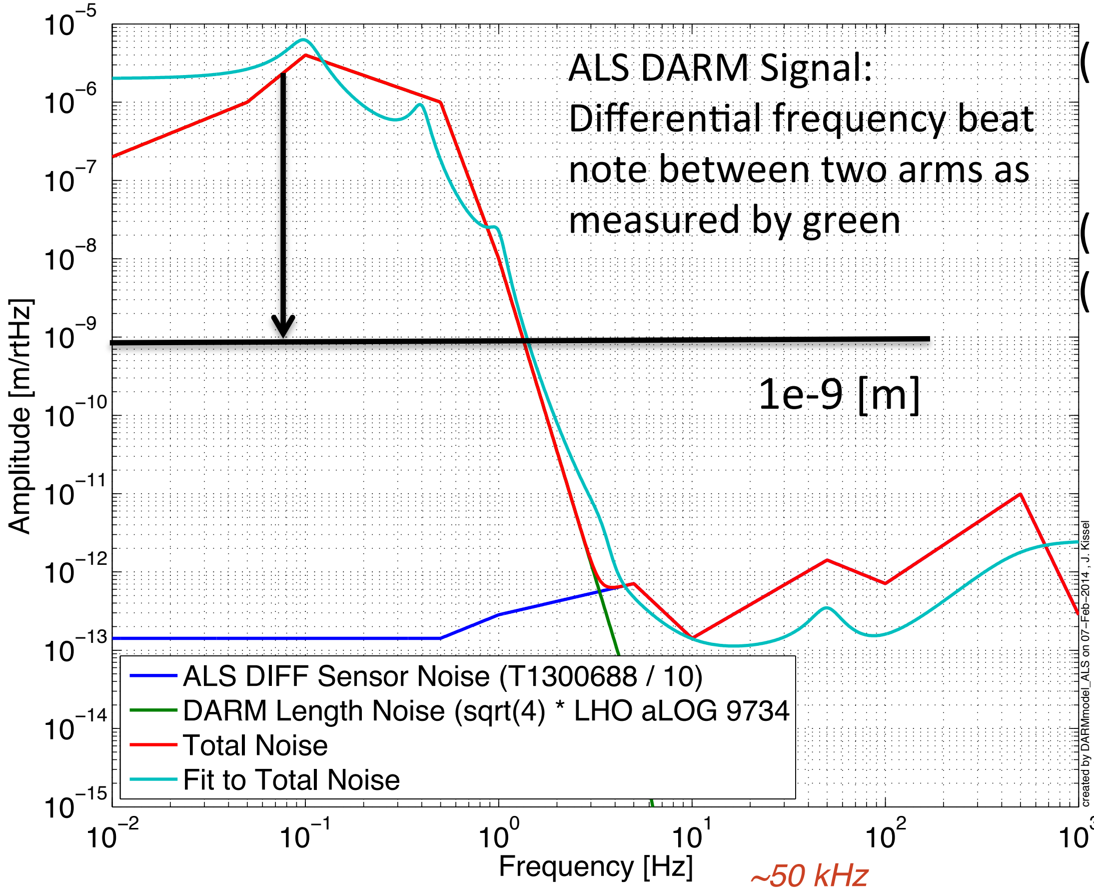
Hierarchical Control (“Classical” Approach)

J. Kissel, for the Hiers

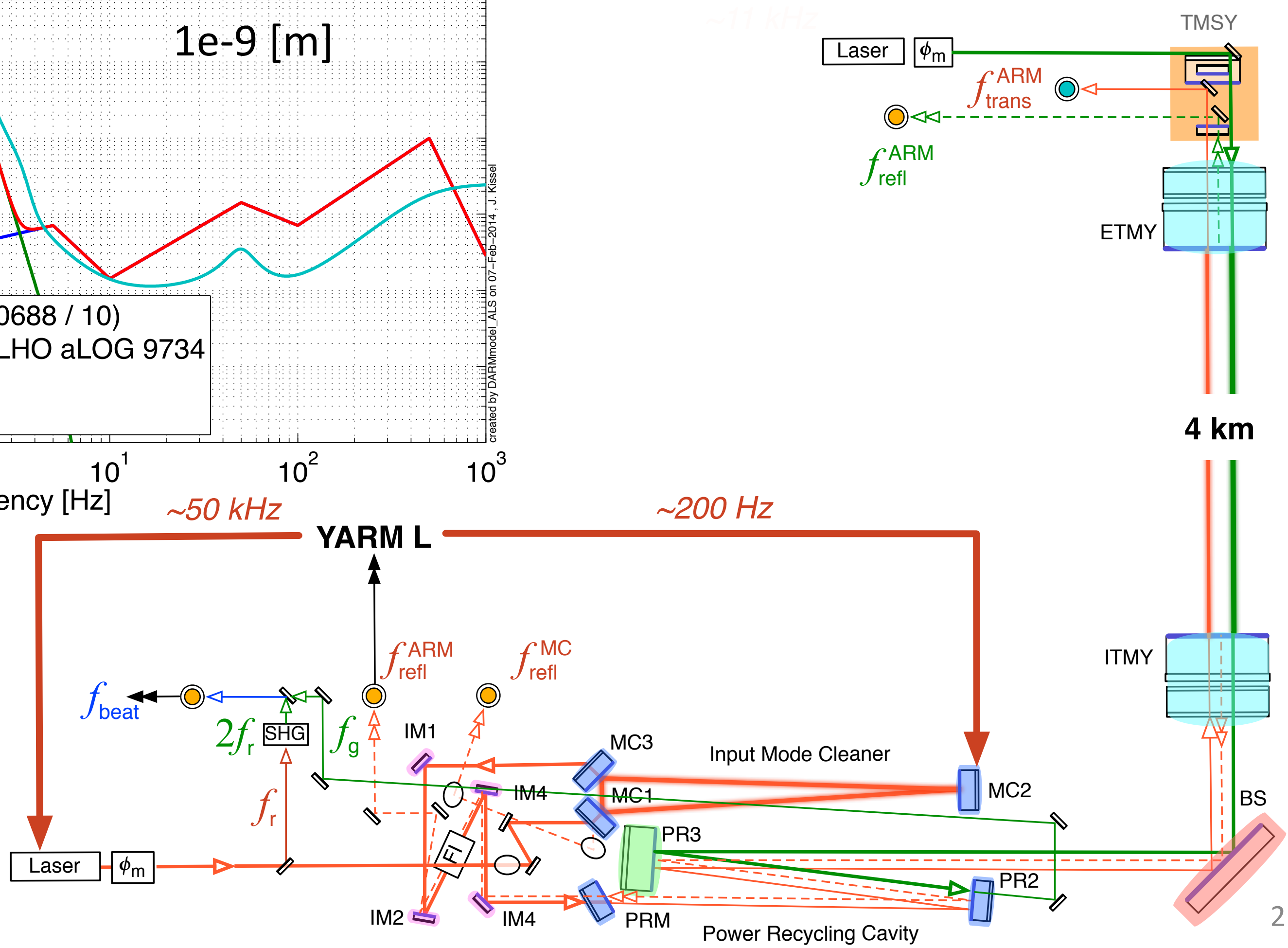
Problem Statement



(1) Reduce input spectrum to **1 [nm] RMS** using **hierarchical feedback** to **middle two stages of ETMs**,

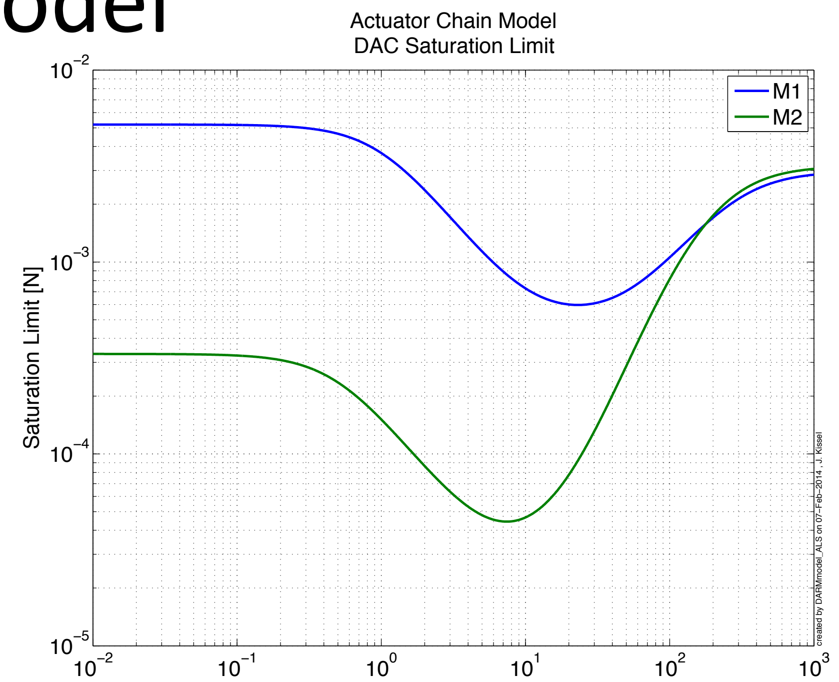
(2) without **saturating the DAC**

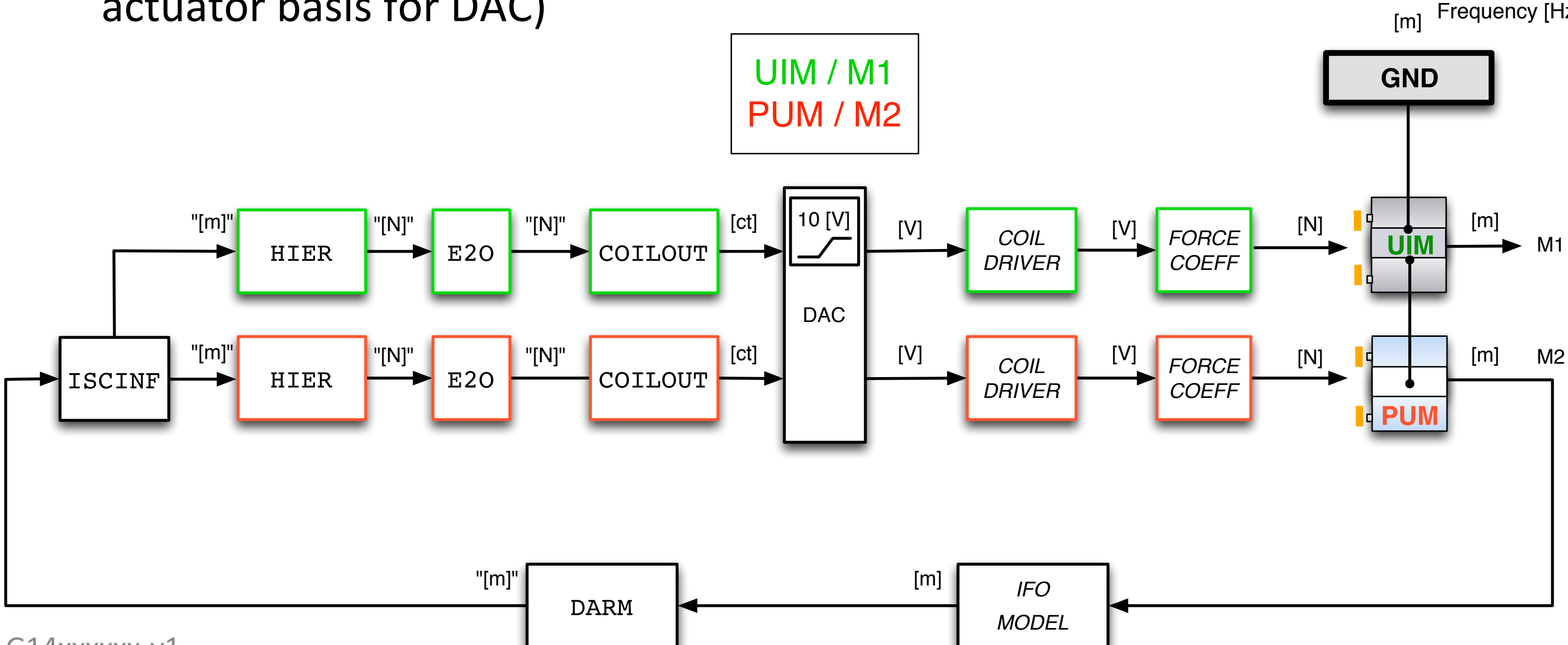
(3) Expected Bandwidth around **10-20 [Hz]**



The Toy Model

- DARM -- > Treat motion of one test mass
- QUAD -- > Double pendulum, parameters roughly of PUM and TST Mass (assuming local damping ON)
- UIM & PUM -- > Equal Masses, No Stage Below
- Same Actuators with Same Actuator Limits
- Same Input Amplitude Spectral Density
- Same output scheme (digital compensation of analog electronics, transformation to actuator basis for DAC)





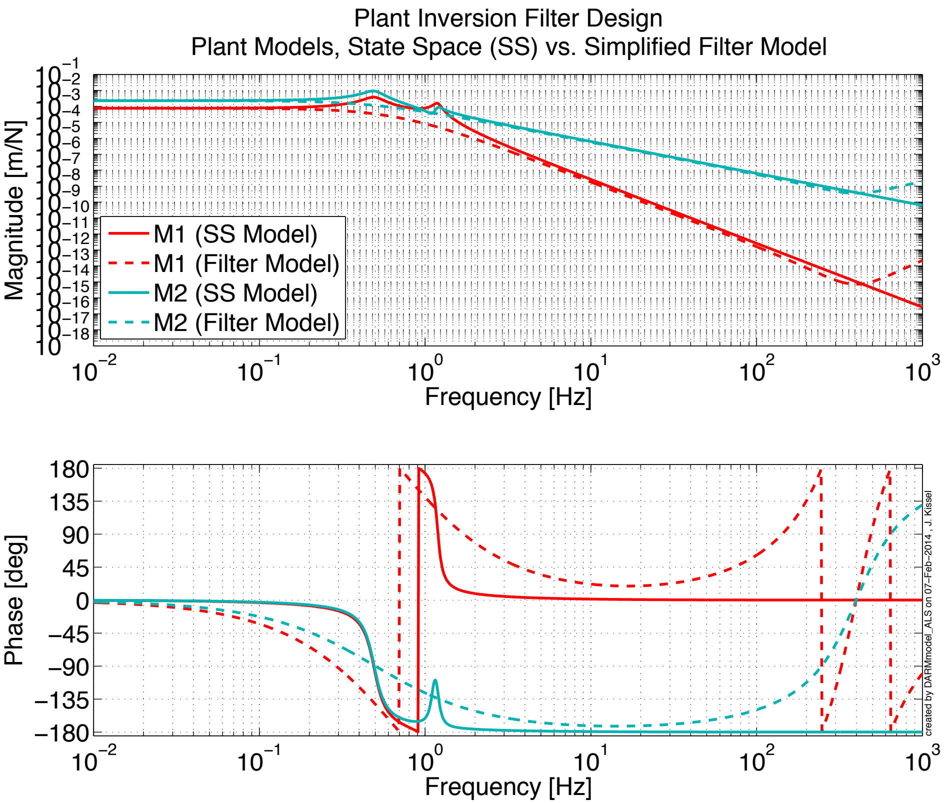
m1 = 40;
m2 = 40;
g = 9.81;
L1 = 0.3;
L2 = 0.6;
k1 = m1*g/L1;
k2 = m2*g/L2;
g1 = 30;
g2 = 30;

The Prescription

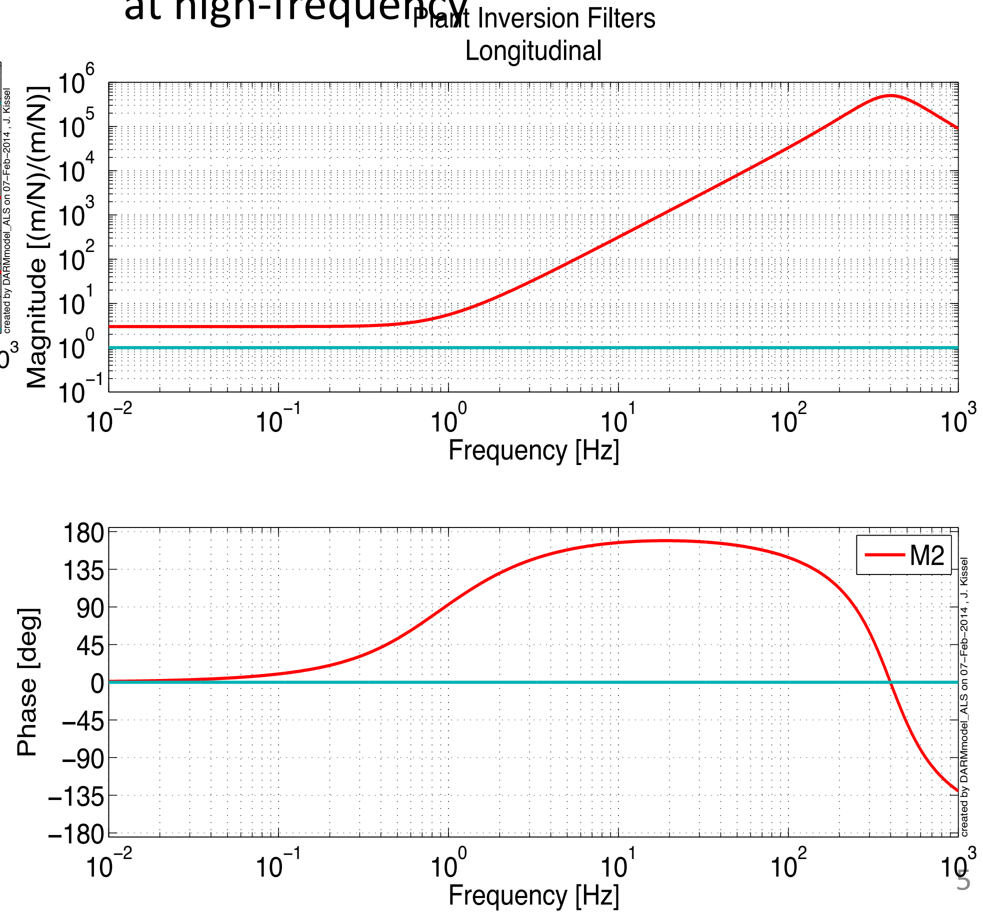
The Distributed Hierarchy

- Create plant inversion filters (so we can use complementary hierarchy filters)
- Design hierarchy filters, check cross-over stability
- Design global control filter, check loop gain stability
- Compute closed loop performance and RMS, check to meet requirement (1)
- Compute control force at DAC, check probability of saturations, RMS, etc. meet requirements (2)
- Iterate on Global Control and Hierarchy authority until you get something that meets requirements
- Try it on the real thing, see if it works, and tweak if necessary

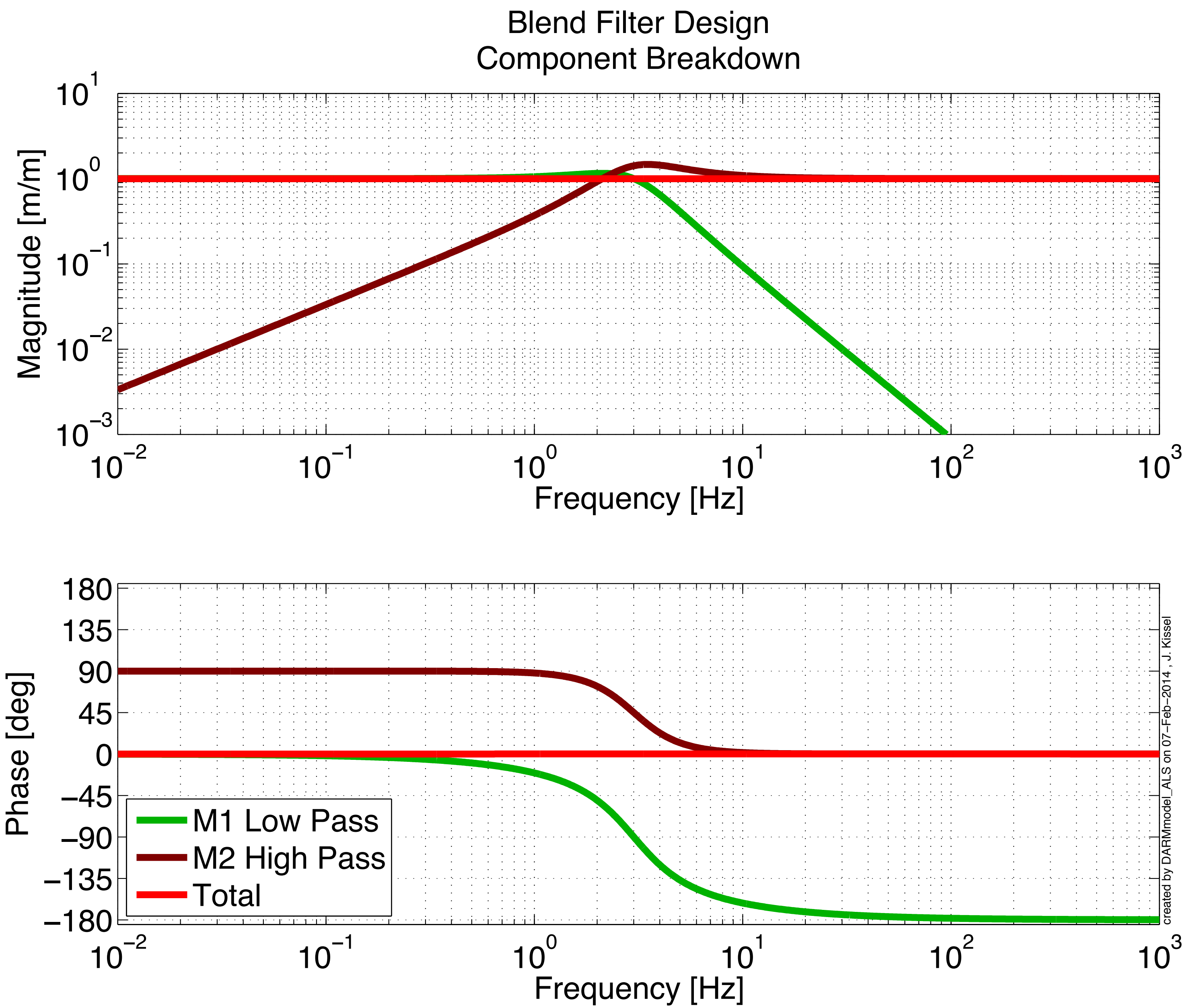
Create Plant Inversion Filters



- Rely on the fact that you're blending above the suspension resonance forest --> Simple Roll-off to the right high-frequency response
- "Turn off" compensation at high frequency, so as to not have infinite gain at high-frequency



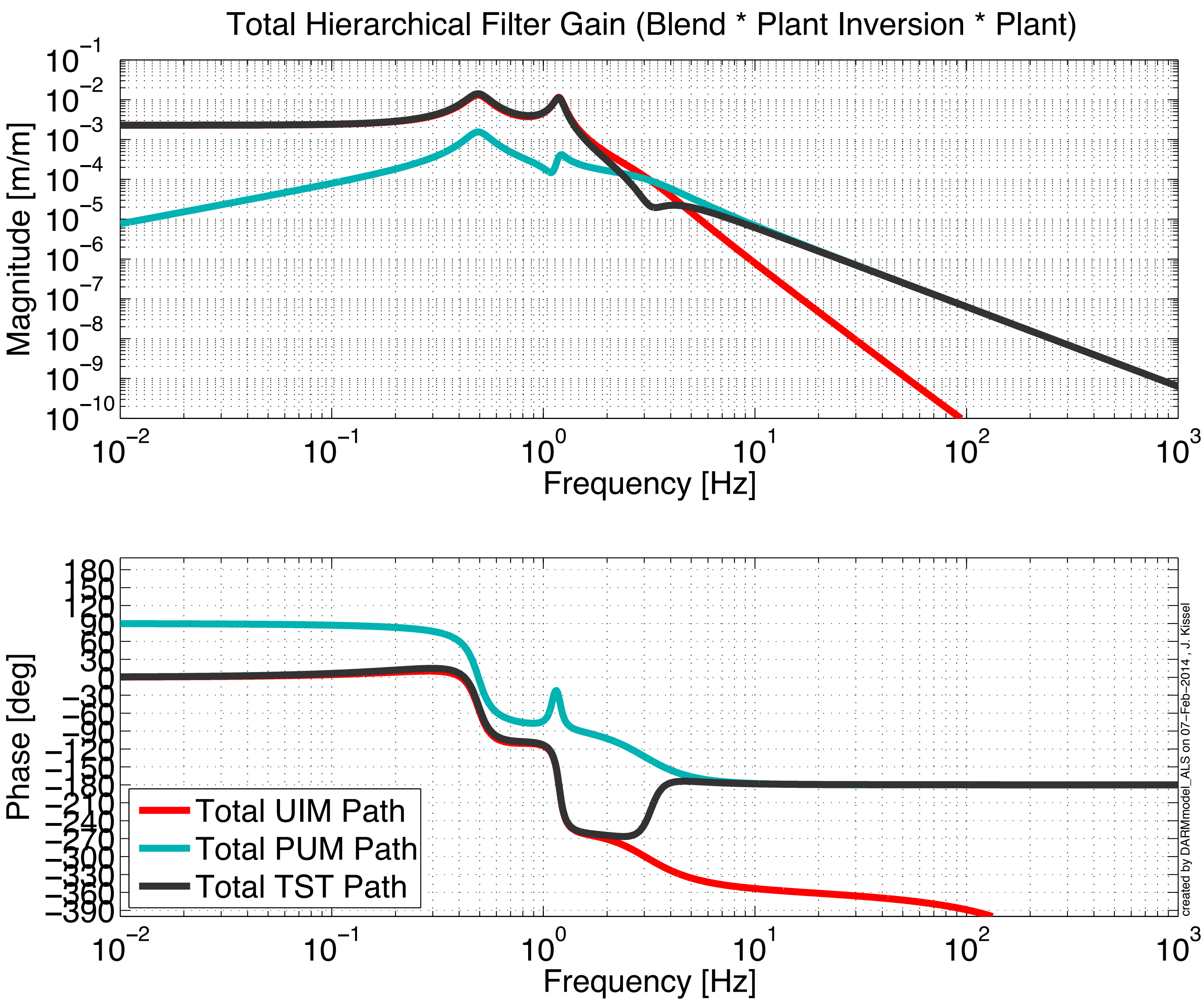
Design Hierarchy Filters



Simple Design:
Start with low-pass: Put corner frequency where you expect upper-stage maximum range to dominate over lower stage. Try a complex pair of poles with a bit of Q … just to make it sassy.

Create high-pass as HP = (1 – LP).

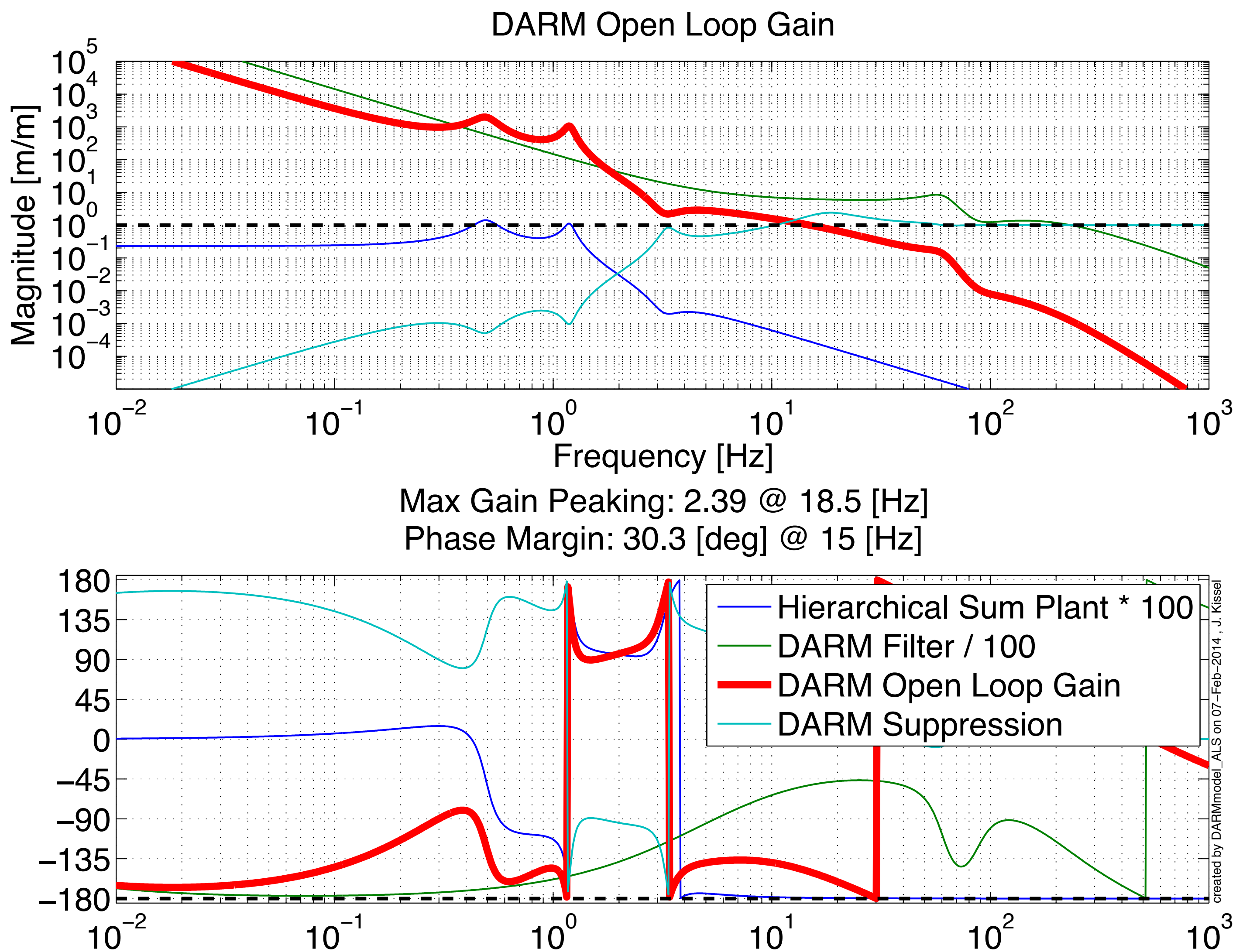
Check Cross-over Stability



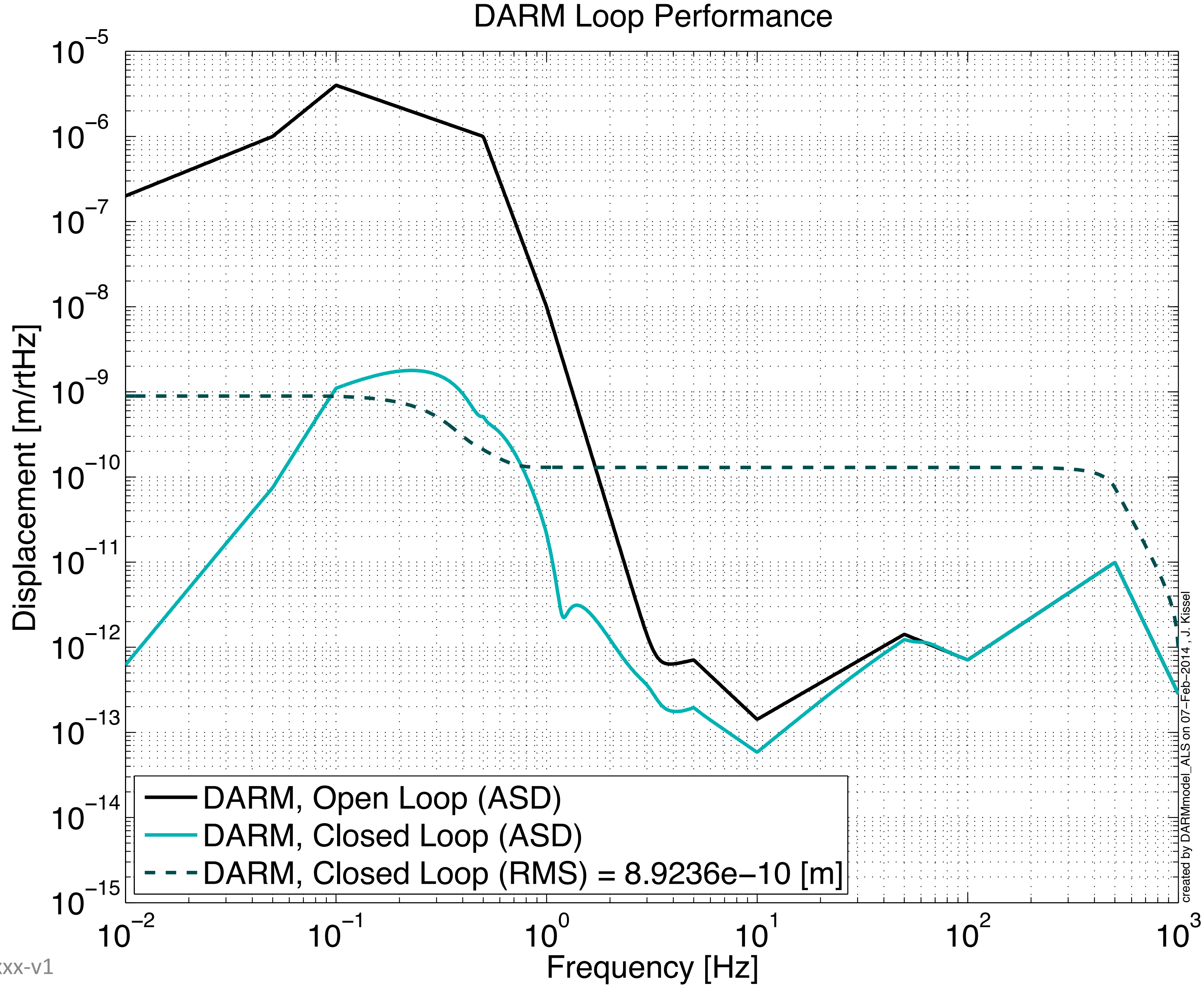
Design Global Control, Check Stability

Design Inputs:

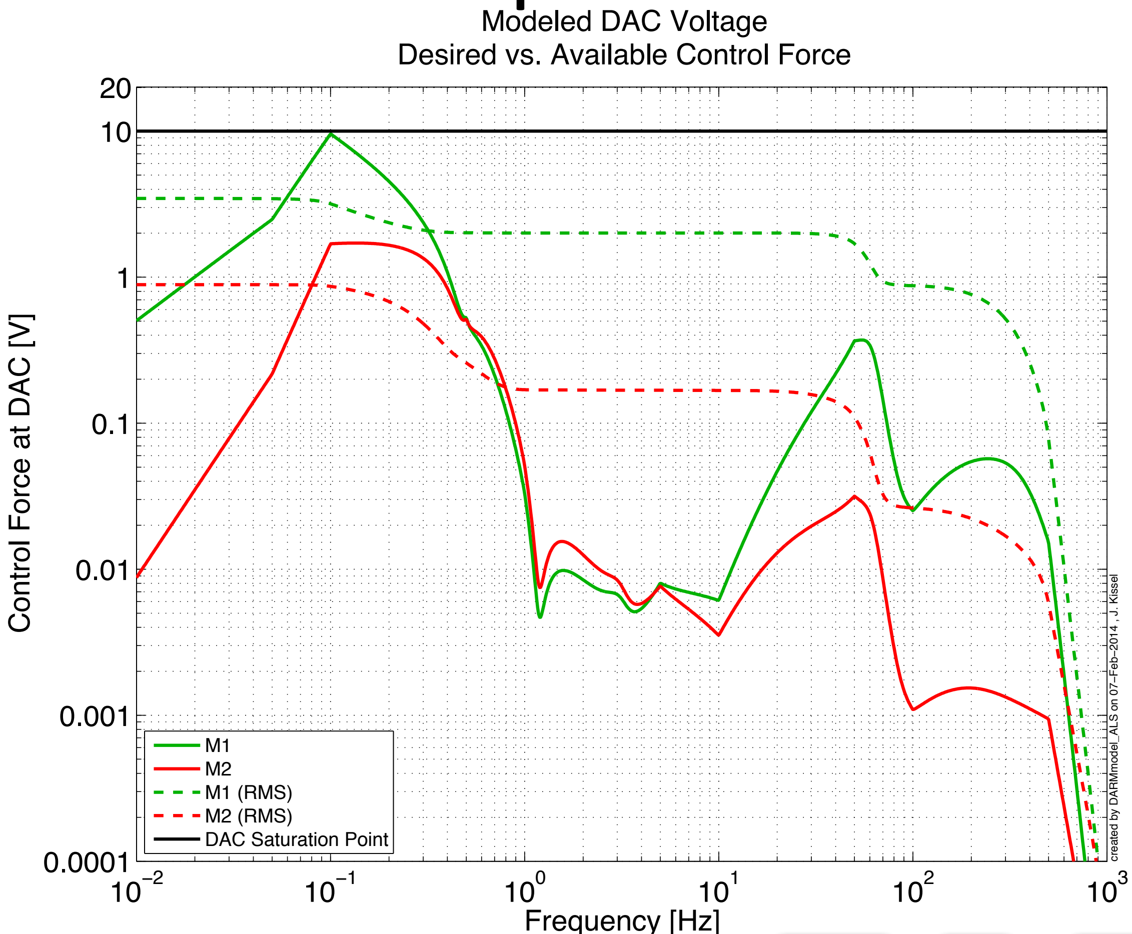
- Knowledge of input spectral density and where you need gain.
- Guess at unity gain frequency.
- Compensate for Plant shape for a stable cross-over.
- Cut-off high-frequency “quickly” to reduce noise.
- Try to minimize gain peaking.
- Shoot for 30-45 ish degree of phase margin.
- Check for actuator saturation.



Compute Closed Loop Performance



Compute Control Forces at DAC



Ask Brett:

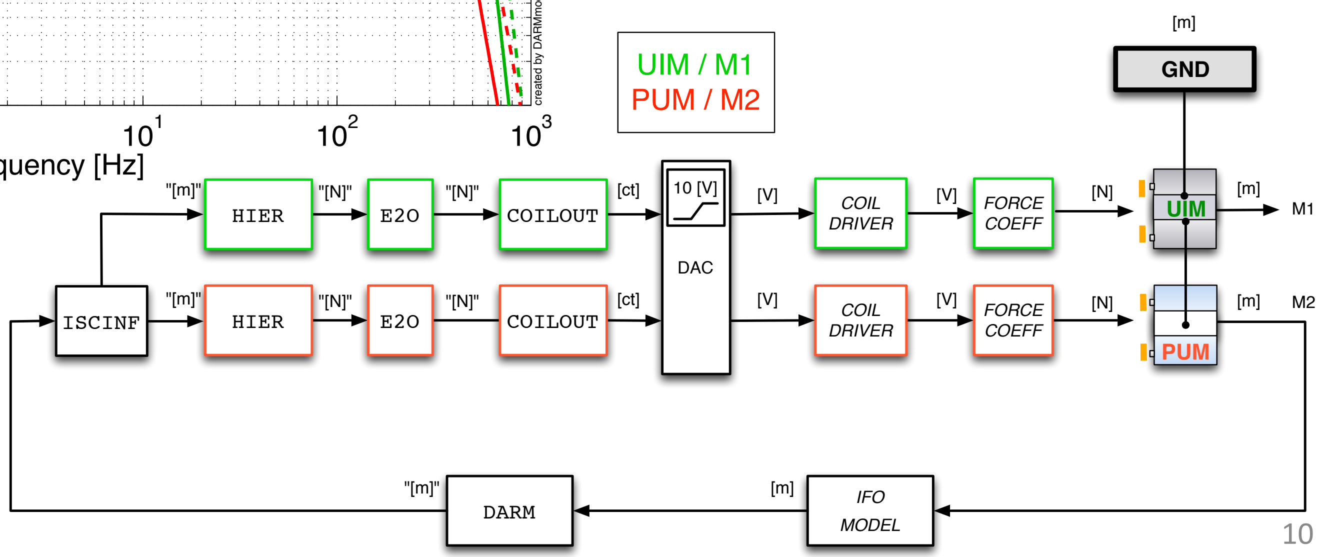
What's the right metric for DAC saturations:

RMS?

Control Force Spectrum?

Probability of Saturation in one time step?

Probability of Saturation over long time?

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Probability of Saturating
in One Time Step:
M1: 0.0038599
M2: 2.027e-29
Probability of Saturating
in One Hour:
M1: 0.0008494
M2: 0
```

The Classical Approach

- Got it done in 3 days (using 8 years of expert controls knowledge, and intimate knowledge of parameters, having already tried 3 times before, and having a lot of software infrastructure in place)
- Lots of steps (though “straight forward” and the math is child’s play)
- Needs lots of a priori knowledge, but may inform cost functions
- Lots of possible solutions that’ll all get the job done “good enough” to get started