LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

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Audit of existing 10.6 μm photodiodes

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LIGO Science Collaboration

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1 Introduction

The purpose of this document is to audit all the VIGO-10.6 mm photodiodes owned by LIGO to determine how many, if any, have low enough noise for Enhanced LIGO TCS. The target RIN level for eLIGO at approximately 1.1E-7 at 150Hz.

The serial numbers of the photodiodes that were tested and their original location are listed in Table 1.

Serial #	Originally from
6836	CIT
9003	LHO
9005	LHO
9006	LLO
9388	LHO
9711	LLO
9768	LHO
9803	LLO
9804	LLO
9805	LLO
9826	LHO
10250	CIT
10492	LHO
11840	CIT

Table 1: The photodiodes under test and their original location.

2 Dark noise as relative intensity noise floor

2.1 RIN at different power levels

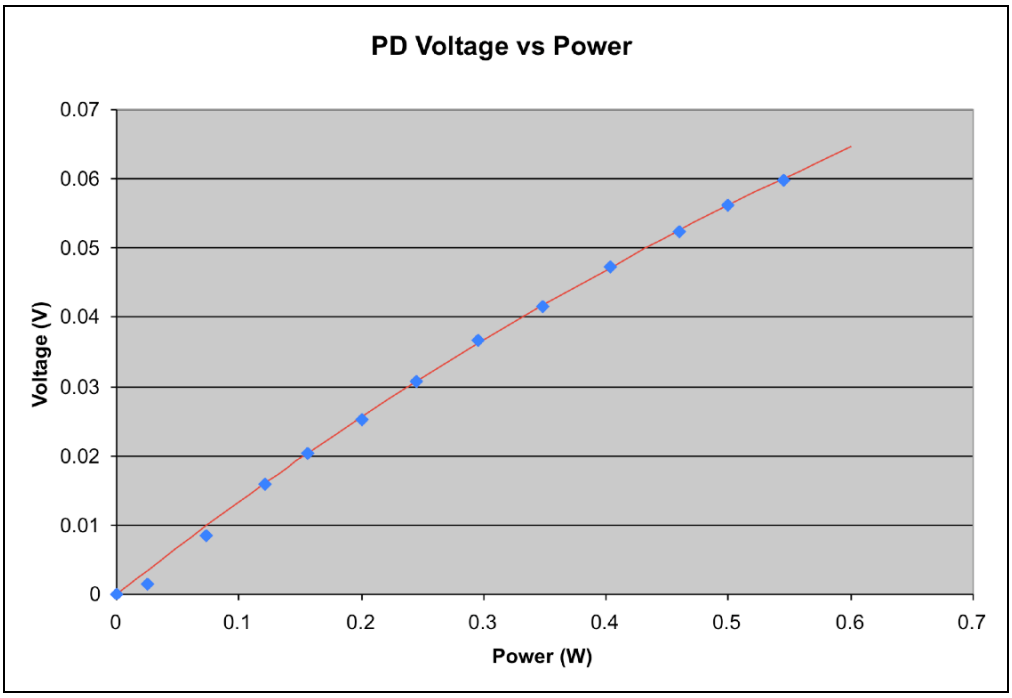

Figure 1: PD output voltage vs incident power for PD 11840.

The above data was fitted to a curve described by $aP/(1+P/b)$, where $a = 0.141\,V/W$ and $b = 1.97\,W$.

In the following tests all the photodiodes had their voltages tested at approximately 240mW incident power. In the eLIGO TCS they will be run at approximately 520mW.

At a given power level, *P*, the relative intensity noise, *dP/P*, (RIN) is given by:

$$P = g[V]$$

$$dP = g'[V]\,dV$$

$$\frac{dP}{P} = \frac{g'[V]\,dV}{g[V]} = \frac{(dP/dV)\,dV}{P}$$

The voltages and small signal gains at the tested and target incident powers are shown in the table below as determined from the fit to the curve in Figure 1. This applies only to PD 11840, but it should be safe to assume, to first order, that all the PDs follow a curve of this shape – we can simply scale this curve by the relative sizes of the voltages on different photodiodes at 240mW. It follows from the above fit that the dark noise floor at 520mW is approximately 60% of that at 240mW.

Power	Voltage	dV/dP
0.239 *W*	30 *mV*	0.122 *V/W*
0.520 *W*	56 *mV*	0.090 *V/W*

3 Photodiode performance

3.1 Output voltage and noise with 250mW incident on PD

Each photodiode was examined using the testbed illustrated in Figure 2.

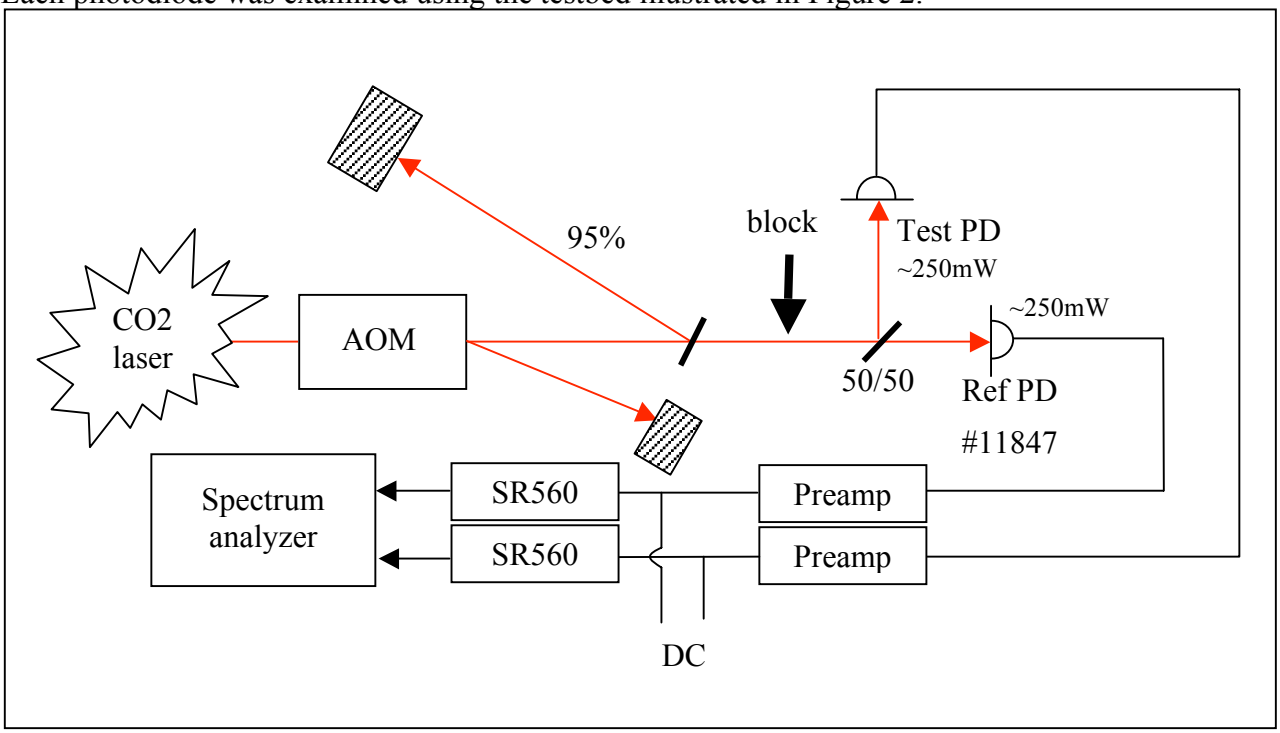

Figure 2: AOM diffraction efficiency was adjusted such that approximately 250mW was incident on each PD. The transmission PD was kept constant for all test PDs and was used to determine the incident laser power for each test.

Each photodiode was placed in the Test PD position and the DC output of the two PDs after the preamps (gain = 100x) was measured with ~250mW of optical power incident on the active

surface. The incident power on the PDs was set to this level so that they were operating in a linear regime below saturation. The laser beam was blocked and the noise after the SR560s (gain = 100x, input = AC coupled, no filter on output) was recorded. The results are shown in Table 2.

Serial #	Voltage (mV)	Noise @ 152Hz [nVrms/SQRT(Hz)]	RIN with ~240mW incident @ 152Hz [per SQRT(Hz)]	RIN with ~520mW incident @ 152Hz [per SQRT(Hz)]
6836	5.10	1.20	2.70E-07	1.62E-07
9003	6.90	2.04	3.41E-07	2.05E-07
9005	6.20	2.74	5.10E-07	3.06E-07
9006	5.80	2.55	5.07E-07	3.04E-07
9388	4.80	1.71	4.11E-07	2.47E-07
9711	5.80	1.42	2.81E-07	1.69E-07
9768	5.00	1.54	3.56E-07	2.13E-07
9803	6.70	1.62	2.79E-07	1.67E-07
9804	4.90	1.37	3.23E-07	1.94E-07
9805	5.20	1.52	3.36E-07	2.02E-07
9826	5.10	1.47	3.33E-07	2.00E-07
10250	2.30	1.89	9.46E-07	5.67E-07
10492	23.83	1.64	7.90E-08	4.74E-08
11840	30.84	1.47	5.48E-08	3.29E-08
11847	30.10	1.66	6.35E-08	3.81E-08

Table 2: The output voltage of all the photodiodes with approximately 240mW of 10.6 μm radiation incident on the active surface. Also shown is the dark noise of the electronics @ 152Hz at the PD when the CO2 laser is blocked and the corresponding minimum RIN at 240mW and 520mW incident.

The data above is plotted in Figure 2.

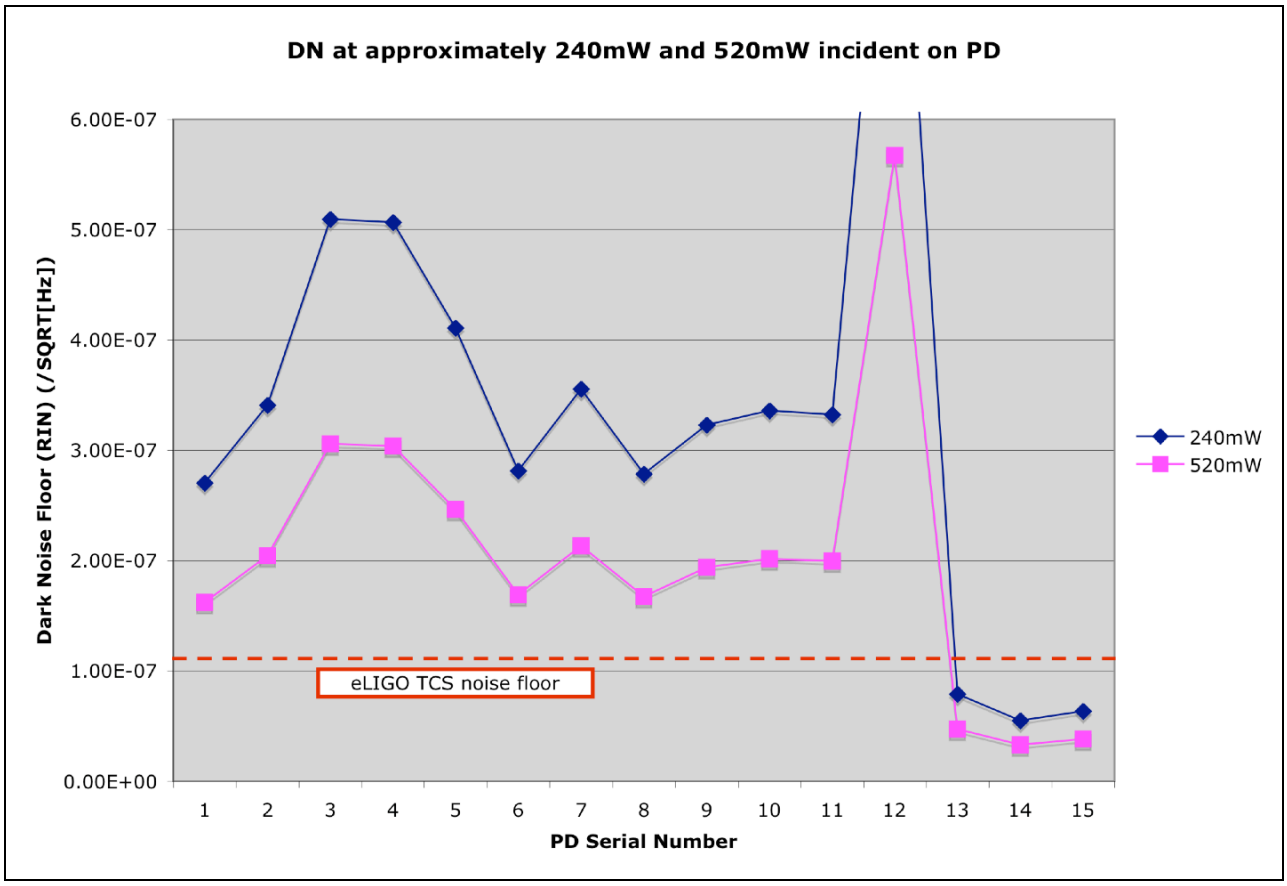

Figure 2: Estimated dark noise floor at 152Hz when 240mW and 520mW are incident on the PDs

3.2 Photodiode noise curves

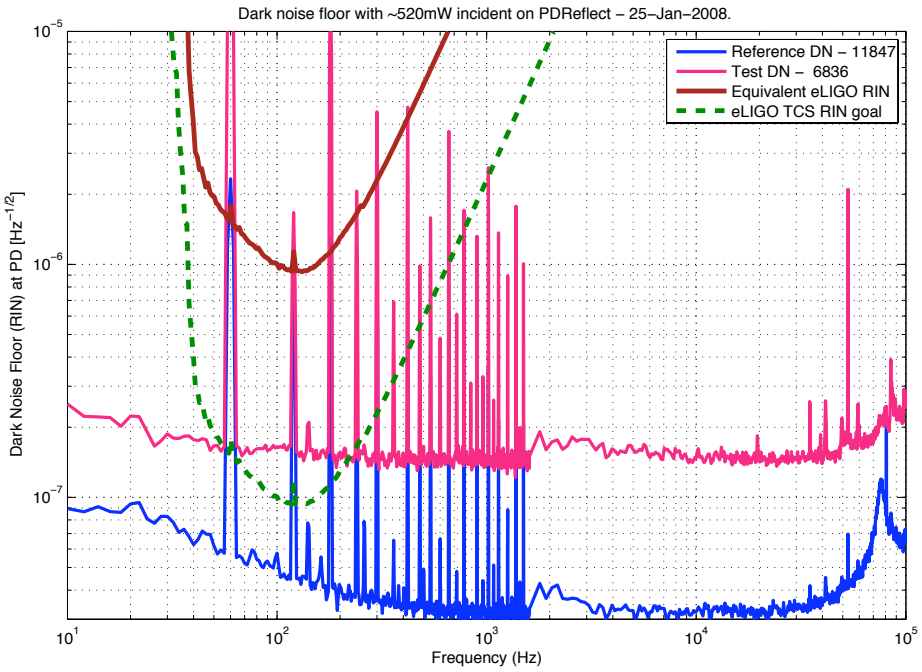

Figure 3: PD 6836 - Dark noise floor as RIN and eLIGO TCS noise goal

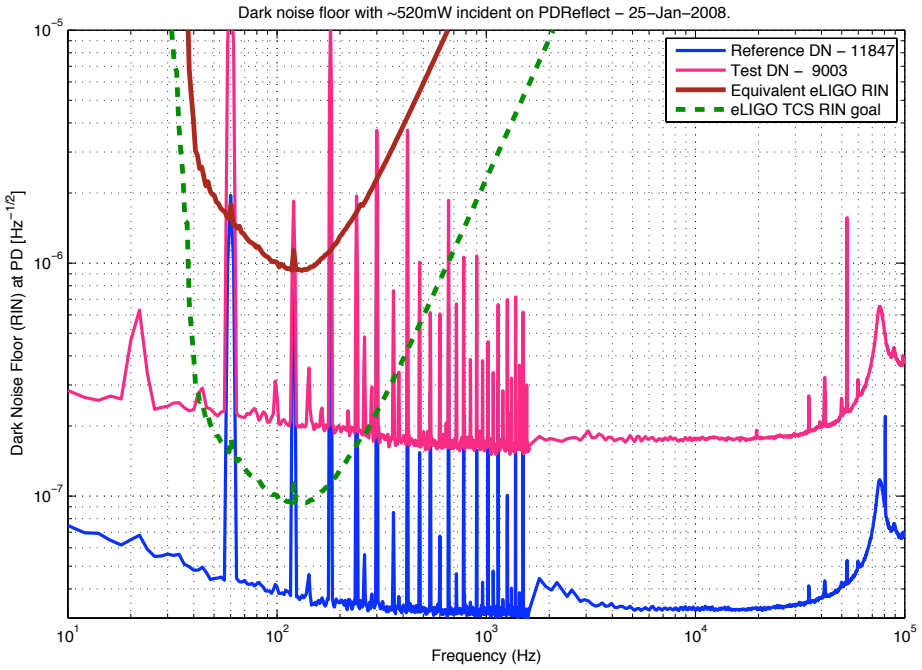

Figure 4: PD 9003 - Dark noise floor as RIN and eLIGO TCS noise goal

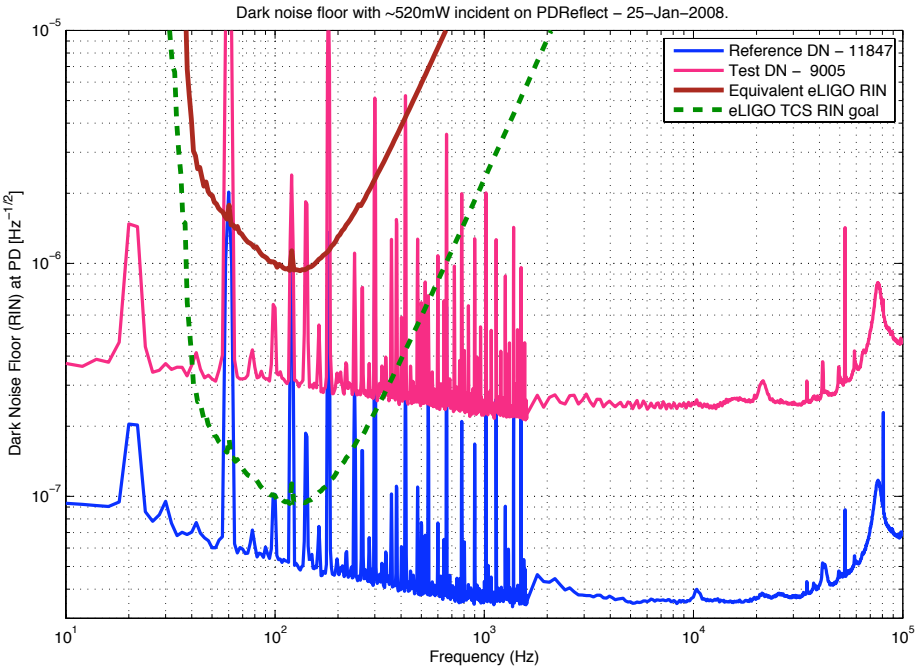

Figure 5: PD 9005 - Dark noise floor as RIN and eLIGO TCS noise goal

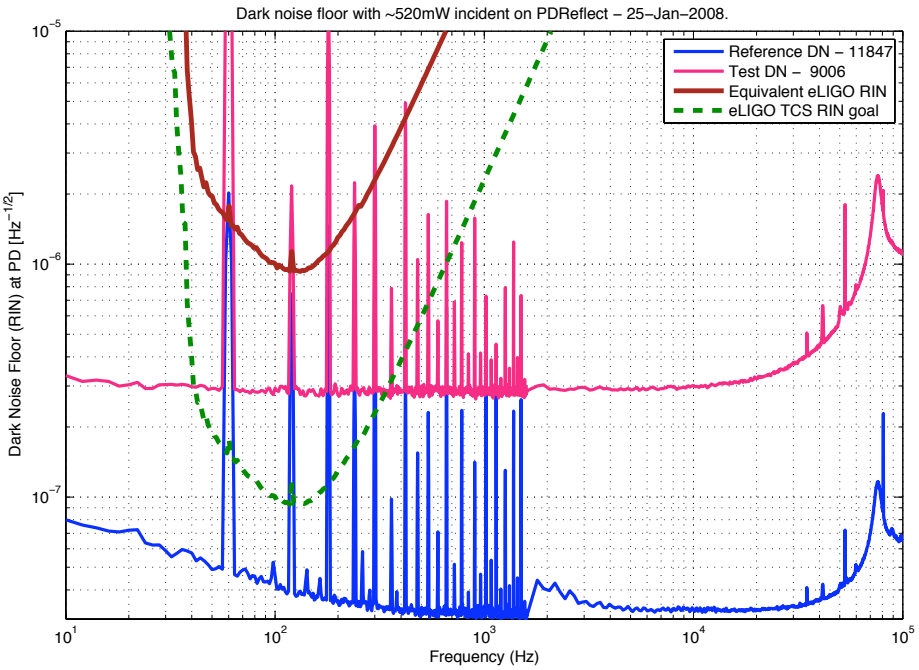

Figure 6: PD 9006 - Dark noise floor as RIN and eLIGO TCS noise goal

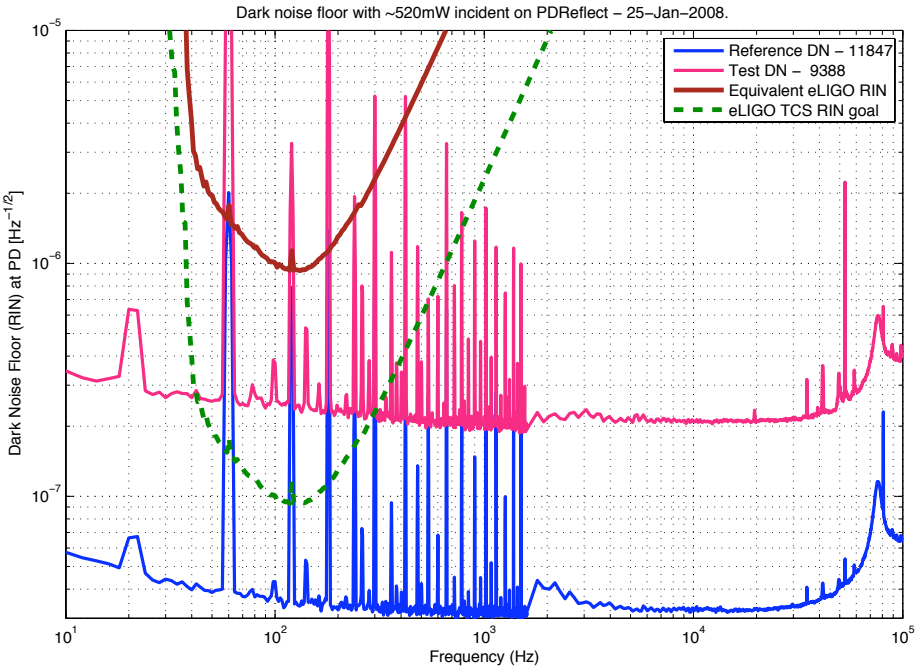

Figure 7: PD 9388 - Dark noise floor as RIN and eLIGO TCS noise goal

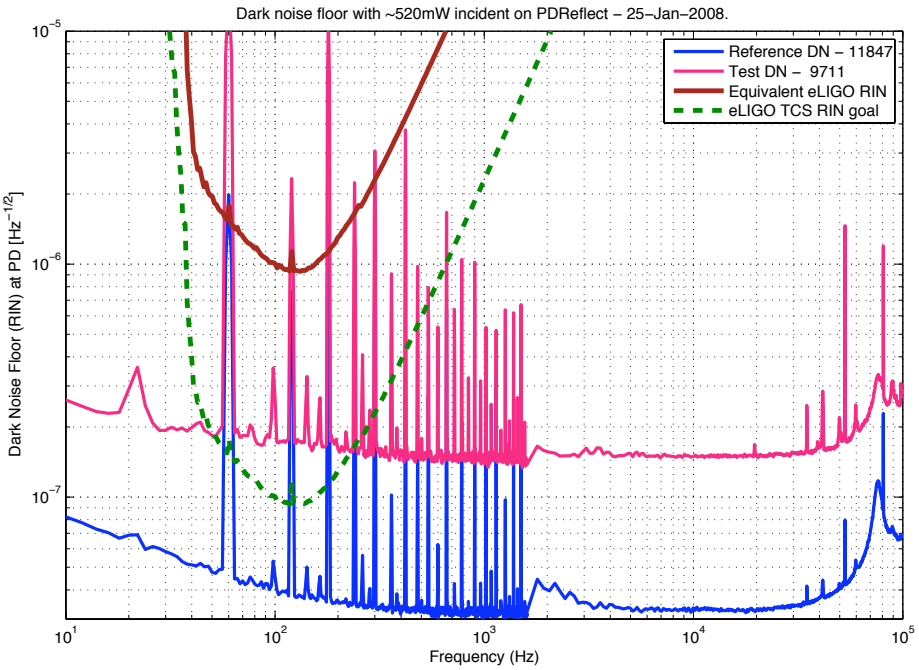

Figure 8: PD 9711 - Dark noise floor as RIN and eLIGO TCS noise goal

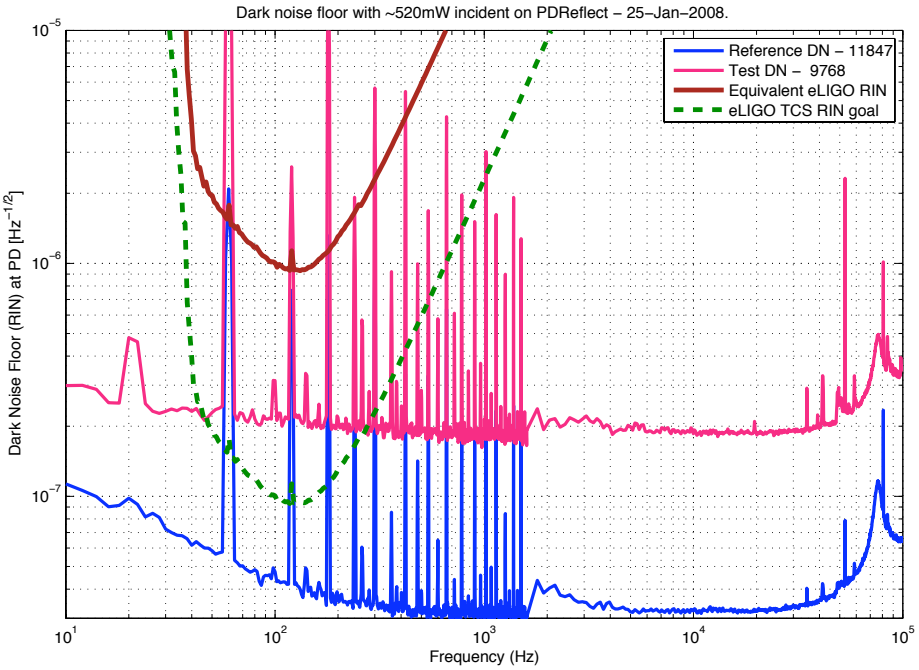

Figure 9: PD 9768 - Dark noise floor as RIN and eLIGO TCS noise goal

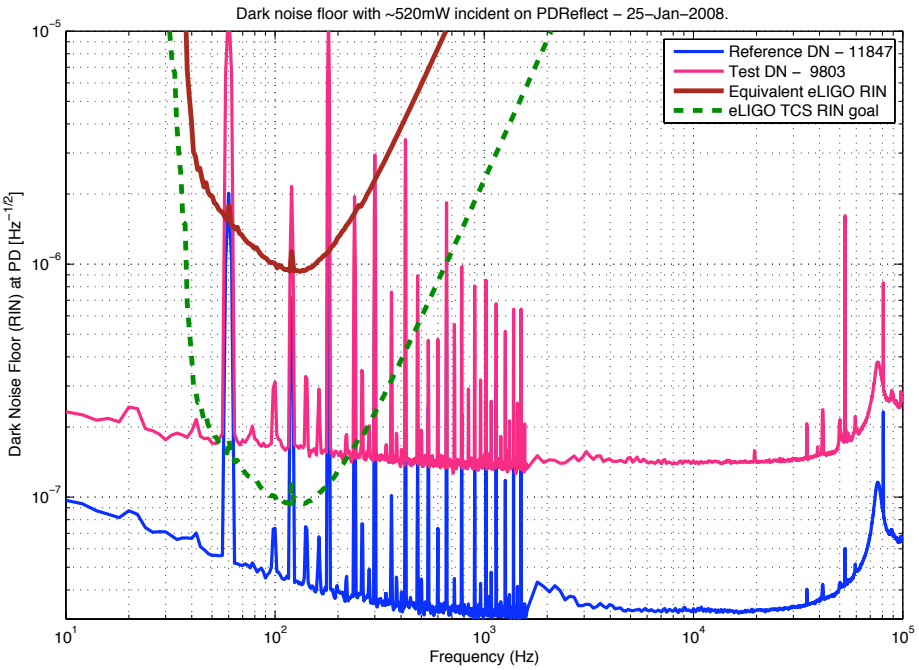

Figure 10: PD 9803 - Dark noise floor as RIN and eLIGO TCS noise goal

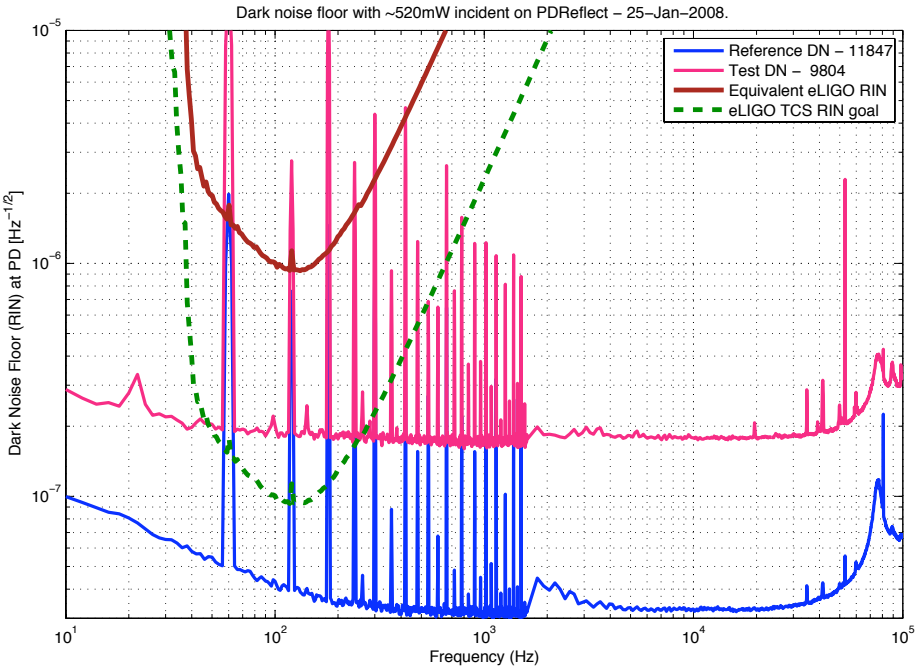

Figure 11: PD 9804 - Dark noise floor as RIN and eLIGO TCS noise goal

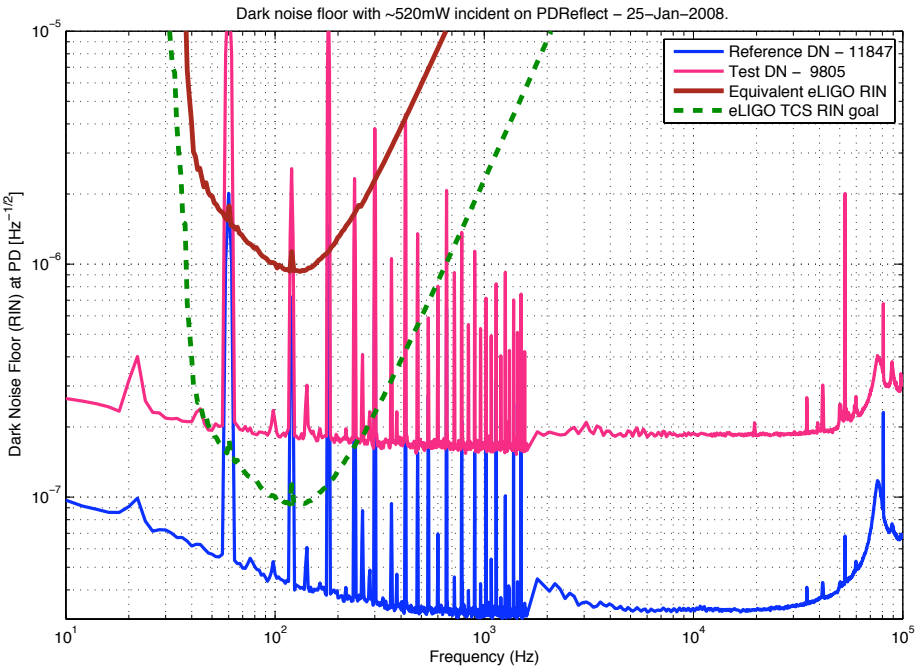

Figure 12: PD 9805 - Dark noise floor as RIN and eLIGO TCS noise goal

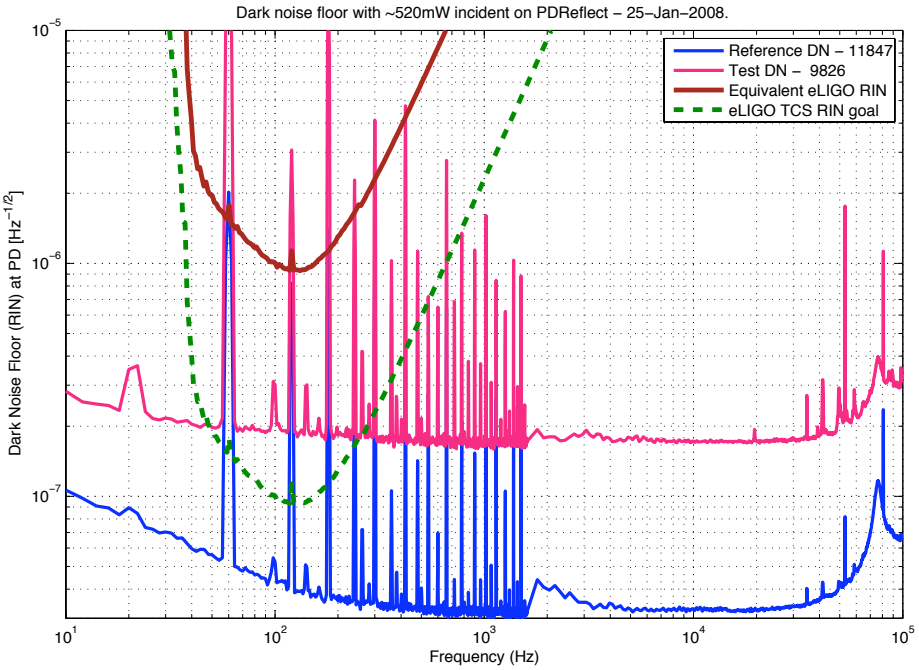

Figure 13: PD 9826 - Dark noise floor as RIN and eLIGO TCS noise goal

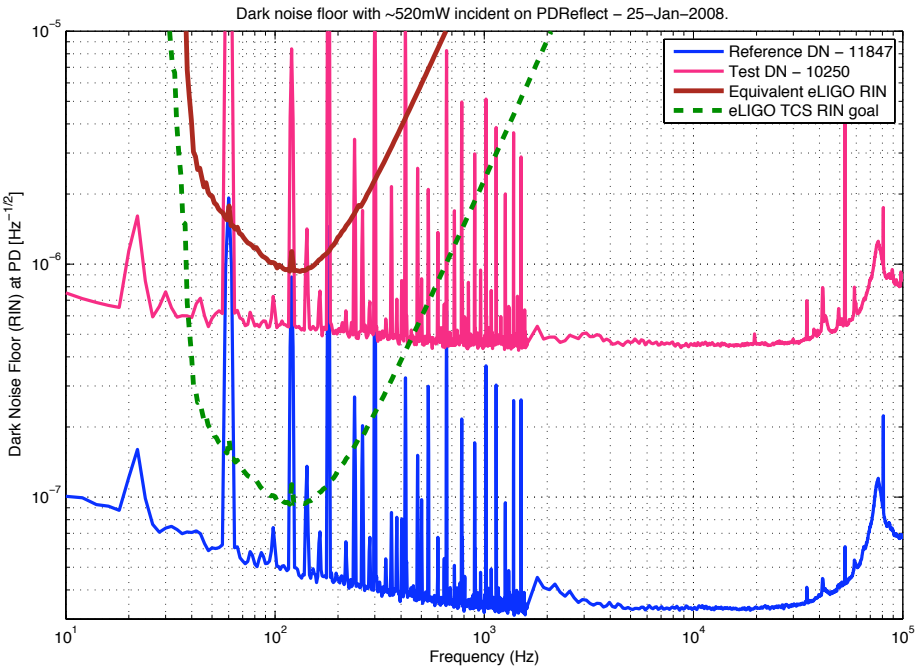

Figure 14: PD 10250 - Dark noise floor as RIN and eLIGO TCS noise goal

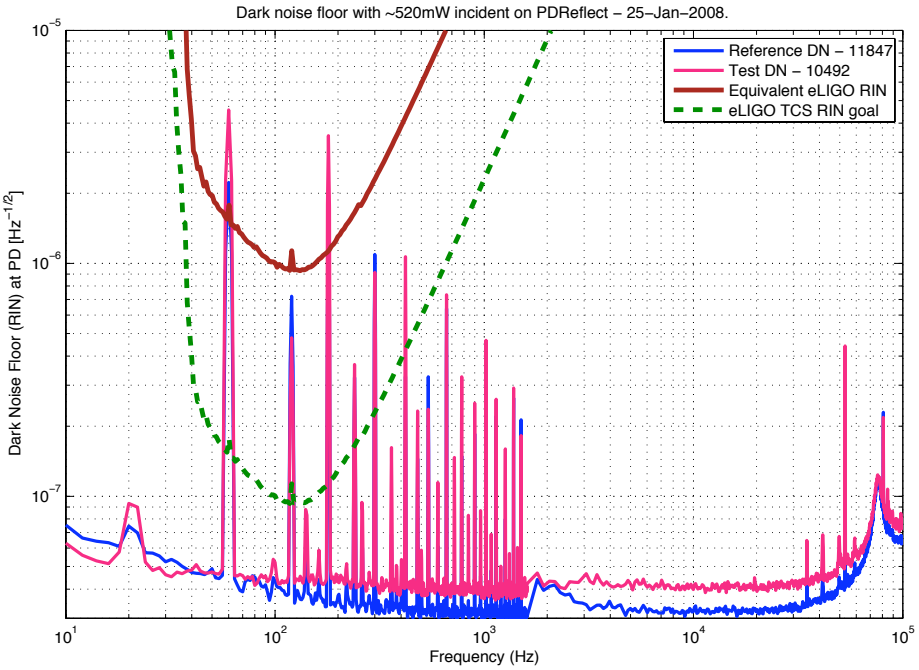

Figure 15: PD 10492 - Dark noise floor as RIN and eLIGO TCS noise goal

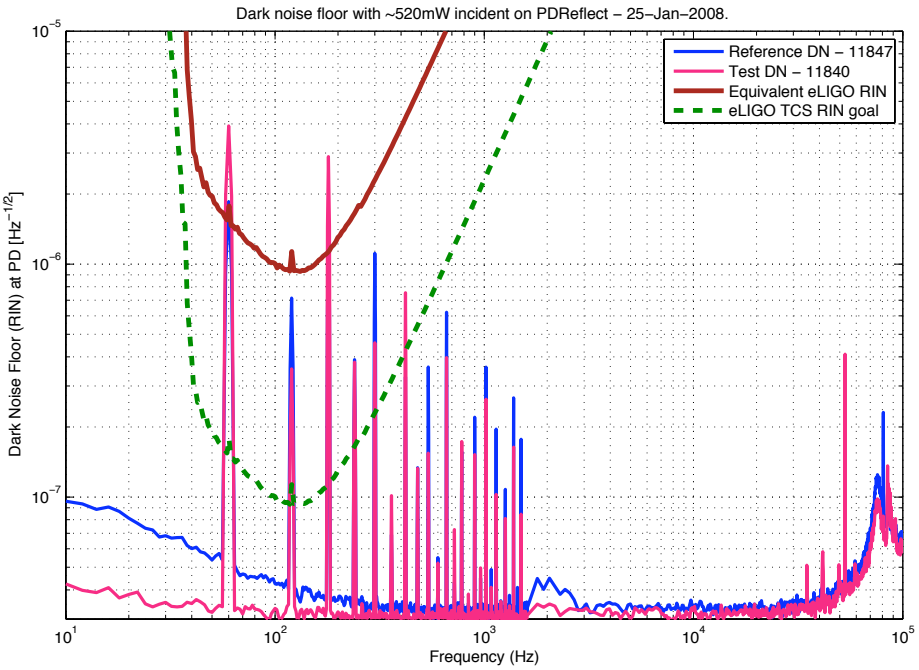

Figure 16: PD 11840 - Dark noise floor as RIN and eLIGO TCS noise goal

4 Summary

Serial #	Suitability for ISS
6836	Out-Loop PD?
9003	PD3?
9005	Not Suitable
9006	Not Suitable
9388	Not Suitable
9711	Out-Loop PD?
9768	PD3?
9803	Out-Loop PD?
9804	PD3?
9805	PD3?
9826	PD3?
10250	Not Suitable
10492	OK for In-Loop PD
11840	OK for In-Loop PD
11847	OK for In-Loop PD