Optimal Temperature Control of the Seismometer

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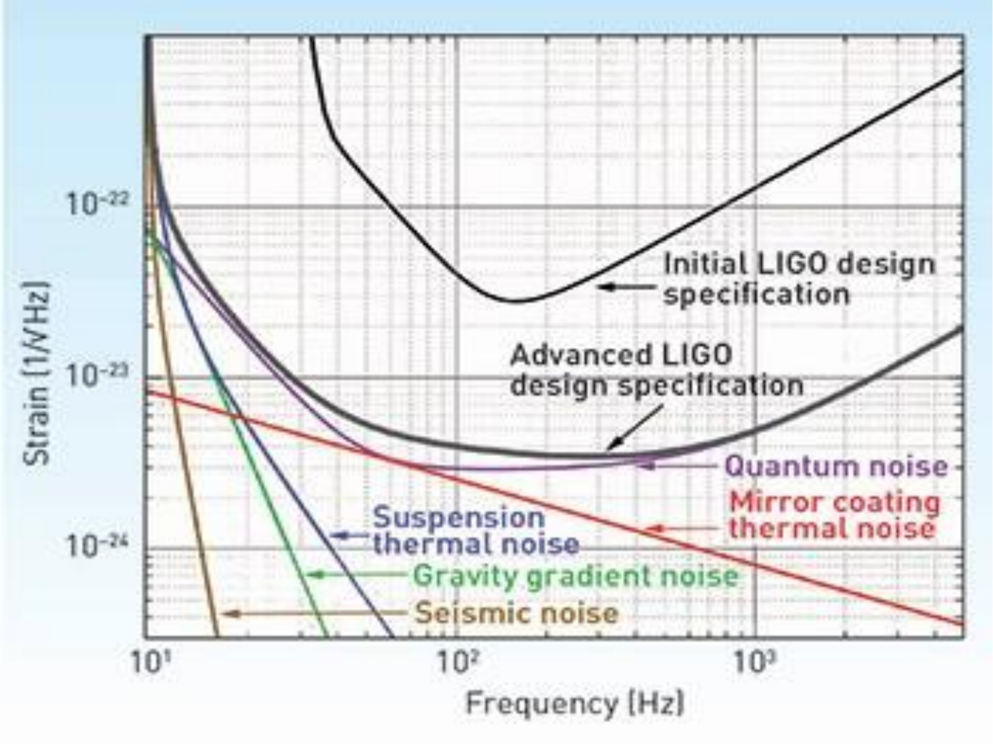
Overview

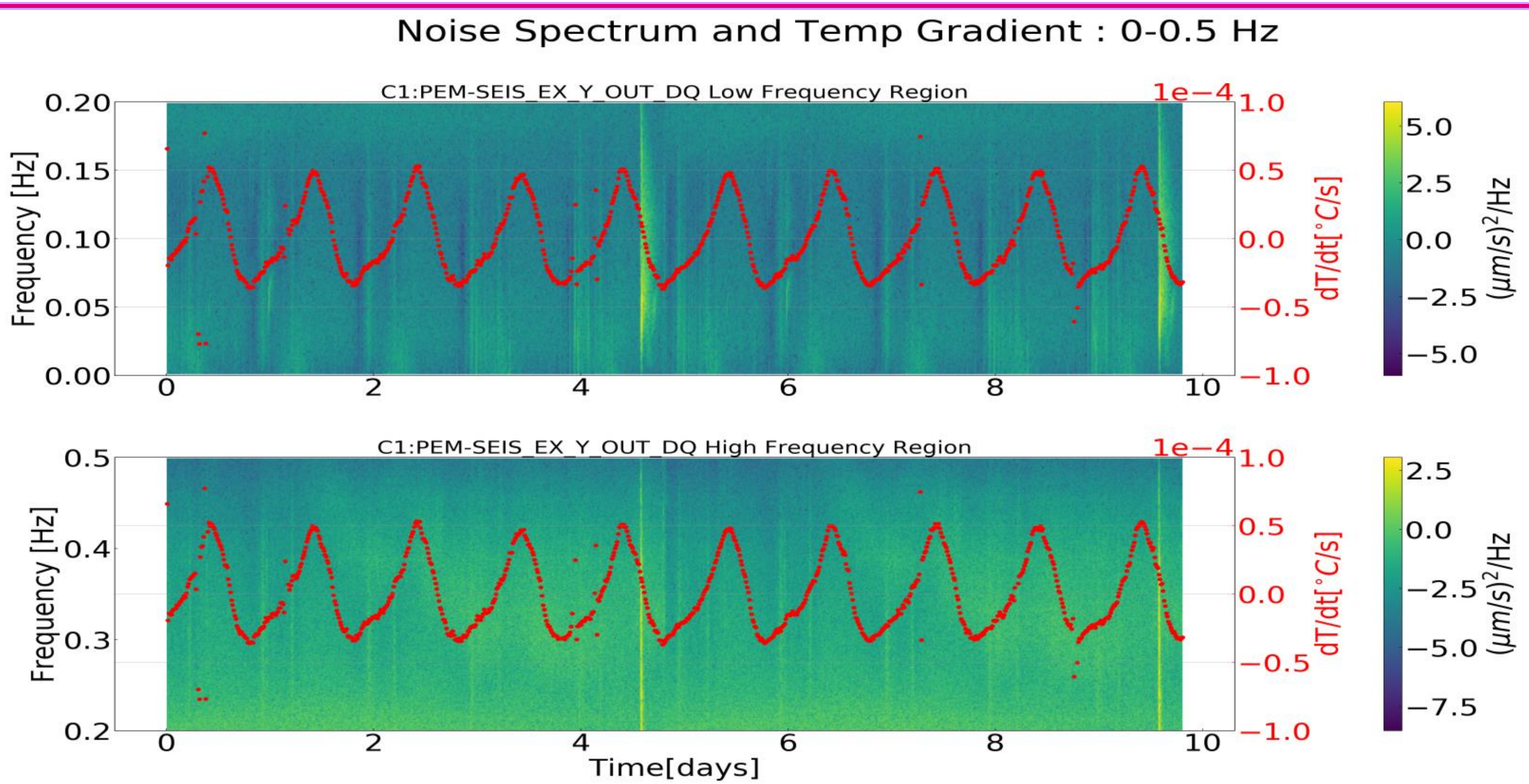
- ❑ Why does LIGO require seismometers and why do these seismometers require temperature stabilisation ?
- ❑ Modelling the temperature control system
- ❑ Developing and optimising the linear PID Controller
- ❑ Designing the Heater Circuit
- ❑ Testing the optimised control system

Introduction



- Low frequency region dominated by seismic noise
- To characterize this seismic noise we can use seismometers.
- Need to make sure noise in the seismometer data is really low !!

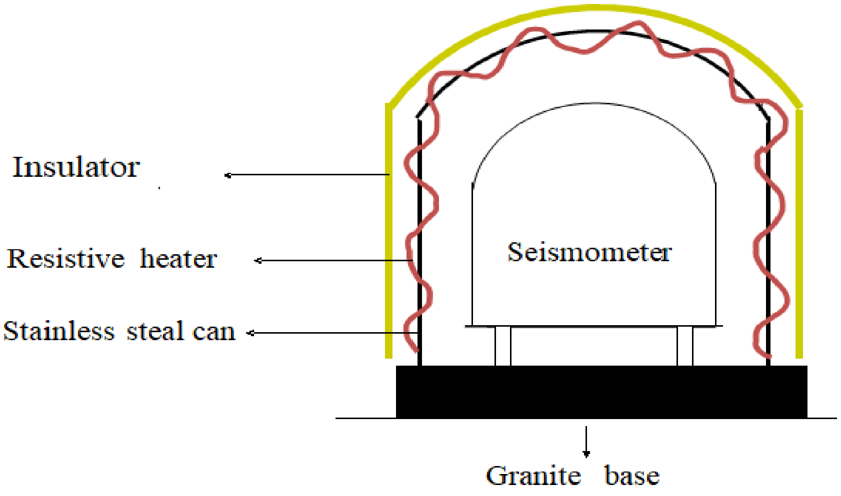
Seismic data noise and temperature

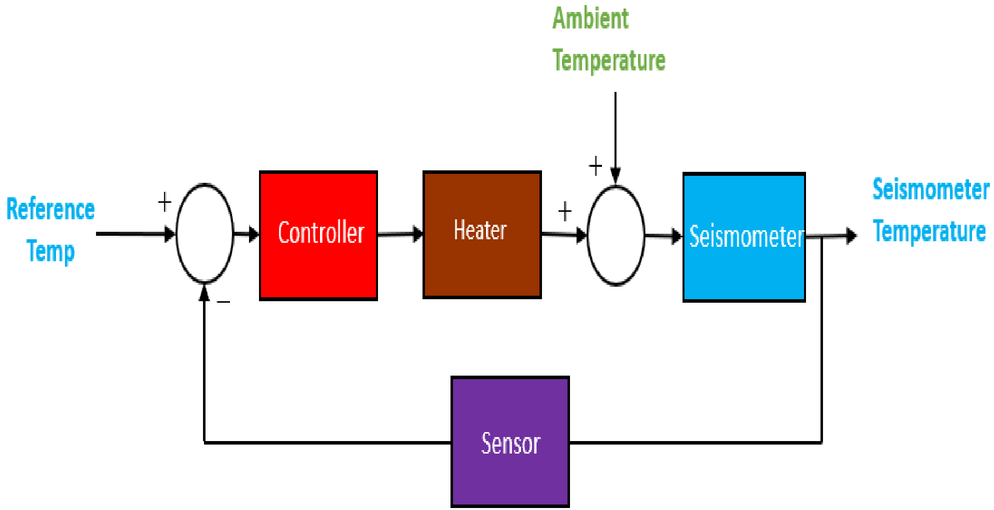


- Noise floor of the seismometer in the background
- The temperature gradient variation is shown in the foreground

To reduce the noise we need to make sure the temperature of seismometer is as stable as possible !!

The Control System





Physical Setup VS Model

Modelling of the plant

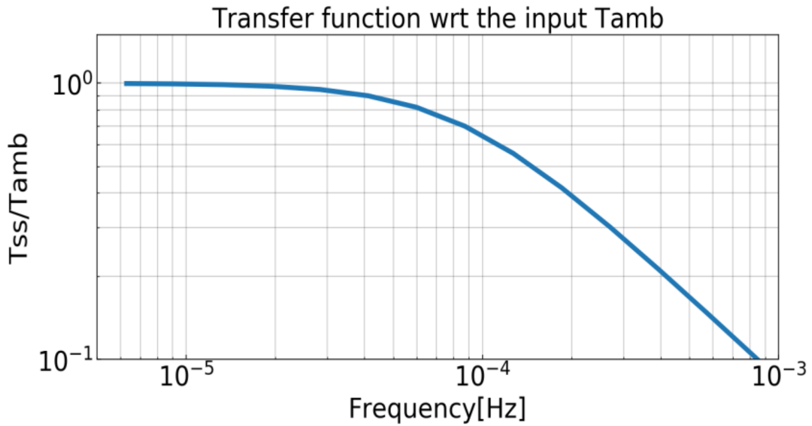
$$P_{in} = \text{Increase in temp of the can} + \text{conductive loss}$$

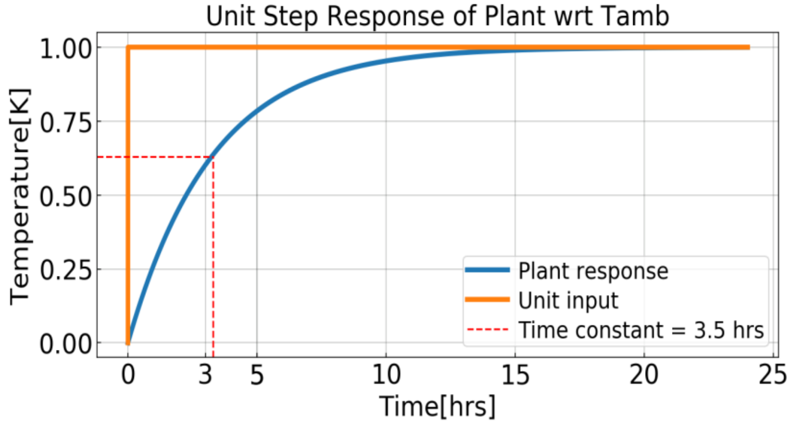
$$P_{in} = M_{SS}C_{SS}\frac{dT_{ss}}{dt} + \frac{K_f A_f}{h_f}\,(T_{ss} - T_{amb})$$

Natural Response of the system :

$$0 \;= M_{SS}C_{SS}\frac{dT_{ss}}{dt} + \frac{K_f A_f}{h_f}\,(T_{ss} - T_{amb})$$

The time constant for the system was =3.5hrs



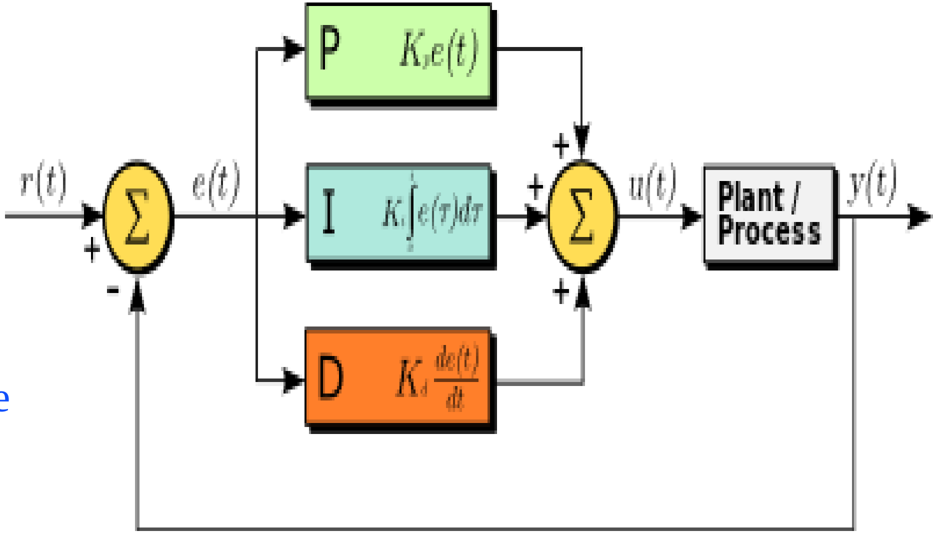


Modelling of the Controller : PID

- Proportional Integral and Derivative controller :

$$PID = K_p e(t) + K_I \int e(t)dt + K_D \frac{de}{dt}$$

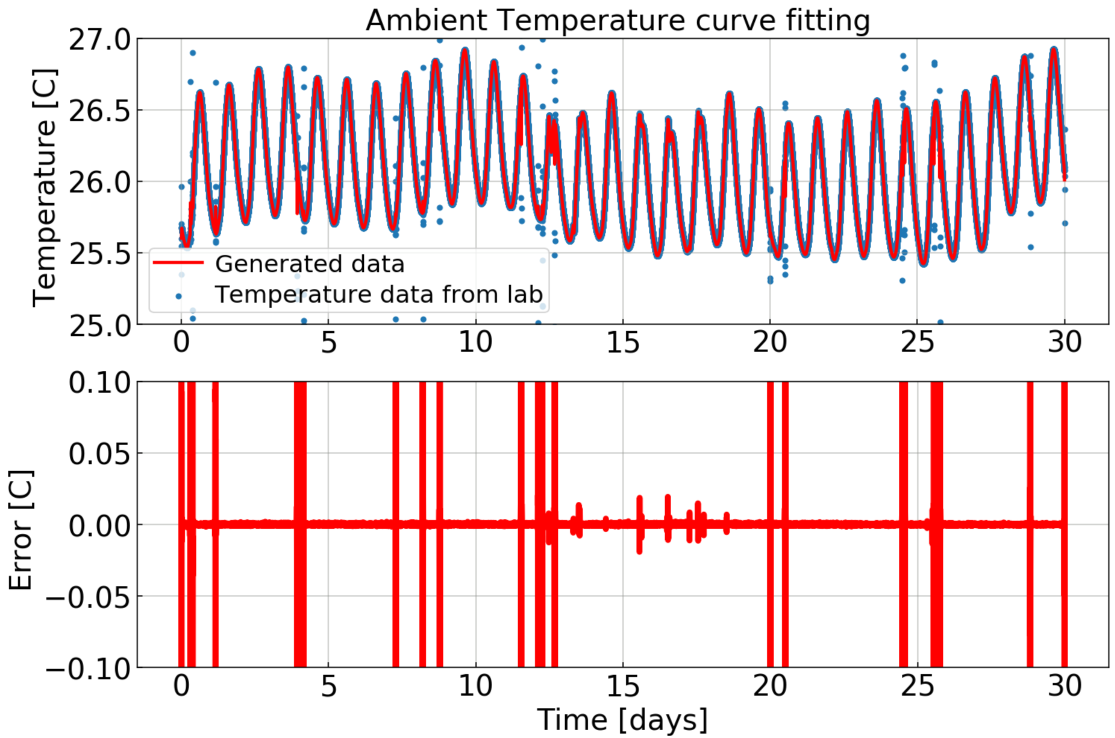
$$H_1(s) = K_p + \frac{K_I}{s} + K_D s$$



- This is a linear controller. We would like to see how well this linear controller, minimizes the steady state error for our system model.

- Acts as a performance benchmark for the non-linear controller i.e. the neural network controller.

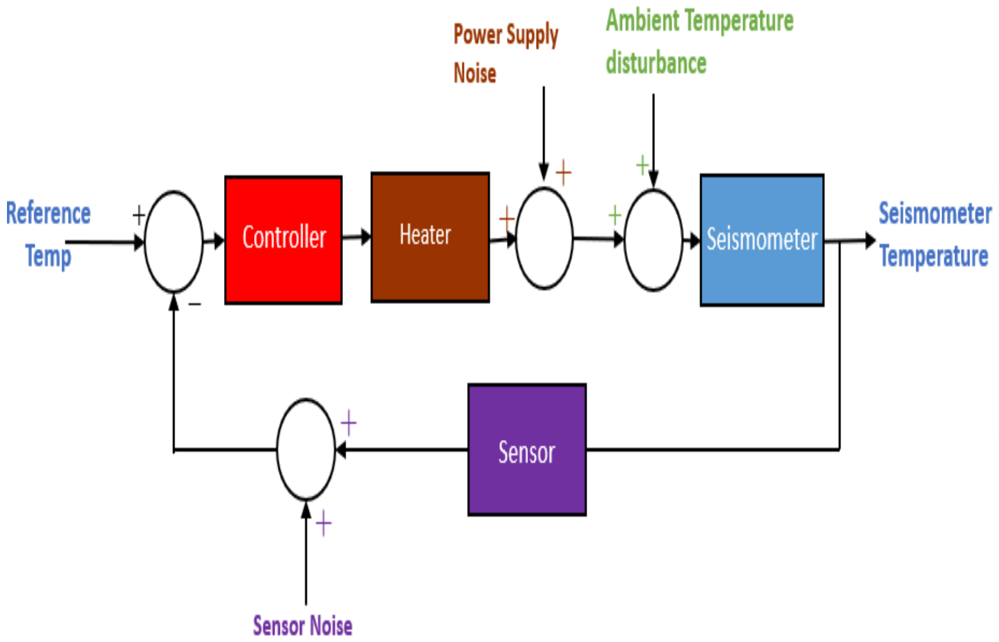
Ambient Temperature Model

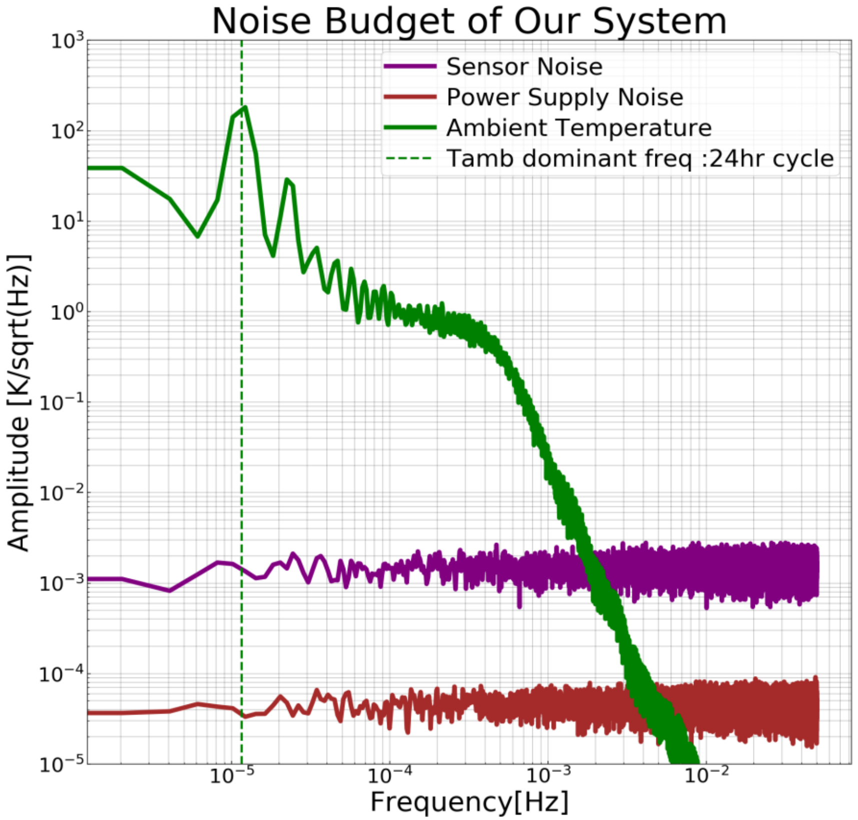


- Data was noisy hence for offline analysis and simulation curve fit function was necessary

- Interpolation function was developed to generate the data as shown.

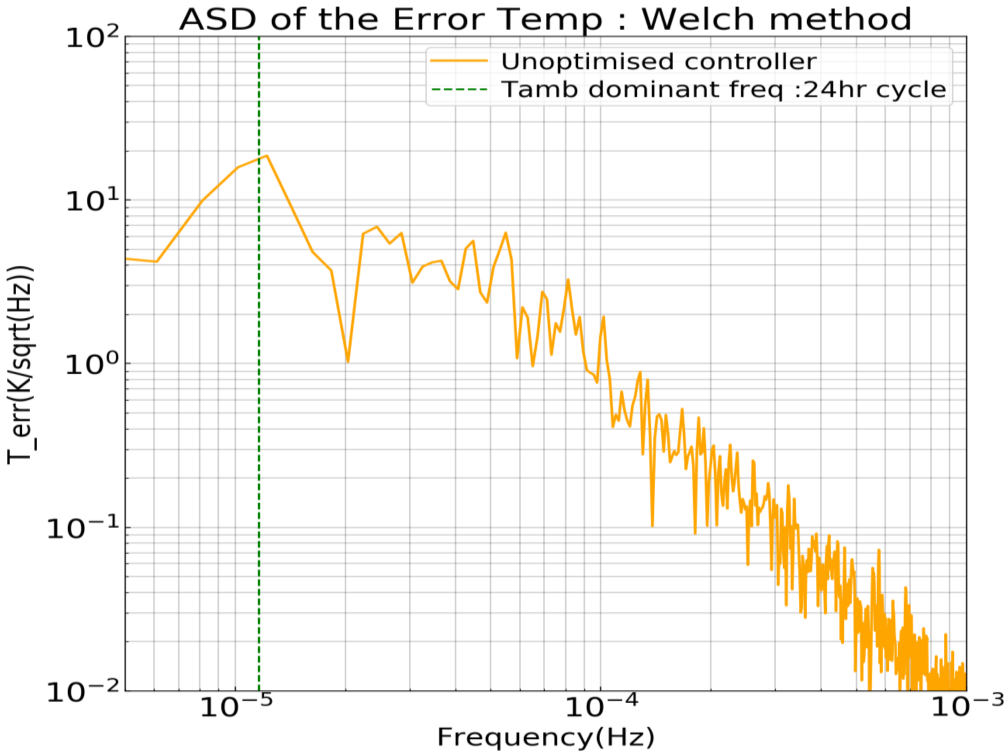
Noise Budget





The total noise and disturbances to our system and the points of injection is shown.

Steady State Error Analysis



- The noise and disturbances to our system aim to upset our set point of our temperature.
- The frequency distribution of this error is shown in the plot.
- The affect of the daily fluctuation of the room temperature can be seen here.

Optimal Control

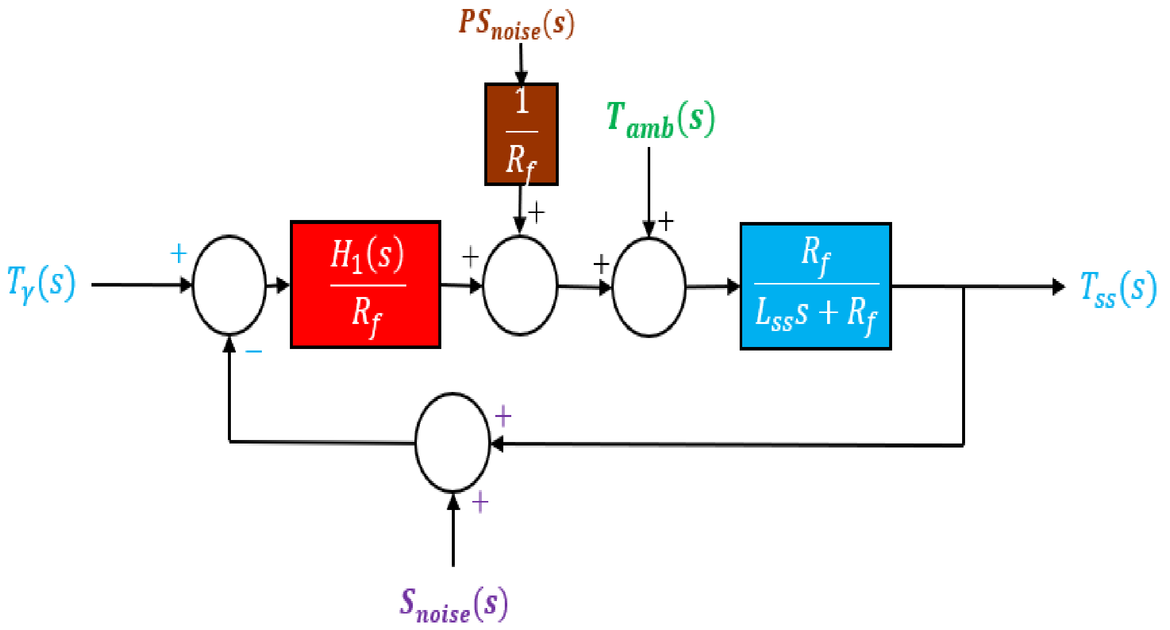
- Some examples of commonly used optimal control on linear systems :

- Linear Quadratic Regulator (LQR) : Formulates the controller which minimizes the energy spent by the control system

$$Cost = x^T Q x + u^T R u$$

- H infinity : Formulates the cost function with the disturbances taken as one of the parameters to be minimized with controller gain provided as a constraint.

Cost Function or The metric



- The total disturbance at the output is the sum of each noise and disturbance source weighted by their transfer function.
- The cost function was designed to be the integral of this disturbance over the frequency band of our choice which was from 0-1 Hz.

$$\Delta T_{ss}^{2}(s) = (Y_{amb}(s) * \Delta T_{amb}(s))^2 + (Y_{PS}(s) * \Delta PS_{noise}(s))^2 + (Y_{Sensor}(s) * \Delta S_{noise}(s))^2$$

$$Cost\ Function = \int_{f1}^{f2} \Delta T_{ss}^{2}(f)df + \max(Phase\ Margin\ of\ Open\ Loop\ System)$$

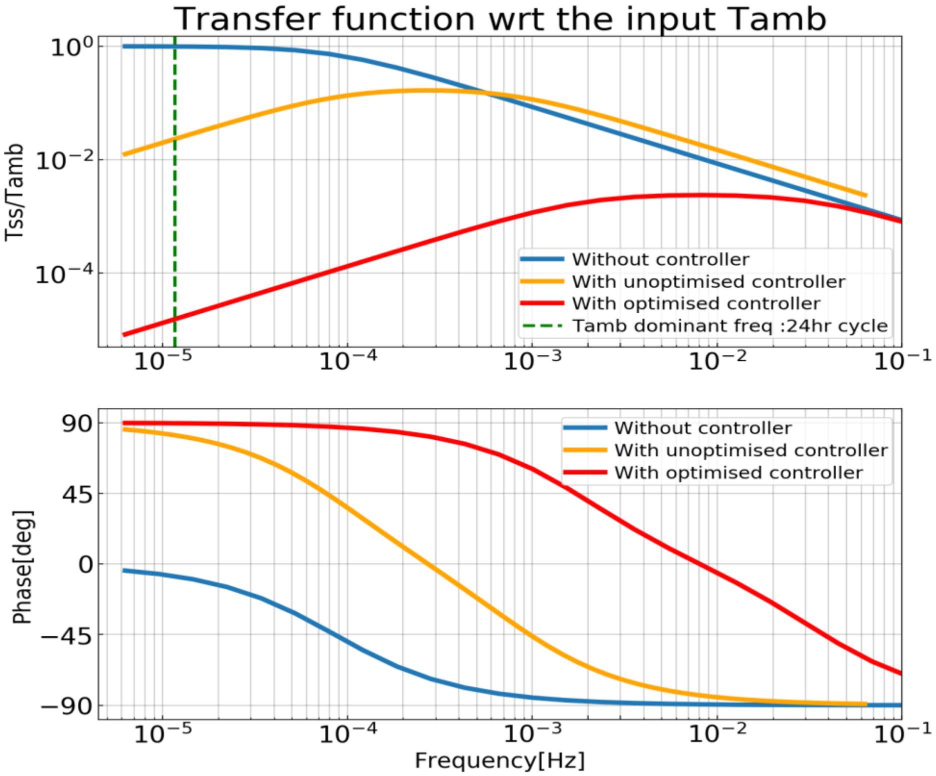
Optimization of the PID coefficients

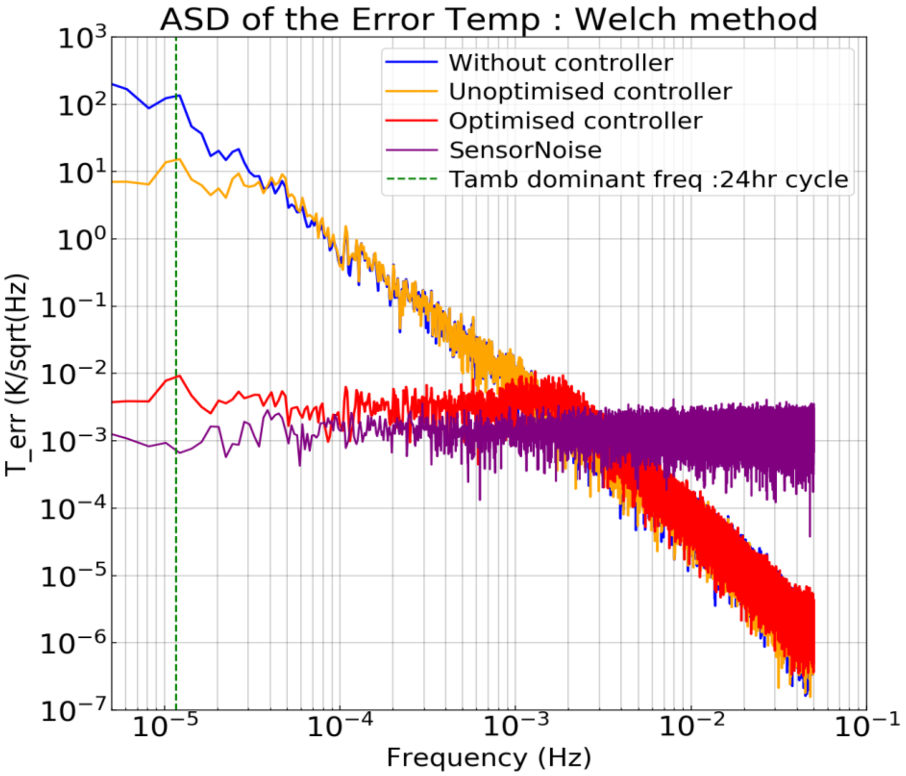
- Due to complicated nature of the cost function iterative algorithm was used .

- The two options which were explored were :
  - Particle Swarm Optimisation (PSO)
  - Genetic Algorithm (GA)

PSO was favoured due to the natural minimisation algorithm it uses and is much faster than GA.

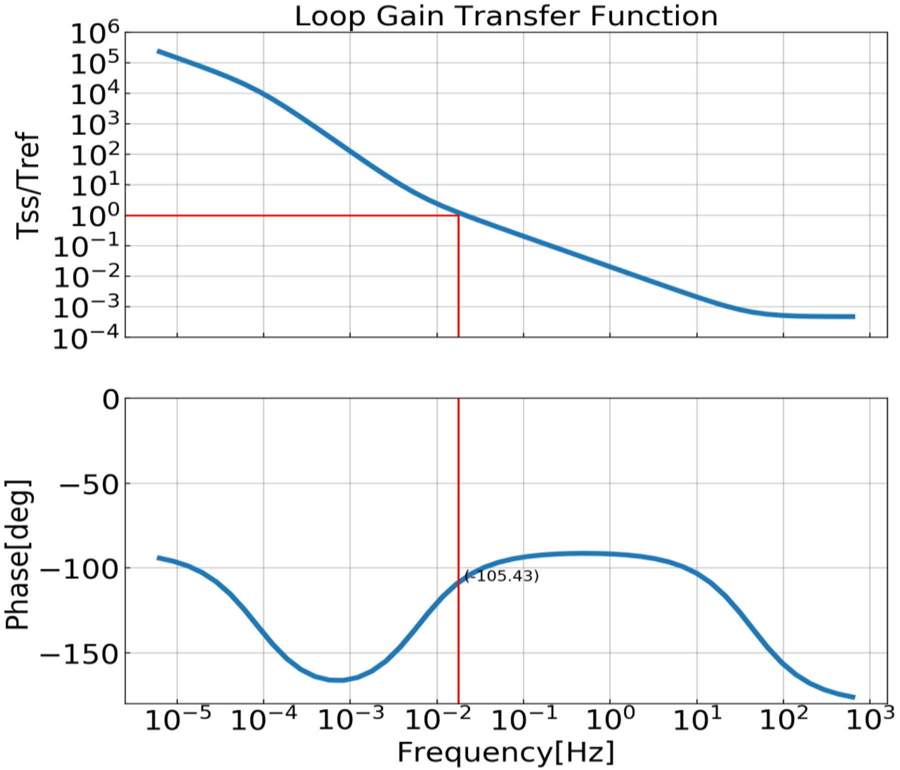
Results of the optimization





With the correct PID coefficients the reduction in error is significant !!

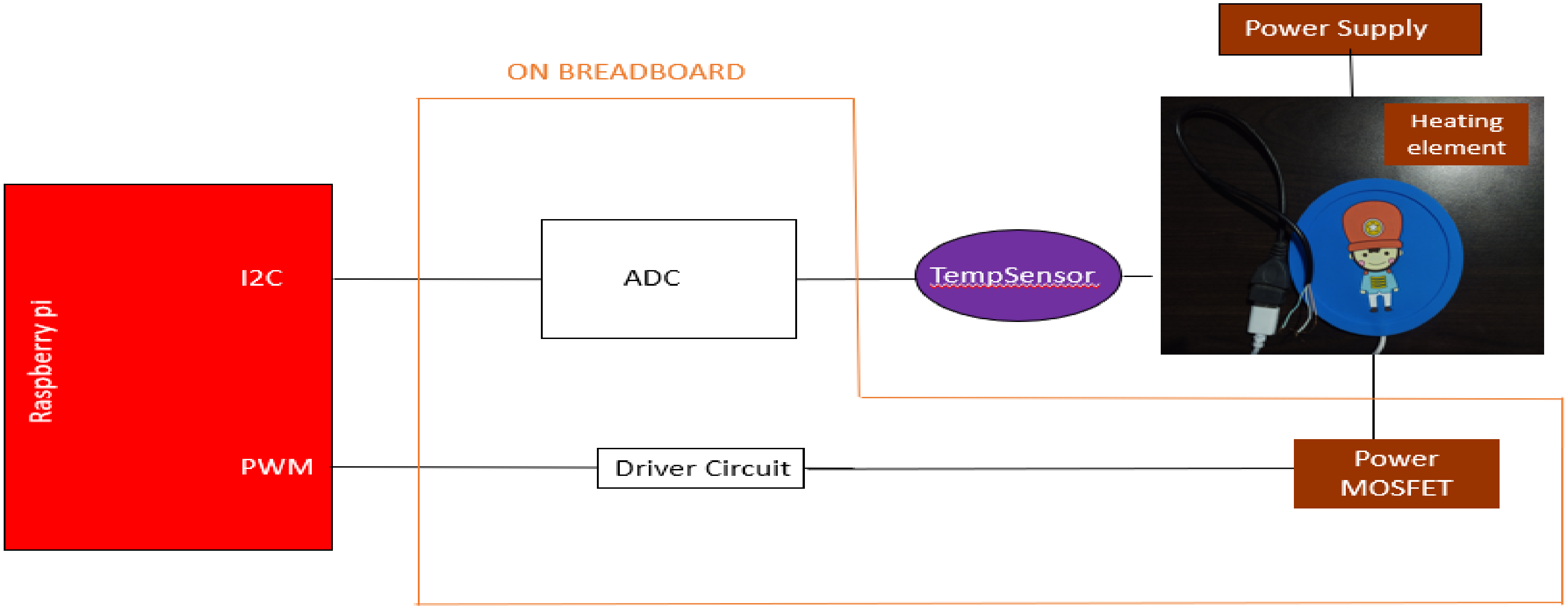
Results of the Optimisation



- The optimised PID coefficients also ensured that the system was stable.
- The loop gain transfer function tells about this stability by looking at its phase margin.

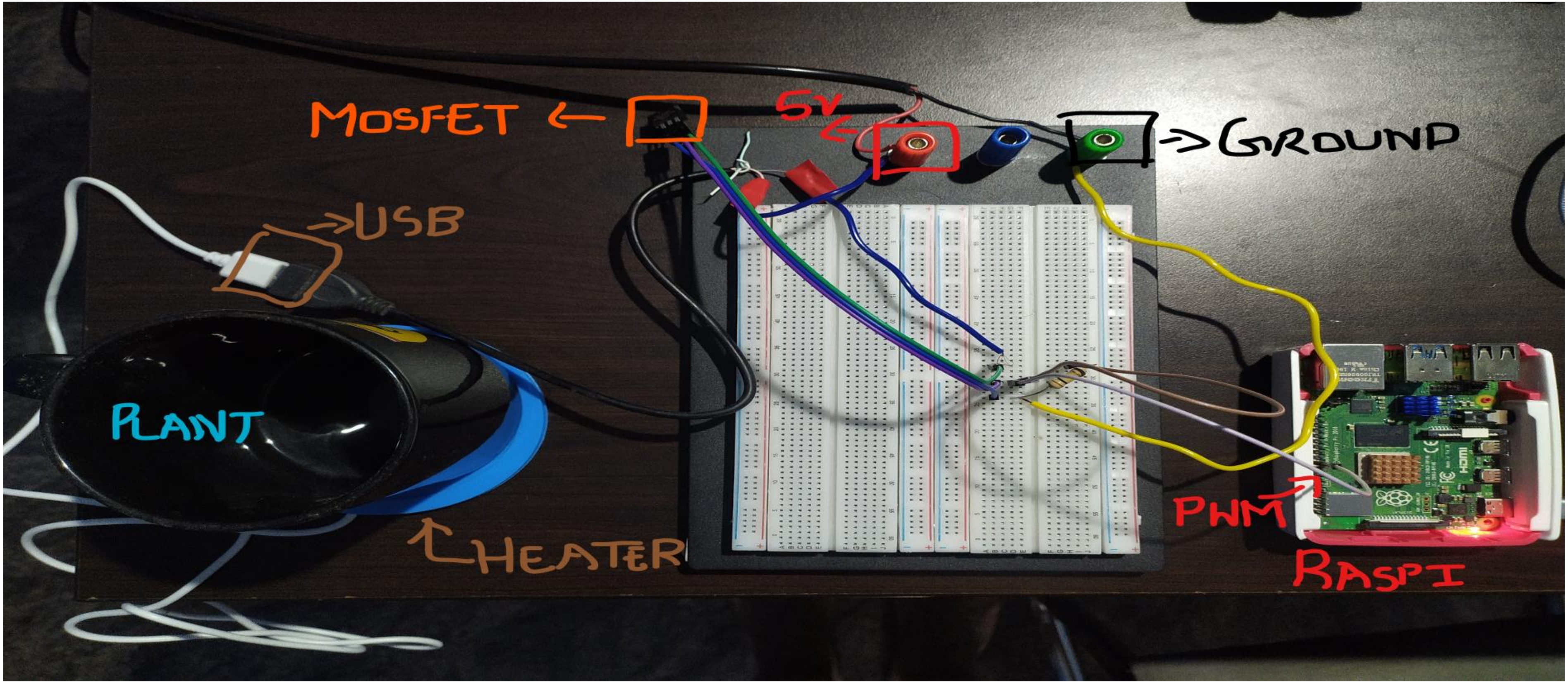
Testing of our control system

REMOTE HEATER CONTROL SETUP : SYSTEM DIAGRAM



Physical testing of our simulated optimised control system

Breadboard Circuit



Summary

- Seismometer and the disturbances to this system was modelled and simulated on python.

- The linear PID controller was developed and was optimised using the PSO algorithm to get the least steady state error.

- Testing of this model on the remote home setup is being carried out.

Future Work

- Short Term :
  - » Closing the feedback loop of the remote setup using the ADC
  - » Designing a more powerful driver circuit to provide higher power to the heater.
  - » Replacing the PID controller with a neural network
  - » Testing the neural network on the physical remote setup

- Long term :
  - » Physical testing of the optimised system on the seismometers in the actual lab environment

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Thanks for listening!

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