LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

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Pre-Stabilized Laser Subsystem Testing and Acceptance - H2 PSL- reinstalled as -H1 PSL-

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Distribution of this document:
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1 Introduction

1.1 Purpose and general description

The purpose of this document is to define the PSL subsystem tests to be performed at the LIGO sites during installation and integration. It will define the measurements to be taken and the performance to be demonstrated before subsystem acceptance.

During the PSL subsystem test the results will be entered in the appropriate sections of this document (in blue ink) and a dedicated DCC number will be assigned such that the resulting document can serve as the test report for that specific PSL system.

This is one of those documents describing the tests and reference measurements for the H2 detector after installation in October 2011.

All measurements for H2 were taken with the fan-filter units in the laser-area enclosure turned on (unless stated otherwise). They will be shut-down in science mode.

The H2 PSL was moved to the H1 location in March 2012. More tests and measurements were performed at this location. These and all information explicitly valid for the PSL installed at the H1 location are marked in green in this document.

During the tests all installed components and software will be documented by serial numbers, release number and photographs as described further down. The resulting test document and links therein serve as a reference document for maintenance purposes, failure diagnostic and longterm performance investigations. Furthermore measured noise levels as well as transfer functions can give important guidance for later integration tasks of other subsystems like the IO or ISC. The testing described in this document covers Phase 2 to Phase 4 testing as defined in M1000211-v2.

All raw-data that form the basis for test results will be saved in data files with a common format (*.txt, *.xls, etc.) at the same DCC number as the completed test report (or under a separate DCC number linked to the test report entry in the DCC)).

This document does not include the testing and acceptance of the outer power stabilization loop as it will be installed much later than the on-table part of the PSL.

The labeling of optical components is according to the PSL table layout (LIGO_D0902114, https://dcc.ligo.org/cgi-bin/private/DocDB/ShowDocument?docid=5629).

1.2 Documentation

Related documents:

E1300176 LHO – PSL DAQ channels after installation

Pictures of the PSL installation can be found at
https://ligoimages.mit.edu/pages/search.php?search=%21collection824
and
https://ligoimages.mit.edu/pages/search.php?search=%21collection1383

Acceptance requires the following documentation to be filed into the Document Control Center (DCC), placed into configuration control and approved. Indicate that each document is accepted by checked off on the following list:

☒ T1100372 Coolant distribution system schematic

☒ T1100373 Coolant system operating & maintenance manual

☒ T1000005 Interlock System Description

☒ T0900610 PSL Table Layout for Advanced LIGO

1.3 Acronyms

AOM	Acousto-Optic Modulator
CB	Control Box
CCD	Charge Coupled Device (camera)
DB	Diode Box
DBB	Diagnostic Bread Board
DCC	Document Control Center
EPICS	Experimental Physics and Industrial Control System: a set of Open Source software tools, libraries and applications developed collaboratively and used worldwide to create distributed soft real-time control systems for scientific instruments
FE	Front End
FSR	Free Spectral Range
FSS	Frequency Stabilization Servo
IL	Interlock Box
LAE	Laser Area Enclosure
LED	Light Emitting Diode
LD	Laser Diode
LDR	Laser Diode Room
LH	Laser Head
LHO	LIGO Hanford Observatory
LLO	LIGO Livingston Observatory
HPFI	High Power Faraday Isolator
HPO	High Power Oscillator?
ISS	Intensity Stabilization Servo
LVEA	Laser Vacuum Equipment Area

medm	a Motif graphical user interface for designing and implementing control screens, called displays, that consist of a collection of graphical objects that display and/or change the values of EPICS process variables
NPRO	Non-Planer Ring Oscillator
OPC	Open Process Control is a software application that acts as an API (Application Programming Interface) or protocol converter
PD	photodiode
PMC	Pre-Mode Cleaner
PS	Power Supply?
PSL	Pre-Stabilized Laser
PZT	Lead zirconate titanate, a piezo-electric actuator
RSD	remote shut down
RIN	Relative Intensity Noise
RPN	Relative Power Noise
rt	real time
TEC	Thermo-Electric Cooler Power Supply
UG	unity gain
VNC	Virtual Network Computing (VNC) is a platform-independent, graphical desktop sharing system that uses the RFB protocol to remotely control another computer
WinCAM	CCD camera for beam shape analysis

1.4 Laser Safety

The PSL was tested for conformance with the Project's laser safety policy and guidelines. For further details see the following documents and the signed interlock test (can be found at the end of E1100539).

M1100255 LHO H2 PSL Standard Operating Procedure

M1200089-v1 LHO H1 PSL Standard Operating Procedure

M960001 LIGO Laser Safety Program

T1000005 aLIGO PSL interlock concept

1.5 Completion and Acceptance

When this document is completed with data entries, it is to be filed into the DCC under a unique E#. Acceptance/approval of this procedure, and each completed version of this document, is indicated with the electronic signature feature in the DCC. The signoff/approval is to be performed by the lead PSL scientist for the observatory where the PSL is fielded, the systems engineer and the systems scientist.

2 Major Subassembly Test

2.1 High Power Laser (HPL)

2.1.1 Chiller

After installing the chillers, a functional test should be performed. No manifolds are connected to the chiller at this time. Since the Beckhoff control is also not installed, the chiller has to be started manually (see chiller manual to do so, the user password is 0020). The expected pre-set values are given in the following tables, as well as the allowed deviations. Some of the pre-settings can be changed if required. Others, for example the water flow, can't be set via the control interface. If the non-changeable parameters are out of specs, please contact TermoTek (Tel. within the US: +1 847 227 9051 ; Tel. in Germany: +49 (0) 7221 9711-161) or LZH.

2.1.1.1 Short-cut test

Connect the water in- and outlet with a short hose (about 1m length, provided by LZH, same type as in final coolant system) to perform this test. *Fill chiller with distilled water (in Germany called bi-distilled). Deionized water is not sufficient!*

Crystal chiller (P325-AW-DI LZH), the upper chiller in the rack

Chiller serial number: 44800

Value	Nominal value	Allowed deviation	Measured / actual value
Set temperature	18 °C	± 0.1 °C*	Set to 18 °C
Water flow	29lpm	± 2lpm	35.5 lpm, turned off after a few seconds, due to flow watchdog (ok, since can be decreased via internal bypass)
Conductivity	4 ... 7 µS/cm	<7 µS/cm*	Since we used *distilled* water, the value was quite high in the beginning, but decreased to the nominal value (accomplished by the chiller's DI cartridge)

***** after cool-down phase

Diode chiller (P605-AW-DI-LZH), the lower chiller in the rack

Chiller serial No. :44806

Value	Nominal value	Allowed deviation	Measured / actual value
Set temperature	Set to 18 °C	± 0.1 °C*	18°C

Water flow	20 lpm	- 0.5 lpm, +10 lpm	40.2 lpm, turned off due to flow interlock (max: > 30 lpm), can be decreased via internal Bypass to nominal value
Conductivity	4 … 7 µS/cm	<7 µS/cm**	Decreasing to nominal value

***** after cool-down phase
** due to the long way to the LAE

2.1.1.2 Test of diode chiller with LD boxes and LD chiller line to LAE connected

Connect the water distributor for the diode rack and for the external power meters / heat sinks at the laser table (laser diodes are off). Fill all pipes with distilled water before starting the chiller. You might need to refill the circuit several times, until all components are filled. Ensure that no obvious leakages occur, before you start the chiller.

	Nominal value	**Allowed deviation**	**Measured / actual value**
Water temperature	Set to 18 °C	- 0.1 °C*, + 1.0 °C**	18°C
Water flow	22.5 l/min	± 7.5 l/min	Reduced to 25.4 lpm via internal bypass (max: > 30 lpm)
Conductivity	4 … 7 µS/cm	<7 µS/cm*	4.9 µS (10/11/2011)

***** after cool-down phase
** due to the long way to the LAE

2.1.1.3 Test of crystal chiller with laser manifold connected

Connect the water distribution manifold for the laser system. (As the HPL is not connected to the manifold at this time, this test is performed with the bypass at this manifold open.) Fill all pipes and hoses with distilled water before starting the chiller. You might need to refill the circuit several times, until all components are filled. Ensure that no obvious leakages occur, before you start the chiller. Open the bypass valve at the LAE water manifold before performing this test!

Value	**Nominal value**	**Allowed deviation**	**Measured / actual value**
Water temperature	Set to 18 °C	- 0.1 °C*, + 1.0 °C**	18.0 °C
Water pressure (manifold inlet) **19.0 l/min**	6.2 bar	± 0.5 bar	6.0 bar
Water pressure (manifold outlet) **19.0 l/min**	2.3 bar	± 0.5 bar	2.4 bar
Pressure drop	3.9 bar	± 1.0 bar	3.6 bar

19.0 l/min			
Conductivity	4 ... 7 µS	<7 µS/cm*	Within this range (controlled)
Cool-down time	15 min	+ 5 min -15 min	5 min (see data from LHO framebuilder)

* after cool-down phase
** due to the long way to the LAE

This test just shows the performance of the chiller. The final flow values (particularly the one to the laser table) have to be set, when all components (crystals, laser heads, power meters, amplifier) are connected (see 2.1.3.4). The flow with the bypass at the water manifold underneath the optical table opened and all components connected has to be ≥ 18 l/min and can be adapted via the integrated bypass valve at the chiller.

2.1.2 Fiber inspection after installation

2.1.2.1 HPO pump fibers

After pulling the 75m/100m fiber bundles from the laser diode room to the LAE, it needs to be ensured that none of the fibers is broken. A laser pointer or a flash lamp can be used to couple light into each fiber from the SMA side. The cap on the freestanding side (inside the LAE) need to be removed and it has to be checked, whether the light is transmitted. If it turns out that one or more fibers are broken, replace the bundle by a spare bundle and send the broken fiber back to the manufacturer (mark the broken fiber(s) with a piece of tape at the SMA side).

Bundle 1 (serial no.: 516581) X passed ☐ failed
Bundle 2 (serial no.: 516569) X passed ☐ failed
Bundle 3 (serial no.: 516565) X passed ☐ failed
Bundle 4 (serial no.: 516563) X passed ☐ failed
Bundle 5 (serial no.: 516567) X passed ☐ failed
Bundle 6 (serial no.: 516583) X passed ☐ failed

Comments:
none

2.1.2.2 Amplifier Fibers:

After pulling the 75m/100m pump fibers from the laser diode room to the LAE, it needs to be ensured that none of the fibers is broken. Couple light from a flash lamp / laser pointer into each fiber and check, whether it is transmitted to the LAE. If it turns out that one or more fibers are broken, replace the bundle by a spare part and send it to the fiber manufacturer for repair (mark the broken fiber(s) with a piece of tape at the SMA side).

The used amplifier fiber bundle was one of the first once and comes with seven instead of 6 fibers. At installation 3 fiber tips were damaged / had spots on it. Two of them (1+4) could be repaired by new polishing fiber #3 is broken and not usable anymore.

2.1.3 Laserdiodes and Beckhoff control

2.1.3.1 Check all installed System Components:

(For test results of section 2.1.3.1 at LHO see E1100540).

Document S/N of all installed electronics components and the completed module level test procedure.

Module Name	Designation	Design Doc. or Part No.	SN	Test Procedure	Completed Test Document
Interlock Box	IL	neoLASE internal document	neoLASE OBS2-IL	E1100539	E1100539
PSL Computer	PSL-PC	see above	32BD-96F4-310	see above	see above
Power Supply	PS1	see above	neoLASE 10041613	see above	see above
Power Supply	PS2	see above	neoLASE 10041608	see above	see above
Power Supply	PS3	see above	neoLASE 10041604	see above	see above
Power Supply	PS4	see above	neoLASE 10041614	see above	see above
Diode Box	DB1	see above	S1107821	see above	see above
Diode Box	DB2	see above	S1107822	see above	see above
Diode Box	DB3	see above	S1107823	see above	see above
Diode Box	DB4	see above	S1107824	see above	see above
Front End Dioded Box	FE-DB	see above	S1107819 S1107820	see above	see above
Termo-Electric Cooler power supply	TEC1	see above	neoLASE 10041606	see above	see above
Termo-Electric Cooler power supply	TEC2	see above	neoLASE 10041611	see above	see above
Control Box	CB	see above	S1107825	see above	see above

Test after Rack installation:

Switch ON the PSL computer, the fiber switches, the interlock box, the control box and the frontend box.

- √ First functionality check (Beckhoff visualization shows updated values which indicates that communication between computer and laser components is ok)

- √ Safety Logic running (switching one of the interlock switches, such as the LDR safety key lock switch)
- √ Set / Change Values:
- √ Reset Lid Counter

Test laser diode control. (DB shortcut bridge needs to be in place)

- √ Test laser diode drive by set 1 A to DB 1-4 and readout the current
- √ Test laser diode temperature control for DB 1-4

2.1.3.2 Computer control and interlock test

(For test results of section 2.1.3.2 at LLO see E1100540).

- √ check if Beckhoff visualization and OPC server are running,
- √ check if VNC server is running and if remote connection is possible
- √ check that passwords are set

perform full interlock test (in accordance with T1000005):

Switch ON all components and RESET all errors. After Reset the interlock relay should be switched ON, ATTENTION this allows Laser operation. Check the interlock events and make sure that they will be displayed on the control screen (corresponding inter-lock and main interlock indicator).

- √ Check key lock switch (IL)
- √ Check push button (IL)
- √ Check Facility interlock (IL)
- √ Check key lock switch (CB)
- √ Check laser pushbutton (LAE)
- √ Check Facility interlock (CB)

Check that in case the main interlock indicator is switched to red the following components will be switched off:

- √ NPRO System stopped (LED Interlock)
- √ FE-DB Laser Diodes stopped
- √ PS1-4 Power Supplies Stopped (RSD, LED)
- √ TEC1-2 Power Supplies Stopped (RSD, LED)
- √ Chiller Chillers switched off
- √ Check internal system relevant safety signals:
- √ Check for DB overtemp. signal
- √ DB1 (open on DB side)
- √ DB2 (open on DB side)

- √ DB3 (open on DB side)
- √ DB4 (open on DB side)
- √ FE-DB (open on DB side)
- √ Check for chiller interlock
- √ Chiller x-tal (open on chiller side)
- √ Chiller diode (open on chiller side)
- √ TEC (Switch off TEC 1)
- √ TEC (Switch off TEC 2)
- √ Lid Interlock Frontend
- √ Lid Interlock High Power Oscillator

2.1.3.3 measure slopes of laser diode boxes and front end laser diodes

Measure the transmitted power through the four connected amplifier pump fiber. Increase the current in 5 A steps for each bundle. (Do not increase diode current further in case 45W output power is reached!)

Current / A	Power Diode 1 / W	Power Diode 2 / W	Power Diode 3 / W	Power Diode 4 / W
10	0,1	0,1	0	0,1
15	3,9	3,7	3,7	3,9
20	8,3	7,8	7,8	7,9
25	12,4	11,8	11,7	12
30	16,7	15,9	15,9	16,1
35	21	20	20,1	20,2
40	25	24,1	24,3	24,3
45	29,4	28,2	28,4	28,3
50	33,7	32,4	32,5	32,2
55	37,6	36,6	36,6	36,5
60	42	40,7	40,7	40,5

Front end slope measurement not redone after move to H1 location.

Connect the HPO fiber bundles to a diode box and run with 9 to 10 A. Use a lens to construct an image of the fiber tip on a viewer card and see, whether light is transmitted through all fibers. This test fails if one of the fibers does not appear at the viewer card. In this case try with little more pump current to ensure that all diodes are running. ***Warning: Keep the damage threshold of the card in mind !***

Measure the transmitted power through the fiber bundle. Do this measurement step-by-step and look at the tip of the fiber bundle. The laser-end of the bundle should be cooled for this test. (An appropriate fiber holder is provided by LZH). Measure the output power of the diode box with a water cooled power meter. Increase the current in 5A steps for each bundle (max 56A). This test fails if the fiber bundle starts glowing. Turn the diode box off immediately, if this happens.

Current / A	Power FB1 / W	Power FB2 / W	Power FB3 / W	Power FB4 / W
8	0	0	0	0
10	3.3	2.1	1.9	1.8
12	14.5	13.2	13.0	12.9
14	26.4	25.3	25.2	25.2
16	38.3	38.1	37.6	37.7
18	50.2	50.7	50.3	50.2
20	61.9	63.4	62.7	62.6
22	73.9	76.0	74.9	75.0
24	86.0	88.8	87.4	87.3
26	97.8	101.5	99.8	99.7
28	109.7	114.0	111.9	112.0
30	121.4	126.6	124.2	124.4
32	133.4	139.5	136.7	136.7
34	145.5	151.4	149.1	148.8
36	157.4	164.4	161.5	161.1
38	169.0	177.2	173.9	163.2
40	180.9	189.9	186.0	185.0
42	192.8	202.1	198.3	197.2
44	204.5	214.7	211.0	209.1
46	216.0	227.4	223.0	221.6
48	227.8	239.7	235.4	233.8
50	239.3	251.8	247.7	246.3
52	250.9	264.2	259.4	257.8
54	262.4	276.3	271.3	269.7
56	273.3	288.8	282.9	281.5
58				
60				

Current / A	Power FB1 / W	Power FB2 / W	Power FB3 / W	Power FB4 /W
8	0	0	0	0
10	2.1	2.1	1.6	1.5
12	12.4	12.1	11.7	12.2
14	23.6	24.1	23.6	24
16	35.1	36.4	35.6	36.2
18	46.7	49.0	47.7	48.7
20	58.5	61.4	59.9	60.8
22	70.4	74	71.8	73
24	82.5	86.5	84.0	85.1

26	94.3	99.1	96.1	97.5
28	106.2	111.5	108.6	109,2
30	118.0	124.2	120.8	121.9
32	129.5	136.7	132.7	132.3
34	141.4	149.3	144.9	145
36	153.1	161.4	157.1	157.7
38	165.1	174.1	170.0	170.1
40	176.4	187.1	182.1	182.5
42	188.2	199.2	194.1	194.2
44	199.5	211.1	206.2	206.1
46	211.1	224.1	218.4	219.4
48	222.5	236.2	230.6	231.1
50	233.5	248.7	242.3	243.5
52	244.8	260.9	254.3	254.7
54	256.4	273.7	266.1	266.5
56	267.6	285.2	278.0	278.1
58	279.1	297.1	290	290.3
60	290.3	310.1	301.1	301.3

Measure the temperatures of the LD-SMA connectors while the diodes are running at 40 A (let them warm up for a 10 minutes). All temperatures should be below 40°C

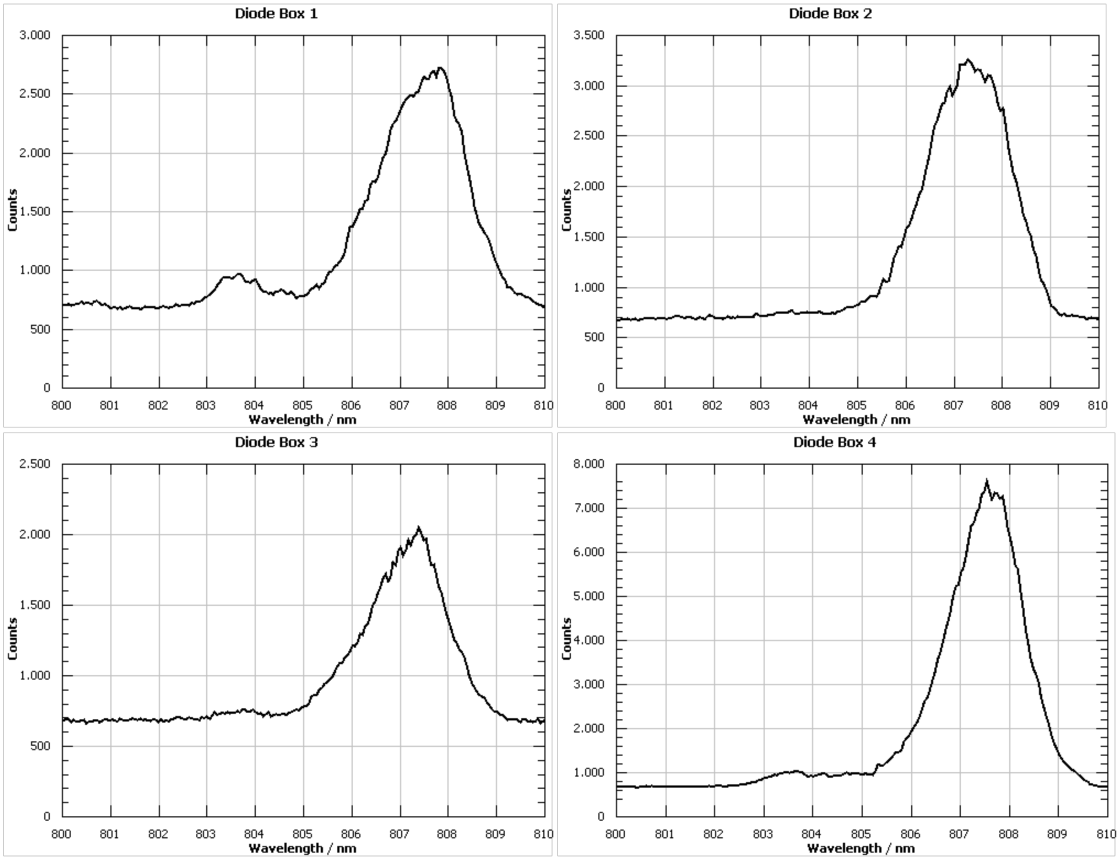
All temperatures had been below 35 deg celsius

Create a table as shown below by applying a linear fit to the data measured above – these values will be needed when starting the laser system.

Power / W	**Current /A (FB1)**	**Current /A (FB2)**	**Current /A (FB3)**	**Current /A (FB4)**
10	10.9	10.9	11.1	11.1
20	12.7	12.6	12.8	12.8
30	14.5	14.3	14.6	14.6
40	16.2	16.0	16.4	16.3
50	18.0	17.8	18.1	18.1
60	19.8	19.5	19.9	19.8
70	21.5	21.2	21.6	21.6
80	23.3	22.9	23.4	23.3
90	25.0	24.7	25.2	25.1
100	26.8	26.4	26.9	26.8
110	28.6	28.1	28.7	28.6
120	30.3	29.8	30.4	30.3
130	32.1	31.6	32.2	32.1

140	33.9	33.3	33.9	33.8
150	35.6	35.0	35.7	35.6
160	37.4	36.8	37.5	37.3
170	39.2	38.5	39.2	39.1
180	40.9	40.2	41.0	40.9
190	42.7	41.9	42.7	42.6
200	44.4	43.6	44.5	44.3
210	46.2	45.4	46.3	46.1
220	48.0	47.1	48.0	47.8
230	49.8	48.8	49.8	49.6
240	51.5	50.5	51.5	51.3
250	53.3	52.3	53.3	53.1
260	55.0	54.0	55.0	54.8
270	56.8	55.7	56.8	56.6
280	58.6	57.4	58.6	58.3
290	60.3	59.2	60.3	60.1
300	62.1	60.9	62.1	61.8

Measure spectra of diode boxes. Include plots of the spectra for each diode box. In addition save the spectra in a data file(s) with a common format (*.txt, *.xls, etc.) at the same DCC number as the completed test report (or under a separate DCC number linked to the test report entry in the DCC.



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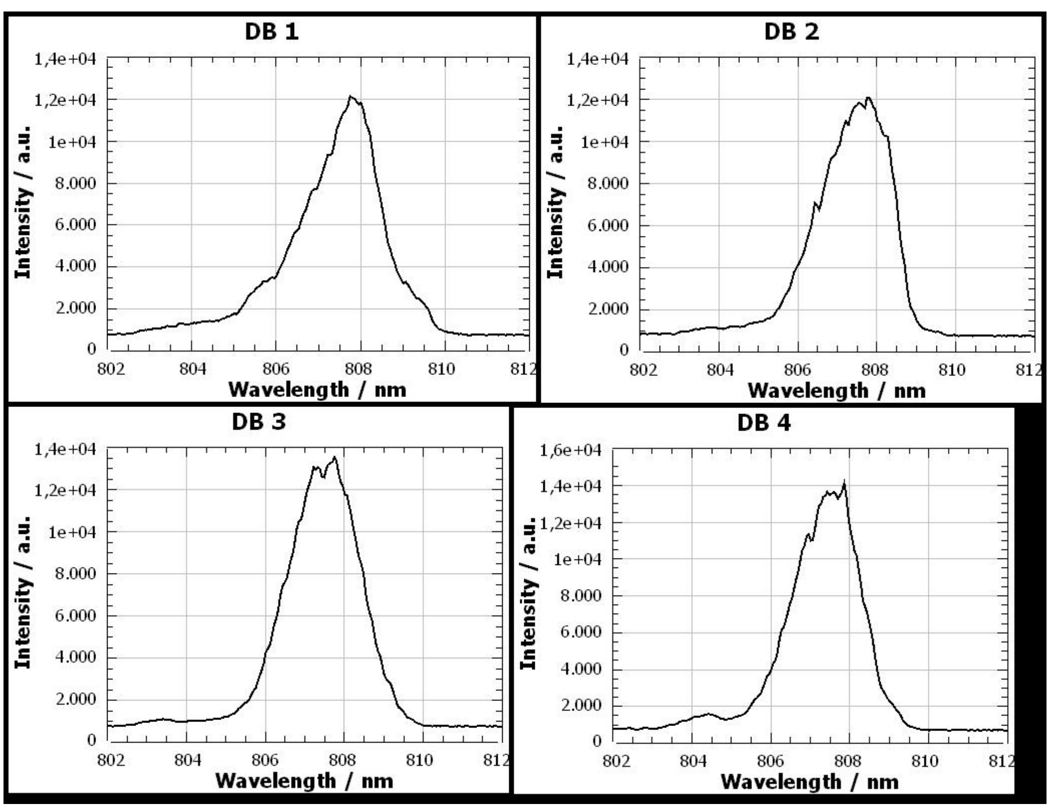
The spectra of the diode boxes for the H1 installation looked as follows:



2.1.3.4 Connect chiller lines to laser

Connect all water lines to the laser and set the water flow rates

For operation, the bypass underneath the optical table needs to be closed. The flows through the components have to be set as described in the lasers user manual (use the valves at the water manifold):

Flow through	Flow rate	Comment
Diode rack	>20 lpm 26 lpm	Diode chiller
Front End	>1.3 lpm, set to 1.5 lpm 1.5 lpm	Crystal chiller, Readout for example at Beckhoff control screen
Laser heads	>0.5 lpm per head, set to 0.6 lpm 0.8 lpm	Crystal chiller, Readout for example at Beckhoff control screen
Power meters and beam blocks	>1.5 lpm, set to 1.5 lpm 1.5 lpm	Crystal chiller, Readout for example at Beckhoff control screen, **concerns only power meters inside the laser box !**
Nd:YAG crystals	> 12 lpm	Crystal chiller, no readout
total crystal chiller flow	>15 lpm, set to maximum at the chiller's bypass 17.2 lpm	Crystal chiller, readout at laser control screen as well as directly at the chiller display

2.1.3.5 Frontend installation

Measure NPRO power

NPRO current / A	Power in front of EOM / W	Power behind Faraday / W
0.7	0	0
0.9	0.1	0.06
1.1	0.3	0.24
1.3	0.59	0.46
1.5	0.92	0.76
1.7	1.28	1.07
1.8	1.45	1.22

1.9	1.62	1.37
2.0	1.75	1.5
2.1	1.9	1.61
2.365	2.14	1.82

Align MOPA

Measure frontend output power and measure frontend power
NPRO Temperature D1: 30.3 °C, D2 24.5°C, xtal 29,64 Diode Current 2A
MOPA output power 35,5W @ 50A
MOPA output power 33.9W (aLOG 2742)

Calibrated diagnostic pick-ups (Calibration from 11\04\11):
Stage 1: 7 W
Stage 2: 15 W
Stage 3: 25 W
pick ups were calibrated to 100% after H1 installation (aLOG 2780)

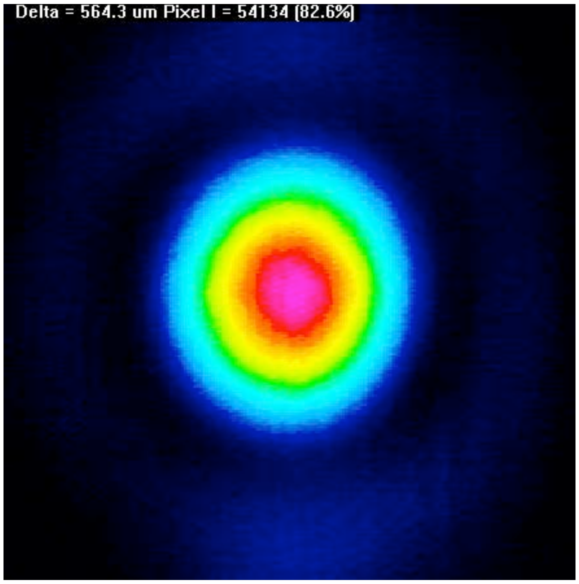
2.1.3.6 free running high-power oscillator (S1107826)

Follow alignment procedure for high-power oscillator as described in LIGO-T0900641.

Sum output power at the external powermeter and powermeter inside the HPFI during bidirectional operation of the high-power oscillator (MOPA turned off): P_{out} = 160 W (power levels after move to H1 location are given in section 2.1.3.8)

Output power on external power meter after MOPA was turned on and NPRO shutter closed: P_{out} =160W

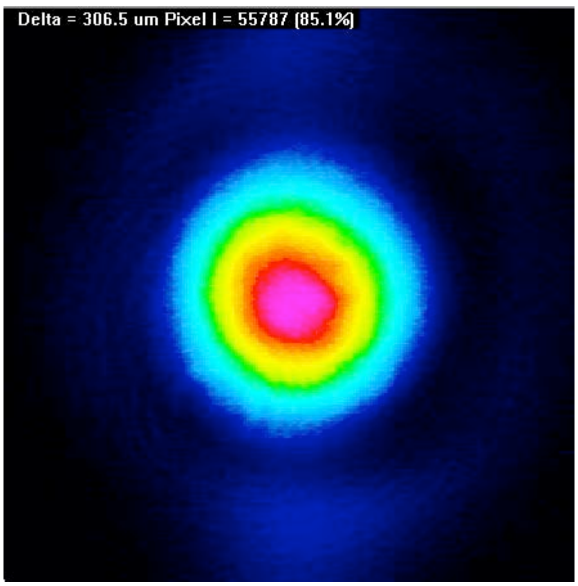
Measure beam profile with WinCam beam analyser at position of CCD2 (see table layout) after installation of corona aperture without screwed in aperture piece:



(file name: 111014-hpofreerunning)

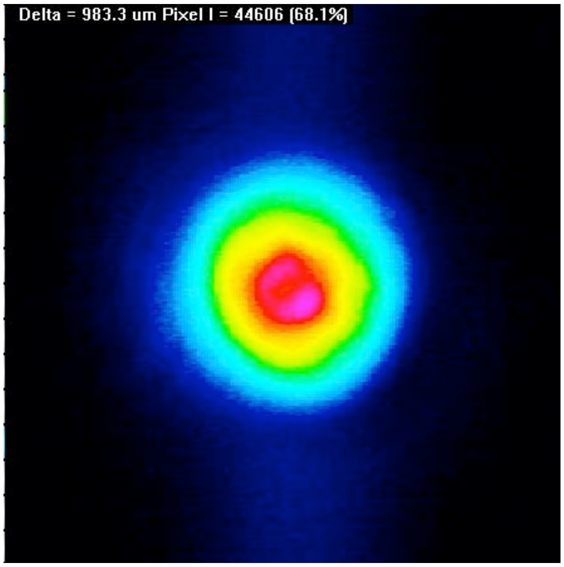
Start injection locking of the system

Output power of the injection locked system after installation of corona aperture without screwed in aperture piece: P_{out} = 205.4 W W



(file name : 111024-hpolocked-with-mount-without-aperture)

Close the external shutter and screw in the aperture piece. Open the external shutter, align the corona aperture mount, and take a beam profile of the locked system. Output power after installation of corona aperture with screwed in aperture piece (diameter:3.2mm, injection locked): P_{out} = 195 W



(file name : 111024-hpolocked-with-mount-aperture3p2)

Power at Brewster plate pickup (measured with power meter): 2.56 W

2.1.3.7 Test HPFI:

Parameters of the high-power oscillator after installation:

Power of free running laser at HPFI power meter: P_{out} = 58 W

Power after HPFI measured with Ophir 10W power detector: P_{out} = 77 mW, realigned after delivery

Voltage of HPFI photodiode: 3.2 V (H2, system not injection locked), 0,0 V (H2, system locked)

The suppression of the HPFI during laser operation is 29.49 dB

Install injection locking:

Name	Designation	Design Doc. or Part No.	SN	Test Procedure	Completed Test Document
injection locking servo	ILS	T0900578 / D1001618	S1107797* S1107803 S1103536	T1000342	S1107797 S1107803
Injection locking PD	ILS-PD	D1002163	S1107852 S1107851 S1107859		S1107852 S1107851 S1107859
injection locking fieldbox	ILS-FB	D1001619	S1107806 S1107807 S1107808	T10000343	S1107806 S1107807 S1107808
35.5 MHz oscillator:		D080705 D080702	S1000548	E1000059	**
35.5 MHz distribution		D1000124	S1000594	T1000256	**

amplifier:					
35.5 MHz delay line phase shifter:		T050250 D0900128	S1103426	T050183	S1103558

Which notch filters are built in? 28.3 kHz, 76.6 kHz, unity gain: ca. 16 kHz

Modulation frequencies of LO and EOM channel linked:

Modulation frequency: 35.5 MHz

LO amplitude: 7 dBm

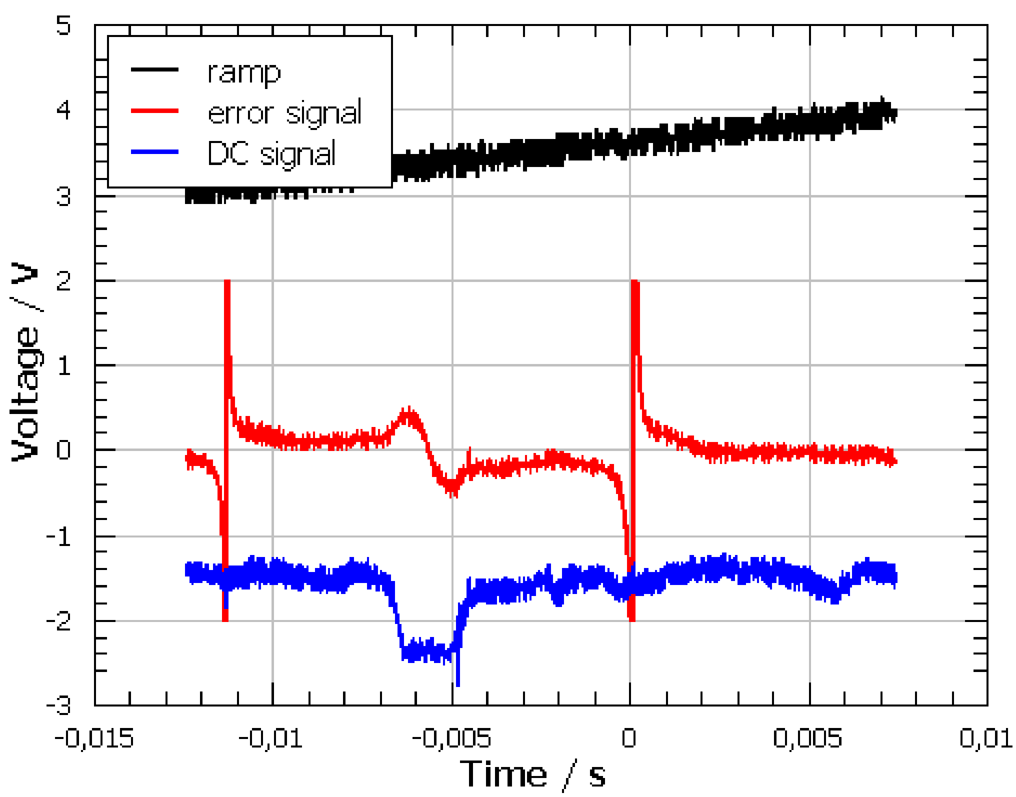
EOM amplitude: 500 mV P-P 300mV_P_P

EOM phase (LO phase set to 0° for reference): 86.0 deg 42deg

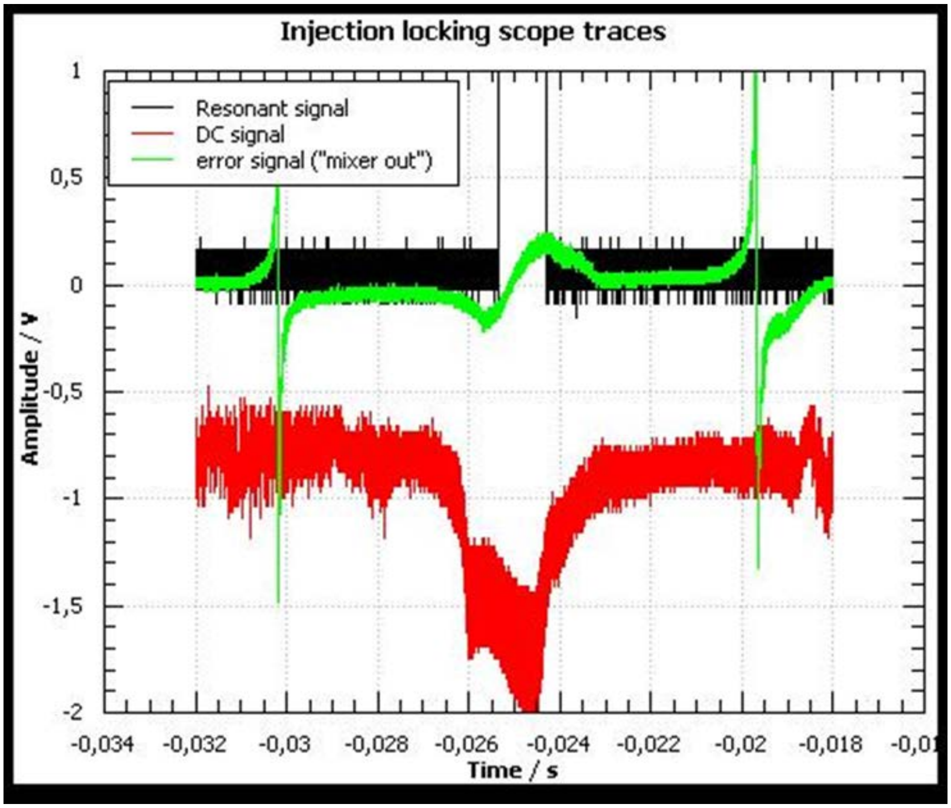
Error signal after alignment of the mode matched MOPA into the high-power oscillator cavity:

Replace the figures below with the measured error signal and save the electronic data in a file with a common format (*.txt, *.xls, etc.) at the same DCC number as the completed test report (or under a separate DCC number linked to the test report entry in the DCC).

Error signal, DC signal and ramp in low resolution after alignment of the mode matched MOPA into the high-power oscillator cavity



(black: ramp, blue: DC, red: error signal) error signal for H1:

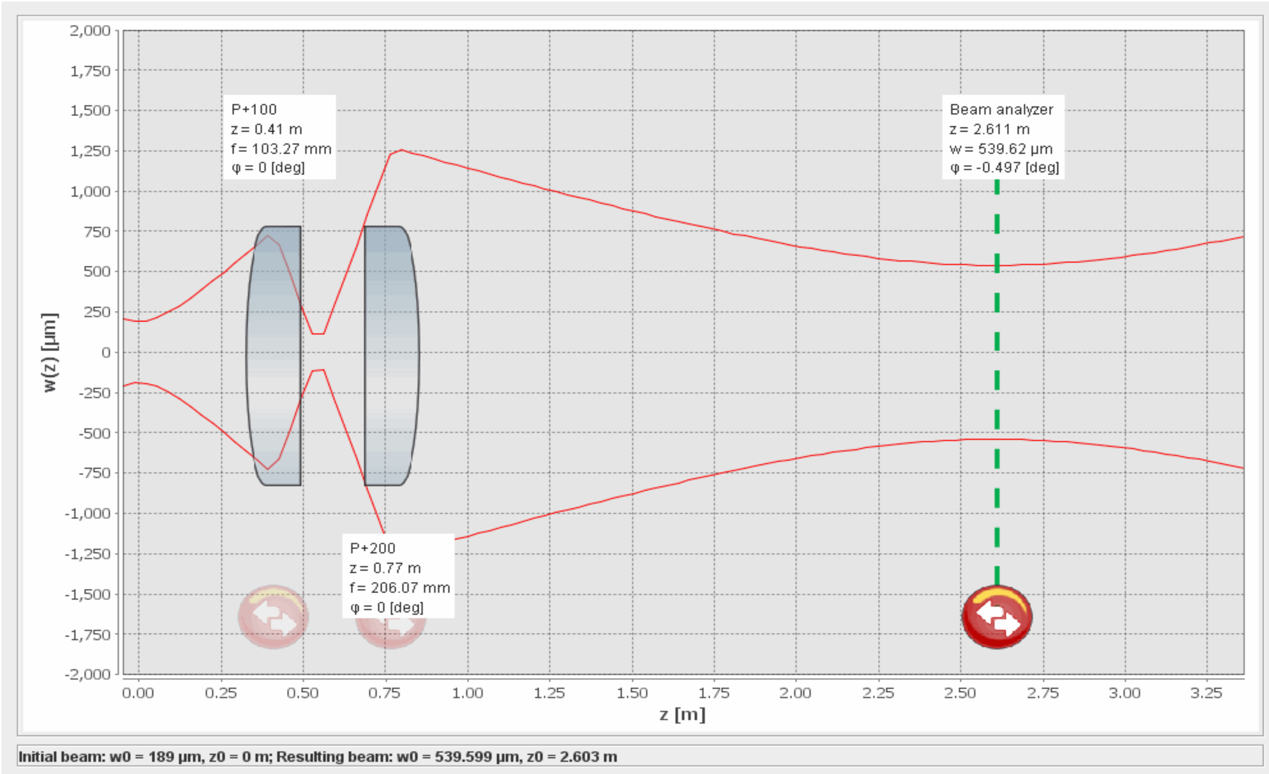


Error signal noise: see 2.2.2 d

Measure the open loop Injection-locking servo transfer function. Use a signal analyser and the dedicated inputs at the front of the injection locking module. Provide a plot of the transfer function below. In addition save the electronic data in a file with a common format (*.txt, *.xls, etc.) at the same DCC number as the completed test report (or under a separate DCC number linked to the test report entry in the DCC

Injection-locking servo transfer function: see 2.2.2 b

Measure beam caustic:



(The beam waist position is 0.677 m downstream the output coupler; the beam waist radius is 540 µm)

All voltages at all (monitoring) photodiodes:

amplifier power: 6.3 V

reverse power (FI reflected): 3.2 V

Brewster Plate reflected: 6.6 V

oscillator internal power: saturated

Beckhoff control loop parameter:

Document the servo gain: -4.7 V

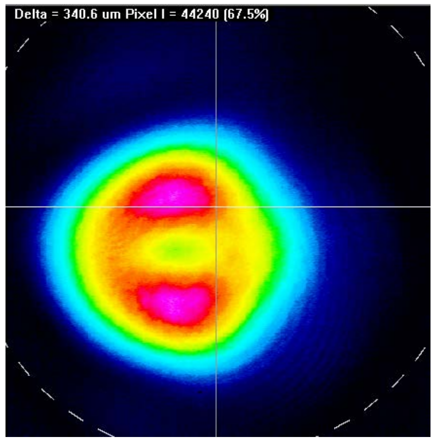
Document the reference level: -1.78 V

Document the error signal offset: 2.0 V

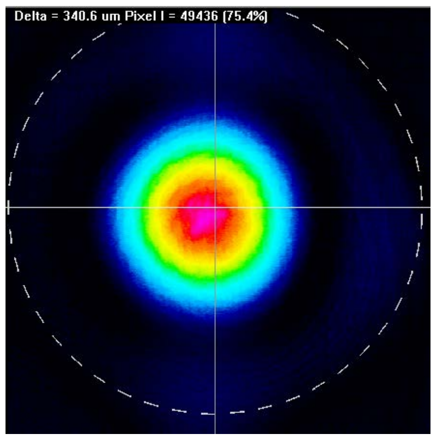
2.1.3.8

Output powers and beam profiles of the HPO after H1 installation

Output power without the 4f imaging lenses between each pair of crystals: 60.2 W, with 32 A pump current per head. The system was “free-running” (amplifier turned off, laser emission in forward and backward direction). Beam profile:

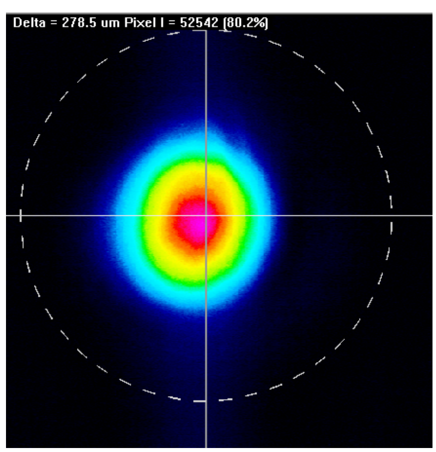


Output power of the freerunning, fully assembled system (amplifier turned off, laser emission in both directions): 160 W. The following pump currents had been used: 51.0 A /48.7 A /48.8 A /49.2 A.



power with corona aperture mount (no aperture): 204W (aLOG 2796)

The injection locked output power with the corona aperture (⌀ 2.6 mm) (pump currents as mentioned above) had been 189 W (measured behind the output window).



2.2 Laser Characterization and Diagnostic Breadboard

The performance of the DBB will be tested by the characterization of the 35W and 200W laser beams.

pre shipment testing:

Name	**Designation**	**Design Doc. or Part No.**	**SN**	**Test Procedure**	**Completed Test Document**
Diagnostic Breadboard	DBB	T0900133	S1107846	See Test Document	S1107846
DBB HV Amplifier module	DBB-HV	T0900133	S1107834 S1107802*	See Test Document	S1107834 S1107802
aLIGO PSL DBB demodulator module	DBB-DEMOD	T0900133	S1107836 S1107835*	See Test Document	S1107836 S1107835
DBB Fieldbox	DBB-FB	T0900133	S1107842 S1107837*	See Test Document	S1107842 S1107837
DBB Miscellaneous module	DBB-MISC	T0900133	S1107839 S1107838*	See Test Document	S1107839 S1107838
DBB calibration module	DBB-CALI	D1101103	S1107840* S1107841	See Test Document	S1107840
DBB AA filter		D070081	S1101684	T070146	S1101684
DBB AI filter		D070081	S1001225	T070146	S1001225

* these Serial Numbers are the units installed, the second SN was given to the spare unit

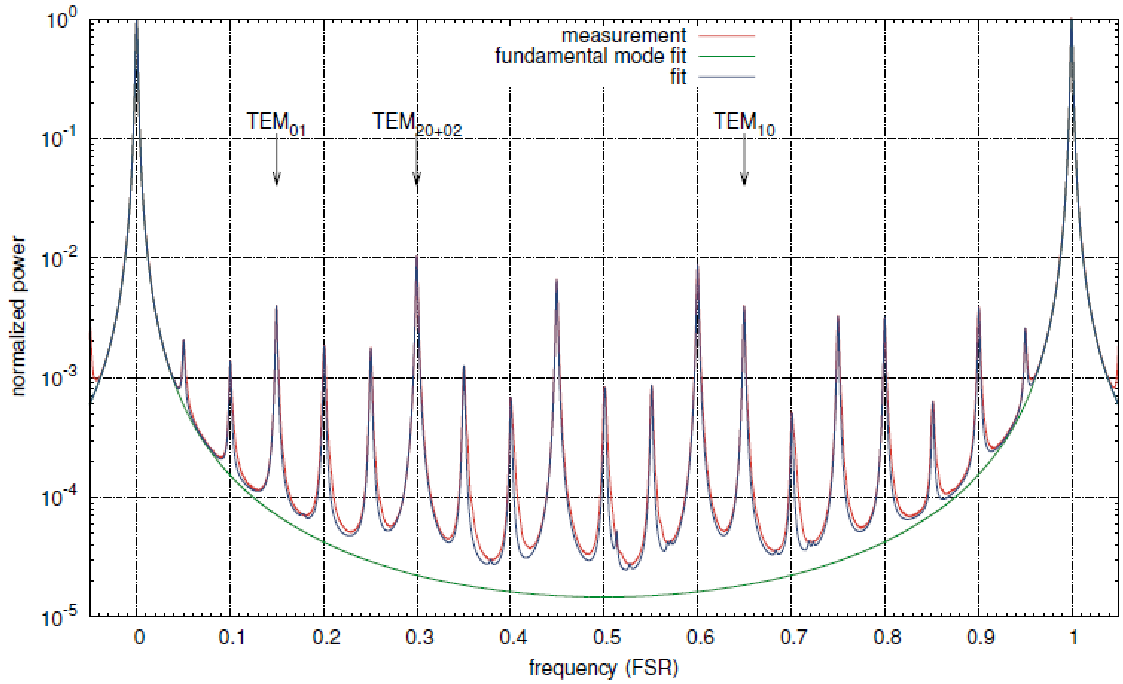
software version DBB rt-modell and medm screens: CDS subversion repository revision 1558

software version DBB automation (\ligo\cds\lho\scripts\psl\noisereports): version 0.3-12

2.2.1 Laser characterization 35W front end (S1107827)

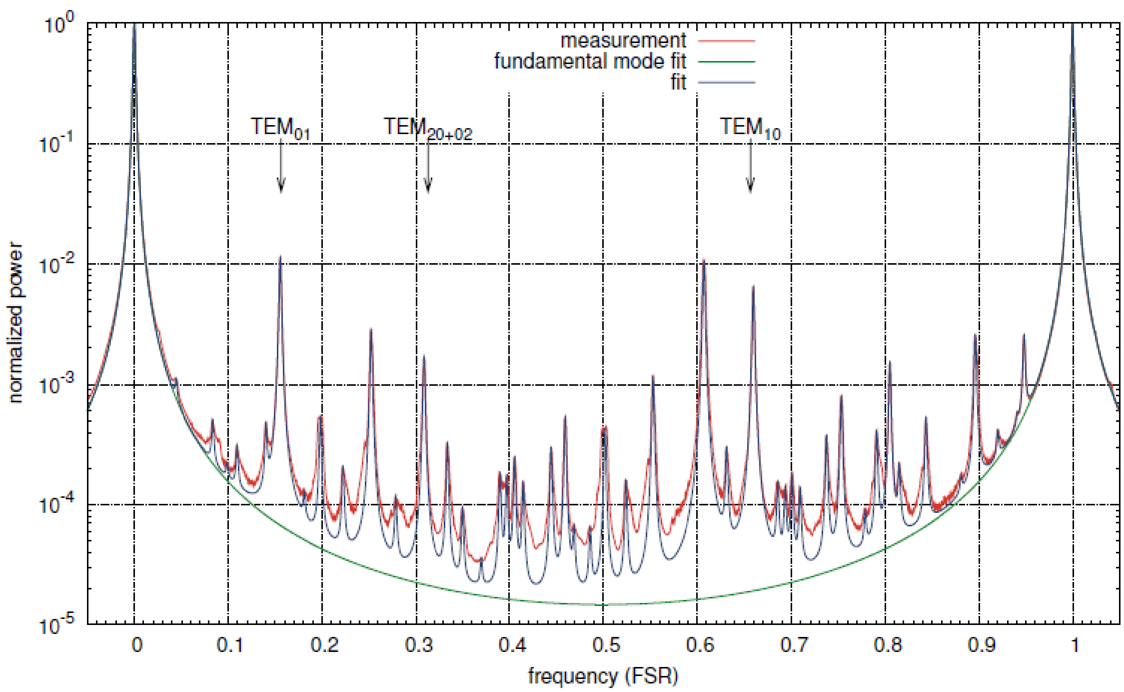
the most relevant 35W front-end DBB characterization (at time of writing) is the one taken after the change in the water distribution system (see ECR E1300188), some of the measurements taken in the weekly scan on 31 May, 2013 (alog page 6582) are copied into this document

a. DBB modescan



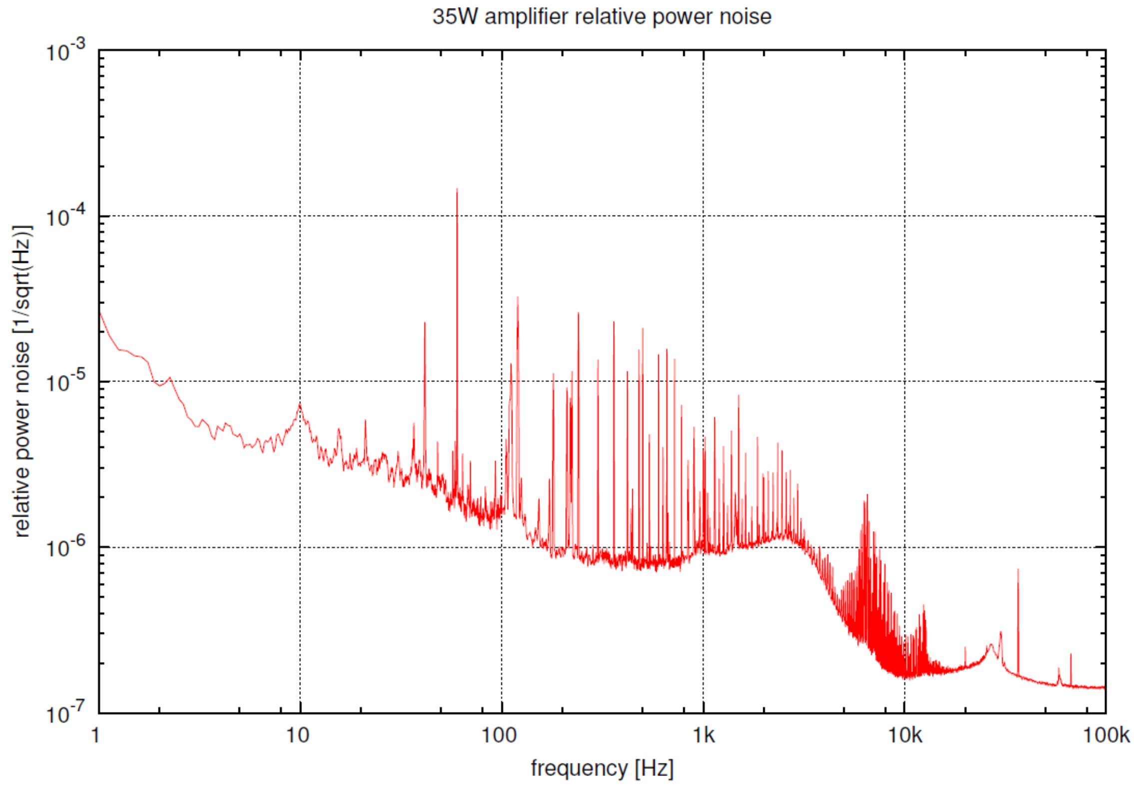
more info in the full mode-scan-report under the following URL:
https://dcc.ligo.org/DocDB/0089/E1200385/001/dbb_msc-001.zip

DBB modescan H1



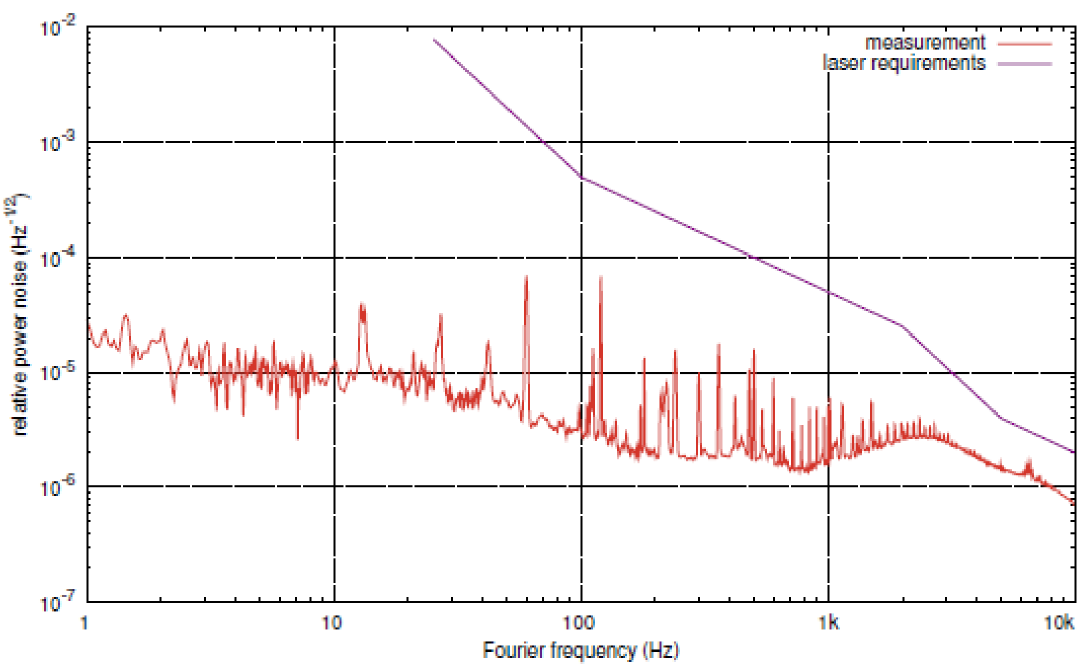
(pdf: aLOG 3187 ; data attached to pdf)

b. DBB relative power noise (RPN) (1Hz – 100kHz) (measure with spectrum analyzer)

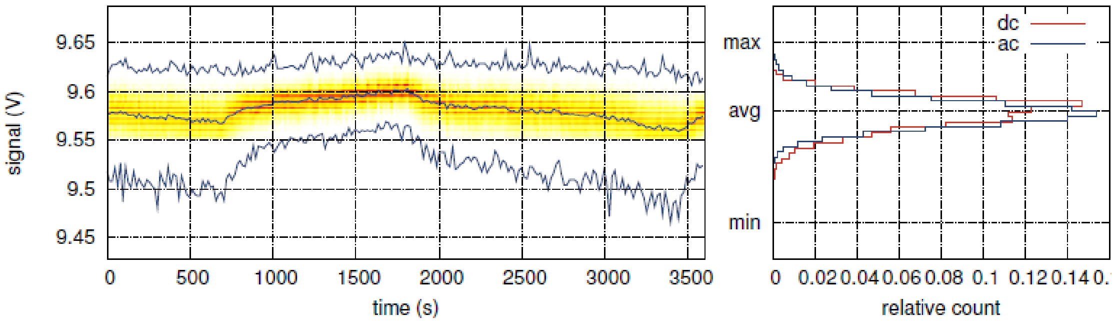


https://dcc.ligo.org/DocDB/0089/E1200385/001/rpn_amp.pdf
https://dcc.ligo.org/DocDB/0089/E1200385/001/rpn_amp.zip

At H1 location after change of water system (alog page 6582)



c. DBB RPN for 1h

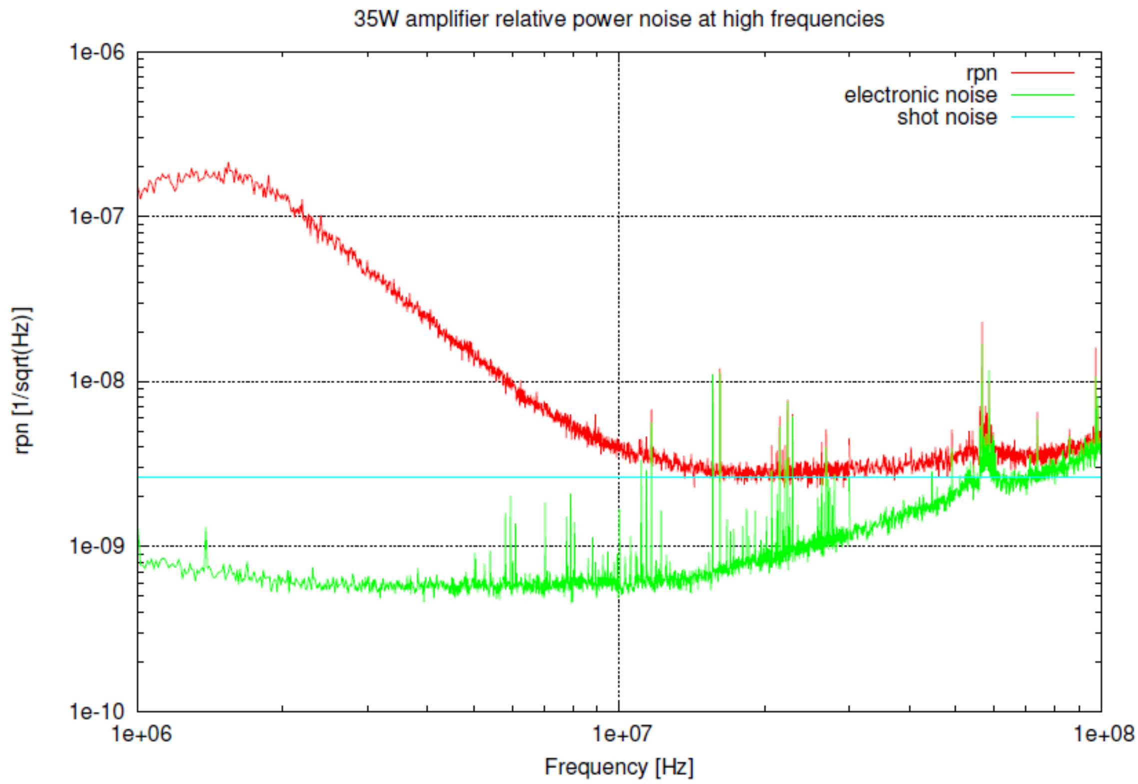


relative peak to peak: 1.9%

more info in full noise report under the following URL:

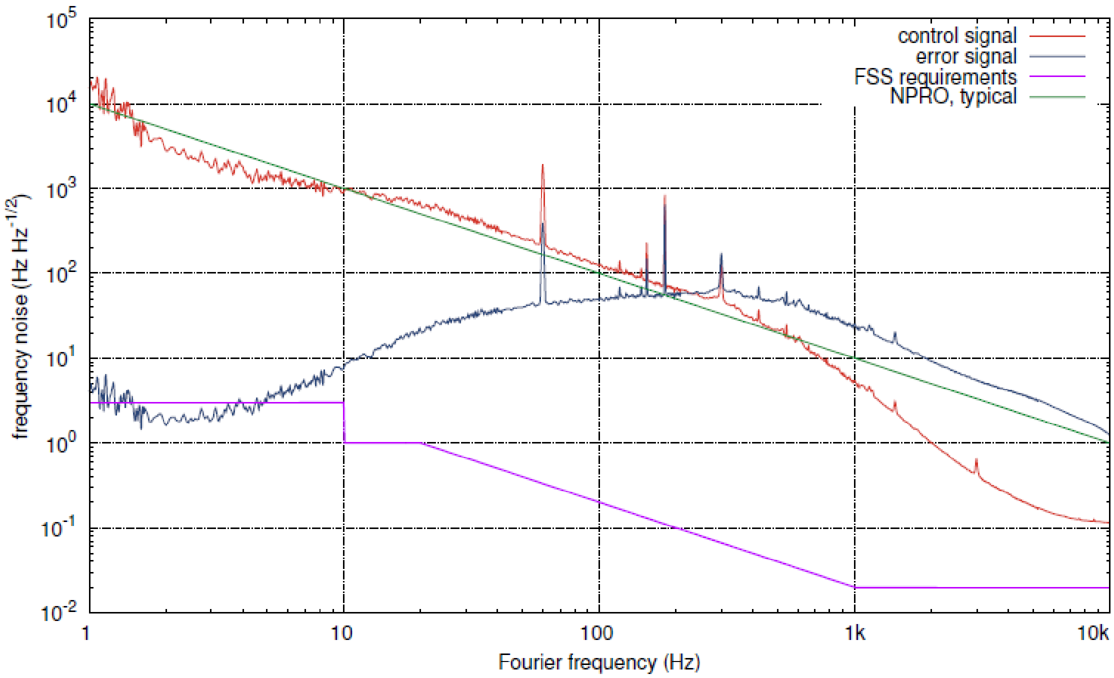
https://dcc.ligo.org/DocDB/0089/E1200385/001/dbb_rpn-002.pdf
https://dcc.ligo.org/DocDB/0089/E1200385/001/dbb_rpn-002.zip

d. DBB RPN at RF (measure with spectrum analyzer)



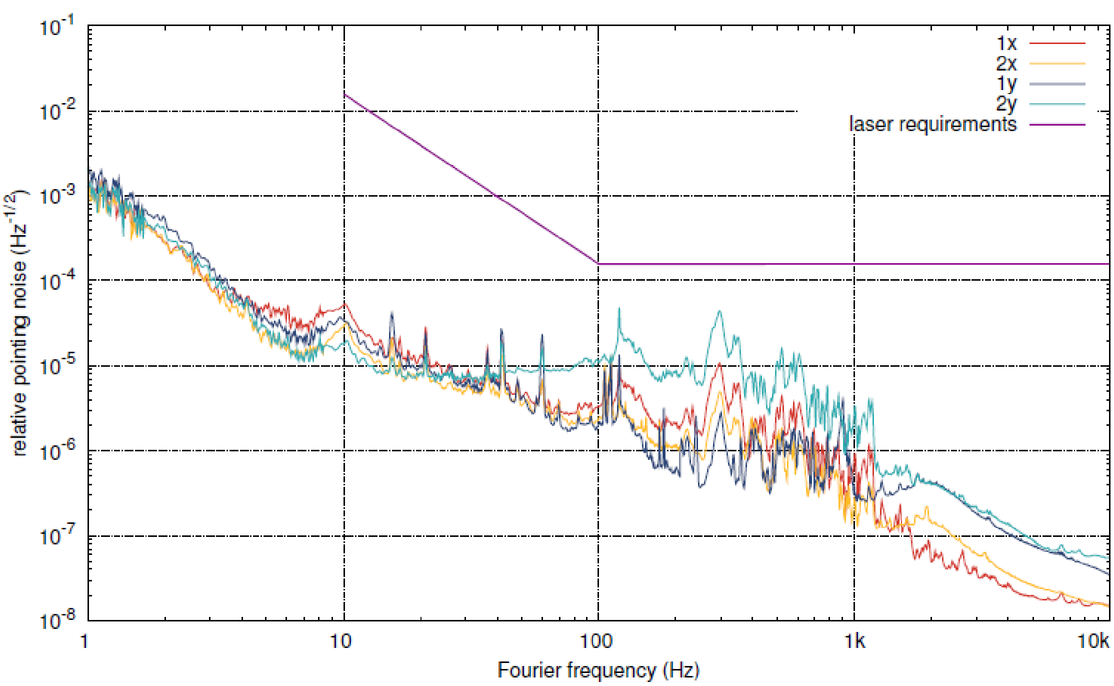
https://dcc.ligo.org/DocDB/0089/E1200385/001/rpnrf_amp.pdf
https://dcc.ligo.org/DocDB/0089/E1200385/001/rpnrf_amp.zip

e. DBB frequency noise



more info in full noise report under the following URL:
https://dcc.ligo.org/DocDB/0089/E1200385/001/dbb_frq-001.pdf
https://dcc.ligo.org/DocDB/0089/E1200385/001/dbb_frq-001.zip

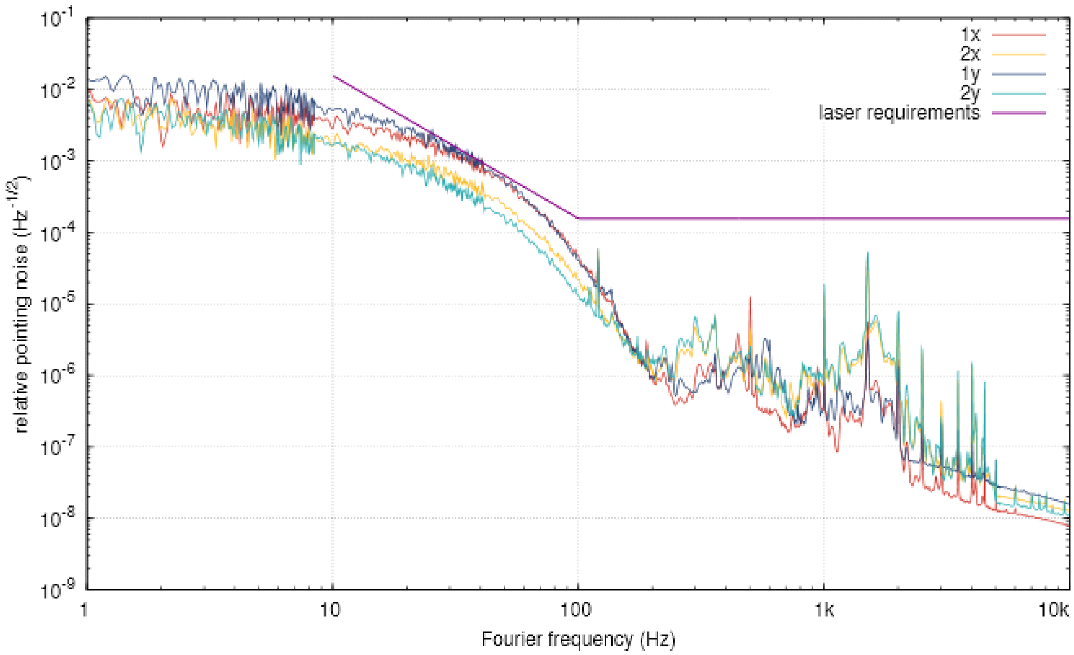
f. <u>DBB pointing noise 1X, 1Y, 2X, 2Y</u>



For this measurement the fan-filter-units in the LAE ceiling were turned off !
more info in full pointing report under the following URL:
https://dcc.ligo.org/DocDB/0089/E1200385/001/dbb_pnt-001.pdf

https://dcc.ligo.org/DocDB/0089/E1200385/001/dbb_pnt-001.zip

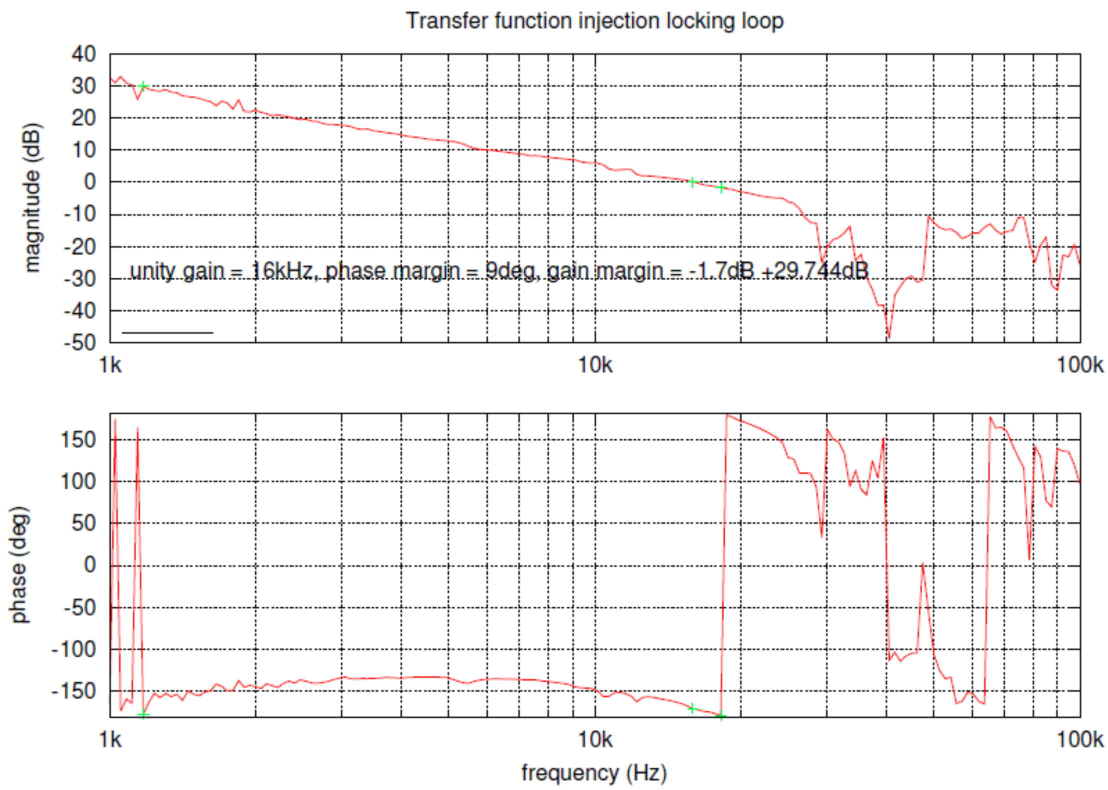
At H1 location after change of water system (alog page 6582)



2.2.2 *Laser characterization 200W* (S1107826)

a. Output power: on PM01: 187 W; calibration factor for PD01: 0.0016515 W/V

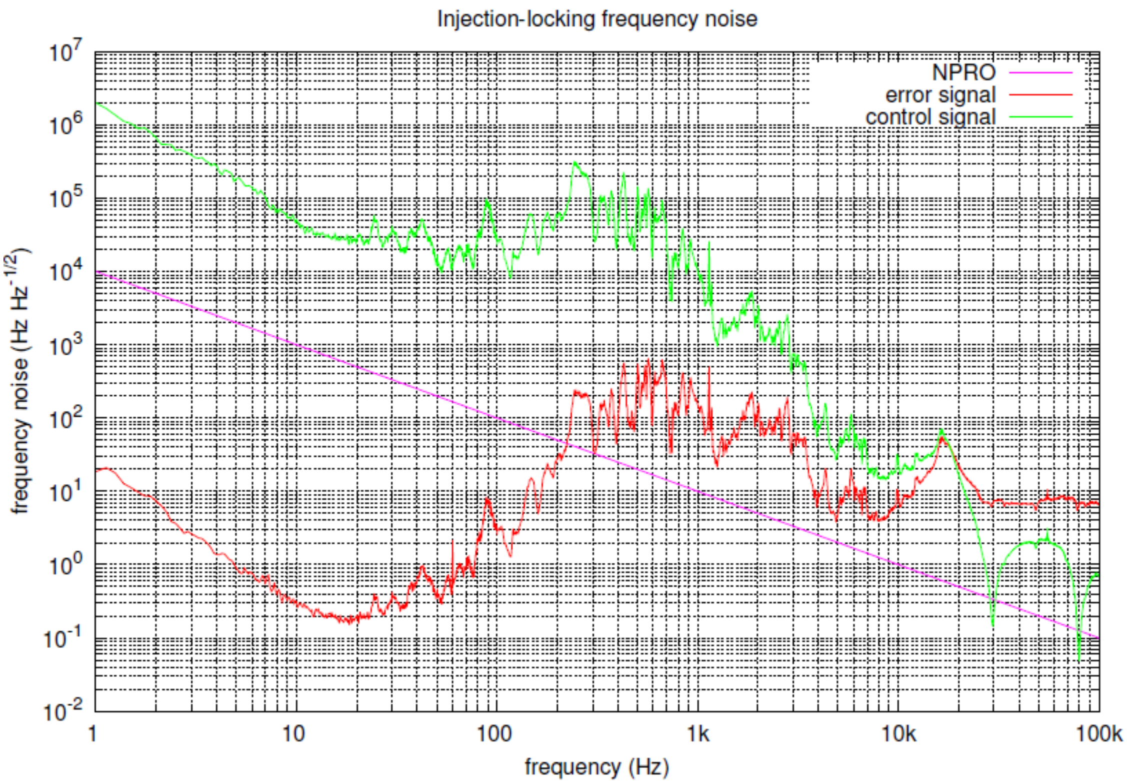
b. Transfer function of injection locking loop + UG frequency



https://dcc.ligo.org/DocDB/0089/E1200385/001/tf_ils.pdf
https://dcc.ligo.org/DocDB/0089/E1200385/001/tf_ils.zip

c. Error signals of injection locking, scope screenshot with error signal, HV mon, resonant, and DC signal of IL PD.
see (2.1.3.8)

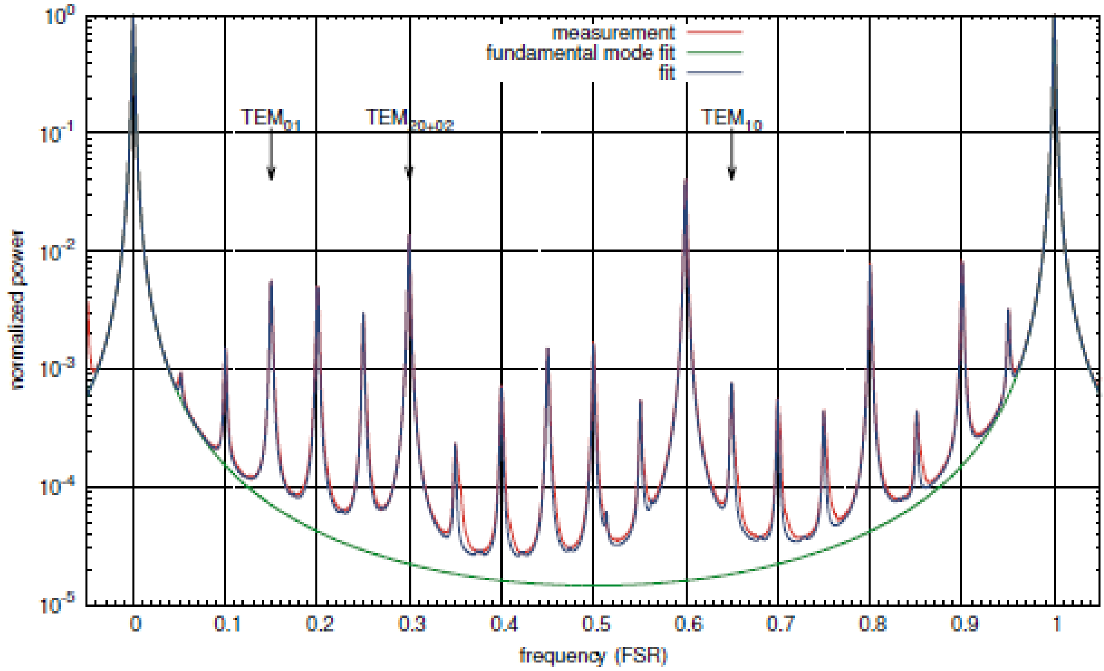
d. Error point noise of injection locking loop + frequency calibration of error signal



https://dcc.ligo.org/DocDB/0089/E1200385/001/frqnoise_ils.pdf
https://dcc.ligo.org/DocDB/0089/E1200385/001/sens_act_noise.zip

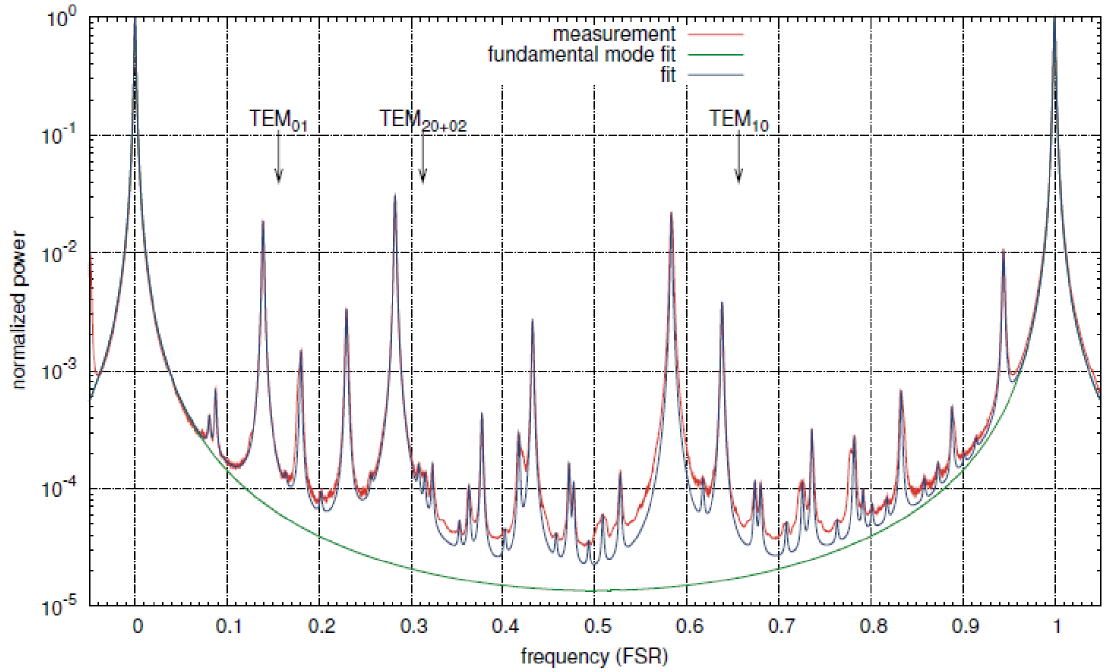
e. Actuator/PZT noise of injection locking loop + frequency calibration of signal
(see 2.2.2 d)

f. DBB modescan



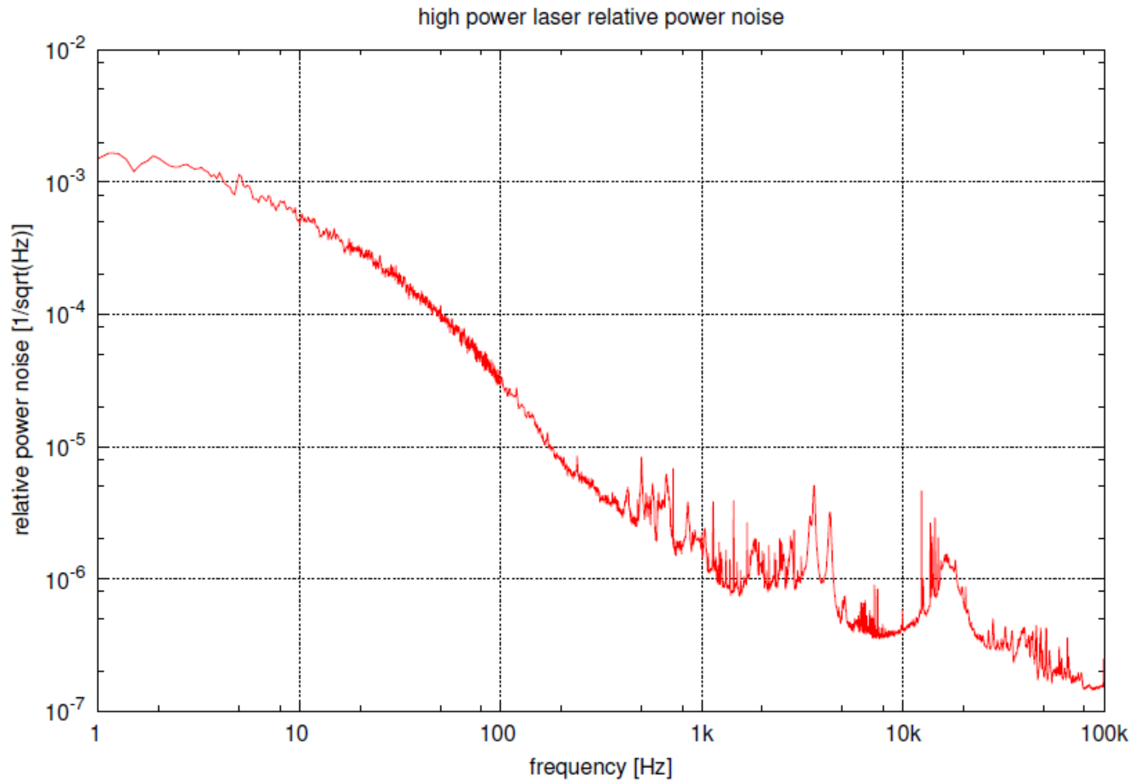
more info in full modescan report under the following URL:
https://dcc.ligo.org/DocDB/0089/E1200385/001/dbb_msc-hpl.pdf
https://dcc.ligo.org/DocDB/0089/E1200385/001/dbb_msc-hpl.zip

DBB modescan H1



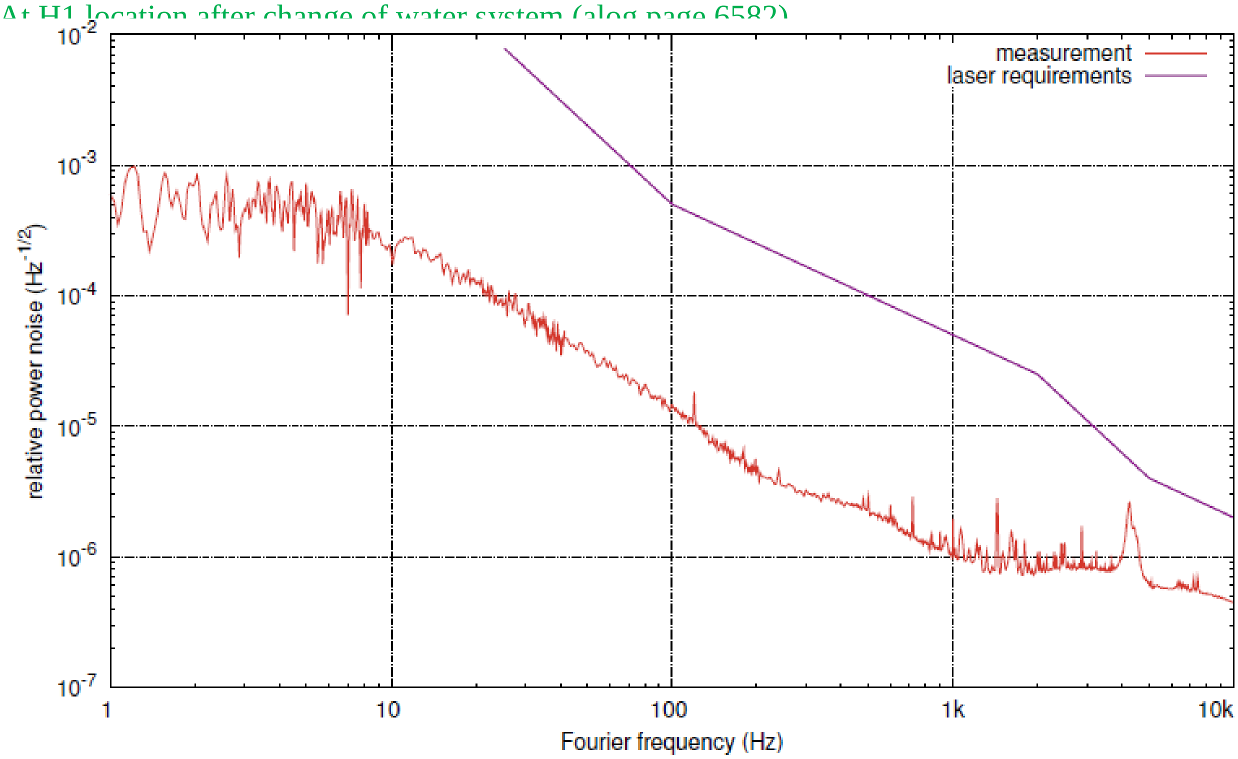
https://dcc.ligo.org/DocDB/0100/E1300129/001/dbb_msc-hpl.pdf
https://dcc.ligo.org/DocDB/0100/E1300129/001/dbb_msc-hpl.zip

g. DBB RPN (1Hz – 100kHz) (measure with spectrum analyzer)

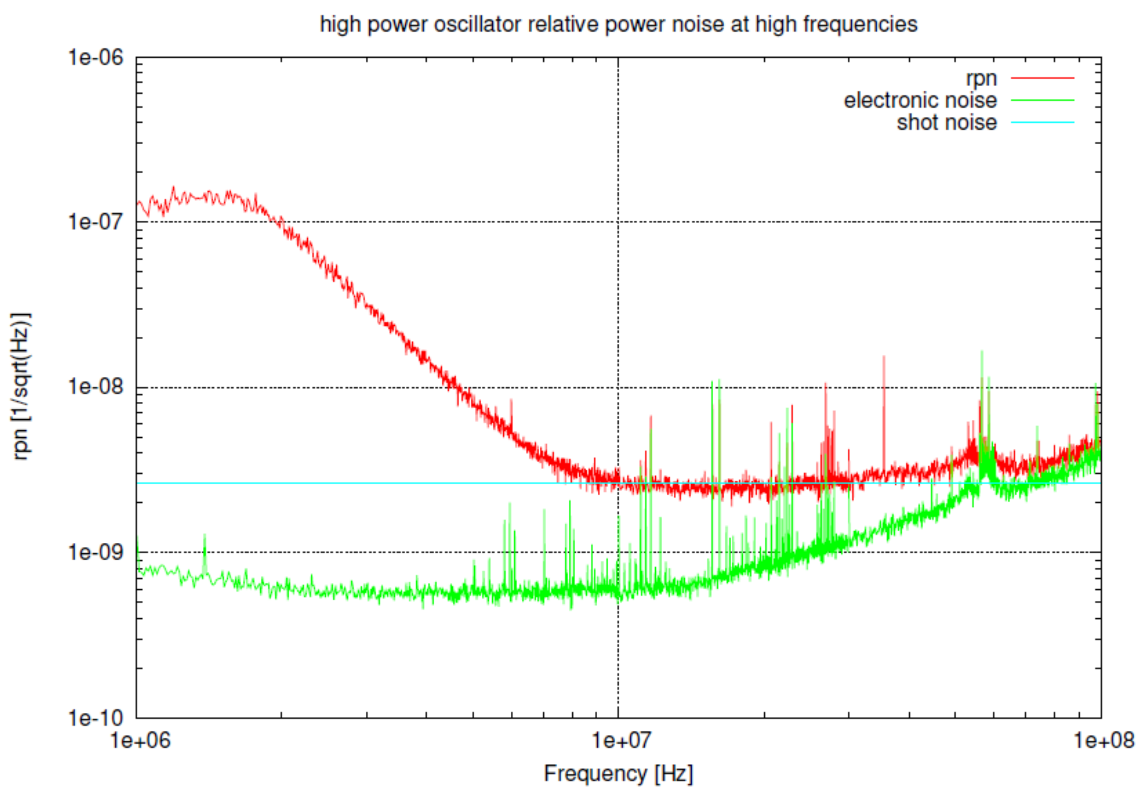


https://dcc.ligo.org/DocDB/0089/E1200385/001/rpn_hpl.pdf
https://dcc.ligo.org/DocDB/0089/E1200385/001/rpn_hpl.zip

At H1 location after change of water system (alog page 6582)

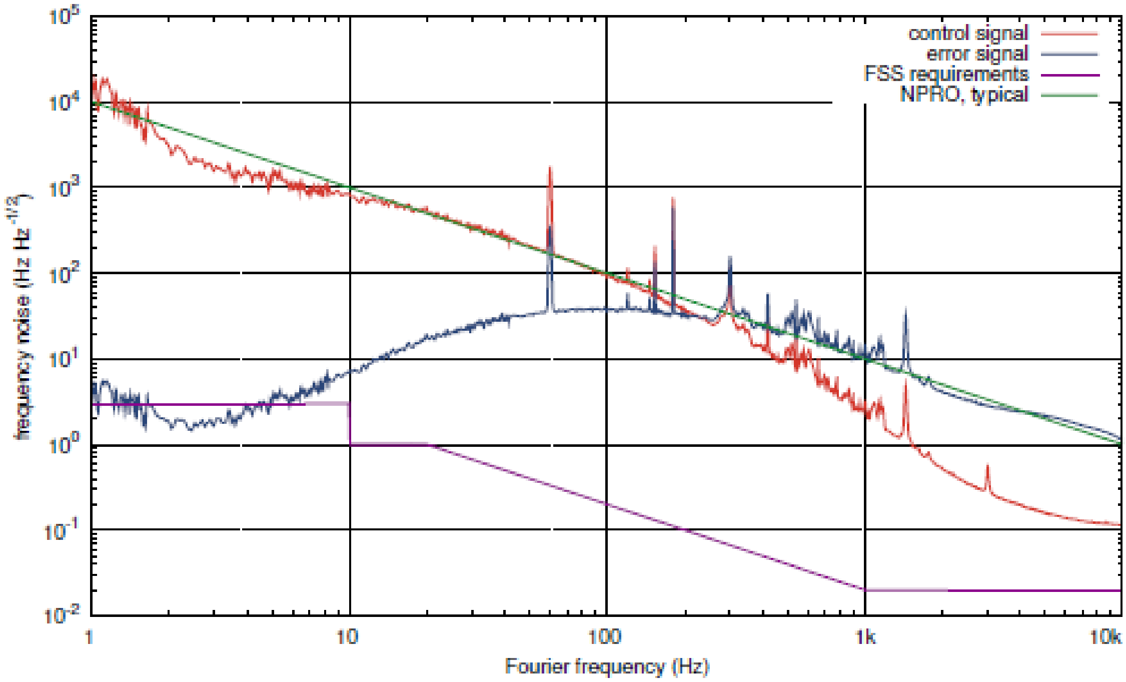


h. DBB RPN at RF (measure with spectrum analyzer)



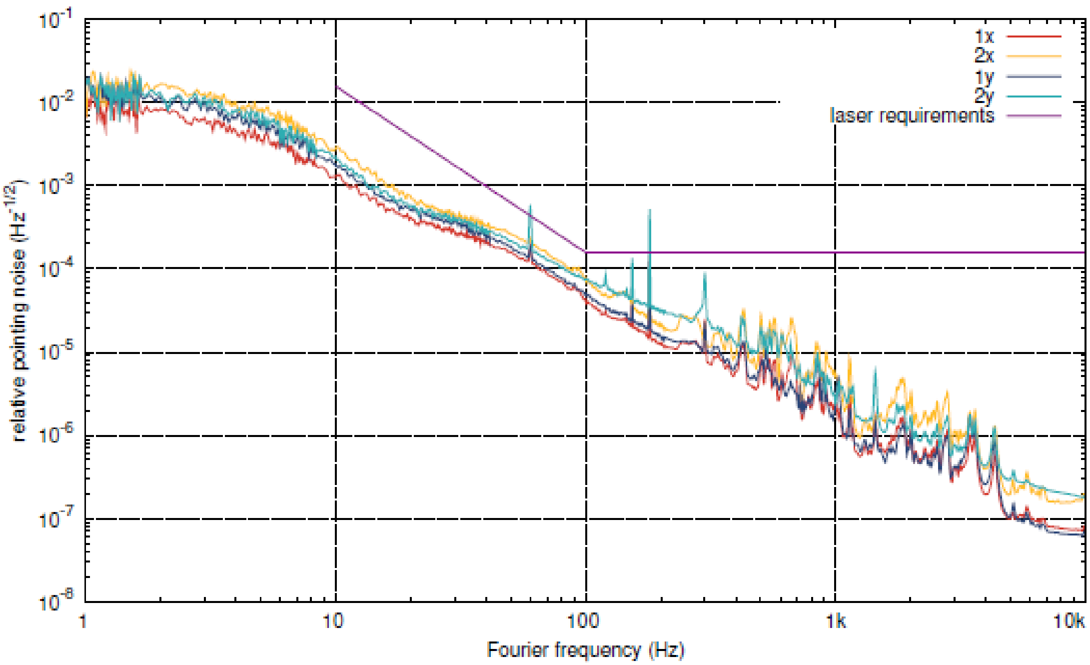
https://dcc.ligo.org/DocDB/0089/E1200385/001/rpnrf_hpo.pdf
https://dcc.ligo.org/DocDB/0089/E1200385/001/rpnrf_hpo.zip

i. DBB frequency noise



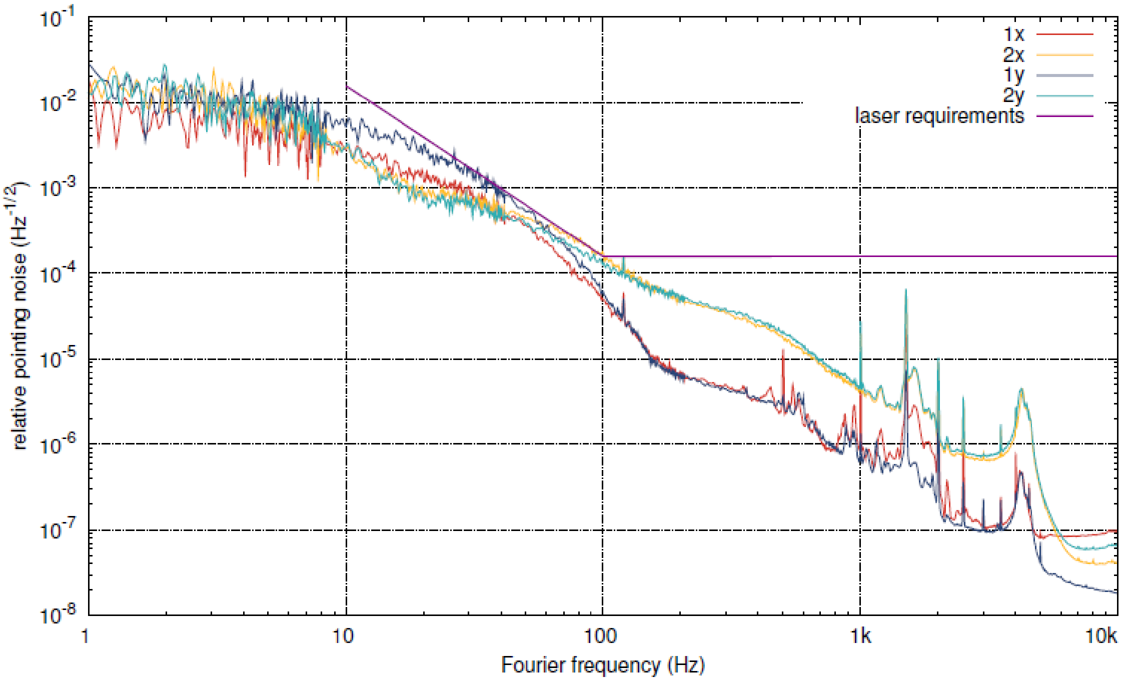
more info in full noise report under the following URL
https://dcc.ligo.org/DocDB/0089/E1200385/001/dbb_frq-hpl.pdf
https://dcc.ligo.org/DocDB/0089/E1200385/001/dbb_frq-hpl.zip

j. <u>DBB pointing noise 1X, 1Y, 2X, 2Y</u>

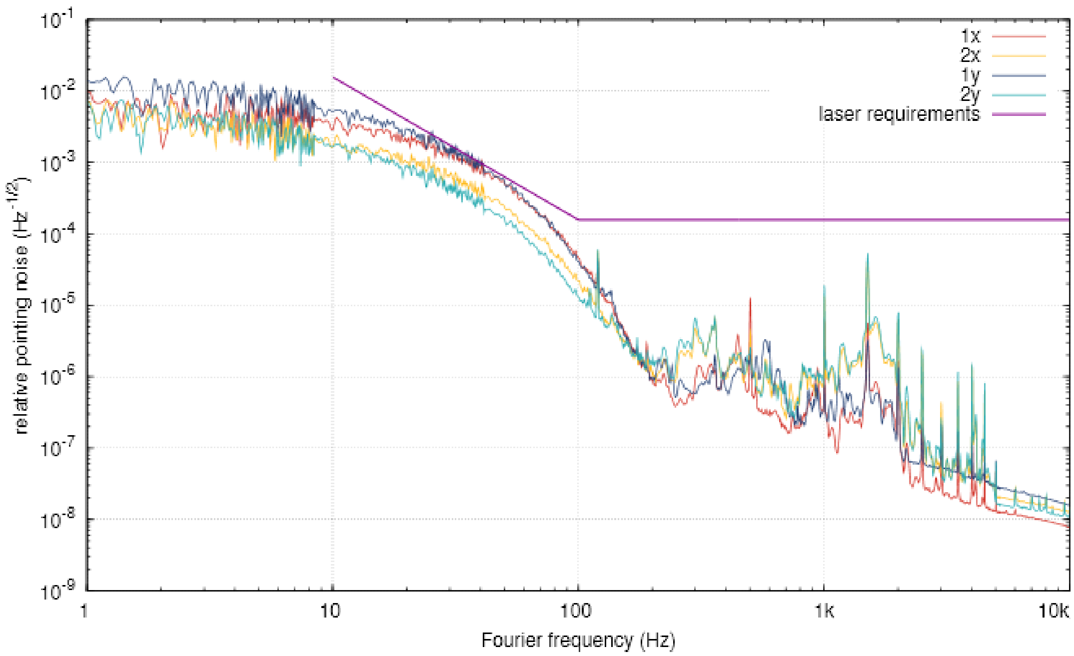


more info in full pointing report under the following URL
https://dcc.ligo.org/DocDB/0089/E1200385/001/dbb_pnt-hpl.pdf
https://dcc.ligo.org/DocDB/0089/E1200385/001/dbb_pnt-hpl.zip

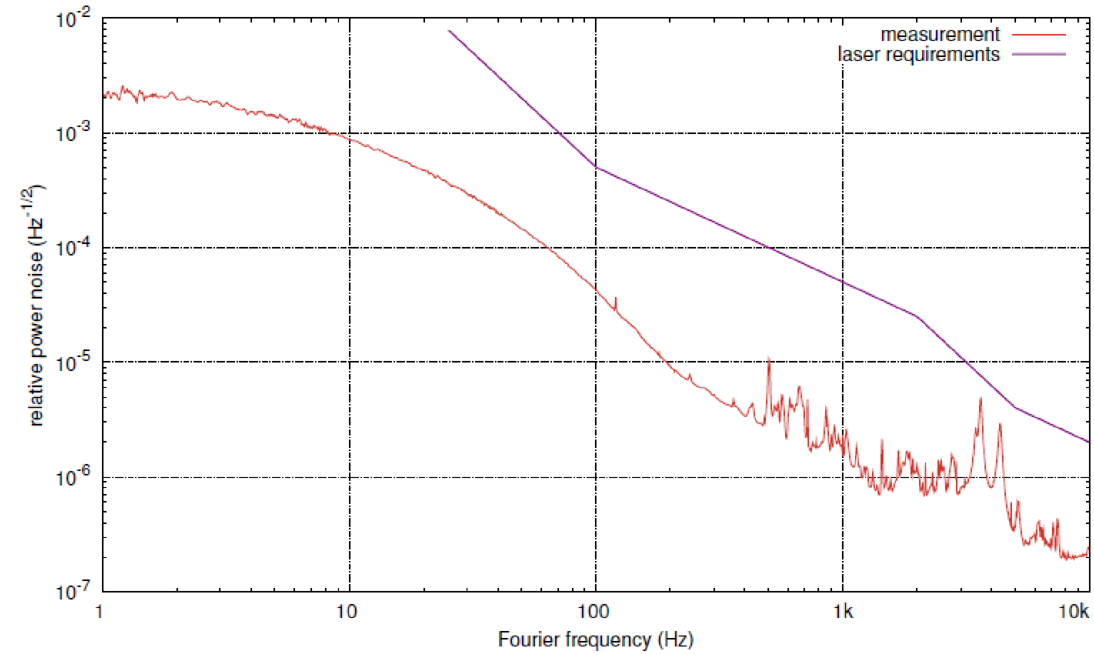
At H1 location after change of water system (alog page 6582)

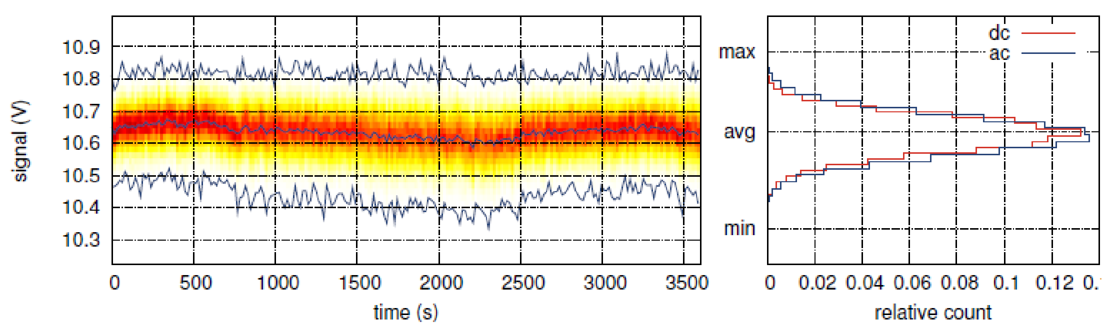


for comparison pointing of 35W laser (2.2.1f and alog page 6582



k. <u>DBB RPN for 1h</u>





more info in full noise report under the following URL:
https://dcc.ligo.org/DocDB/0089/E1200385/001/dbb_rpn-hpl.pdf
https://dcc.ligo.org/DocDB/0089/E1200385/001/dbb_rpn-hpl.zip

l. <u>DC power of internal photodiodes (in high power mode, locked state)</u>

PD AMP: 6.9V
PD BP: 3.07V
PD INT: 7.5V
PD ISO: 30mV (locked

2.3 Pre-Modecleaner

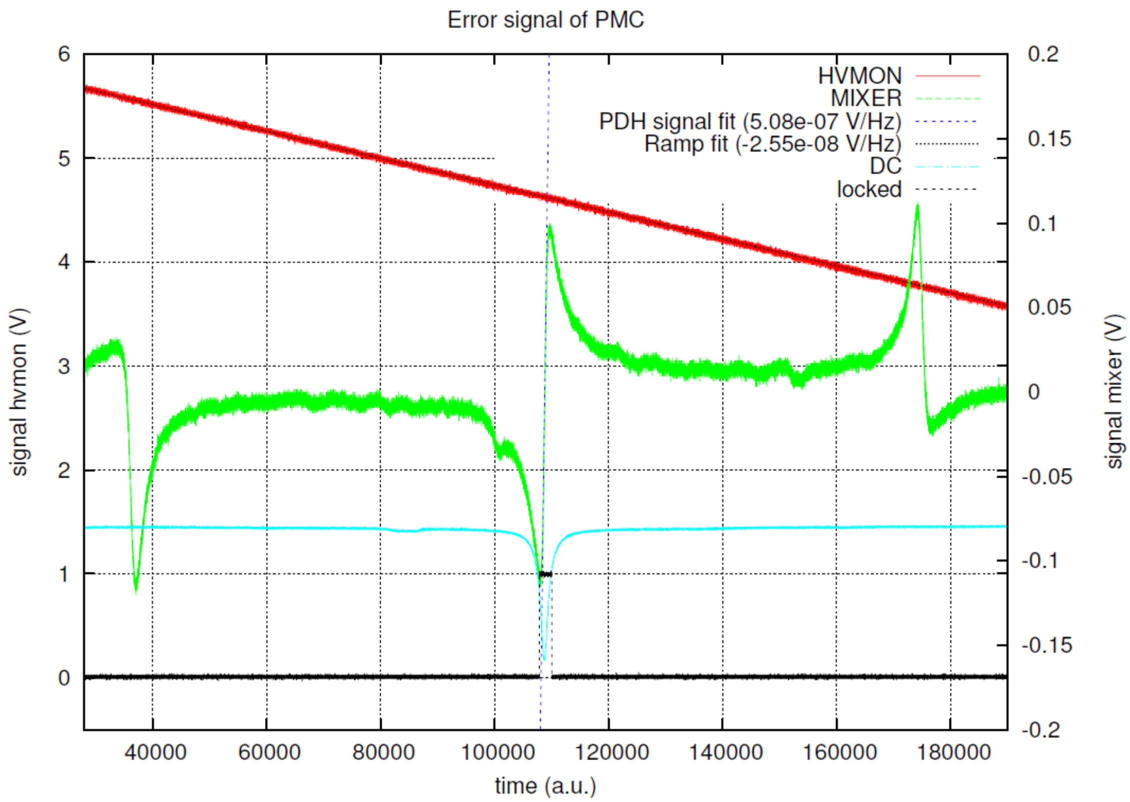
pre shipment testing:

Name	**Designation**	**Design Doc. or Part No.**	**SN**	**Test Procedure**	**Completed Test Document**
Pre-Modecleaner	PMC	T0900616	S1107833 S1107832	T1000429	S1107833 S1107832
PMC Servo		D1001618	S1107798 S1107814*	T1000342	S1107798 S1107814
PMC Fieldbox	PMC-FB	D1001619	S1107808 S1107809*	T10000343	S1107808 S1107807
PMC photodiode	PMC-PD	D1101123	S1107850 S1107848		S1107850 S1107848
PMC oscillator, amp. and phase shifter	see ILS 2.1.3.7	D080702 D1000124 D0900128	S1000548 S1000594 S1103426		
PMC AA filter		D070081	S1001251	T070146	S1001251
PMC AI filter		D070081	S1001236	T070146	S1001236

* these Serial Numbers are the units installed, the second SN was given to the spare unit

LO Amplitude: 7dBm

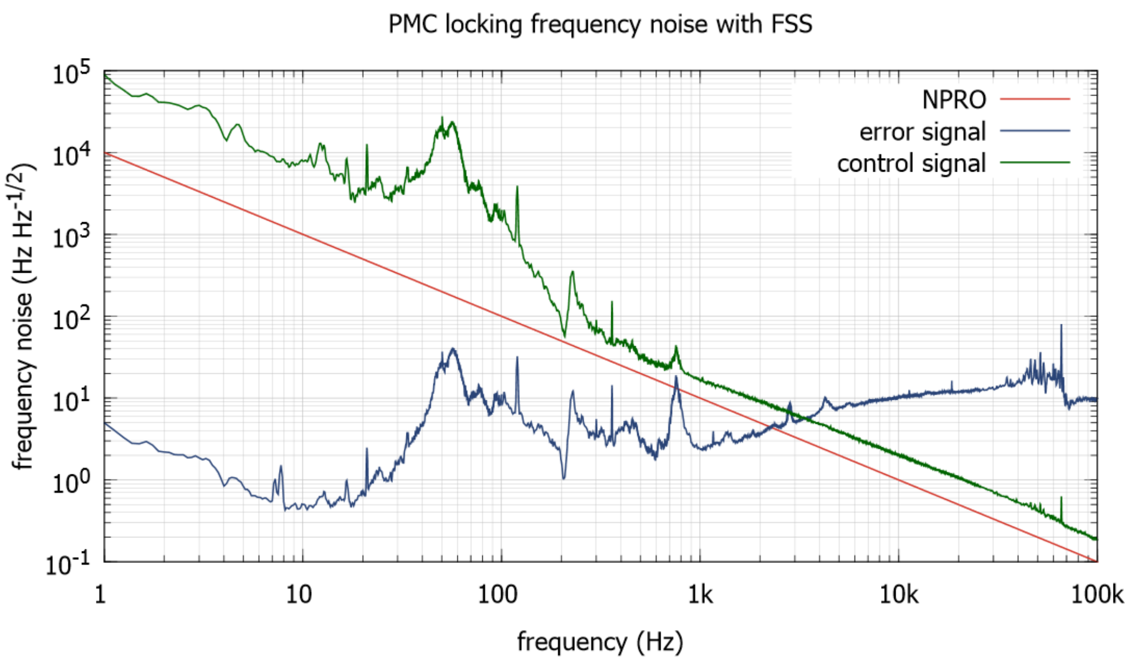
a. <u>Error signal, scope screenshot with error signal, HV mon, resonant, and DC signal of locking PD.</u>



https://dcc.ligo.org/DocDB/0089/E1200385/001/errorsignal_pmc.pdf
https://dcc.ligo.org/DocDB/0089/E1200385/001/errorsignal_pmc.zip

b. Error point noise of PMC locking loop + frequency calibration of error signal, with FSS

At H1 location after 15 month of operation (Aug 2013), FSS on

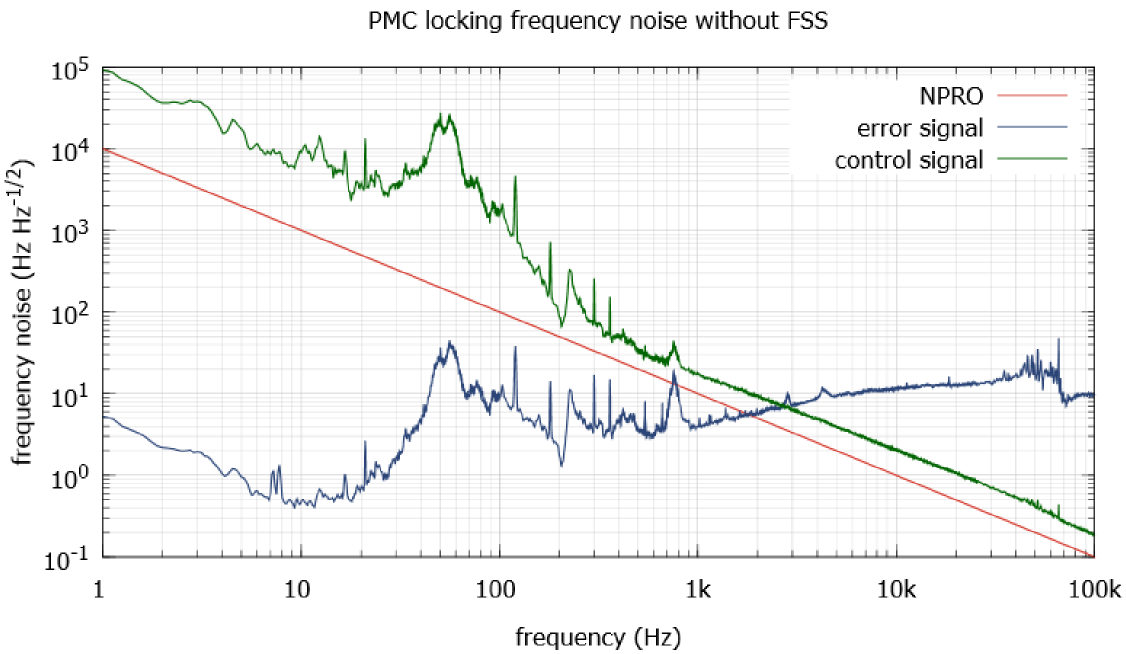


PMC noise with FSS on

PMC noise with FSS on - data

c. Actuator/PZT noise of PMC locking loop + frequency calibration of signal, with FSS
see above

Error point noise of PMC locking loop + frequency calibration of error signal, without FSS
At H1 location after 15 month of operation (Aug 2013), FSS on

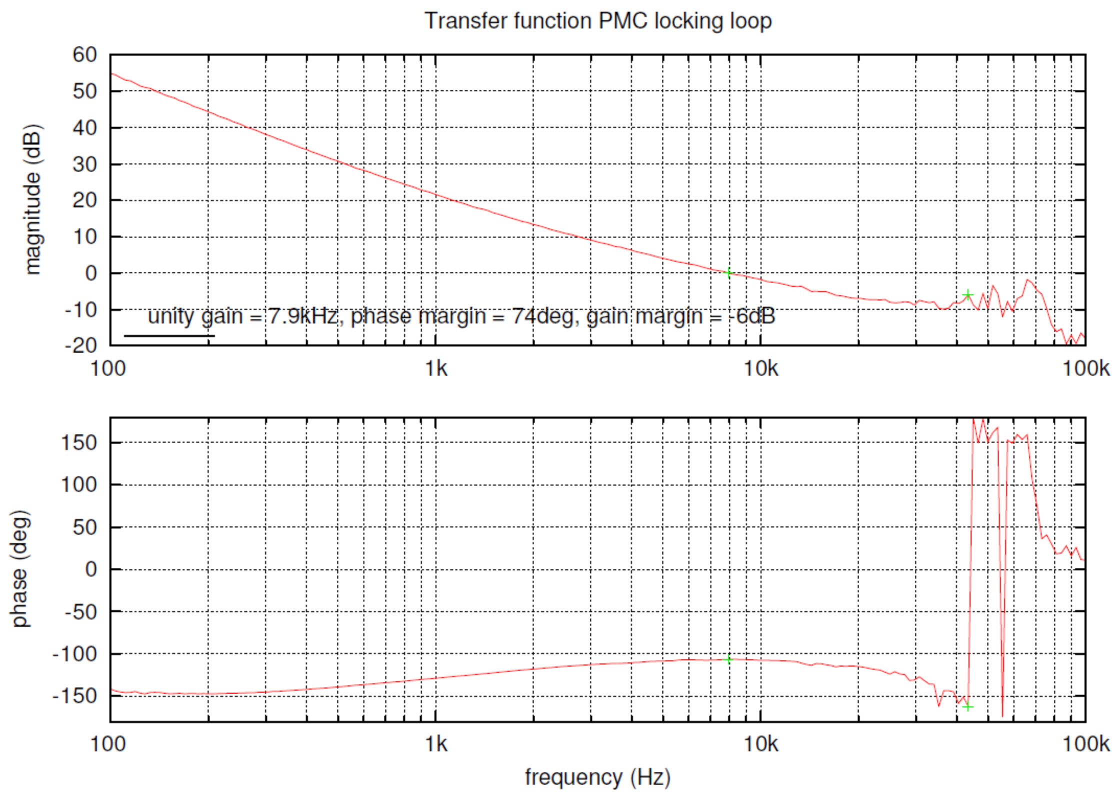


PMC noise with FSS off

PMC noise with FSS off - data

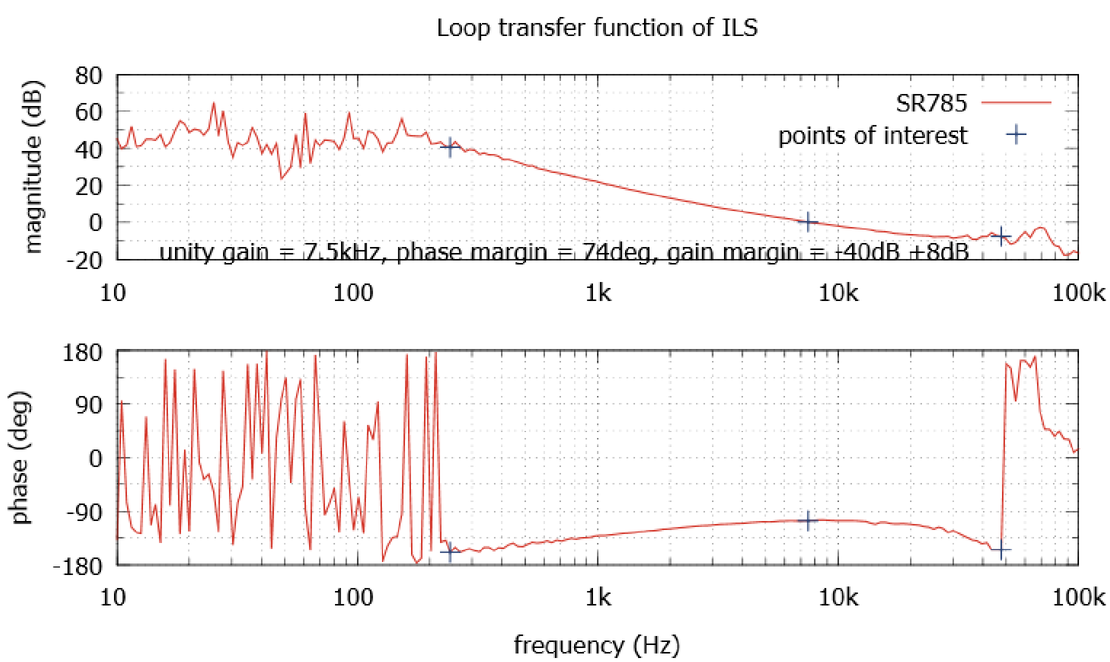
d. Actuator/PZT noise of PMC locking loop + frequency calibration of signal, without FSS
see 2.3.d

e. Transfer function of PMC locking loop + UG frequency



https://dcc.ligo.org/DocDB/0089/E1200385/001/tf_PMC.pdf
https://dcc.ligo.org/DocDB/0089/E1200385/001/tf_PMC.zip

At H1 location after 15 month of operation (Aug 2013)



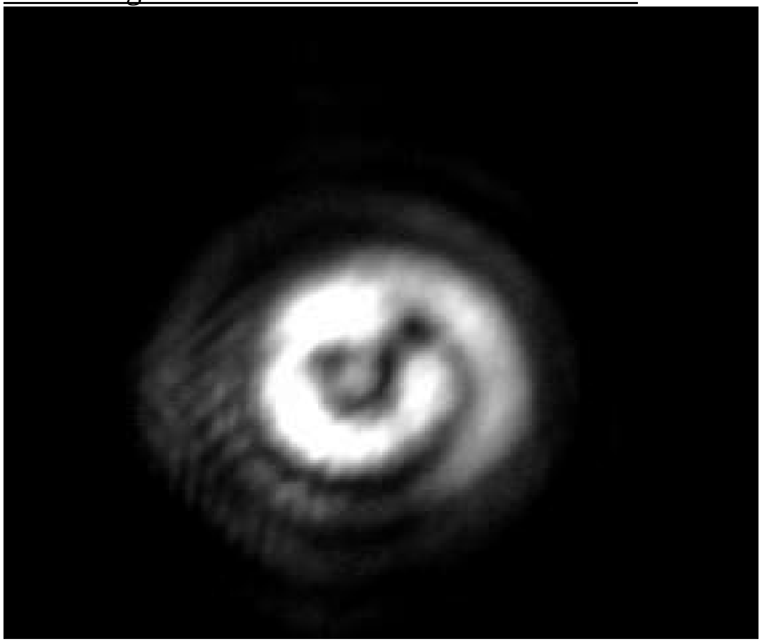
PMC loop transfer function

PMC loop transfer function - data

f. Dynamic range of PMC PZT in FSR (measured at reference system at AEI)
PZT range: 2.3 FSR (for 382V)

g. DC voltage of PMC locking PD
in locked state: 0.13V
unlocked: 1.4V => mode-matching efficiency >92%
(TI resistor: 1k)

h. CCD image of reflected mode / transmitted mode

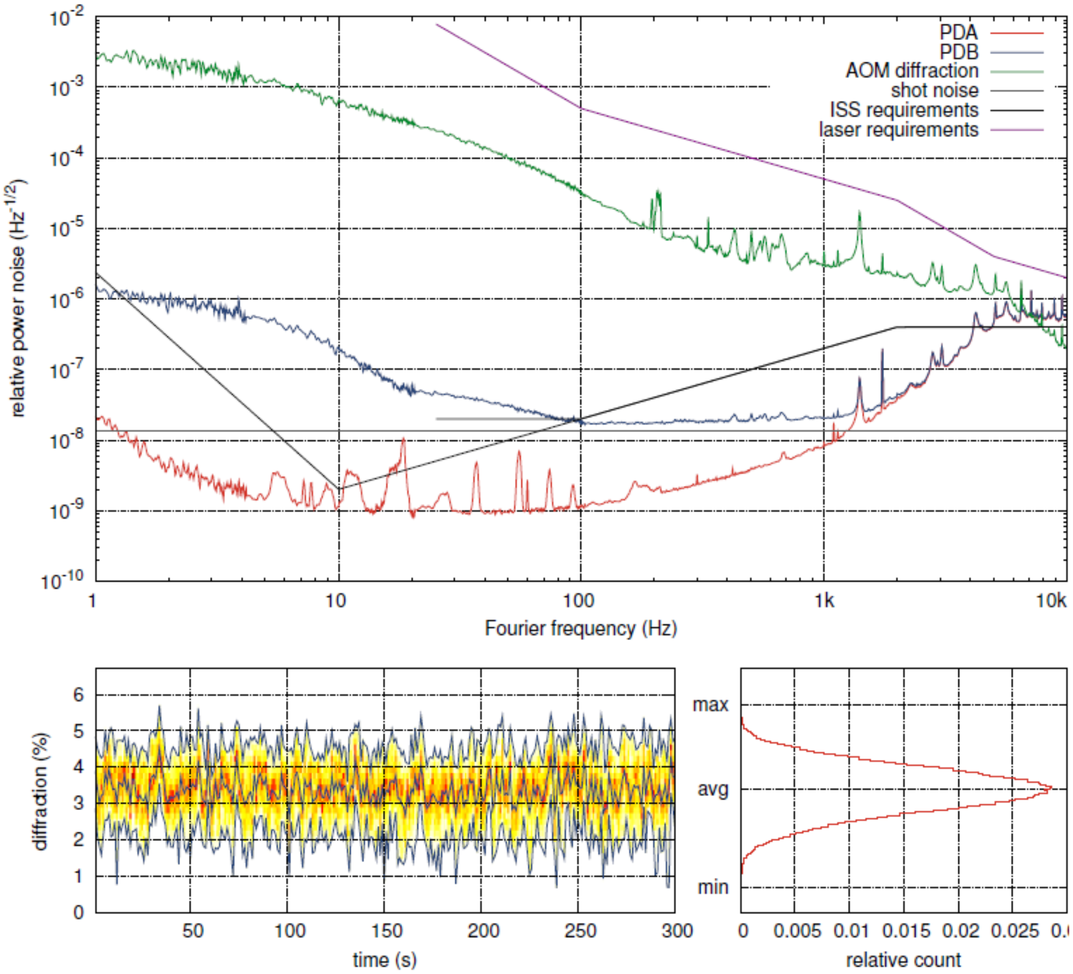


2.4 Power Stabilization (inner loop on PSL table)

pre shipment testing:

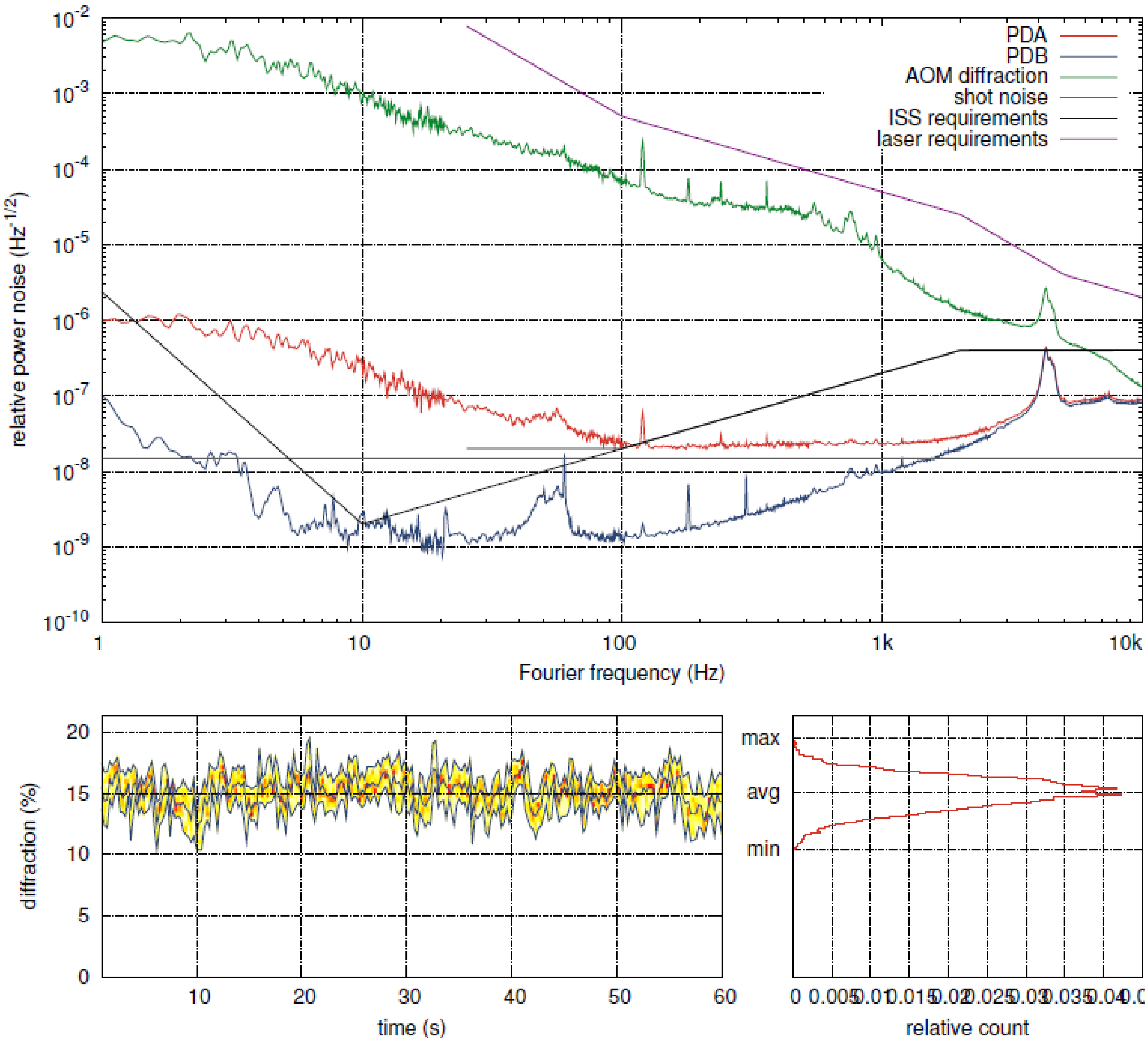
Name	**Designation**	**Design Doc. or Part No.**	**SN**	**Test Procedure**	**Completed Test Document**
ISS Servo		D1001985	S1107804* S1107805		S1107804 S1107805
ISS sensing box		D1003121 D1001998 D1002280	S1107810 S1107811	E1000748 T1000473 E1000467	S1107810 S1107811
ISS acousto optical modulator driver		See S1103745	S1107812 S1107813	NA	NA
ISS AA filter		D070081	S1001249	T070146	S1001249
ISS AI filter		D070081	S1001234	T070146	S1001234

a) In-loop/out-of-loop RPN measurement

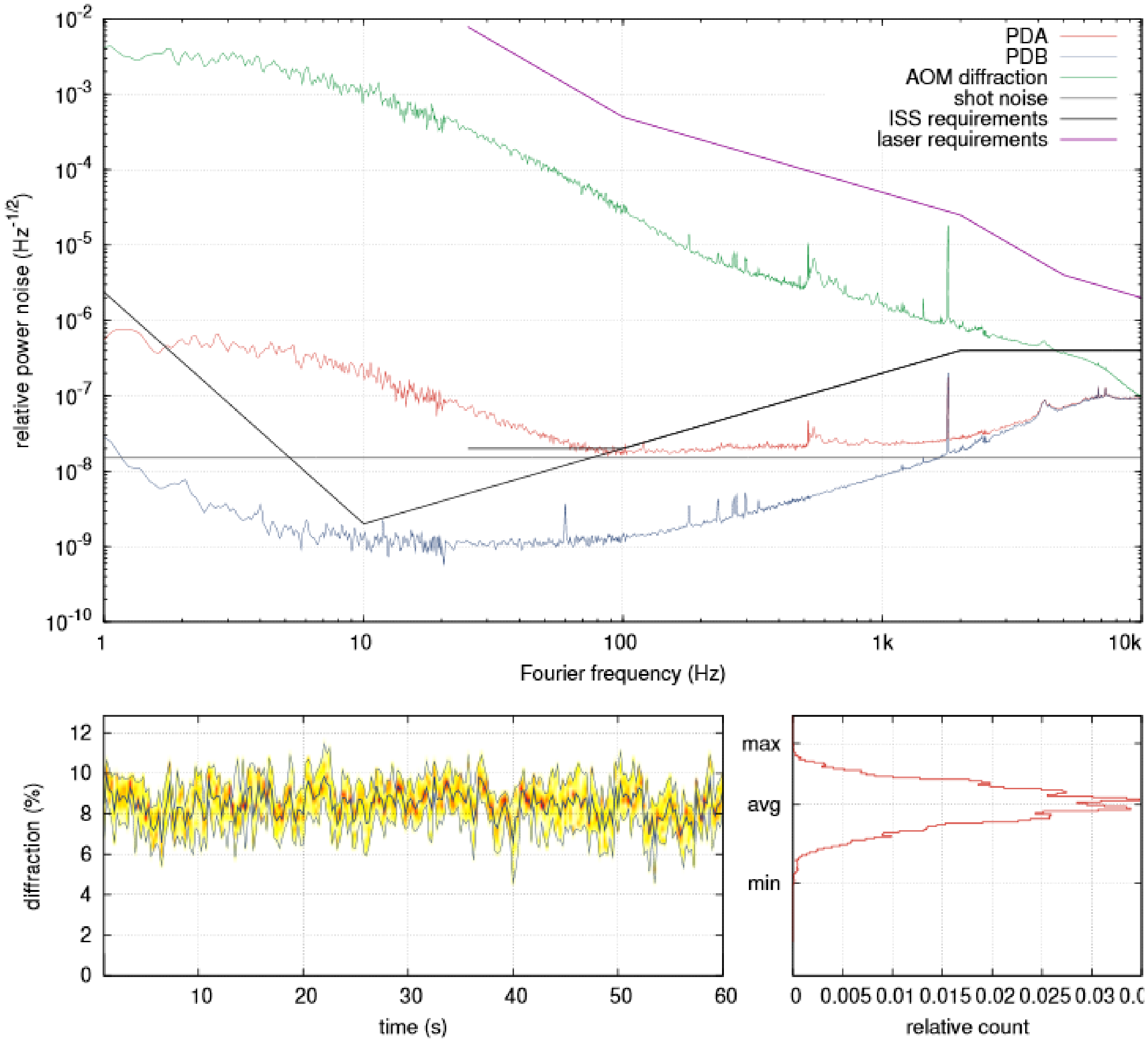


more info in full noise report under the following URL:
https://dcc.ligo.org/DocDB/0089/E1200385/001/iss_rpn-002.pdf
https://dcc.ligo.org/DocDB/0089/E1200385/001/iss_rpn-002.zip

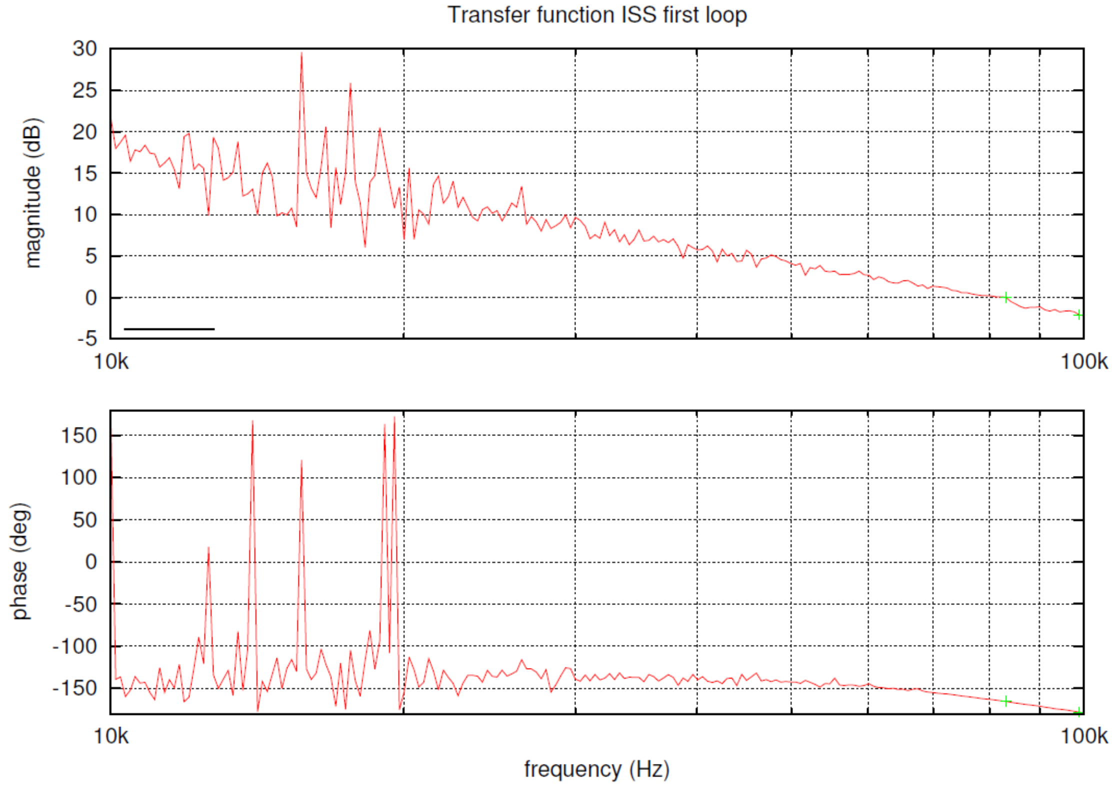
At H1 location after change of water system (6582)



At H1 location after 15 month of operation (Aug 2013)

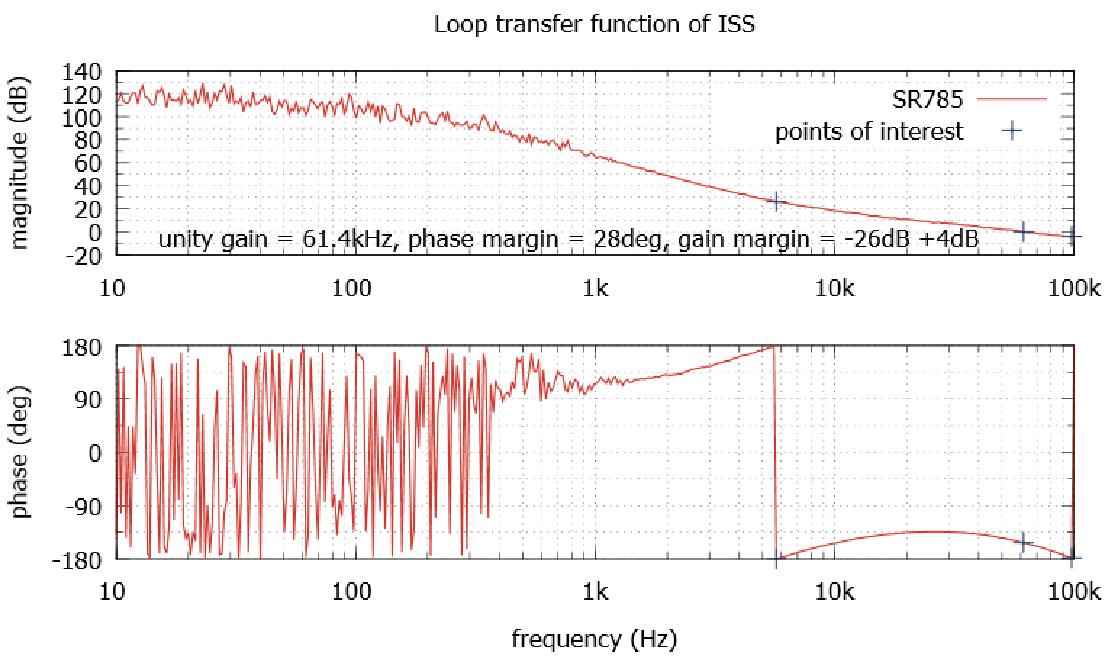


b) <u>Transfer function of ISS loop + UG frequency</u>



https://dcc.ligo.org/DocDB/0089/E1200385/001/tf_issfl.pdf
https://dcc.ligo.org/DocDB/0089/E1200385/001/tf_issfl.zip

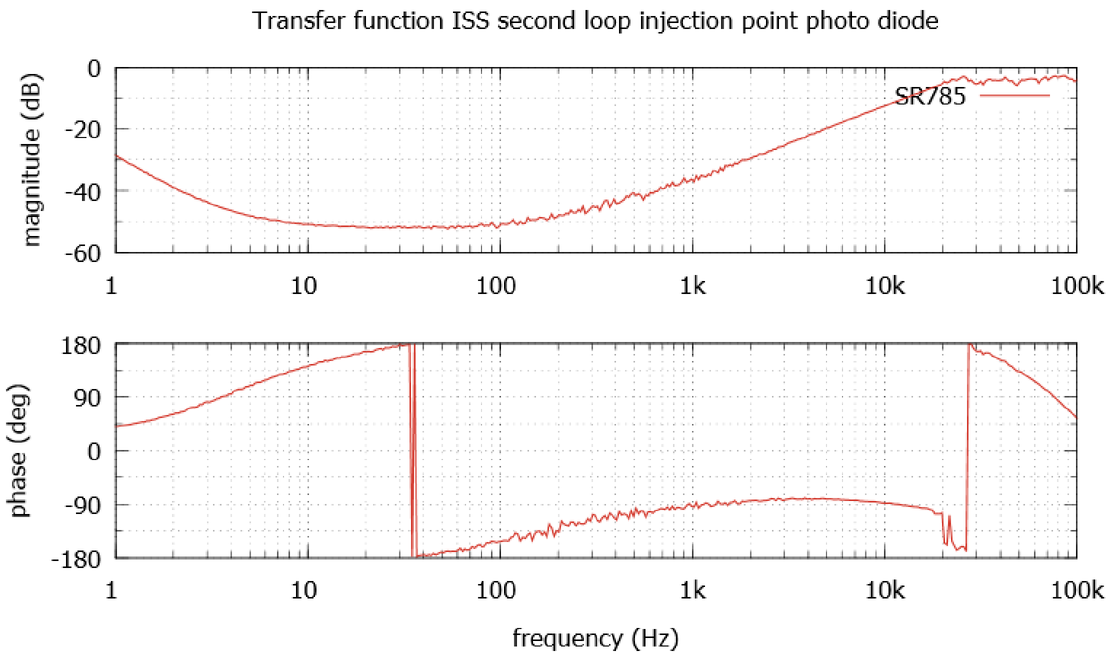
At H1 location after 15 month of operation (Aug 2013)



ISS loop transfer function
ISS loop transfer function - data

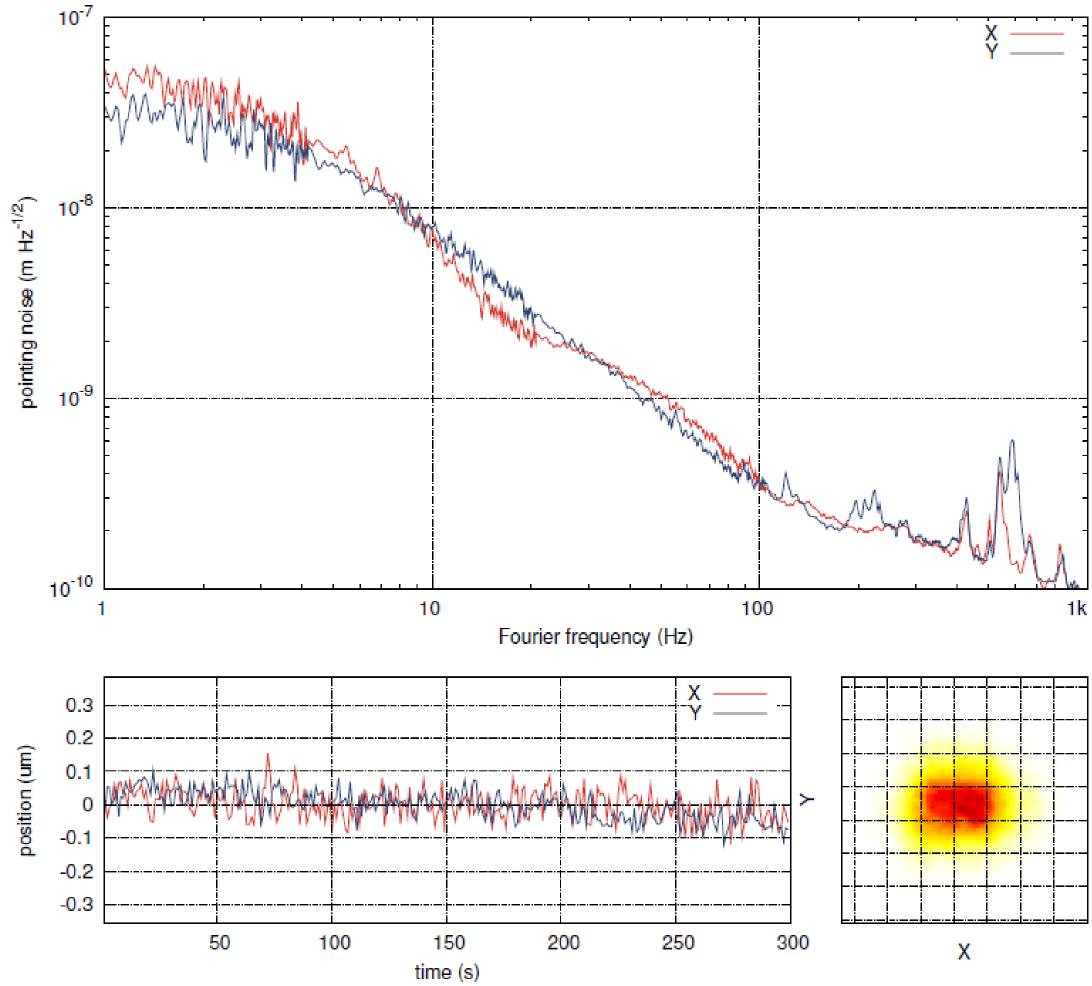
c) Transfer function from outer-loop injection port to out-of-loop PD

At H1 location after 15 month of operation (Aug 2013)



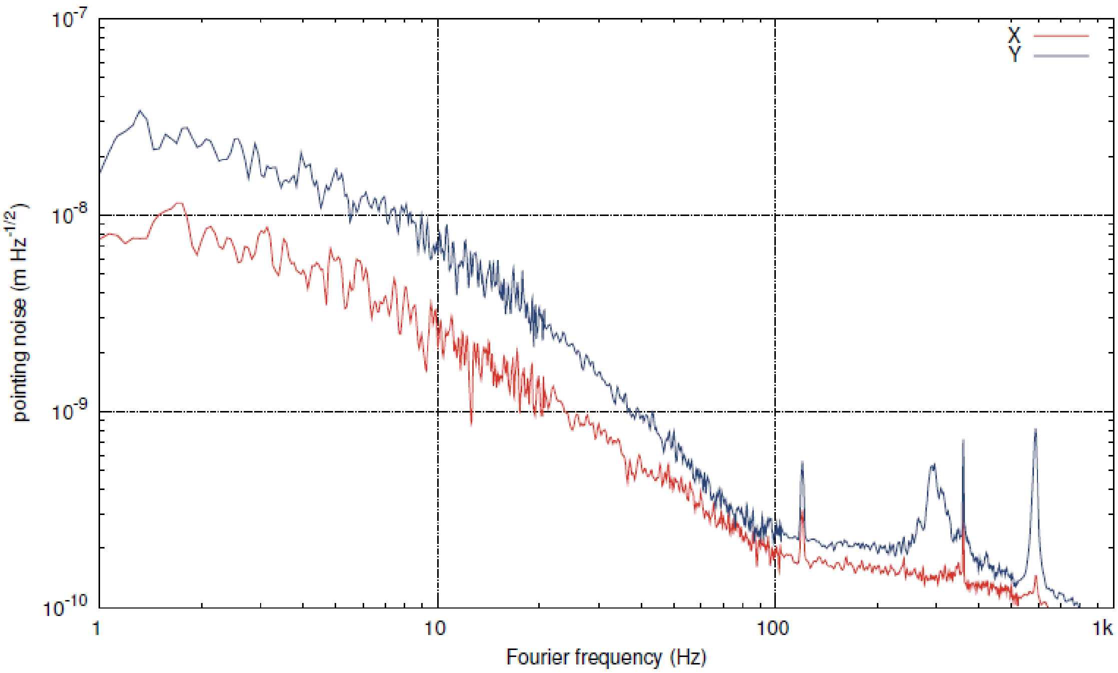
ISS transfer function outer-loop injection
ISS transfer function outer-loop injection - data

d) Pointing X, Y + calibration

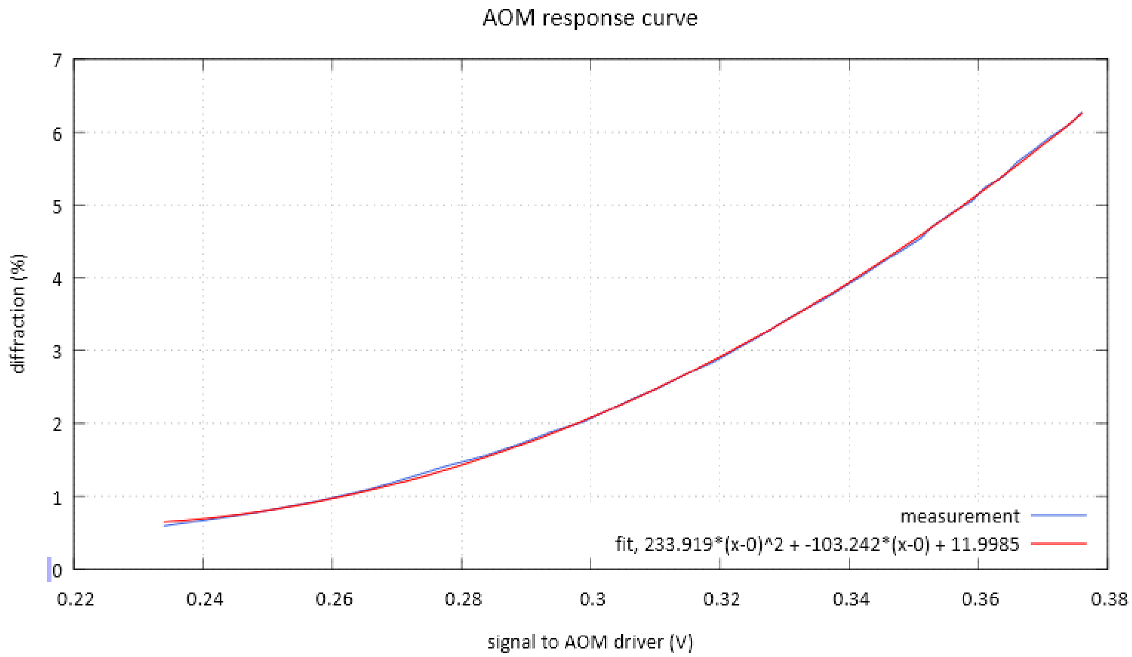


for pdf and data see URLs given in 2.4a

At H1 location after change of water system (6582)

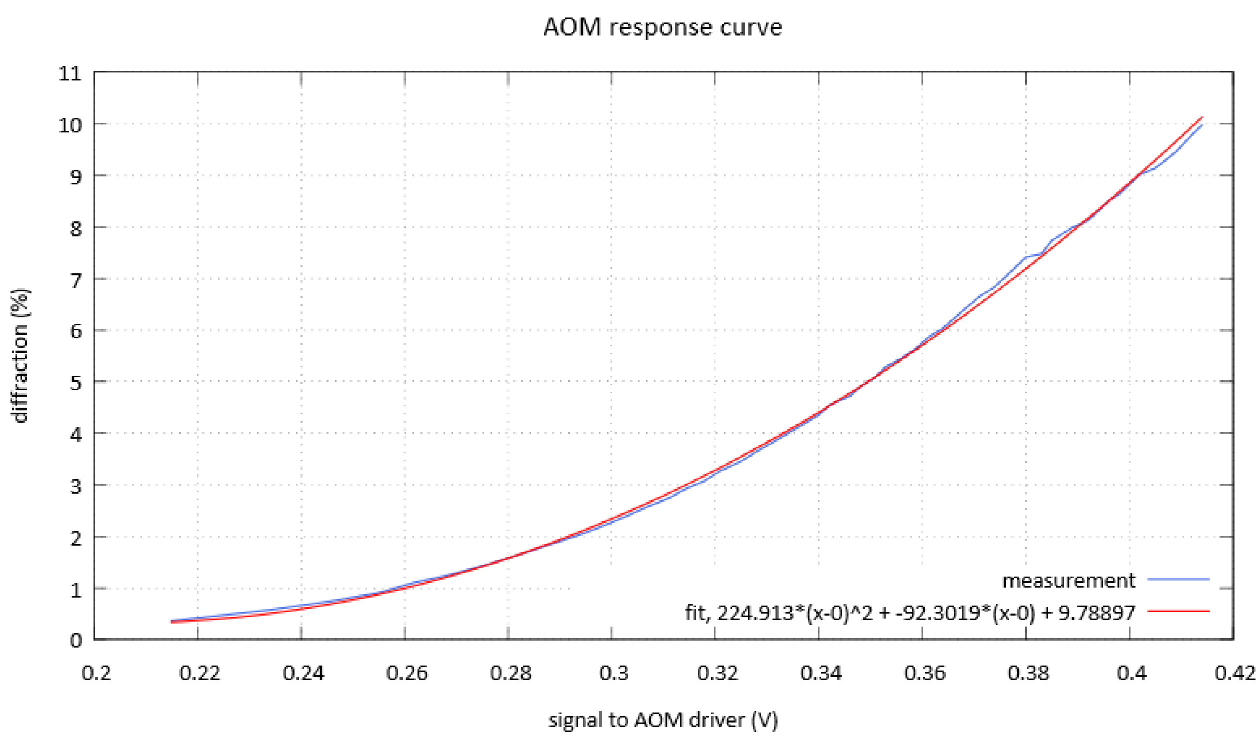


e) <u>Actuator linearity</u>



https://dcc.ligo.org/DocDB/0089/E1200385/001/actlin.pdf
<u>https://dcc.ligo.org/DocDB/0089/E1200385/001/actlin.zip</u>

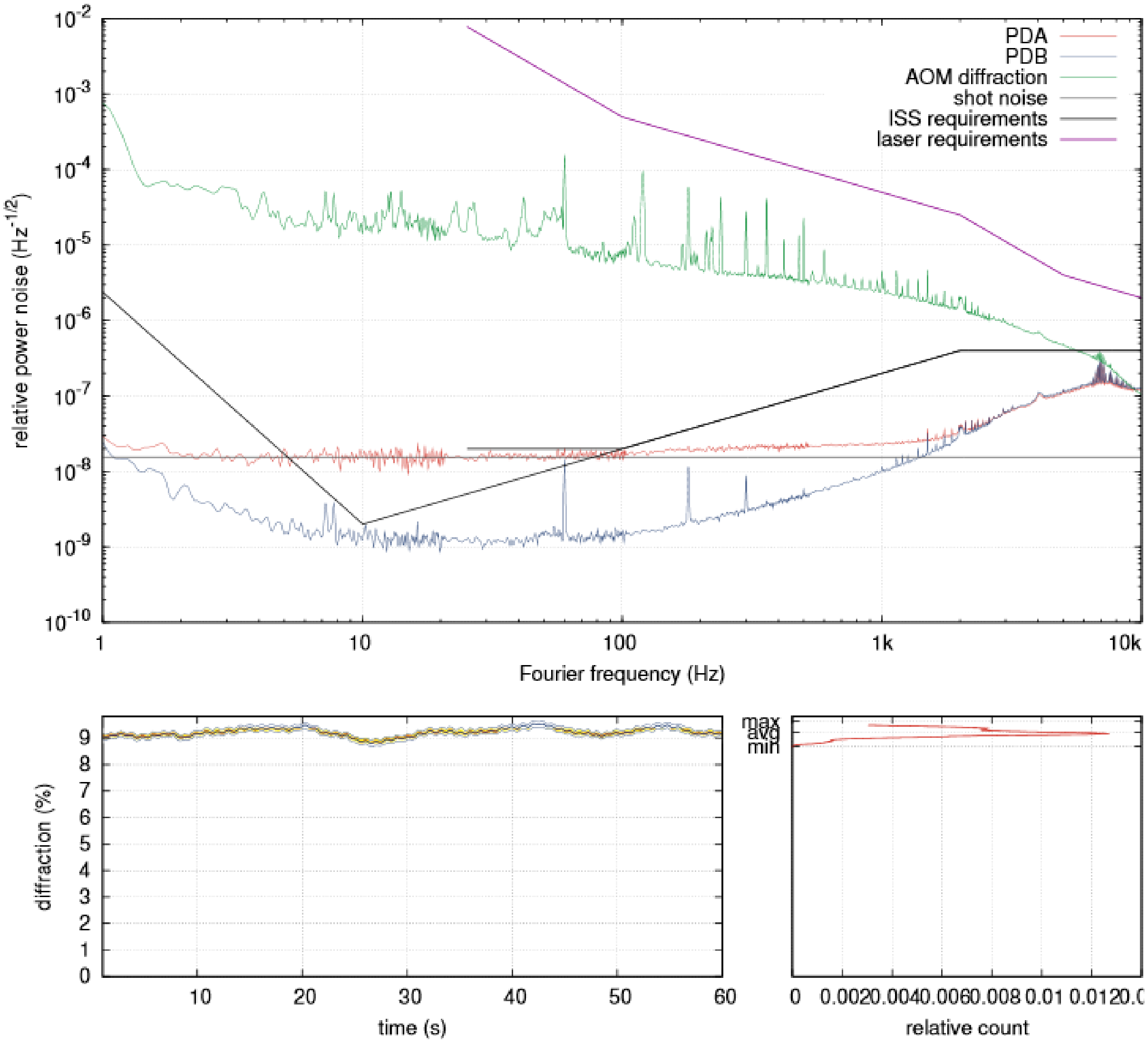
At H1 location after 15 month of operation (Aug 2013)



ISS actuator linearity
ISS actuator linearity - data

f) In-loop/out-of-loop RPN measurement – low power mode

At H1 location in Feb 2013 (during weekly laser maintenance), FFUs off



ISS relative power noise - inner loop (low power mode)
ISS relative power noise - inner loop (low power mode) - data

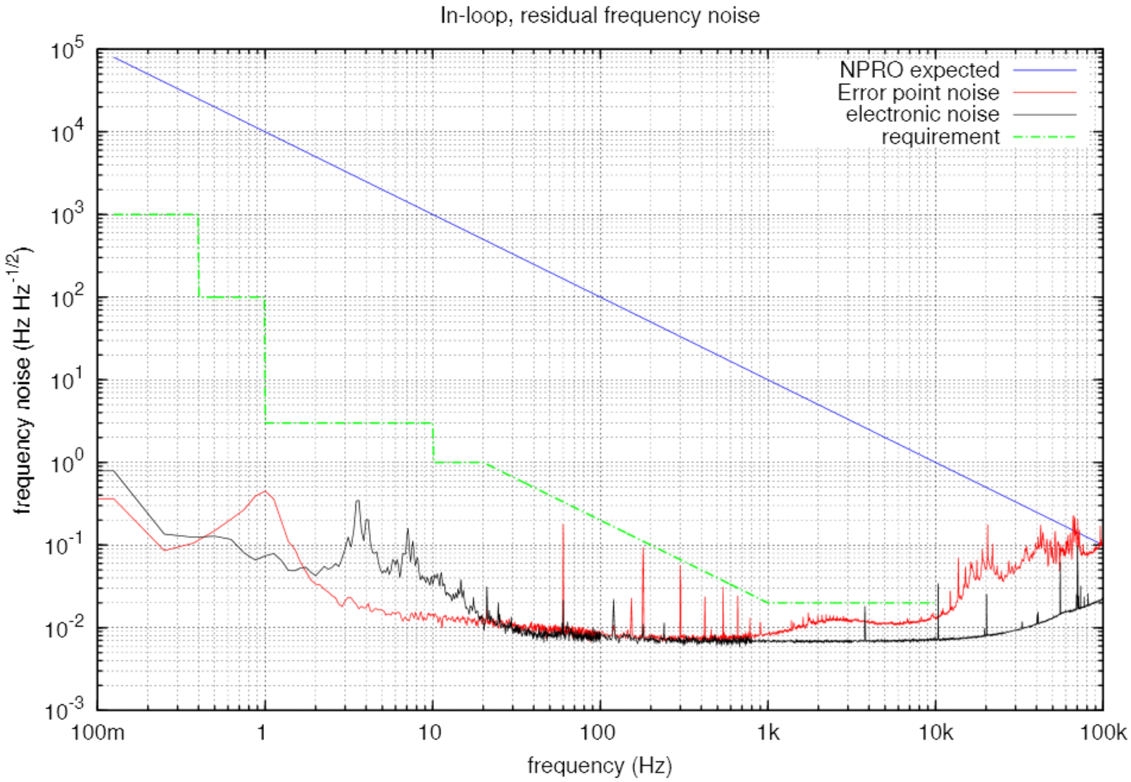
2.5 Frequency Stabilization

pre shipment testing:

Name	**Designation**	**Design Doc. or Part No.**	**SN**	**Test Procedure**	**Completed Test Document**
FSS table top servo		D040105 T1100119 D1100371	S1107799 TTFSS tuning	E040418	
FSS TTFSS field box 2		D1100367	S1107844* S1107816	not available	S1107844 S1107816
FSS rf-photodiode		D980454	S1107817		
FSS temperature sensor interface box		not available	S1107831	S1103686	
FSS VCO 2		D980401	S1107818		
FSS VCO fieldbox		D1100369	S1107845* S1107815	not available	
FSS AA filter		D070081	S1001250	T070146	S1001250
FSS AI filter		D070081	S1001235	T070146	S1001235
FSS rf summation box		D040469			
21 MHz oscillator:		D080705	S1000543	E1000059	
distribution amplifier:		D1000124	S1000593	T1000256	
delay line phase shifter:		T050250	S1103421	T050183	

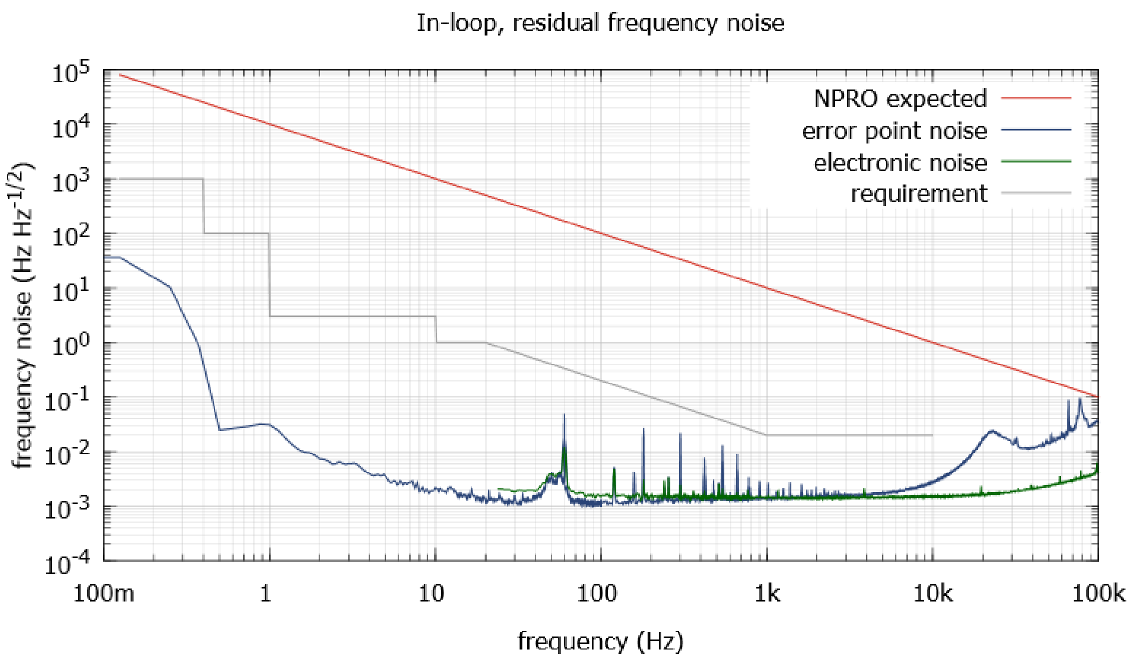
* these Serial Numbers are the units installed, the second SN was given to the spare unit

a. Error point noise + calibration factor (Hz/V)



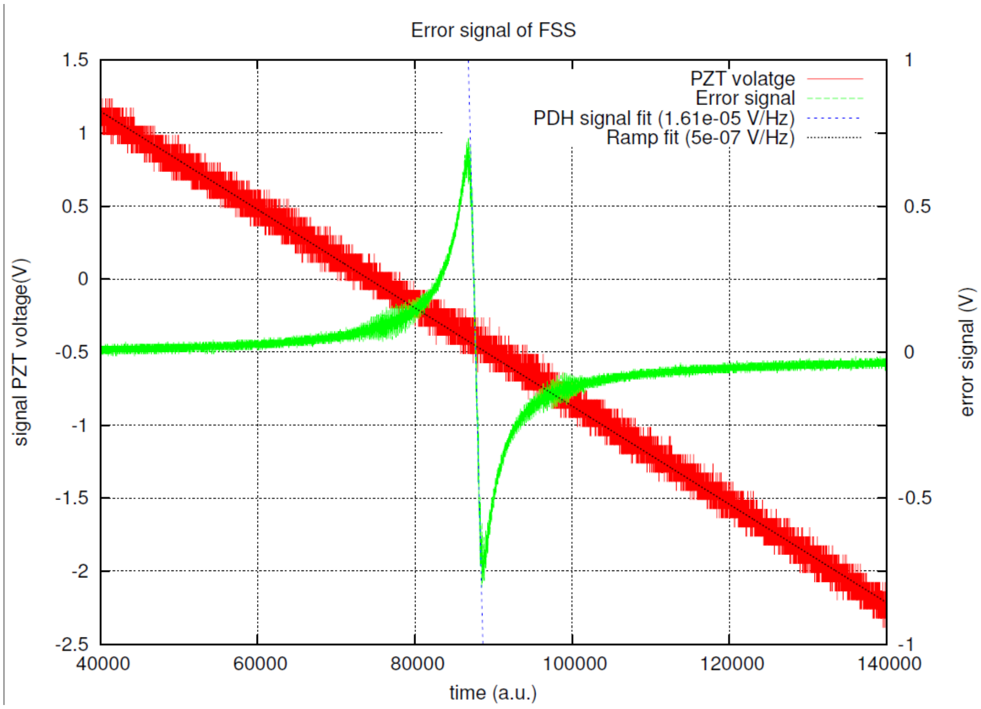
https://dcc.ligo.org/DocDB/0089/E1200385/001/fss_inloop.pdf
https://dcc.ligo.org/DocDB/0089/E1200385/001/fss.zip

At H1 location after 15 month of operation (Aug 2013)



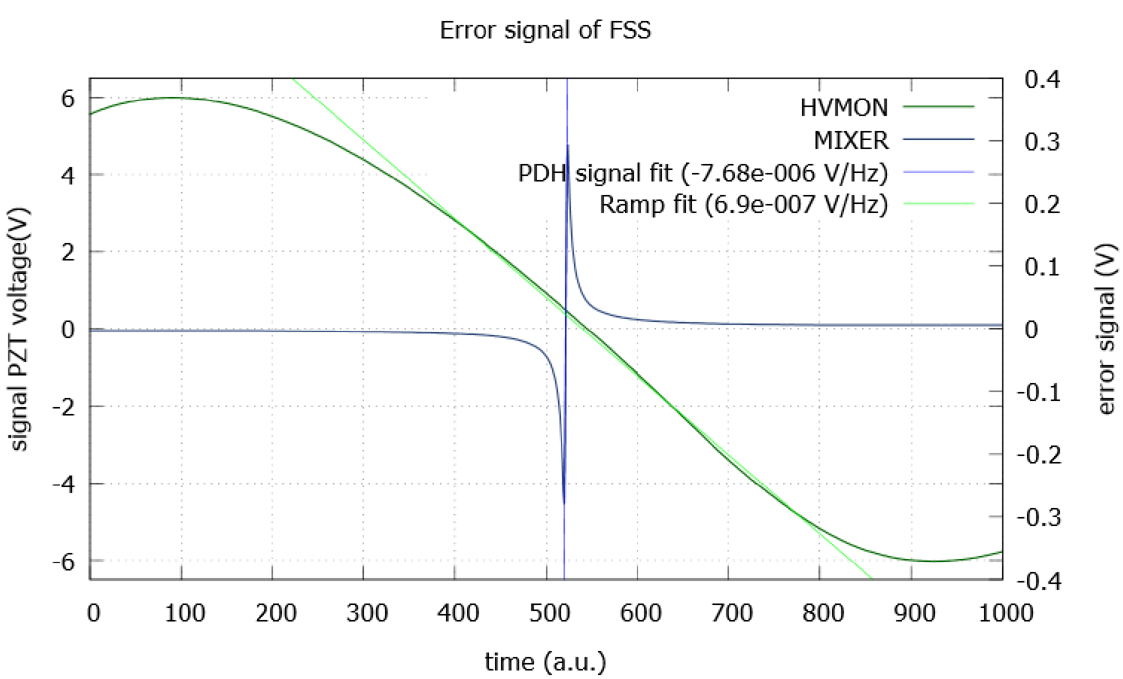
FSS error signal (noise spectrum),
FSS error signal (noise spectrum) - data

b. Error signal, scope screenshot



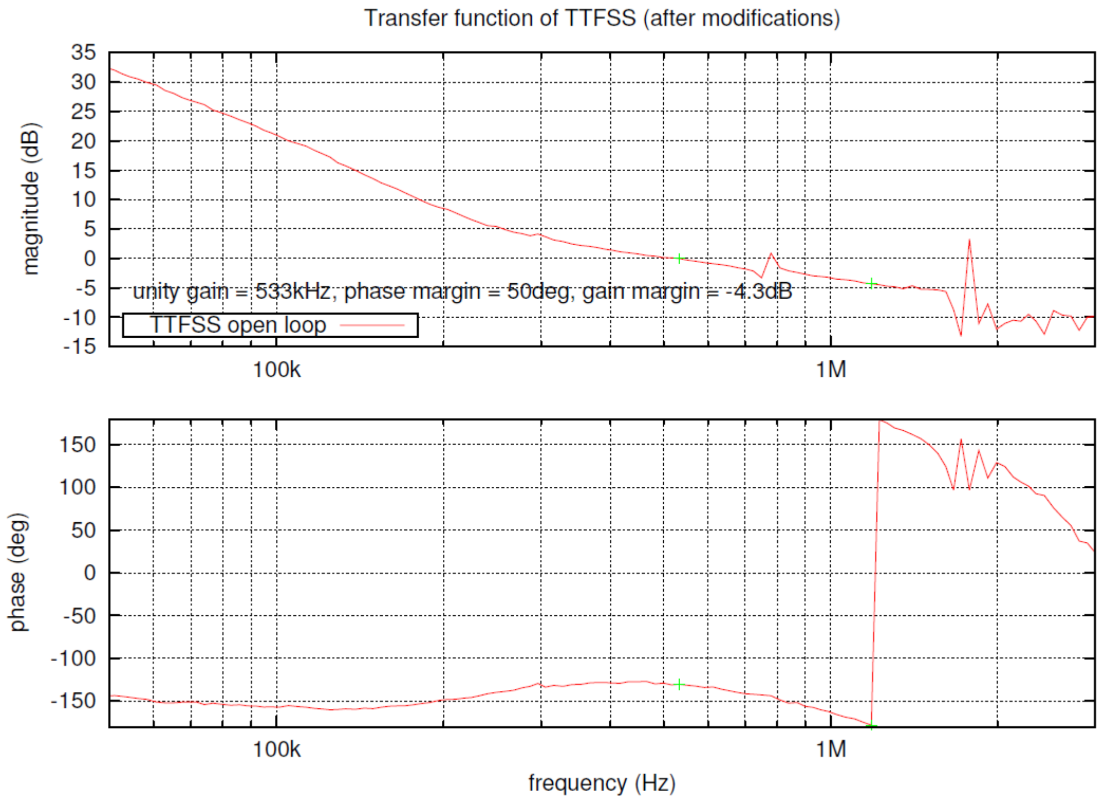
https://dcc.ligo.org/DocDB/0089/E1200385/001/errorsignal_fss.pdf
https://dcc.ligo.org/DocDB/0089/E1200385/001/errorsignal_fss.zip

At H1 location after 15 month of operation (Aug 2013)



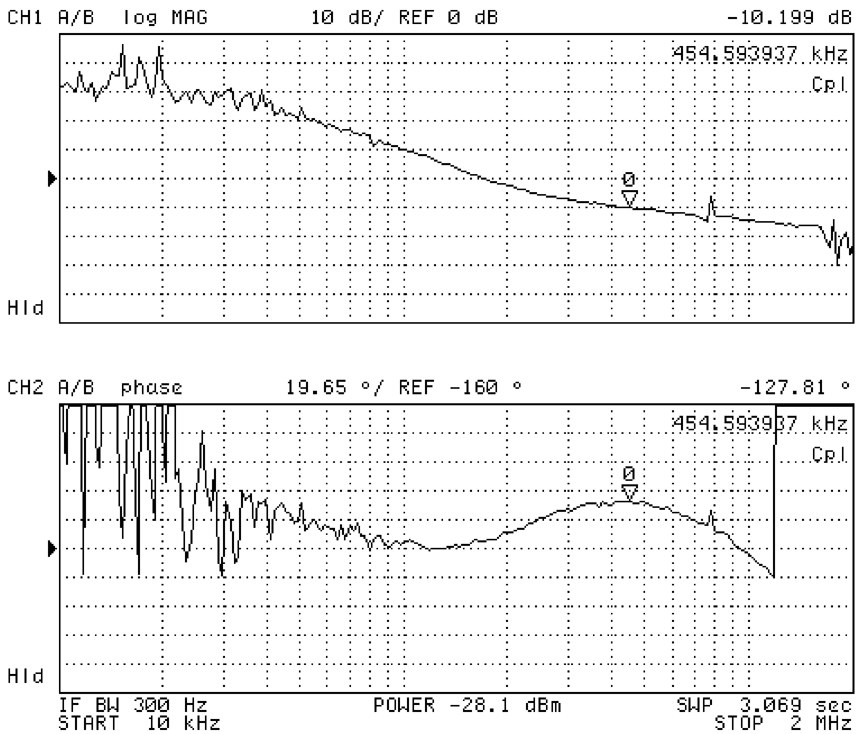
FSS error signal (time series unocked)
FSS error signal (time series unocked) - data

c. Transfer function of loop + UG frequency

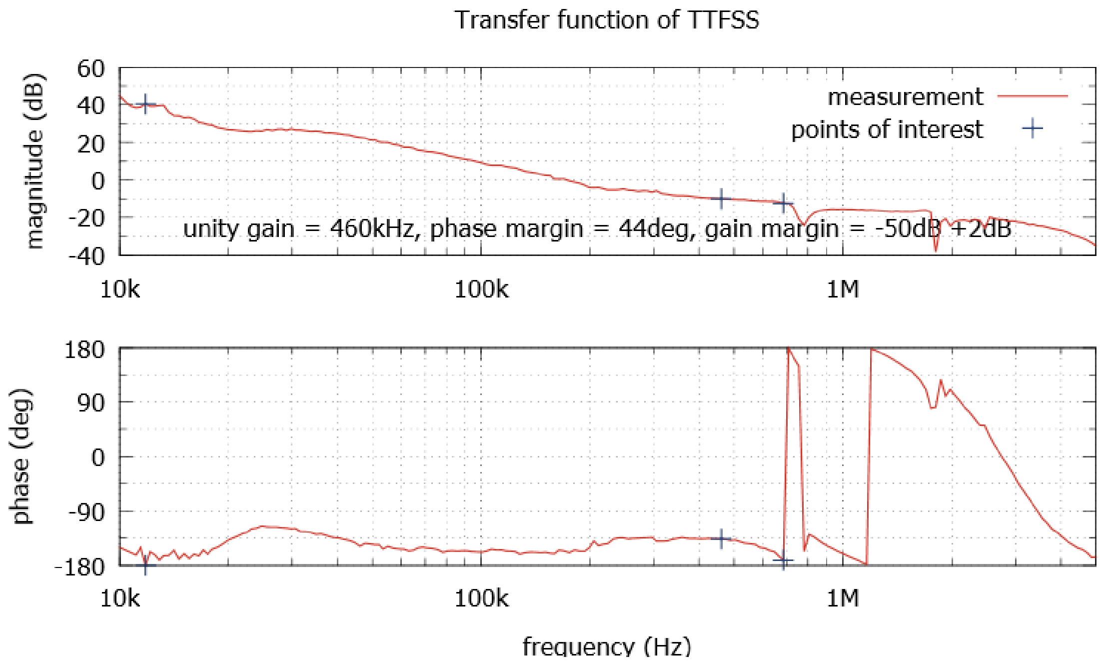


https://dcc.ligo.org/DocDB/0089/E1200385/001/tf_FSS.pdf
https://dcc.ligo.org/DocDB/0089/E1200385/001/tf_FSS.zip

remeasured after move to H1 (aLOG 2072)



At H1 location after 15 month of operation (Aug 2013)

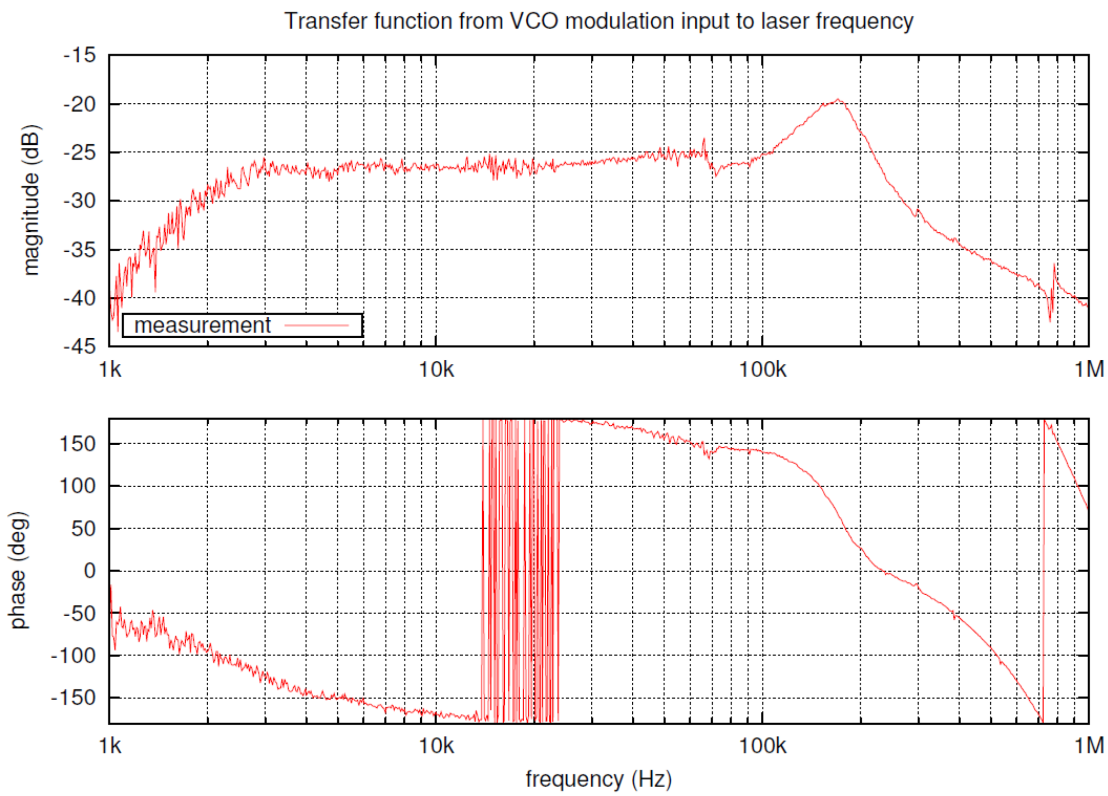


FSS loop transfer function

FSS loop transfer function - data

d. <u>AOM double pass efficiency</u>
56% (single pass)
30% (double pass)
60% (double pass) (aLOG 6005)

e. <u>Transfer function from VCO modulation input to laser frequency</u>



(no calibration in Hz/V available, should be similar to PSL #1 at LLO, has to be measured again once the new VCO is installed)
https://dcc.ligo.org/DocDB/0089/E1200385/001/tf_VCO-fq.pdf
https://dcc.ligo.org/DocDB/0089/E1200385/001/tf_VCO-fq.zip

H1 measurement will be made by Rick in Oct 2013

f. <u>DC voltage of RF photodiode</u>
rf PD DC unlocked 80mV
rf PD DC locked 17mV

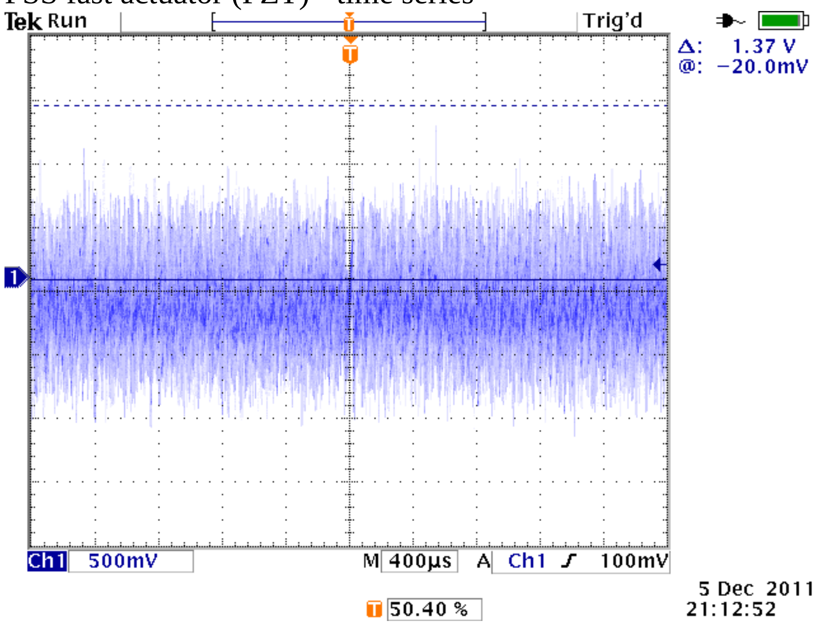
g. <u>Transfer function from error modulation input to laser frequency</u>
not applicable as no longer part of the control scheme

h. Power transmitted by reference cavity, absolute + relative
ref caf trans 4.87mW (injected 5.72mW, 85% transmission)
ref cav trans @ ALS port 4.72mW

ref caf trans 30mW (injected 50mW) aLOG 7544
ref cav trans @ ALS port 12mW in low power mode (14W) aLOG 7573

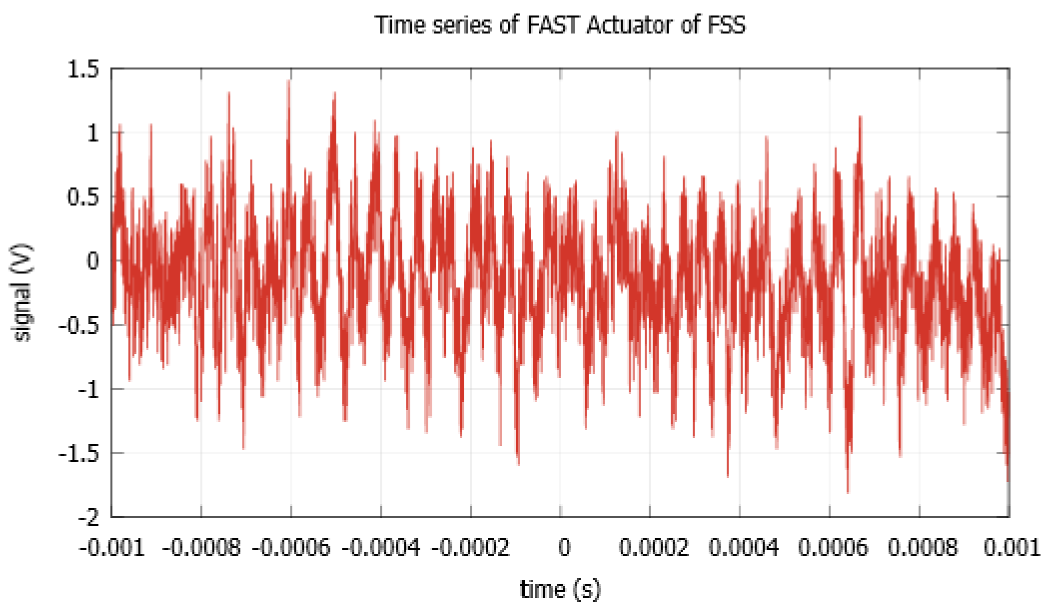
i. spectrum of PZT control signals, time series temperature loop control signal, time series of pockels cell

FSS fast actuator (PZT) - time series



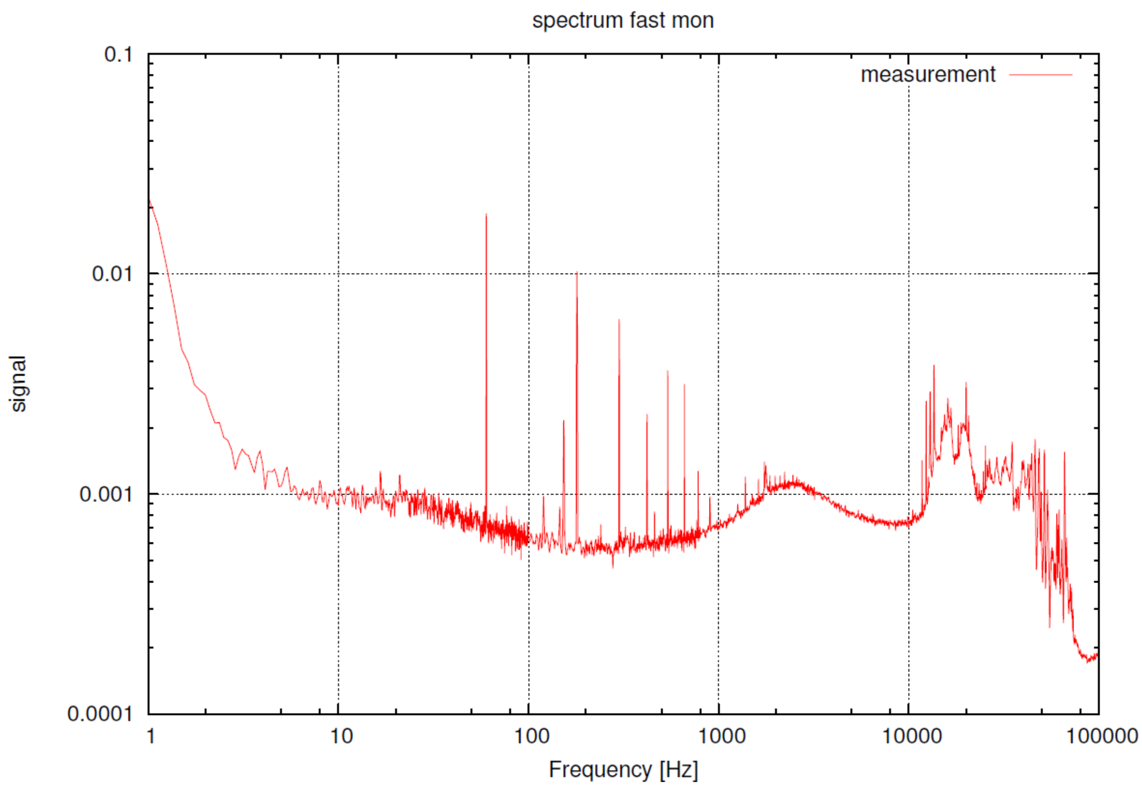
https://dcc.ligo.org/DocDB/0089/E1200385/001/tseries_fastm.PNG

At H1 location after 15 month of operation (Aug 2013)



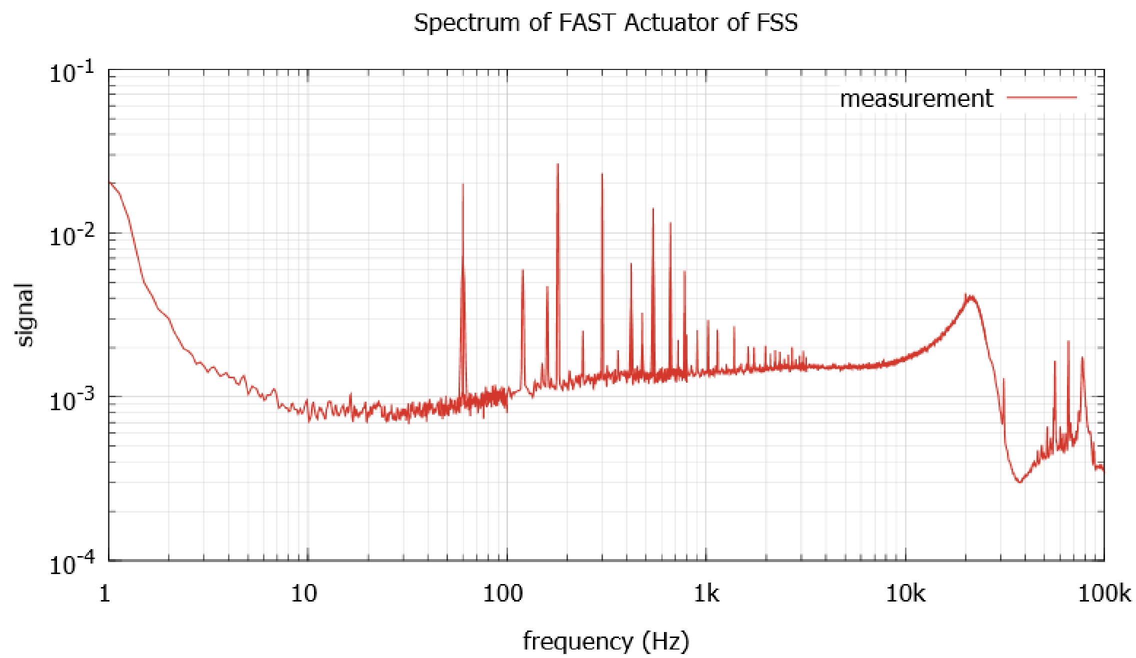
[FSS fast actuator time series]

FSS fast actuator (PZT) - spectrum



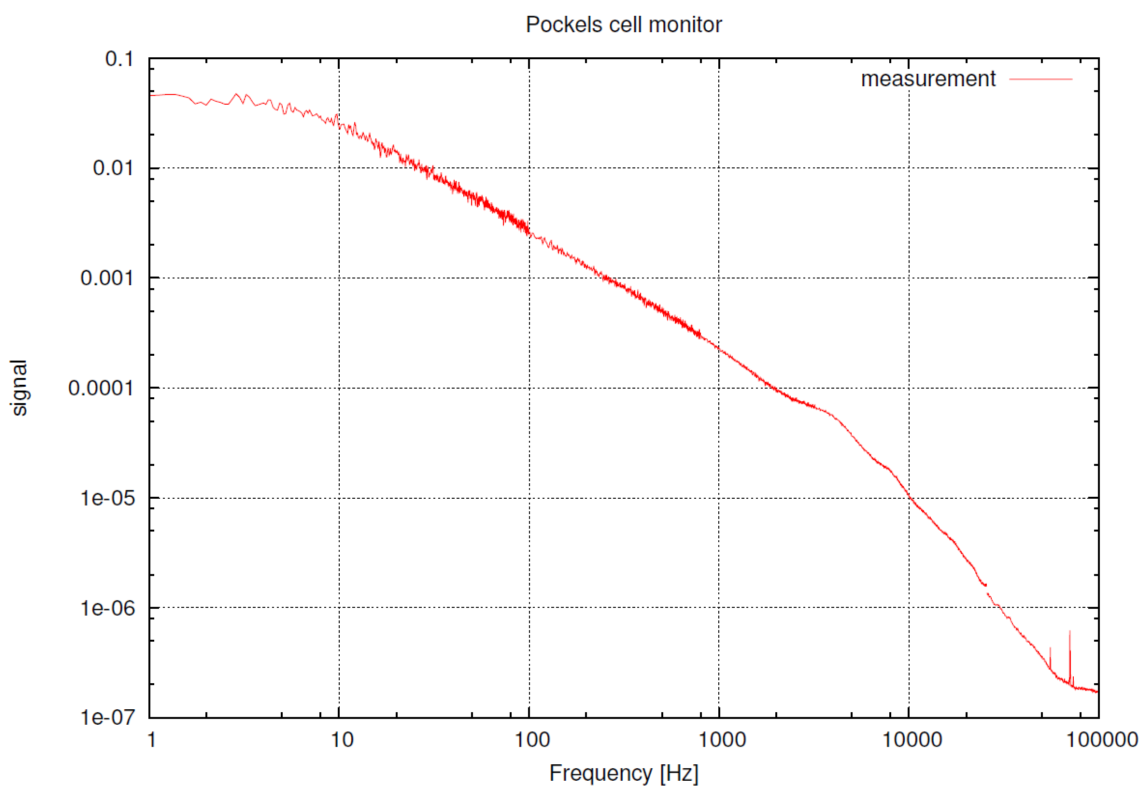
calibration: 5E-7V/Hz , 2E6 Hz/V (see 2.5.b)
https://dcc.ligo.org/DocDB/0089/E1200385/001/spec_fastm.pdf
https://dcc.ligo.org/DocDB/0089/E1200385/001/fastmon.zip

At H1 location after 15 month of operation (Aug 2013)



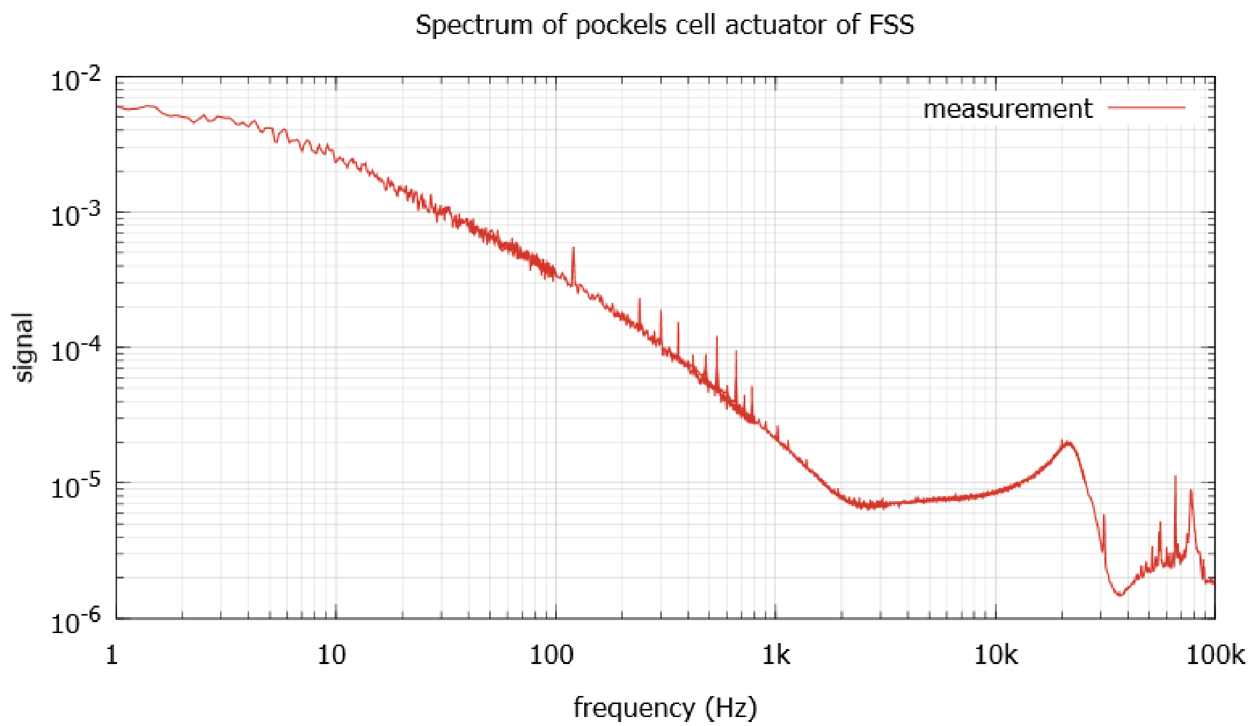
FSS fast actuator spectrum

FSS PC actuator (PZT) - spectrum



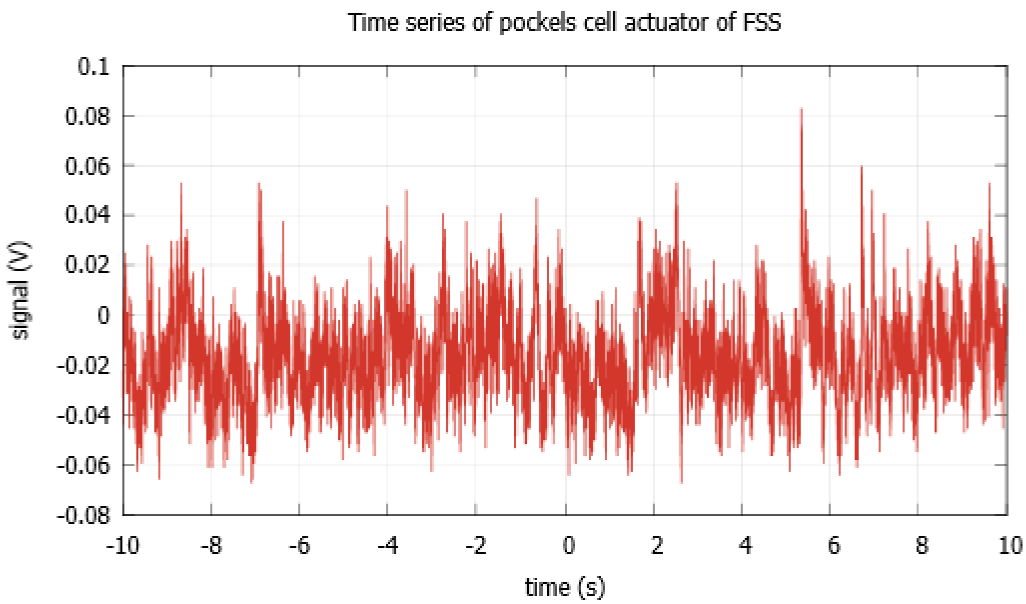
https://dcc.ligo.org/DocDB/0089/E1200385/001/spec_pcm.pdf
https://dcc.ligo.org/DocDB/0089/E1200385/001/PCmon.zip

At H1 location after 15 month of operation (Aug 2013)



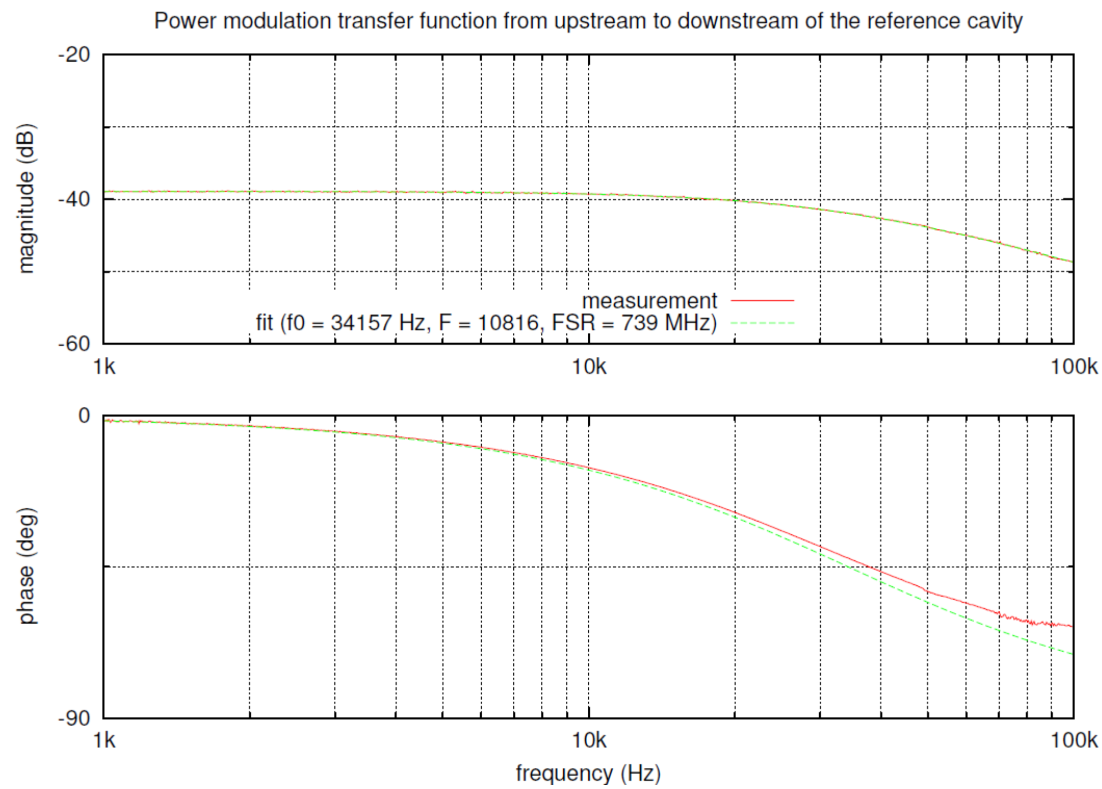
FSS pockels cell actuator spectrum
FSS pockels cell actuator data

FSS PC actuator (PZT) – time series
At H1 location after 15 month of operation (Aug 2013)



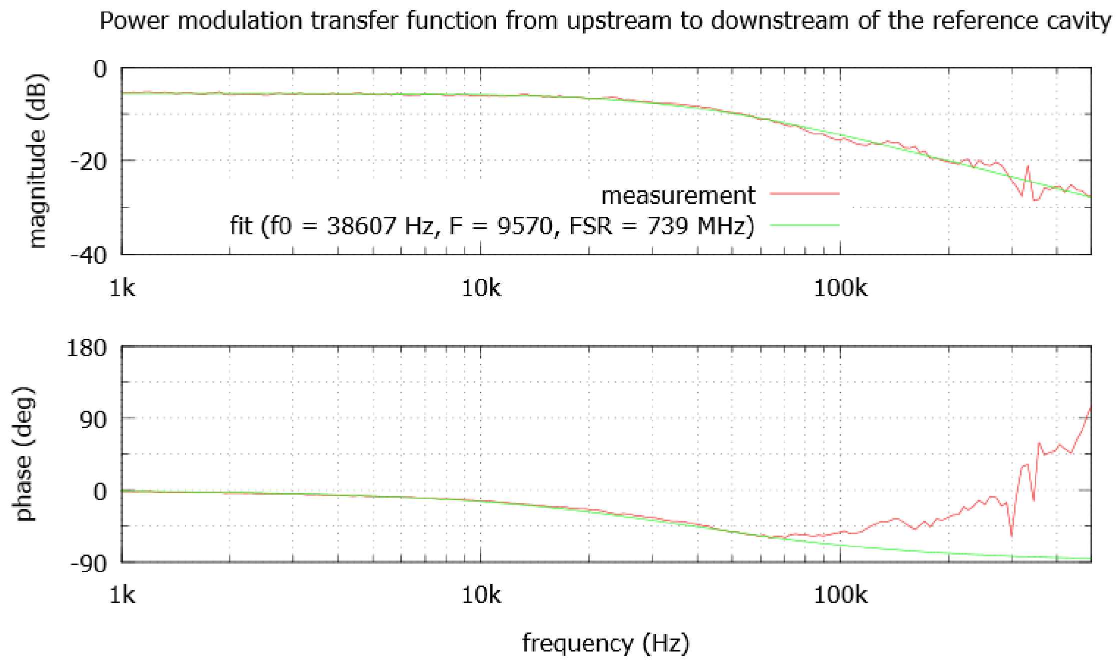
FSS pockels cell actuator time series

j. <u>Finesse of reference cavity</u>
F=10816
(to determine the Finesse the laser power was modulated and a transferfuction from ISS PD to PDin transmission of ref. Cavity was measured to calculate the cavity pole)



https://dcc.ligo.org/DocDB/0089/E1200385/001/tf_refcav.pdf
https://dcc.ligo.org/DocDB/0089/E1200385/001/tf_refcav.zip

At H1 location after 15 month of operation (Aug 2013) – different reference cavity than used at H2 location



reference cavity AM transfer function
reference cavity AM transfer function - data

2.6 Miscellaneous

Name	**Designation**	**Design Doc. or Part No.**	**SN**	**Test Procedure**	**Completed Test Document**
Power monitoring photo diode		D1002929	S1107864 S1107860 S1107858 S1107857 S1107856		S1107864 S1107860 S1107858 S1107857 S1107856
Monitoring photo diode		D1002164	S1107865 S1107863 S1107862 S1107861 S1107855 S1107854 S1107853 S1107849		S1107865 S1107863 S1107862 S1107861 S1107855 S1107854 S1107853 S1107849
FSS transmission photo diode		D1002164	S1103592		S1103592
PSL table power distribution unit		D1002708	S1107830 S1107829 S1107828		S1107830 S1107829 S1107828

PSL monitoring fieldbox		D1002292	S1107801 S1107800*	E1000696	S1107801 S1107800*
PSL input/output fieldbox		D1300008	S1300306	E1300027	S1300306
PSL CCD breakout panel		D1100115	S1107843	NA	S1107843

* these Serial Numbers are the units installed, the second SN was given to the spare unit

3 Integrated PSL Tests

3.1 cold start

a "cold start" of system similar to the one documented in E1200494 chapter 3 for LLO (power and software off) was successfully performed on 7 Dec 2012 (morning Hanford time), data can be retrieved from frame files if required

3.2 photos

photos LHO H2 PSL installation (https://ligoimages.mit.edu/index.php?url=https%3A//ligoimages.mit.edu/pages/search.php%3Fsearch%3D%2521collection824)

photos LHO H1 PSL installation
https://ligoimages.mit.edu/pages/search.php?search=%21collection1383

3.3 MEDM and Beckhoff screens

MEDM and Beckhoff screen shots after installation (https://dcc.ligo.org/DocDB/0089/E1200385/001/MEDM_screens.zip)

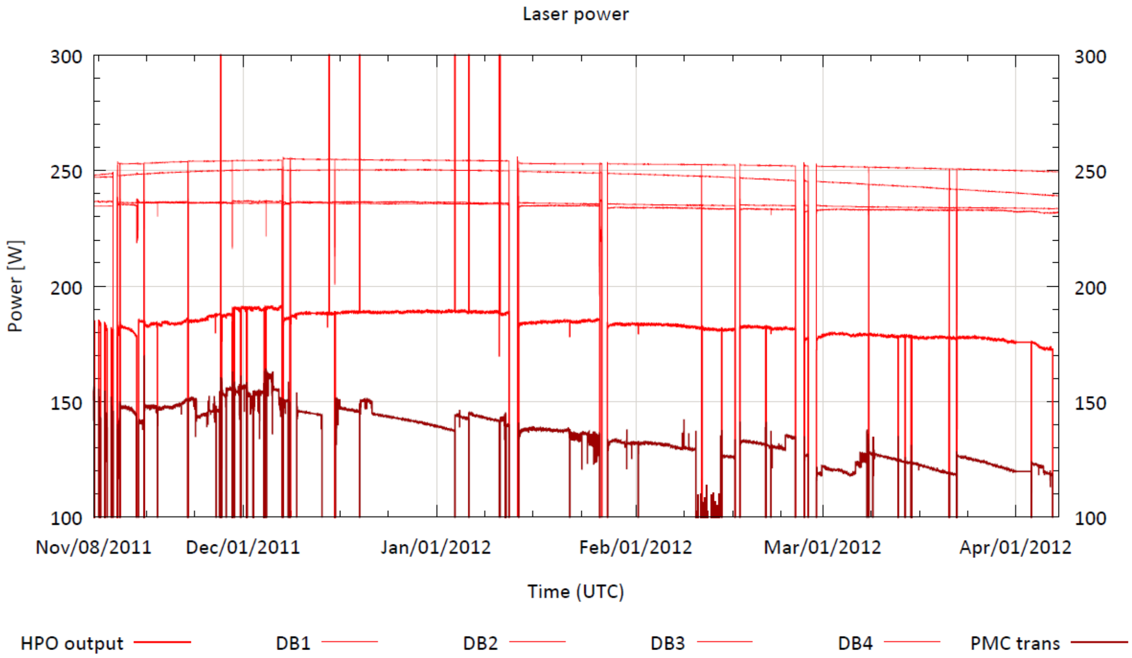
no modifications after move to H1 location

3.4 long term performance

for serveral PSL channels we took data over 5 month

3.4.1 summary plot with the power at different locations

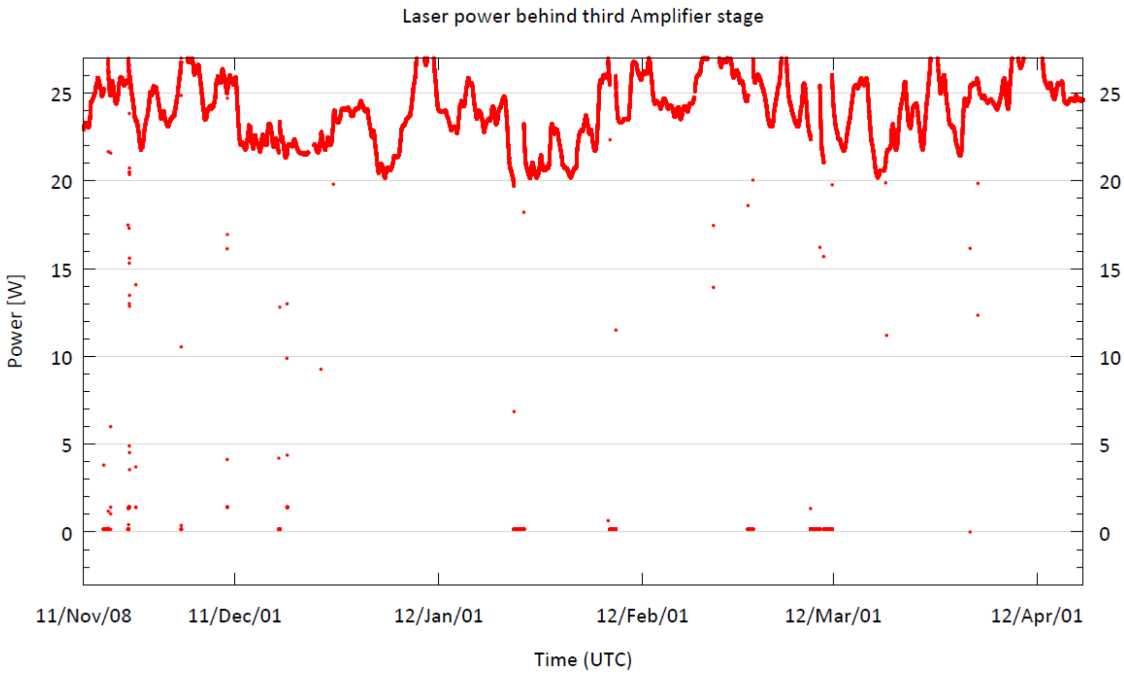
HPO output: power leaving the 200W HPO box;
DB1-DB4: pumplight monitors at the 4 HPO crystal (power sum of diode box 1-4);
PMC trans: power transmitted by the PMC



DCC LINK: H2:PSL-PWR_ALL

3.4.2 35 W laser front end

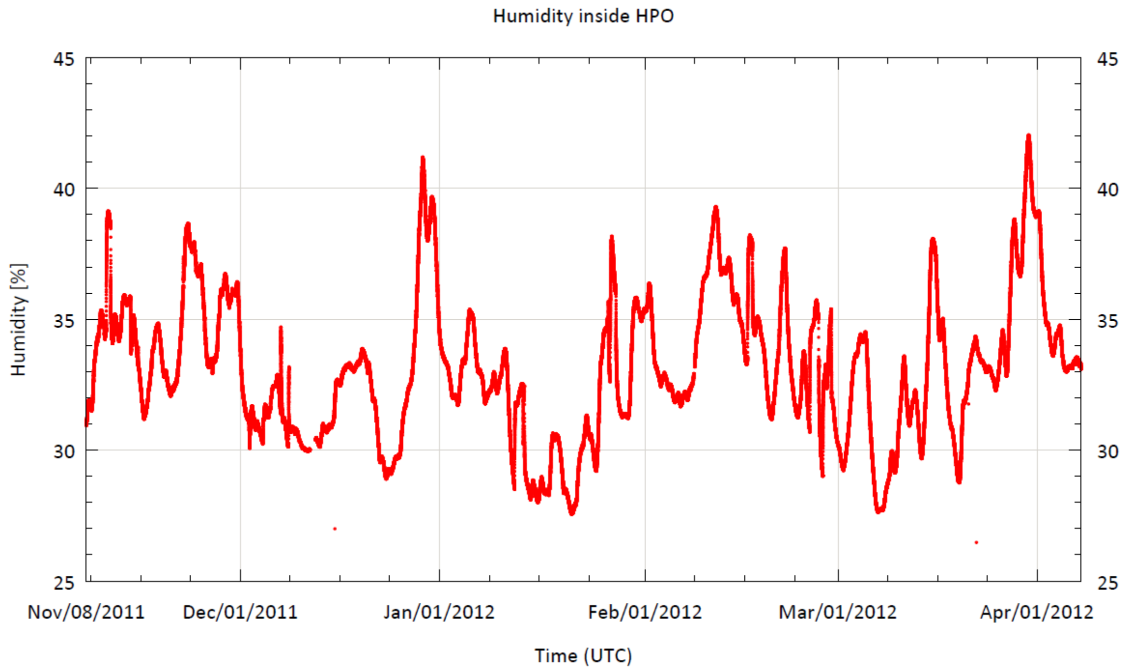
3.4.2.1 power after third amplification stage



DCC LINK: H2:PSL-AMP_PWR3
DCC LINK: H2:PSL-AMP_PWR3 - data

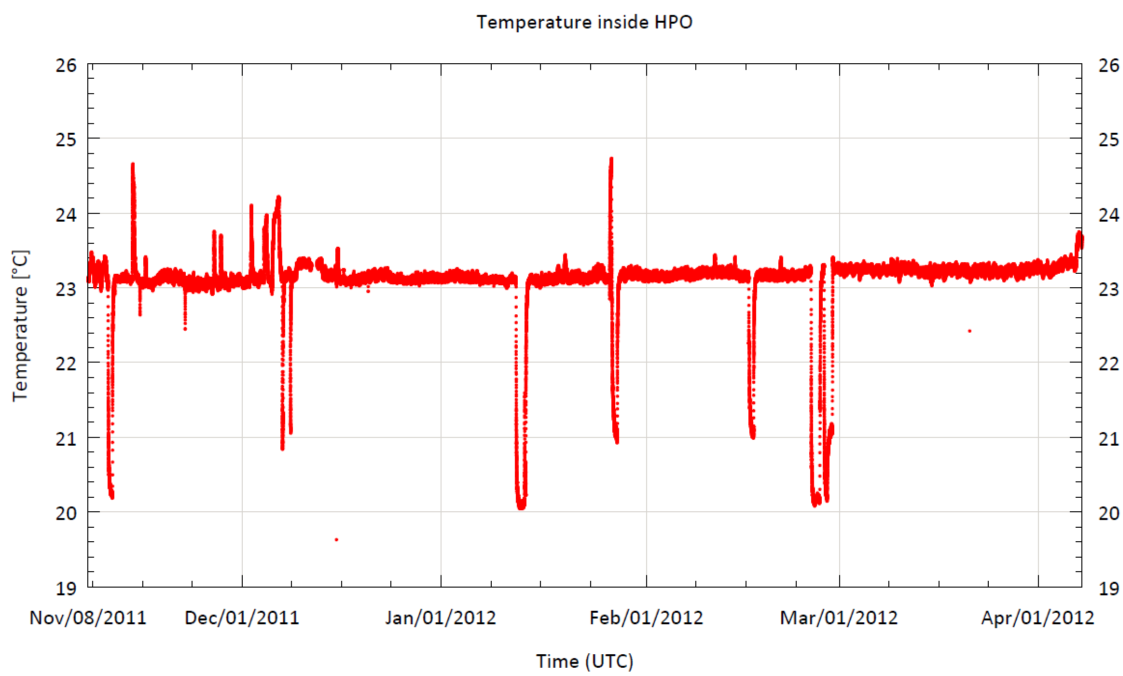
3.4.3 200W high power oscillator

3.4.3.1 Humidity in HPL housing



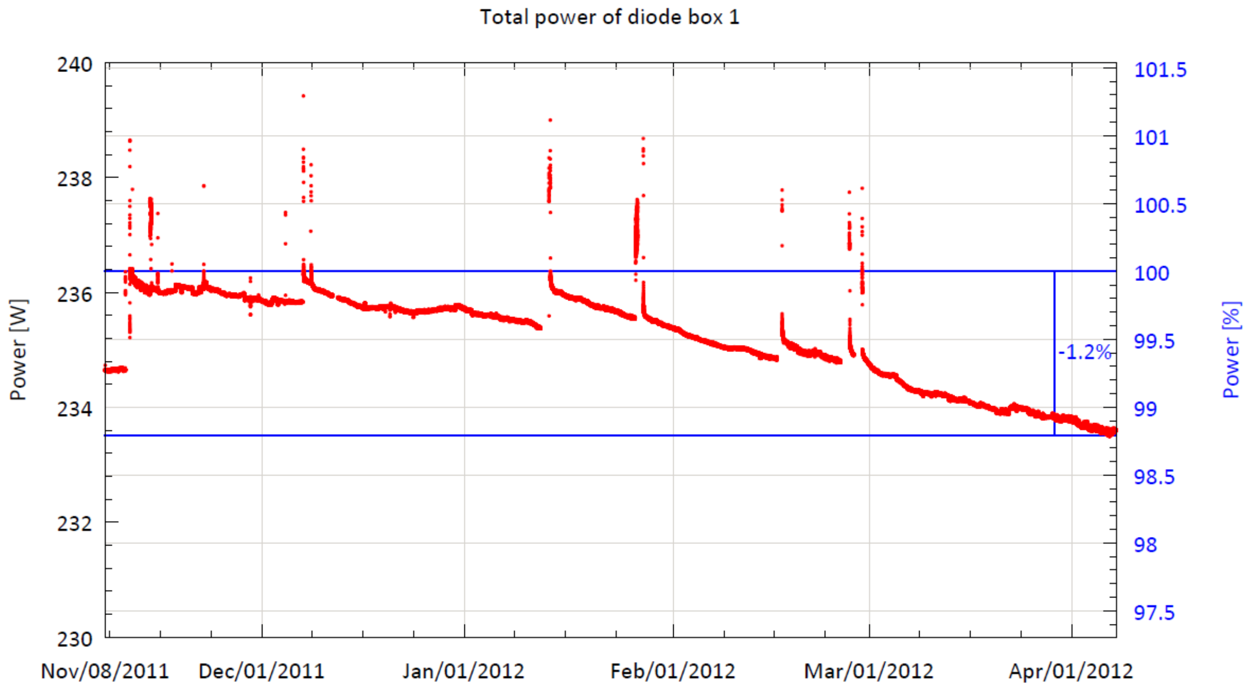
DCC LINK: H2:PSL-OSC_BOXHUM
DCC LINK: H2:PSL-OSC_BOXHUM - data

3.4.3.2 Temperature in HPL housing



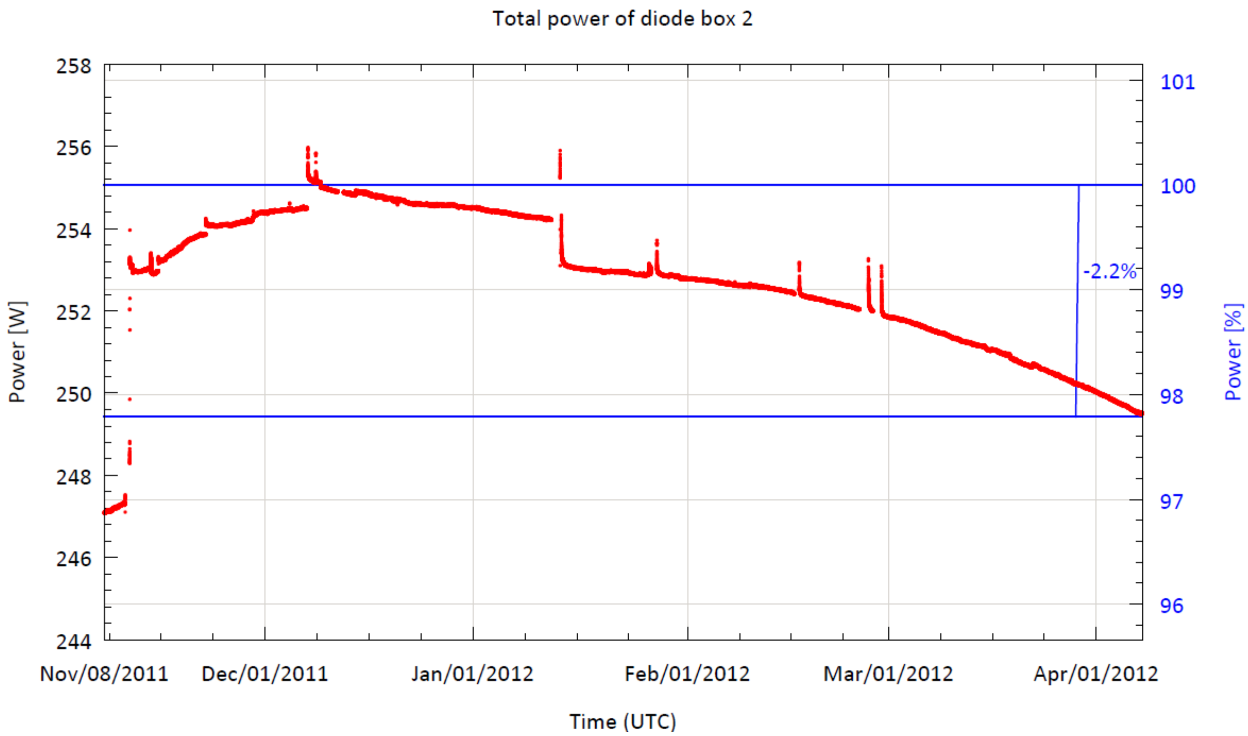
DCC LINK: H2:PSL-OSC_BOXTEMP
DCC LINK: H2:PSL-OSC_BOXTEMP - data

3.4.3.3 power of laser diode box #1



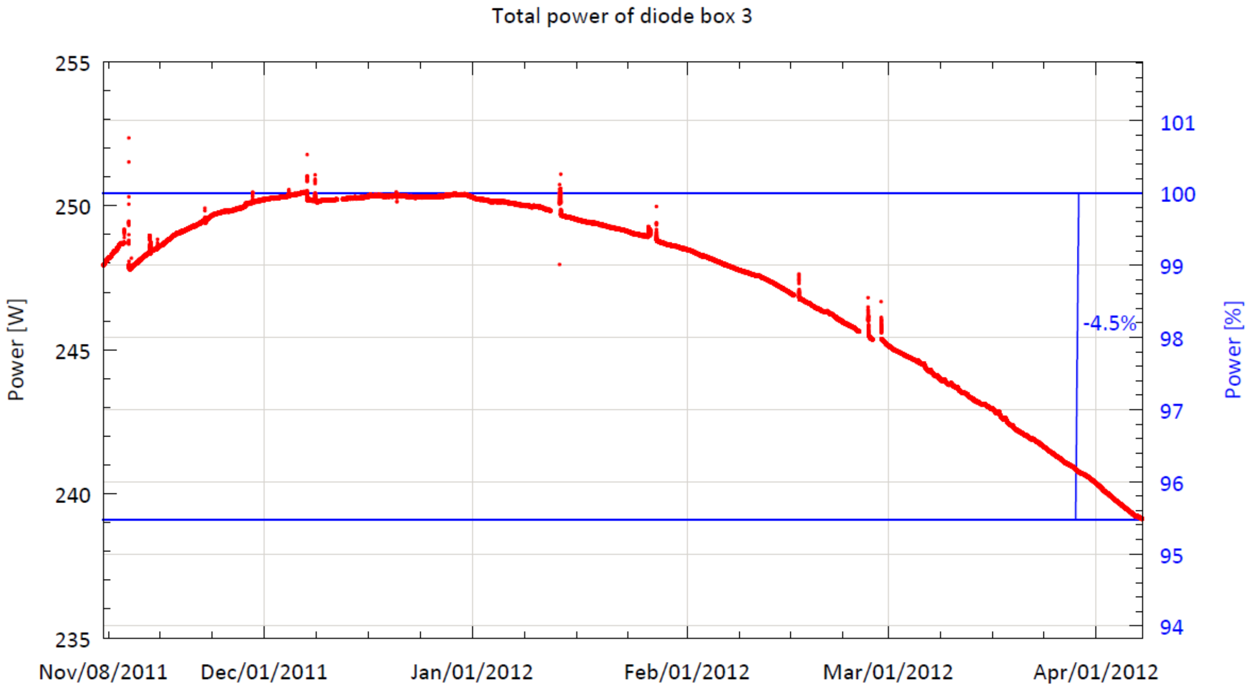
DCC LINK: H2:PSL-OSC_DB1_PWR
DCC LINK: H2:PSL-OSC_DB1_PWR - data

3.4.3.4 power of laser diode box #2



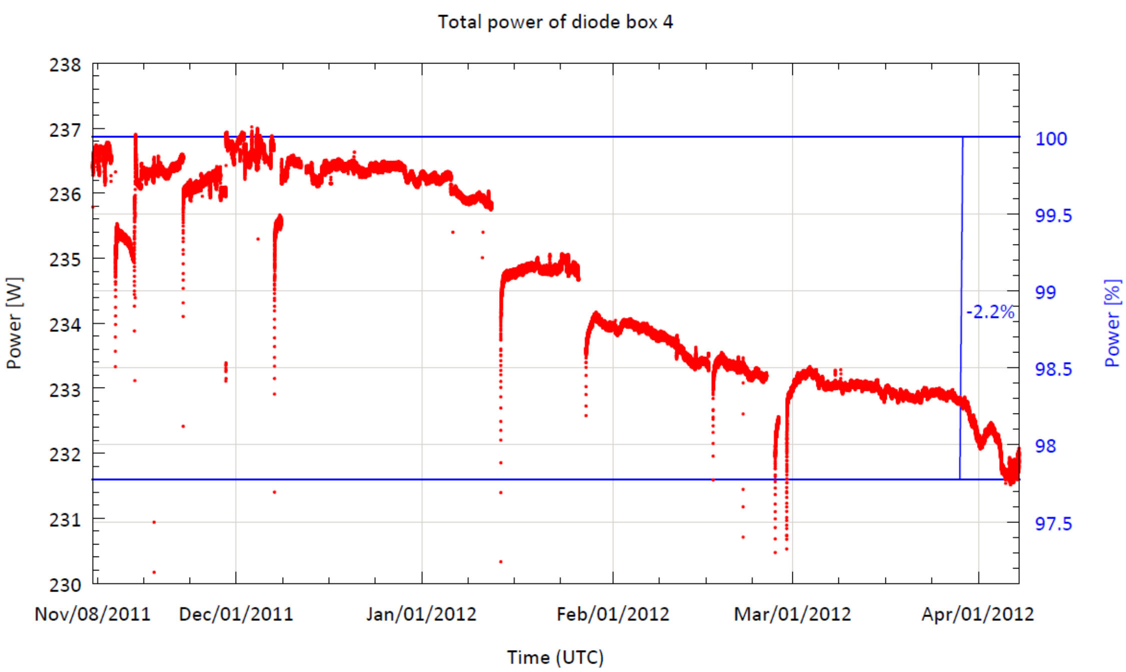
DCC LINK: H2:PSL-OSC_DB2_PWR
DCC LINK: H2:PSL-OSC_DB2_PWR - data

3.4.3.5 power of laser diode box #3



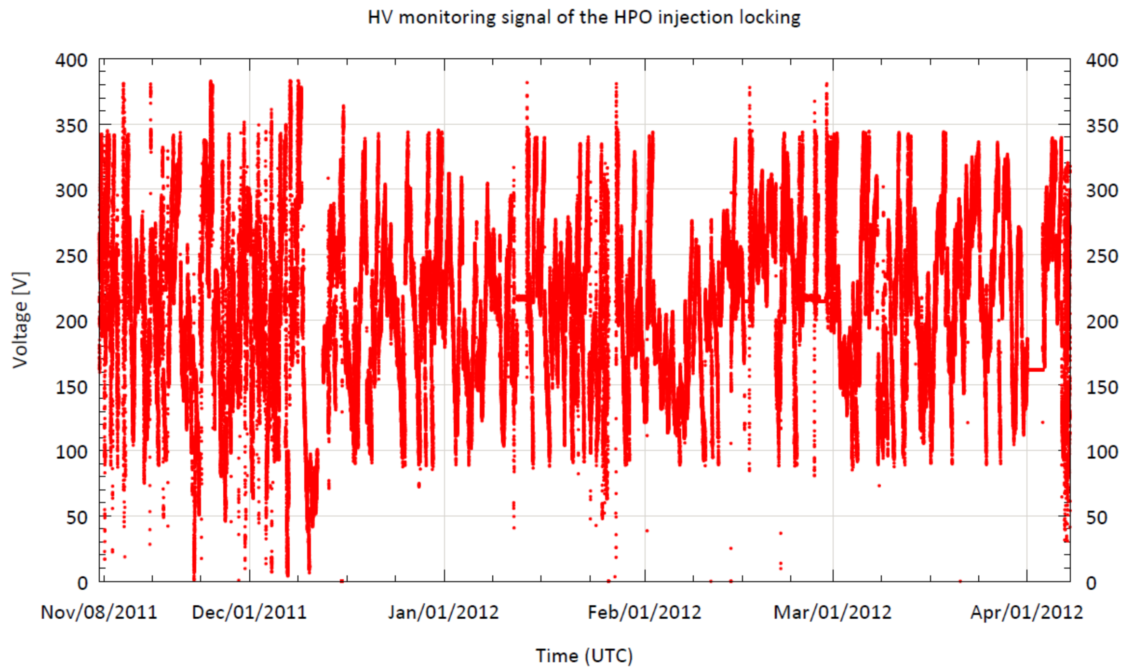
DCC LINK: H2:PSL-OSC_DB3_PWR
DCC LINK: H2:PSL-OSC_DB3_PWR - data

3.4.3.6 power of laser diode box #4



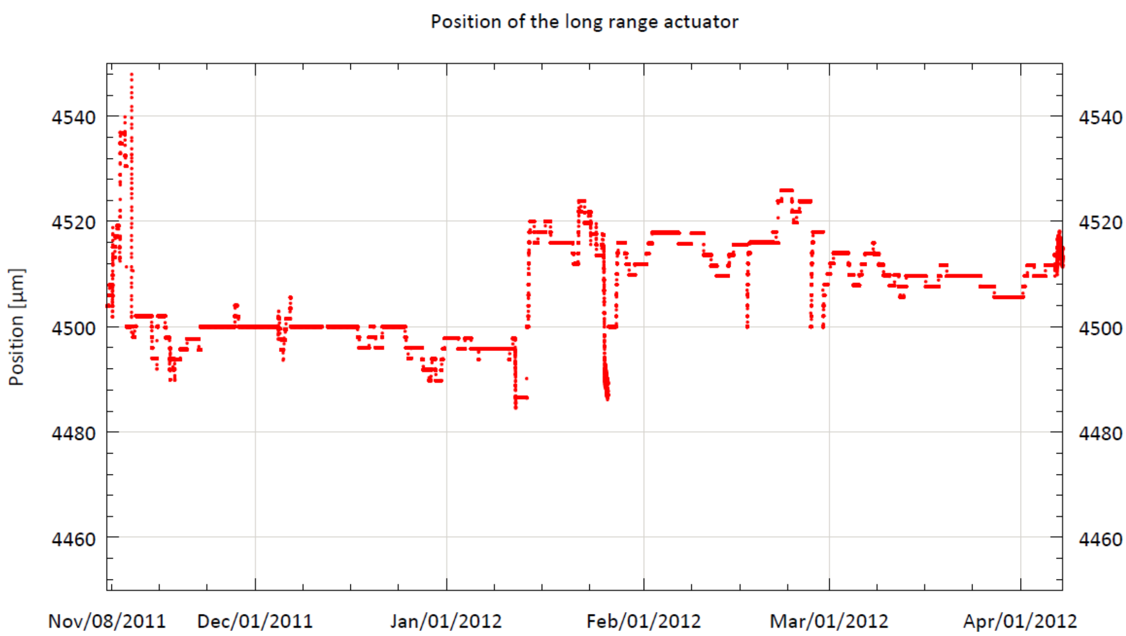
DCC LINK: H2:PSL-OSC_DB4_PWR
DCC LINK: H2:PSL-OSC_DB4_PWR - data

3.4.3.6.1 injection locking PZT actuator



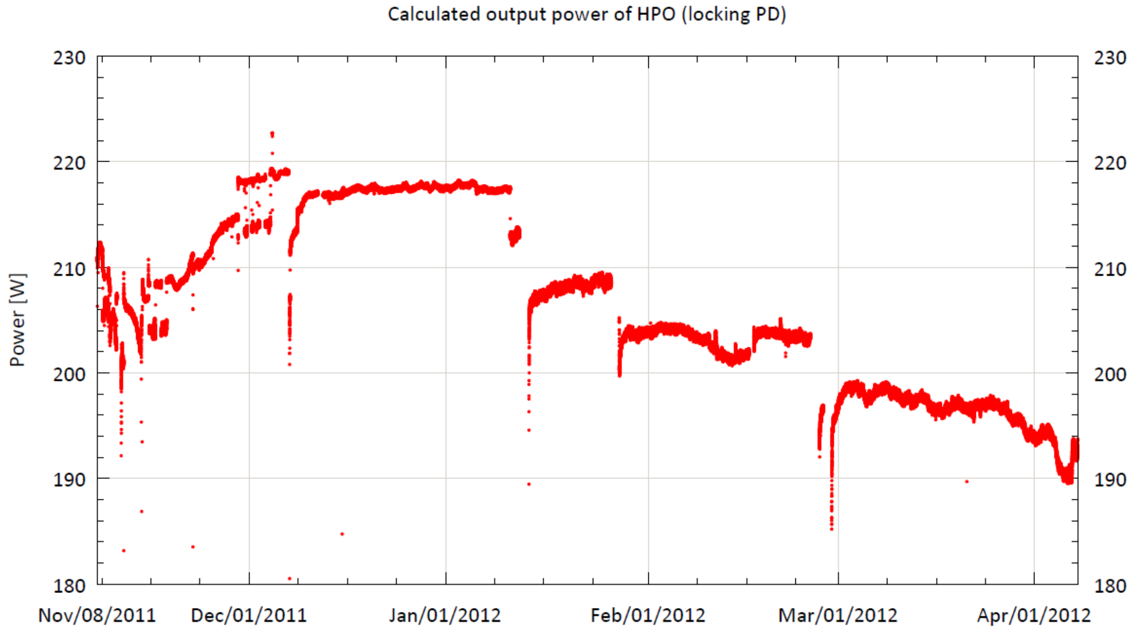
DCC LINK: H2:PSL-ILS_HV_MON_OUTPUT
DCC LINK: H2:PSL-ILS_HV_MON_OUTPUT - data

3.4.3.7 long range actuator (offloads injection locking PZT actuator)



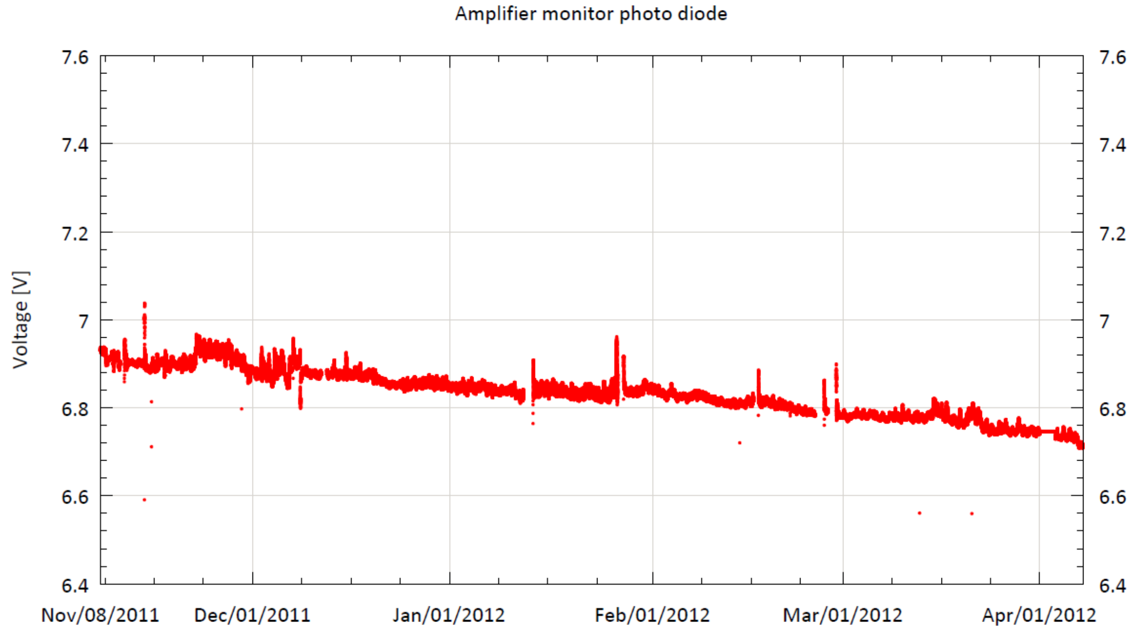
DCC LINK: H2:PSL-OSC_LRAPOS
DCC LINK: H2:PSL-OSC_LRAPOS - data

3.4.3.8 HPL power monitoring photodiode in HPL box (before corona aperture)



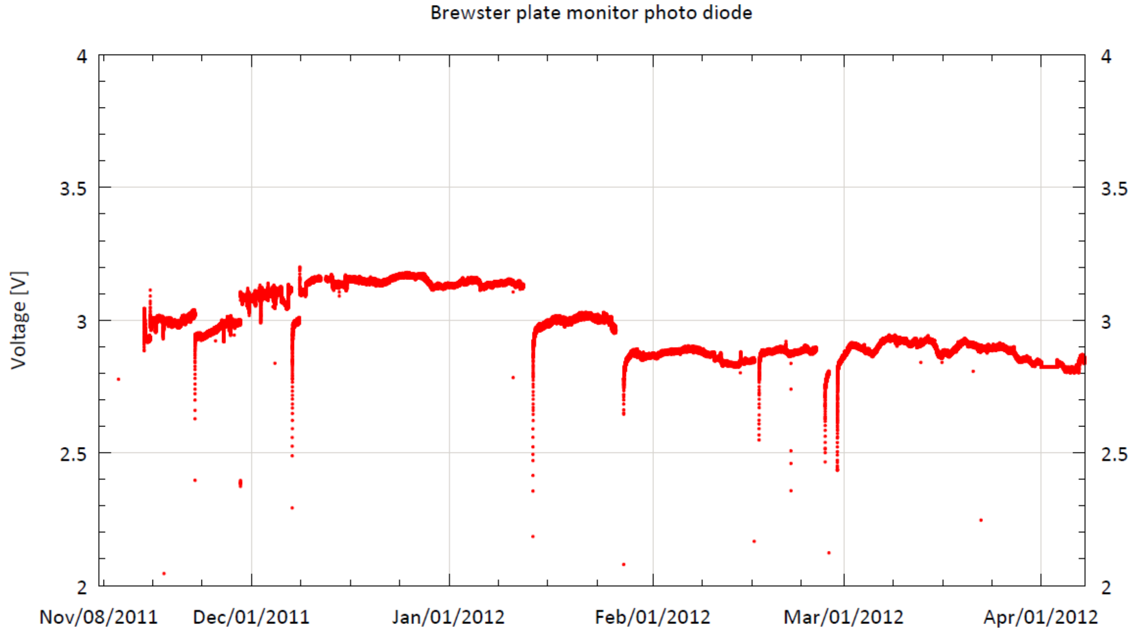
DCC LINK: H2:PSL-OSC_PDLOCKDC_PWR
DCC LINK: H2:PSL-OSC_PDLOCKDC_PWR - data

3.4.3.9 injected power monitoring photodiode (35W laser after Faraday Isolator)



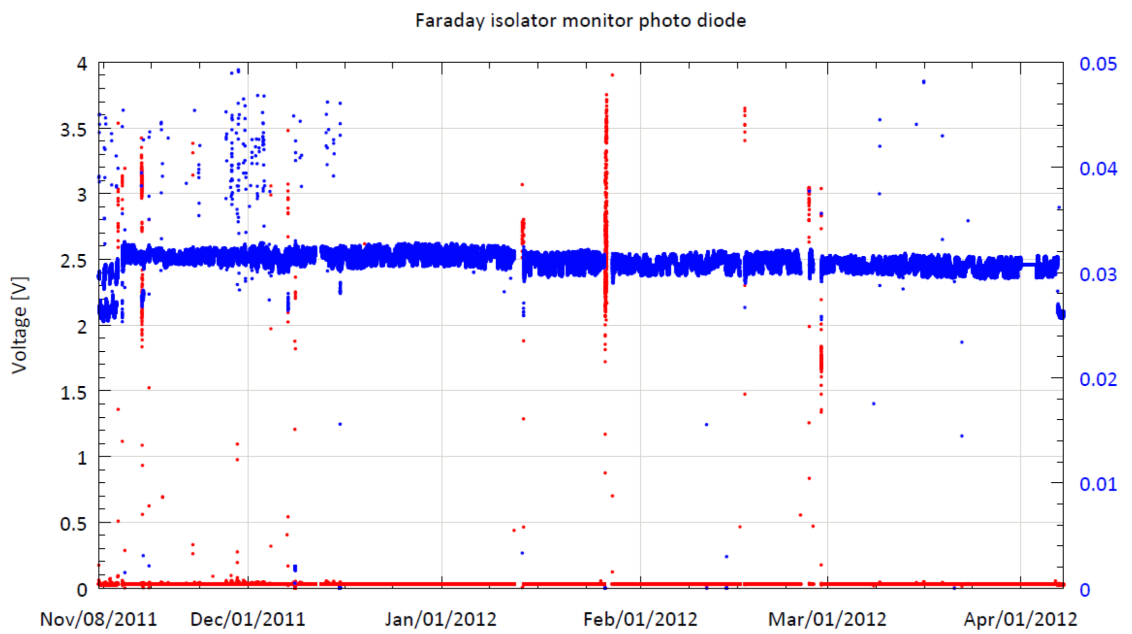
DCC LINK: H2:PSL-OSC_PD_AMP_DC_OUTPUT
DCC LINK: H2:PSL-OSC_PD_AMP_DC_OUTPUT - data

3.4.3.10 HPL Brewster plate power monitoring photodiode



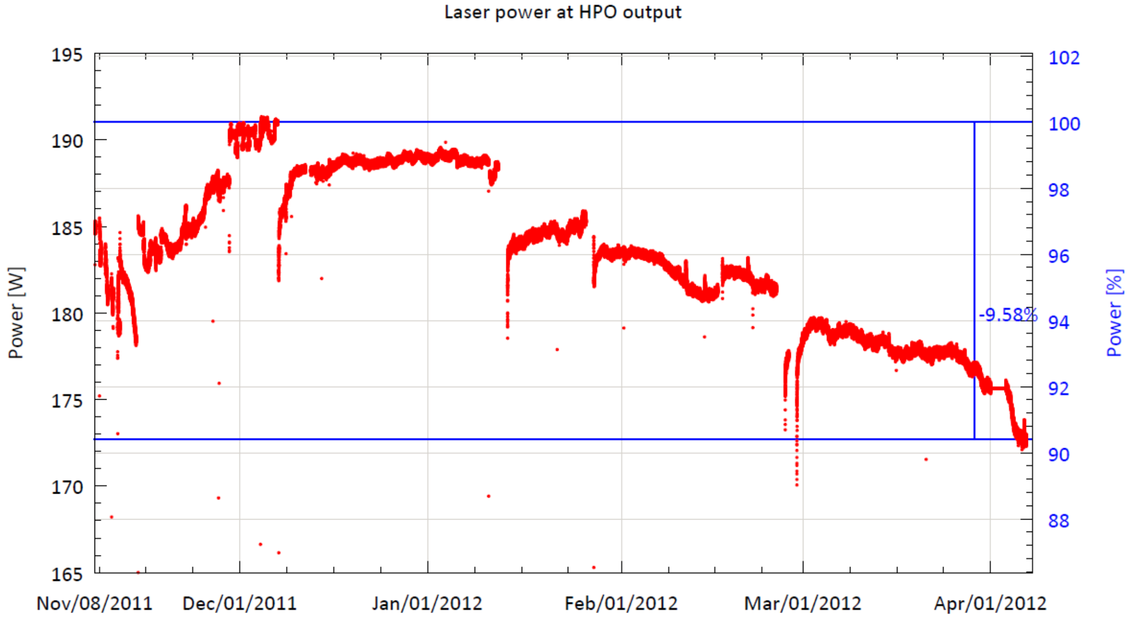
DCC LINK: H2:PSL-OSC_PD_BP_DC_OUTPUT
DCC LINK: H2:PSL-OSC_PD_BP_DC_OUTPUT - data

3.4.3.11 HPL Faraday Isolator power monitoring photodiode (power travelling in wrong direction in high power oscillator)



DCC LINK: H2:PSL-OSC_PD_ISO_DC_OUTPUT
DCC LINK: H2:PSL-OSC_PD_ISO_DC_OUTPUT - data

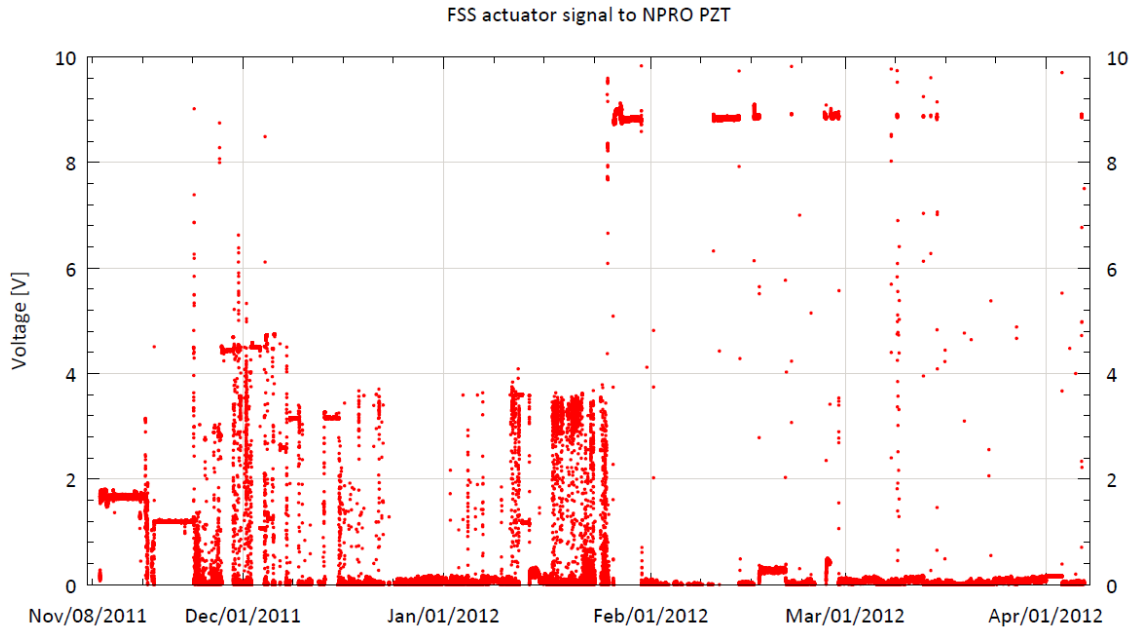
3.4.3.12 HPL power monitor photodiode outside of HPL box



DCC LINK: H2:PSL-PWR_HPL_DC_OUTPUT
DCC LINK: H2:PSL-PWR_HPL_DC_OUTPUT

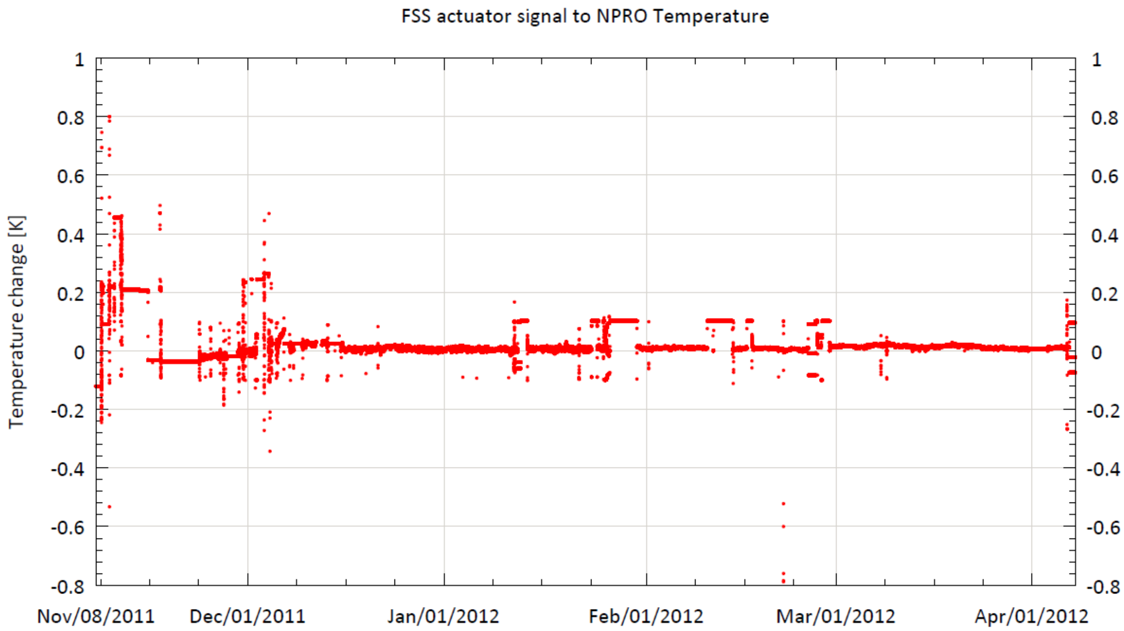
3.4.4 FSS

3.4.4.1 FSS PZT actuator



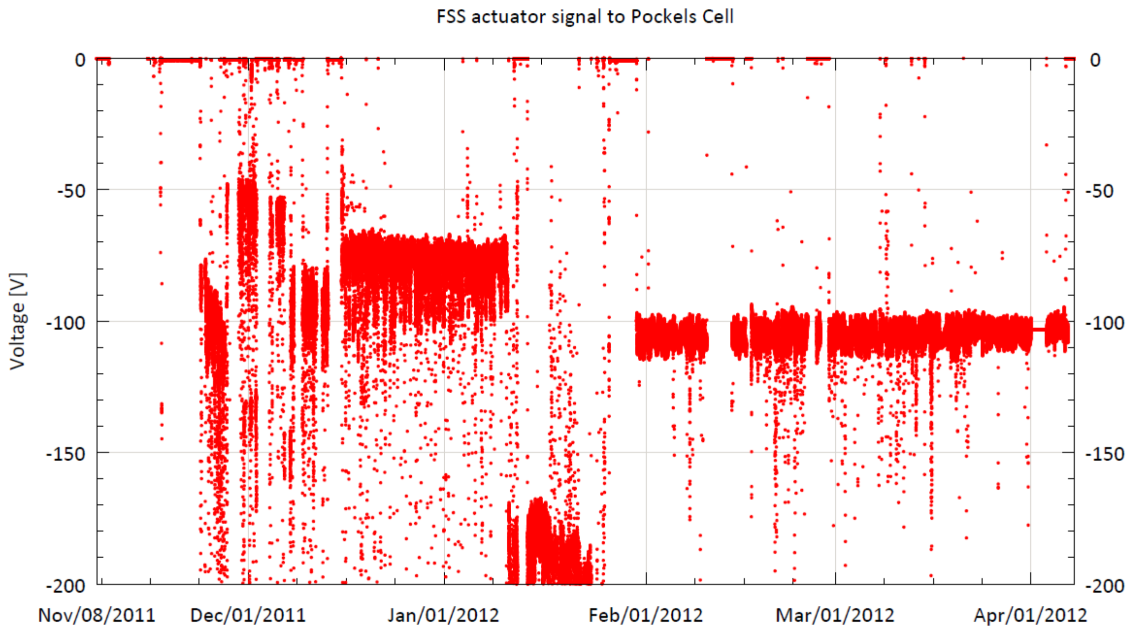
DCC LINK: H2:PSL-FSS_FAST_MON_OUTPUT
DCC LINK: H2:PSL-FSS_FAST_MON_OUTPUT - data

3.4.4.2 FSS TEMP actuator



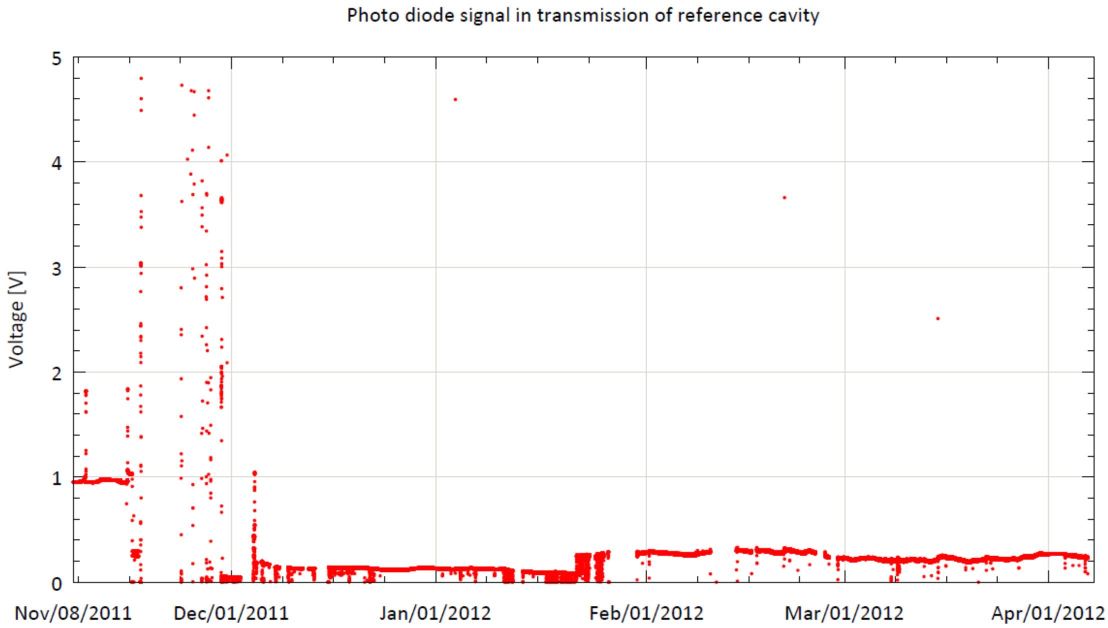
DCC LINK: H2:PSL-FSS_NPRO_TEMP_INMON
DCC LINK: H2:PSL-FSS_NPRO_TEMP_INMON - data

3.4.4.3 FSS PC actuator



DCC LINK: H2:PSL-FSS_PC_MON_OUTPUT
DCC LINK: H2:PSL-FSS_PC_MON_OUTPUT - data

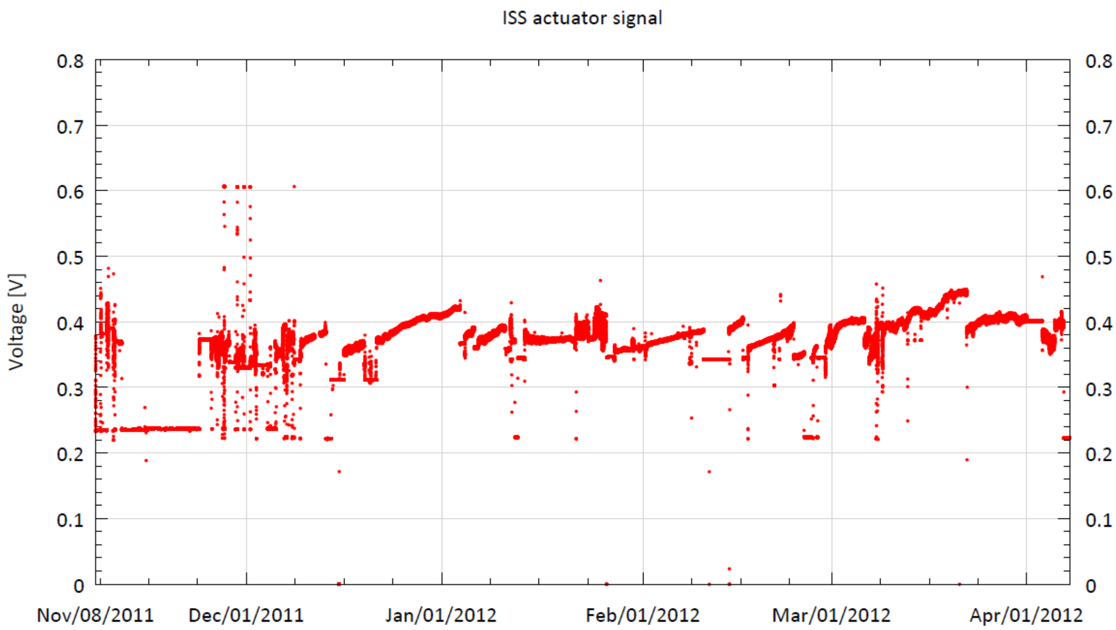
3.4.4.4 FSS reference cavity transmission photodiode



DCC LINK: H2:PSL-FSS_TPD_DC_OUTPUT
DCC LINK: H2:PSL-FSS_TPD_DC_OUTPUT - data

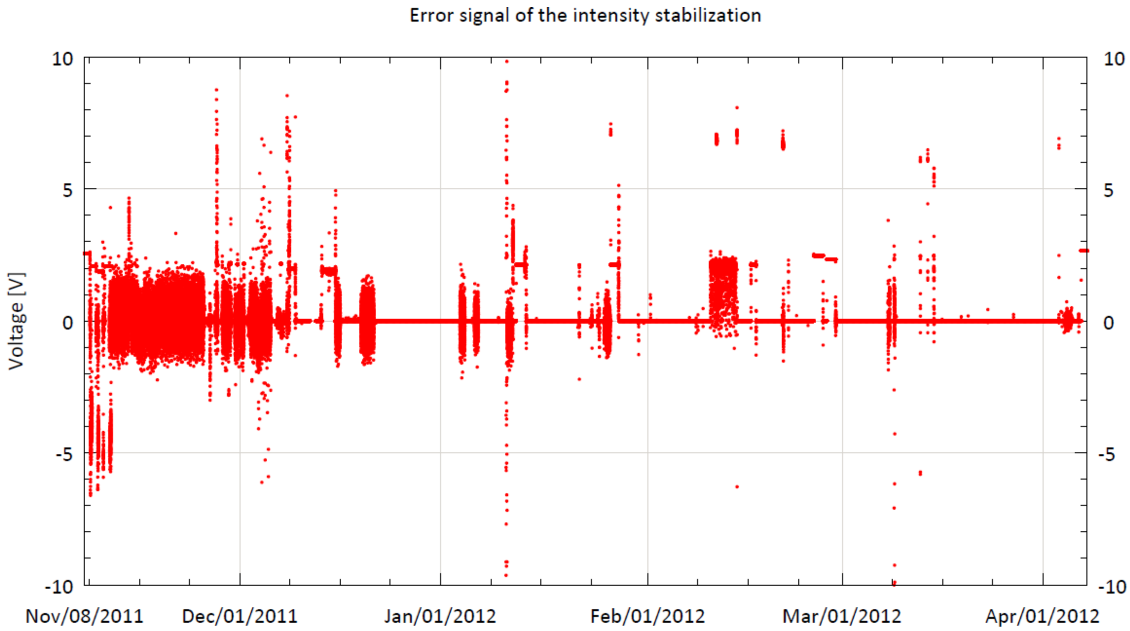
3.4.5 ISS

3.4.5.1 ISS actuator signal (AOM driver)



DCC LINK: H2:PSL-ISS_AOM_DRIVER_MON_OUTPUT
DCC LINK: H2:PSL-ISS_AOM_DRIVER_MON_OUTPUT - data

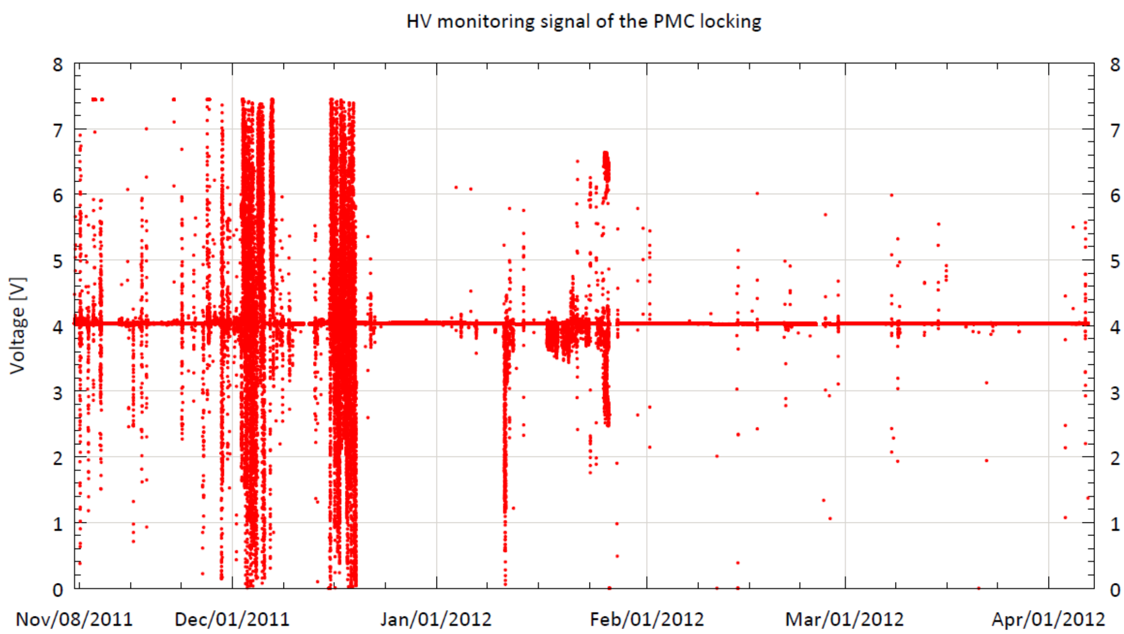
3.4.5.2 ISS error signal



DCC LINK: H2:PSL-ISS_TRANSFER1_B_OUTPUT
DCC LINK: H2:PSL-ISS_TRANSFER1_B_OUTPUT - data

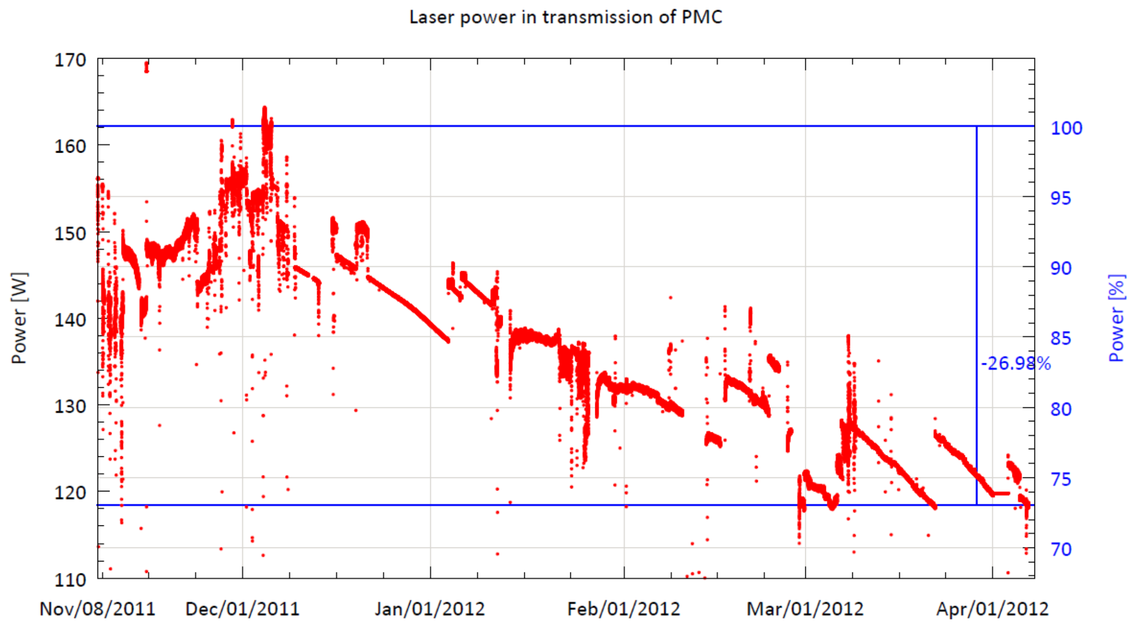
3.4.6 PMC

3.4.6.1 PMC length actuator



DCC LINK: H2:PSL-PMC_HV_MON_OUTPUT
DCC LINK: H2:PSL-PMC_HV_MON_OUTPUT - data

3.4.6.2 power transmitted by PMC



DCC LINK: H2:PSL-PWR_PMC_TRANS_OUTPUT
DCC LINK: H2:PSL-PWR_PMC_TRANS_OUTPUT - data

4 Performance vs PSL design requirements (T050036)

a. Power at IO interface (downstream of PMC): ≥ 165W for more than one week
163W without further stabilization; ~150W with ISS, FSS

b. Higher order mode power < 5W
we see 8.5% higher order mode content upstream of PMC -> expect less than 1% downstream of PMC, this was demonstrated at the reference system at AEI

c. Polarization ration (p-pol/s-pol) better than 100:1
we demonstrated 67000:1 at reference system at AEI and measured at IO attenuator downstream of PMC 203:1

d. Beam height at IO interface 10cm +/- 0.5cm, angle of beam axis: ± 2 deg with respect to the vertical plane defined by the table surface
beam height measured to be 10cm, beam angle 0.375 deg

e. Demonstrate fast lock acquisition:
sequence injection locking, PMC locking, ISS switched on within 10 sec (with FSS turned off), FSS locking within 120
verified, FSS lock acquisition algorithm improved in July 2013 (aLOG7557)

f. Power fluctuations at PSL/IO interface: ≤ 5% over 24h
not measured at H1/H2, verified at LLO, (see E1100716)

g. Demonstrate power adjust capability at the PSL/IO interface via EPICS: 1% peak-to-peak variations (response time >10 sec)

Demonstrated power adjust capability at the PSL/IO interface via EPICS: 1% peak-to-peak variations (response time >10 sec) at L1 PSL

h. Demonstrate control band (0.1Hz – 10Hz) power stability requirements (see T050036-v2) could be demonstrated in-loop but not out-of-loop without the ISS outer loop (see 2.4a)

i. Demonstrate inner-loop power stability (as defined in G1000106 and accepted in the FDR report 1000084-v2)
- in high-power mode requirements are met above 100Hz, noise at 30Hz is about factor of 2 too high (see 2.4a)
in low power mode requirements were met

j. Demonstrate that power noise at line harmonics is less than 30dB above the broadband noise (1Hz bandwidth) in the surrounding frequency range
requirement met in low and high power mode

k. Demonstrate power noise between 10 kHz and 9 MHz to be below $2x10^{-7}$ $(Hz)^{-1/2}$ (narrow signals above this level may be acceptable depending on their exact frequency)
power noise above 10kHz not measured, verified at LLO, (see E1100716)

l. Demonstrate that noise eater is functioning and that free running power noise between 9 MHz and 100 MHz multiplied by the PMC power noise transfer function is below $1x10^{-9}$ $(Hz)^{-1/2}$.
free running noise requirement demonstrated in "high power optical AC coupling paper" for reference system (Kwee et al., Optics Letters, Vol. 36, No. 18, p. 3563),

m. Demonstrate that the beam pointing measured with the DBB multiplied with the PMC pointing transfer function meet the pointing noise requirement.
demonstrated even before reduction of vibrations caused by turbulent water flow through quick connects

n. FSS: show that wideband frequency actuator meets requirement (less than 20deg phase lag at 50kHz)
no measurements done with new VCO

o. Demonstrate that error signal meets FSS requirement.
demonstrated (see 2.5.a)

p. Robustness: Demonstrate that FSS stay in lock if step function with amplitude of … is injected into VCO input
no test performed at LHO, at LLO FSS stayed in lock with 360mV step function applied to VCO input

q. Perform a full DBB characterization run (higher order mode content, power noise, frequency noise, pointing fluctuations) and show that all measured quantities are within a factor of 3 of the references system.
demonstrated

r. Demonstrate that PSL operates stable in low power mode (24h demonstration)
demonstrated

5 remaining actions

After the installation not all requirements were demonstrated and a few topics to-do items were identified during the acceptance review. The following topics need attention:

1.	☐	
2.	☐	
3.		
4.	☐	
5.	☐	
6.	☐	
7.	☐	
8.	☐	
9.	☐	
10.	☐	
11.	☐	
12.	☐	
13.	☐	
14.	☐	