LIGO 32 Channel Low Noise ADC

Marc Pirello & Daniel Sigg

E2300322

Outline

- History
  - LIGO Timing Board (completed and installed post Covid 2022)
  - LIGO DAC (completed and installed for O5 2026)
  - LIGO ADC (prototype hell)
  - LIGO FDS (future)
- Prototype
  - Layout Issues
  - Current Issues
  - Heat Issues aka Space Heater Issues

History

- LIGO Timing Board
  - Simplified design for legacy Duotone board.
  - Completed 2020, deployed along with V5 IO Chassis.
- LIGO DAC
  - Increased channel density, massive cost reduction over COTS boards.
  - Completed 2025, deployed LHO for O5 2026.
- LIGO ADC
  - Improved performance, cost reduction over COTS boards.
  - Completed 2026, production 2026.
- LIGO FDS
  - Required to improve bandwidth of common mode servo.
  - Prototype Spring 2026

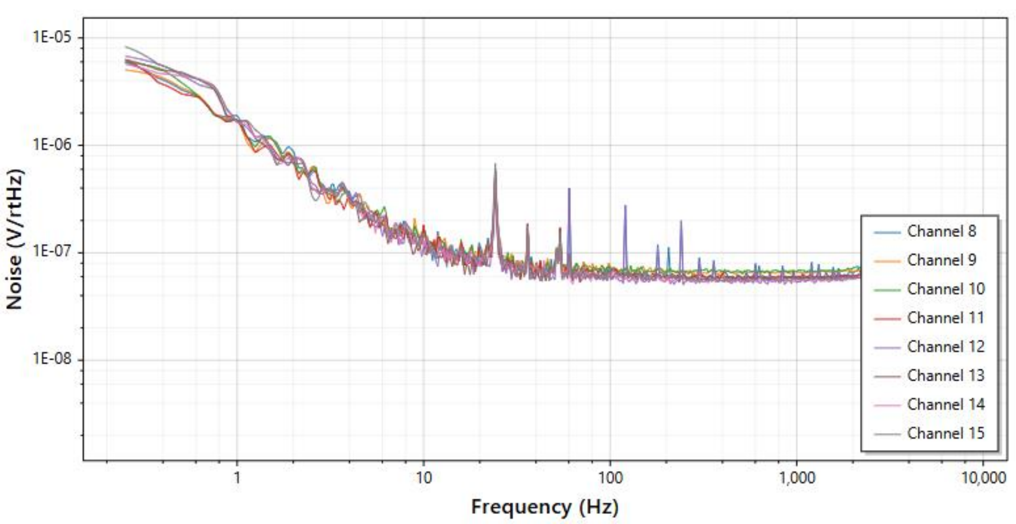
Production Timing Board

- The timing board is required to propagate site GPS timing to the LIGO DAC and LIGO ADC boards.
- This allows the LIGO DAC and LIGO ADC to phase lock with the site, using the same 2^n timing as the site, and reducing low frequency products from unlocked drifting clocks.
- The timing board paired with the DAC and ADC boards allow these boards to keep their own microsecond timing.

Production LIGO DAC Results

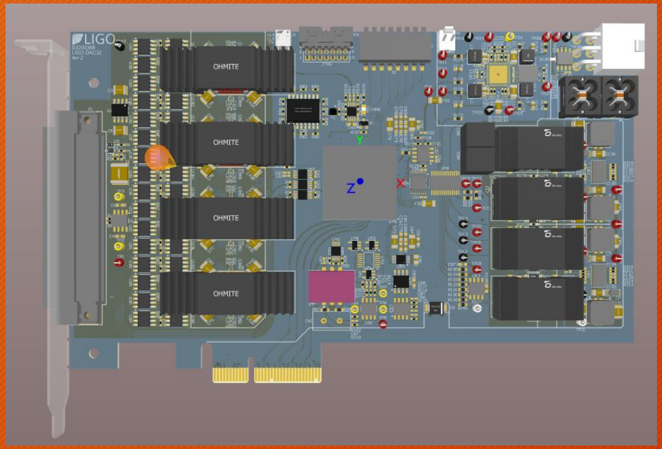
- Noise performance of the LIGO DAC at 100 HZ is typically less than 200nV/rtHz, 1kHz is less than 100nV/rtHz.
- Channel density replaces 4 of the 20 bit DACS with one of the LIGO DACS. This allows more flexibility in IO chassis deployment.
- Cost of the LIGO DAC is $2500 for 32 channels compared to $10k for 8 channels, or $40k for 32 channels.

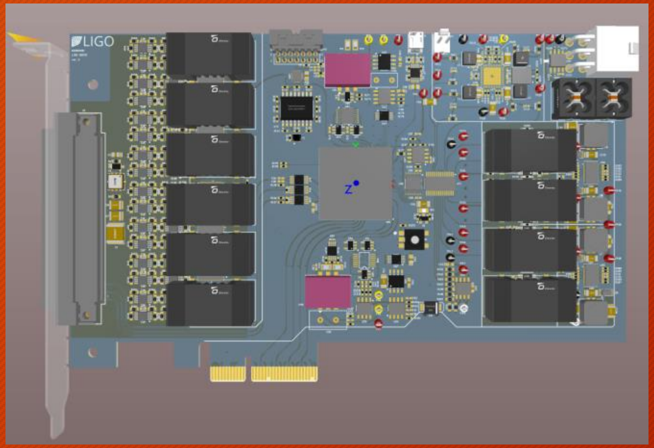
```
Measure DAC Noise
Measure noise of DAC with constant output

Date: 03 February 2026 14:56:03
Engineer:
DUT: D2200368-v2
Serial: S2500000-v1

Set DAC outputs to:    8.0000V
DAC noise measurement requirements Freq   100 Hz, Noise <  200 nV/√Hz,   Freq   1000 Hz, Noise <  100 nV/√Hz
DAC Noise Measurement Results:
  Channel  0: Freq   100 Hz, Noise      73 nV/√Hz,   Freq   1000 Hz, Noise      63 nV/√Hz
  Channel  1: Freq   100 Hz, Noise      78 nV/√Hz,   Freq   1000 Hz, Noise      63 nV/√Hz
  Channel  2: Freq   100 Hz, Noise      74 nV/√Hz,   Freq   1000 Hz, Noise      57 nV/√Hz
  Channel  3: Freq   100 Hz, Noise      68 nV/√Hz,   Freq   1000 Hz, Noise      55 nV/√Hz
  Channel  4: Freq   100 Hz, Noise      95 nV/√Hz,   Freq   1000 Hz, Noise      63 nV/√Hz
  Channel  5: Freq   100 Hz, Noise     159 nV/√Hz,   Freq   1000 Hz, Noise      62 nV/√Hz
  Channel  6: Freq   100 Hz, Noise     104 nV/√Hz,   Freq   1000 Hz, Noise      67 nV/√Hz
  Channel  7: Freq   100 Hz, Noise      89 nV/√Hz,   Freq   1000 Hz, Noise      58 nV/√Hz
  Channel  8: Freq   100 Hz, Noise      72 nV/√Hz,   Freq   1000 Hz, Noise      63 nV/√Hz
  Channel  9: Freq   100 Hz, Noise      73 nV/√Hz,   Freq   1000 Hz, Noise      65 nV/√Hz
  Channel 10: Freq   100 Hz, Noise      74 nV/√Hz,   Freq   1000 Hz, Noise      66 nV/√Hz
  Channel 11: Freq   100 Hz, Noise      69 nV/√Hz,   Freq   1000 Hz, Noise      64 nV/√Hz
  Channel 12: Freq   100 Hz, Noise      67 nV/√Hz,   Freq   1000 Hz, Noise      59 nV/√Hz
  Channel 13: Freq   100 Hz, Noise      69 nV/√Hz,   Freq   1000 Hz, Noise      59 nV/√Hz
  Channel 14: Freq   100 Hz, Noise      68 nV/√Hz,   Freq   1000 Hz, Noise      60 nV/√Hz
  Channel 15: Freq   100 Hz, Noise      66 nV/√Hz,   Freq   1000 Hz, Noise      59 nV/√Hz
  Channel 16: Freq   100 Hz, Noise      76 nV/√Hz,   Freq   1000 Hz, Noise      63 nV/√Hz
  Channel 17: Freq   100 Hz, Noise      80 nV/√Hz,   Freq   1000 Hz, Noise      69 nV/√Hz
  Channel 18: Freq   100 Hz, Noise      73 nV/√Hz,   Freq   1000 Hz, Noise      58 nV/√Hz
  Channel 19: Freq   100 Hz, Noise      69 nV/√Hz,   Freq   1000 Hz, Noise      59 nV/√Hz
  Channel 20: Freq   100 Hz, Noise      75 nV/√Hz,   Freq   1000 Hz, Noise      64 nV/√Hz
  Channel 21: Freq   100 Hz, Noise      71 nV/√Hz,   Freq   1000 Hz, Noise      58 nV/√Hz
  Channel 22: Freq   100 Hz, Noise      77 nV/√Hz,   Freq   1000 Hz, Noise      67 nV/√Hz
  Channel 23: Freq   100 Hz, Noise      71 nV/√Hz,   Freq   1000 Hz, Noise      55 nV/√Hz
  Channel 24: Freq   100 Hz, Noise      87 nV/√Hz,   Freq   1000 Hz, Noise      63 nV/√Hz
  Channel 25: Freq   100 Hz, Noise      97 nV/√Hz,   Freq   1000 Hz, Noise      72 nV/√Hz
  Channel 26: Freq   100 Hz, Noise      86 nV/√Hz,   Freq   1000 Hz, Noise      60 nV/√Hz
  Channel 27: Freq   100 Hz, Noise      82 nV/√Hz,   Freq   1000 Hz, Noise      59 nV/√Hz
  Channel 28: Freq   100 Hz, Noise      85 nV/√Hz,   Freq   1000 Hz, Noise      63 nV/√Hz
  Channel 29: Freq   100 Hz, Noise      85 nV/√Hz,   Freq   1000 Hz, Noise      57 nV/√Hz
  Channel 30: Freq   100 Hz, Noise      92 nV/√Hz,   Freq   1000 Hz, Noise      64 nV/√Hz
  Channel 31: Freq   100 Hz, Noise      85 nV/√Hz,   Freq   1000 Hz, Noise      55 nV/√Hz
DAC noise measurement passed
```

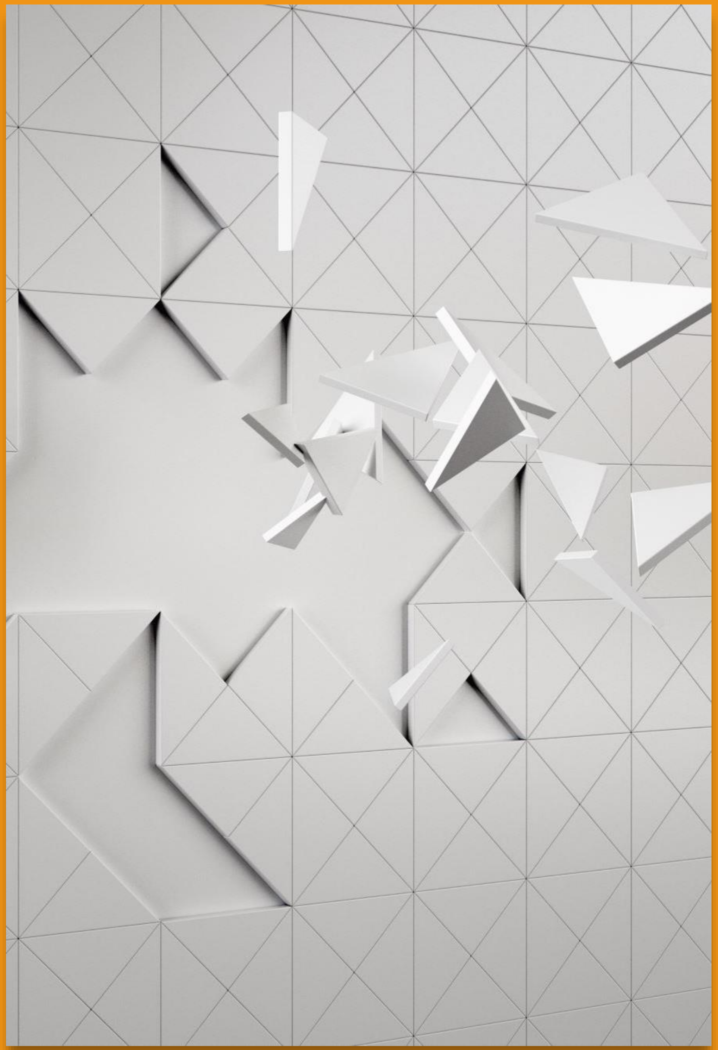


Prototype

- Many solutions were common between the DAC and ADC.
- Problems solved on the DAC propagate to solutions on the ADC, and vice versa.
- With the full production of the DAC, the ADC benefits from all of the lessons learned on the DAC.

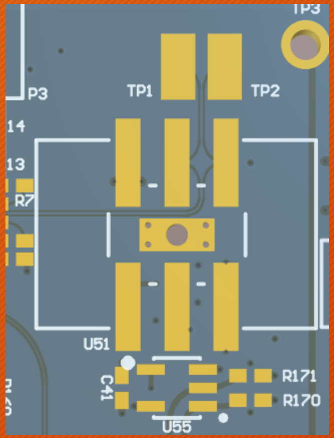


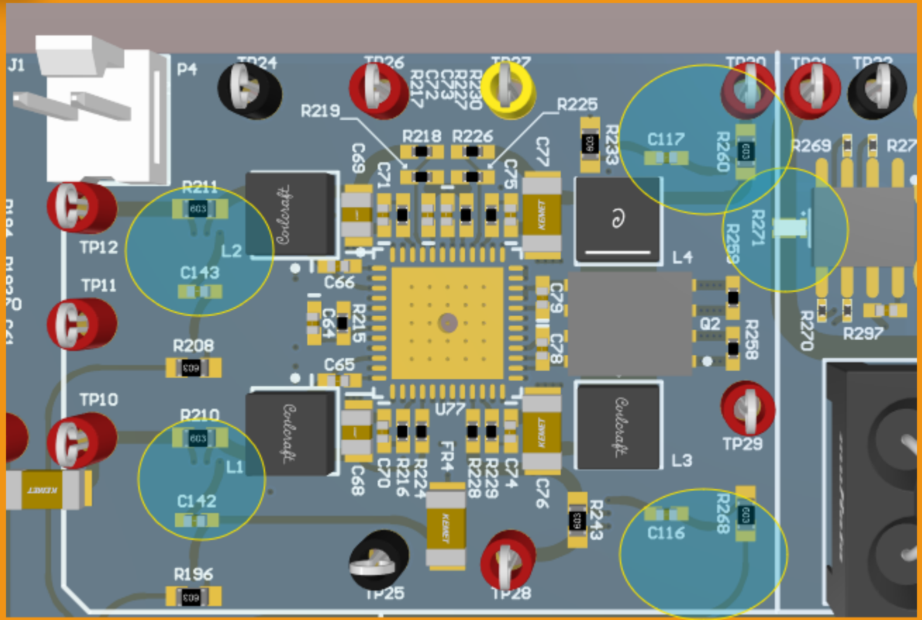




Prototype - Layout Issues

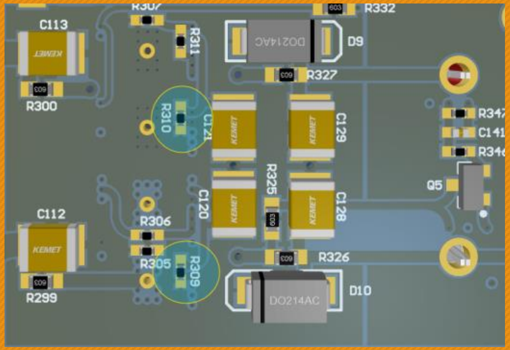
- Current Sensors were all wrong on the original DAC and that issue propagated to the ADC. In the production DAC these issues were solved, and this solution has been implemented on the ADC.
- Pads were fixed on the ADC to allow more VCXO options for locking phase, SI-TIME.

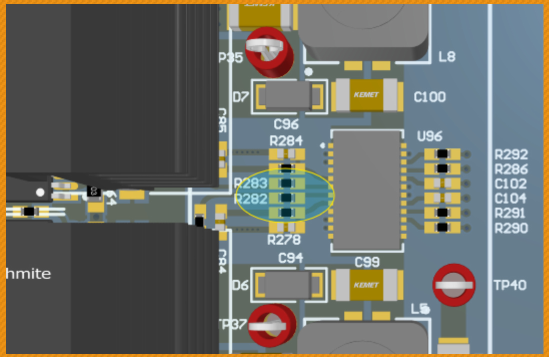


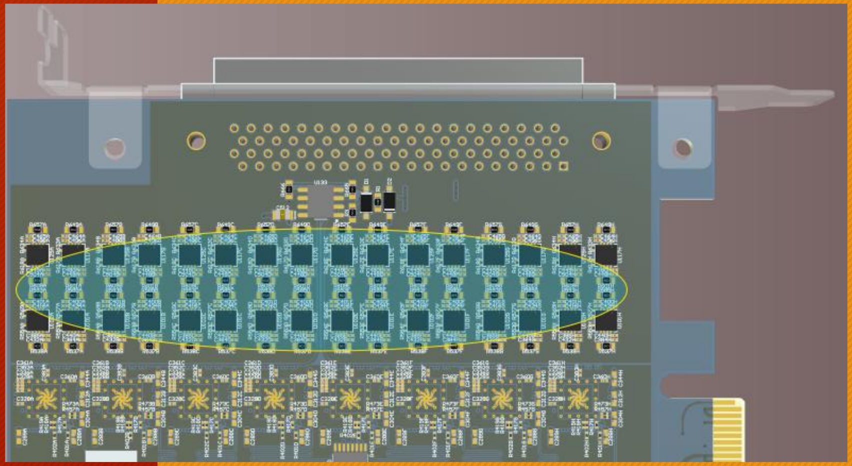


Prototype – Current Issues

- Initial current draw for the stock ADC was 2A at 12V, we were not ready for this and the power dissipation was not sufficient, this caused lots of heat, see next slide.
- We reduced the +/- 15V rails to +/-12.5V then finally to +/-11.2V which is sufficient margin for the front end opamp rails. We also reduced the +4V supply to +2.5V further reducing current loss. These two changes reduced current draw by 250mA.
- Swapping the OPA1612 out with the ADA4084-2 reduced the current by another 500mA, putting us at parity with the DAC current draw.
- COM reference front end supply from +11.2V to +5V further reduces current by 110ma. This is a 4.096V reference will run fine on +5V.





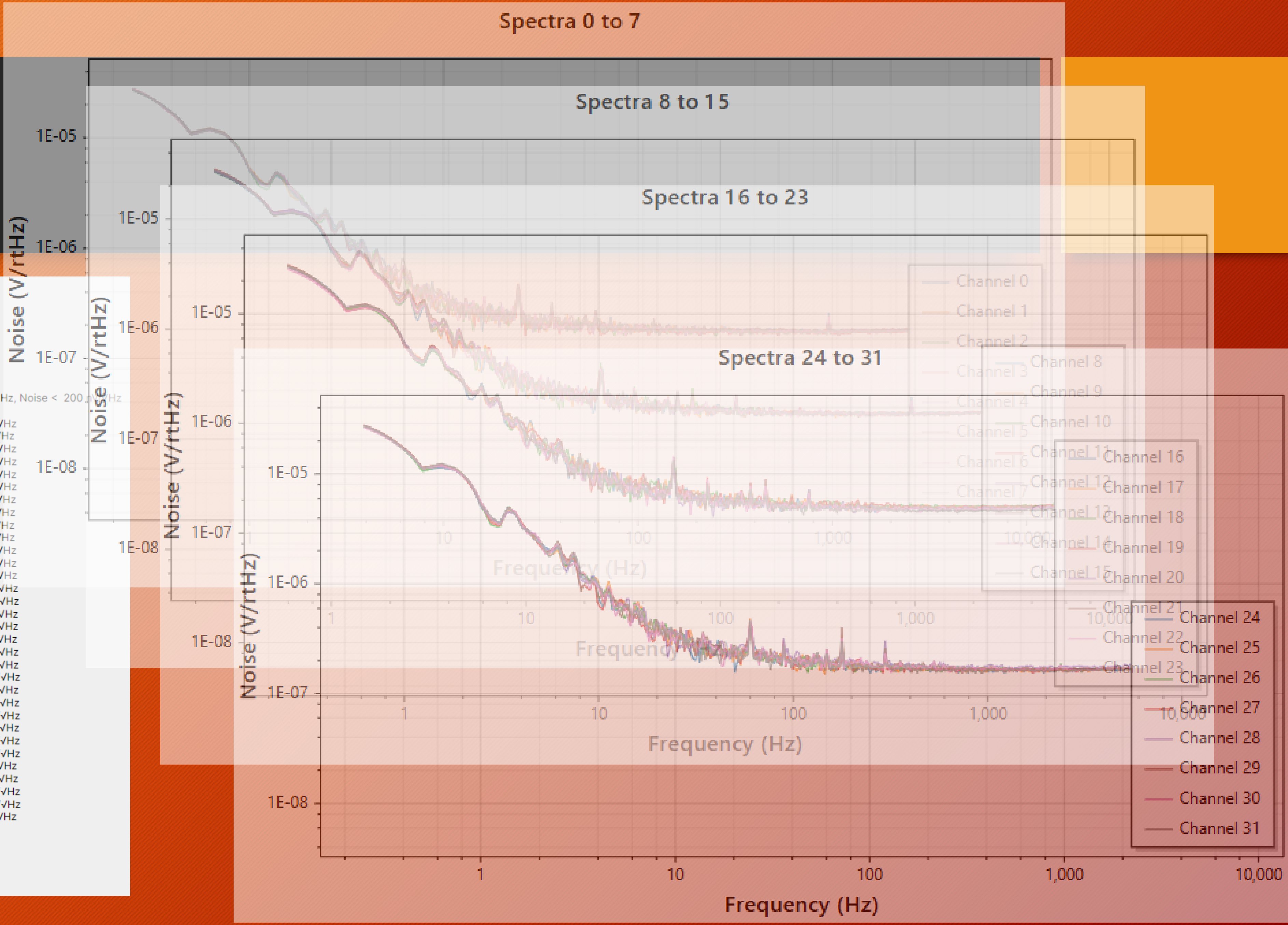


Prototype – Heat Issues

- The stock LIGO ADC was hot. Daniel called it a space heater.
- By reducing current we have solved the heat issue. We also found better FPGA heatsinks from Radian which are more affordable and that conform to the PCIe space requirements.
- The fully upgraded ADC board measured 57.1C after many hours of testing in an enclosed IO chassis, matching the production DAC for heat generation.

Results

```
Measure ADC Noise
Measure noise of ADC with constant input

Date: 03 February 2026 15:06:38
Engineer:
DUT: D2200368-v2
Serial: S2500000-v1

Set DAC outputs to:    8.0000V
ADC noise measurement requirements Freq    100 Hz, Noise <  300 nV/√Hz,    Freq   1000 Hz, Noise <  200 nV/√Hz
ADC Noise Measurement Results:
  Channel  0: Freq   100 Hz, Noise       188 nV/√Hz,    Freq   1000 Hz, Noise       165 nV/√Hz
  Channel  1: Freq   100 Hz, Noise       185 nV/√Hz,    Freq   1000 Hz, Noise       167 nV/√Hz
  Channel  2: Freq   100 Hz, Noise       185 nV/√Hz,    Freq   1000 Hz, Noise       166 nV/√Hz
  Channel  3: Freq   100 Hz, Noise       186 nV/√Hz,    Freq   1000 Hz, Noise       165 nV/√Hz
  Channel  4: Freq   100 Hz, Noise       186 nV/√Hz,    Freq   1000 Hz, Noise       173 nV/√Hz
  Channel  5: Freq   100 Hz, Noise       183 nV/√Hz,    Freq   1000 Hz, Noise       169 nV/√Hz
  Channel  6: Freq   100 Hz, Noise       190 nV/√Hz,    Freq   1000 Hz, Noise       174 nV/√Hz
  Channel  7: Freq   100 Hz, Noise       185 nV/√Hz,    Freq   1000 Hz, Noise       167 nV/√Hz
  Channel  8: Freq   100 Hz, Noise       191 nV/√Hz,    Freq   1000 Hz, Noise       172 nV/√Hz
  Channel  9: Freq   100 Hz, Noise       184 nV/√Hz,    Freq   1000 Hz, Noise       171 nV/√Hz
  Channel 10: Freq   100 Hz, Noise       191 nV/√Hz,    Freq   1000 Hz, Noise       175 nV/√Hz
  Channel 11: Freq   100 Hz, Noise       193 nV/√Hz,    Freq   1000 Hz, Noise       172 nV/√Hz
  Channel 12: Freq   100 Hz, Noise       177 nV/√Hz,    Freq   1000 Hz, Noise       167 nV/√Hz
  Channel 13: Freq   100 Hz, Noise       179 nV/√Hz,    Freq   1000 Hz, Noise       169 nV/√Hz
  Channel 14: Freq   100 Hz, Noise       183 nV/√Hz,    Freq   1000 Hz, Noise       166 nV/√Hz
  Channel 15: Freq   100 Hz, Noise       178 nV/√Hz,    Freq   1000 Hz, Noise       164 nV/√Hz
  Channel 16: Freq   100 Hz, Noise       183 nV/√Hz,    Freq   1000 Hz, Noise       167 nV/√Hz
  Channel 17: Freq   100 Hz, Noise       187 nV/√Hz,    Freq   1000 Hz, Noise       168 nV/√Hz
  Channel 18: Freq   100 Hz, Noise       183 nV/√Hz,    Freq   1000 Hz, Noise       165 nV/√Hz
  Channel 19: Freq   100 Hz, Noise       185 nV/√Hz,    Freq   1000 Hz, Noise       163 nV/√Hz
  Channel 20: Freq   100 Hz, Noise       190 nV/√Hz,    Freq   1000 Hz, Noise       168 nV/√Hz
  Channel 21: Freq   100 Hz, Noise       184 nV/√Hz,    Freq   1000 Hz, Noise       166 nV/√Hz
  Channel 22: Freq   100 Hz, Noise       179 nV/√Hz,    Freq   1000 Hz, Noise       166 nV/√Hz
  Channel 23: Freq   100 Hz, Noise       173 nV/√Hz,    Freq   1000 Hz, Noise       164 nV/√Hz
  Channel 24: Freq   100 Hz, Noise       175 nV/√Hz,    Freq   1000 Hz, Noise       158 nV/√Hz
  Channel 25: Freq   100 Hz, Noise       168 nV/√Hz,    Freq   1000 Hz, Noise       159 nV/√Hz
  Channel 26: Freq   100 Hz, Noise       180 nV/√Hz,    Freq   1000 Hz, Noise       160 nV/√Hz
  Channel 27: Freq   100 Hz, Noise       179 nV/√Hz,    Freq   1000 Hz, Noise       161 nV/√Hz
  Channel 28: Freq   100 Hz, Noise       181 nV/√Hz,    Freq   1000 Hz, Noise       165 nV/√Hz
  Channel 29: Freq   100 Hz, Noise       183 nV/√Hz,    Freq   1000 Hz, Noise       168 nV/√Hz
  Channel 30: Freq   100 Hz, Noise       192 nV/√Hz,    Freq   1000 Hz, Noise       164 nV/√Hz
  Channel 31: Freq   100 Hz, Noise       179 nV/√Hz,    Freq   1000 Hz, Noise       161 nV/√Hz
ADC noise measurement passed
Figure01: Spectra 0 to 7
Figure02: Spectra 8 to 15
Figure03: Spectra 16 to 23
Figure04: Spectra 24 to 31
```



Results Discussion – Daniel Notes

- The GS PCI66-16AI64SSA noise measures at 4uV/rtHz at 100Hz with small input signal
- The LIGO AD32 ADC noise measures at 200nV/rtHz at 100Hz with small input signal.
- Left is 0V input signal, Right is 10V input signal