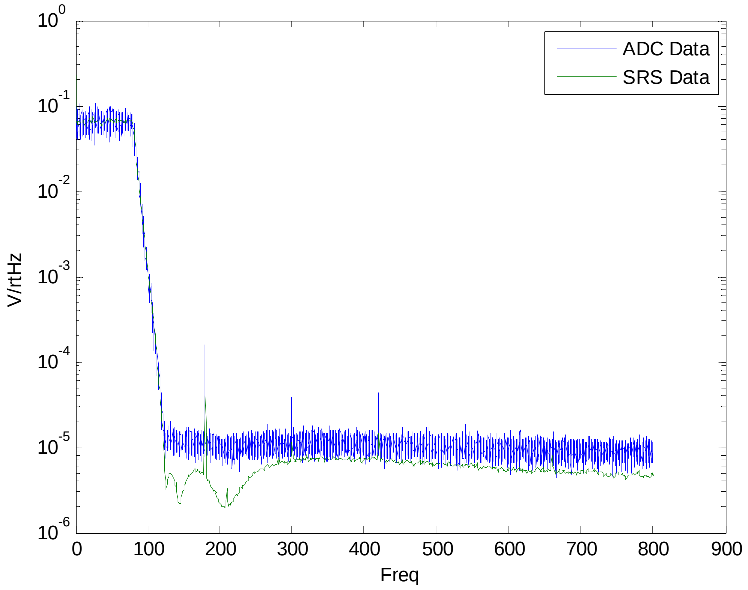


Both the ADC data and the SR785 data show the various harmonics of the 100Hz tone, but the SR785 harmonic levels are consistently well below the harmonic levels measured by the ADC, therefore it is reasonable safe to assume that the harmonic distortion shown on the ADC traces is a true measure of the harmonic distortion produced by the ADC module. The highest peak measured using a 10V tone into the ADC is the third harmonic and it is more than 80dB below the fundamental tone. It should also be noted that the harmonics measured using the 1V tone are consistently lower in magnitude than the 10V case, but are less than the 20dB difference in the fundamental tone magnitudes. If the harmonics are ignored, the input referred noise of the ADC is approximately 10uV/√Hz in both the 10V and 1V case.

The ADC chip used on the board is a Linear Technology LT1864. The datasheet can be found at: http://www.linear.com/pc/downloadDocument.do?navId=H0,C1,C1155,C1001,C1158,P2143,D4062 . The Spurious Free Dynamic Range (SFDR) quoted for the chip in the datasheet is ~95dB for an input frequency of 100Hz. The SFDR measured above for the 10V tone is approximately 85dB, slightly worse than expected.

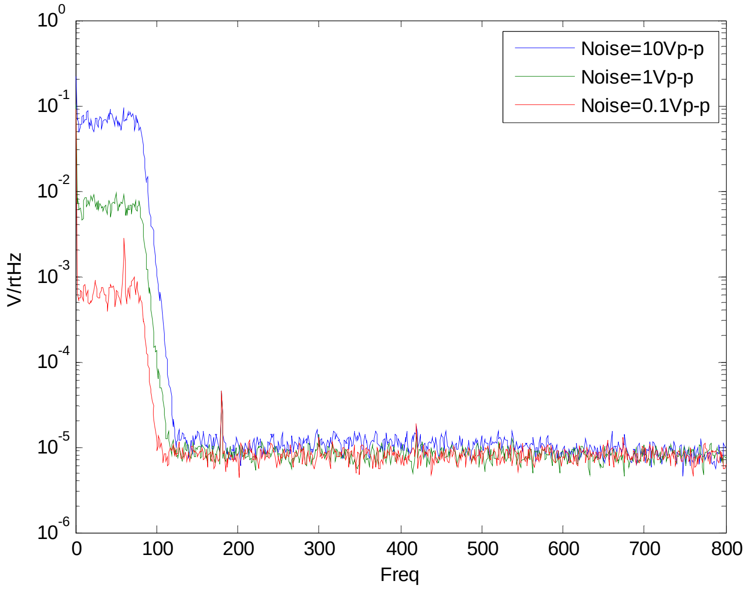
## 2.2 Shaped Noise Test Results

The figure below is a plot of the measured ADC (blue) and SR785 (green) noise using a 10V white noise source and the SR650 programmable filter described above.



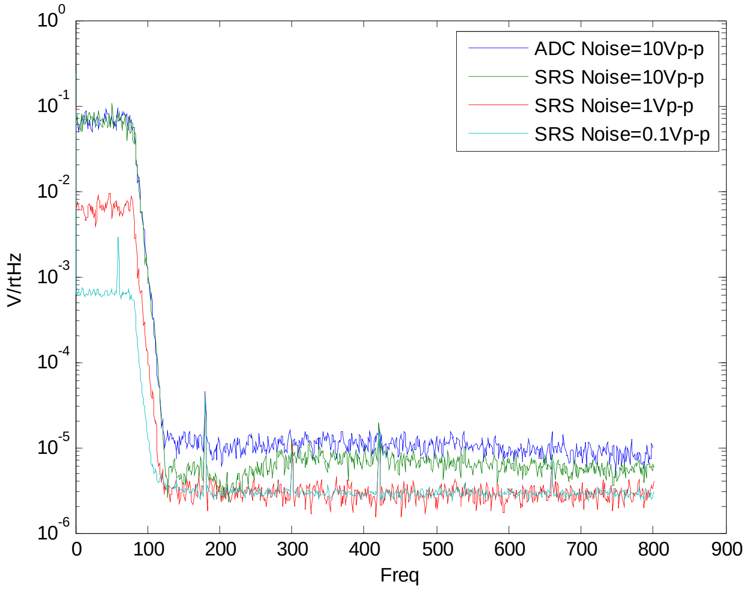
The ADC noise for frequencies greater than 100Hz is approximately 10uV/√Hz and is flat. Using the SR785, the shape of the filter can clearly be seen below the 10uV/√Hz level. While it is not shown on the plot, the flat noise floor of the ADC extends out to the Nyquist frequency of 8192Hz while the SR785 trace follows the trajectory of the 3rd order, 750Hz anti-Alias filter.

The plot below shows the measured noise for the ADC using 3 different white noise levels, 10V (blue), 1V (green) and 0.1V (red).



In all three cases, the out of band input-referred noise of the ADC is approximately 10uV/√Hz and no out of band “bumps” were observed up to the 8192Hz Nyquist frequency.

The figure below shows the SR785 response at the same three levels along with the 10V ADC data. Note that the out of band input-referred noise for the 1V and 0.1V levels is approximately 3uV/√Hz.



# 3 Conclusions and Observations

## 3.1 Input-Referred Noise

The measurements show that the input referred noise of the ADC module using a 16384 sample rate is approximately 10uV/√Hz. A figure of merit that has been adopted by LIGO to characterize ADC is defined as the full-scale peak to peak range of the ADC divided by the input-referred noise. In the case of the General Standards ADC this figure would be:

$$\text{FOM}_{\text{PCI66}}\text{=40Vp-p/10uV= 132dB}$$

In comparison, the Pentek 6102ADC used in LIGO would have an FOM of:

$$\text{FOM}_{6102}\text{=10Vp-p/15uV= 116dB}$$

and the ICS-110 would have an FOM of:

$$\text{FOM}_{\text{ICS110}}\text{=4Vp-p/0.3uV= 142dB}$$

The ICS110 has a better FOM, but also suffers from a pipeline delay that makes it inappropriate for systems with unity gain bandwidths of more than 10Hz.

## 3.2 Further Testing

Further testing of the PCI66 ADC module should be conducted. Daniel Sigg has suggested a suite of tests that should be performed on all ADCs used in Advanced LIGO. These tests are outlined in an email sent on 6/28/2006 (the text of the email is printed in the appendix of this document) and include:

- Two-tone tests
- Red noise tests
- Out of Band Rejection tests
- Channel to Channel Crosstalk

The PCI66 ADC module is capable of sampling to frequencies as high as 200KHz. In some very early tests conducted at CIT, the sample frequency of the ADC was increased to 131072Hz and the data was decimated to 16384 samples/second. In these tests, the input referred noise of the ADC was observed to drop by the square root of the increase in sample frequency as predicted by theory. These tests should be repeated and the results documented.

Future tests should be done using anti-alias filters that are more suitable for the sampling frequency being used. The filters used in these tests were actually built for a 2048Hz sample system and were the only filters available at the time. In the very near future filters for 16384Hz and 32768Hz sample systems will be available.

# Appendix

Some ideas on how to test the converters. The tests are the "same" for ADCs and DACs. A test consist of a signal source and a measurement setup. In case of an ADC test the signal source is analog and the measurement is done in software with the captured ADC data. In case of a DAC test the signal source is a computer generated waveform and the measurement setup is in hardware. To check the performance of the test setup one can use the analog measurement setup to verify the analog signal source.

Required equipment are a low noise signal source as well as a couple of filter modules.

100Hz Sine Test.
Apply a 100Hz sine wave with amplitudes at 39Vpp, 4Vpp, 400mVpp, 40mVpp
Make sure the noise at f > 200Hz is <10nV/rtHz
Determine ADC noise at f > 200Hz as function of excitation amplitude

1kHz Sine Test
Apply a 1kHz sine wave with amplitudes at 39Vpp, 4Vpp, 400mVpp, 40mVpp
Make sure the noise at f < 500Hz is <10nV/rtHz
Determine ADC noise at f > 200Hz as function of excitation amplitude

White Noise Test
Apply white noise with an amplitude of 10Vrms, 1Vrms, 100mVrms and a stopband/
notch filter at 100Hz
Determine ADC noise at f = 100Hz as function of excitation amplitude

Red Noise Test
Apply a 1/f (in amplitude) noise with an amplitude of 10Vrms, 1Vrms, 100mVrms and
a stopband/notch filter at 100Hz
Determine ADC noise at f = 100Hz as function of excitation amplitude

Harmonic Test
Apply a 1kHz sine wave with an amplitude of 39Vpp
Determine the harmonic power

Two-Tone Test
Apply a 1kHz and a 100Hz sine wave with an amplitude of 10Vpp each.
Determine the intermodulation product

Out-of-Band Rejection
Apply a 100kHz sine wave with an amplitude of 39Vpp and 4Vpp
Make sure the noise at f < 50kHz is <10nV/rtHz
Determine the power at aliased frequencies
Determine the noise level in band

Channel-to-Channel Crosstalk
Apply a 1kHz sine wave with an amplitudes of 39Vpp on channel 1
Determine the power at 1kHz in channel 2