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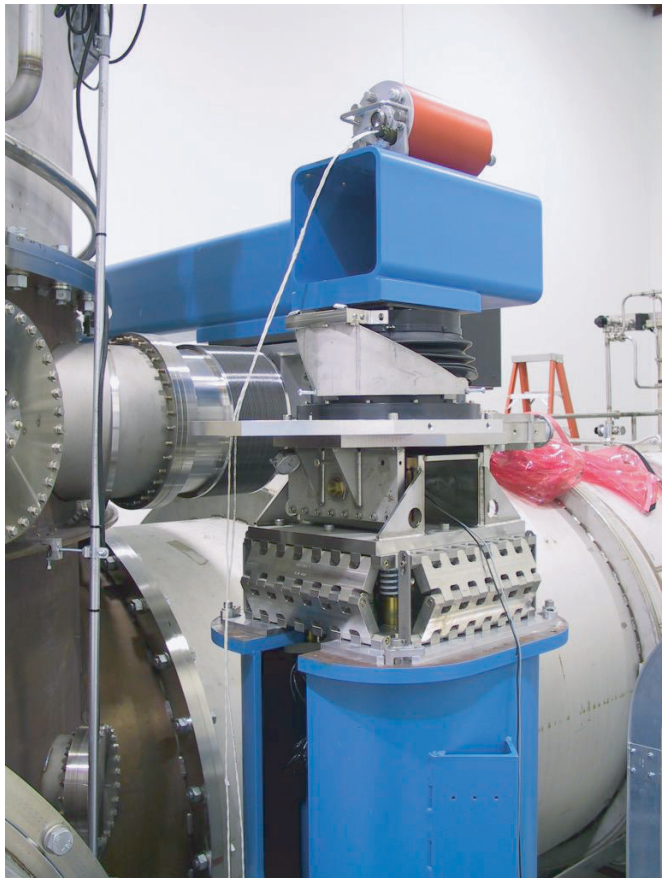
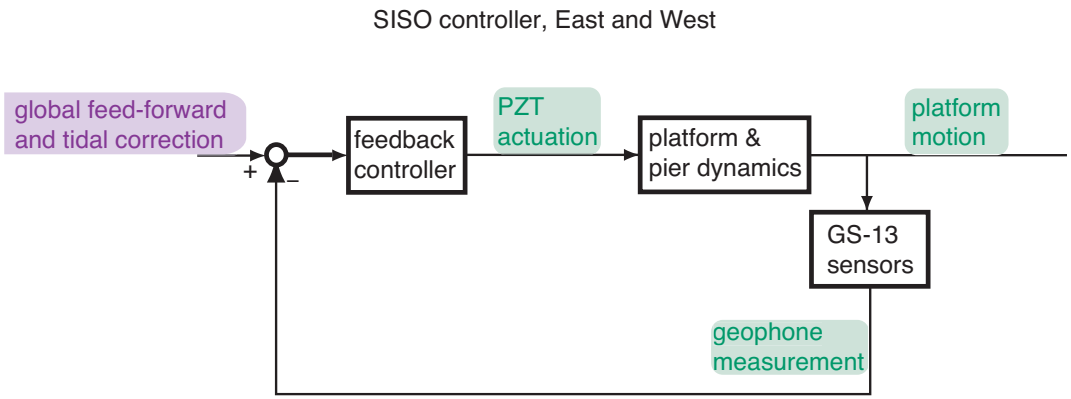
2-DOF external active seismic isolation test

- Proof-of-principle test for external seismic isolation layer.
- Existing fine actuators in end (and mid) station, driven in pairs, can move stack base in beam direction and in yaw.
- 'Borrowed' GS-13 seismometers placed on crossbeams above FAS provide inertial error signals for 2, 1-DOF SISO servos.
- dSpace signal processing board and software in PC allows rapid controller/compensation development and provides GUI control panel.

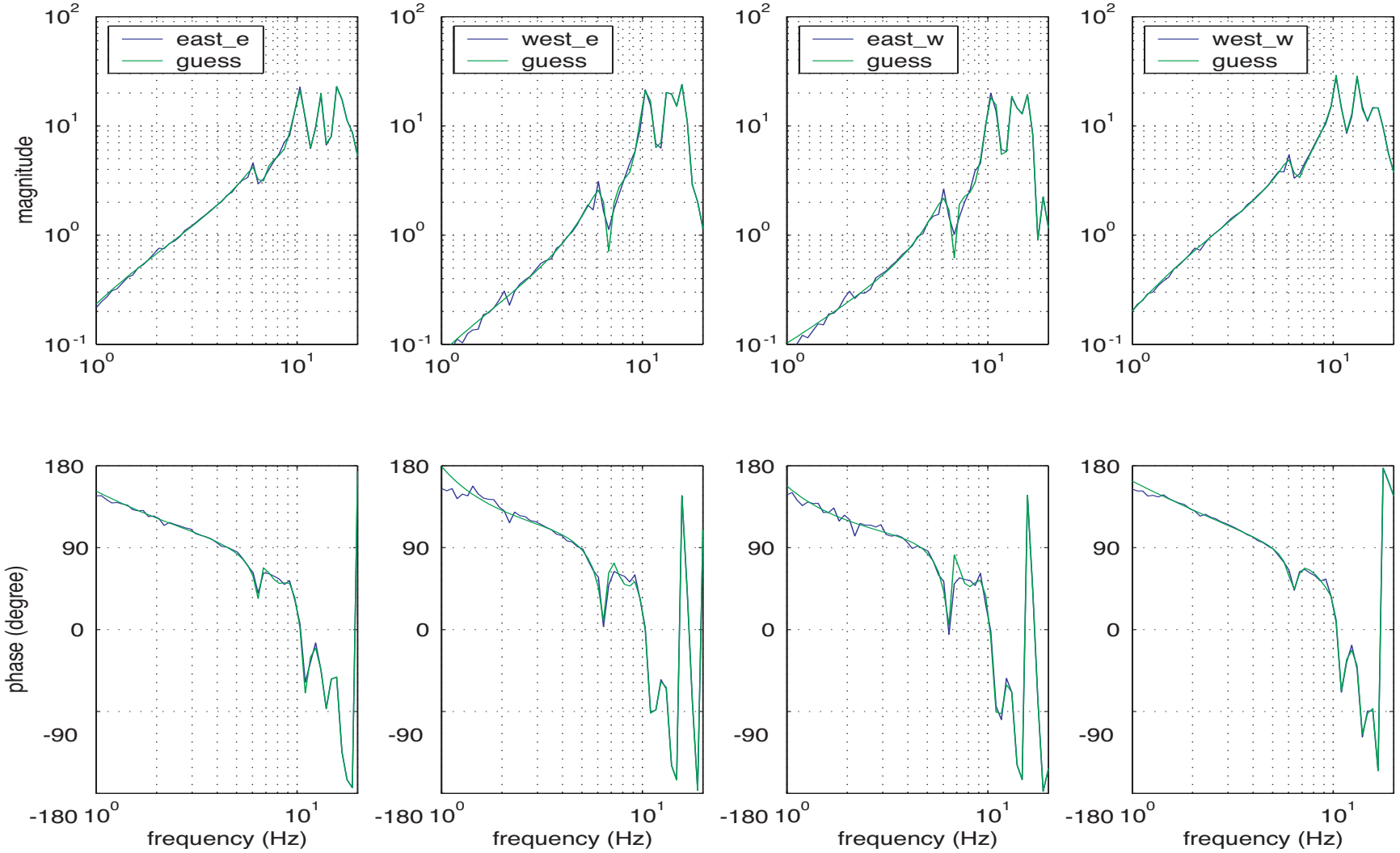
Geophone and Fine Actuator





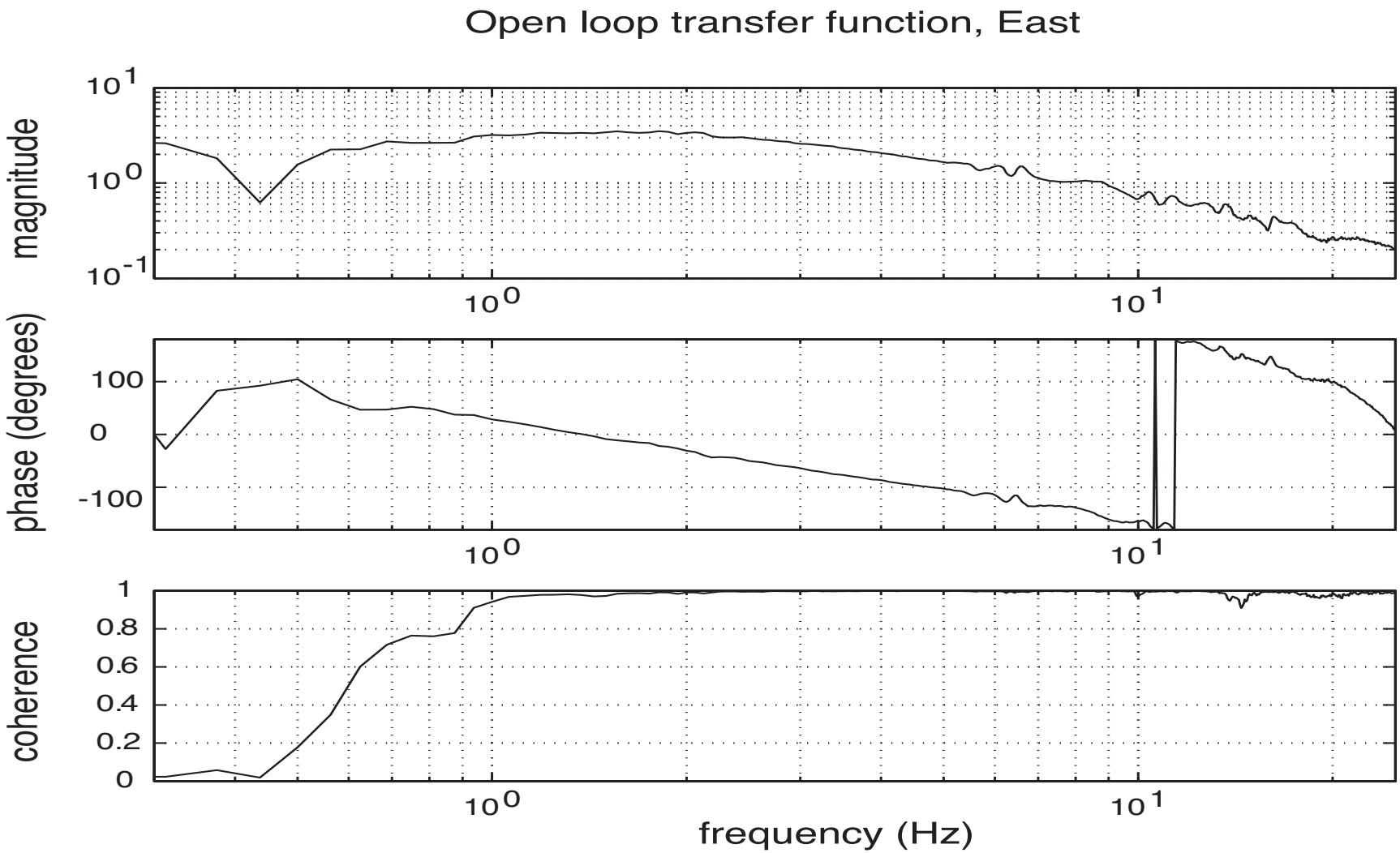
2×2 Plant transfer function measurement and fit

- TFs from each actuator to each sensor measured, 1 - 20 Hz.
- each TF component is fit to about 10 complex poles and 10 complex zeros, and hand-adjusted to gently remove RHP poles and zeros.
- Diagonal terms only a few times larger than cross terms, so SISO loops are not the clear choice, but. . .
- Note the 6 Hz feature, which shows up mostly in the cross terms; this may be reaction from a strong yaw stack mode.


east_e
guess
west_e
guess
east_w
guess
west_w
guess
magnitude
phase (degree)
frequency (Hz)
frequency (Hz)
frequency (Hz)
frequency (Hz)

Compensation design and OLTF measurement

- Compensation designed to "undo" features below 20 Hz, by canceling fitted poles and zeros.
- In general, this is impossible, as RHP poles may be needed; in this case, the hand-made East and West compensation filters worked well alone.
- Open-loop measurement with compensation for each side looks smooth and stable.


Open loop transfer function, East
magnitude
phase (degrees)
coherence
frequency (Hz)
10^1
10^0
10^-1
100
0
-100
1
0.8
0.6
0.4
0.2
0

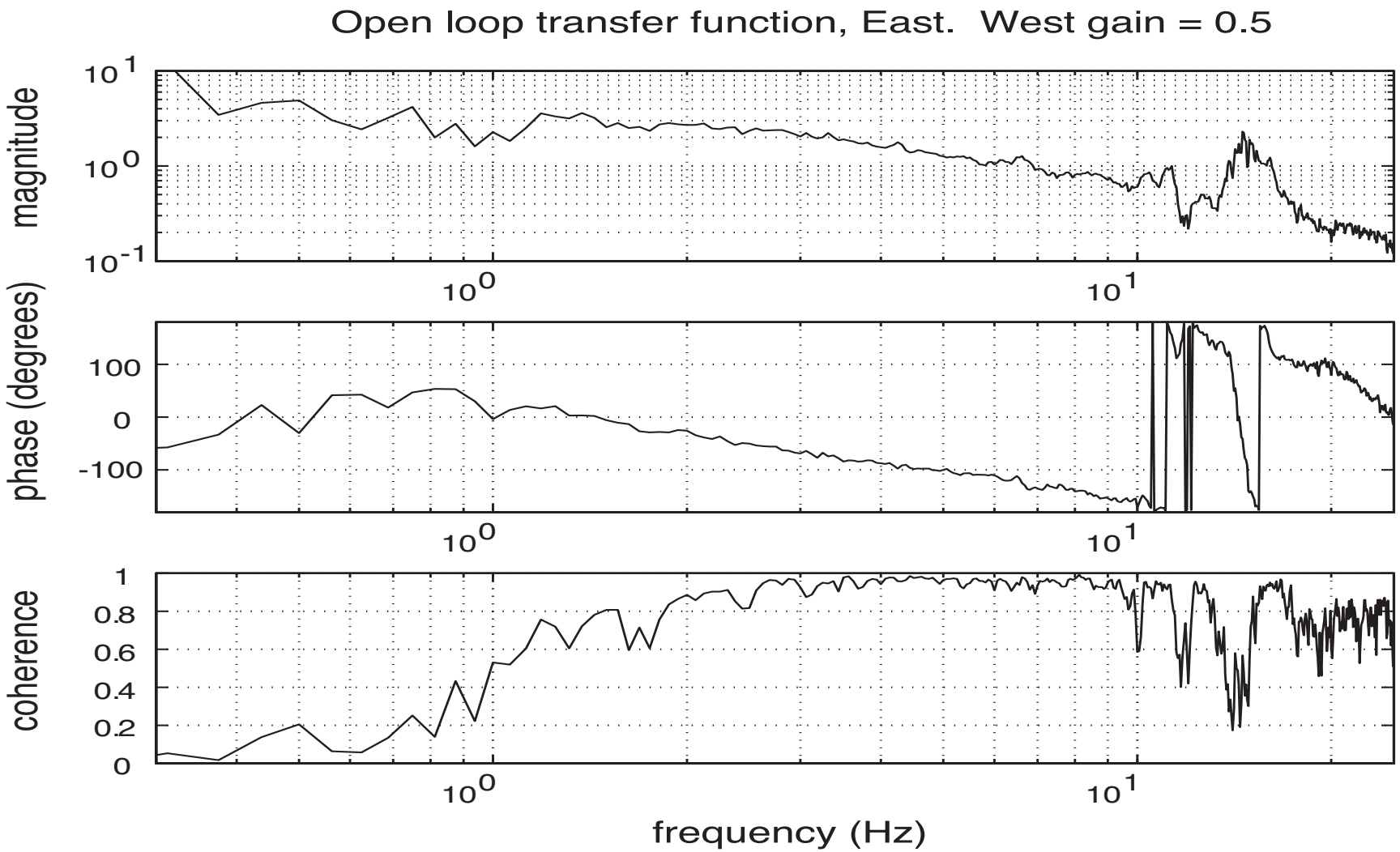
Effect of too-high gain in other loop

- Compensation designed this way stops working when the other controlled DOF's significantly change the dynamics; this happens when the cross terms in the plant are about the same size (at some frequencies) as the diagonal terms.

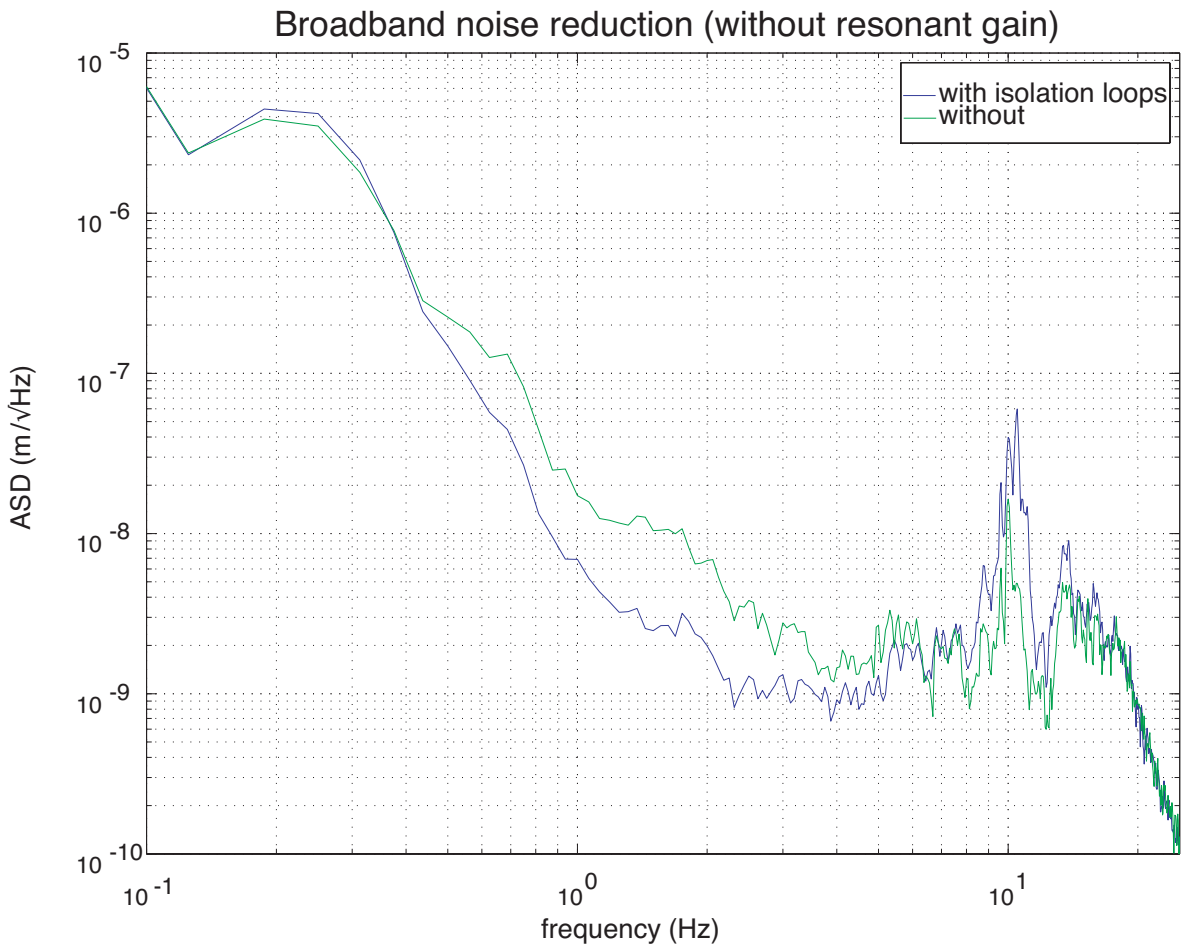
- This can be seen by closing one loop and measuring the other's OLTF.

- In our case, this limits the loop gain to about 10 - 15 dB; the badly-behaved modes were suppressed with band-stop filters.

- Ideally, one would carry out SYS-ID on *all* of the plant data, producing a TF matrix constrained mathematically to be well-behaved. This is to be studied.

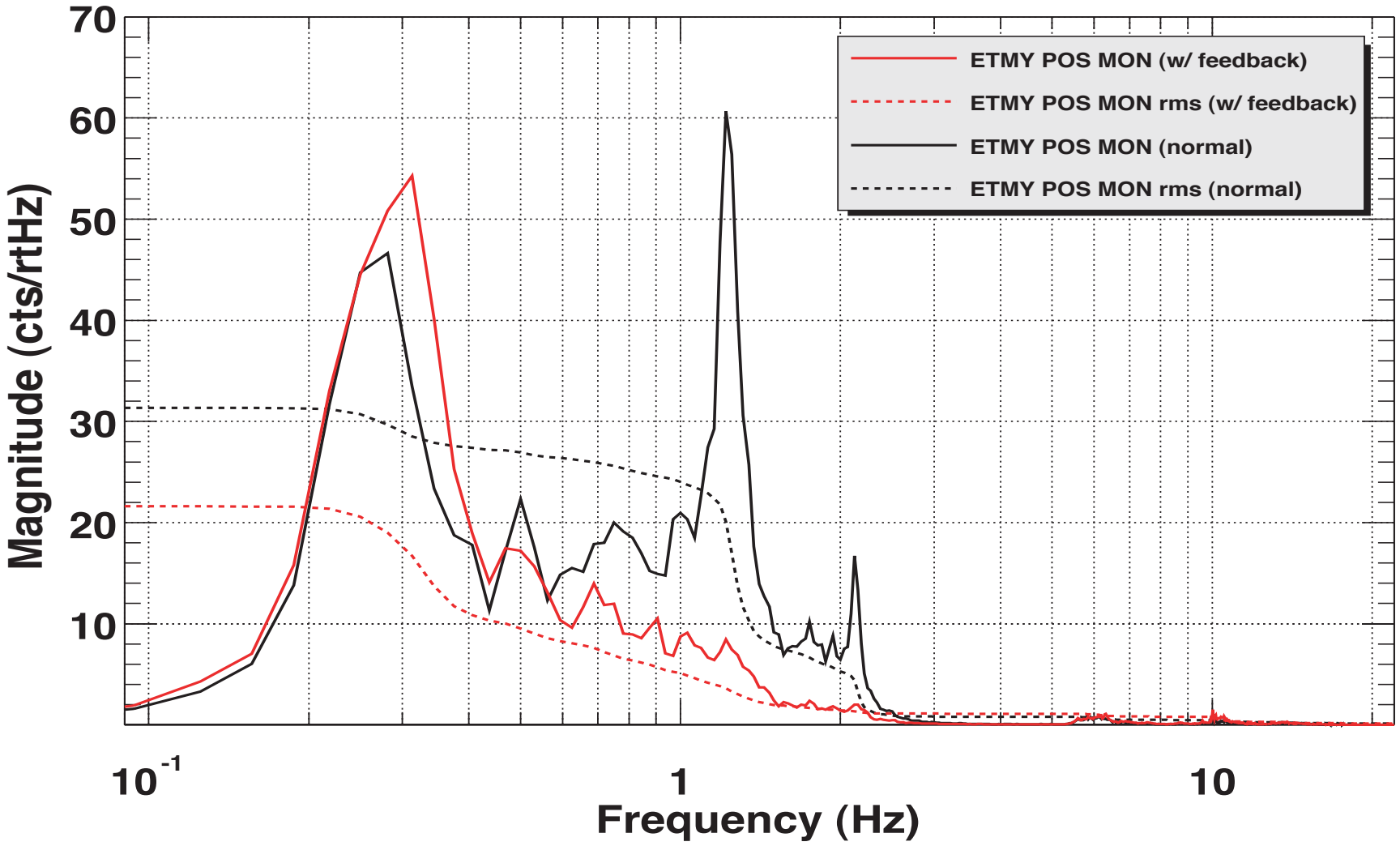

Open loop transfer function, East. West gain = 0.5
magnitude
phase (degrees)
coherence
frequency (Hz)

Noise reduction at crossbeam



Noise reduction at test mass

- Test mass (ETMY) and its LED/photodiode local sensors used measure vibration on stack payload, with and without external active isolation.
- Resonant gain added at two troublesome stack modes (1.2 and 2.1 Hz), allowing factor of a few more gain there without destabilizing overall servo.
- This resulted in about a factor of 7 decrease in motion seen by the test mass at the stack modes.


ETMY POS MON (w/ feedback)
ETMY POS MON rms (w/ feedback)
ETMY POS MON (normal)
ETMY POS MON rms (normal)
Magnitude (cts/rtHz)
70
60
50
40
30
20
10
10^-1
1
10
Frequency (Hz)

Noise reduction in arm control signal

- LLO Y-arm was locked with ETMY's experimental experimental seismic isolation loop closed.
- Naively expected to see factor of $\sqrt{2}$ improvement in arm control signal, since only one end was affected.
- Since most of the 2.1 Hz noise happened to be coming from the Y-end that night, we saw a factor of 5 decrease in that peak.

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