

**LHO 2_{KM} CAVITY
COMMISSIONING:
SERVO CHARACTERIZATION
AND PERFORMANCE**

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Director's Review
1 May 2000**

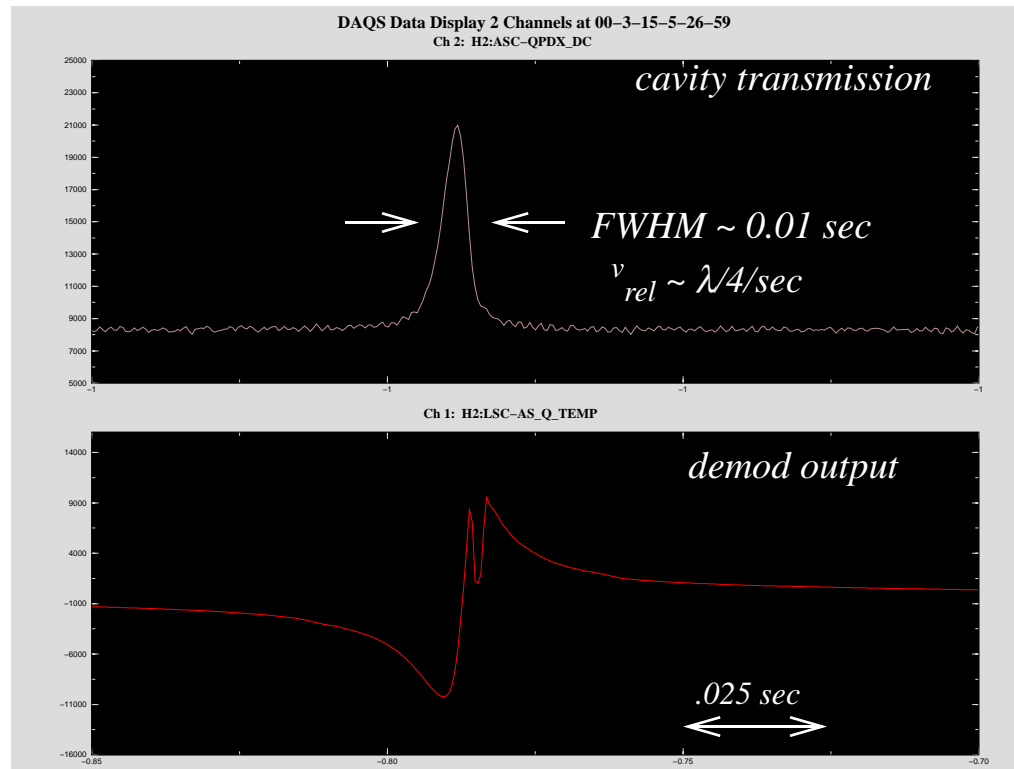
Goals

□ 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

Cavity length locking

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



□ Initially, fringe velocity was much ($\sim 10x$) 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 \leftrightarrow 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: $1/f$; $1 \text{ Hz} < f < 20 \text{ Hz}$: $1/f^3$
- ◆ 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

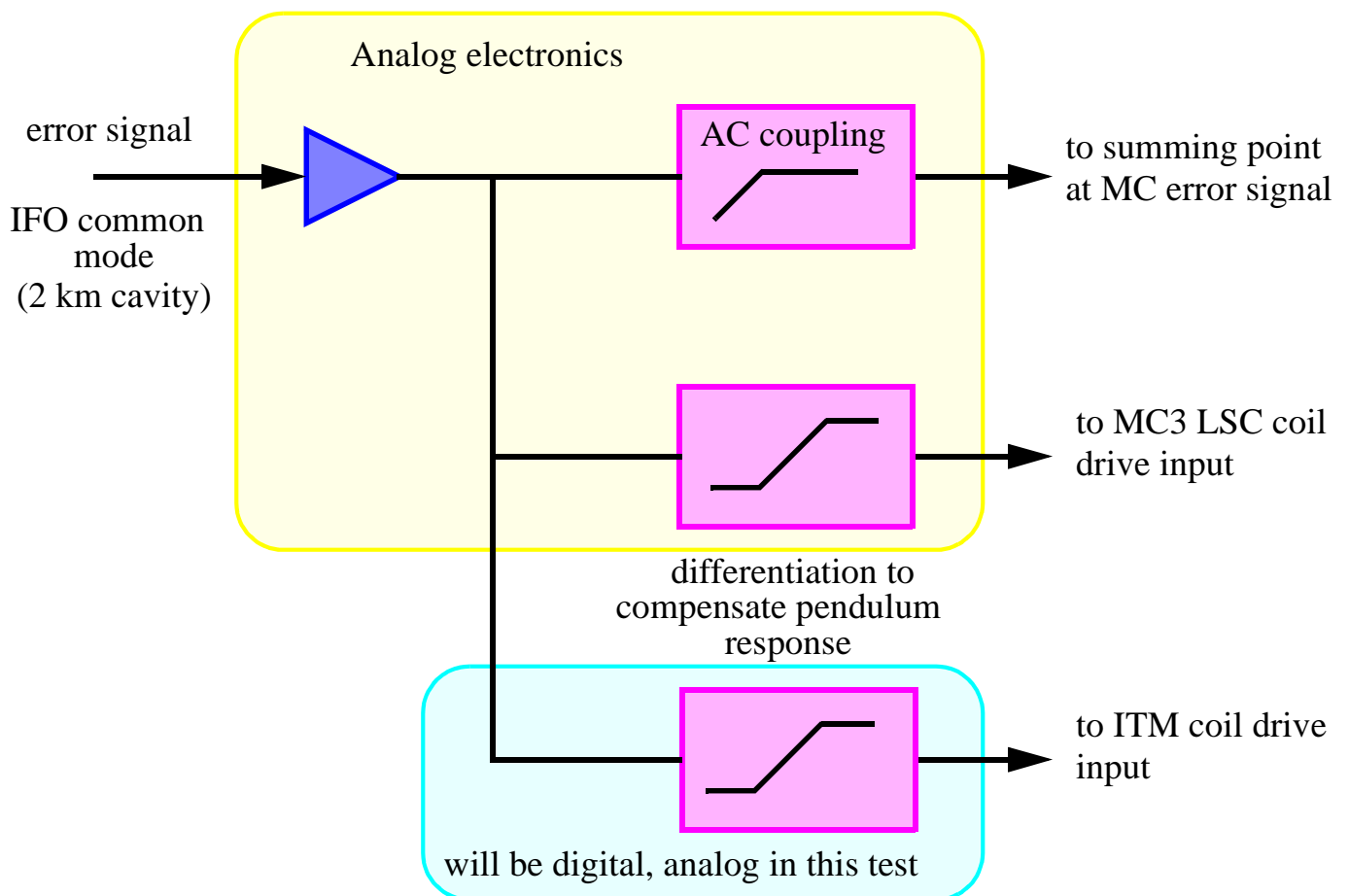
□ Automatic locking sequencer implemented

- ◆ 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

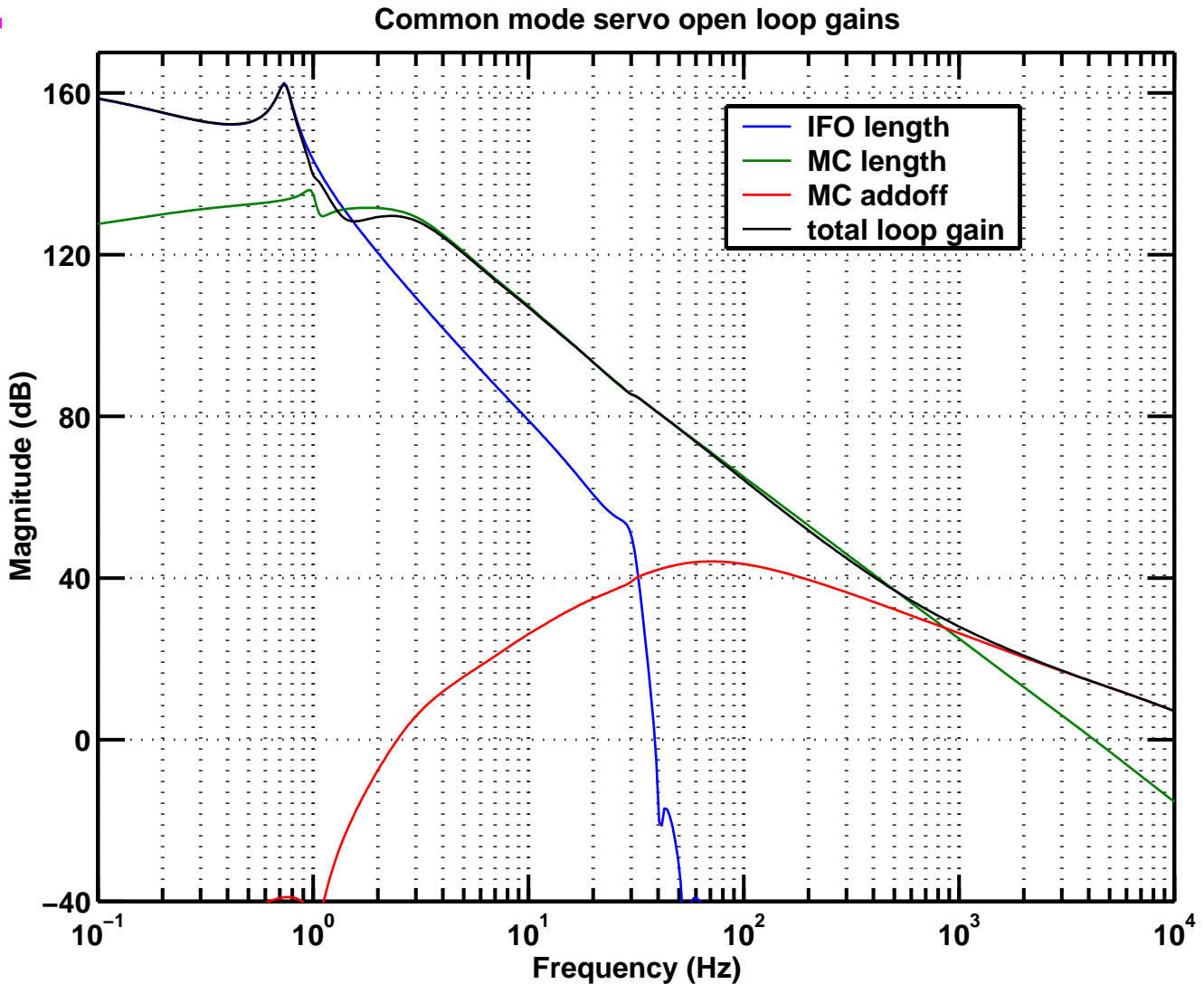
Common mode servo

□ 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

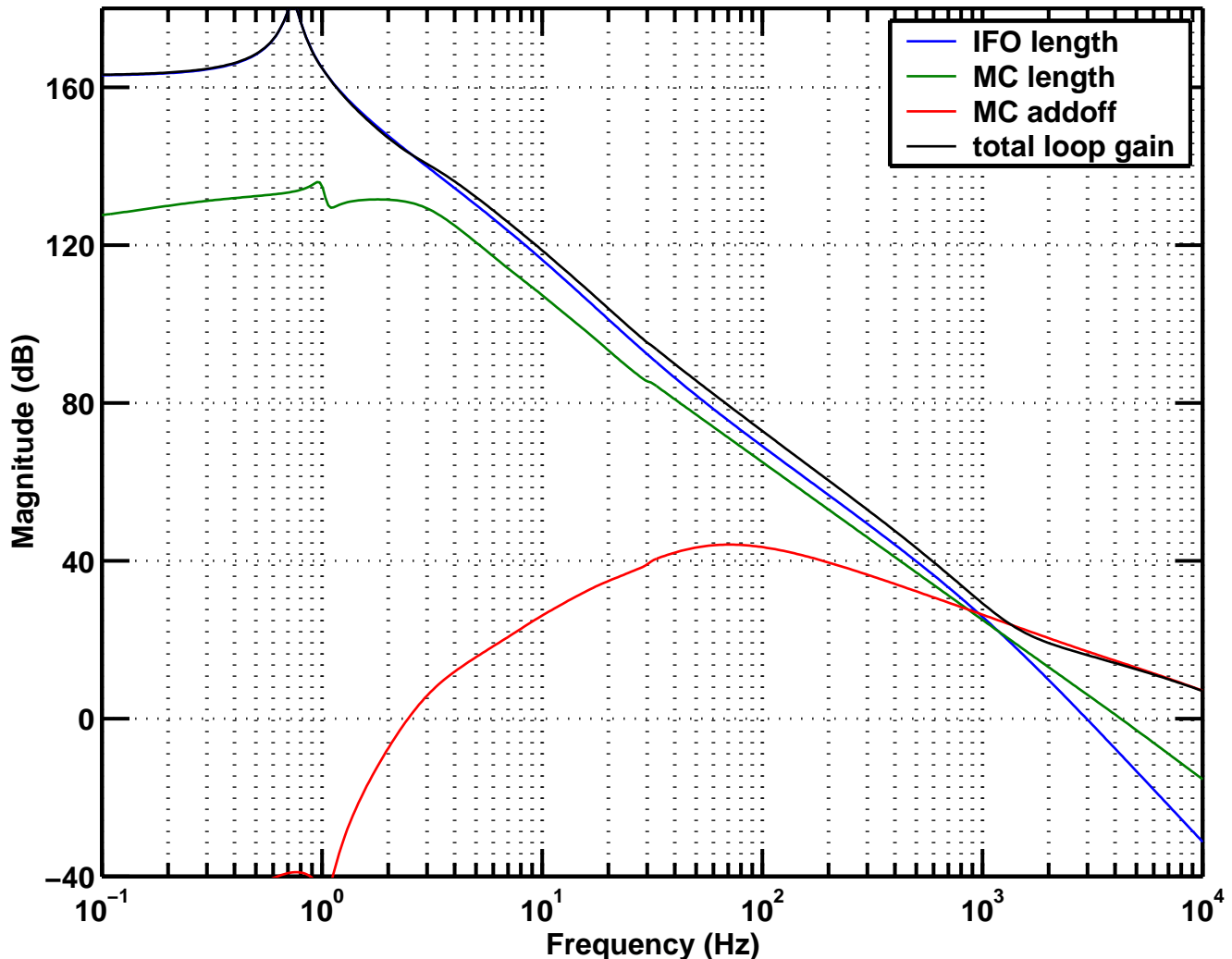


Servo design



- ❑ 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 ...

Modified servo response

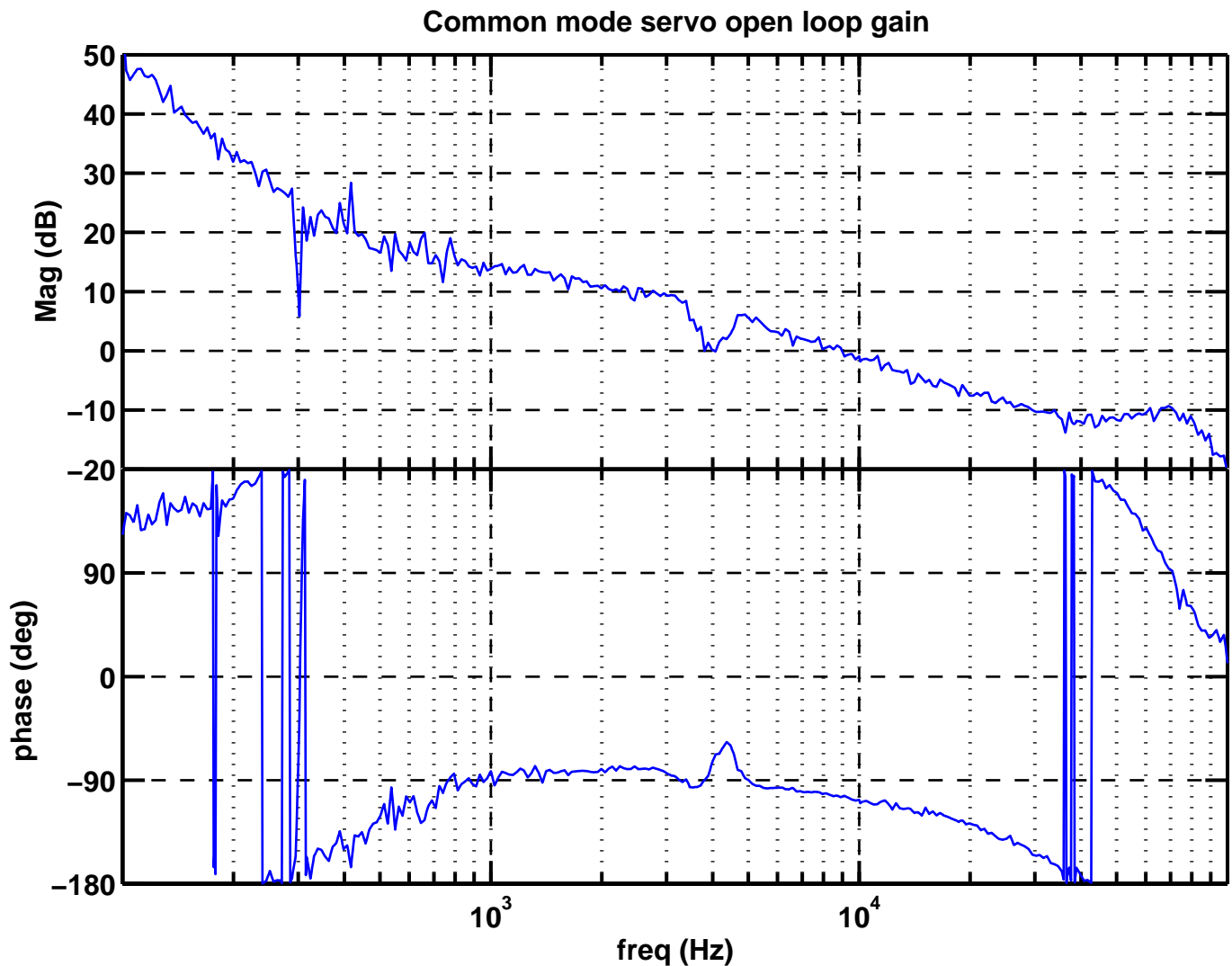


□ Cross-over between ITM & MC length paths

- ◆ 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)

Loop gain

- ◆ Calculated from closed loop measurement:

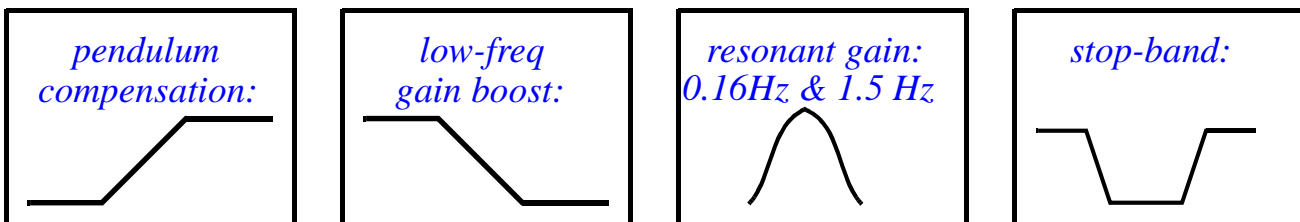
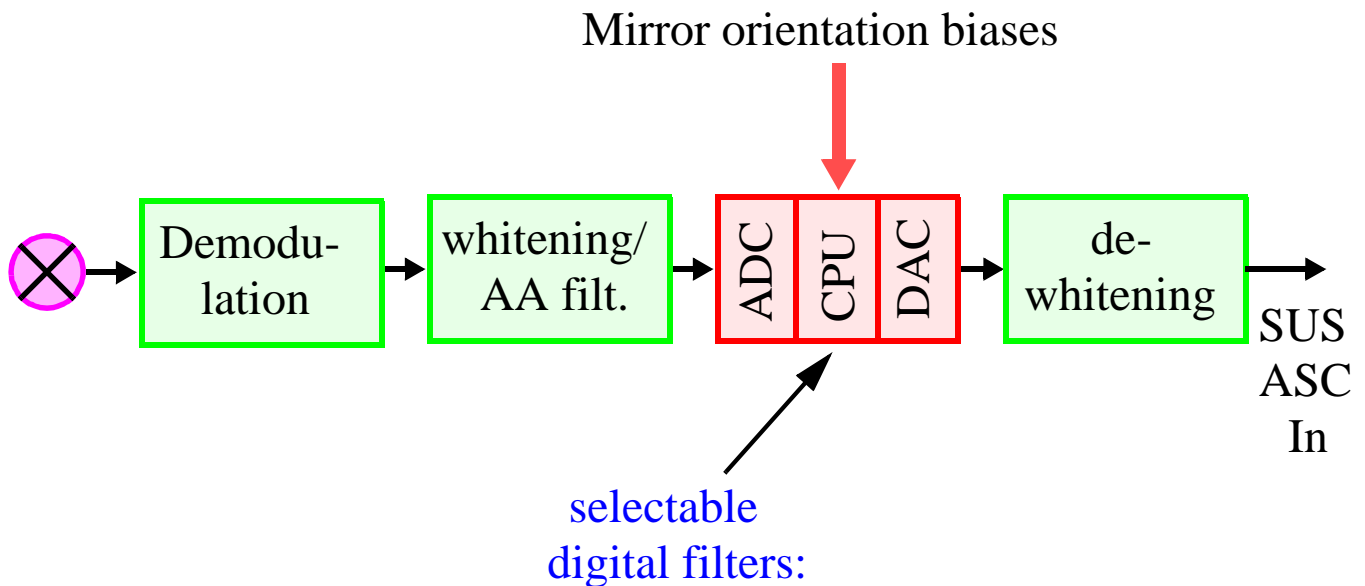


- ◆ Unity gain frequency: 9 kHz; phase margin: 80 deg.
- ◆ Could go up to 20 kHz u.g.f. (design value)

ASC system tests

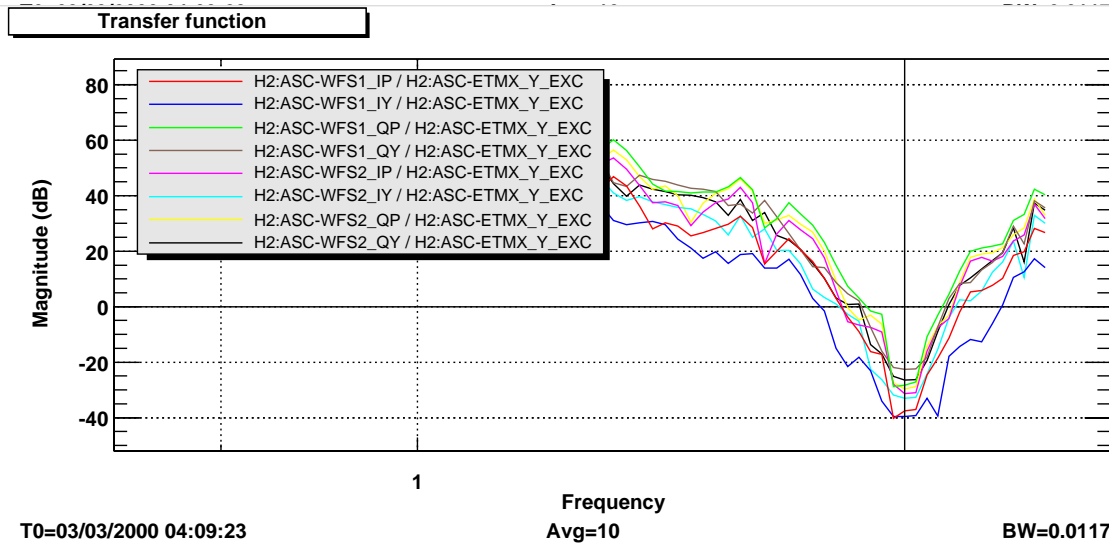
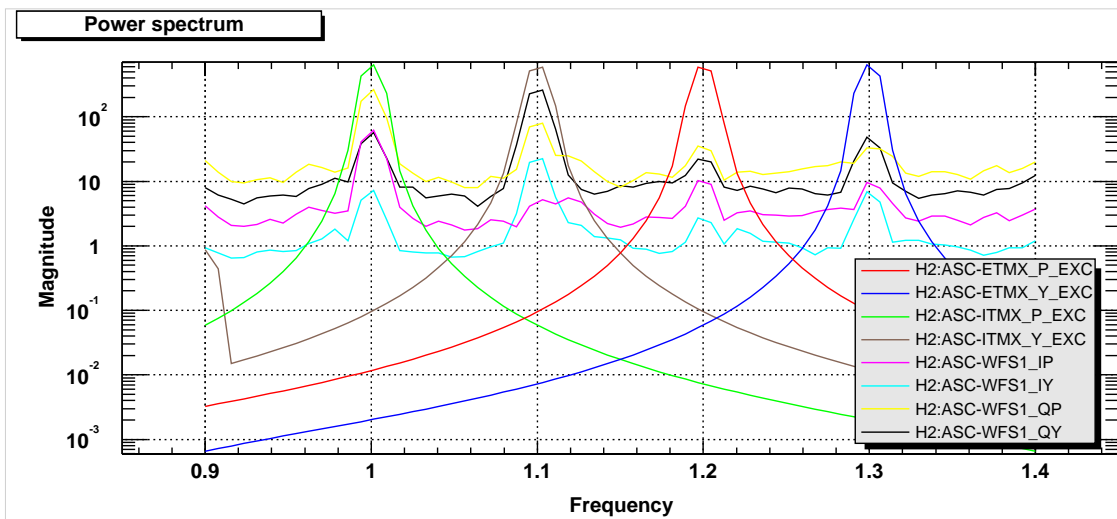
□ Complete sensing & control test of ~1/2 the ASC system:

- ◆ 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

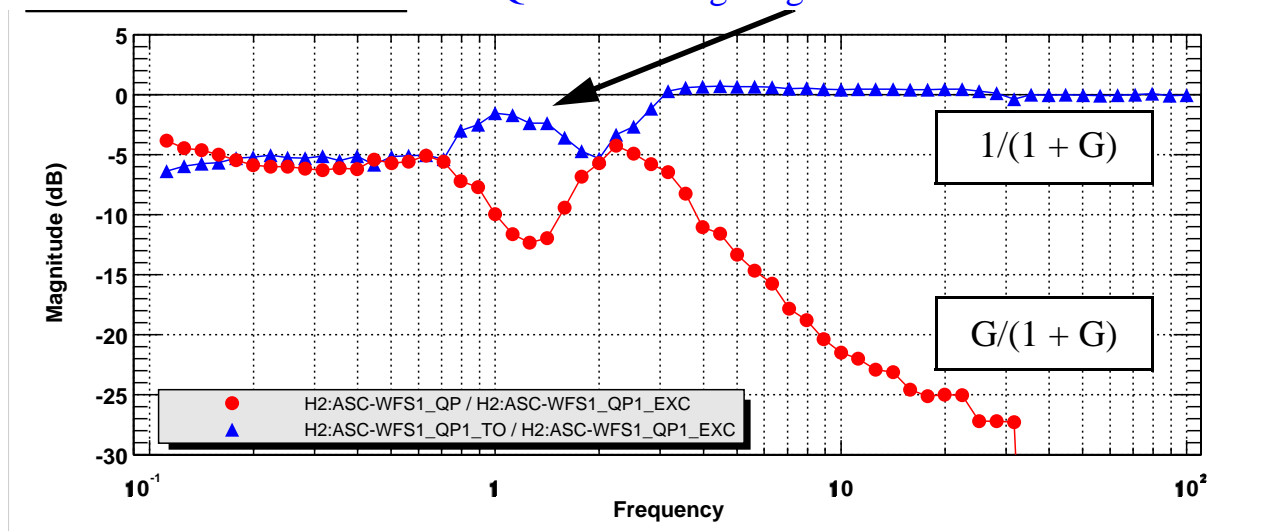
- ◆ All six TM orientation d.o.f. are modulated through a digital interface
- ◆ FFT of WFS & QPD signals (each quadrant, if desired) taken to establish response



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:

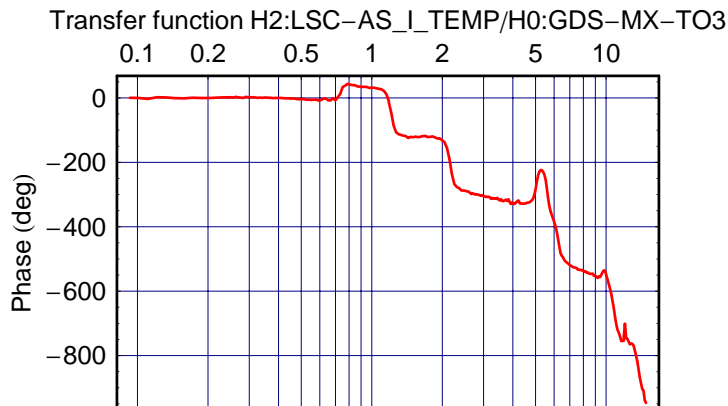
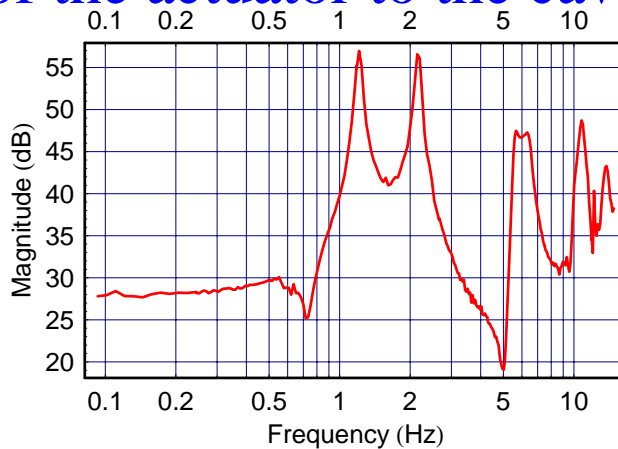


Revised control scheme:

- ◆ 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, $Q \sim 10$.

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 $\sim 10^3$ 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 $\sim 100x$ better mirror angle stability! (next talk)
- **Stack fine actuator works**