Piezoelectric Pre-Isolation and Microseism Feedforward for S2

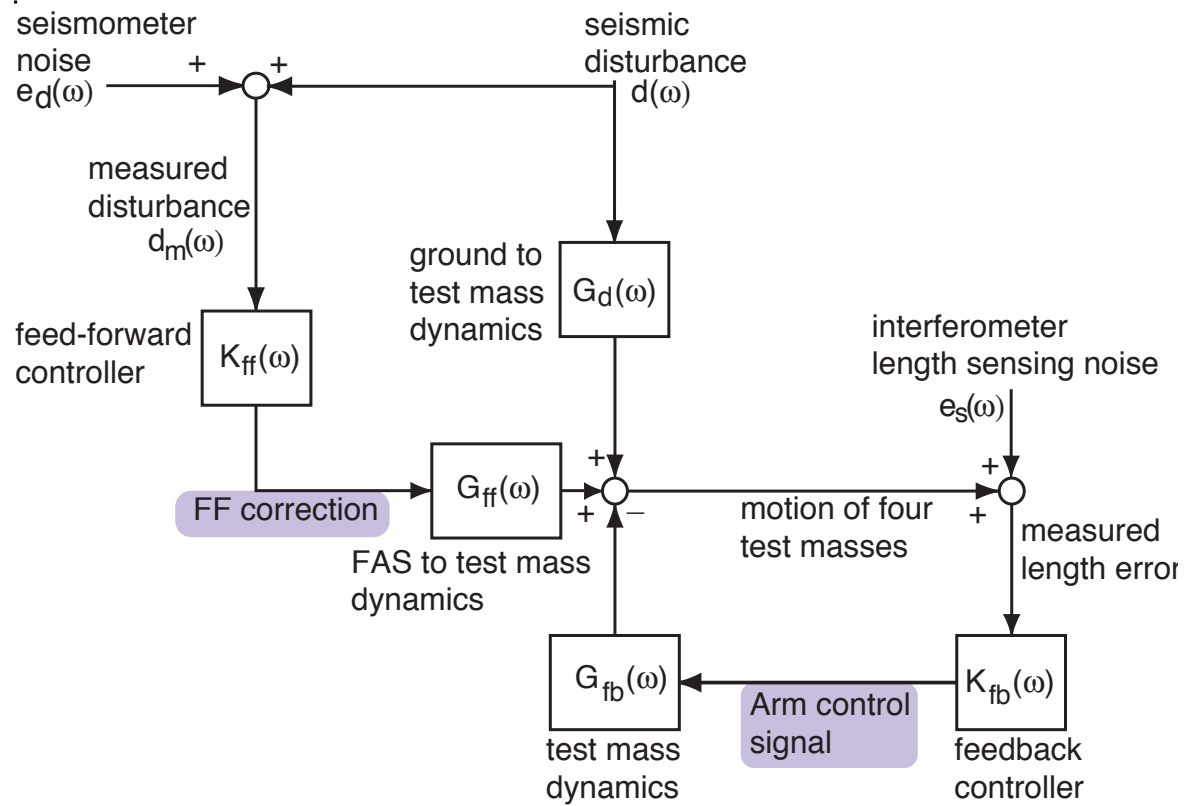## Joe Giaime, Ed Daw, LSU
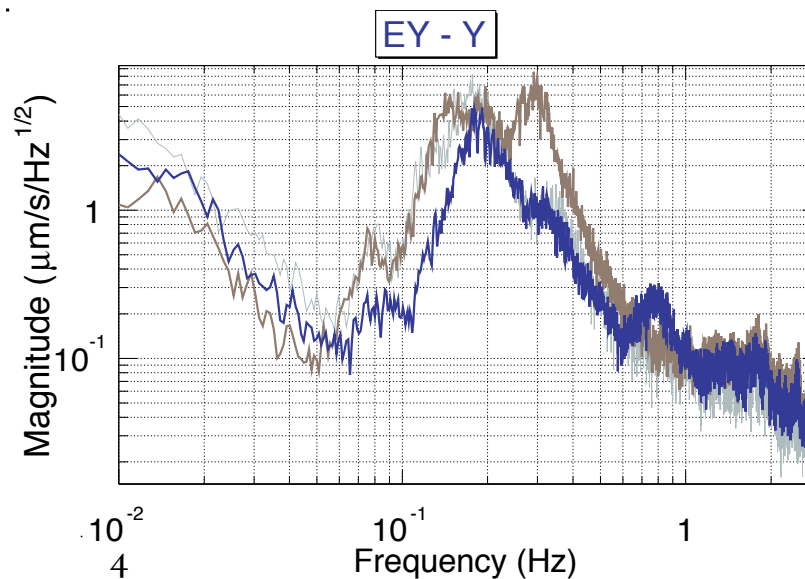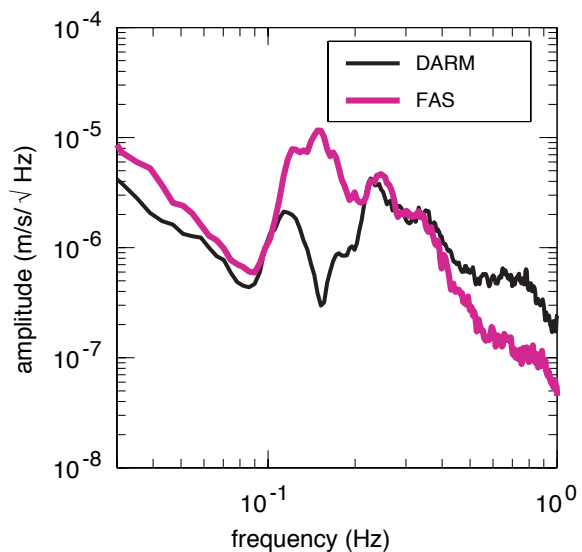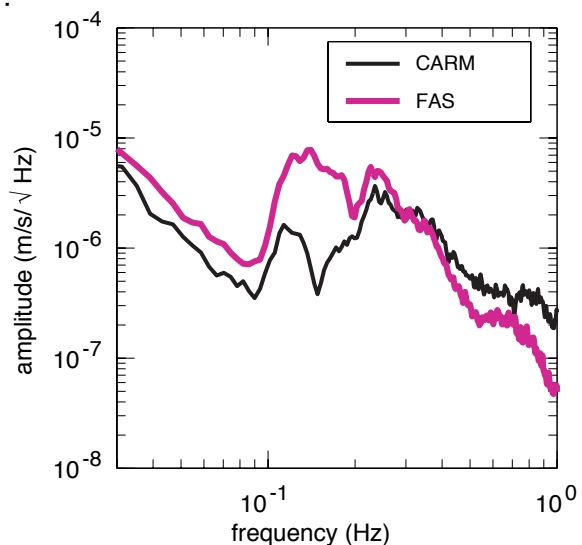
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PEPI & Feedforward used during S1

- S1 feedforward correction filters were severely bandpassed to decrease sensitivity to low-frequency tilts and to avoid ringing up the stack modes.

- S1 PEPI feedback controller was optimized to reduce motion at the external seismic isolation structure that would excite the lowest two isolation stack modes.
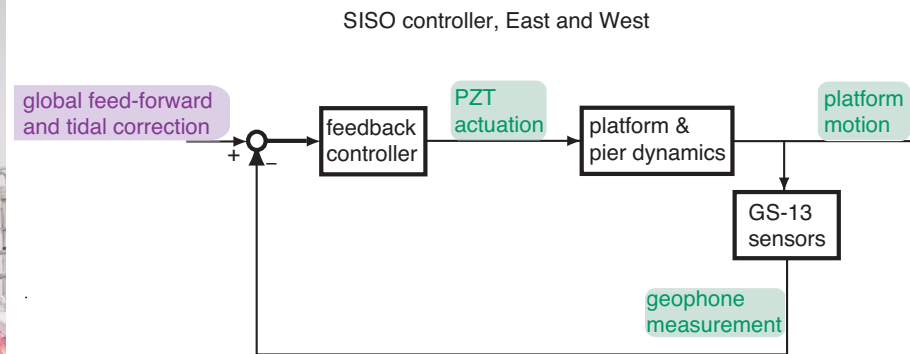
Microseism Feedforward

seismometer
noise
$e_d(\omega)$

seismic
disturbance
$d(\omega)$

measured
disturbance
$d_m(\omega)$

ground to
test mass
dynamics

$G_d(\omega)$

interferometer
length sensing noise
$e_s(\omega)$

feed-forward
controller

$K_{ff}(\omega)$

FF correction

$G_{ff}(\omega)$

FAS to test mass
dynamics

motion of four
test masses

measured
length error

$G_{fb}(\omega)$

Arm control
signal

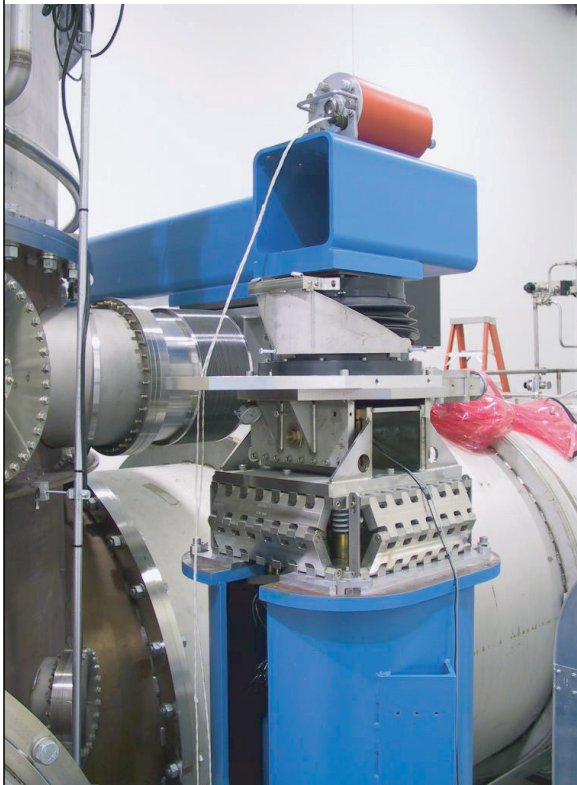$K_{fb}(\omega)$

test mass
dynamics

feedback
controller

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S1 FF Performance

- Arm length error well corrected by the FAS signals in the 0.1–0.2 Hz band only.

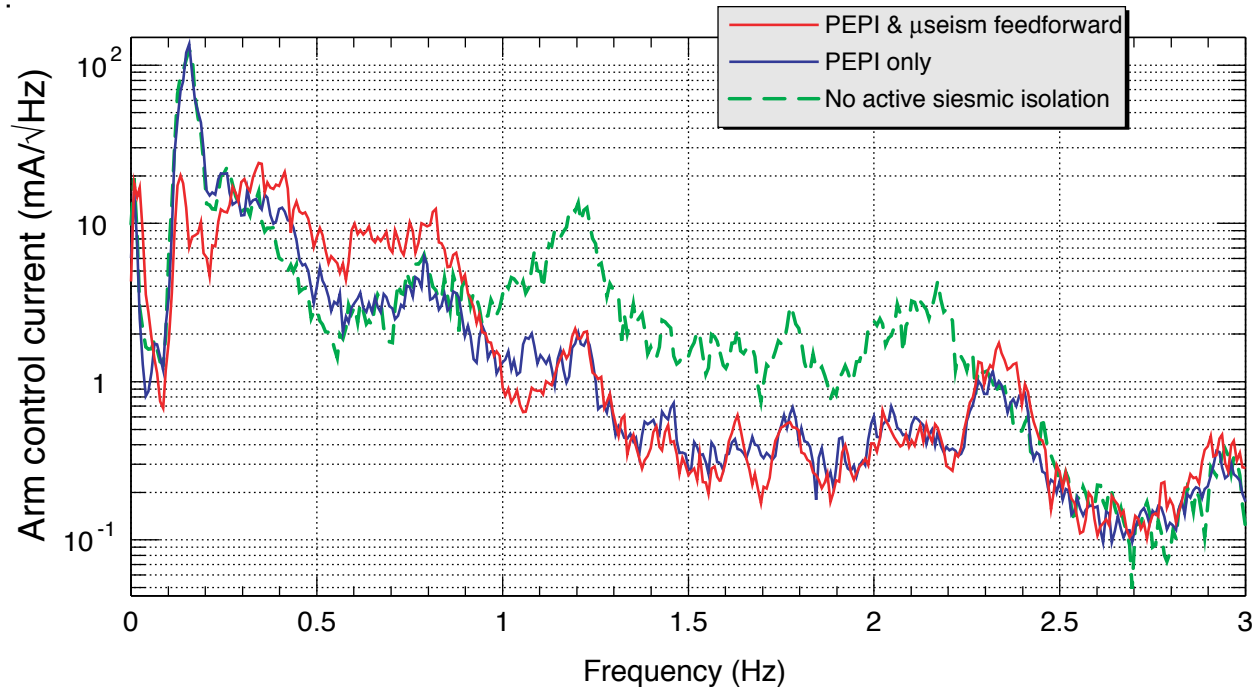- LLO enjoys microseism peak as high as 0.3 Hz during Gulf storms.

PEPI: Piezoelectric pre-isolation

SISO controller, East and West

global feed-forward
and tidal correction

PZT
actuation

platform
motion

feedback
controller

platform &
pier dynamics

GS-13
sensors

geophone
measurement

- Feedback to to FAS from local geophones placed on test mass chamber crossbeams.

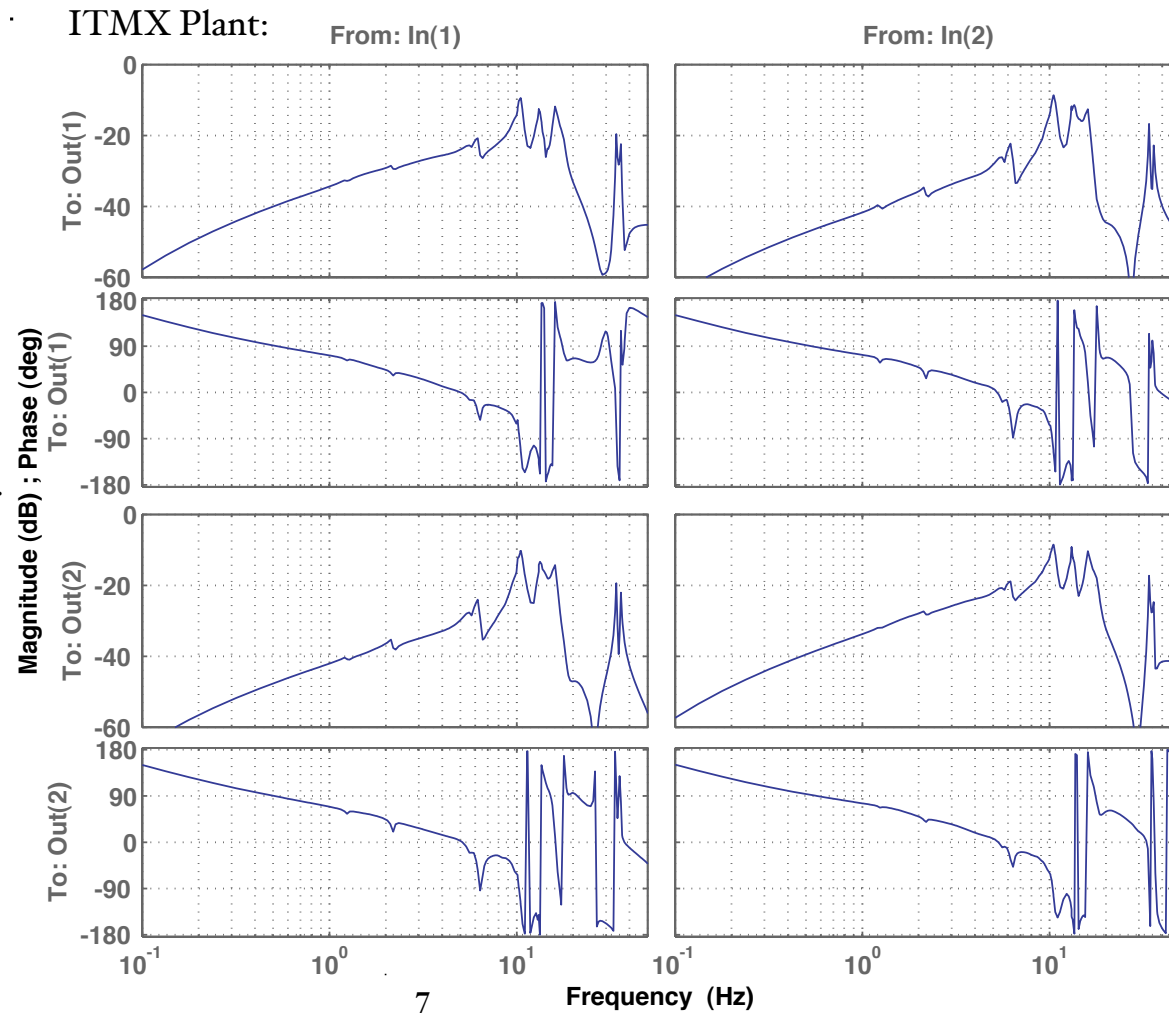- Goal was to reduce 1.2 and 2.1 Hz beam-direction disturbance to stack.

Sɪ PEPI/FF performance

- At 0.15 Hz microseismic peak, and in the 1–2.5 Hz band PEPI/FF allowed less test mass actuation to maintain lock.

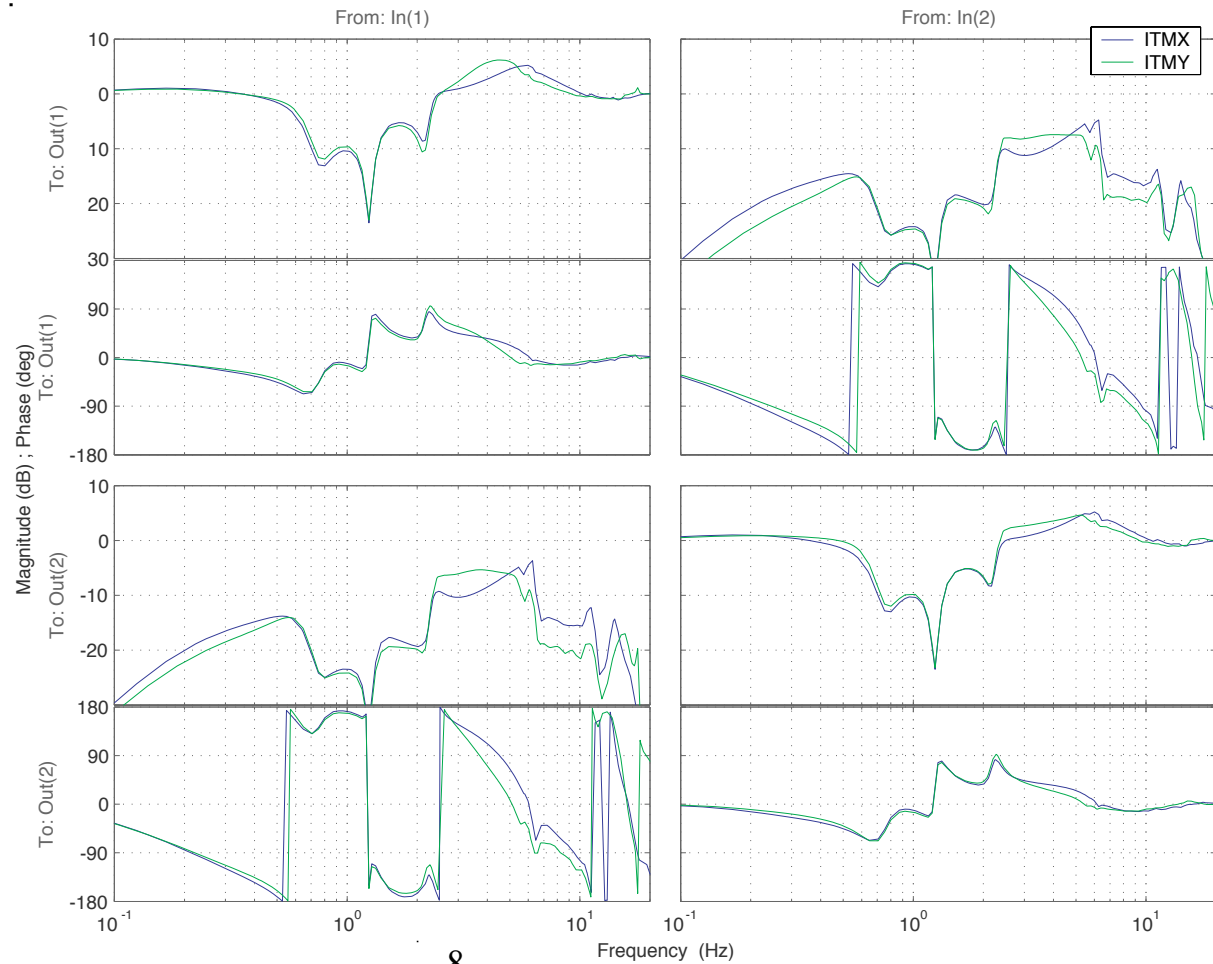- In 0.3–0.7 Hz band, the system added noise.

PEPI controller re-design for S2

ITMX Plant:

- Goal: Extend noise reduction down in frequency.

- 2 x 2 plant measured for each TM SEI system.

- Each fitted to 2 x 2 MIMO state space.

- Dual SISO controller designed, using MIMO model to test performance.

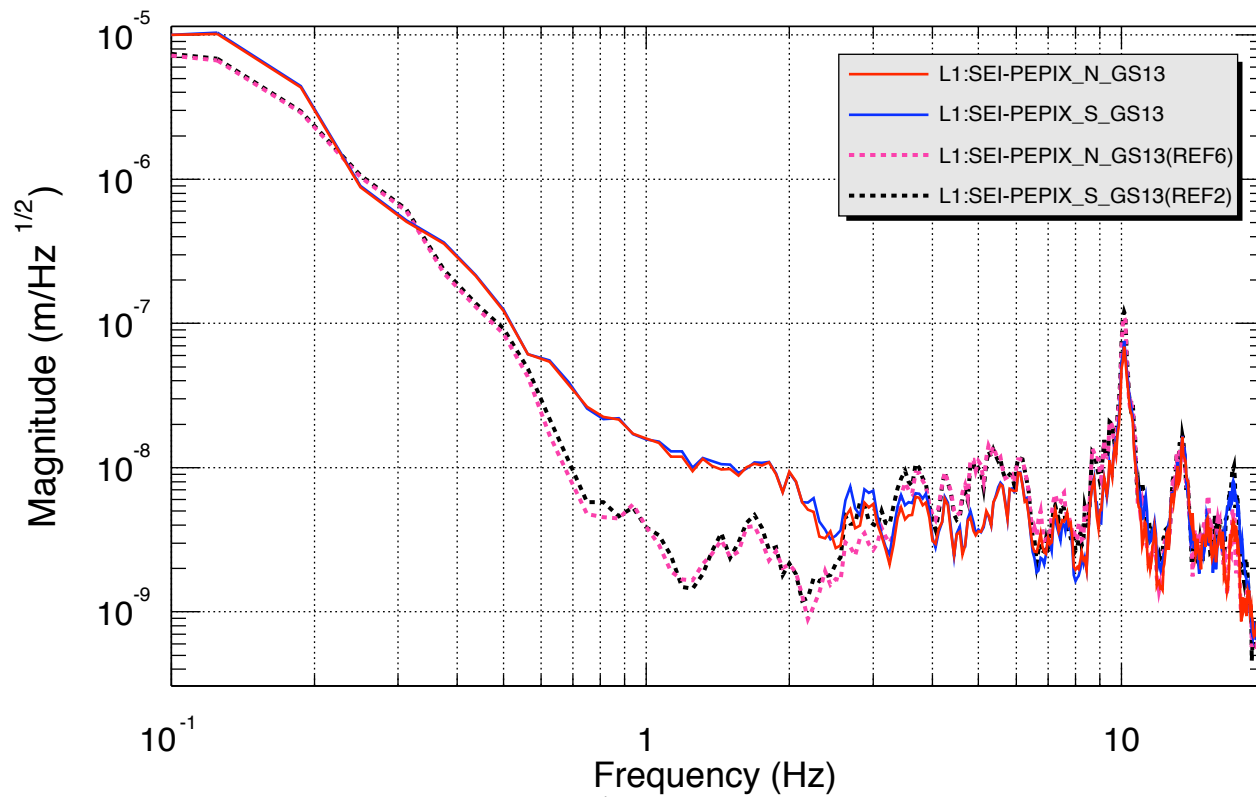- No 'developmental' oscillation allowed!

Modeled closed-loop sensitivity

- Controller uses resonant gain at 0.75, 1.2 and 2.1 Hz.

- Sensitivity off-axis terms just becoming important at chosen gain.

- Minimal gain peaking at 0.15 Hz: ≈ 0.8 dB.
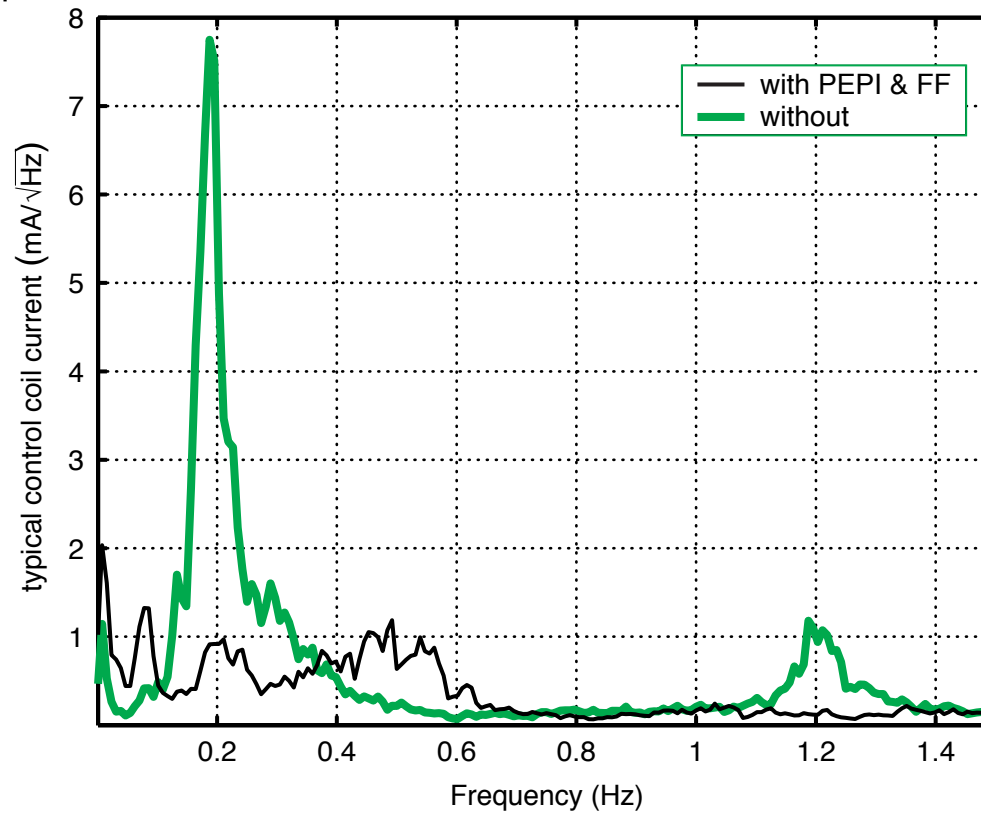
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Noise reduction at crossbeam

Feedforward correction redesign for S2

- The new PEPI changes both the response of the test mass to LF ground motion, and the response of the FAS to correction signals.

- Two sets of sys-id data were taken with the interferometer operating and the new PEPI enabled.

  - CTRL signals versus seismometer signals = **A**.

  - CTRL signals versus FAS command signals = **B**.

- FF correction function is $-\mathbf{A}\,\mathbf{B}^{-1}$, with notches at stack modes.

- This could only be approximated, since **B** has right half plane zeros.

Combined PEPI/FF performance.

- FF reduction extended up to 0.35 Hz

- PEPI removes excess FF noise down to about 0.65 Hz

- Bad zone reduced from 0.2–0.8 to 0.35–0.65.

- RMS motion reduced by factor of 3.

ITM PEPI adds glitches, so we turn it off after acquisition

ETM PEPI stays on all the time, and reduces the arm displacement noise.
ITM PEPI quiets the arms, but adds a fraction of the microseism to the Michelson signals.
Test to answer the question: Should we keep ITM PEPI on or off during science mode?