LHO 2KM CAVITY COMMISSIONING:

SERVO CHARACTERIZATION AND PERFORMANCE

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Director's Review

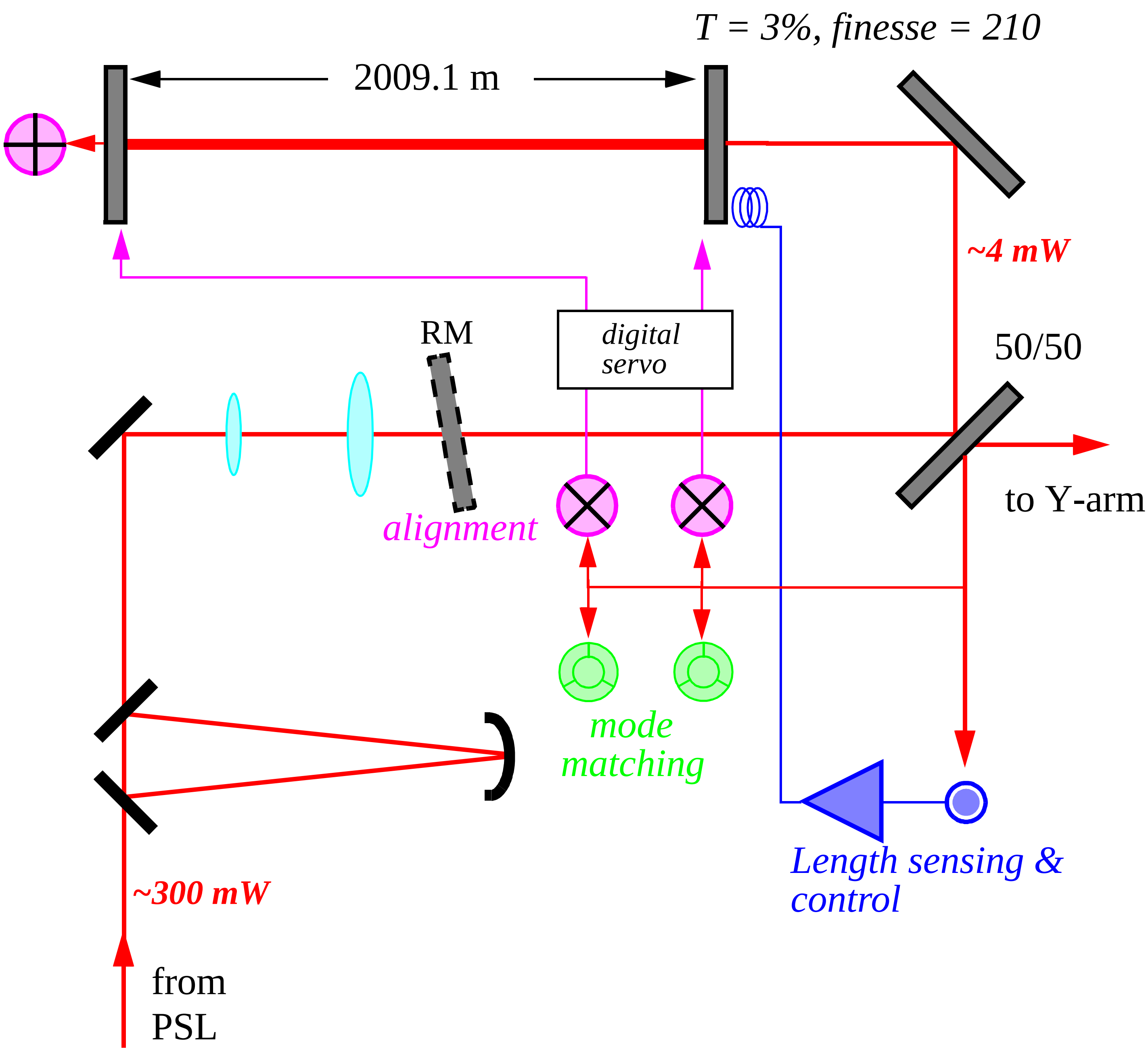
1 May 2000

G000112-00-D

Goals

- Servos
  - experience with lock acquisition
  - dealing with test mass resonances
  - test alignment servo (digital)
  - test final stage of frequency stabilization (common mode servo)
  - characterize stack fine actuators

2km X-arm



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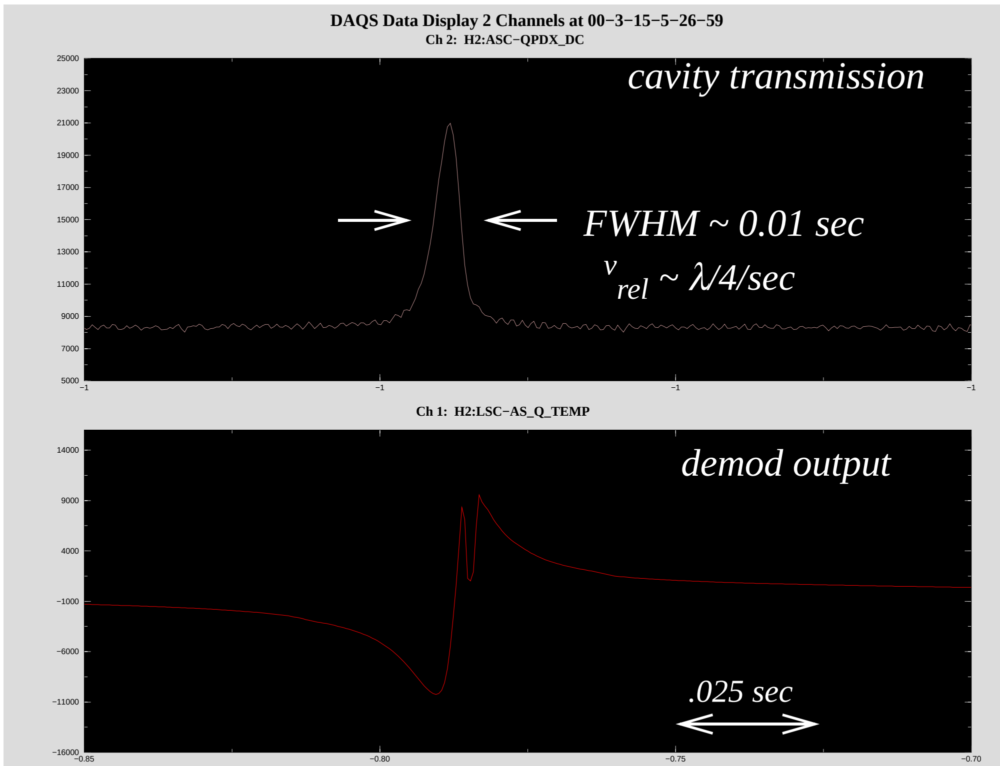
Cavity length locking

Cavity free-swinging (optics locally damped) through a resonance:



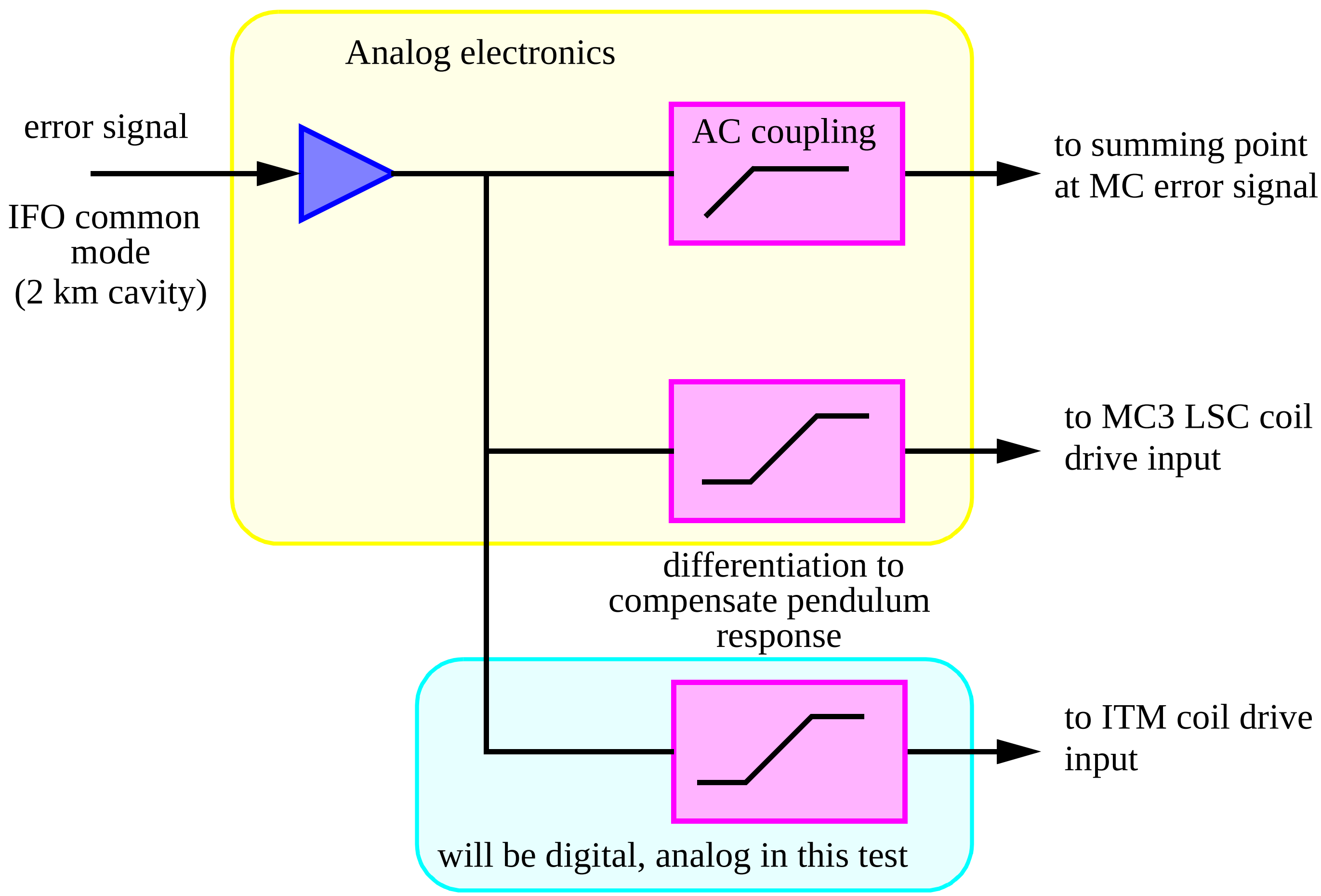
- Initially, fringe velocity was much (~10x) faster, *due to mode cleaner length fluctuations*
  - MC length fluctuations (f<20 Hz) turn into frequency fluctuations, which are large compared to the arm cavity linewidth (multiplied up by MC/arm length ratio of ~100)
  - Alleviated by holding the MC length more closely to the PSL input frequency:
    - increasing the MC length <-> PSL frequency crossover freq. (variable)
    - adding a resonant gain stage at the first stack resonance (1.5 Hz)

‘Lock acquisition’ servo

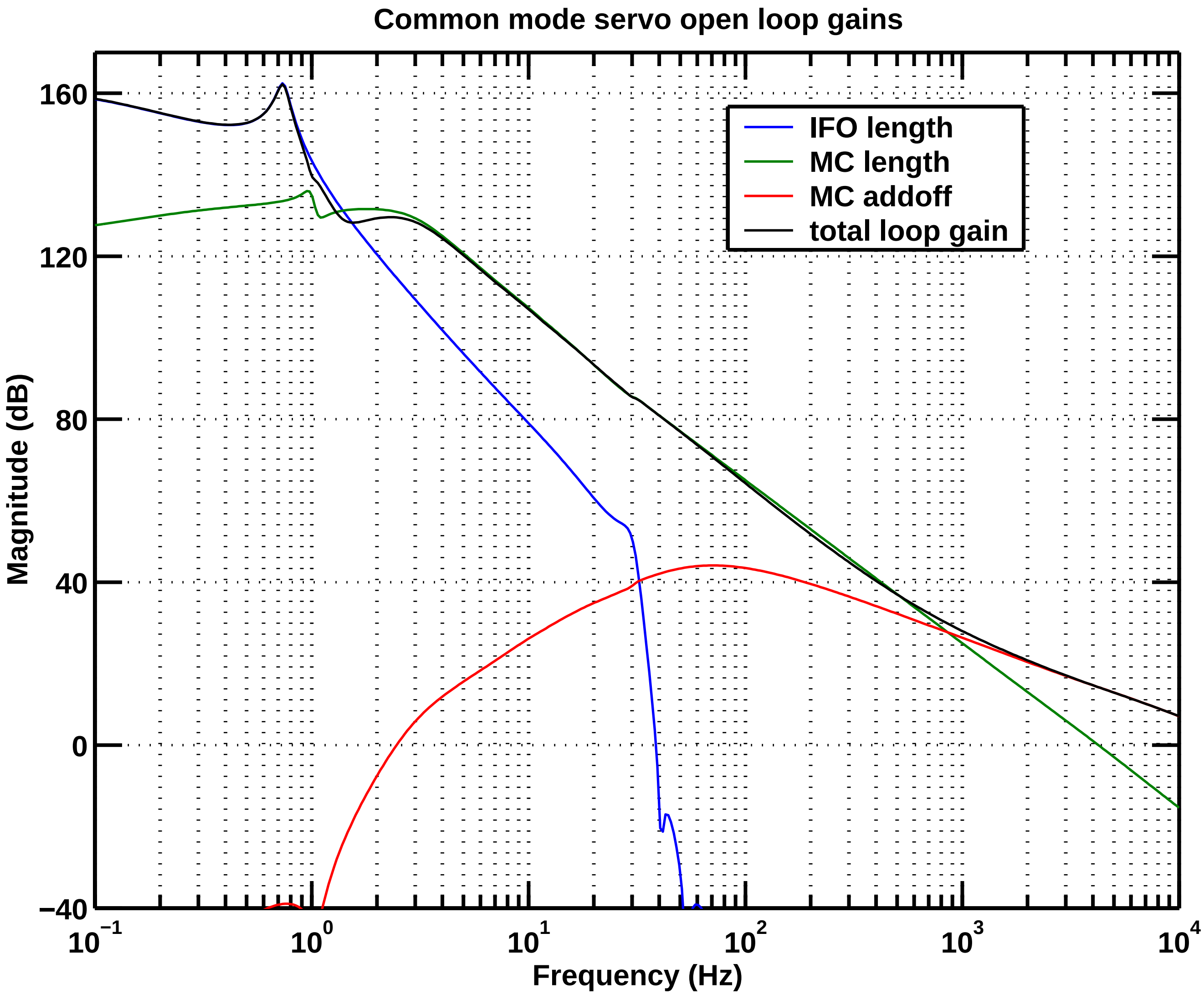
- Analog servo, feedback to ITM only
  - designed to be the servo which acquires State 4 of the interferometer (wider bandwidth possible w/ analog servo)
  - in fact, system locks best (only?) at relatively low BW (< 100 Hz); gain is then turned up after acquiring lock
    - unity gain frequency: ~300 Hz
    - $f > 30$ Hz: $1/f$; $1\ \text{Hz} < f < 20$ Hz: $1/f^3$
  - loses lock when out of range (due to tidal stretching of arms, after stabilizing PSL reference chamber temp)
- Test mass resonances
  - initial strategy was to notch out the first two axisymmetric modes (9.4 kHz & 14 kHz)
  - didn’t work: first non-axisymmetric (6.2 kHz, very high Q) mode and many higher frequency (>20 kHz) modes rung up
  - solution: notch added at 6.2 kHz; loop roll-off above ~10kHz increased with additional poles
- Automatic locking sequencer implemented
  - roughly a 10 step process that brings the system from an unlocked state to locked with the final gain settings
  - takes 1-2 minutes, mostly to bring in ASC servos

Common mode servo

- Provides final level of frequency stabilization
  - takes the common mode error signal, and feeds it back primarily to the mode cleaner (whose own servo acts to correct the frequency)
  - some low-freq feedback to the common arm length, to damp the pendula and provide a DC path



Servo design



- ❑ Problem: low frequency gain in ITM path (0.1 Hz pole) prevented lock
  - probably due to misalignment induced by large control signals
  - solution: 0.1 Hz pole moved to 10 Hz, leading to ...

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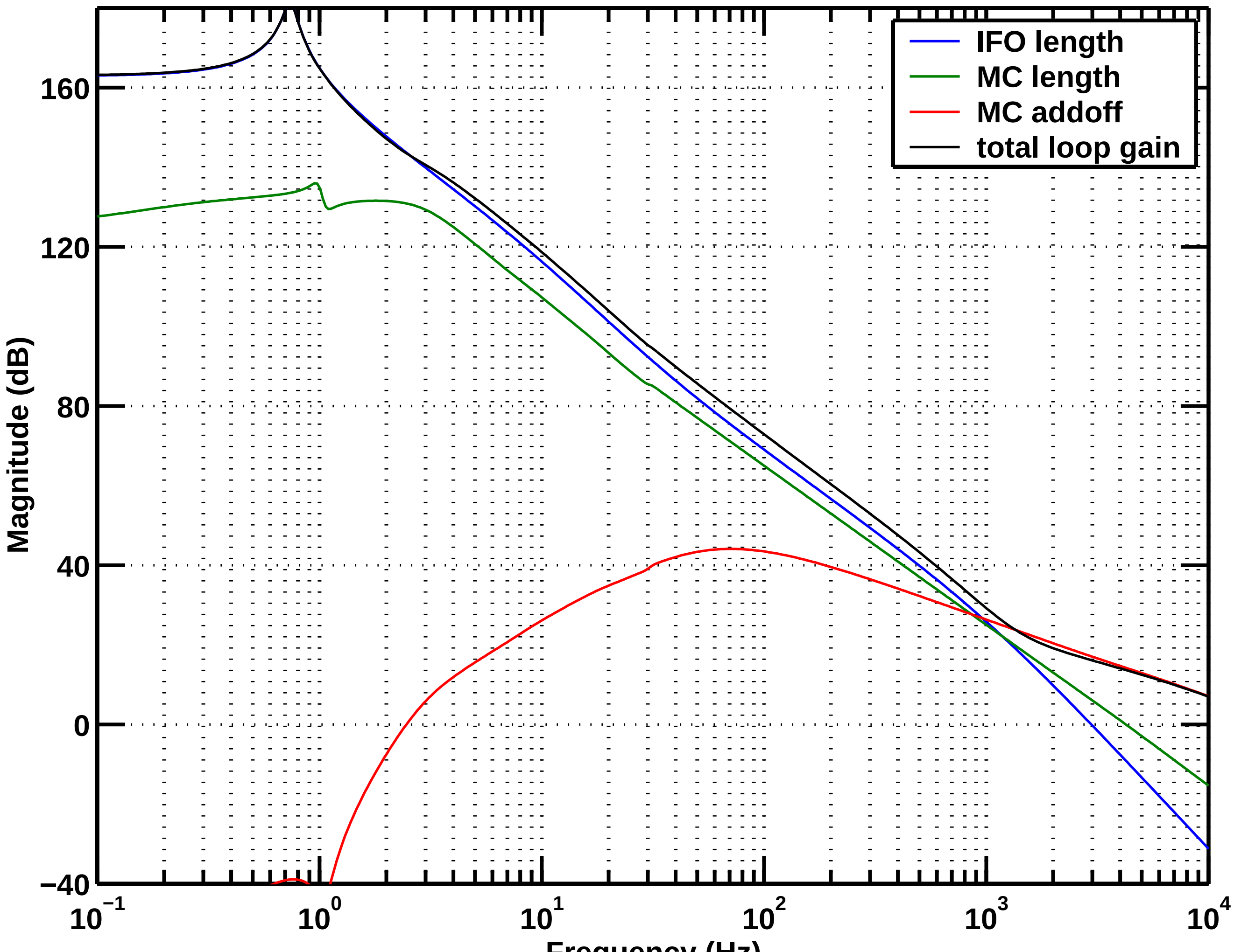
Modified servo response



- Cross-over between ITM & MC length paths
  - MC path wasn't dominate at any frequencies (thus couldn't engage the ITM low-pass filter)
  - needed to be able to increase ITM low-frequency gain after locking (will be easy with digital controller)

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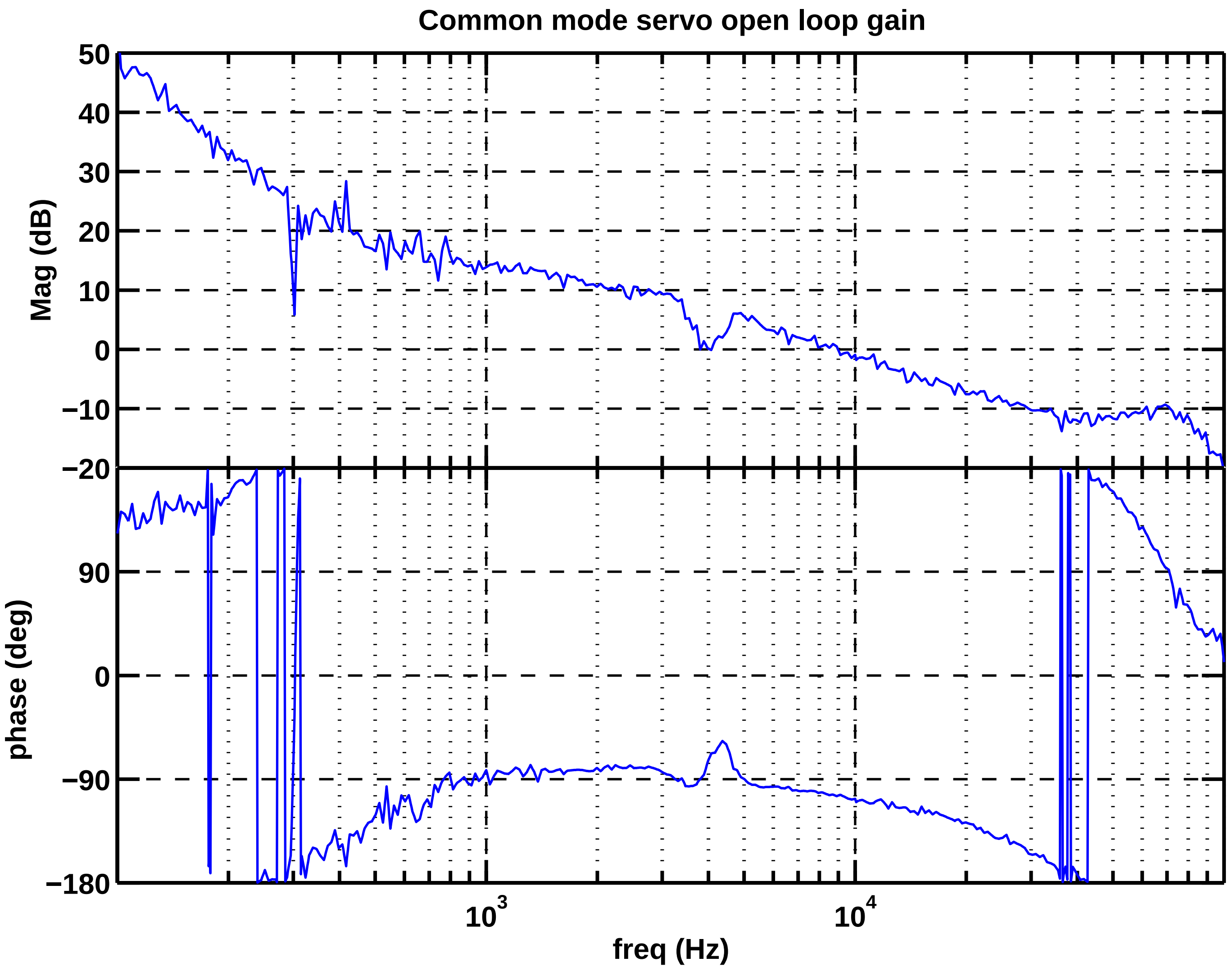
Loop gain

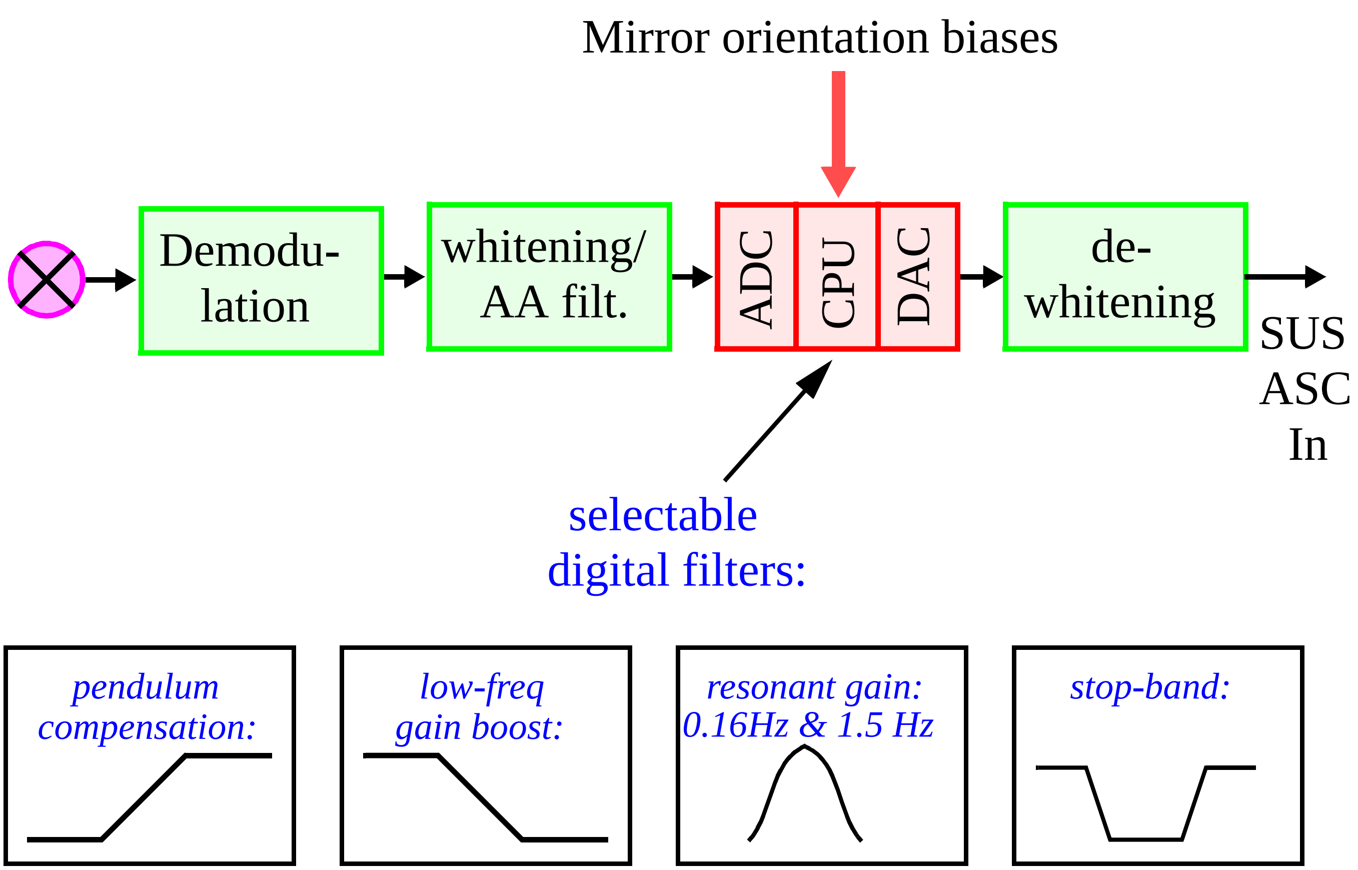
- Calculated from closed loop measurement:



- Unity gain frequency: 9 kHz; phase margin: 80 deg.
- Could go up to 20 kHz u.g.f. (design value)

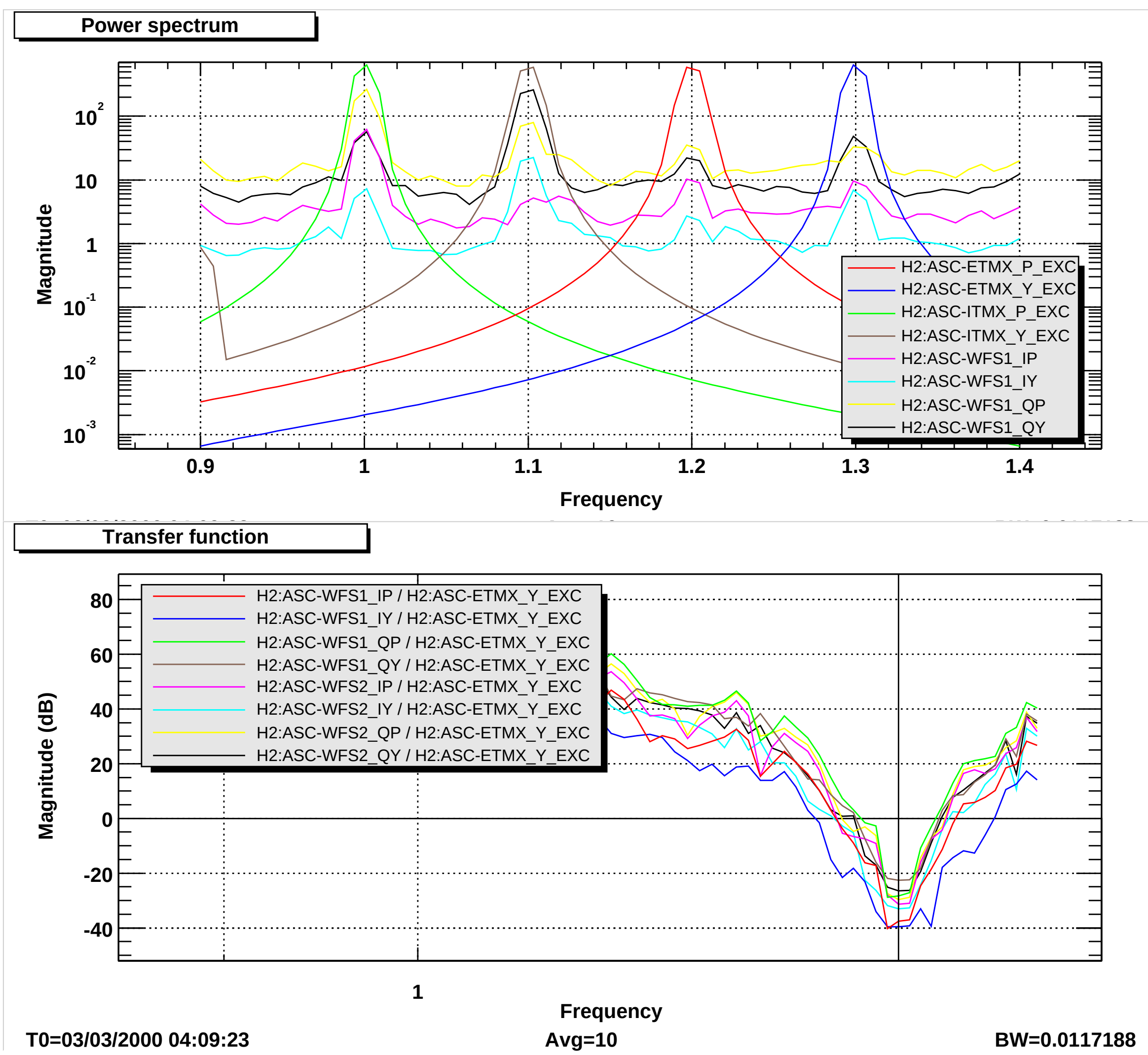
ASC system tests

- Complete sensing & control test of ~1/2 the ASC system:
  - 2 Wavefront Sensor (WFS) (4 d.o.f.) vs. 4 WFS (10 d.o.f.)
  - 1 Quadrant Position Detector (QPD) vs. 2 QPD
  - Signal conditioning and processing chain:



Measuring the sensing matrix

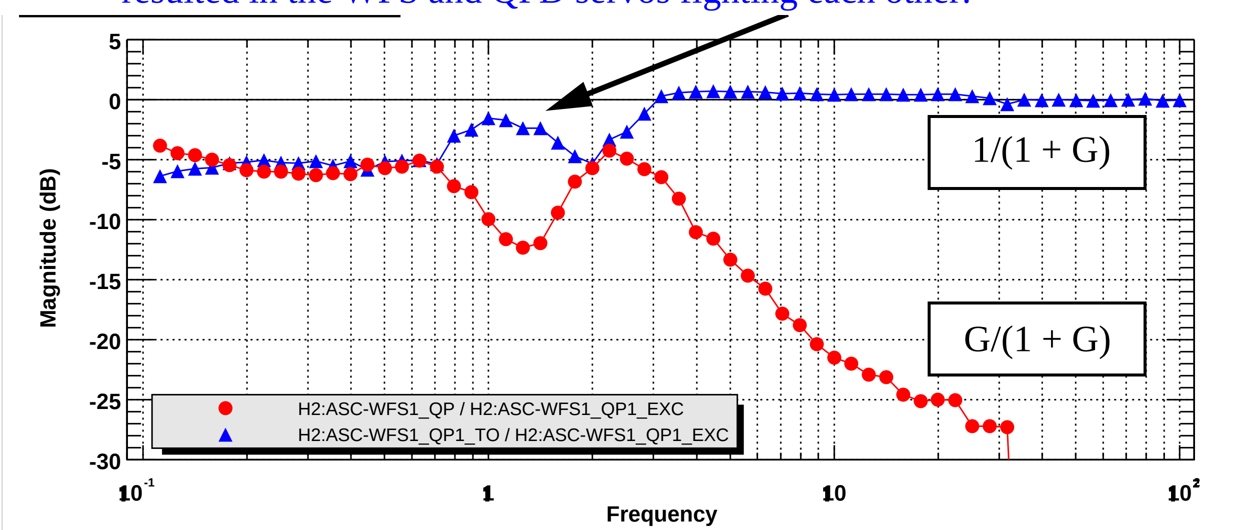
- All six TM orientation d.o.f. are modulated through a digital interface
- FFT of WFS & QPD signals (each quadrant, if desired) taken to establish response



Alignment controls

❑ Original control scheme:

- WFS signals combined to provide feedback signals to the 2 test masses (5 in full ifo; 5x5 matrix), w/ bandwidths up to ~5 Hz
- QPD signals then sense input beam direction, at freq's where WFS gain is high; thus QPD signals fed back to input beam only (2x2 matrix), with low bandwidth (<1Hz)
- input beam fluctuations were not small or slow
  - needed wider bandwidth to stabilize them
  - resulted in the WFS and QPD servos fighting each other:

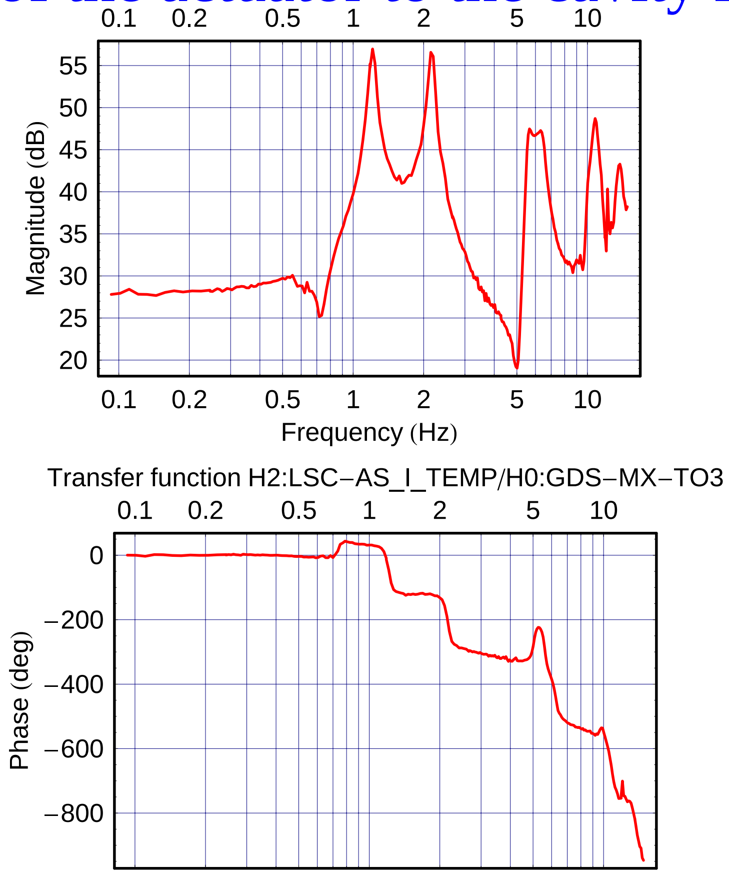


❑ Revised control scheme:

- 7x7 matrix transforms WFS/QPD signals to mirror angles
  - gain peaking seen at 3Hz
  - stack resonant gain filter needs to be retuned for f = 1.2 Hz, Q ~10.

Stack fine actuator test

- ETM stacks are equipped with 4 PZTs at the external support points, used to:
  - track the differential tidal stretching of the arms
  - suppress the arm length changes due to the 6-8 sec microseism, in a feedforward loop
- Used the locked 2km cavity to measure the response of the actuator to the cavity length



Summary & Conclusions

- Learned significance of mode cleaner length fluctuations, developed ways to deal with them
- Lock acquisition lessons
  - preference for locking at low gain (supported by modeling)
  - need to tune suspension controller to produce minimum angular cross-coupling at low-frequency
- Common mode servo
  - needs more work to get relative gains of 3 paths correct (should be easier with digital test mass path)
  - design BW of 20 kHz looks easily achievable
  - still need ~10^3 more frequency suppression! (next talk)
- Alignment servos
  - need to combine all sensors (WFS &QPD) in control matrix
  - servo work to do: suppress stack mode; determine bandwidth limitation
  - still need ~100x better mirror angle stability! (next talk)
- Stack fine actuator works