Kalman filter based state estimation of the thermal state of a reference cavity

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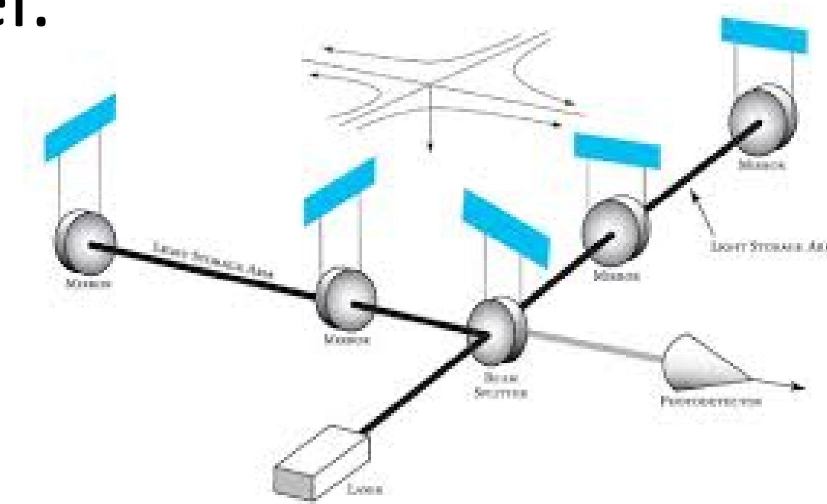
Contents of the talk

LIGO

- LIGO?-Laser interferometer Gravitational Wave observatory.
- Reference Cavity-Pre stabilized lasers are used to give frequency and intensity stabilized light to the interferometer.



Motivation

- Reference cavities are dependent on temperature
- Thermal gradients in test masses are dependent on-
  - Thermal Compensation system
  - Heat flow
  - Self absorption of interferometer power
- Thermal gradients cause thermal lenses which disrupt control systems.
- We need to know the thermal state to control the thermal gradients

Modelling of thermal effects

- Built 1D finite element models of an optic such as silica glass rod in-

1. MATLAB
2. COMSOL
3. Analytically, and compare them.

- Built 2D axisymmetric models of a glass cylinder.
- Built state space formalism based Kalman filter models.

$$X_k = F_K * X_{k-1} + B * U_{k-1}$$

Where X_k is state matrix at step k, F_K is propogation matrix and $B * U_{k-1}$ is input matrix.

❖ Models will be useful in studying and estimating the state of LIGO test masses.

Remainder of Thermal laws

- **Conduction**

$$P_{con} = -kA\frac{dT}{dz}$$

k=Thermal conductivity of the material
dT=Temperature gradient
A=cross section area
dz=distance between two elements
q=heat flux density

- **Radiation/absorption**

$$\boldsymbol{P_{rad}} = \in \boldsymbol{\sigma A T^4}$$

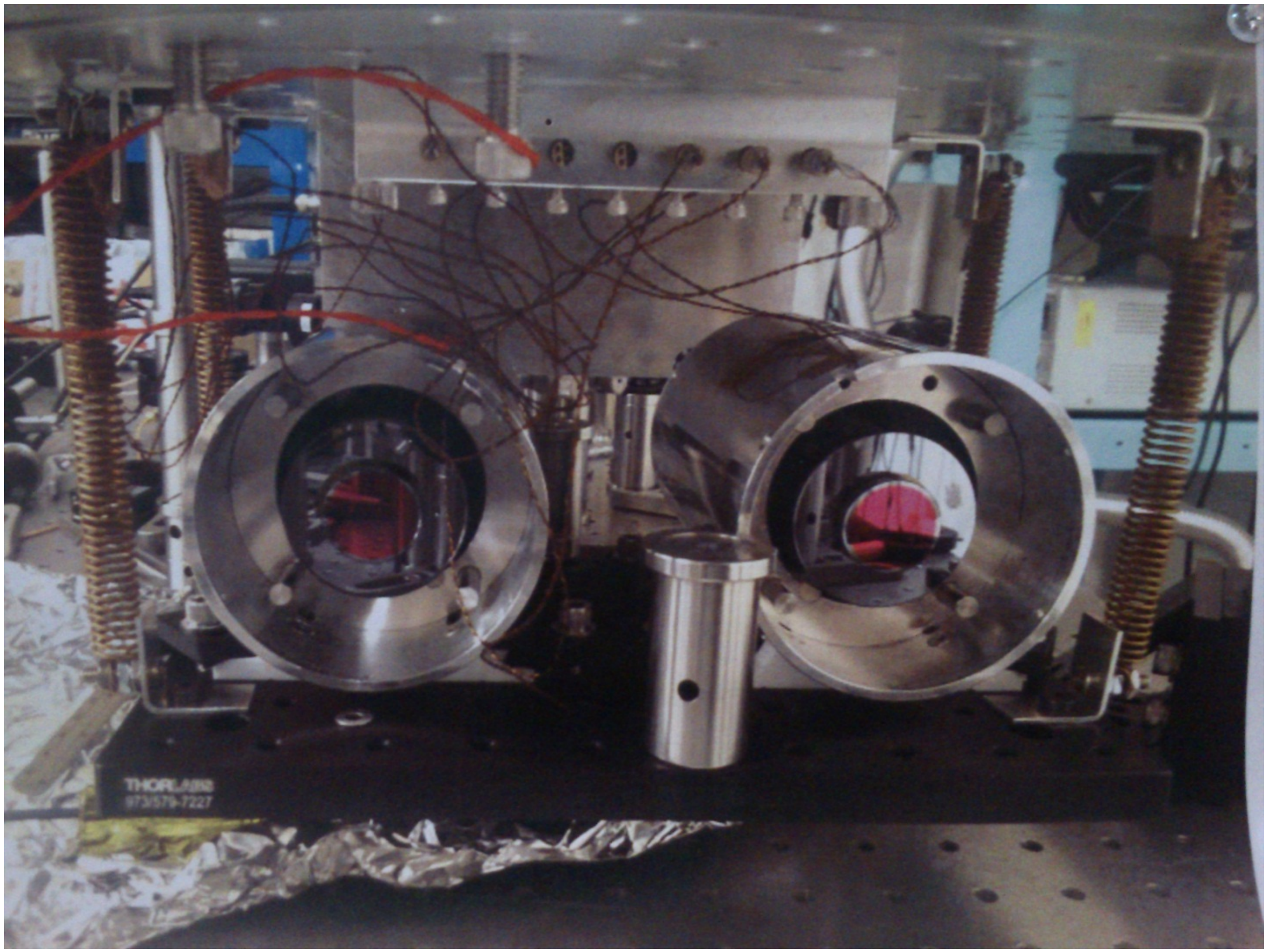
∈=emissivity of material
σ=Stefan Boltzmann's Constant
A=Surface area
T=temperature of the material

- **Convection**

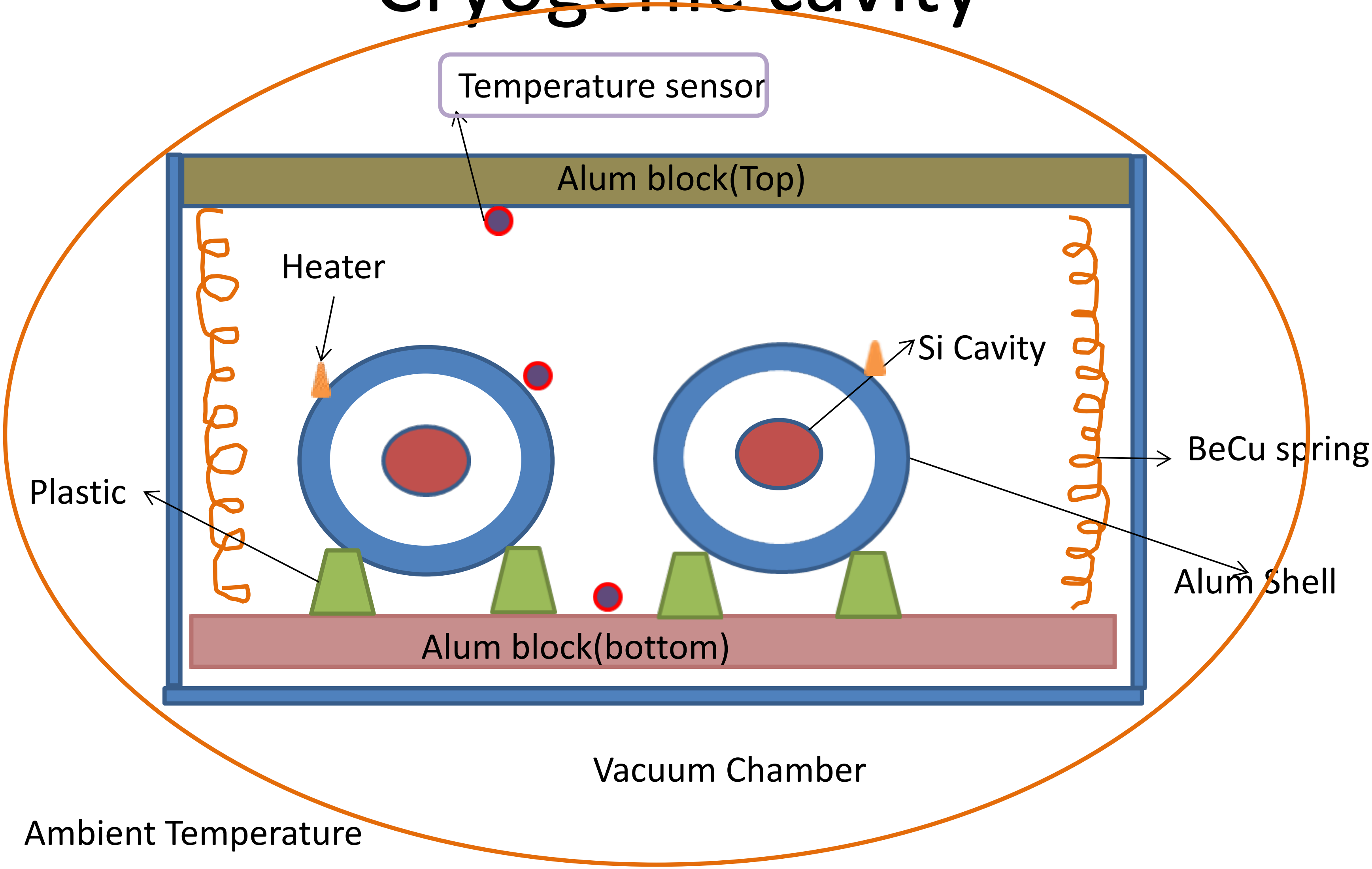
Ignored

❖ We have to **linearize** these equations in order to solve.

Cryogenic cavity!



Cryogenic cavity



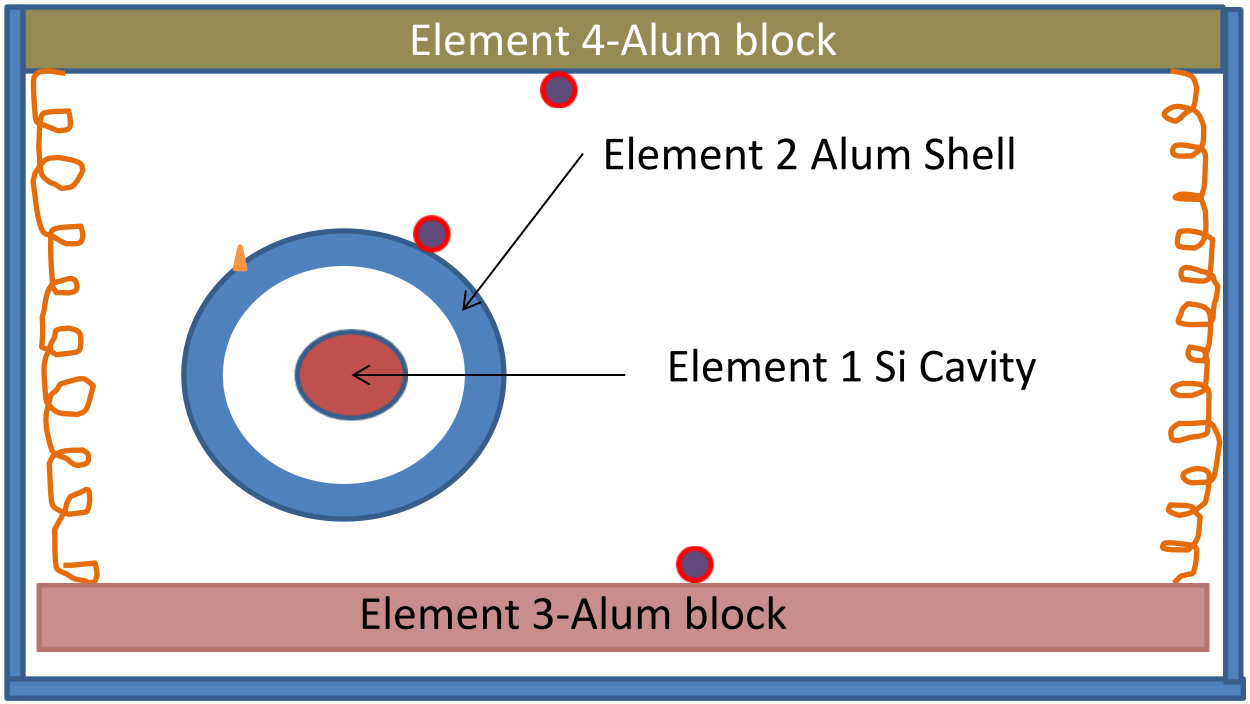
Model assumptions:

- Conduction through plastic is neglected
- West cavity is neglected
- Top and bottom alum blocks exchange energy through conduction process only.
- Assuming emissivity is equal to 1,initially.
- Inputs are ambient temperature and power of the heater.

❖ We make these assumptions to make the problem simple.

State Vector Elements

- Temperature of each element is our state vector.



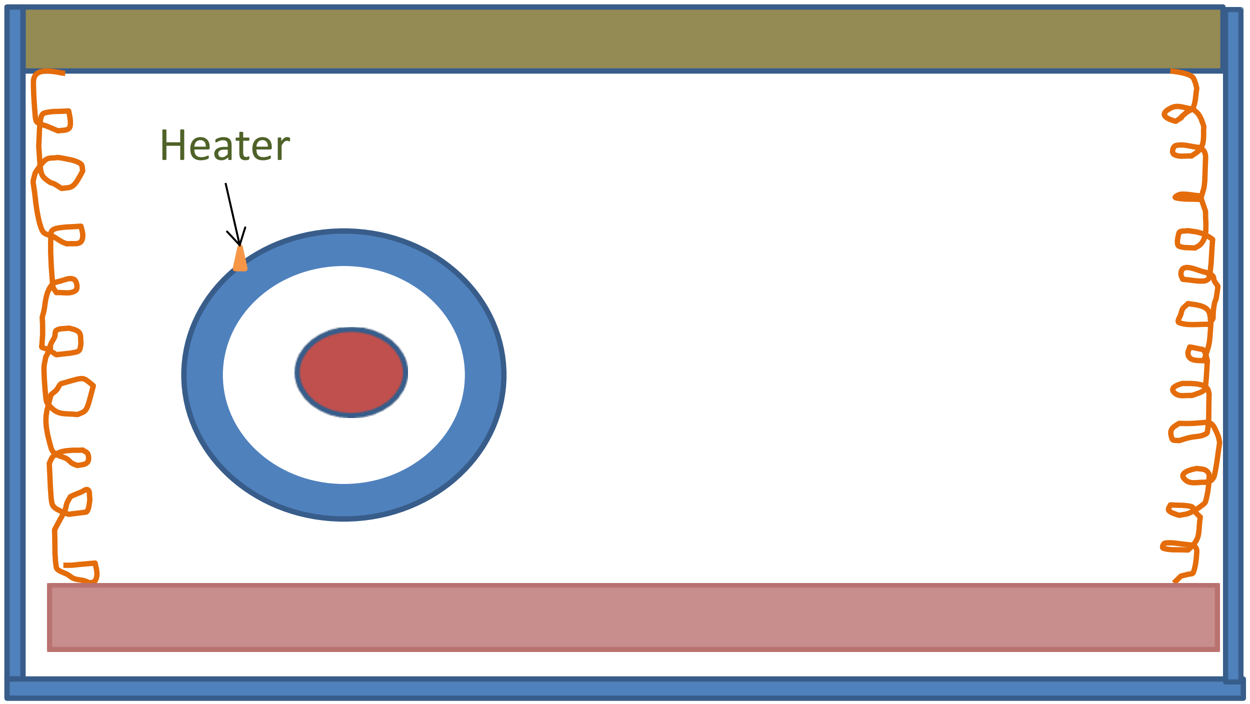
$$X_k = \begin{matrix} T1 \\ T2 \\ T3 \\ T4 \end{matrix}$$

Inputs(external influences)

Two types of inputs-

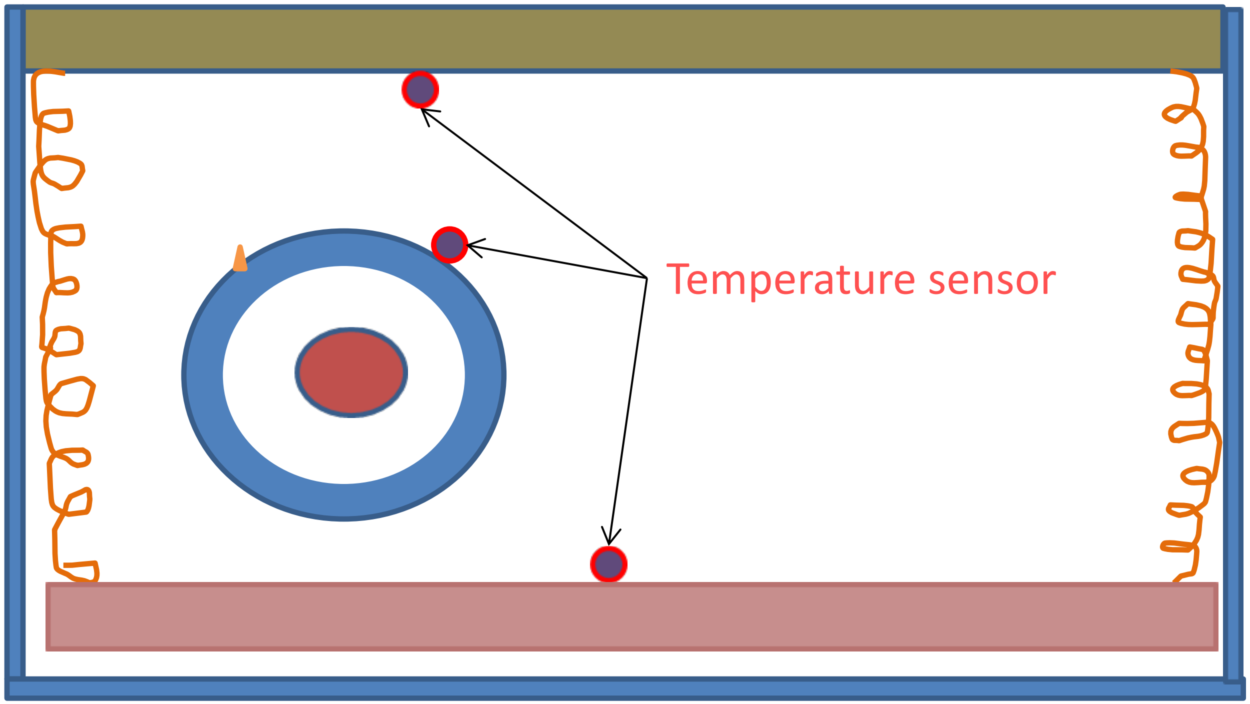
- Controlled input-heater
- Monitored Input-ambient temperature.

Ambient Temperature

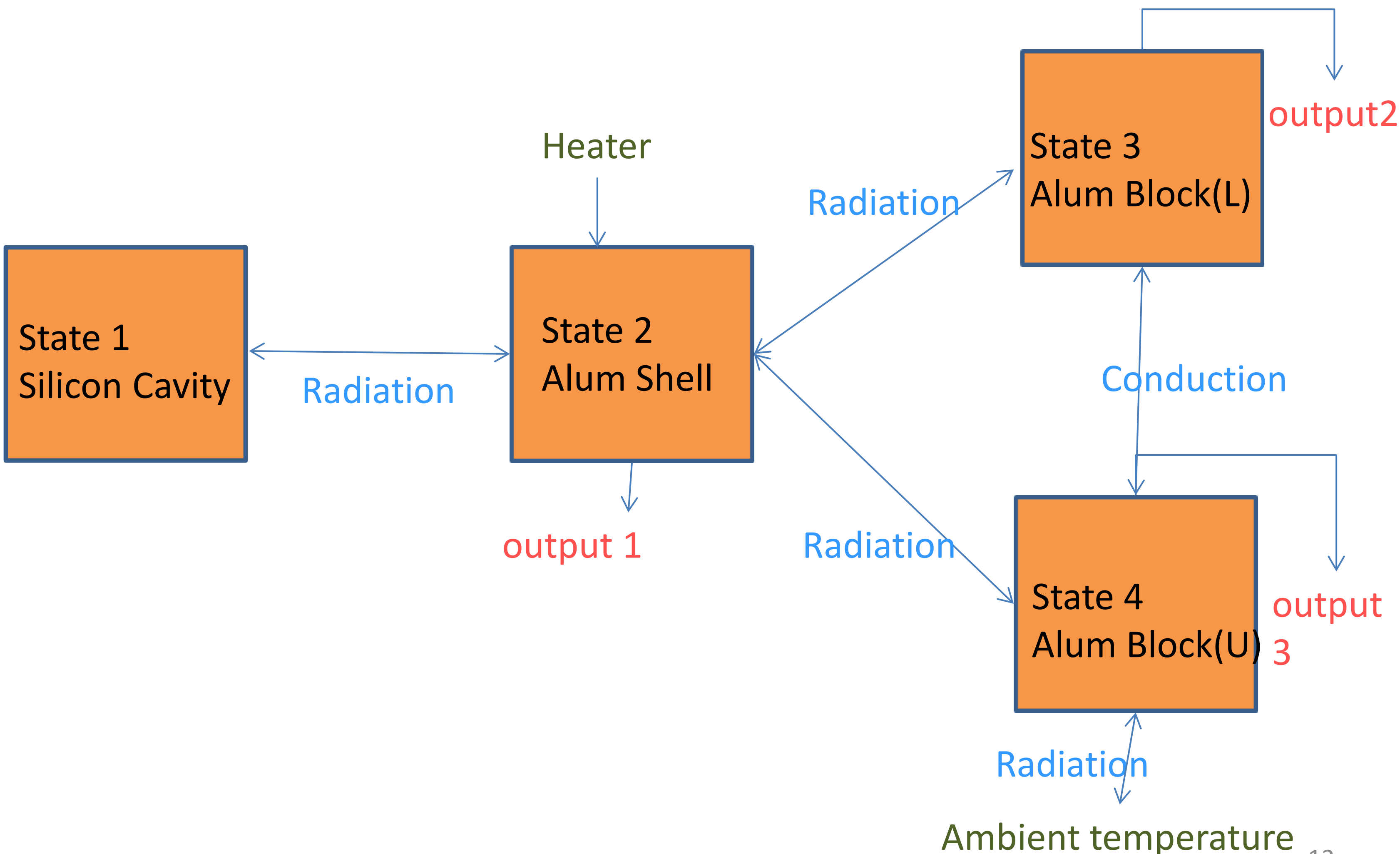


Measurements

Temperature sensors give outputs.



Our state space model of the cavity

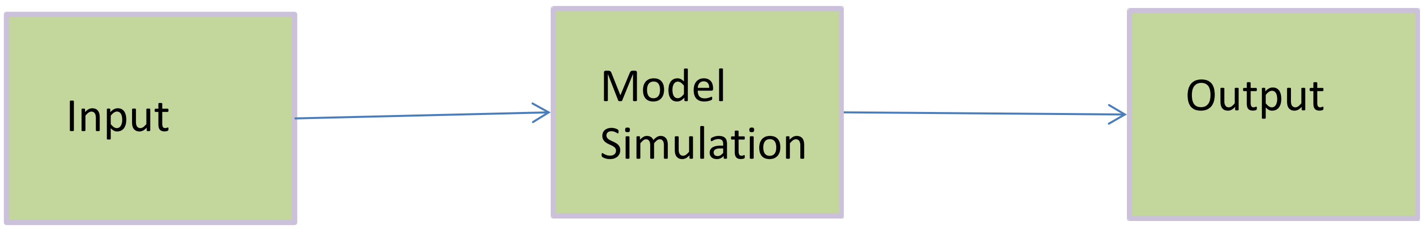


Building models

- Linearized the equations for various state
- Built Kalman filter formalism based on state space model.
- Parameter estimation(Future work).

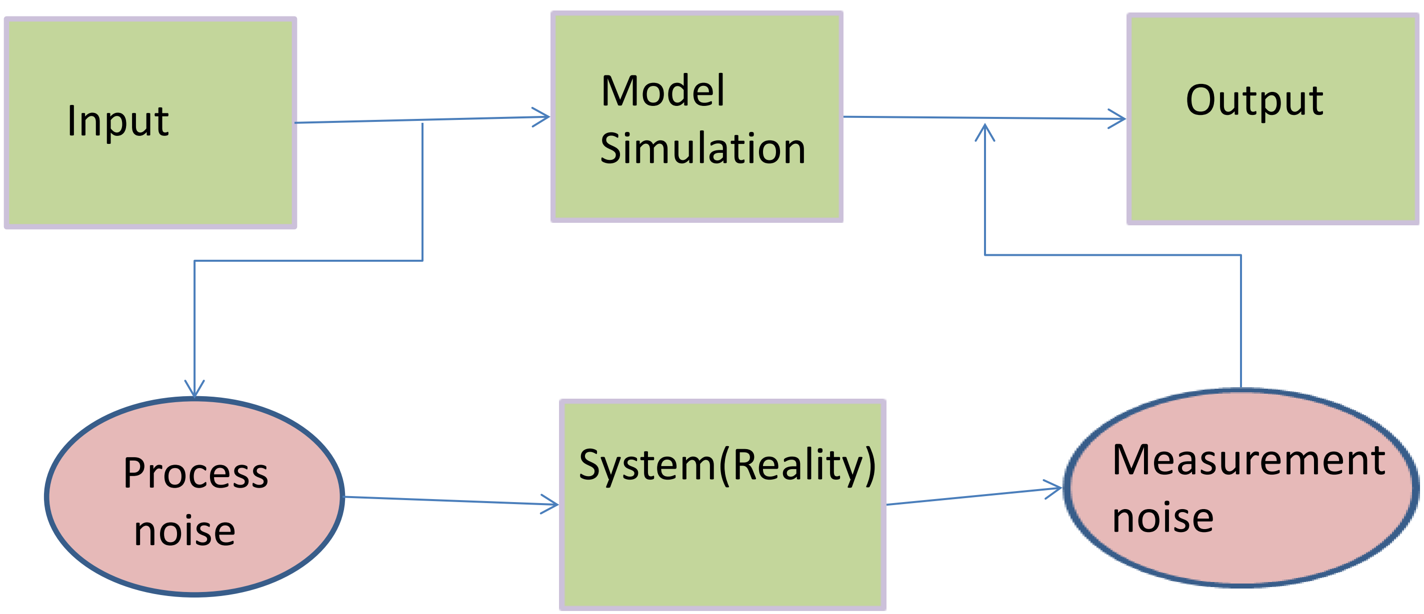
Pure simulation

- State space model of pure simulation



Kalman filter

- Schematic diagram of Kalman filter



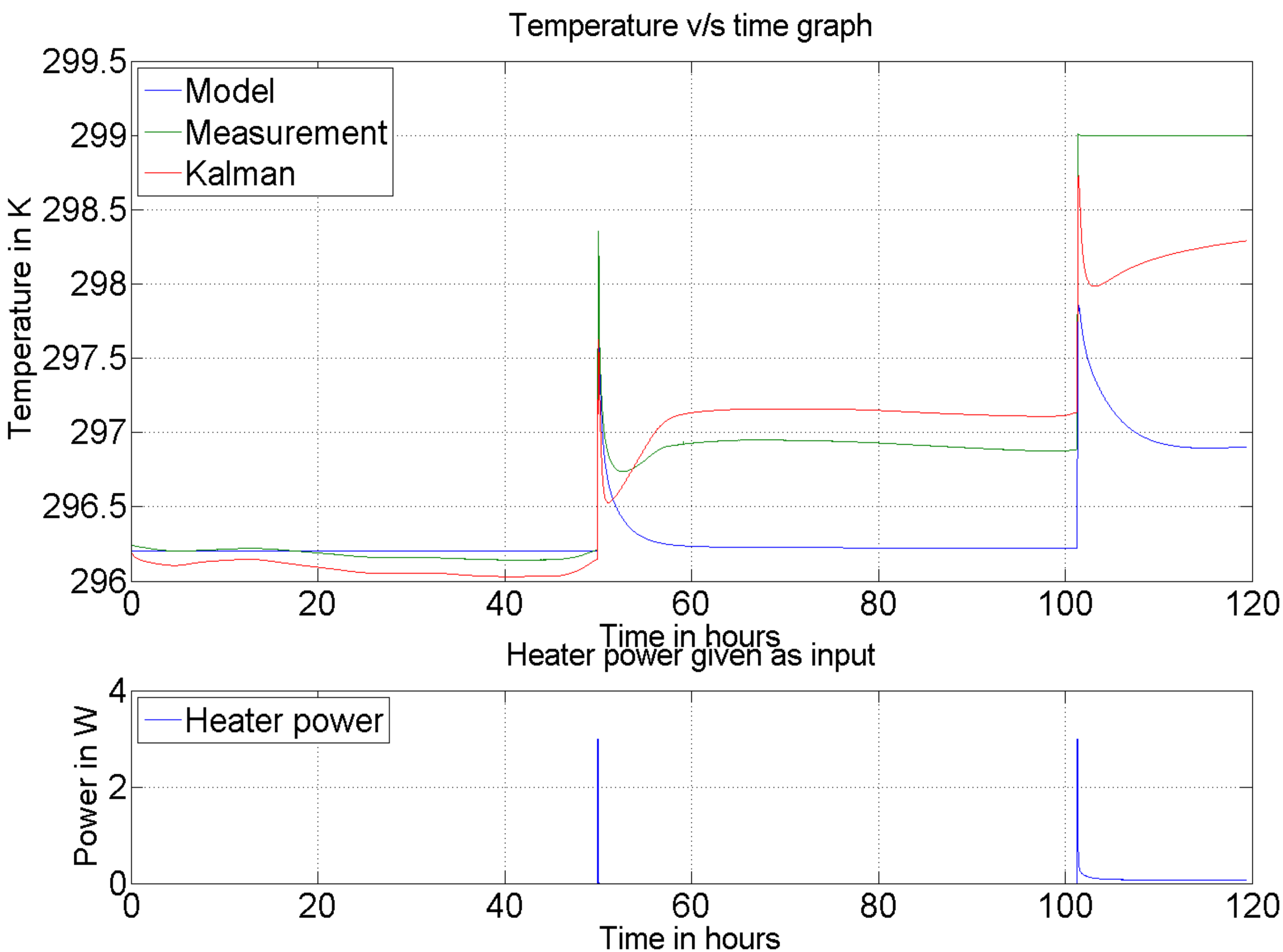
Kalman filter

- Kalman filter estimates the next state of the system with least variance

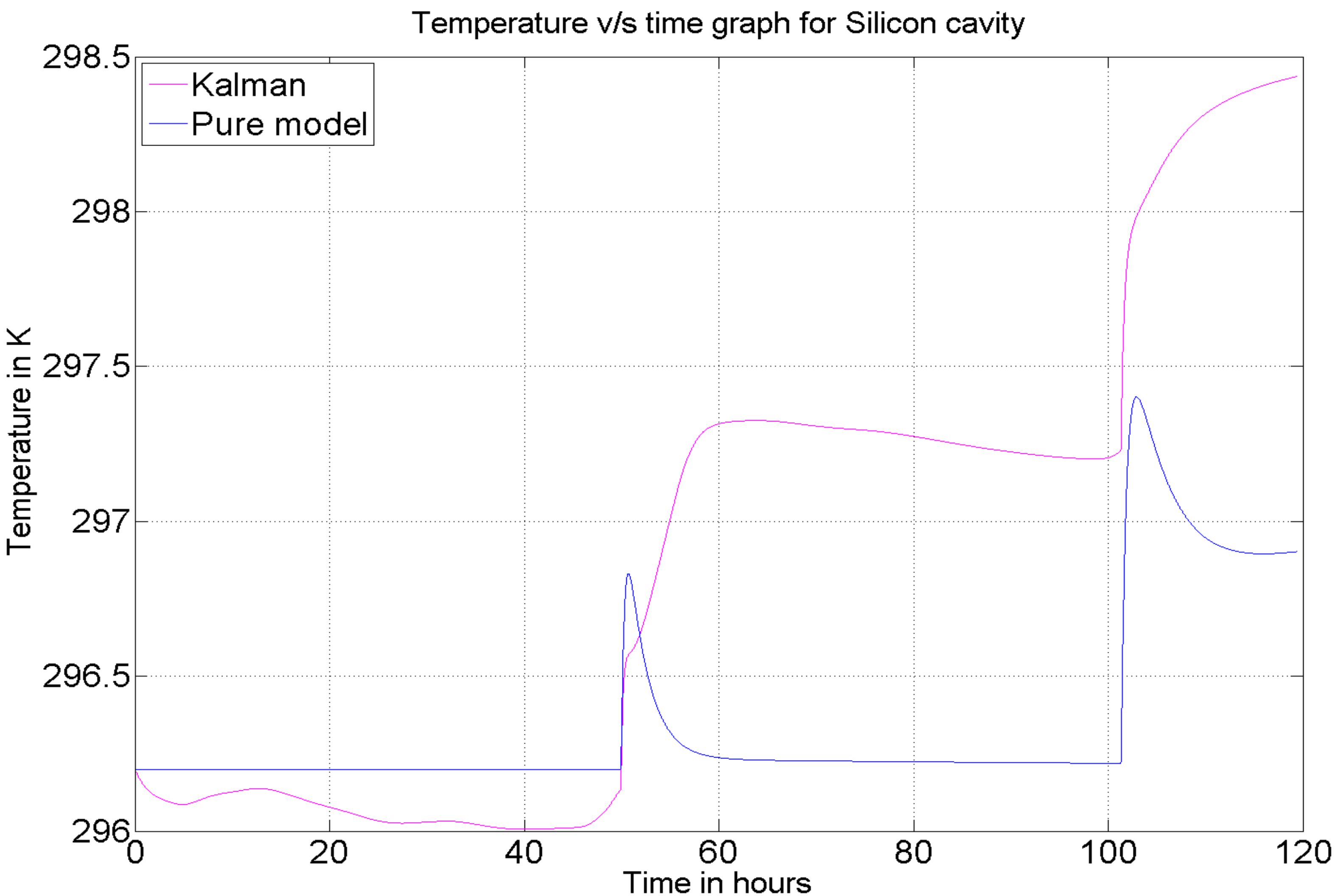
1. By weighting the inputs.
2. By weighting the outputs(measurements).

- Applying Kalman filter formalism to our model to get more precise state estimation

Results and comparison



Estimation of unknown variables



Conclusion

- Produced State space model of the reference cavity.
- Applied Kalman filter model using real data.
- Identified that parameters need to be updated in our model(Future work)

Thank you!