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CALIFORNIA INSTITUTE OF TECHNOLOGY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Technical Note **LIGO-T11XXXXX–vX** 2023/07/12

LIGO SURF 2023
Interim Report I

Implementing Nonlinear Control in a Classical Experiment to Reduce Measurement Noise

Andrei C. Diaconu, Advait Mehla

California Institute of Technology
LIGO Project, MS 18-34
Pasadena, CA 91125
Phone (626) 395-2129
Fax (626) 304-9834
E-mail: info@ligo.caltech.edu

Massachusetts Institute of Technology
LIGO Project, Room NW22-295
Cambridge, MA 02139
Phone (617) 253-4824
Fax (617) 253-7014
E-mail: info@ligo.mit.edu

LIGO Hanford Observatory
Route 10, Mile Marker 2
Richland, WA 99352
Phone (509) 372-8106
Fax (509) 372-8137
E-mail: info@ligo.caltech.edu

LIGO Livingston Observatory
19100 LIGO Lane
Livingston, LA 70754
Phone (225) 686-3100
Fax (225) 686-7189
E-mail: info@ligo.caltech.edu

http://www.ligo.caltech.edu/

1 Temperature Sensor Circuit

For our main detector we use an AD590 transducer manufactured by Analog Devices. This sensor puts out a current that is directly proportional to the temperature, with a proportionality constant of $1\mu A/K$ in absolute temperature.

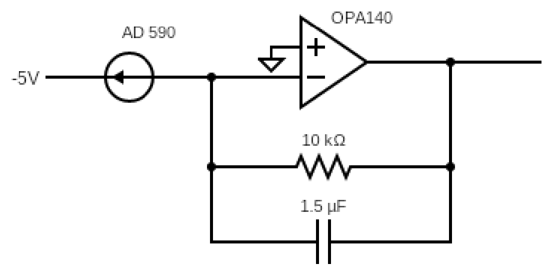

Figure 1: Temperature sensor circuit

This circuit is used to convert the current signal put out by the AD590 into voltage that can be read by the ADC. As the ADC itself, we are using a RaspberryPi computer with a WaveShare AD/DA board, which is equipped with an ADS1256 ADC chip. This board has 8 input channels with a range of 0-5V. This design puts out 2.98 V for a temperature of 298 K, and has a feedback capacitor to act as a low pass filter of roughly 10 Hz to filter out the high frequency noise. In this application, we use an OPA140 op-amp due to its superior noise specifications that provide us with a lower noise floor for our sensor. Below (Figure 2). This result was computed both with LTSpice and with the python package zero. As you can see, we achieved a noise specification that is more than three orders of magnitude lower than the measured environment temperature fluctuations at frequencies lower than 1 Hz.

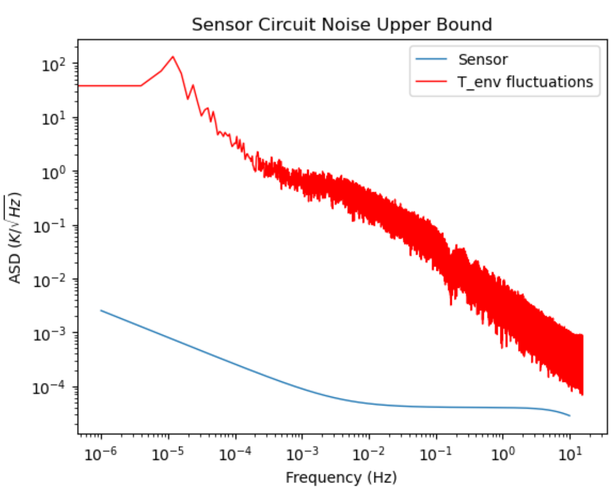

Figure 2: Sensor noise v/s ambient fluctuations

This circuit has been built on a soldered perf-board with 4 TIA channels.

2 Revised Heater Circuit

We designed a heater circuit that will be used to regulate the current used to heat up the test mass. The idea is to be able to use the voltage put out by our ADC (the RaspberryPi) to regulate how much heating power is delivered to the puck. This design has two major advantages:

1. The output current through the load does not depend on the RaspberryPi input signal. Here the RaspberryPi input is just simply serves as a switch.
2. The efficiency is maximized by the fact that the entire voltage of the power source is delivered to the load. Hence, we are not wasting any power on any auxiliary components.
3. The voltage of the RaspberryPi is used just as a switch for the MOSFET meaning that the voltage noise of the RaspberryPi will not influence the power delivered to the load.

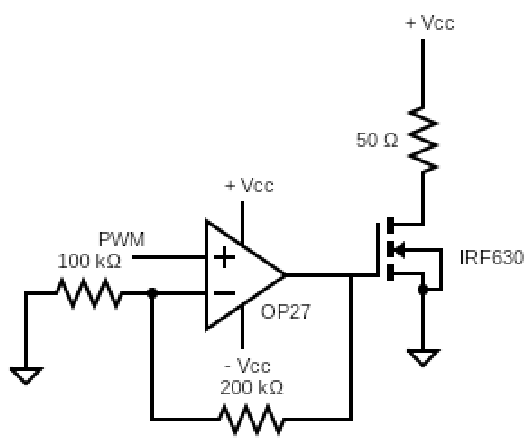

Figure 3: Heater circuit diagram.

One concern with this circuit is that the MOSFET may now behave linearly at intermediary voltages, and that there would be a delay between switching the MOSFET on and off. In the figure below you can see the waveform of the drain voltage for this circuit: the rise time is approximately 500 ns, which is a negligible fraction of signal's period of 1ms, and thus this effect can be taken as negligible. Moreover, the MOSFET does not heat up appreciably during operation.

Currently this design is still being improved, with the next goal being to shield the output power from power supply noise.

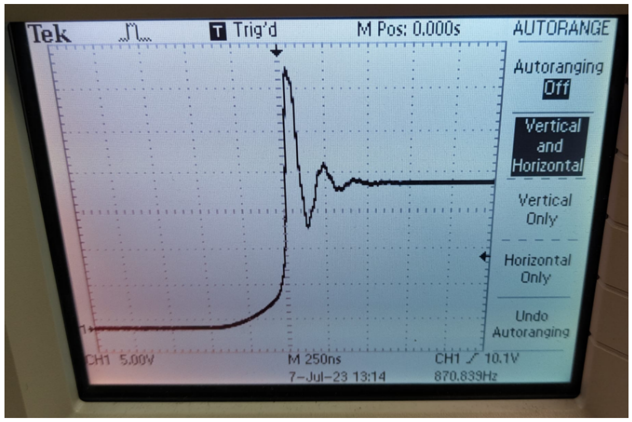

Figure 4: Drain voltage waveform with a 1 kHz PWM

3 Thermal Modelling

We also fitted the parameters of the uninsulated puck step response. The temperature of the puck was assumed to follow the equation:

$$\frac{dQ_p}{dt} = m_p c_p \frac{dT_p}{dt} = -hS(T_p - T_{env}) + H \tag{1}$$

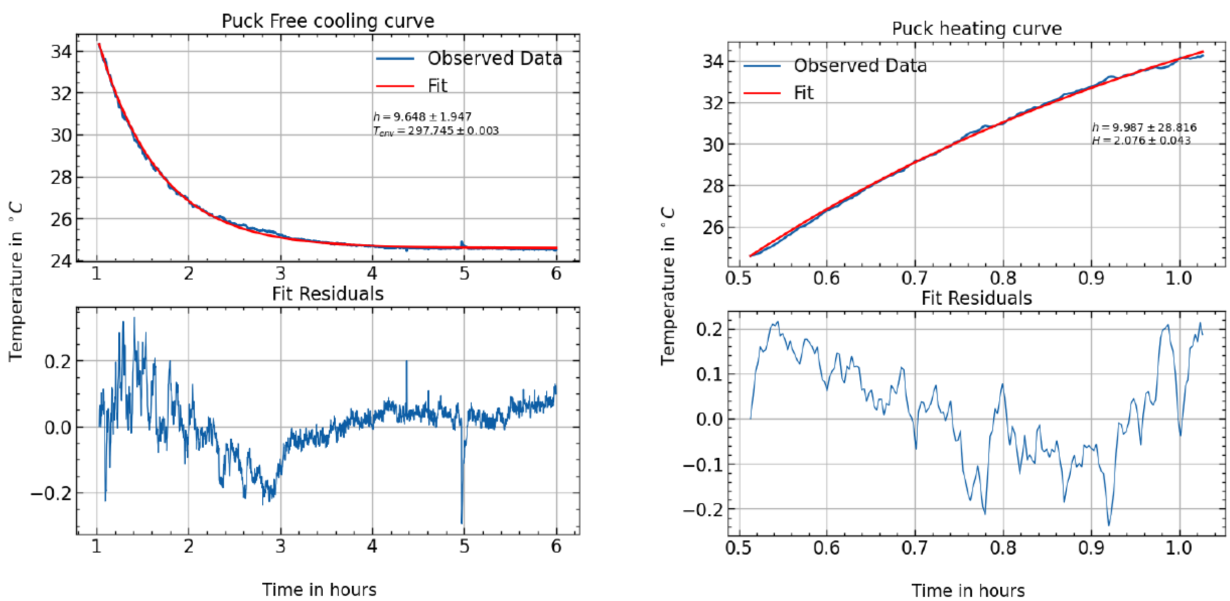

Figure 5: Fits to the heating and cooling curves

Here, h is the convective heat transfer coefficient, S is the total exposed surface area, and H is the rate at which heat is supplied. I used the lmfit package to fit parameters of this model. The only free parameters here are h, which is completely unknown, and H which is known up to a constant, since the heat supplied is not completely delivered to the puck due to losses from the heater resistor itself. $T_e nv$ was also left as a free parameter as it was not actively monitored with a sensor.

4 Acknowledgements

I want to thank my gracious donors who funded my SURF through the Larson Scholarship. I also want to thank my lab partner Advait Mehla, a current LIGO SURF student, with whom I have worked on the above presented results and report.