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LIGO

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Reference cavity temperature control

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This document describes the reference cavity temperature control loop. It summarizes the status and experiments that have already been done at the LIGO Livingston site.

Contents

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References

[1] T050036 Pre-Stabilized Laser Design Requirements

[2] T0900649 PSL Final Design

[3] D980400 PSL temperature box

[4] T1000470 H1 Reference Cavity Residual Thermal Gradient Study

[5] D1300949 aLIGO PSL reference cavity heater/fieldbox

1 Introduction

For the temperature control of the reference cavity tank, a slow digital control loop was designed and is presented in this document. Stabilizing the temperature of the reference cavity the thermal expansion on long time scales of the cavity spacer is minimized. In iLIGO an additional signal was added to compensate for length changes of the interferometer arms caused by tidal forces. At this point it is not decided whether this approach is necessary for aLIGO.

The requirements for the reference cavity temperature stabilization are specified in [1] and section 3.2 of [2]. Currently the temperature of the laser room is not stable enough, especially due to frequent room state changes from science to commissioning mode (this involves turning on and off HEPA fans and ACs). Therefore active temperature control of the reference cavity is required.

2 Changes from the iLIGO configuration

The iLIGO configuration consisted of a MINCO PID controller in a local control loop. The high current was provided by an HP power supply. To read out the AD590 temperature sensors, that are mounted to the reference cavity tank, a readout box [3] is sitting next to the reference cavity on the PSL table. The loop is characterized in [4].

Since for aLIGO all devices powered from AC are not permitted in the LVEA, the HP power supply has to be replaced or moved out of the PSL rack. Replacing the MINCO PID controller with a digital controller makes it possible to swap filter coefficients very fast and operate it remotely. Therefore a new heater/fieldbox [5] was designed and tested. It provides power and builds the signal interface to the PSL temperature box. It has additional filter banks for signal conditioning and whitening of the signals coming from the PSL temperature box [3] before they enter the data acquisition system. A picture of the electronics front panel is shown in figure 1.

A high output current is provided by a TIP122 transistor that is used to power the heater pads. There are two heater pads wrapped around the reference cavity tank, which each have a resistance of 26 Ω and are connected in parallel to the output of the TIP122. With the heater/fieldbox powered from 24 V it can provide up to 34 W.

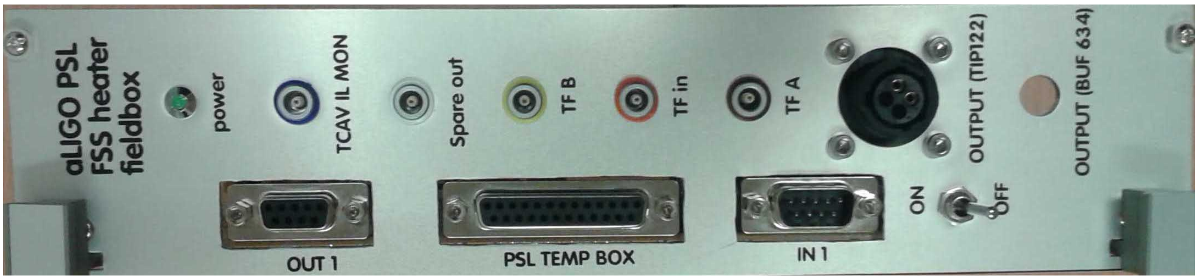

Figure 1: Frontpanel of heater/fieldbox.

3 Description of the control loop

The schematics of the new control loop is shown in figure 2. The AD590 temperature sensors produce a current that is converted to a voltage in the PSL temperature box. The signals are sent to the fieldbox, where the whitening is done. The controller is implemented digitally in the control and data system and the control signal is sent back to the heater, which can provide the high current to drive the heat pads on the reference cavity.

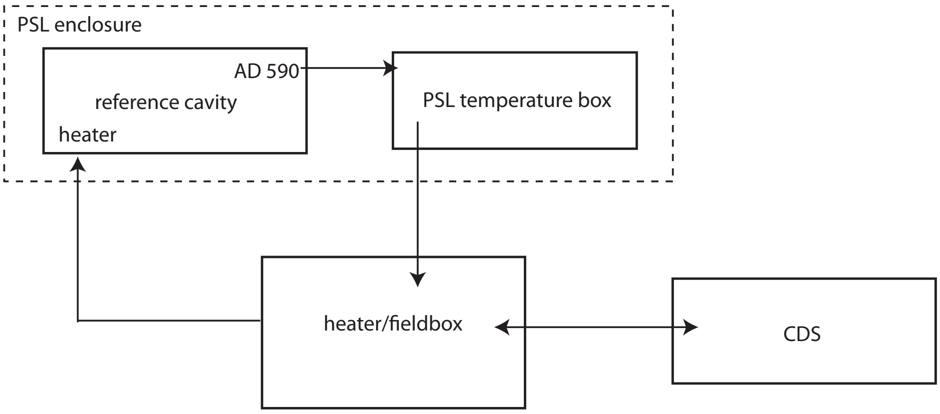

Figure 2: Schematics of temperature control

3.1 Sensor

There are four in loop AD590 temperature sensors that are summed in the temperature box. The transfer function is plotted in figure 3. Furthermore two other AD590 monitor the out of loop signal and the ambient temperature.

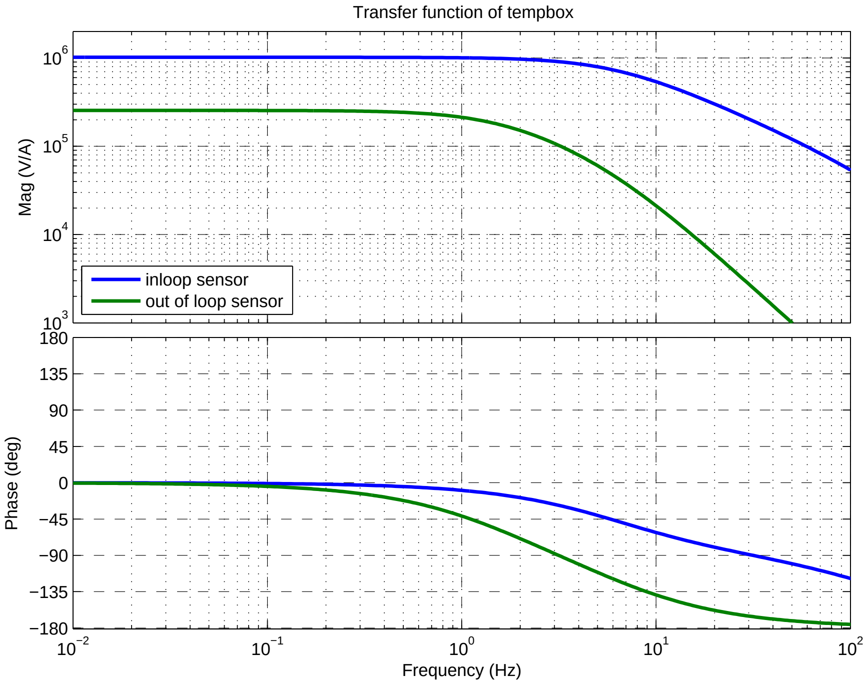

Figure 3: Transfer function of temperature box

3.1.1 Calibration of AD590 temperature sensors

For the DC calibration of the AD590 an 47 kΩ resistor with low tolerance was connected to the temperature box instead of the AD590. Together with the internal 1 kΩ resistor in front of the transimpedance stage it creates a current of 312.5 μA. Knowing that the AD590 is calibrated to supply 1 μA/K, the temperature calibration can be done accordingly. However, it was discovered that the 15 V which supply the AD590 changes depending on how many devices are connected. For the AD590 this is not a problem, because it accepts a wide input voltage range, but it makes the calibration inaccurate.

3.2 Heater/Fieldbox

The circuit schematics for the heater fieldbox are documented in [5]. For the signals coming from the temperature box there is a possibility to whiten the signal individually. It is also possible to subtract a DC voltage from each signal. The reference voltage settings can be changed by swapping a resistor and need to be adjusted at the site.

The heater is introducing an offset that sets the output to the middle of the range. Thereby the reference cavity does not cool down entirely, when the control loop is switched off. The output to the heater can be switched off on the front panel. The status of the output is monitored and accessible via CDS.

3.3 Actuator

In the iLIGO configuration a temperature of 38.8 degree Celsius was achieved with approximately of 18 W supplied to the heater.

Since the AD590 are mounted on the tank and not sensing the temperature of the heater pad, the thermal time constant has to be considered for the control loop design. The thermal time constant of the tank was measured by applying a voltage step on the heater and watch the temperature rise. The result is plotted in figure 4 and has a thermal constant of 1.28 h. This corresponds to a pole at 215.6 μHz in control loop.

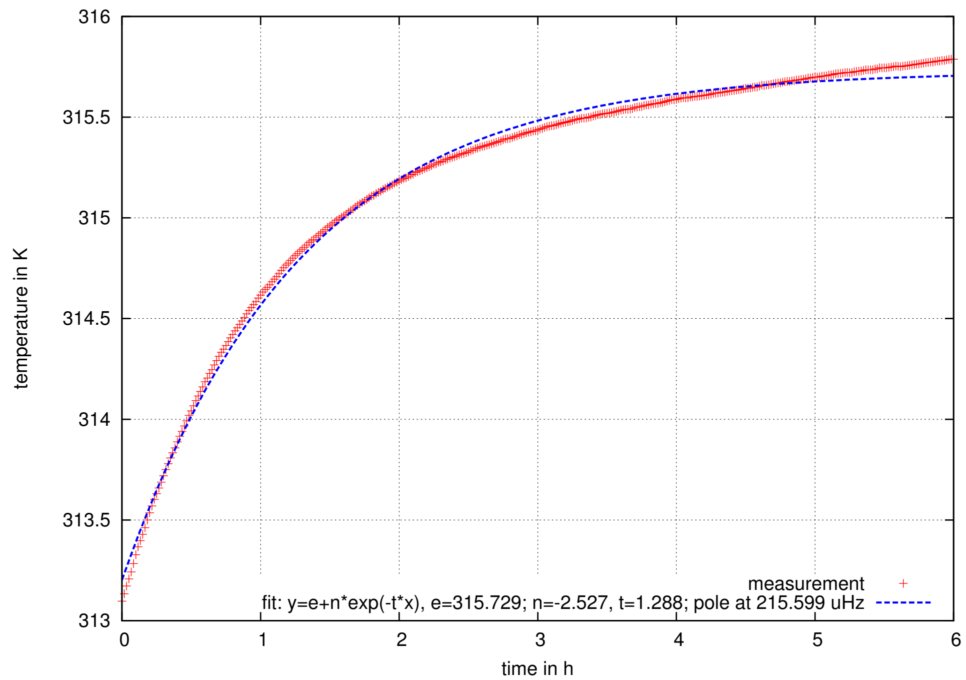

Figure 4: Time constant of reference cavity tank

3.4 Controller

Basically the controller just needs to provide a proportional gain, since the low pass through the cavity tank already provides a 1/f. Additional gain at very low frequencies can be added.

The control loop uses a voltage signal to actuate the temperature. These quantities have a quadratic relation and could lead to instabilities in the control loop. As the temperature is not shifted extensively, there were no non-linear effects observed so far. However, implementing a square root part in the digital control loop might be beneficial to eliminate non-linear effects.

The current LLO MEDM screen is shown in figure 5.

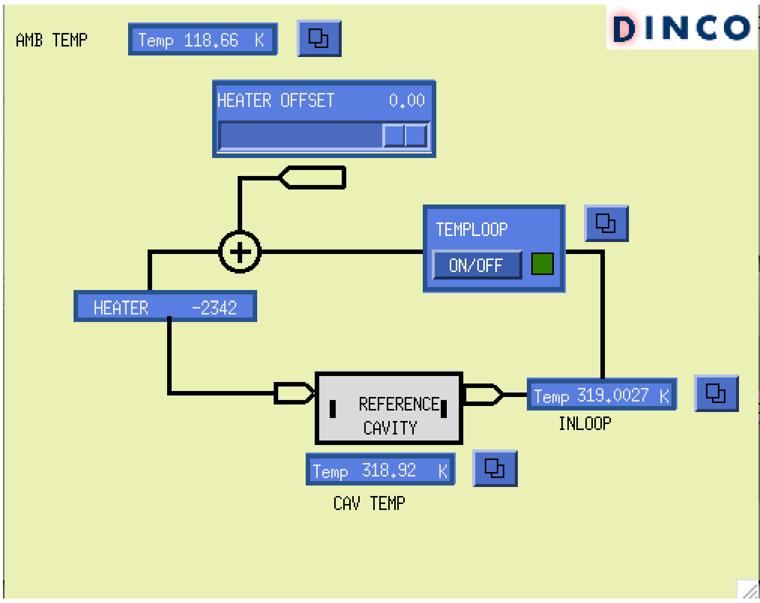

Figure 5: LLO MEDM screen

4 Performance

A measurement of a preliminary configuration (figure 6) is showing that the in loop fluctuation are on the order of 2 mK and 40 mK for the out of loop sensor, while the ambient temperature is varying by 200 mK over two days.

For the frequency stabilization it is also important to know, how the temperature change effects the NPRO frequency. A time constant of 5.12 h was measured by applying a temperature step on the heater and monitor the crystal temperature (see figure 7). This time constant is longer than the one for the temperature sensor, because it takes additional time to transfer heat from the tank to the spacer.

5 Thermal enclosure

- so far the tank is insulated with styrofoam
- there is no final design $\Rightarrow$ reference design from Caltech experiments?

6 Further steps

- implement new heater/fieldbox (-v2)
- procedure for calibration of AD590
- noise of DAQ at low frequencies and proper whitening for channels

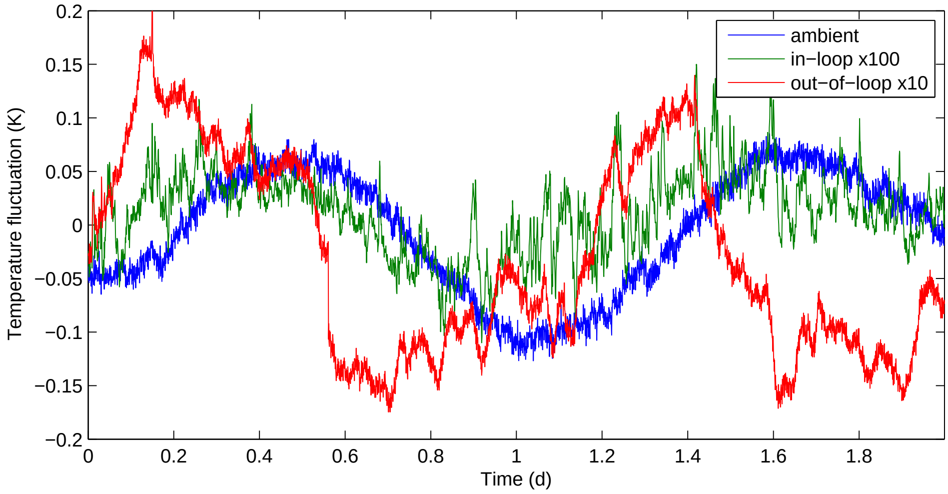

Figure 6: Temperature fluctuations over two days

- implementation of controller in common PSL model and loop optimization
- relocate in loop sensors AD590 and mount them to the heater instead of the tank to avoid low pass from tank
- check that all surface mount resistors on the temperature box are thin film resistors (with better low frequency noise)

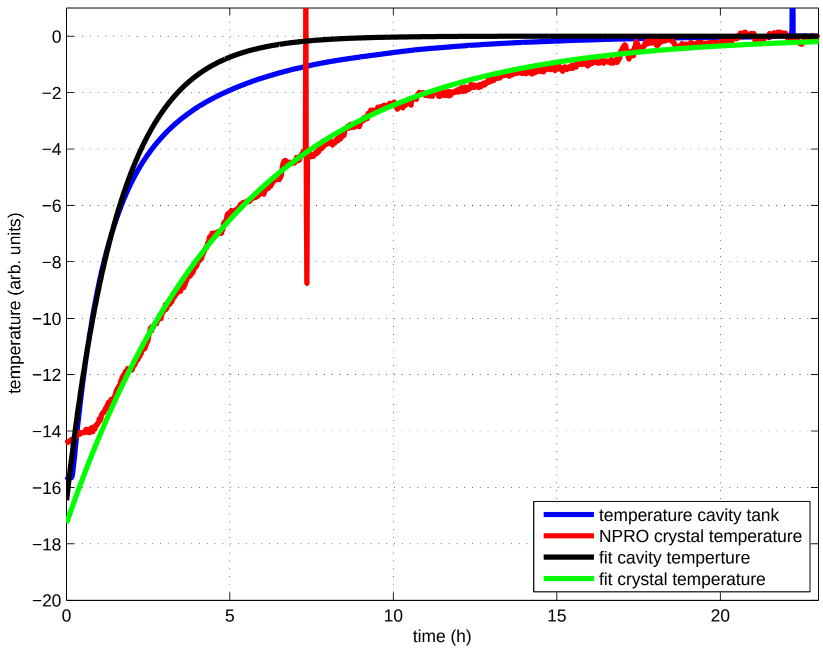

Figure 7: Changes of NPRO frequency due to change in reference cavity temperature. Changes occur with a time constant of 5.12 h (according to the fit).