Cavity Error Calibration Notes for a Damped Triple Pendulum

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G1201058-v1

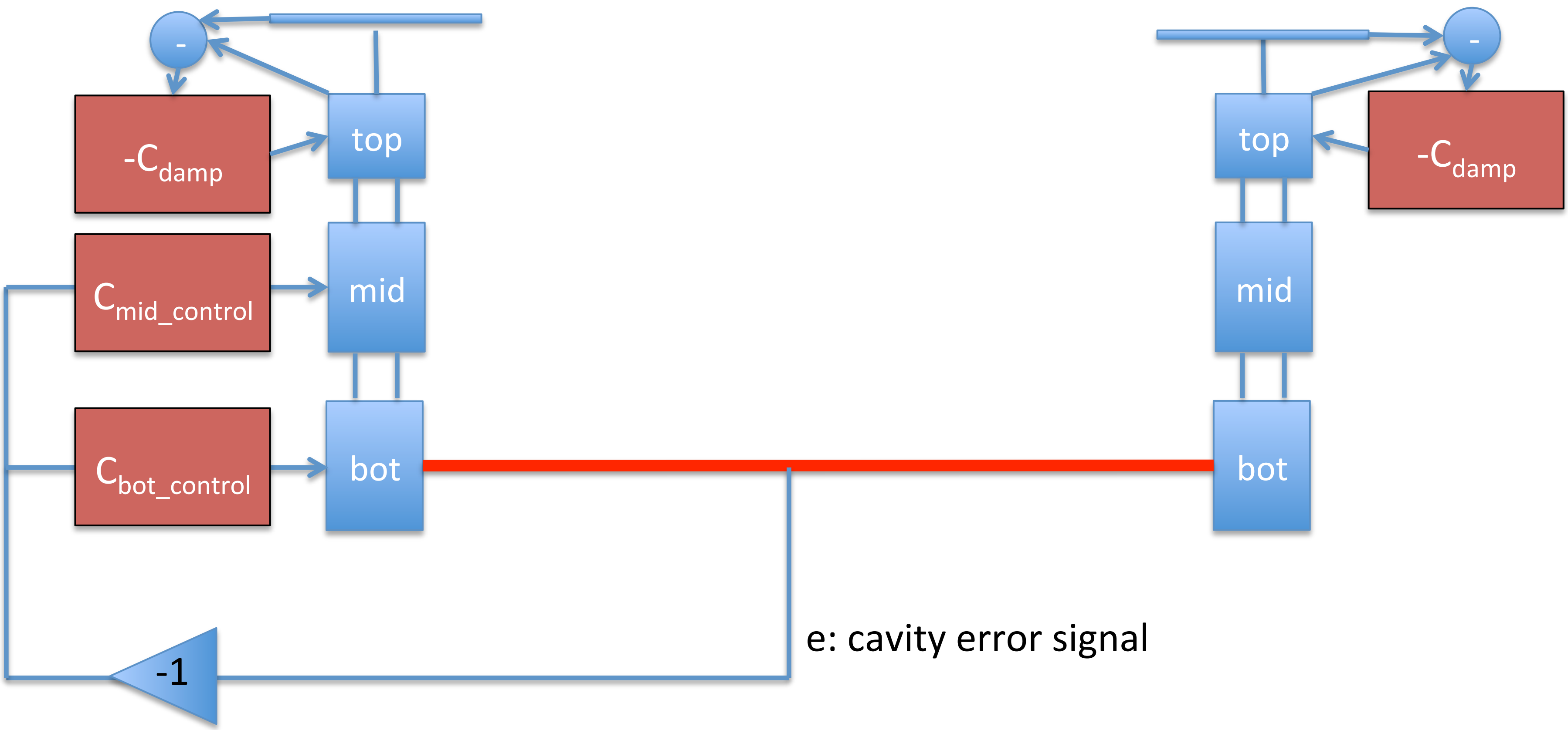
Purpose

- To show the basic theory for generating a noise budget for a locked cavity in a simple, yet complete way.
- **Disclaimer**: This is meant to be a simple overview. The implementation details such as electronic filters, input/output matrices, software gains, etc. are not included. Nonetheless, the theory may be considered complete because the aforementioned details can be thought of as part of the control elements and/or the plant.

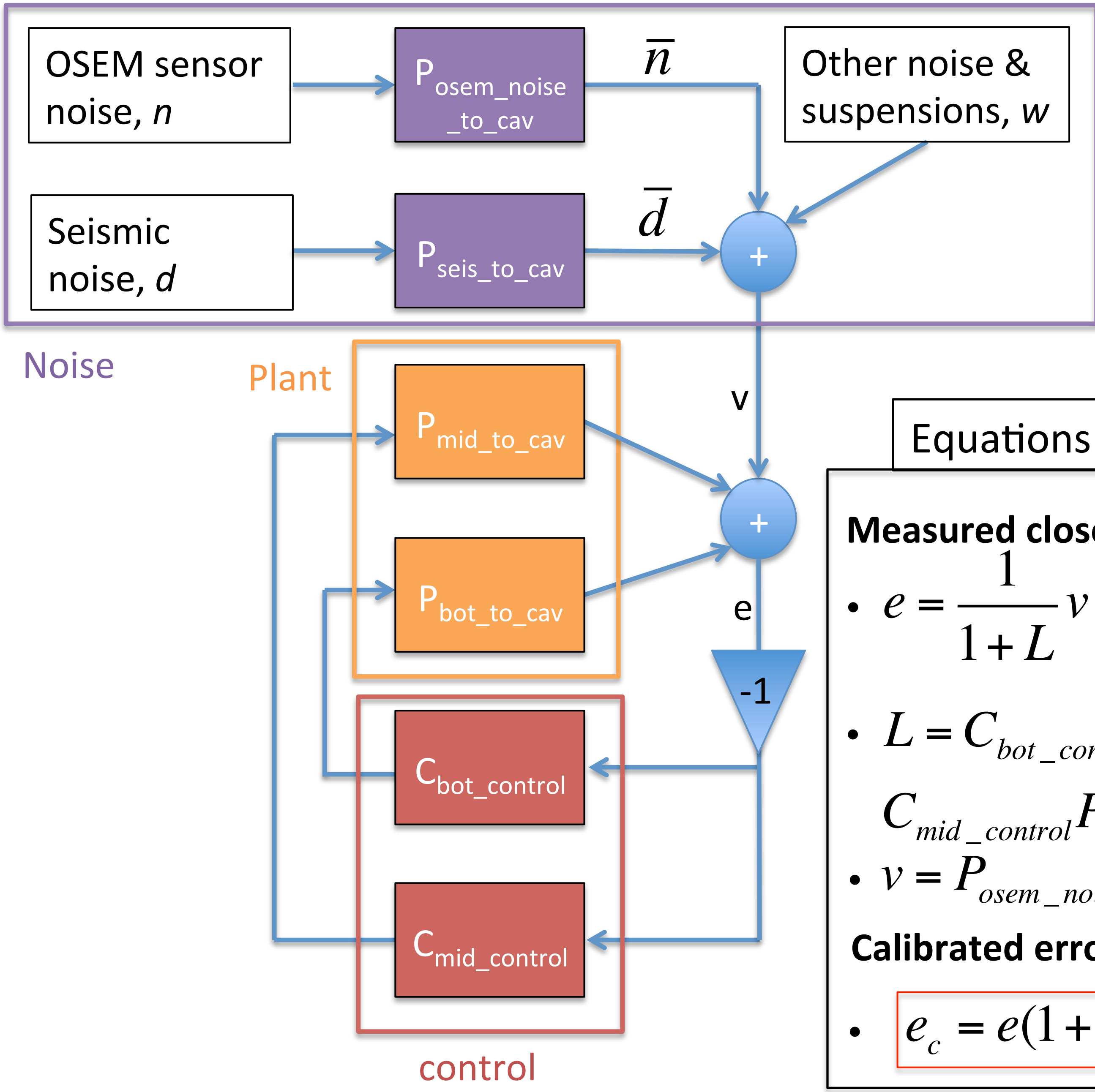
Contents

- Cavity Schematic with damping and hierarchical control
- Block diagram of the hierarchical sus in cavity
- Noise budget calibration steps
- Structure of the damped elements of the block diagram
- MATLAB code to build a damped pendulum model
- Simulated noise budget calibration plot
- Extras: simulated hierarchical loop gain

Schematic Diagram (no noise)



Block Diagram (hierarchical sus, noise)



Equations to calibrate cavity signal

Measured closed Loop Error Signal

- $e = \frac{1}{1+L} v$
- $L = C_{bot\_control} P_{bot\_to\_cav} + C_{mid\_control} P_{mid\_to\_cav}$
- $v = P_{osem\_noise\_to\_cav} n + P_{seis\_to\_cav} d + w$

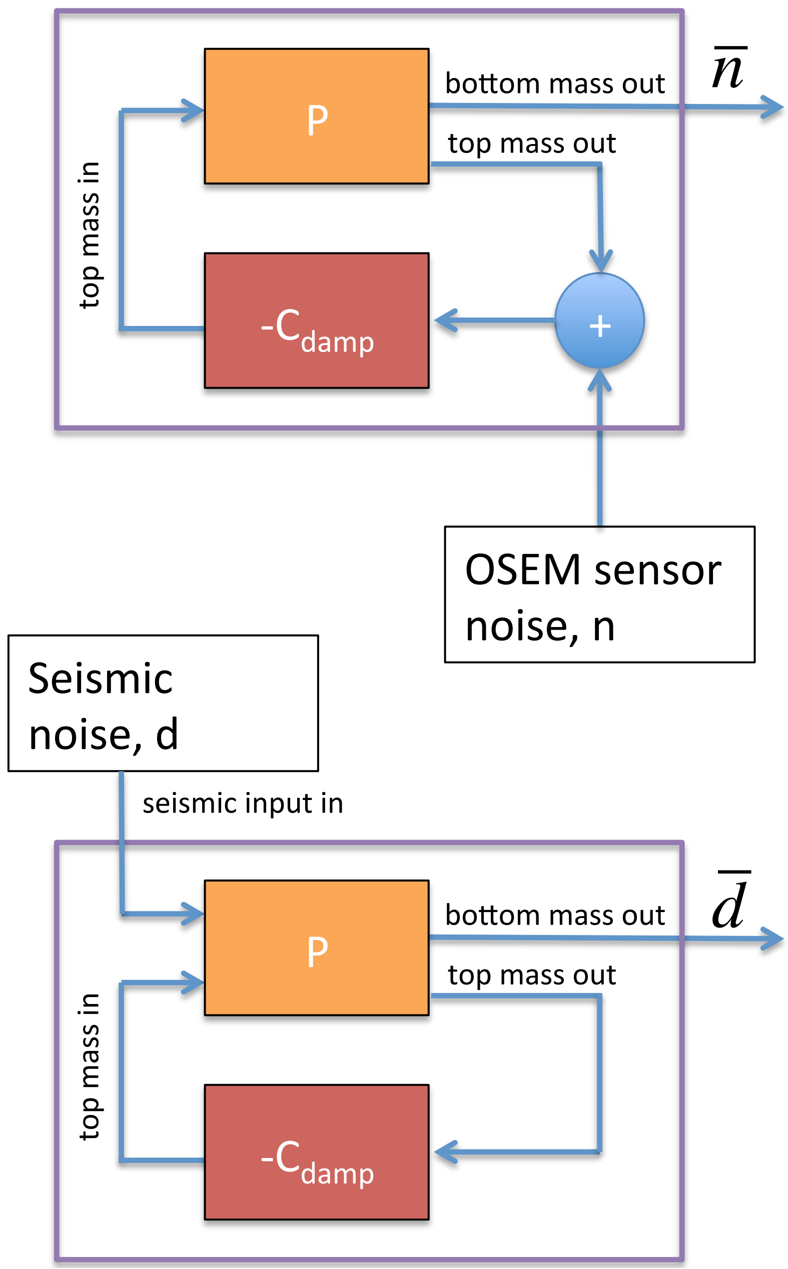
Calibrated error signal e_c for noise budget

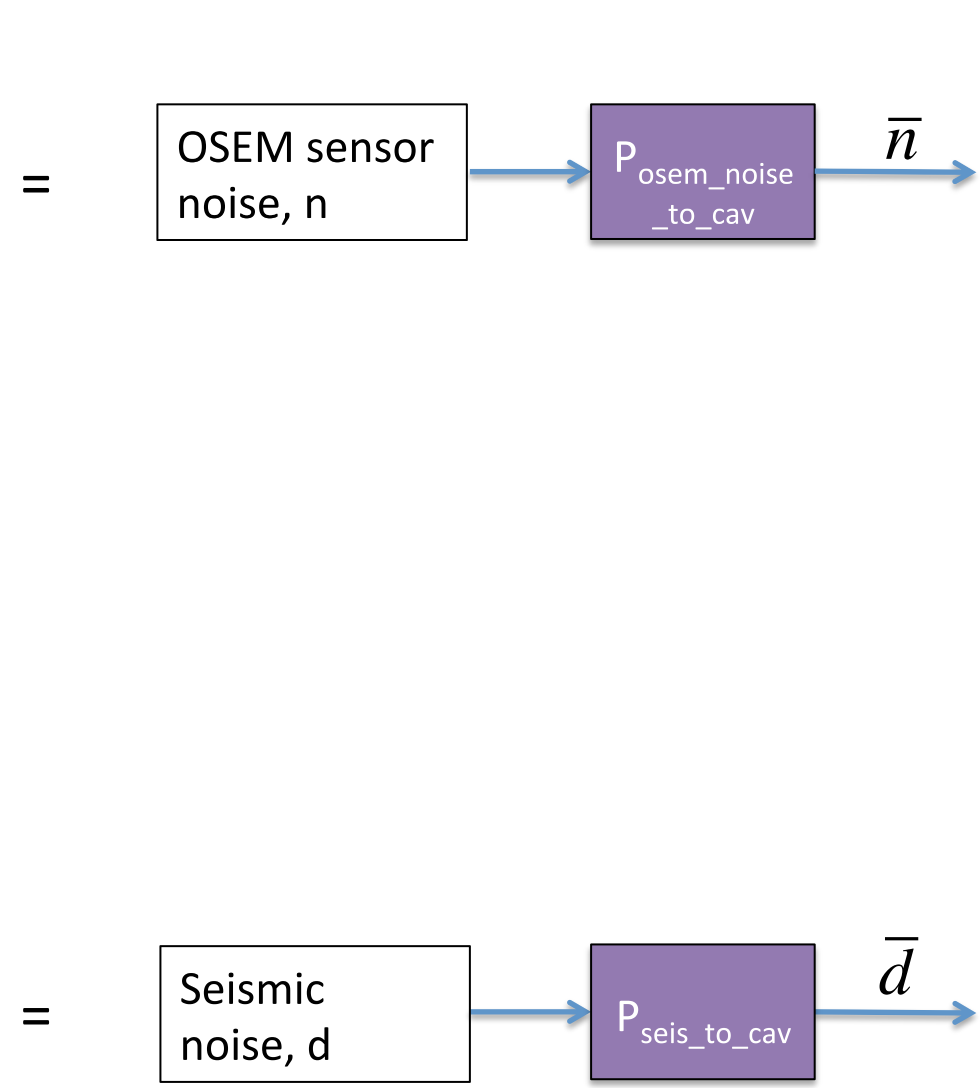
- $e_c = e(1+L) = v$

Steps to Calibrate the Closed Loop Error for the Noise Budget

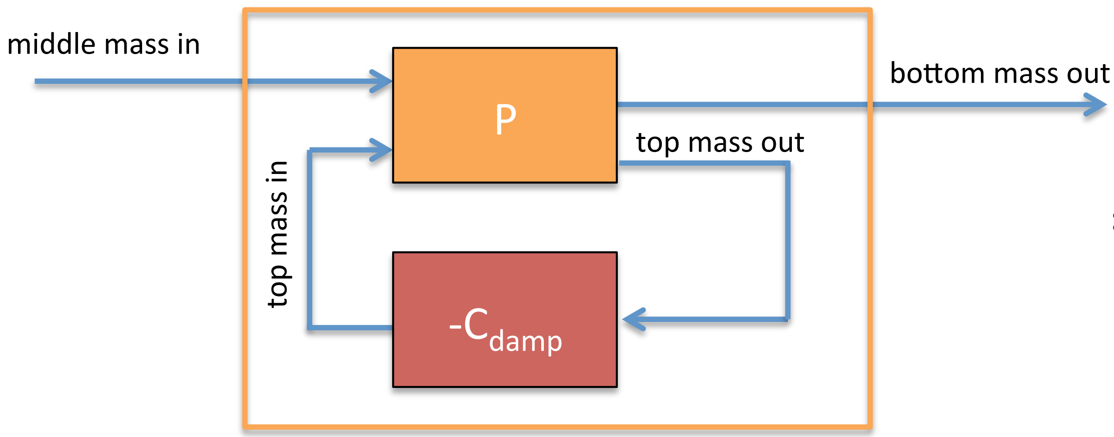
- Generate a multi-input-multi-output **damped** pendulum model *P* (if damping is applied)
- Generate a model of the loop gain transfer function *L* using the damped model *P* and the hierarchical feedback filters *C*
- The calibrated error e_c is *e* times *(1+L)*, $e_c=e(1+L)$.
- The noise components of the noise budget (e.g. OSEM noise, seismic noise) are simply filtered by the damped plant *P* as appropriate **without** the loop gain *L.* These noises are suppressed by *(1+L)* in the closed loop, but then the calibration would undo it by multiplying by *(1+L),* so the *(1+L)* cancels out.

Damped Pendulum Elements





Damped Pendulum Elements



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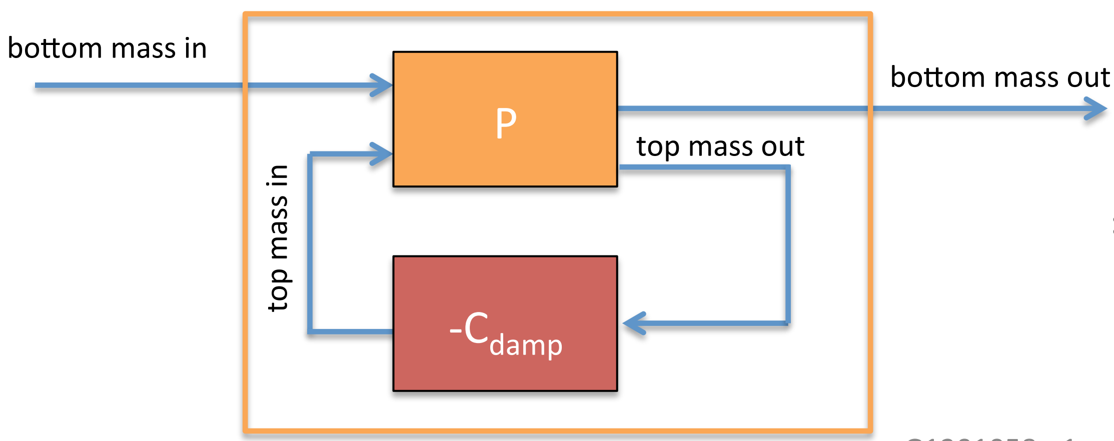

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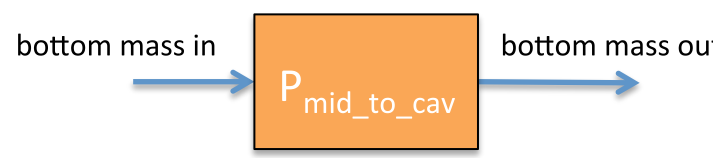


MATLAB to build a damped L-P model

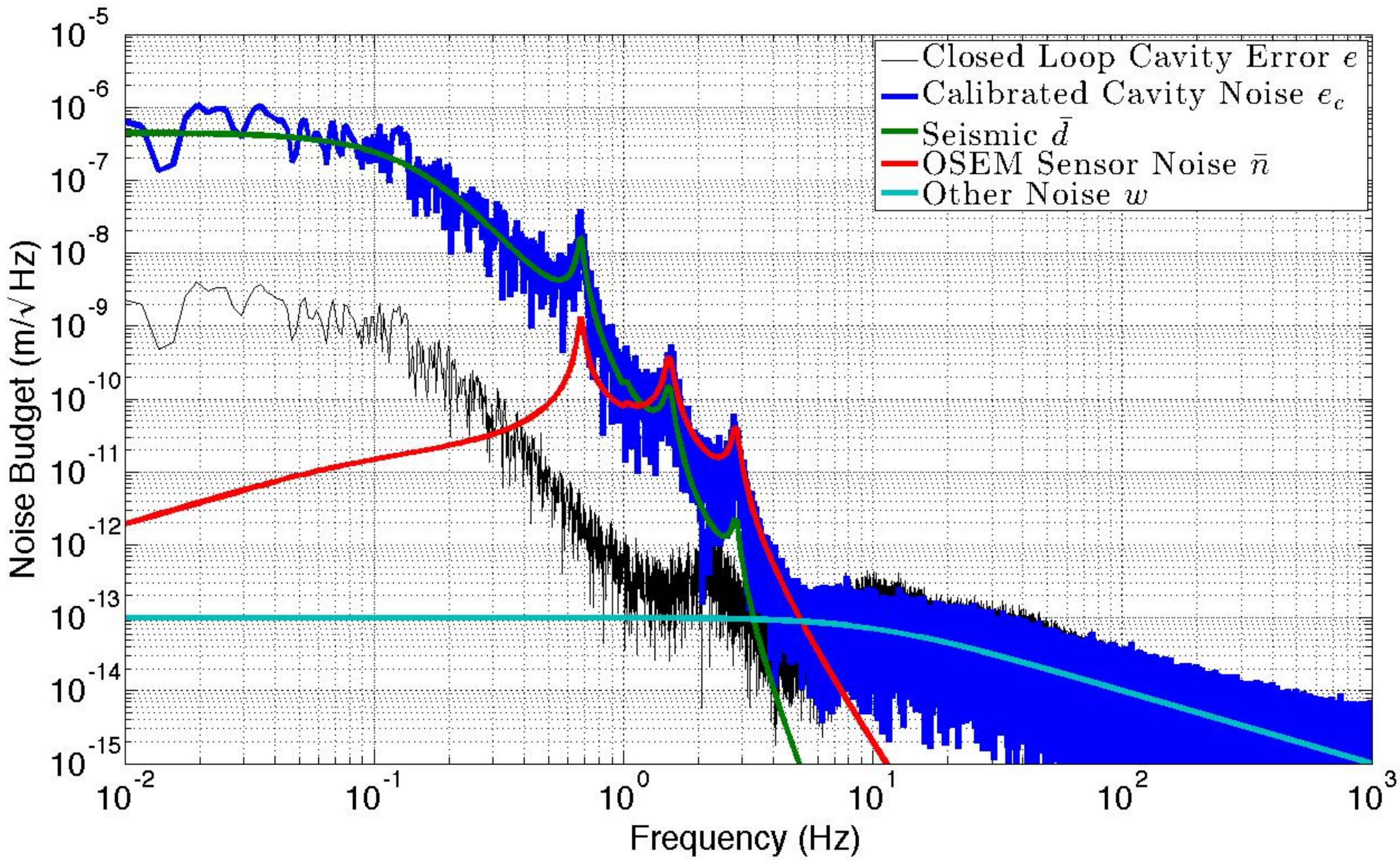
A very similar process occurs in svn/sus/trunk/Common/MatlabTools/TripleModel_Production/generate_Triple_Model_Production.m

```
% Longitudinal and Pitch Damping filters
Damping.longitudinal = zpk(0,-2*pi*30*[1;1],2e5); % or whatever damping you like
Damping.pitch        = zpk(0,-2*pi*30*[1;1],2e3); % or whatever damping you like

% HSTS Model
mbtrip = ssmake3MBf('hstsopt_metal');
TripMod.LP.undamped = model_cut_triple(mbtrip,'lp');  % simplify to 6x8 L-P model

% Building a damped long-pitch SUS model: TripMod.LP.damped
SusPlusDamp = append(TripMod.LP.undamped,Damping.longitudinal,Damping.pitch);  % merge
% SUS model and damping into temporary lumped state space system.
% Making input-output connections between SUS and damping. cnxnMatrix defines which inputs
% go to which outputs and with what signs. The left column is the input indices of
% SusPlusDamp, the right is the output indices. See MATLAB help on the append and
% connect pair of commands for more details.
cnxnMatrix = [ 3 -7       % L damping filter output to top mass L force input
               9  1       % top mass L output to L damping filter input
               4 -8       % L damping filter output to top mass L force input
              10 2];      % top mass L output to L damping filter input
  inputs = 1:10; % L seismic, pitch seismic, all 6 SUS long-pitch force inputs, L
% damping filter input for sensor noise, P damping filter input for sensor noise
  outputs = 1:6; % all 6 long-pitch SUS outputs
TripMod.LP.damped = connect(SusPlusDamp,cnxnMatrix,inputs,outputs); % 6x10 damped L-P SUS
```

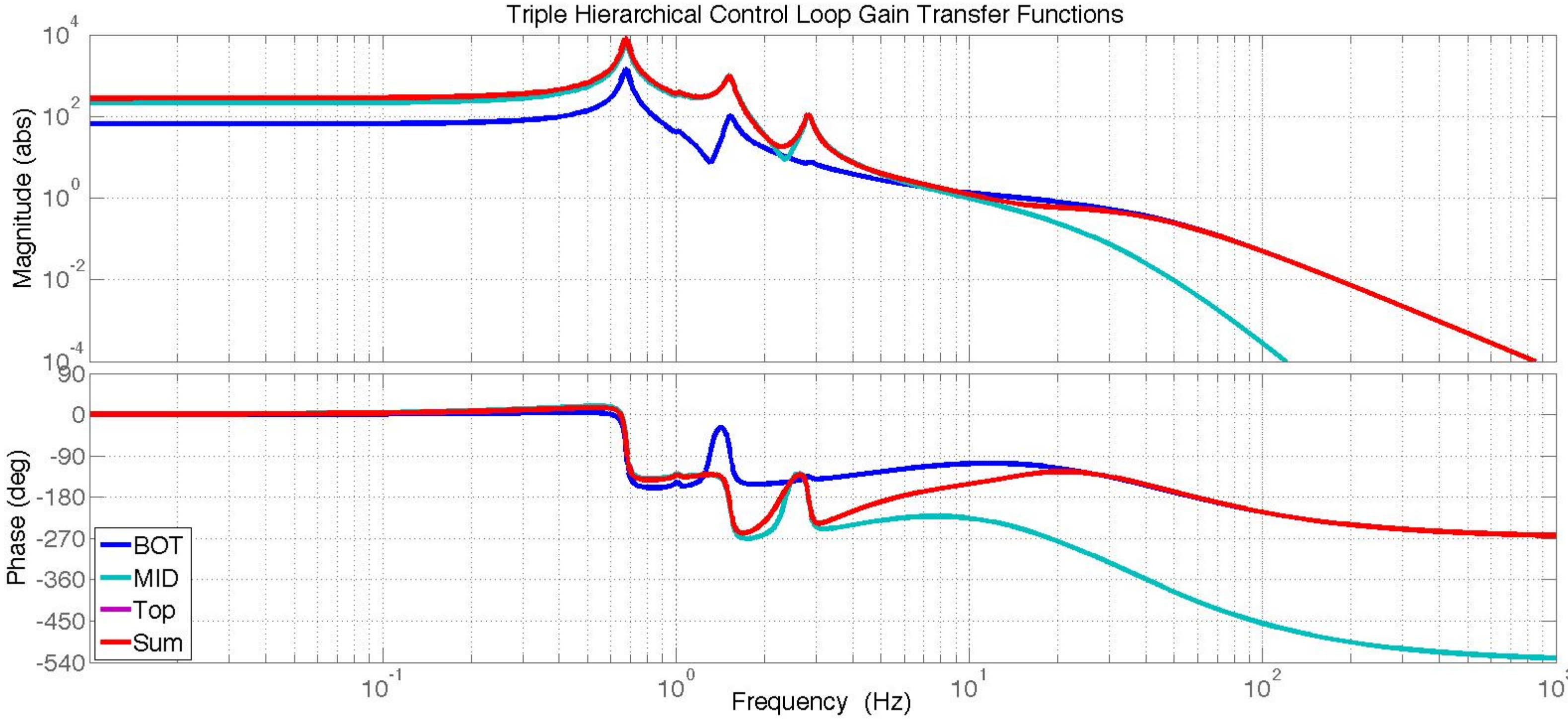
Simulated Noise Budget Calibration



Note: All noises except OSEM sensor noise are arbitrary

Extras

Hierarchical loop gain used in simulation



$$C_{mid\_control} = \frac{(3.29e4)(s+18.22)^2}{(s+106.2)^2(s+131.9)} C_{bot\_control}$$

$$C_{damp\_long} = \text{zpk(0,-2*pi*30*[1;1],2e5])}$$

$$C_{bot\_control} = \frac{(4.44e7)(s+39.04)^2}{(s+227.5)^2(s+282.7)}$$

$$C_{damp\_pitch} = \text{zpk(0,-2*pi*30*[1;1],2e3])}$$