LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

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Pre-Stabilized Laser Subsystem Testing and Acceptance

- L1 PSL-

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Distribution of this document:
LIGO Science Collaboration

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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 L1 detector after installation in July 2011.

All measurements for L1 were taken with the fan-filter units in the laser-area enclosure turned on. (They will be shut-down in science mode).

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 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)).

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:

E1100674 LLO - PSL DAQ channels after installation

Pictures of the PSL after the installation was finished can be found at
https://ligoimages.mit.edu/pages/search.php?search=%21collection666

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).

M1100038 LLO Installation 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: 42304

Value	Nominal value	Allowed deviation	Measured / actual value
Set temperature	18 °C	± 0.1 °C*	Set to 18 °C
Water flow	29lpm	± 2lpm	Set to 29 lpm via Bypass (35.5 lpm max)
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. :42307

Value	Nominal value	Allowed deviation	Measured / actual value
Set temperature	Set to 18 °C	± 0.1 °C*	18°C
Water flow	20 lpm	-0.5lpm, +10 lpm	Reduced to 28 lpm via internal bypass (max: > 30 lpm)
Conductivity	4 … 7 µS/cm	<7 µS/cm**	5.2 µS (6/20/2011)

* after cool-down phase

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 28 lpm via internal bypass (max: > 30 lpm)
Conductivity	4 … 7 µS/cm	<7 µS/cm*	6.1 µS (6/20/2011)

* 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) **16.2 l/min**	6.2 bar	± 0.5 bar	6.2 bar
Water pressure (manifold outlet) **16.2 l/min**	2.3 bar	± 0.5 bar	2.3 bar
Pressure drop **16.2 l/min**	3.9 bar	± 1.0 bar	3.9 bar
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 LLO 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.: F514599)	☐ passed	X failed*
Bundle 2 (serial no.: forgot to note)	X passed	☐ failed
Bundle 3 (serial no.: forgot to note)	X passed	☐ failed
Bundle 4 (serial no.: forgot to note)	X passed	☐ failed
Bundle 5 (serial no.: forgot to note)	X passed	☐ failed
Bundle 6 (serial no.: forgot to note)	X passed	☐ failed

Comments:
*The fiber bundle passed all the tests first and failed during operation in the high power oscillator. It has been send back to the manufacturer for repair. Logbook entry (page 848):

> *(...) Multimode alignment of the freerunning HPO (32 A). We found a glowing fiber tip at head #1. We already saw some strange structures at one of the fibers, when we put it into the HPO-box, but used this fiber bundle anyway, since it passed all our incoming tests. We replaced fiber bundle No.1 with fiber bundle No. 5. The temperatures of all SMA connectors (the diode side) were below 40 °C.(...)*

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).

after minor cleaning all amplifier fibers were ok (see LLO aLIGO labbook pages 776, 785, 796)

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 LLO see E1100539).

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 OBS1-IL	E1100539	E1100539
PSL Computer	PSL-PC	see above	13C2-AE98-310	see above	see above
Power Supply	PS1	see above	neoLASE 10033947	see above	see above
Power Supply	PS2	see above	neoLASE 10033942	see above	see above
Power Supply	PS3	see above	neoLASE 10033940	see above	see above
Power Supply	PS4	see above	neoLASE 10033945	see above	see above
Diode Box	DB1	see above	S1103747	see above	see above
Diode Box	DB2	see above	S1103748	see above	see above
Diode Box	DB3	see above	S1103749	see above	see above
Diode Box	DB4	see above	S1103750	see above	see above
Front End Dioded Box	FE-DB	see above	S1103751	see above	see above
Termo-Electric Cooler power supply	TEC1	see above	neoLASE 10033941	see above	see above
Termo-Electric Cooler power supply	TEC2	see above	neoLASE 10033944	see above	see above
Control Box	CB	see above	S1103746	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 E1100539).

- ☐ 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!)

NPRO slopes (file: NPRO-slope.txt in DCC link)

NPRO current /A	**Power infront of EOM / W**	**Power behind Faraday / W**
0.7	0	0
0.9	0.09	0.05
1.1	0.36	0.22
1.3	0.7	0.47
1.5	1.09	0.8
1.7	1.46	1.13
1.8	1.6	1.27
1.9	1.73	1.37
2.0	1.85	1.47
2.11	1.98	1.56

Amplifier slope (file: Amplifier-pump-diode-slope.txt in DCC link)

Current / A	**Power Diode 1 / W**	**Power Diode 2 / W**	**Power Diode 3 / W**	**Power Diode 4 / W**
10	0.1	0.1	0.1	0.2
15	3.7	4.2	4.0	4.4
20	7.6	8.4	8.2	8.7
25	11.5	12.5	12.3	13.1
30	15.6	16.5	16.6	17.3
35	19.5	20.5	20.9	21.7
40	23.4	24.6	25.2	26.1
45	27.3	28.7	29.6	30.4
50	31.2	32.9	33.9	34.9
55	35.0	37.2	28.3	39.4
60	38.9	41.5	42.4	43.8

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 !***

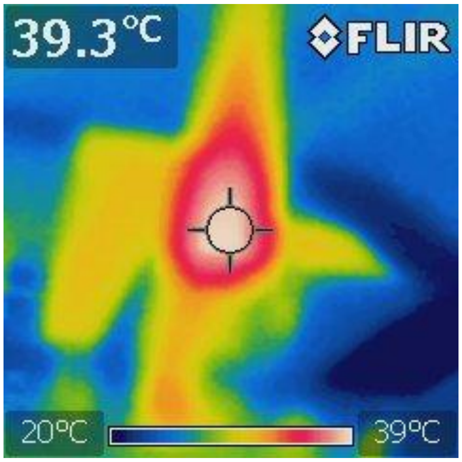
Measure the transmitted power through the fiber bundle. Do this measurement step-by-step and look at the tip of the fiber bundle. The laser-end of the bundle should be cooled for this test. (An appropriate fiber holder is provided by LZH). Measure the output power of the diode box with a water cooled 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.

Oscillator slopes
(file: Oscillator-pump-diode-slope.txt and Oscillator-pump-diode-fit.txt in DCC link)

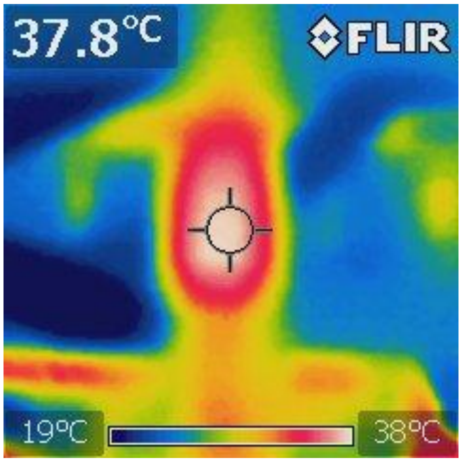
Current / A	**Power FB1 / W**	**Power FB2 / W**	**Power FB3 / W**	**Power FB4 / W**
8	0	0	0	1.1
10	3.4	3.9	3.2	3.0
12	14.7	15.3	13.8	13.3
14	26.5	27.0	25.2	24.9
16	37.9	38.9	36.7	36.6
18	49.5	50.7	48.2	48.2
20	60.6	62.2	59.8	60.1
22	72.1	74.1	71.2	71.9
24	83.7	85.7	82.7	83.3
26	95.0	97.3	94.2	95.0
28	106.3	108.9	105.6	106.7
30	117.5	120.8	117.1	118.1
32	128.8,	132.2	128.8	129.3
34	140.0	143.6	140.1	140.9
36	151.5	155.1	151.7	152.0
38	163.2	166.8	163.3	163.2
40	174.8	178.8	174.7	174.8
42	186.1	190.3	186.1	186.2
44	197.7	202.1	197.9	198.8
46	209.1	214.1	209.2	209.5
48	220.6	225.7	220.4	221.1
50	232.0	237.4	231.8	232.9
52	243.2	248.8	243.3	244.4
54	254.6	260.6	254,2	255.7
56	265.9	272.2	265.2	267.0
58				
60				

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

IR picture of the diodes with the highest temperatures found:



Box 3, diode 4



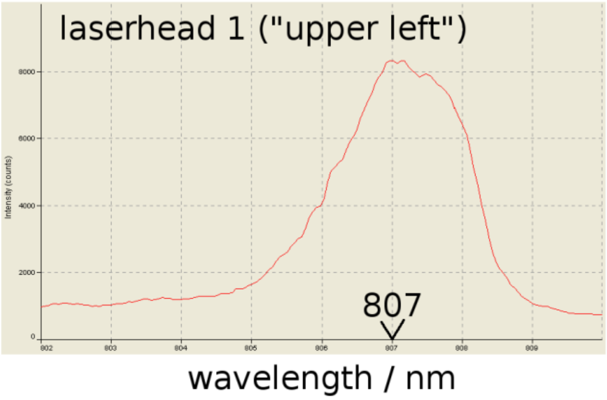
box 3, diode 5

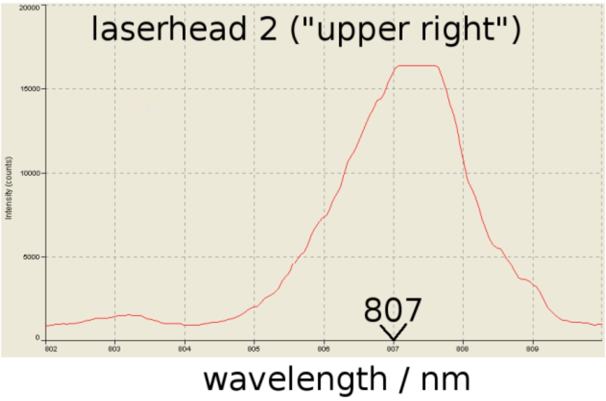
Create a table as shown below by applying a linear fit to the data measured above – these values will be needed when starting the laser system.

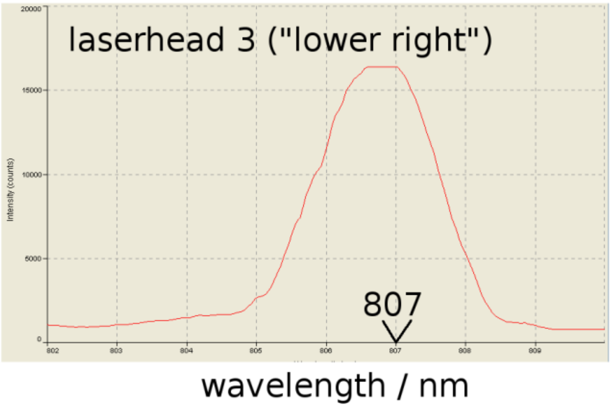
Power / W	**Current /A (FB1)**	**Current /A (FB2)**	**Current /A (FB3)**	**Current /A (FB4)**
10	10.9	10.9	11.1	11.1
20	12.7	12.6	12.8	12.8
30	14.5	14.3	14.6	14.6
40	16.2	16.0	16.4	16.3
50	18.0	17.8	18.1	18.1
60	19.8	19.5	19.9	19.8
70	21.5	21.2	21.6	21.6
80	23.3	22.9	23.4	23.3
90	25.0	24.7	25.2	25.1
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

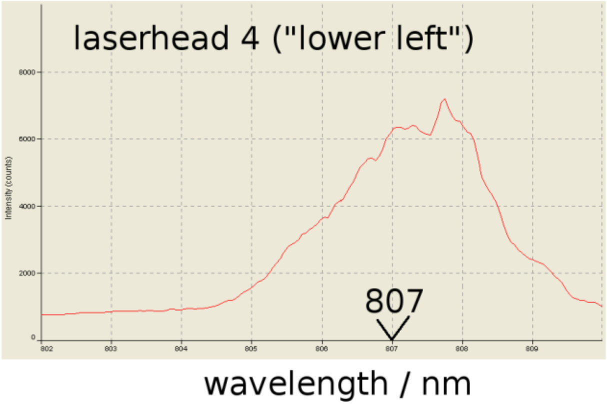
260	55.0	54.0	55.0	54.8
270	56.8	55.7	56.8	56.6
280	58.6	57.4	58.6	58.3
290	60.3	59.2	60.3	60.1
300	62.1	60.9	62.1	61.8

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.









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	Diode chiller

Front End	>1.3 lpm, set to 1.5 lpm	Crystal chiller, Readout for example at Beckhoff control screen
Laser heads	>0.5 lpm per head, set to 0.6 lpm	Crystal chiller, Readout for example at Beckhoff control screen
Power meters and beam blocks	>1.5 lpm, set to 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	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	0.09	0.05
1.1	0.36	0.22
1.3	0.7	0.47
1.5	1.09	0.8
1.7	1.46	1.13
1.8	1.6	1.27
1.9	1.73	1.37
2.0	1.85	1.47
2.11	1.98	1.56

During the LLO installation the NPRO had been replaced with a the spare NPRO called "SPARE2", SN 1639A) (See LLO logbook entry page 1097 and 1110).

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We put in the new NPRO and measured the slope between the polarization optics
and the EOM, and behind the Faraday-isolator, respectively:

NPRO current / A        Power in front of EOM / W       Power behind Faraday / W
0.7                      0                               0
0.9                      0.09                            0.05
1.1                      0.36                            0.22
1.3                      0.7                             0.47
1.5                      1.09                            0.8
1.7                      1.46                            1.13
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1.8                    1.6                           1.27
1.9                    1.73                          1.37
2.0                    1.85                          1.47
2.11                   1.98                          1.56
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We optimized the NPRO's beam path by aligning the mirrors behind the NPRO at 1.8 A and improved the power transmission as follows:

- upstream EOM: 1.63 W
- between EOM and AOM: 1.57 W
- behind AOM: 1.53 W
- behind Faraday: 1.35 W

At the working point of 2 A the power behind the Faraday was 1.6 W. Alignment of the mirror set directly in front of amplifier at 30 A current of amplifier's pump diodes resulted in 14.3 W output. The operation current for the diodes is 47 A. Here, we got 35.6 W out of the amplifier after alignment of the EOM and AOM.

EOM-alignment:

- 1.2 VDC voltage on alignment photodiode
- signal at oscilloscope: 15 mV peak-peak, 35.5 MHz
- with NPRO shutter closed (electronic disturbances ?): 17.5 mV peak-peak

AOM-alignment:

- approximately 11° phase loss at 100 kHz"

Align MOPA

Measure frontend output power and measure frontend power

Logbook entry:

(…) Alignment of the mirror set directly in front of amplifier at 30 A current of amplifier's pump diodes resulted in 14.3 W output. The operation current for the diodes is 47 A. Here, we got 35.6 W out of the amplifier after alignment of the EOM and AOM (…)

Calibrated diagnostic pick-ups (Calibration from June, 15th 2011):

Stage 1: 7.1 W

Stage 2: 14.4 W

Stage 3: 24.2 W

2.1.3.6 free running high-power oscillator (S1103594)

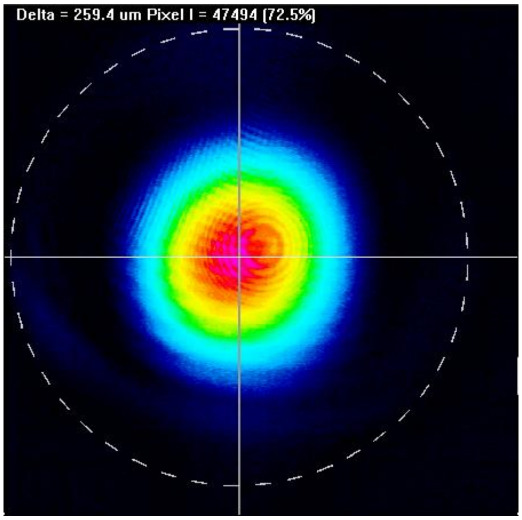
Follow alignment procedure for high-power oscillator as described in LIGO-T0900641.

Sum output power at the external powermeter and powermeter inside the HPFI during bidirectional operation of the high-power oscillator (MOPA turned off): $P_{out} = 157.8$ W

Output power on external power meter after MOPA was turned on and NPRO shutter closed: $P_{out} = 160.4$W

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

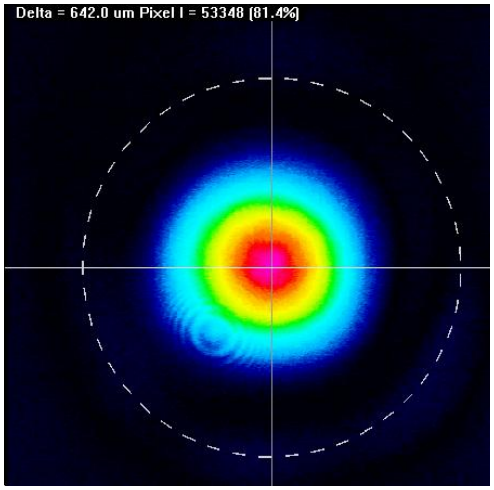
(Include a plot of the beam profile here and save the beam profile in a data file with a common format (*.txt, *.xls, etc.) at the same DCC number as the completed test report (or under a separate DCC number linked to the test report entry in the DCC)).



(file: 110614-freerunning-160p4W in DCC link)

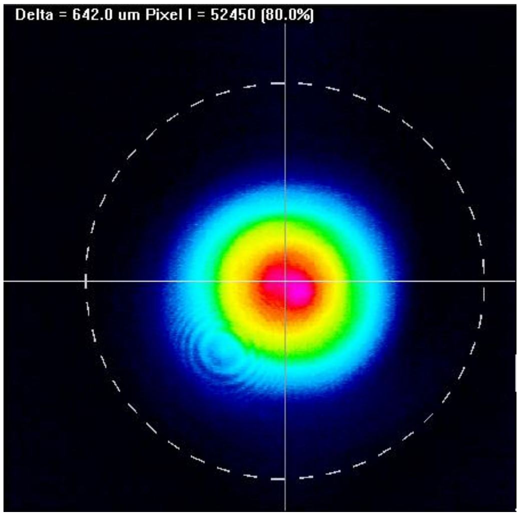
Start injection locking of the system

Output power of the injection locked system after installation of corona aperture without screwed in aperture piece: P_{out} = 203.0 W



(file: 110616-locked-woaperture in DCC link)

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 (injection locked): P_{out} = 186.7W



(file: 110616-locked-with aperture in DCC link)

Power at Brewster plate pickup (measured with power meter): < 1 W

2.1.3.7 Test HPFI:

Parameters of the high-power oscillator after installation:(at LLO this measurement was not performed, here we give the values measured at LZH before shipping)

Power of free running laser at HPFI power meter: P_{out} = 66 W (LZH)

Power after HPFI measured with Ophir 10W power detector: P_{out} = 70mW (LZH)

Voltage of HPFI photodiode: 1,3 V (LLO, system not injection locked), 0,0 V (LLO, system locked)

2.1.3.8 Install injection locking:

Name	**Designation**	**Design Doc. or Part No.**	**SN**	**Test Procedure**	**Completed Test Document**
injection locking servo	ILS	T0900578 / D1001618	S1103536	T1000342	Tested according to T1000342
injection locking fieldbox	ILS-FB	D1001619	S1103541	T10000343	S1103541
35.5 MHz oscillator:		D080705	**	E1000059	**
35.5 MHz distribution amplifier:		D1000124	**	T1000256	**
35.5 MHz delay line phase shifter:		T050250	S1103558	T050183	S1103558

** was not available during installation at LLO

Which notch filters are built in? two notch filters (frequencies not documented)

Modulation frequencies of LO and EOM channel linked:

Modulation frequency: 35.5 MHz

LO amplitude: 7dBm

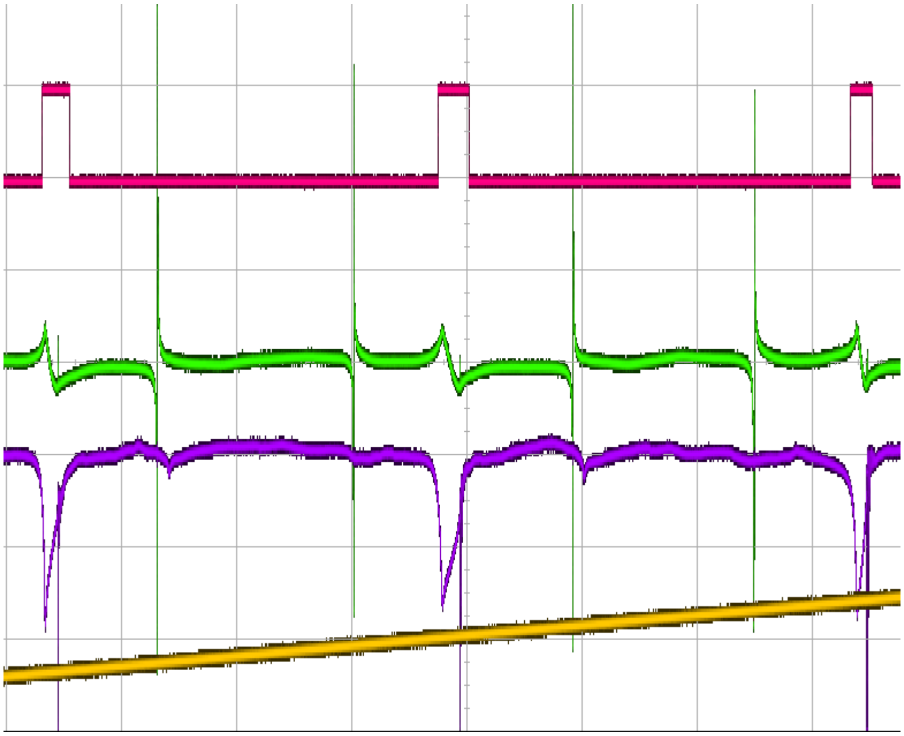
EOM amplitude: 500 mV P-P (-2dBm, -4dm @connector into FE box)

EOM phase (LO phase set to 0° for reference): +148deg

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



(yellow: ramp, violet: DC, green: error signal, pink: resonant signal (file: in folder error-singnla-traces in DCC link))

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:

(LLO Logbook Entry 872):
We used the following setup to find the Lasers waist position and width:
lens with nominal focal length of 200 mm (ca. 220 mm at 1064 nm wavelength) at a position 1710 mm behind the lasers output coupling mirror.

We measured the beam diameter of the attenuated beam with a CCD-camera at several positions behind the lens. The focal position was found 225mm behind the lens with a beam diameter of 113 µm. From this one can calculate that the beam coming out of the resonator is almost collimated (waist size around 350 µm in radius, around 500 mm behind the oscillators output coupler).

The data can be found in file ‘HPL-caustic.txt in DCC link)’

All voltages at all (monitoring) photodiodes (see 2.2.2 l):

Beckhoff control loop parameter:

Document the servo gain: -9.6 V

Document the reference level: -1.5 V

Document the error signal offset: -1.5 V

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:

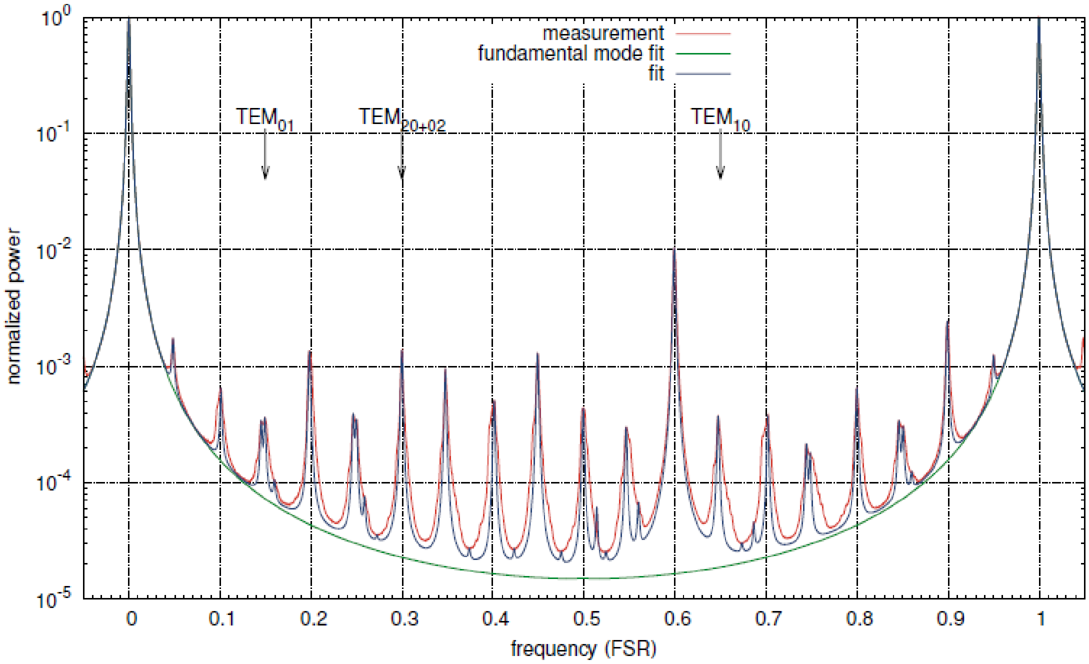
Name	**Designation**	**Design Doc. or Part No.**	**SN**	**Test Procedure**	**Completed Test Document**
Diagnostic Breadboard	DBB	T0900133	S1102963	See Test Document	E1100120
DBB HV Amplifier module	DBB-HV	T0900133	S1103544	See Test Document	E1100121
aLIGO PSL DBB demodulator module	DBB-DEMOD	T0900133	S1103548	See Test Document	E1100120
DBB Fieldbox	DBB-FB	T0900133	S1103546	See Test Document	E1100120
DBB Miscellaneous module	DBB-MISC	T0900133	S1103550	See Test Document	E1100120
DBB calibration module	DBB-CALI	D1101103	S1103551	See Test Document	E1100120
DBB AA filter		D070081	S1101683	T070146	S1101683
DBB AI filter		D070081	S1001224	T070146	S1001224

software version DBB rt-modell and medm screens: CDS subversion repository revision 489

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

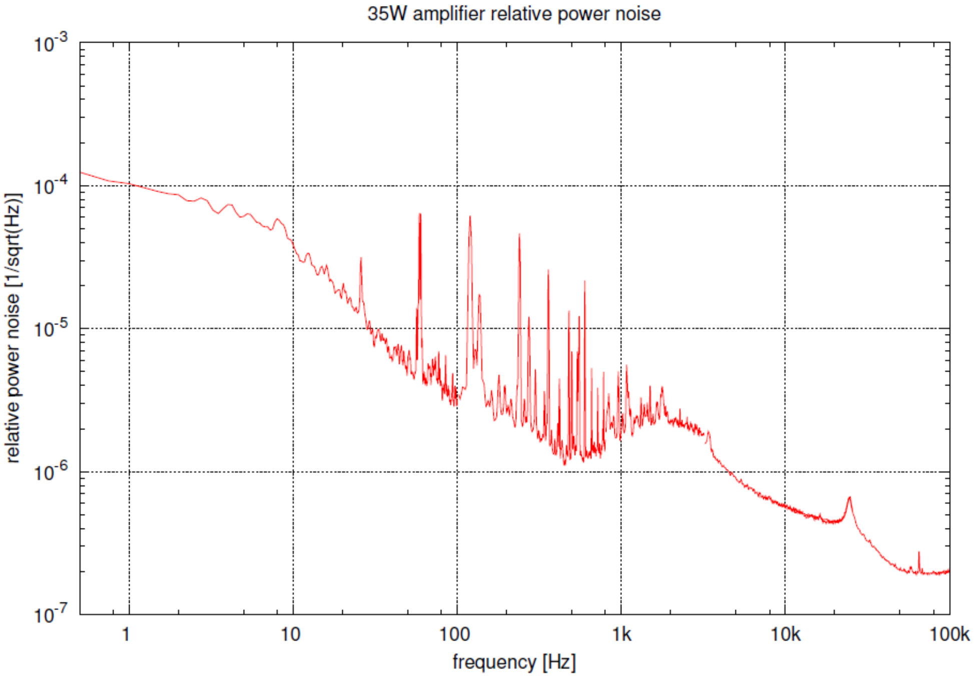
2.2.1 Laser characterization 35W front end (S1103591)

a. DBB modescan



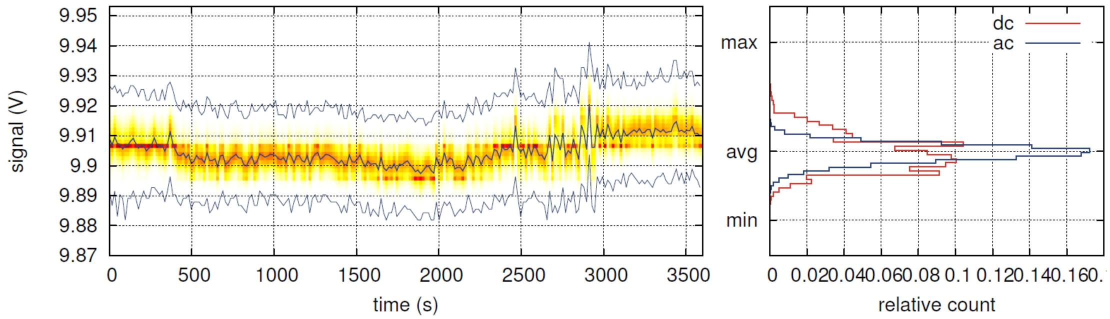
more info in the full mode-scan-report under the following URL:
https://dcc.ligo.org/DocDB/0068/E1100716/001/dbb_msc-004.pdf
https://dcc.ligo.org/DocDB/0068/E1100716/001/dbb_msc-004.zip

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



https://dcc.ligo.org/DocDB/0068/E1100716/001/rpn100k.pdf
https://dcc.ligo.org/DocDB/0068/E1100716/001/rpn100k.zip

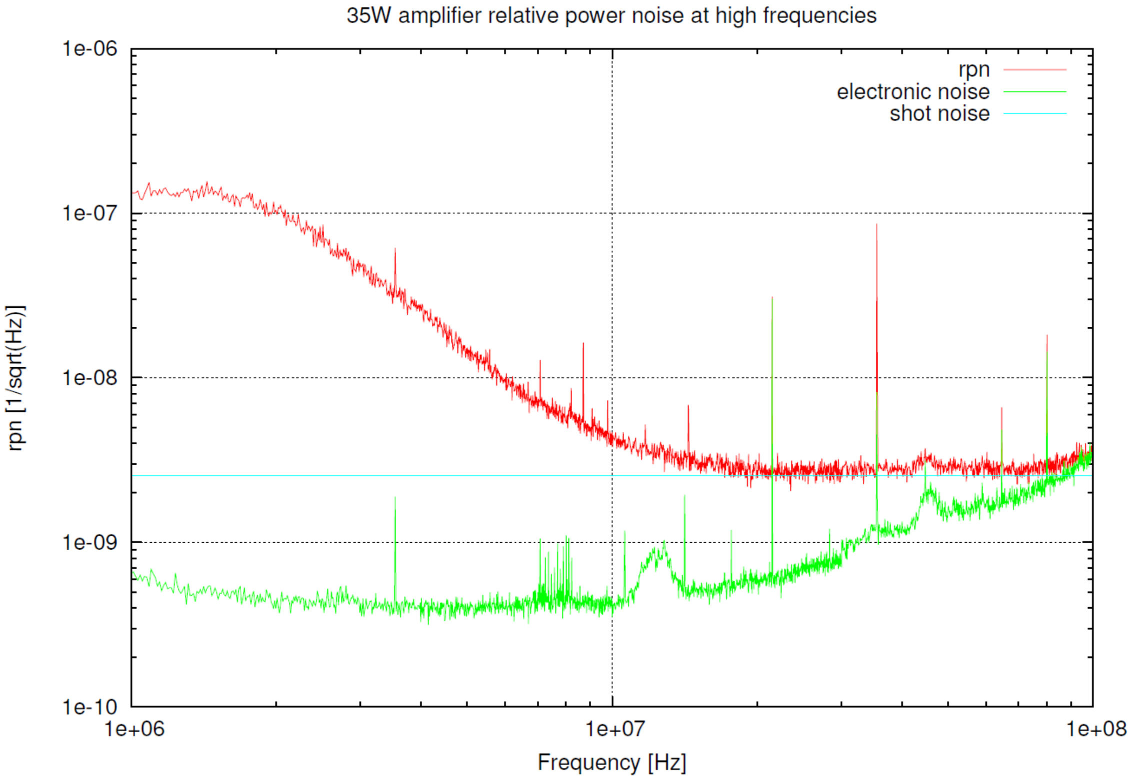
c. DBB RPN for 1h



relative peak to peak: 0.6%

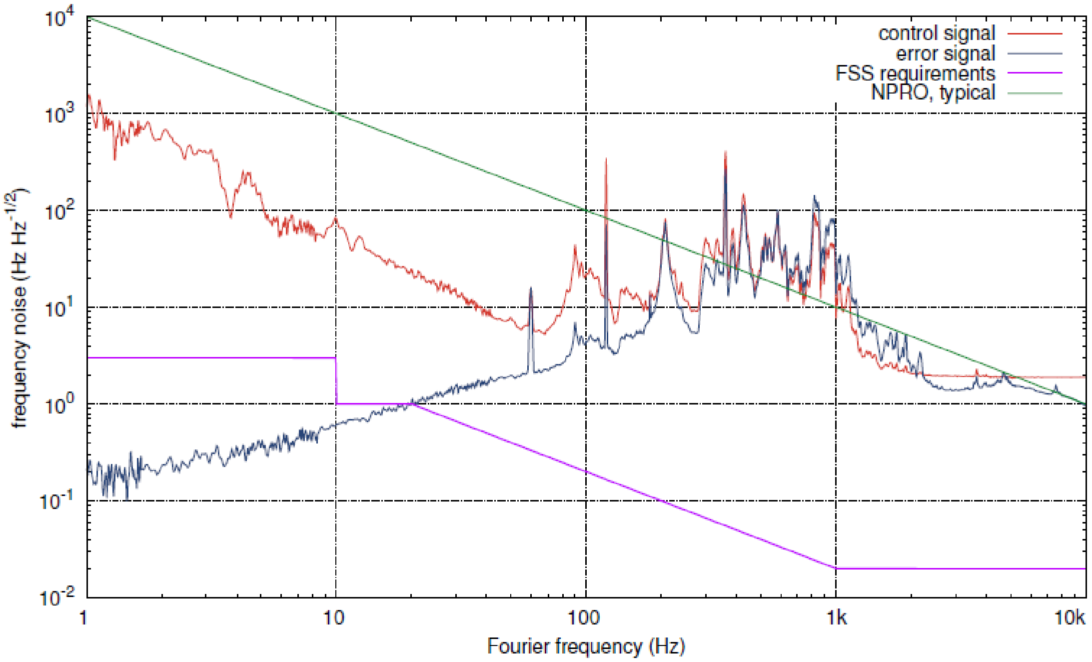
more info in full noise report under the following URL:
https://dcc.ligo.org/DocDB/0068/E1100716/001/dbb_rpn-004.pdf
https://dcc.ligo.org/DocDB/0068/E1100716/001/dbb_rpn-004.zip

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



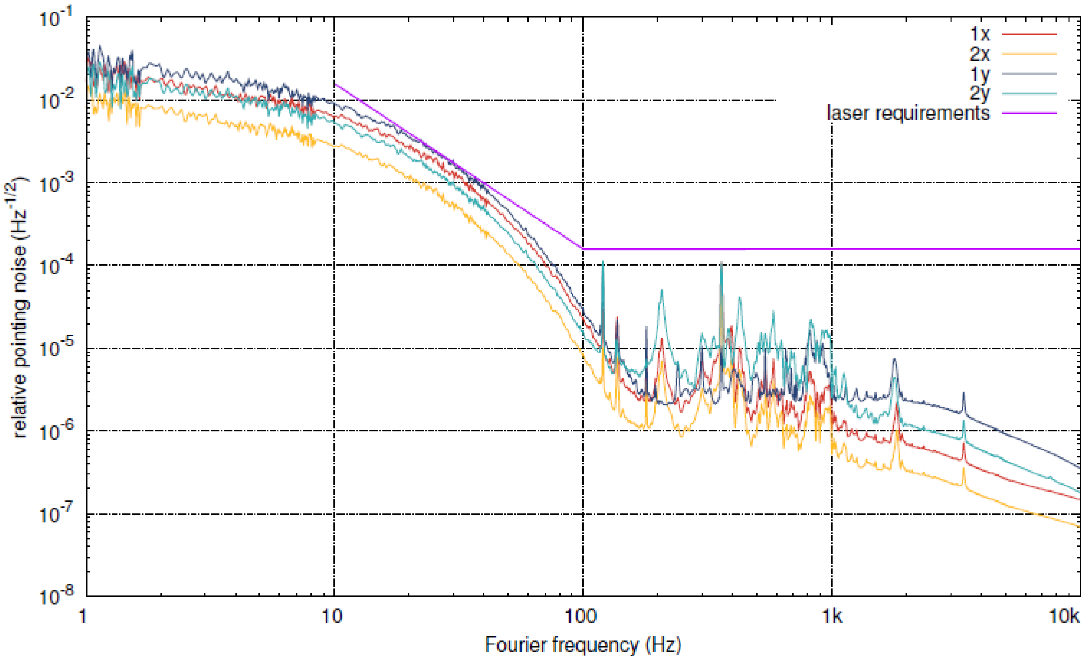
https://dcc.ligo.org/DocDB/0068/E1100716/001/rpn.pdf
https://dcc.ligo.org/DocDB/0068/E1100716/001/DBB_RPN_rf.zip

e. DBB frequency noise (FSS on)



more info in full noise report under the following URL:
https://dcc.ligo.org/DocDB/0068/E1100716/001/dbb_frq-001.pdf
https://dcc.ligo.org/DocDB/0068/E1100716/001/dbb_frq-001.zip

f. DBB pointing noise 1X, 1Y, 2X, 2Y



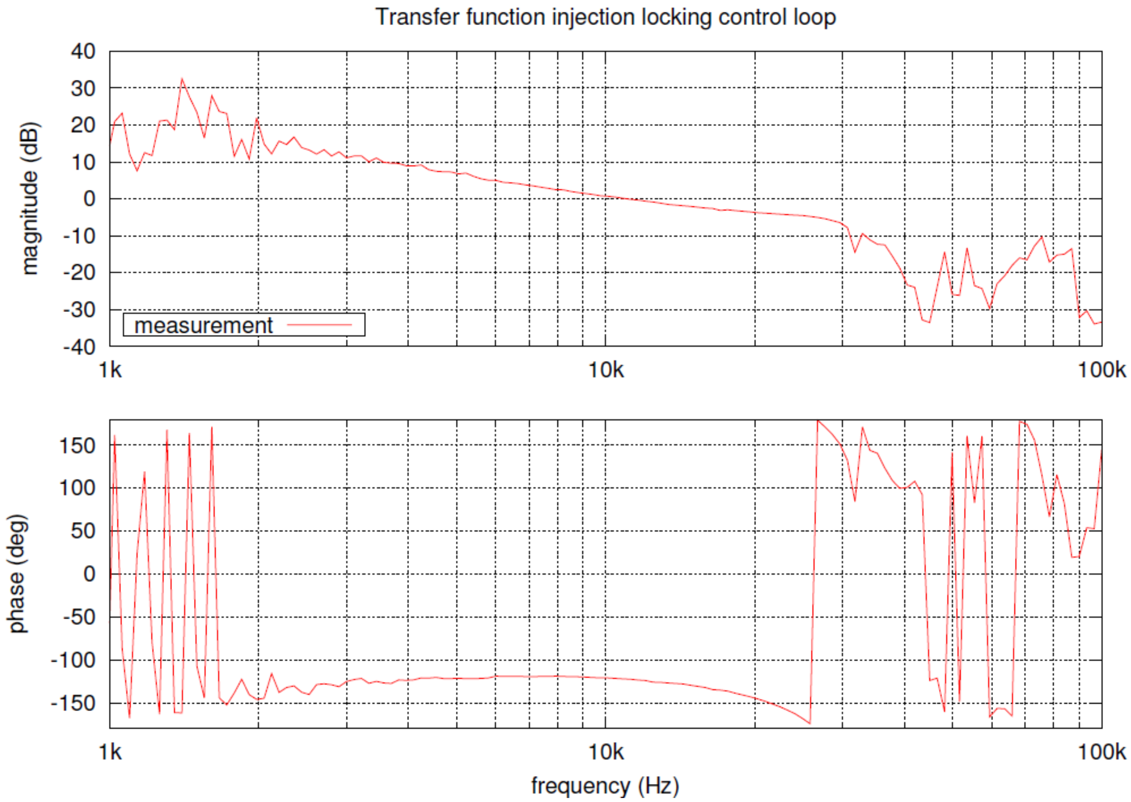
more info in full pointing report under the following URL:
https://dcc.ligo.org/DocDB/0068/E1100716/001/dbb_frq-001.pdf
https://dcc.ligo.org/DocDB/0068/E1100716/001/dbb_frq-001.zip

2.2.2 Laser characterization 200W (S1103594)

a. Output power

- power on PM01: 188W
- calibration factor for PD01: 0.0134 W/V

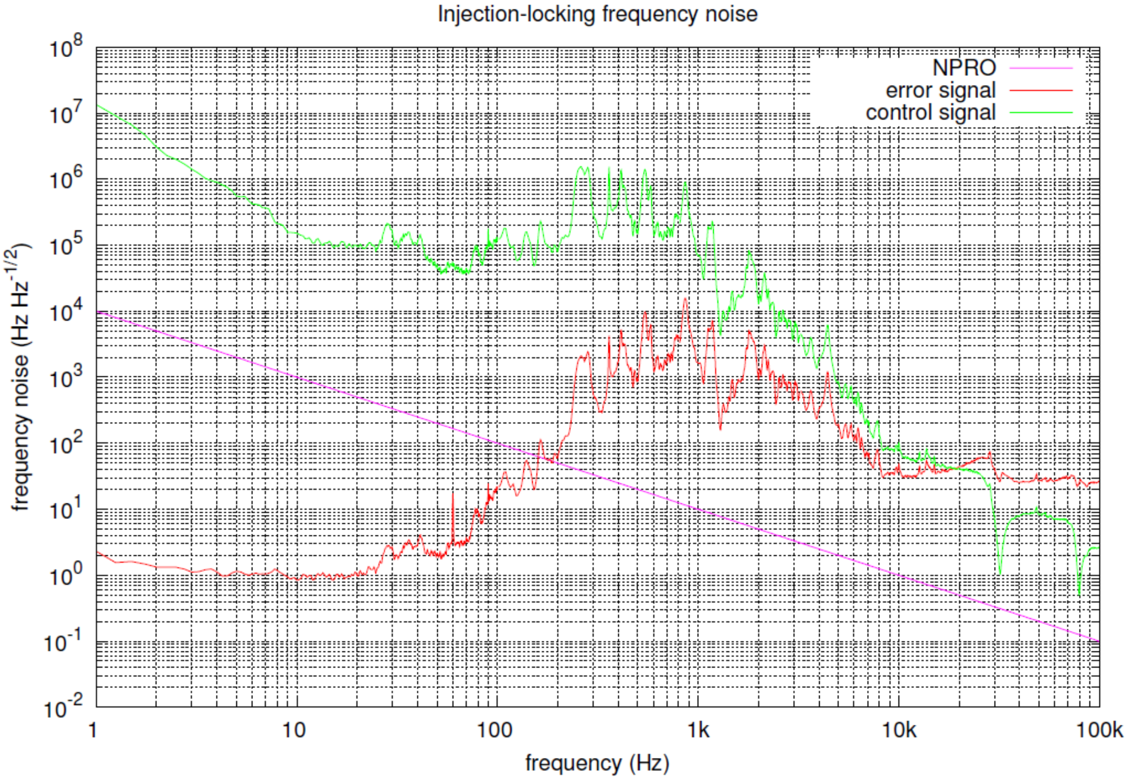
b. Transfer function of injection locking loop + UG frequency



https://dcc.ligo.org/DocDB/0068/E1100716/001/injection_locking_tf.pdf
https://dcc.ligo.org/DocDB/0068/E1100716/001/injection_locking_TF.zip

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

d. <u>Error point noise of injection locking loop + frequency calibration of error signal</u>

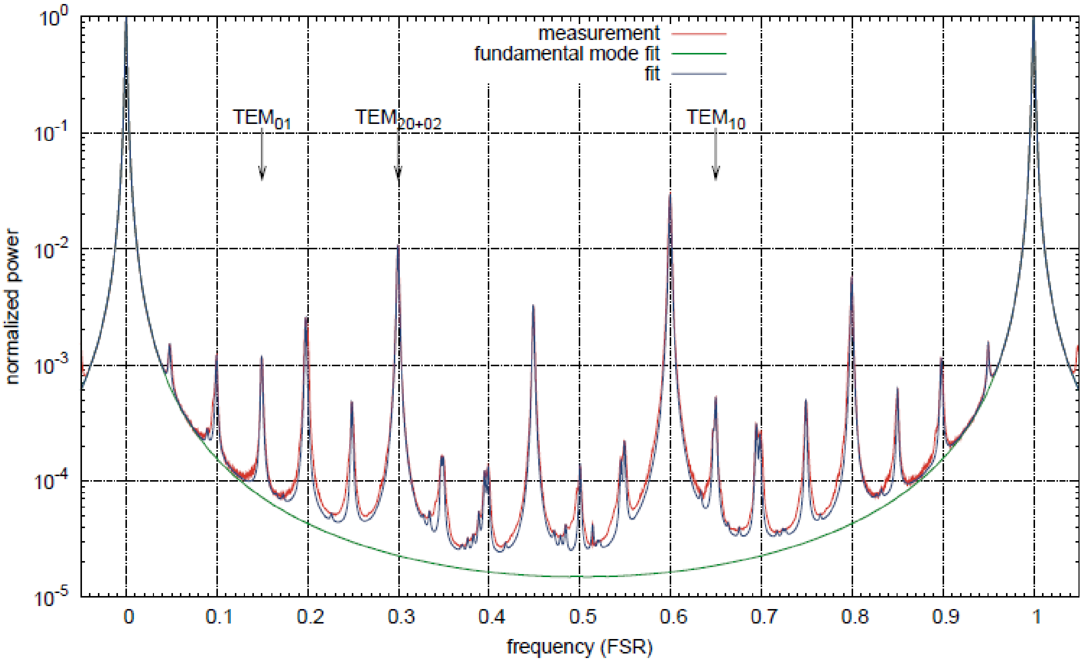


(detailed calibration info can be found in gnuplot *.plt file in zip foler)

https://dcc.ligo.org/DocDB/0068/E1100716/001/frqnoise.pdf
https://dcc.ligo.org/DocDB/0068/E1100716/001/injection_locking_error_point.zip
https://dcc.ligo.org/DocDB/0068/E1100716/001/injection_locking_actuator_noise.zip

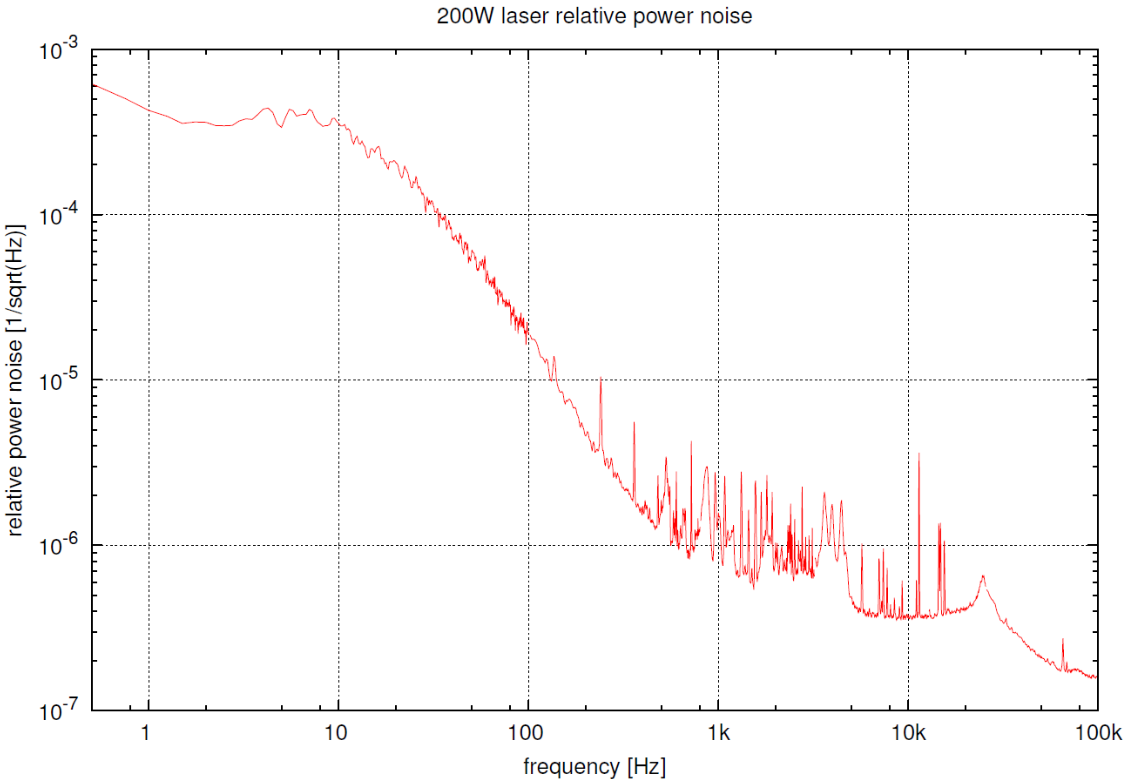
e. <u>Actuator/PZT noise of injection locking loop + frequency calibration of signal</u>
(see 2.2.2 d)

f. DBB modescan



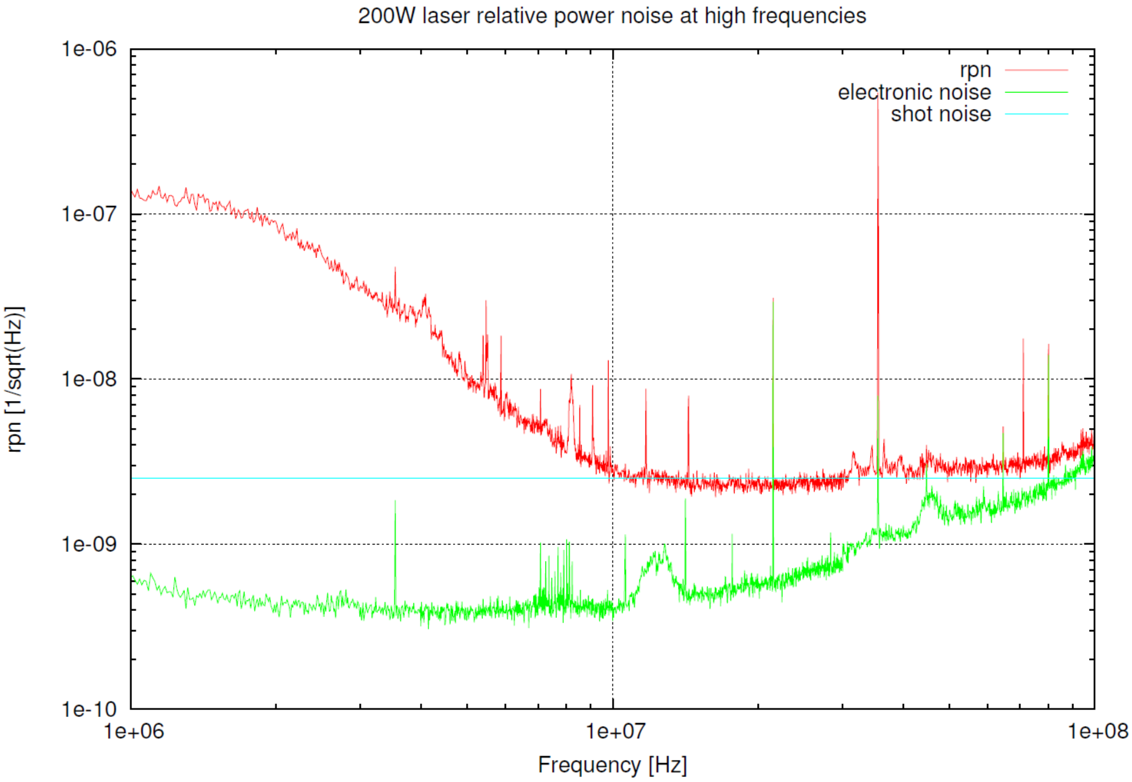
more info in full modescan report under the following URL:
https://dcc.ligo.org/DocDB/0068/E1100716/001/dbb_msc-016.pdf
https://dcc.ligo.org/DocDB/0068/E1100716/001/dbb_msc-016.zip

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



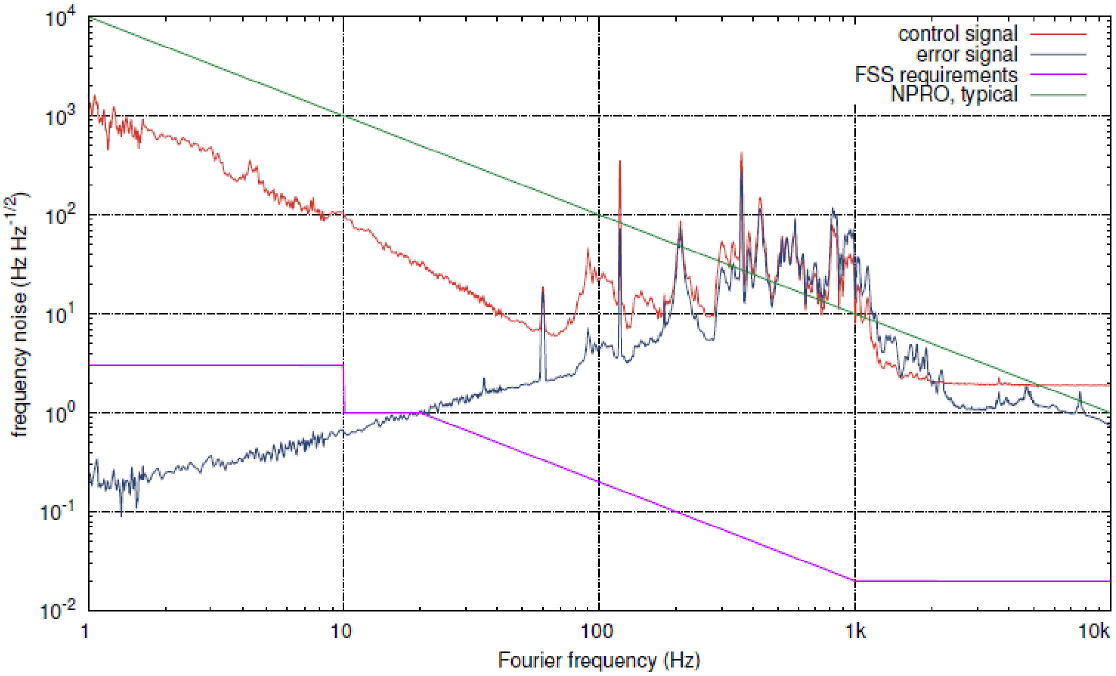
https://dcc.ligo.org/DocDB/0068/E1100716/001/rpn_200W.pdf
https://dcc.ligo.org/DocDB/0068/E1100716/001/rpn_200W.zip

DBB RPN at RF (measure with spectrum analyzer)



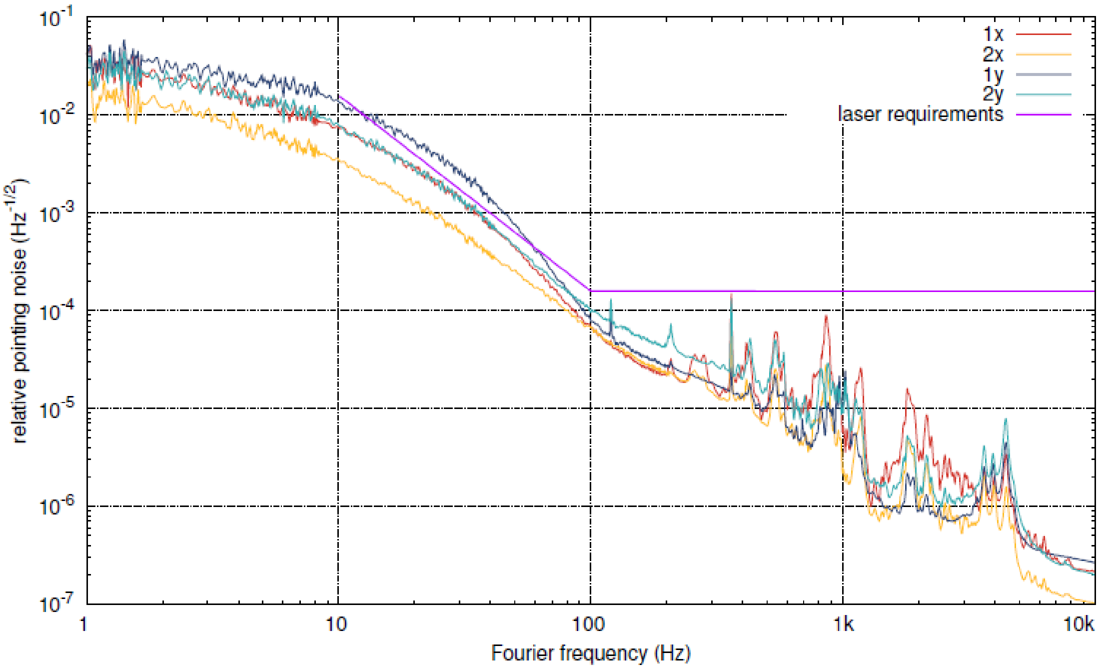
https://dcc.ligo.org/DocDB/0068/E1100716/001/rpn_200W_rf.pdf
https://dcc.ligo.org/DocDB/0068/E1100716/001/rpn_200W_rf.zip

h. DBB frequency noise (FSS on)



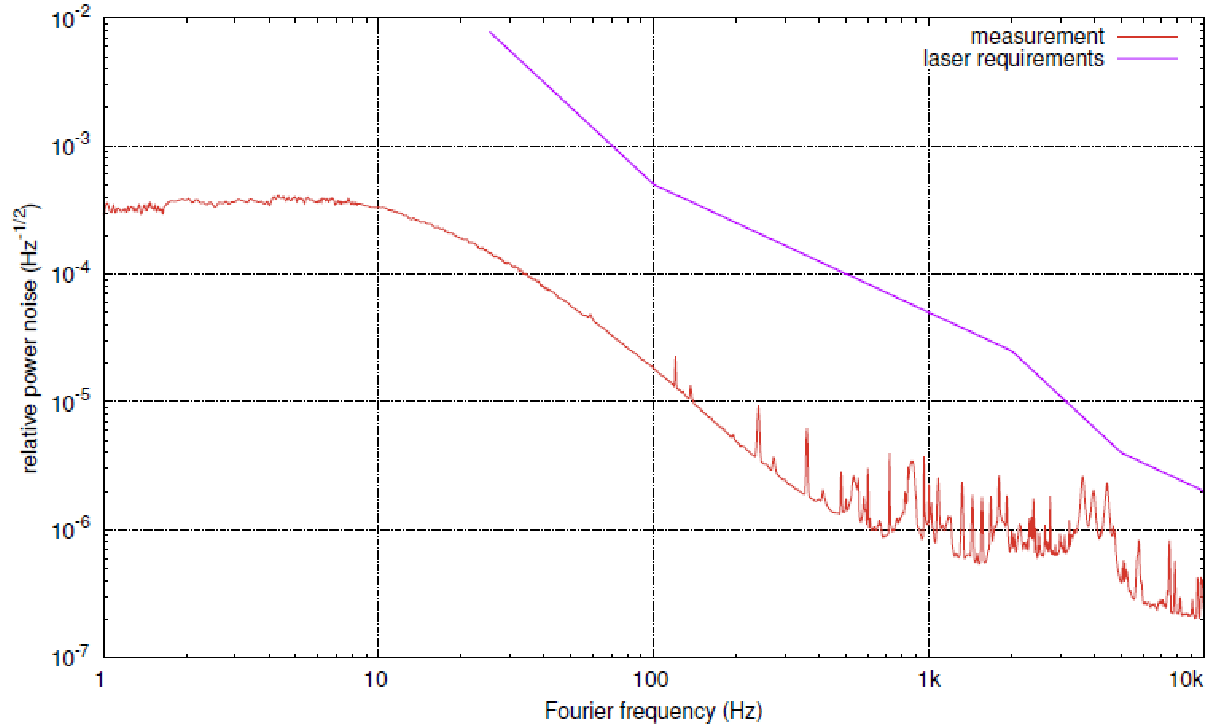
more info in full noise report under the following URL
https://dcc.ligo.org/DocDB/0068/E1100716/001/dbb_frq-002.pdf
https://dcc.ligo.org/DocDB/0068/E1100716/001/dbb_frq-002.zip

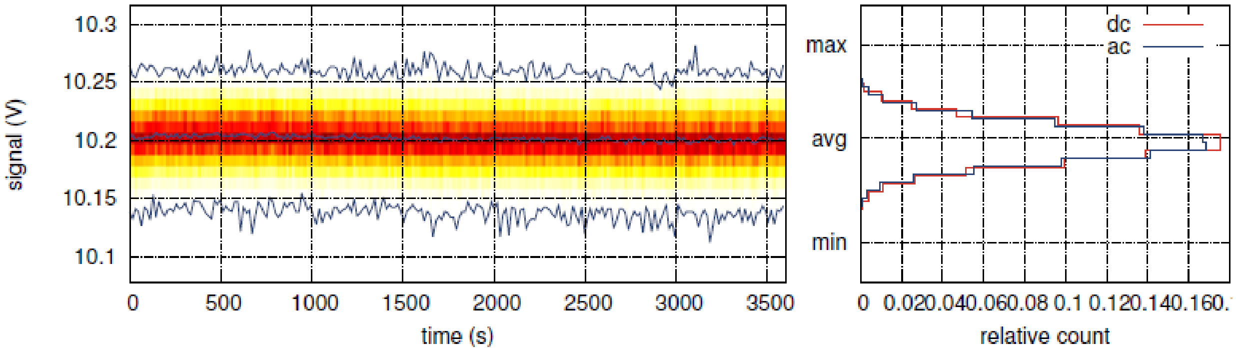
i. DBB pointing noise 1X, 1Y, 2X, 2Y



more info in full pointing report under the following URL
https://dcc.ligo.org/DocDB/0068/E1100716/001/dbb_pnt-002.pdf
https://dcc.ligo.org/DocDB/0068/E1100716/001/dbb_pnt-002.zip

j. DBB RPN for 1h





more info in full noise report under the following URL:
https://dcc.ligo.org/DocDB/0068/E1100716/001/dbb_rpn-003.pdf
https://dcc.ligo.org/DocDB/0068/E1100716/001/dbb_rpn-003.zip

k. DC power of internal photodiodes (in high power mode, locked state)

PD AMP:	216.1mV
PD BP:	78.6mV
PD OSC:	1.89V
PD ISO:	5.89mV (locked

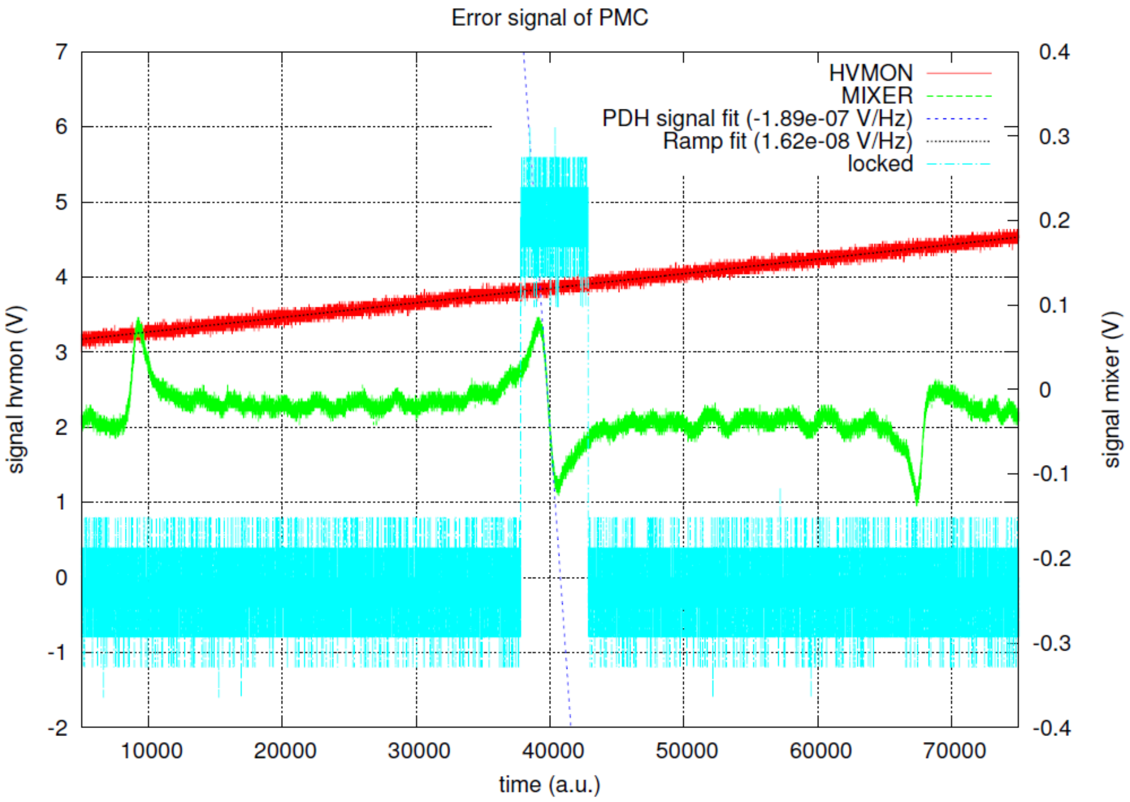
2.3 Pre-Modecleaner

pre shipment testing:

Name	**Designation**	**Design Doc. or Part No.**	**SN**	**Test Procedure**	**Completed Test Document**
Pre-Modecleaner	PMC	T0900616	S1102964	T1000429	E1100123
PMC Servo		D1001618	S1103538	T1000342	S1103538
PMC Fieldbox	PMC-FB	D1001619	S1103540	T10000343	
PMC photodiode	PMC-PD	D1101123	S1103588		
PMC oscillator and delay line phase shifter	see ILS 2.1.3.8				
PMC AA filter		D070081	S1001246	T070146	S1001246
PMC AI filter		D070081	S1001229	T070146	S1001229

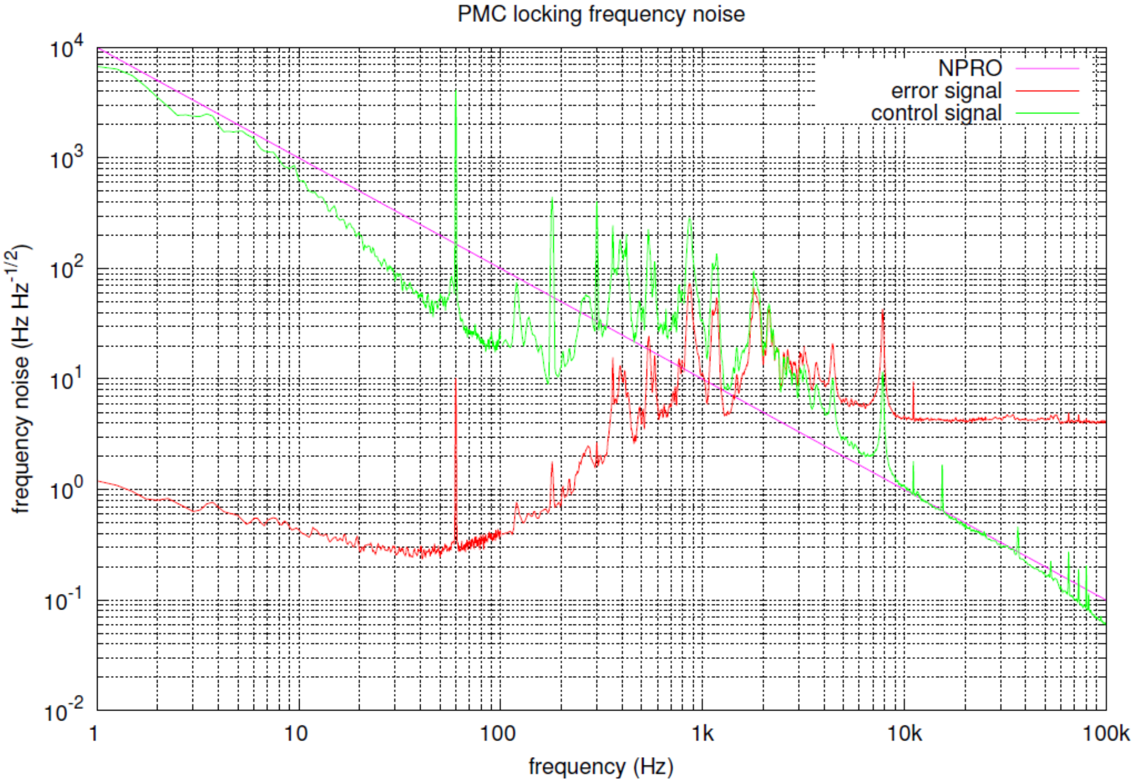
LO Amplitude: 7dBm

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



https://dcc.ligo.org/DocDB/0068/E1100716/001/PMC_errorsignal.pdf
https://dcc.ligo.org/DocDB/0068/E1100716/001/PMC_errorsignal.zip

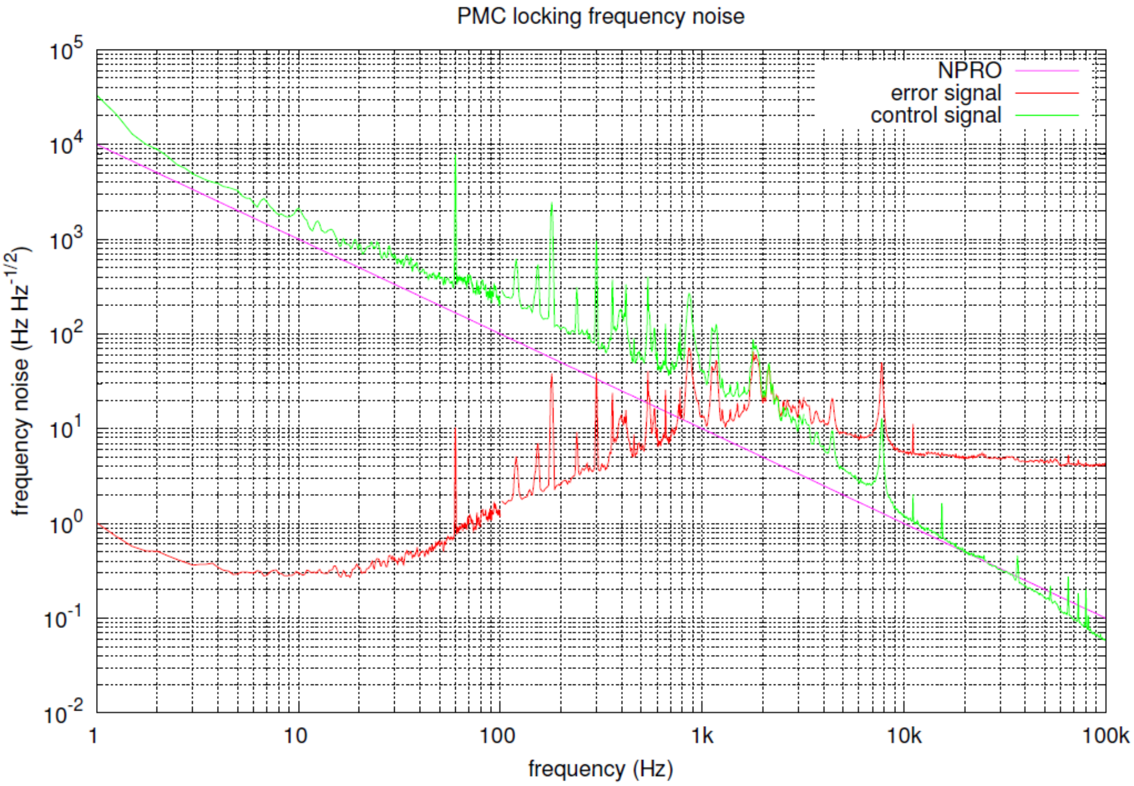
b. Error point noise of PMC locking loop + frequency calibration of error signal, with FSS



(error point above 10kHz limited by electronic noise)
https://dcc.ligo.org/DocDB/0068/E1100716/001/PMC_noiseFSSon.pdf
https://dcc.ligo.org/DocDB/0068/E1100716/001/PMCnoiseFSSon_error_pioint.zip
https://dcc.ligo.org/DocDB/0068/E1100716/001/PMCnoiseFSSon_actuator.zip

c. Actuator/PZT noise of PMC locking loop + frequency calibration of signal, with FSS
see 2.3.b

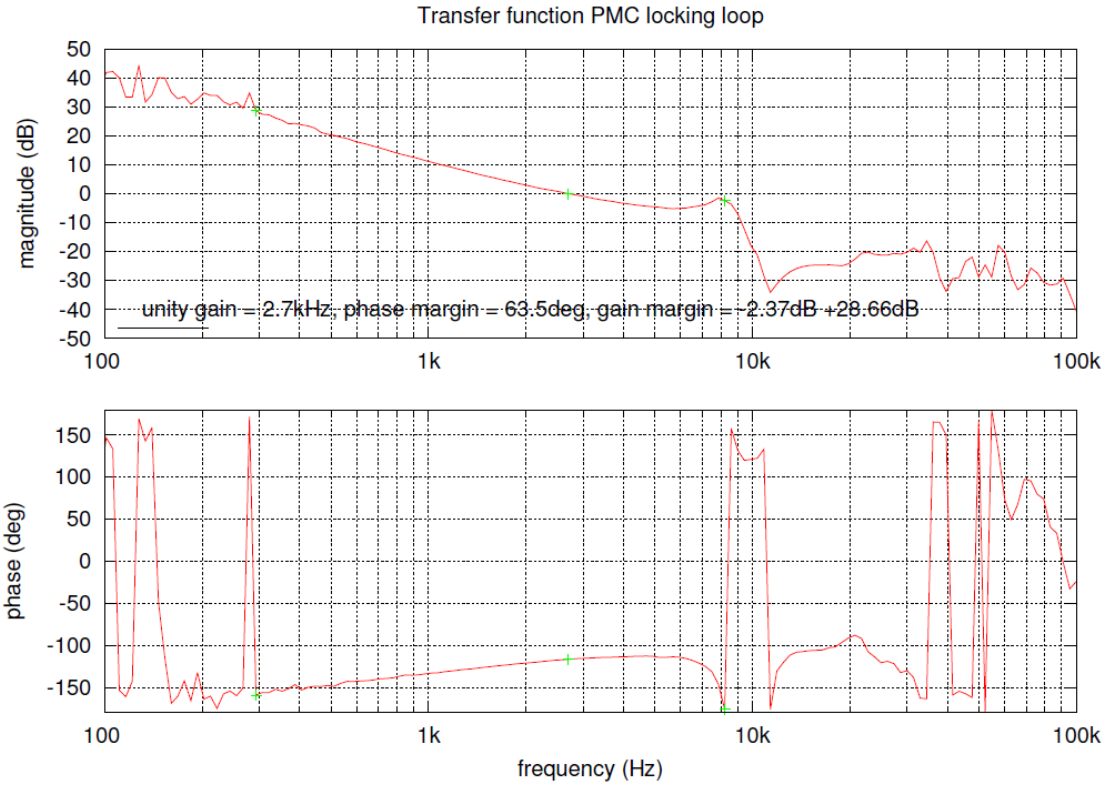
d. <u>Error point noise of PMC locking loop + frequency calibration of error signal, without FSS</u>



(error point above 10kHz limited by electronic noise)
https://dcc.ligo.org/DocDB/0068/E1100716/001/PMC_frqnoise_FFSoff.pdf
https://dcc.ligo.org/DocDB/0068/E1100716/001/PMCnoiseFSSoff_error_point.zip
https://dcc.ligo.org/DocDB/0068/E1100716/001/PMCnoiseFSSoff_actuator.zip

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

f. Transfer function of PMC locking loop + UG frequency

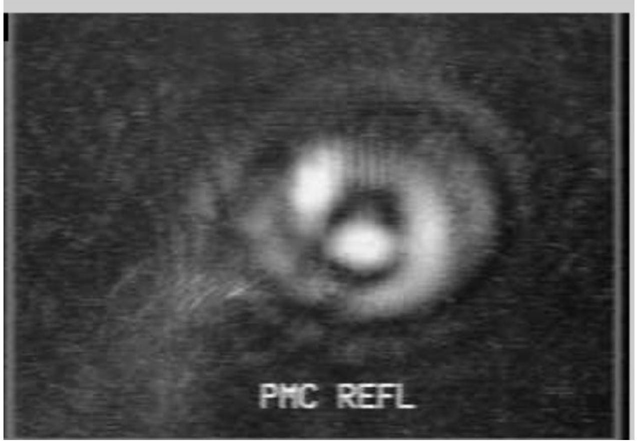


https://dcc.ligo.org/DocDB/0068/E1100716/001/tf.pdf
https://dcc.ligo.org/DocDB/0068/E1100716/001/PMC_loopTF.zip

g. Dynamic range of PMC PZT in FSR (measured at reference system at AEI)
PZT range: 2.3 FSR (for 382V), the PZT is not linear and this number is only give as an order of magnitude reference

h. DC voltage of PMC locking PD
in locked state: 0.14V
unlocked: 1.56V => mode-matching efficiency >89% (if corrected for higher order modes measured in 2.2.2: mode-matching efficiency > 94%

i. CCD image of reflected mode / transmitted mode

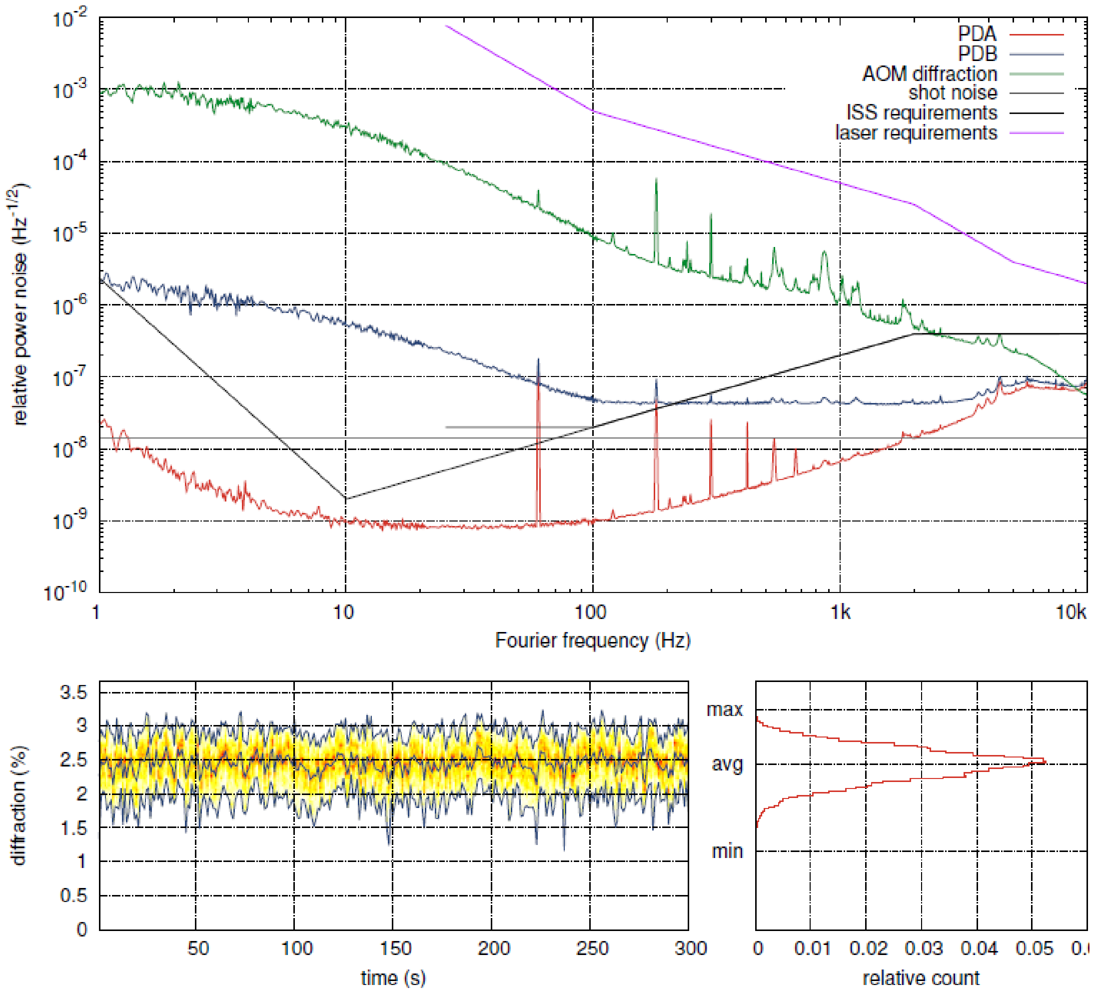


2.4 Power Stabilization (inner loop on PSL table)

pre shipment testing:

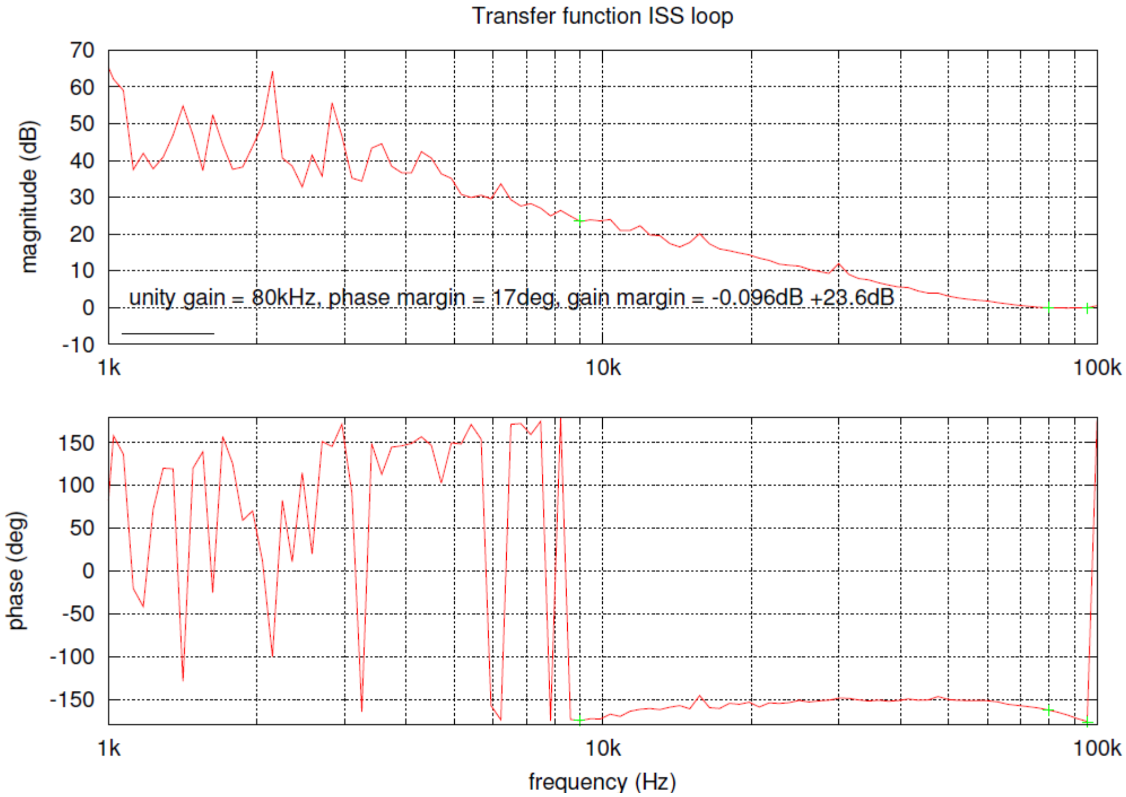
Name	**Designation**	**Design Doc. or Part No.**	**SN**	**Test Procedure**	**Completed Test Document**
ISS Servo		D1001985	S1103557		
ISS sensing box		D1003121 D1001998 D1002280	S1102967	E1000748 T1000473 E1000467	E1100125
ISS acousto optical modulator driver		See S1103745	S1103745	NA	NA
ISS AA filter		D070081	S1001244	T070146	S1001244
ISS AI filter		D070081	S1001231	T070146	S1001231

a. <u>In-loop/out-of-loop RPN measurement</u>



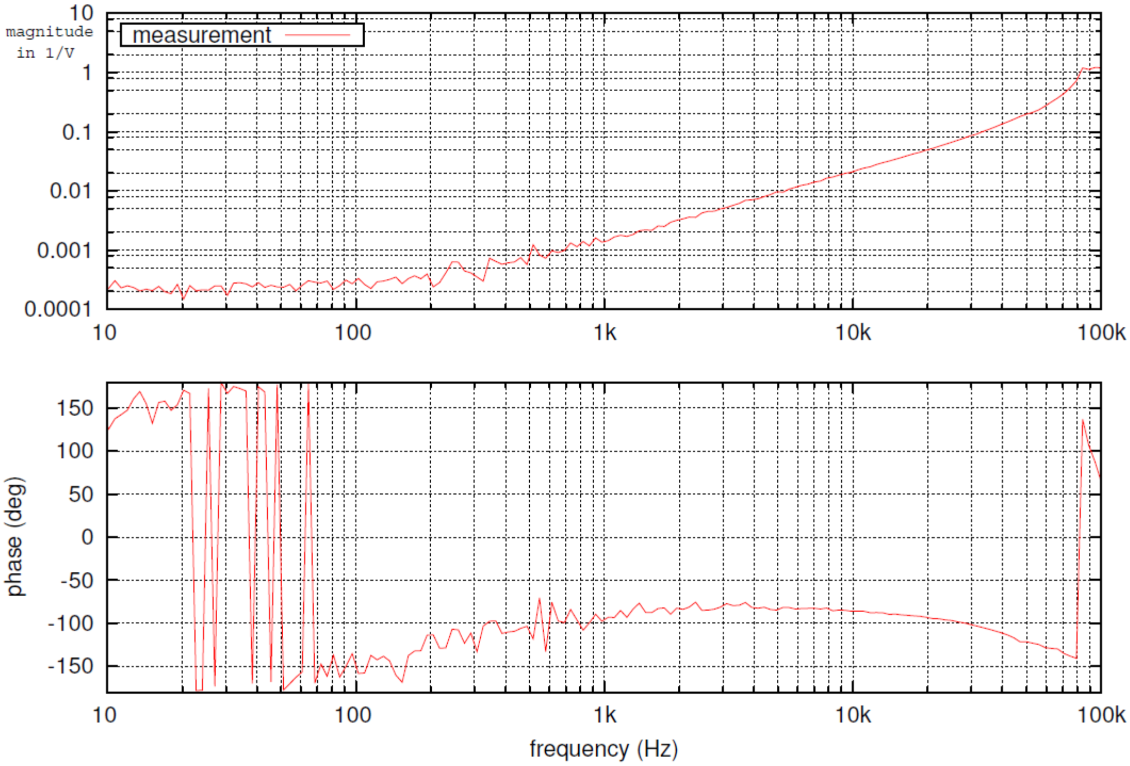
more info in full noise report under the following URL:
https://dcc.ligo.org/DocDB/0068/E1100716/001/iss_rpn-002.pdf
https://dcc.ligo.org/DocDB/0068/E1100716/001/iss_rpn-002.zip

b. Transfer function of ISS loop + UG frequency



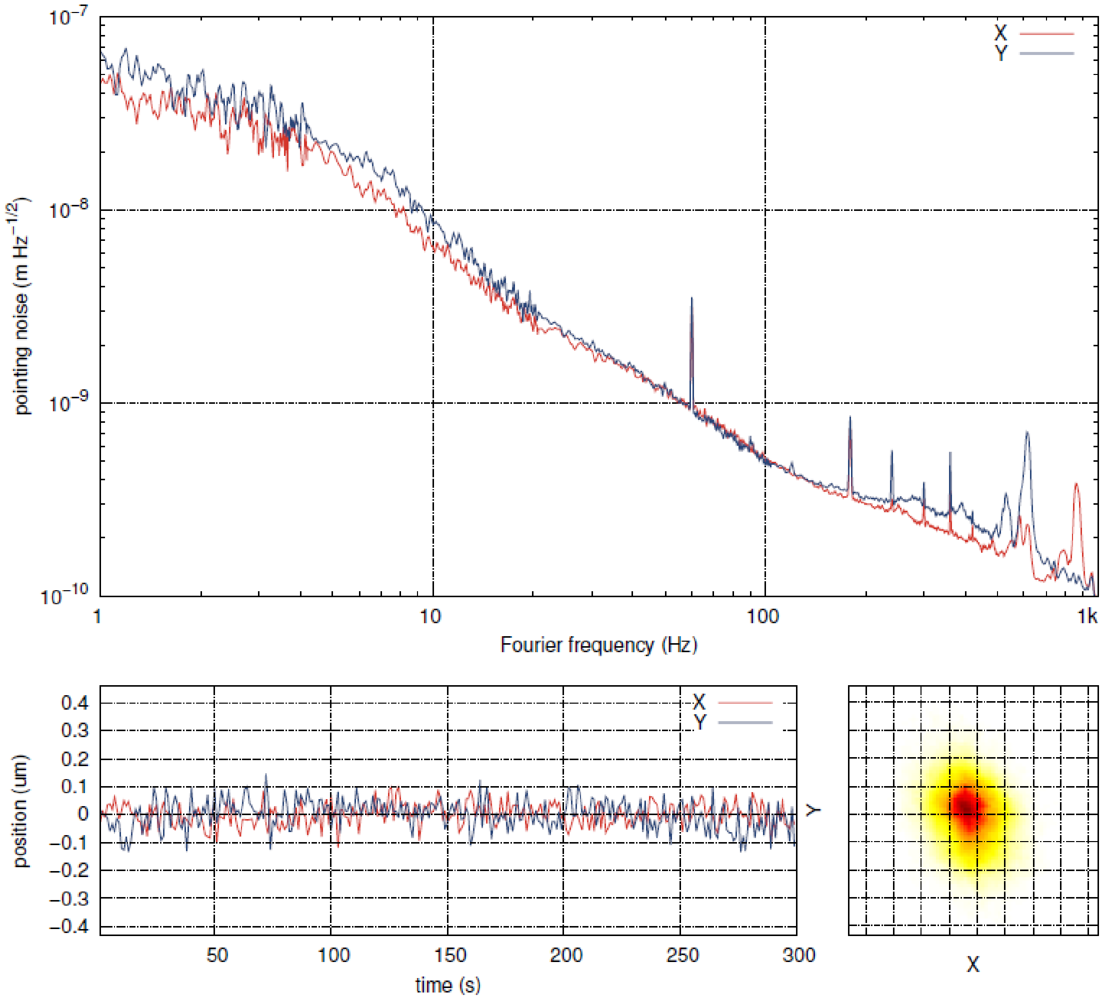
measured with 100kHz FFT Analyzer, region around 100kHz should be re-measured and loop gain should be adjusted to get reasonable gain margin,
https://dcc.ligo.org/DocDB/0068/E1100716/001/ISS_tf.pdf
https://dcc.ligo.org/DocDB/0068/E1100716/001/ISS_TF.zip

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



plotted are relative power modulation per volt injected into error point of inner loop
https://dcc.ligo.org/DocDB/0068/E1100716/001/error_point_injectionTF.pdf
https://dcc.ligo.org/DocDB/0068/E1100716/001/error_point_injectionTF.zip

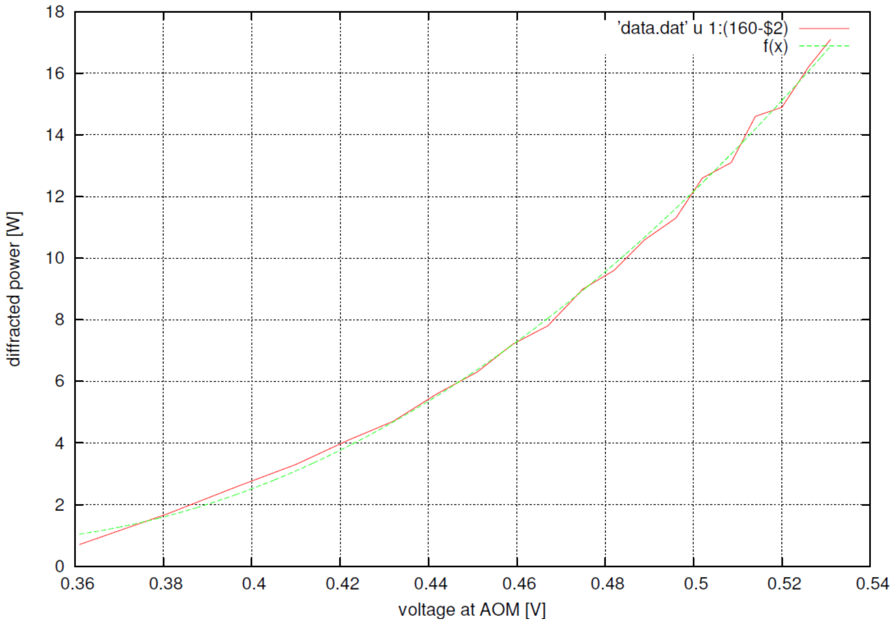
d. Pointing X, Y + calibration



for pdf and data see URLs given in 2.4

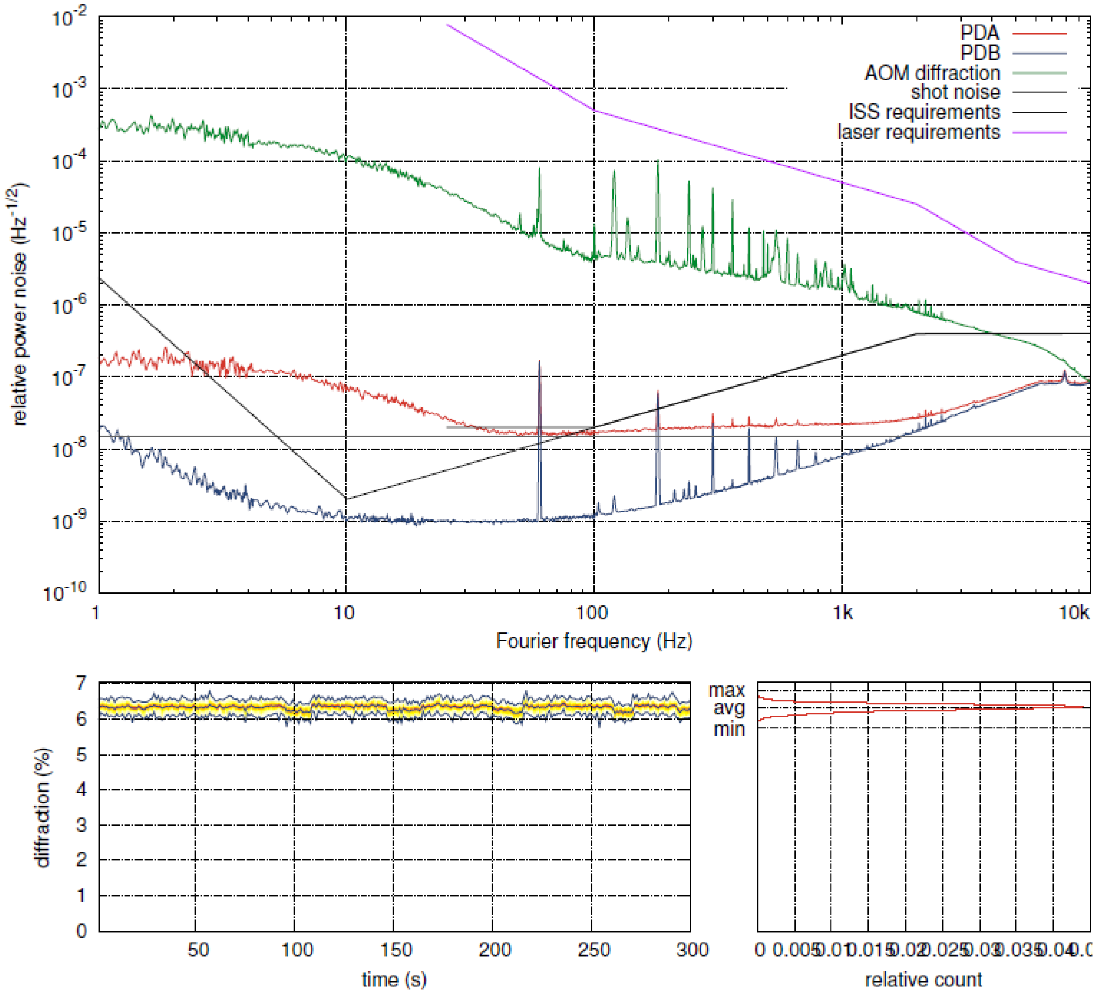
(note that these pointing fluctuations are measured in the ISS box on a beam leaking out of the PMC, hence the measured spectrum can be used as a rough estimate of the beam pointing of the high-power beam at the output of the PMC)

e. Actuator linearity



https://dcc.ligo.org/DocDB/0068/E1100716/001/actlin.pdf
https://dcc.ligo.org/DocDB/0068/E1100716/001/actlin.zip

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



more info in full noise report under the following URL:
https://dcc.ligo.org/DocDB/0068/E1100716/001/iss_rpn-002_low_power.pdf
https://dcc.ligo.org/DocDB/0068/E1100716/001/iss_rpn-002_low_power.zip

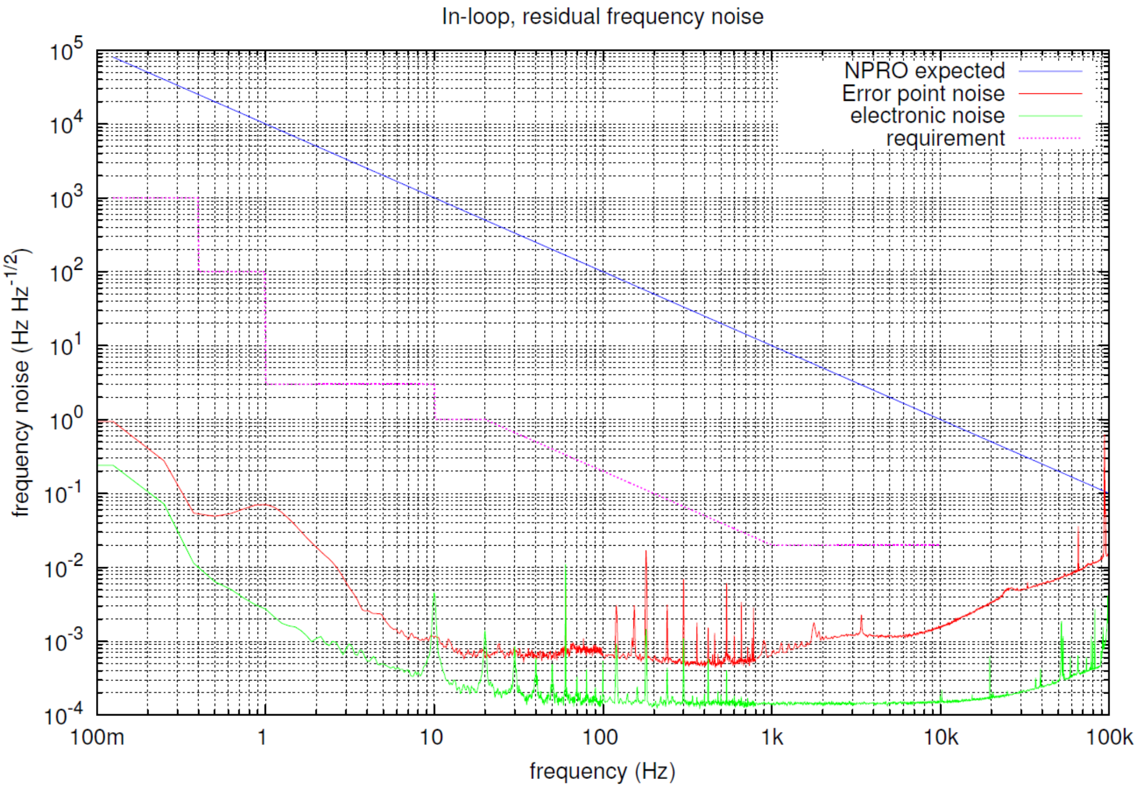
2.5 Frequency Stabilization

pre shipment testing:

Name	**Designation**	**Design Doc. or Part No.**	**SN**	**Test Procedure**	**Completed Test Document**
FSS table top servo*		D040105 T1100119 D1100371	S1103596*	E040418	
FSS TTFSS field box 2		D1100367	S1103554	not available	
FSS rf-photodiode		D980454	XXXX		
FSS temperature sensor interface box		not available	S1103686	S1103686	
FSS VCO 2		D980401	S1103755		
FSS VCO fieldbox		D1100369	S1103555	not available	
FSS AA filter		D070081	S1001245	T070146	S1001245
FSS AI filter		D070081	S1001232	T070146	S1001232
FSS rf summation box		D040469	S1103598		
21 MHz oscillator:		D080705		E1000059	
distribution amplifier:		D1000124		T1000256	
delay line phase shifter:		T050250	S1103561	T050183	S1103561

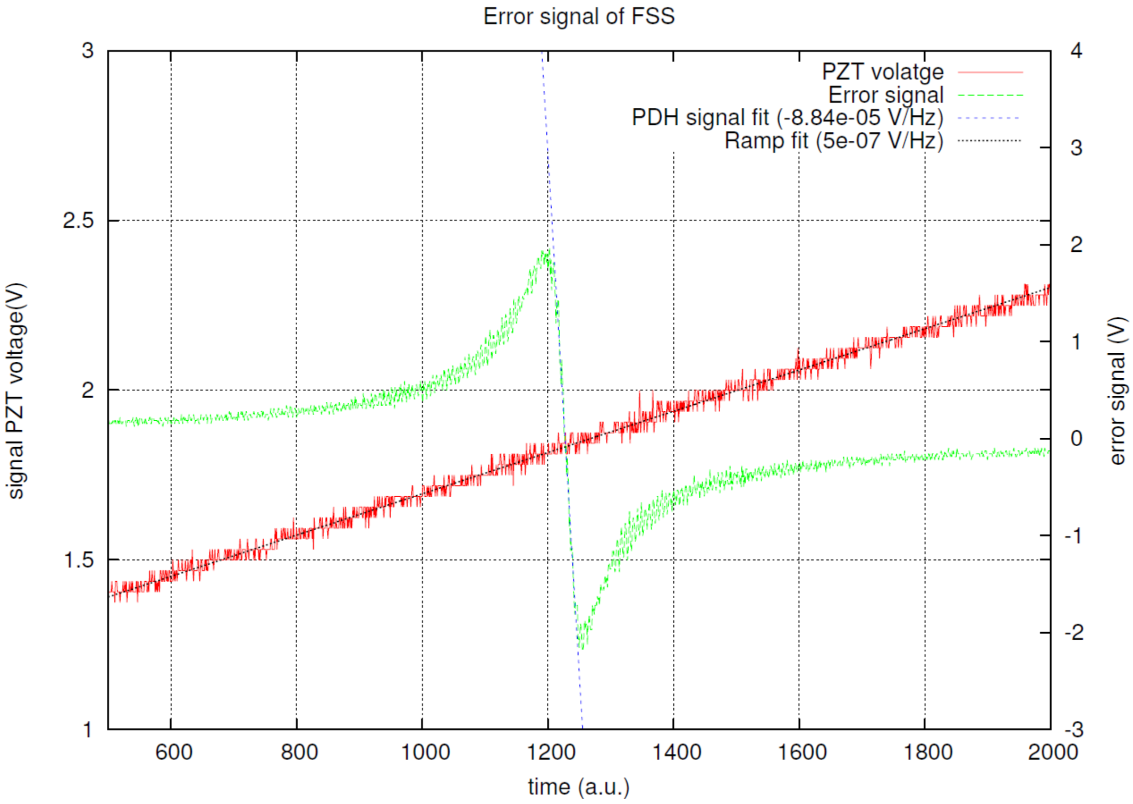
* initial LIGO electronic, Revision B with modifications documented in e-traveler (paper version), further modifications were made according to T1100119 prior to aLIGO installation

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



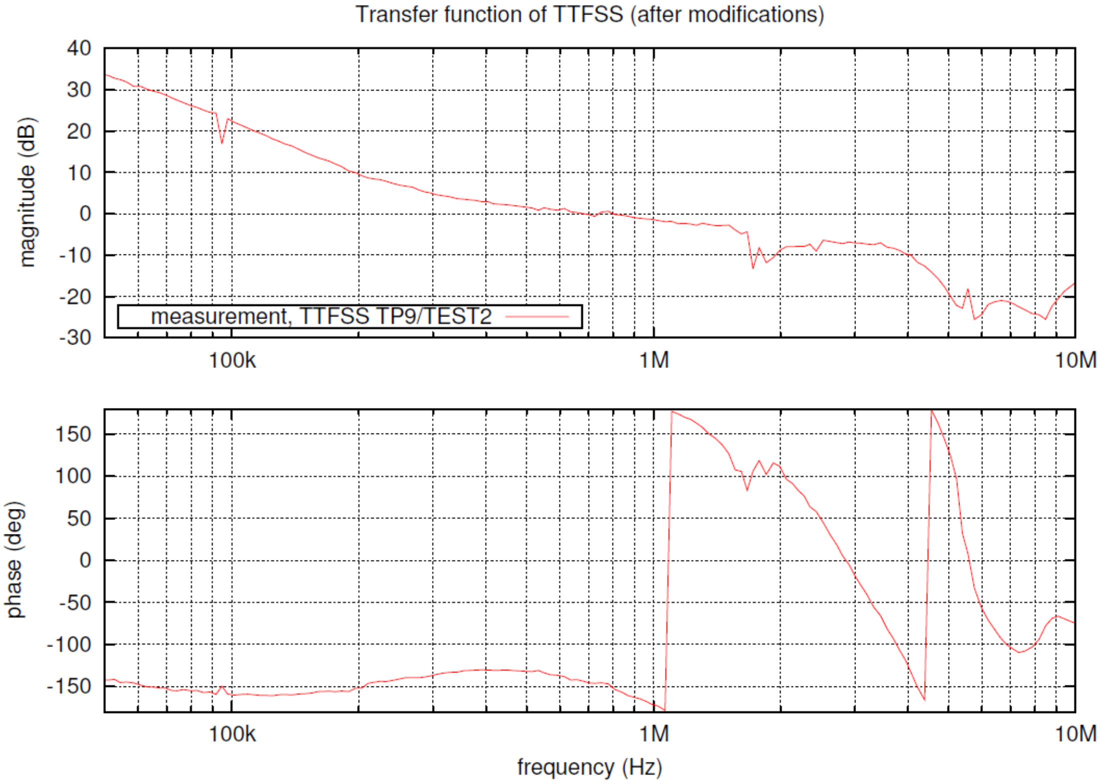
https://dcc.ligo.org/DocDB/0068/E1100716/001/freqnoise_FSS.pdf
https://dcc.ligo.org/DocDB/0068/E1100716/001/freqnoise_FSS.zip

b. Error signal (time series)



https://dcc.ligo.org/DocDB/0068/E1100716/001/errorsignal_FSS.pdf
https://dcc.ligo.org/DocDB/0068/E1100716/001/errorsignal_FSS.zip

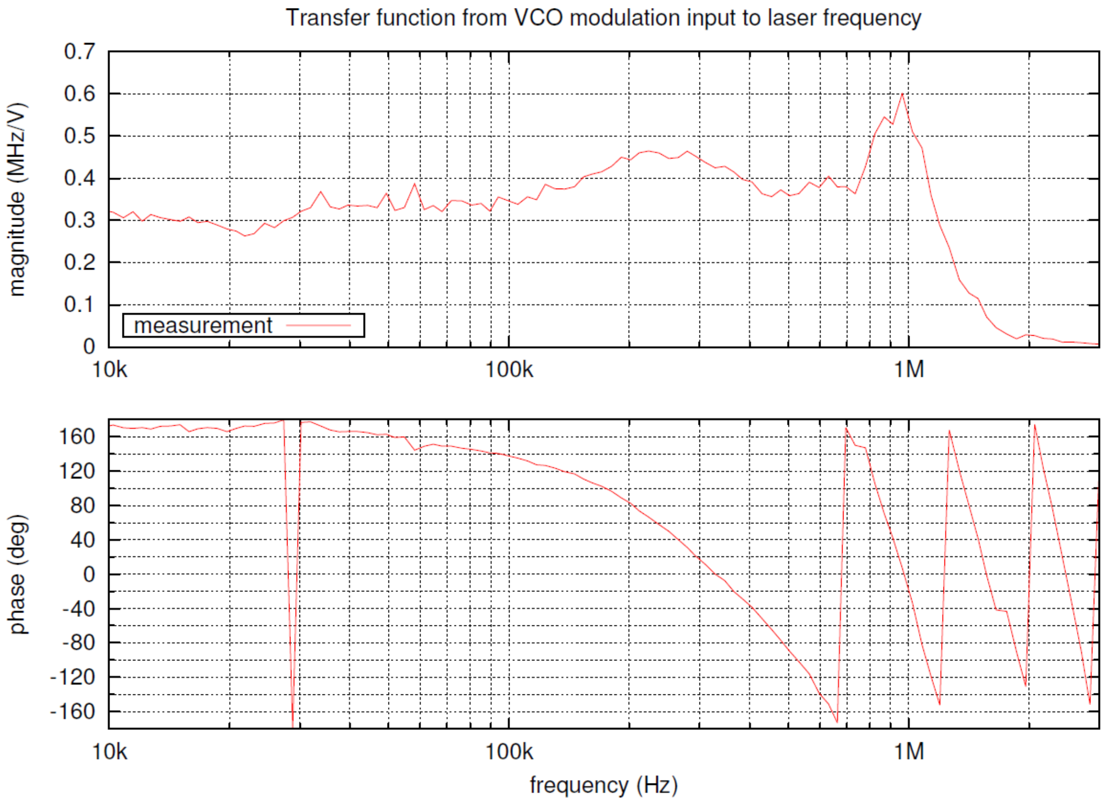
c. FSS loop transferfunction



https://dcc.ligo.org/DocDB/0068/E1100716/001/TTFSSTF.pdf
https://dcc.ligo.org/DocDB/0068/E1100716/001/TTFSSTF.zip

d. AOM double pass efficiency
15.4% (should to be optimized later)

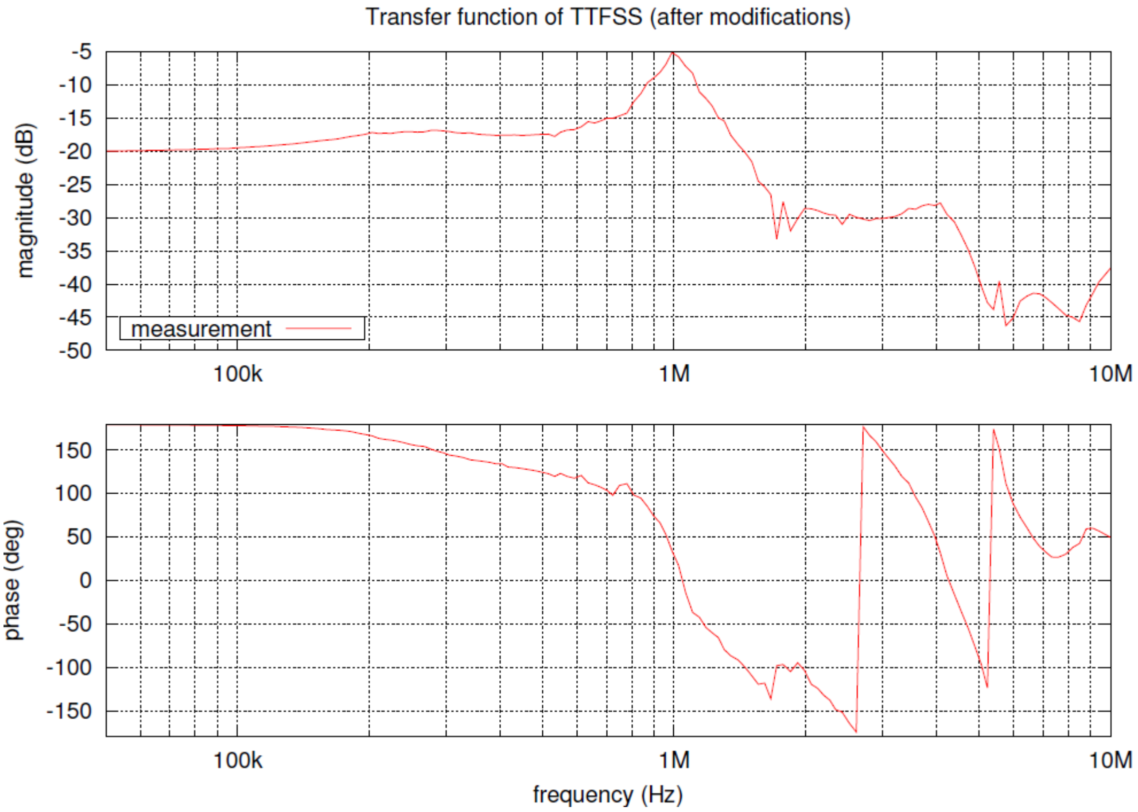
e. Transfer function from VCO modulation input to laser frequency



https://dcc.ligo.org/DocDB/0068/E1100716/001/VCO_tf.pdf
https://dcc.ligo.org/DocDB/0068/E1100716/001/VCO_TF.zip

f. <u>DC voltage of RF photodiode</u>
rf PD DC unlocked 0.46V (corresponds to 4.6mA photocurrent)
rf PD DC locked 0.032V

g. Transfer function from error modulation input to laser frequency

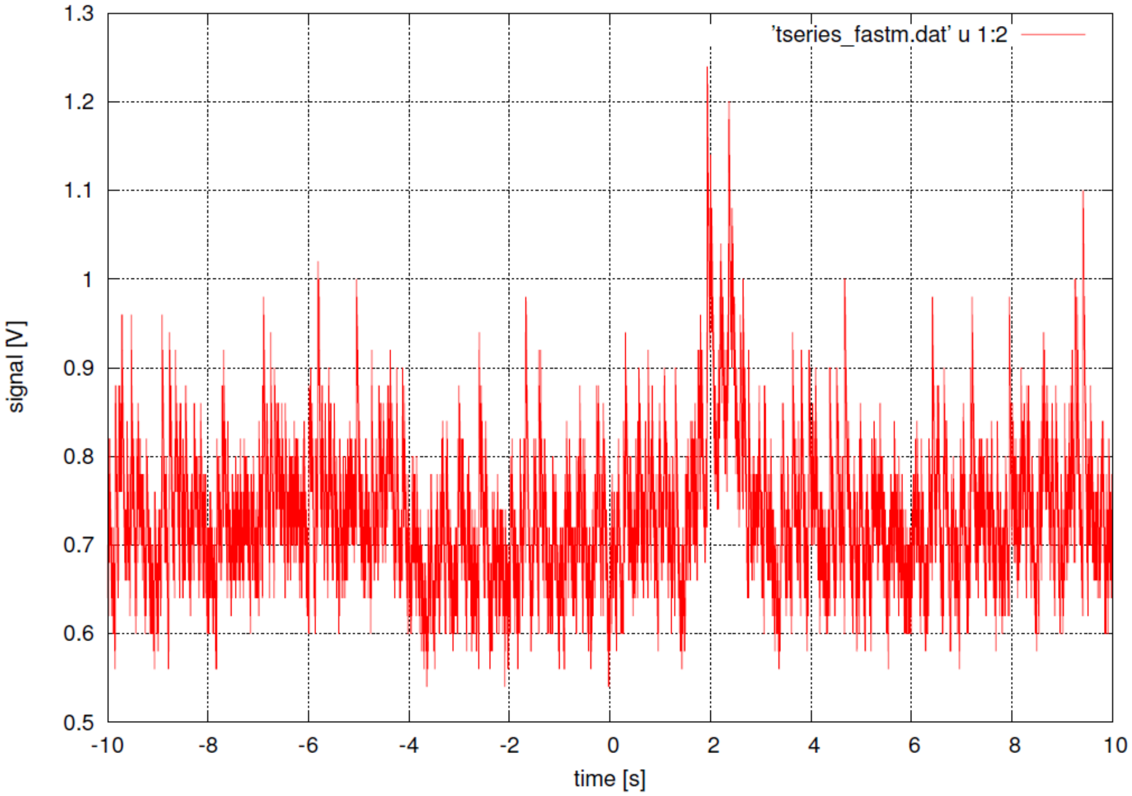


https://dcc.ligo.org/DocDB/0068/E1100716/001/ERRIJTF.pdf
https://dcc.ligo.org/DocDB/0068/E1100716/001/ERRIJTF.zip

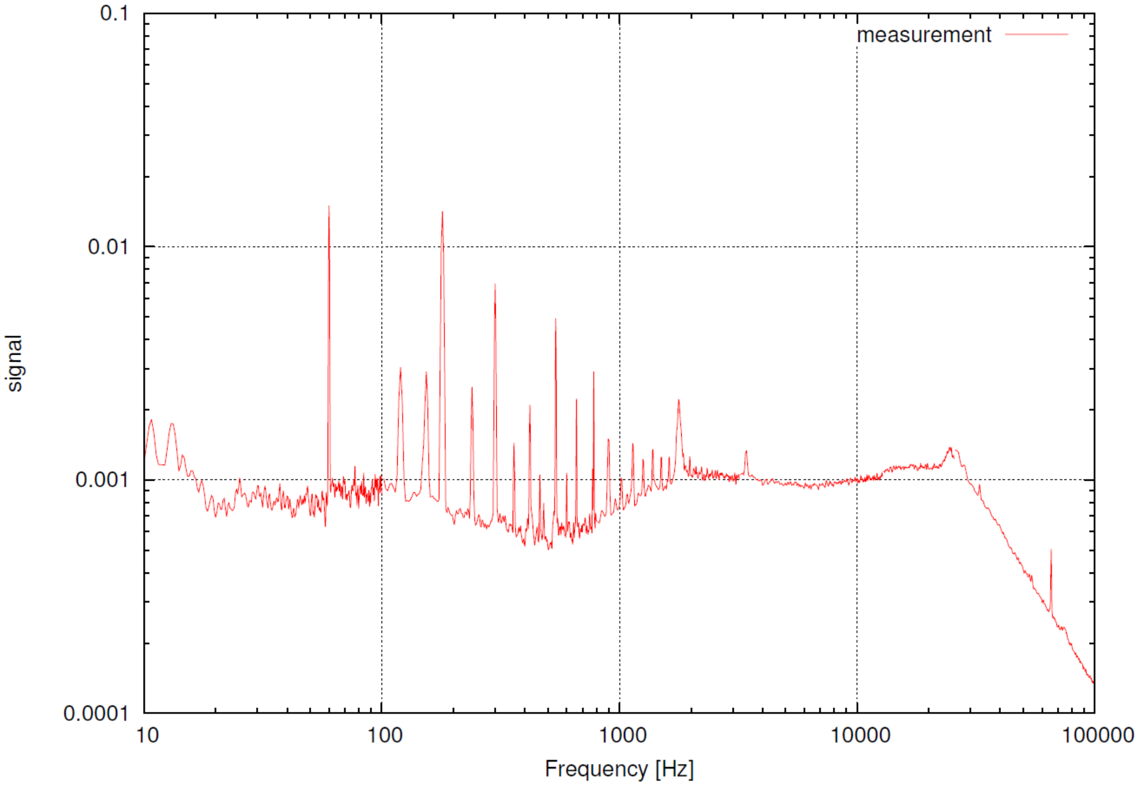
h. Power transmitted by reference cavity, absolute + relative
ref caf trans 4.87mW (injected 5.72mW, 85% transmission)
ref cav trans @ ALS port 4.72mW

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

FSS fast actuator (PZT) - time series

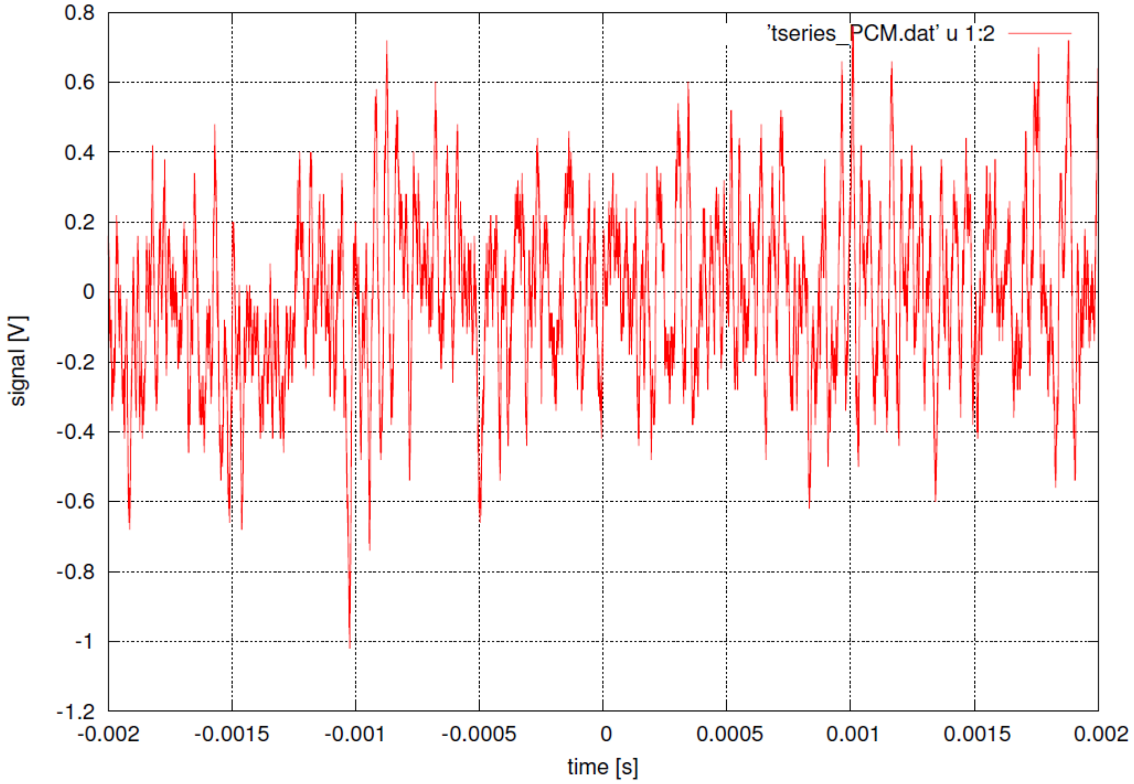


FSS fast actuator (PZT) – spectrum



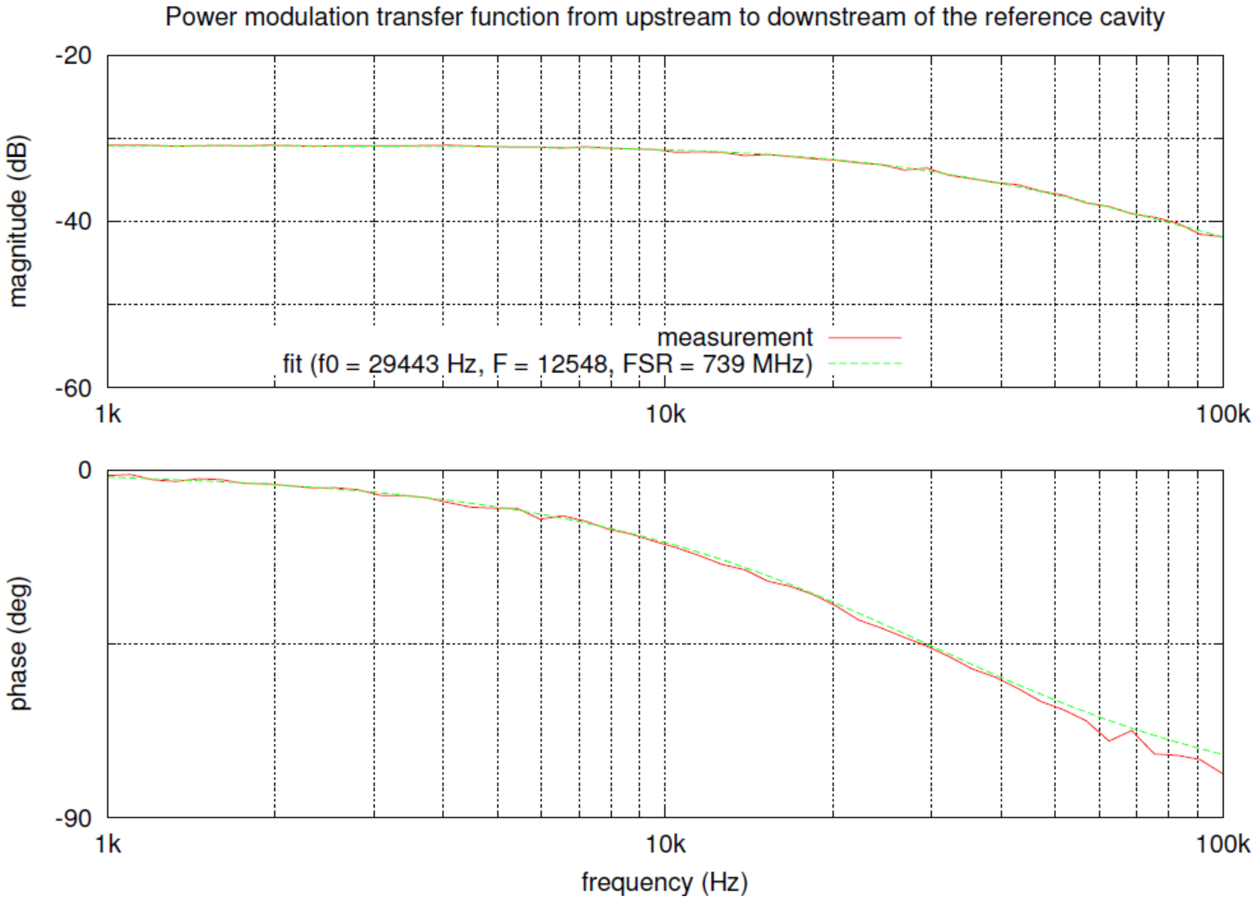
https://dcc.ligo.org/DocDB/0068/E1100716/001/FSS_fast_spec.pdf
https://dcc.ligo.org/DocDB/0068/E1100716/001/FSS_Fast.zip
https://dcc.ligo.org/DocDB/0068/E1100716/001/TTFSSTF.pdf

FSS PC actuator (PZT) – time series



https://dcc.ligo.org/DocDB/0068/E1100716/001/FSS_PC_tseries.pdf
https://dcc.ligo.org/DocDB/0068/E1100716/001/FSS_PC_tseries.zip

j. <u>Finesse of reference cavity</u>
F=12548
(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/0068/E1100716/001/Finesse_tf.pdf
https://dcc.ligo.org/DocDB/0068/E1100716/001/Finesse_tf.zip

2.6 Miscellaneous

Name	**Designation**	**Design Doc. or Part No.**	**SN**	**Test Procedure**	**Completed Test Document**
Power monitoring photo diode			S1103590		
FSS transmission photo diode			S1103592		
PSL table power distribution unit		D1002708	S1103734 S1103735 S1103736		
PSL monitoring fieldbox		D1002292	S1103263	E1000696	S1103263
PSL CCD breakout panel		D1100115	S1103562	NA	NA

3 Integrated PSL Tests

3.1 perform “cold start” and document startup procedure

acquire 24 hour DAQ reference data beginning with “cold start” of system, note down duration and time of longest lock observed (control loop independently and full PSL)

from aLIGO LLO Logbook: (https://alog.ligo-la.caltech.edu/aLOG/index.php?callRep=1359):

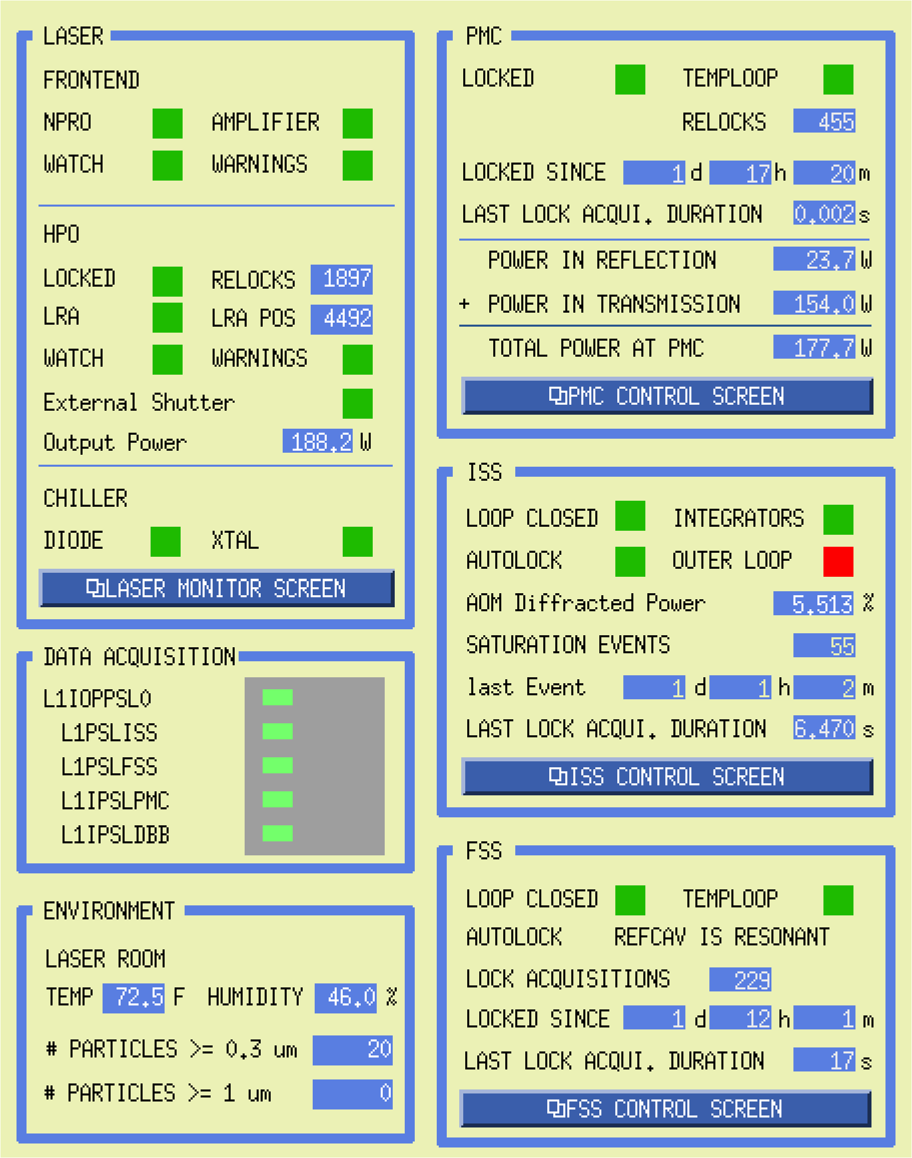
```
The test procedure of the PSL calls for a cold start of the full system.

July 15
The laser was shut-down at 12:10 (LLO time)
restarted the laser at 13:34 (LLO time)
- turned HP oscillator on: power 155W (running in both directions, front end
off)
- after 3 min turned injection locking on: 214.4W on power head of external
shutter
- reading of injection locking photodiode: 232.5W
- turned PMC auto-lock on: immediate locking of PMC
- turnde FSS auto-lock on: first lock after 34s, (after 5 min stable locking
for 10 min, after 25 min stable locking for at least 2 hours)
- turned ISS on: first instable locking as reference level was too large, after
adjusting of reference level stable locking
- PMC transmitted power 156.7W (with ISS diffracted power of 3.5%)

Jul 16
- around 3am (UTC) FSS relocked several times, adjusted the oscillation-monitor
threshold
- 13:49 (UTC) reduced the ISS reference level to increase the average
diffraction from 4% to 6%

Jul 17
14:49 UTC
- continues lock durations: PMC ~ 43 hours, ISS 25 hours, FSS 36 hours
19:08 (UTC)
- realized that FSS was oscillating since 16 July 2:45 (UTC), relocked FSS and
changed gain
22:02 (UTC) probably earlier (21:28 utc)
short power outage LLO, laser shut down
```

3.2 take photos of laser table, LVEA electronics, LDR, chiller and water manifolds

see https://ligoimages.mit.edu/pages/search.php?search=%21collection666

3.3 screen shots of medm and Beckhoff screens

see https://dcc.ligo.org/DocDB/0068/E1100716/001/LLO PSL MEDM and Beckhoff screens after installation.pdf screen shots of LaserStatus MEDM screen in high power mode, taken on 17 July 2011 at 16:49 UTC, approximately 1day and 17h after cold start)



FRONTEND
NPRO 🟩 AMPLIFIER 🟩
WATCH 🟩 WARNINGS 🟩

HPO
LOCKED 🟩 RELOCKS 1897
LRA 🟩 LRA POS 4492
WATCH 🟩 WARNINGS 🟩
External Shutter 🟩
Output Power 188.2 W

CHILLER
DIODE 🟩 XTAL 🟩

L1IOPPSL0 🟩
L1PSLISS 🟩
L1PSLFSS 🟩
L1IPSLPMC 🟩
L1IPSLDBB 🟩

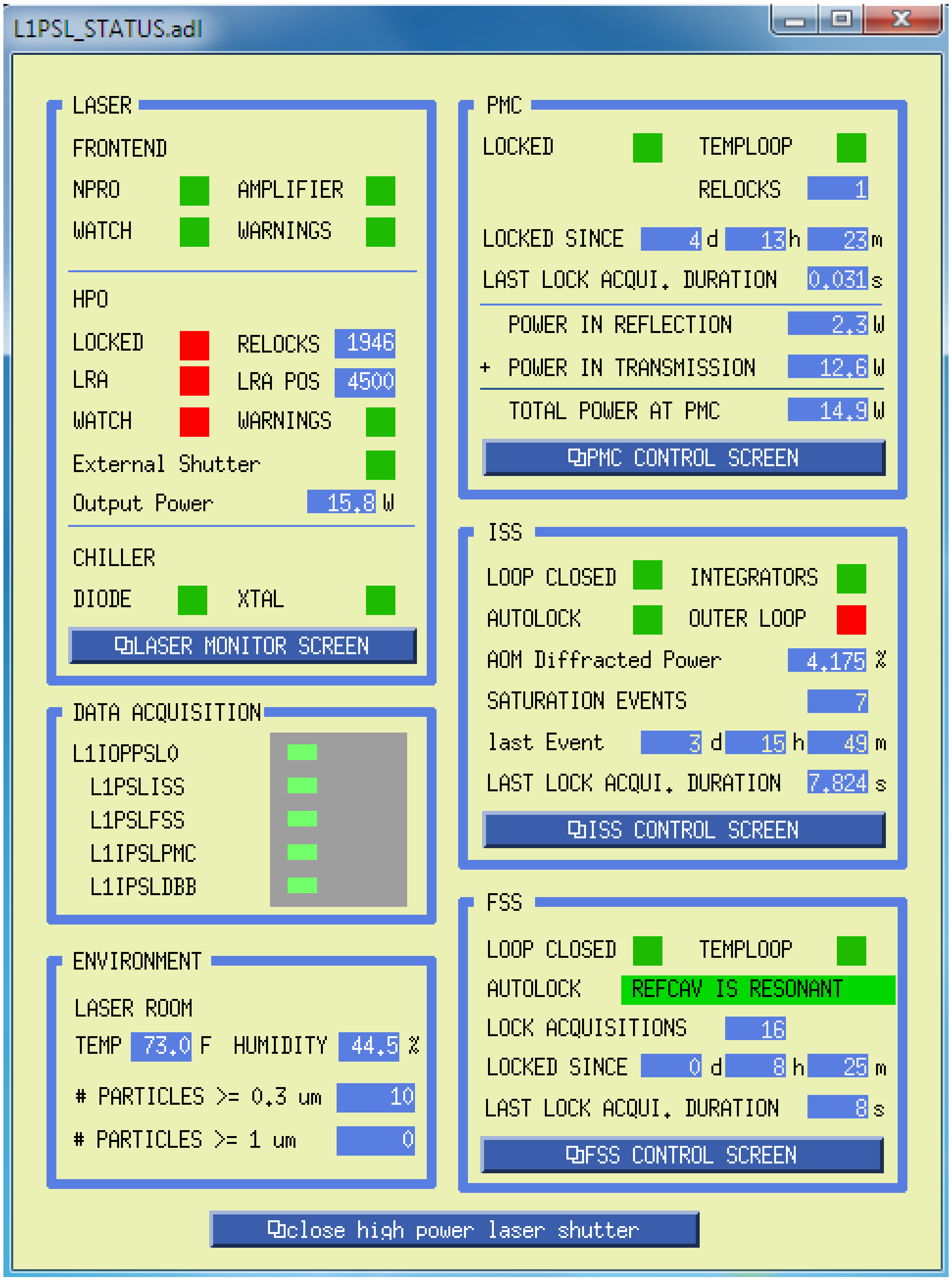
LASER ROOM
TEMP 72.5 F HUMIDITY 46.0 %
PARTICLES >= 0.3 um 20
PARTICLES >= 1 um 0

LOCKED 🟩 TEMPLOOP 🟩
RELOCKS 455
LOCKED SINCE 1 d 17 h 20 m
LAST LOCK ACQUI. DURATION 0.002 s
POWER IN REFLECTION 23.7 W
\+ POWER IN TRANSMISSION 154.0 W
TOTAL POWER AT PMC 177.7 W

LOOP CLOSED 🟩 INTEGRATORS 🟩
AUTOLOCK 🟩 OUTER LOOP 🟥
AOM Diffracted Power 5.513 %
SATURATION EVENTS 55
last Event 1 d 1 h 2 m
LAST LOCK ACQUI. DURATION 6.470 s

LOOP CLOSED 🟩 TEMPLOOP 🟩
AUTOLOCK REFCAV IS RESONANT
LOCK ACQUISITIONS 229
LOCKED SINCE 1 d 12 h 1 m
LAST LOCK ACQUI. DURATION 17 s

screen shots of LaserStatus MEDM screen in low power mode,
(screen shot taken on 25 July 2011 at 9:39 (UTC)



LASER

FRONTEND
NPRO 🟩 AMPLIFIER 🟩
WATCH 🟩 WARNINGS 🟩

HPO
LOCKED 🟥 RELOCKS 1946
LRA 🟥 LRA POS 4500
WATCH 🟥 WARNINGS 🟩
External Shutter 🟩
Output Power 15.8 W

CHILLER
DIODE 🟩 XTAL 🟩

DATA ACQUISITION
L1IOPPSL0 🟩
L1PSLISS 🟩
L1PSLFSS 🟩
L1IPSLPMC 🟩
L1IPSLDBB 🟩

ENVIRONMENT
LASER ROOM
TEMP 73.0 F HUMIDITY 44.5 %
PARTICLES >= 0.3 um 10
PARTICLES >= 1 um 0

PMC
LOCKED 🟩 TEMPLOOP 🟩
RELOCKS 1
LOCKED SINCE 4 d 13 h 23 m
LAST LOCK ACQUI. DURATION 0.031 s
POWER IN REFLECTION 2.3 W
+ POWER IN TRANSMISSION 12.6 W
TOTAL POWER AT PMC 14.9 W

ISS
LOOP CLOSED 🟩 INTEGRATORS 🟩
AUTOLOCK 🟩 OUTER LOOP 🟥
AOM Diffracted Power 4.175 %
SATURATION EVENTS 7
last Event 3 d 15 h 49 m
LAST LOCK ACQUI. DURATION 7.824 s

FSS
LOOP CLOSED 🟩 TEMPLOOP 🟩
AUTOLOCK REFCAV IS RESONANT
LOCK ACQUISITIONS 16
LOCKED SINCE 0 d 8 h 25 m
LAST LOCK ACQUI. DURATION 8 s

4 Performance vs PSL design requirements (T050036)

a. Power at IO interface (downstream of PMC): ≥ 165W for more than one week
with ISS on (approx.. 5% power diffracted by ISS-AOM we get 154W downstream of PMC

b. Higher order mode power < 5W
we see 5.3% higher order mode content (~9W) 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 100.5mm, beam angle less than 2deg

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, see for example cold start

f. Power fluctuations at PSL/IO interface: ≤ 5% over 24h
not verified with external photodiode downstream of PMC (DC coupled ISS is, however, stable for several days and we do not expect ISS reference voltage to fluctuate by 5%)

g. Demonstrate power adjust capability at the PSL/IO interface via EPICS: 1% peak-to-peak variations (response time >10 sec)
not demonstrated, EPICS variable for power control is available

h. Demonstrate control band (0.1Hz – 10Hz) power stability requirements (see T050036-v4)
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 200Hz, noise at 30Hz is about factor of 10 too high (see 2.4a)
in low power mode requirements are met (see 2.4.f)

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 2×10^{-7} $(\mathrm{Hz})^{-1/2}$ (narrow signals above this level may be acceptable depending on their exact frequency)
demonstrated above 500kHz, between 10kHz and 500kHz more measurements are required

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 1×10^{-9} $(\mathrm{Hz})^{-1/2}$.
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.
performance close or below requirements for all DOFs (see 2.2.2i)

n. FSS: show that wideband frequency actuator meets requirement (less than 20deg phase lag at 50kHz)
demonstrated (see 2.5.e)

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
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.	☐	observatory staff will add photos of the components on the table, as well as photos of the interior of the 35W head and the 200W power amplifier
2.	☒	the DBB frequency plots in 2.2.1 should be noted as reference only, with conditions for measurement (e.g. fan/filter unit on)
3.	☒	in section 2.3g, add voltage required for 1 FSR
4.	☒	in section 2.5, add PZT calibration performed at AEI 3 yrs ago
5.	☒	mode matching into the PMC: cite injected, rejected & transmitted power
6.	☒	resolve ambiguity regarding schematic for the "FSS Table Top Servo" -- see section 2.5 of E1100716-v1
7.	☒	optimize double pass efficiency of FSS AOM
8.	☒	measure pointing of beam at output of PMC with ISS quadrant diode
9.	☐	continue investigations and mitigations of vibrations on optical table caused by turbulent cooling water flow in the high-power-laser heads (follow up of T1200171-v1 investigations)
10.	☒	optimize loop gain in ISS and re-measure 2.4b
11.	☒	measure power drift at PSL/IO interface (see 4.f), requirement: <5% over 24h, measurement is possible once PMC transmission photodiode is installed (change request pending)
12.	☒	demonstrate power adjust capability at the PSL/IO interface via EPICS: 1% peak-to-peak variations (response time >10 sec) (see 4.h), can be done once PMC transmission photodiode is installed
13.	☐	continue investigations of excess power noise (see 4i) at AEI, might become obsolete if outer-loop performs to specs
14.	☒	measure power noise between 10kHz and 500kHz (see 4.k)

documentation/measurements to close the remaining actions

(the pdf version and data to all measurements can be found as “other files” attached to https://dcc.ligo.org/cgi-bin/private/DocDB/ShowDocument?docid=68165)

No 7: Investigation of low PSL AOM diffraction efficiency

At the installation of the PSL we found that the diffraction efficiency of the FSS AOM was surprisingly low. Additionally R. Adhekari was suspecting during IMC commissioning that the beam waist was not at the center of the VCO.

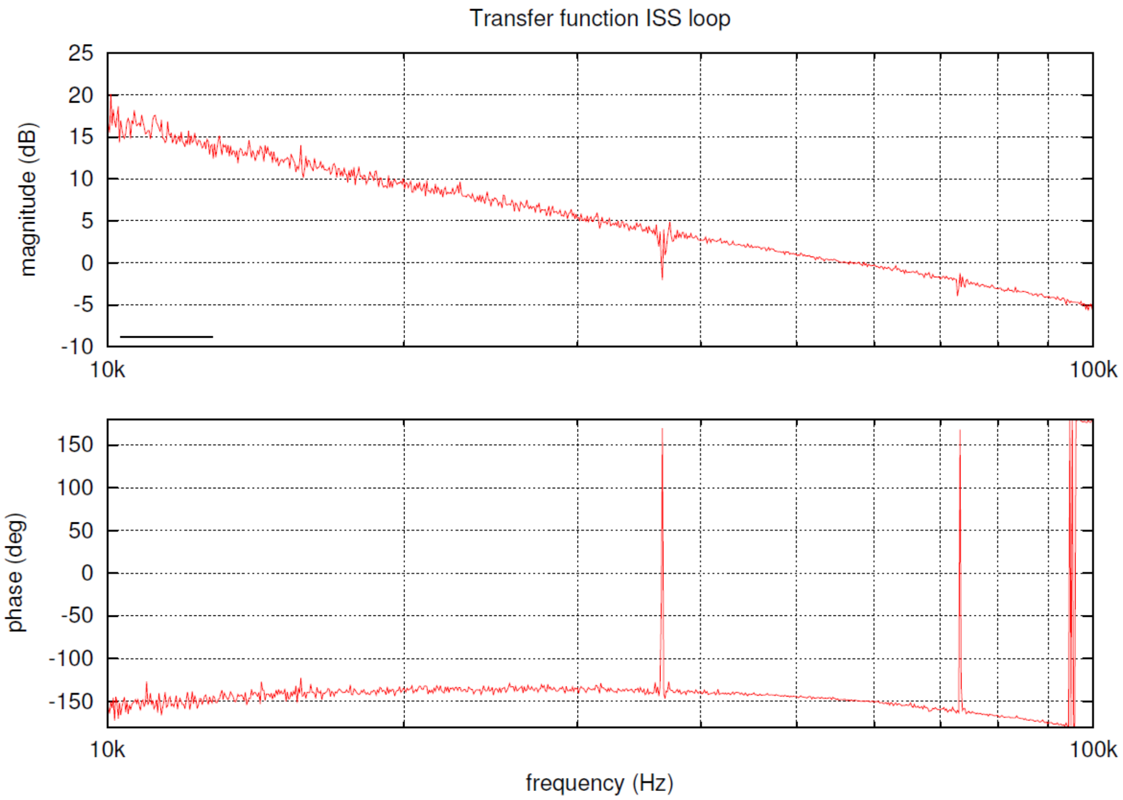
A WinCam measurement of the beam size showed that the waist size(170um) was in accordance to the AOM specs (80% diffraction efficiency at 1.3W drive with more than 90um beam radius). However, the waist position is 65mm upstream of the center of the AOM leading to a beam size of 213um at the single pass and 152um at the double pass.

We measured the diffraction efficiency with the old VCO (D980401, see table first column) and then looked at the rf power applied to the AOM. It was 28.57dBm and therefore too low (it is supposed to be 31dBm). In order to check how much the diffraction efficiency is at the nominal power level we added an rf amplifier (Mini-Circuits ZHL-3A) and took another measurement (second column). It seems that without any optimization of the alignment we got close to the AOM specs. Jan Pöld will check whether we are missing some gain in the signal that drives the rf amplifier (modlevel) or if the amplifier itself does not act as expected (He was told this happened before).

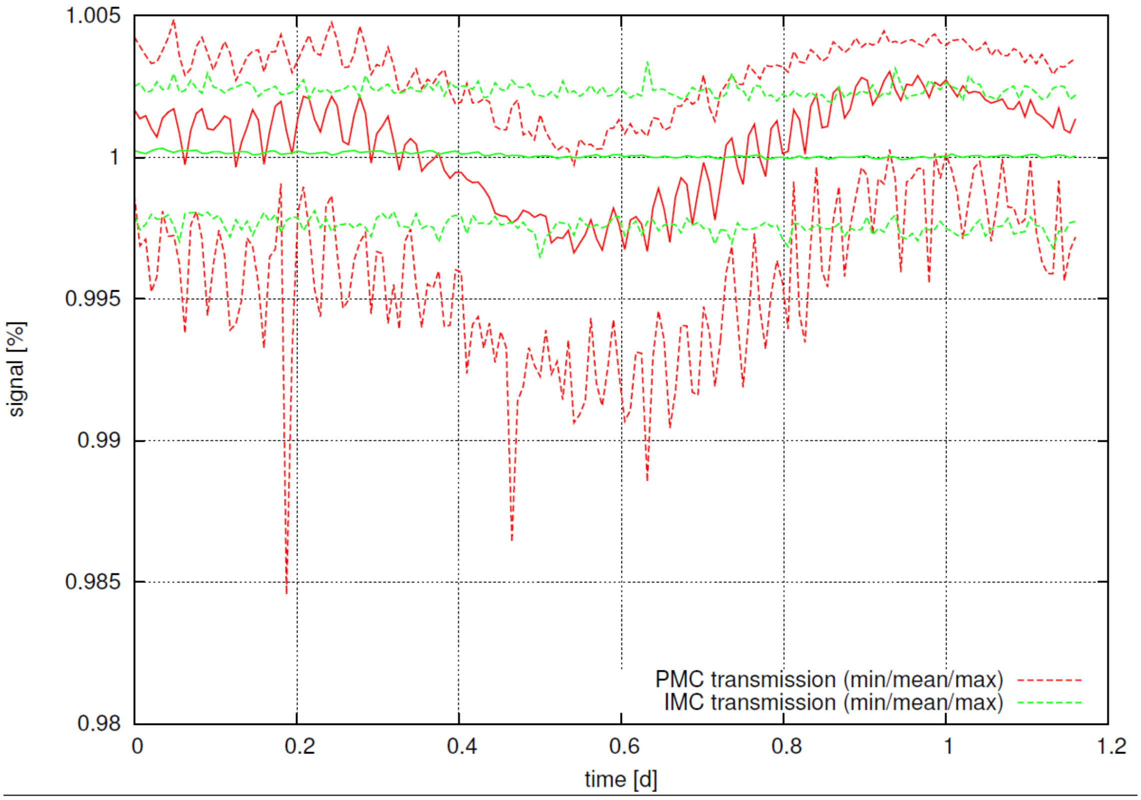
	VCO w/o amplifier (28.5dBm)	VCO w amplifier (31dBm)
input beam	25.5mW	28.7mW
after single pass	10.5mW	19.57mW
double pass	4.65mW	13mW
diffraction efficiency	0.41	0.68

No 8: measurement was already done but not recognized during review (see 2.4d)

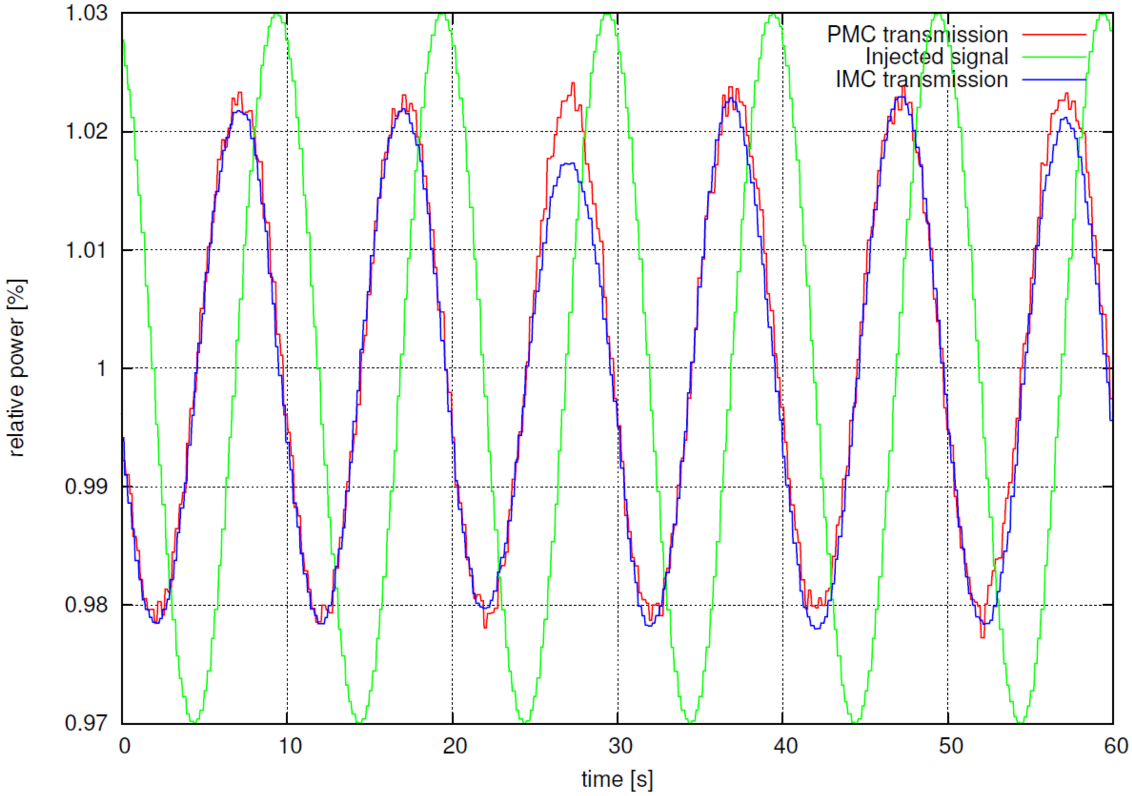
No 10: ISS transfer function was optimized: UGF=55kHz, phase margin>30deg


Transfer function ISS loop
magnitude (dB)
25
20
15
10
5
0
-5
-10
10k
100k
phase (deg)
150
100
50
0
-50
-100
-150
10k
100k
frequency (Hz)

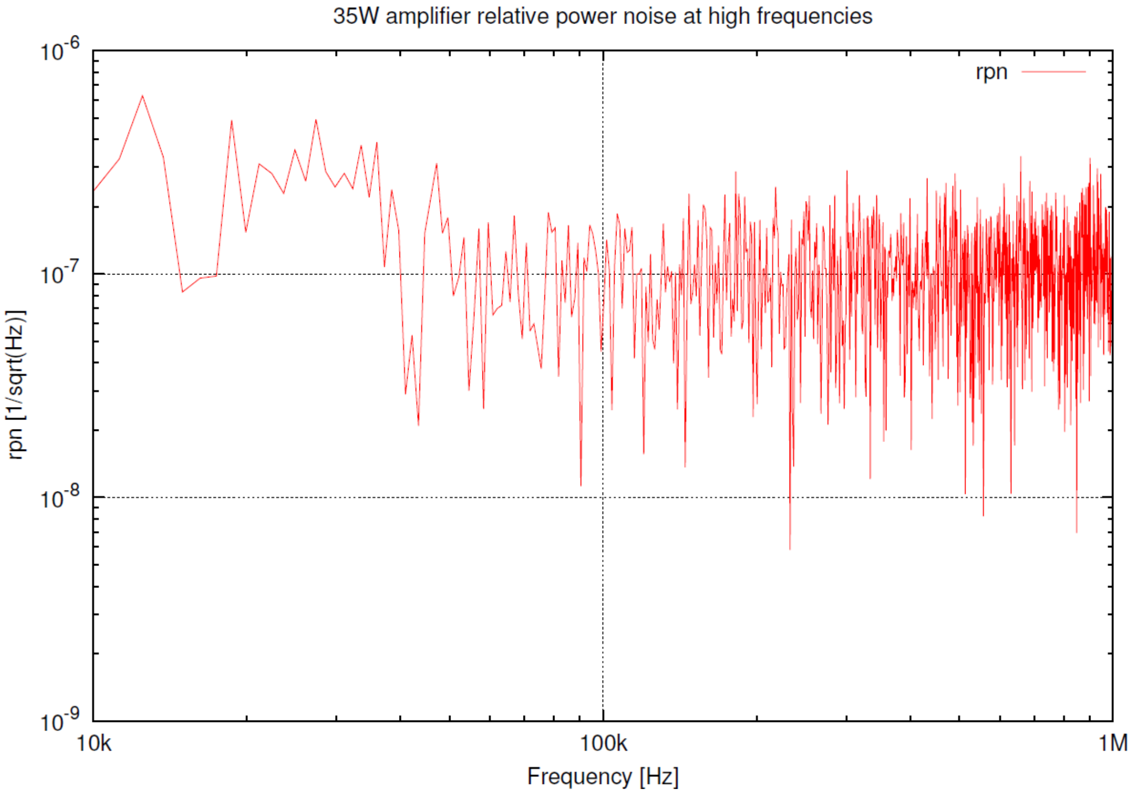
No 11:


1.005
1
0.995
0.99
0.985
0.98
signal [%]
PMC transmission (min/mean/max)
IMC transmission (min/mean/max)
0
0.2
0.4
0.6
0.8
1
1.2
time [d]

No 12:


1.03
1.02
1.01
1
0.99
0.98
0.97
relative power [%]
0
10
20
30
40
50
60
time [s]
PMC transmission
Injected signal
IMC transmission

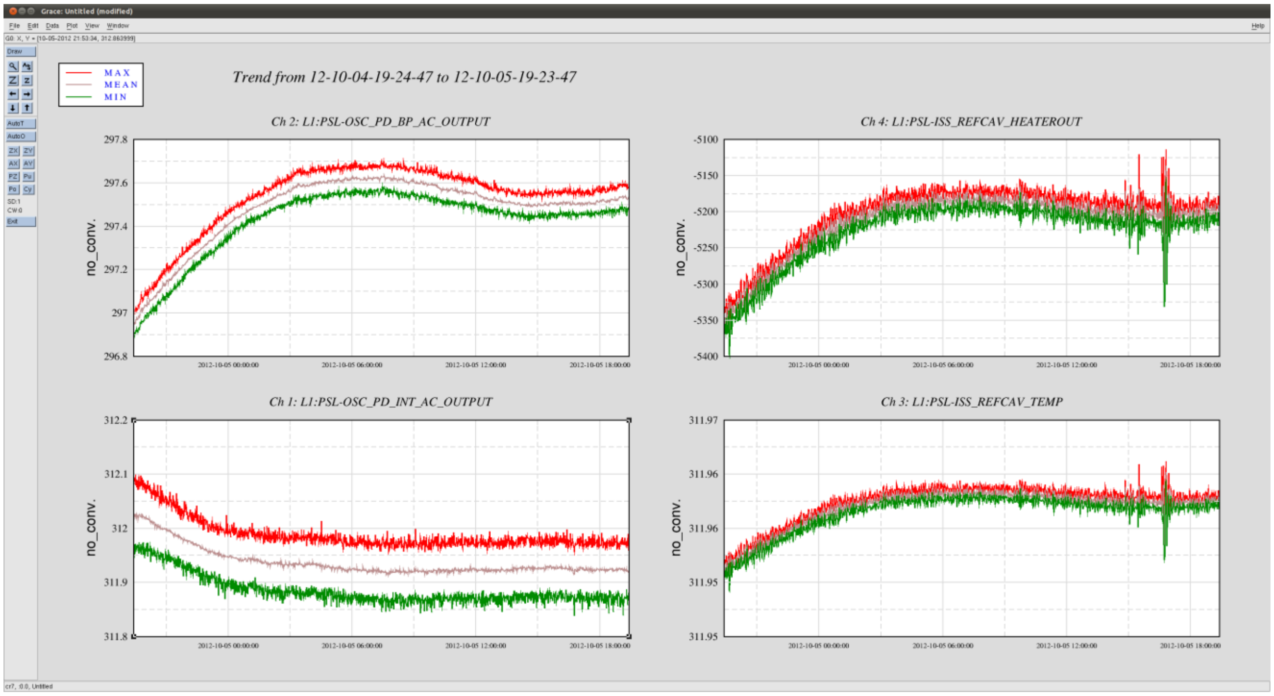
No 14:


35W amplifier relative power noise at high frequencies
10^{-6}
10^{-7}
10^{-8}
10^{-9}
rpn [1/sqrt(Hz)]
10k
100k
1M
Frequency [Hz]
rpn

additional measurement: Reference cavity temperature stabilization

Jan Pöld finally calibrated all the temperature sensors that are mounted on the reference cavity and switched the heater back on. It is still running with a digital control loop (Dinco) that has a pole at 100mHz. As for iLIGO we use the average of four AD590s as in loop sensors (Refcav_Temp) and control the heater with a HP power supply (also from iLIGO). The operating temperature is 38.8degC and roughly 18W are necessary to keep it at this temperature and the reference cavity is insulated with yellow painted styrofoam (iLIGO). Another AD590 is used as out of loop sensor.

The measurement is showing a 1 day trend of the ambient temperature (L1:PSL-OSC_PD_BP_AC), the in loop sensor (L1:PSL_ISS_REFCAV_TEMP), the out of loop sensor (L1:PSL-OSC_PD_INT_AC) all calibrated in Kelvin and the control signal to the heater (L1:PSL-ISS_REFCAV_HEATEROUT) in counts. During the measurement the HEPAs and AC were off and the makeup air running at 100%. The peak to peak fluctuations are between 10mK (in loop) and 100mK (out of loop).



https://dcc.ligo.org/DocDB/0068/E1100716/004/refcav_heater24h.png