Tuning the LIGO I Suspension Controllers - A Work In Progress - 10/27/00

- Contributors
  - Mark Barton (LIGO Caltech)
  - Gabriela Gonzalez (Penn State)
  - Steve Penn (Syracuse)
  - Betsy Weaver (LHO)
- References
  - T000003-A, Suspension Controller Tuning Procedure

Overview

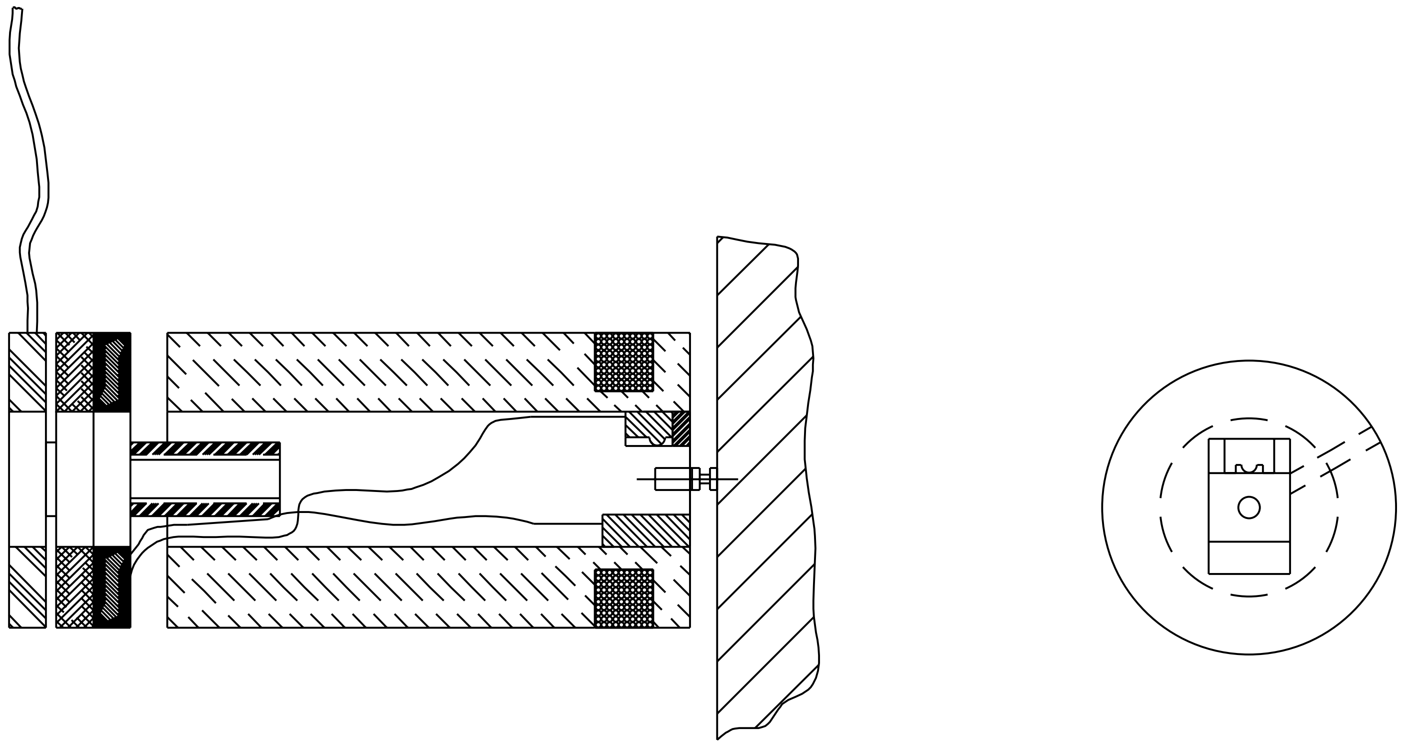
- Need for suspension control
- Controller electronics
- DAQS interface
- The operators' viewpoint
- Tuning the input matrix
  - Normal modes
- Tuning the output matrix
  - OSEM method
  - Optical lever method
- Puzzles

Suspension Structure (LOS)

Need for Suspension Control

- Pendulum is a vibration isolator, but only at HF
  - Large resonant motions due to pendulum modes around 0.7-1.0 Hz
  - Other motions due to stack modes up to 10-14 Hz
- Need for local control to reduce amplitude/velocity to enable locking
- Need for inputs from global control system to maintain lock and stay close to correct operating point despite
  - differential tidal elongation of arms
  - residual seismic noise
- Therefore,
  - Sense position of five different points on the optic (4 face points, 1 side)
  - Apply feedback forces via coils acting on magnets glued to the optic

Sensor/Actuator (OSEM) Schematic



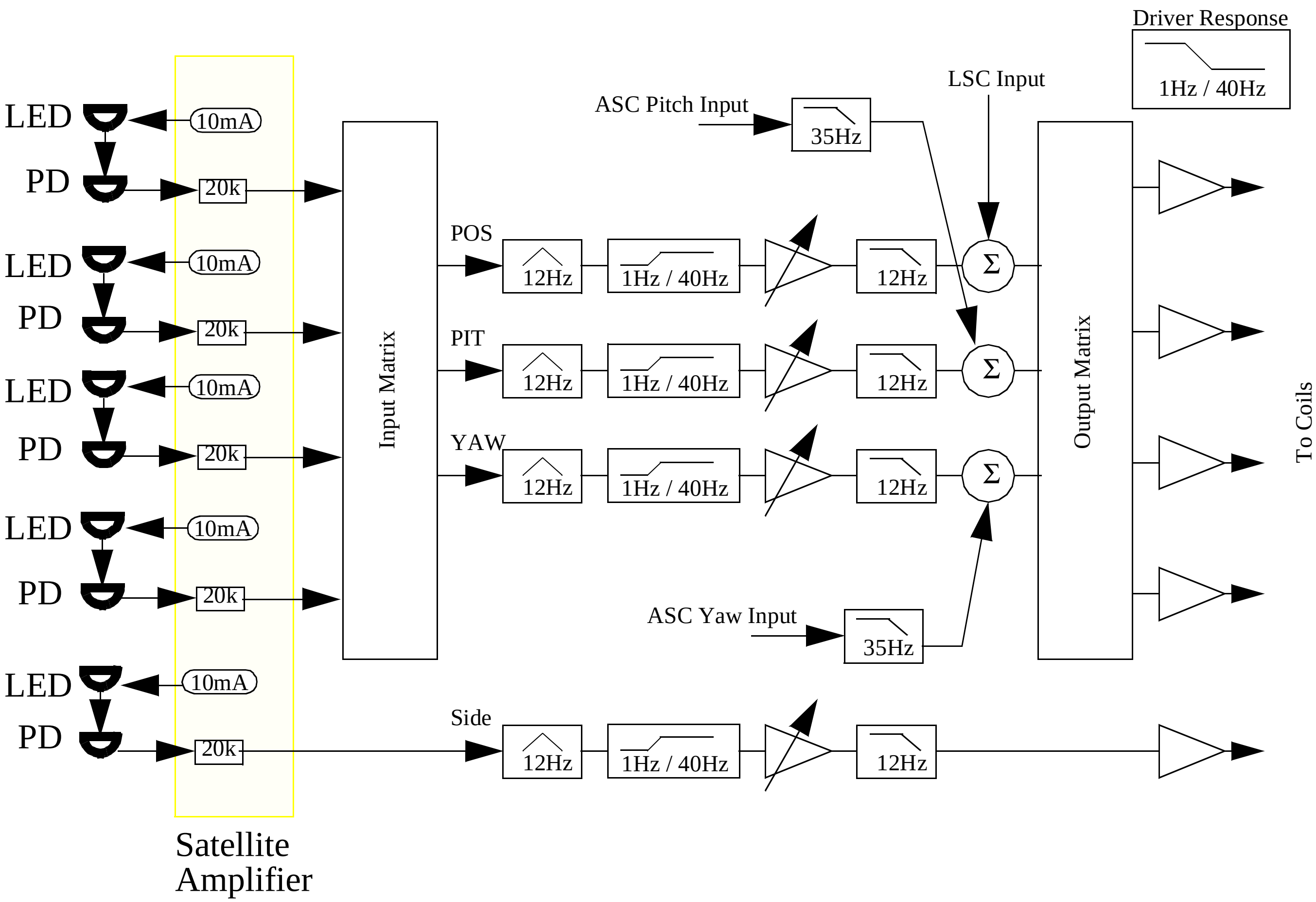
OSEM Design Detail

- Design features:
  - Cylindrical Macor body
  - Molybdenum conductive plating for static discharge
  - IR shadow sensor senses position of tip of optic magnet
  - Coil applies AC and small DC forces to optic magnet
  - Optional pitch adjustment magnet (PAM) applies larger DC forces
- The sensitivity of the sensors and the strength of the coil-magnet pairs varies from unit to unit due to component variations
- Need variable gain stages in the electronics to compensate for this
- Need a procedure for setting the gains in the electronics

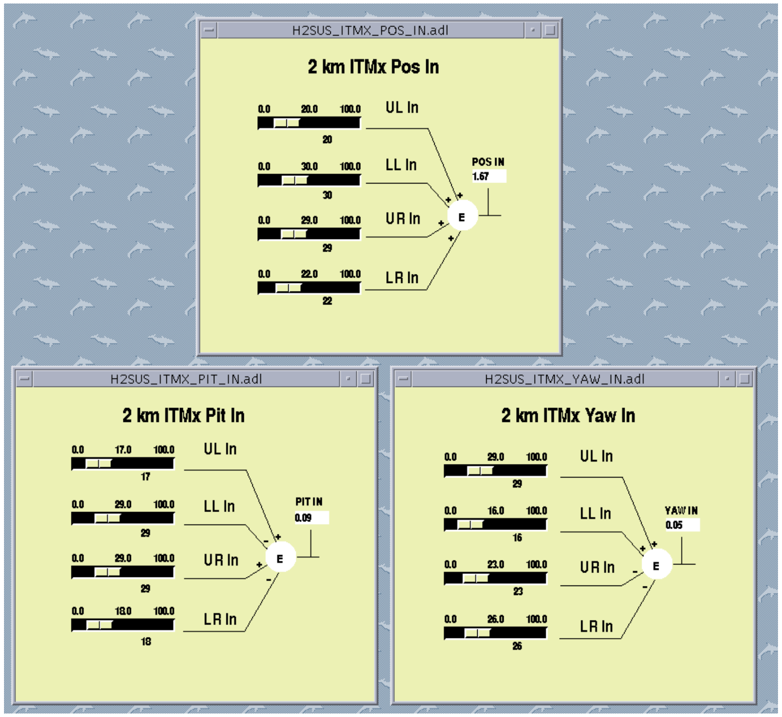
Controller Design

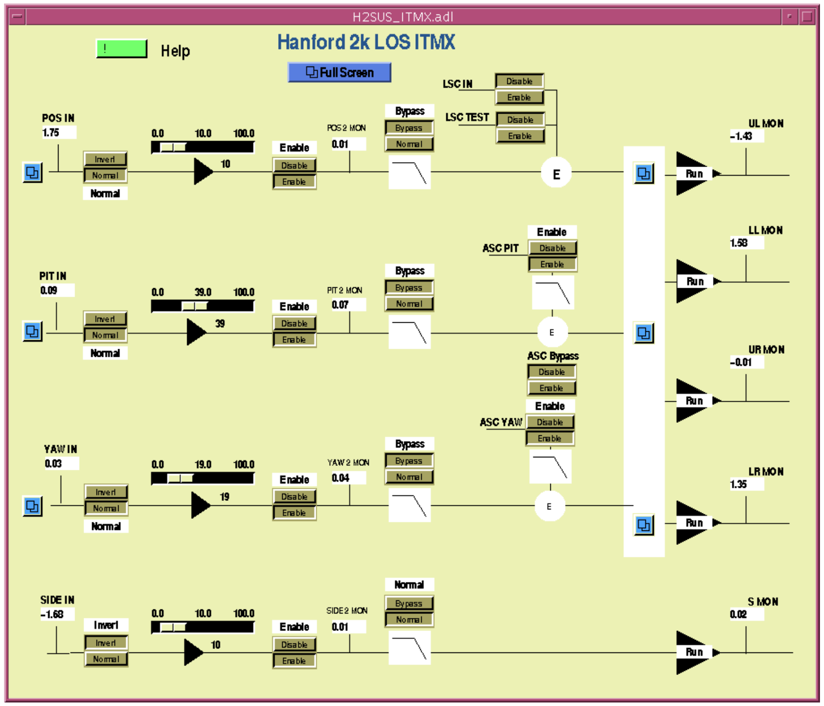
- Inputs from 4 face OSEMS and 1 side OSEM
- Input matrix diagonalizes 4 face OSEM signals to produce POS, PIT and YAW signals
  - gains adjustable in 0.1 % increments from 0 to 100%, nominal 25%
  - signs hardwired
- POS, PIT, YAW signals go to 3 single-input-single-output (SISO) controllers
- Output matrix produces 4 coil driver signals
  - gains adjustable in 0.1 % increments from 0 to 100%, nominal 100%
  - signs hardwired
- Side servo independent of
- Signal outputs to DAQS
- Control inputs from EPICSController Block Diagram

Controller Block Diagram

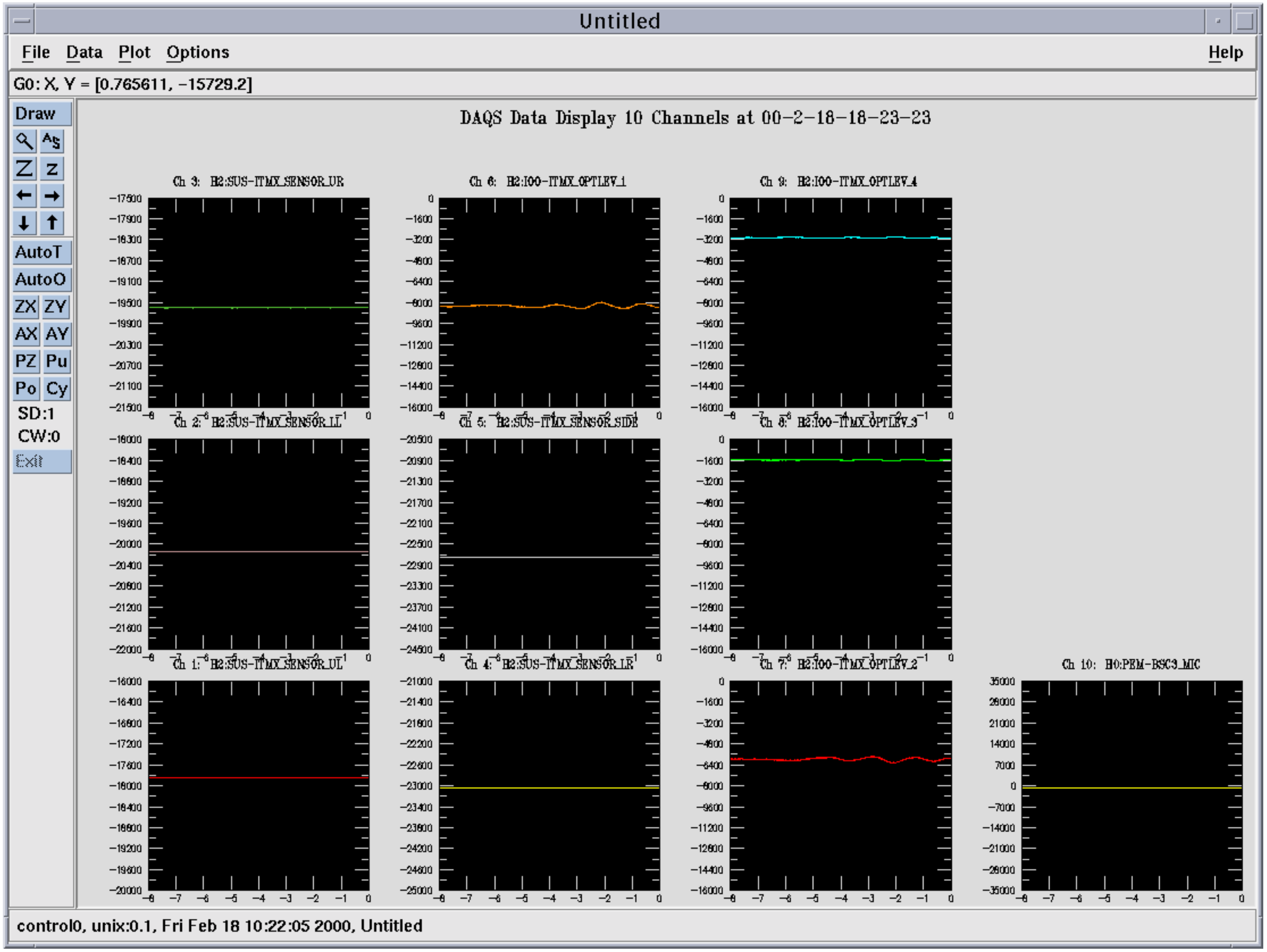


Operator's Viewpoint (i)
Controller Screen





Operator's Viewpoint (ii)
DataViewer

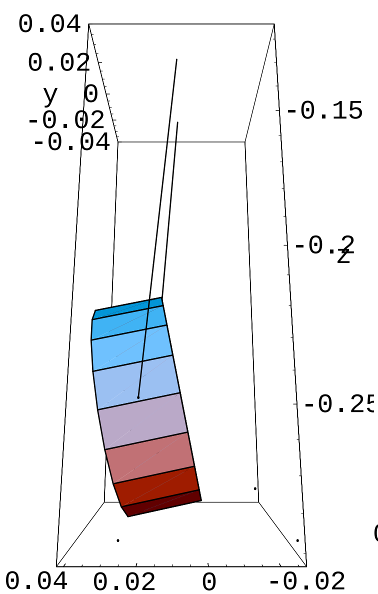


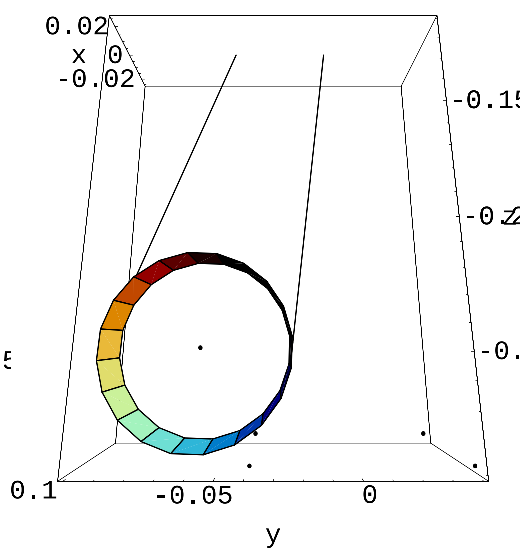
Input Matrix Tuning Overview

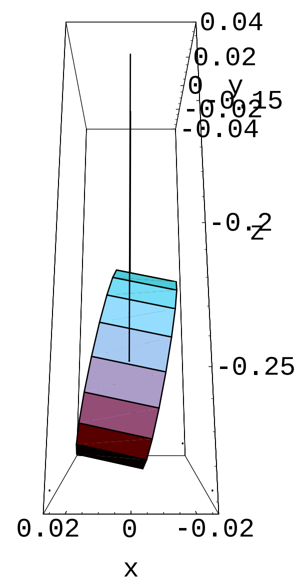
- Current strategy uses measurements of normal modes of the optic with the servos disabled:
  - Calculate mode shapes and frequencies analytically using nominal parameters
  - Record sensor signals with optic dangling freely
  - FFT sensor signals and identify mode peaks
  - Use pitch mode frequency to calculate exact value of d_{PITCH} parameter (actual value commonly differs from nominal due to manufacturing/assembly tolerances)
  - Use measured d_{PITCH} and nominal values of other parameters to recalculate mode shapes with more accurate position-pitch cross-coupling
  - Identify sensor amplitudes at the mode frequencies
  - Assume physical input to the sensors conforms to the mode model
  - Choose gains such that <sensor output>*<gain> conforms to the mode model

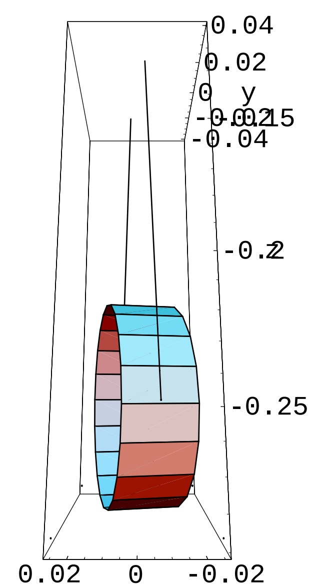
Normal Mode Calculation

- Four modes are of interest:
  - "pendulum" - axial position with a bit of pitch cross-coupling
  - "side"/"transverse" - at right angles to "pendulum"
  - "yaw" - a fairly pure yaw mode
  - "pitch" - mostly pitch with a bit of position cross-coupling



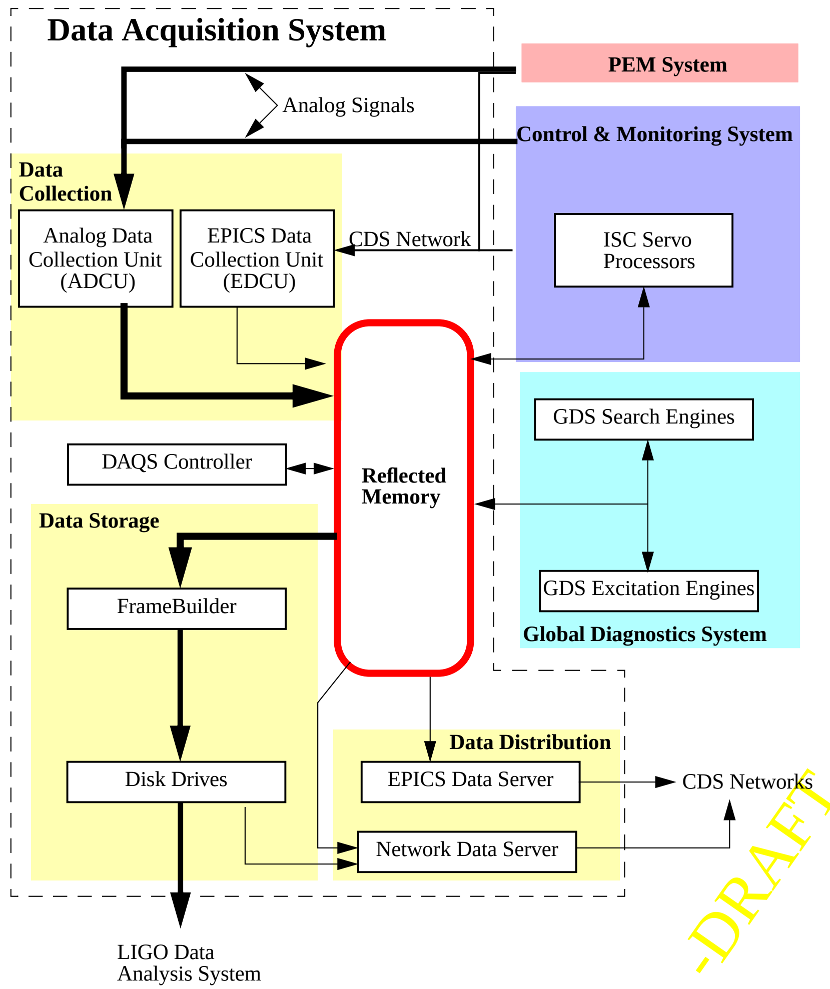




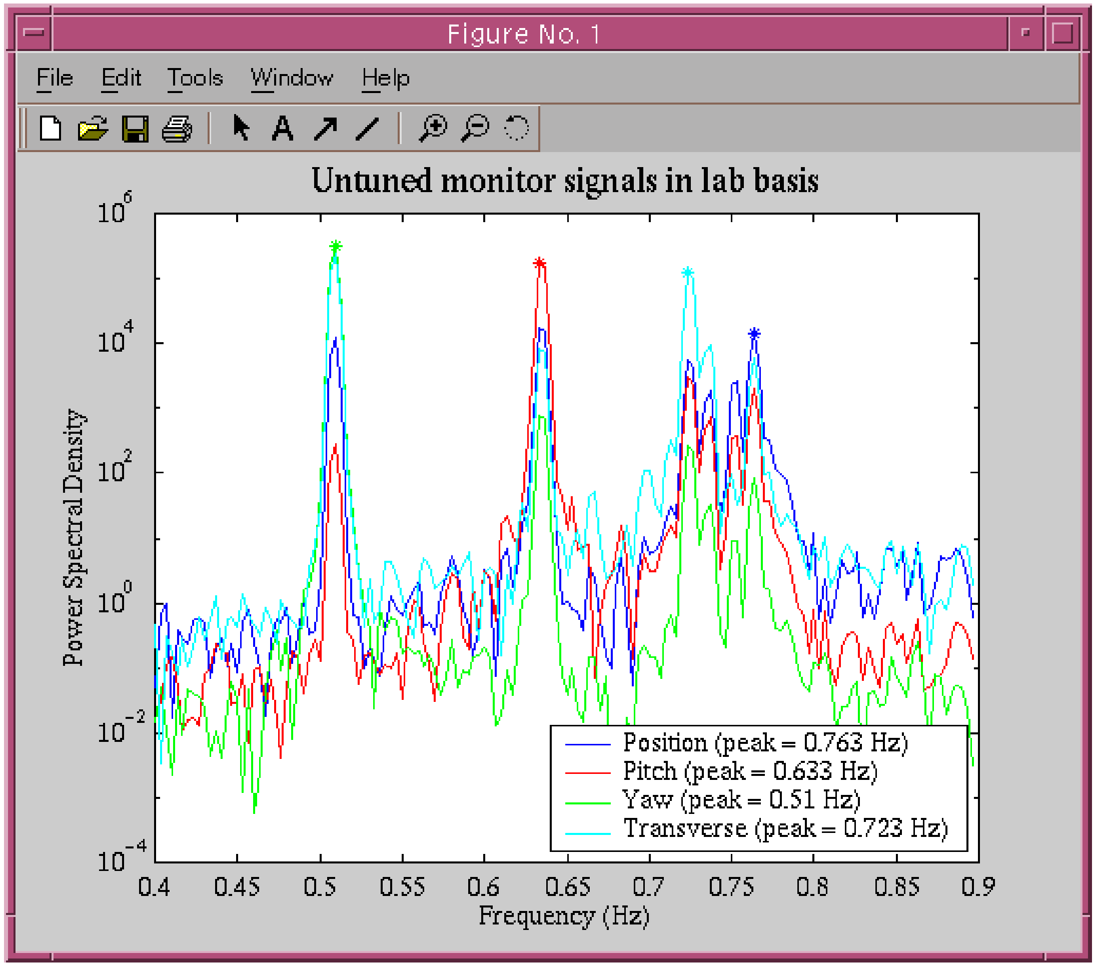


Data Taking

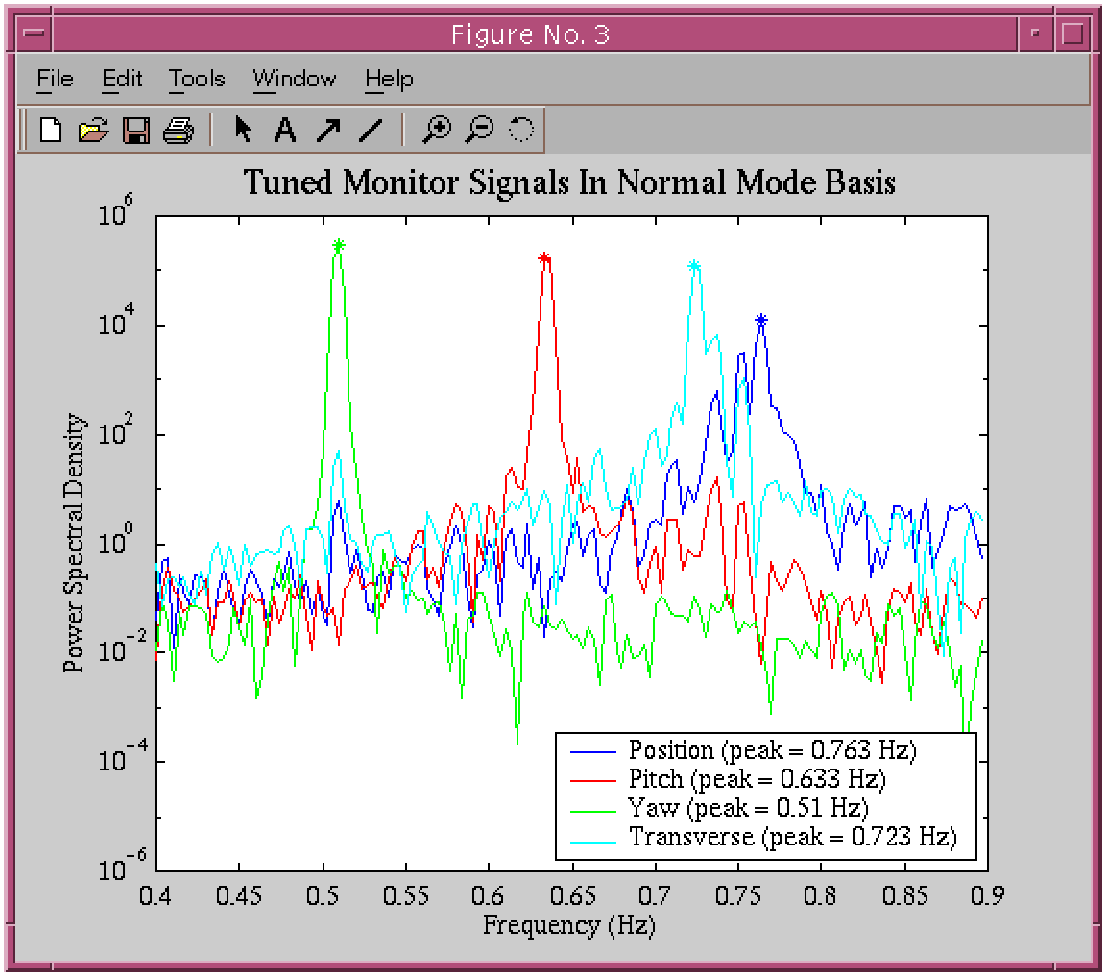
- The outputs of the controller are acquired by and ADCU in the DAQS system.
- The digitized data go to the Network Data Server, either directly (real time data) or via the Frame Builder and disk drive (old data).
- A Matlab utility running on a CDS workstation in the control room downloads the output of the appropriate channels for the desired time interval.



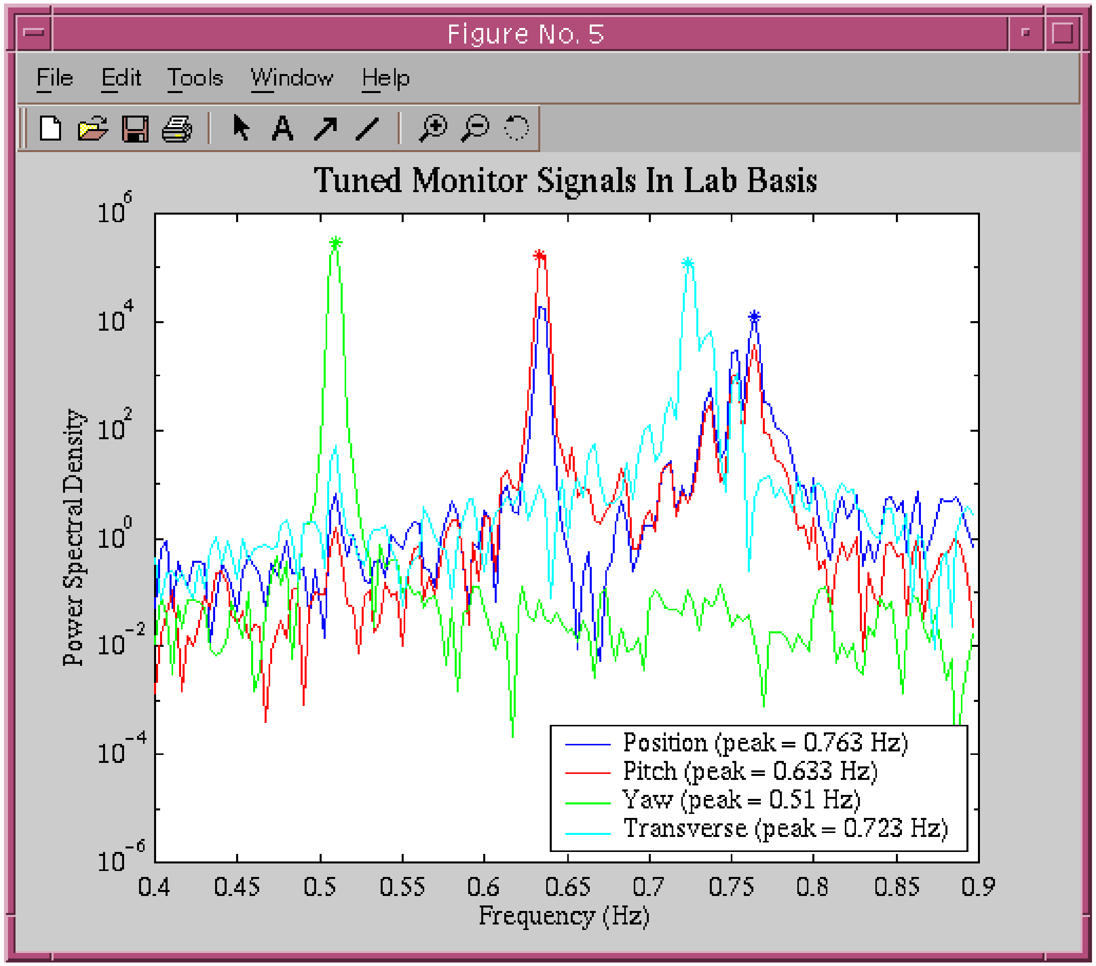
Peak Identification



Allowance For Cross-Coupling



Effect of Tuning



Status

- Consistency is good
  - across data sets taken at different times (≈1%)
  - across data sets of different lengths (provided position and side peaks are well resolved)
- However a discrepancy is suspected between OSEM and optical lever measurements of pitch and yaw
  - noticed through effect on output matrix tuning (see later)
  - corresponding to ≈5% imbalance in sensors for SOS, 10% for LOS
- The discrepancy is being investigated. Suspects include
  - PAM magnets (LOS only)
  - improper FFT windowing
  - insufficient data record length -> insufficient position/side mode separation

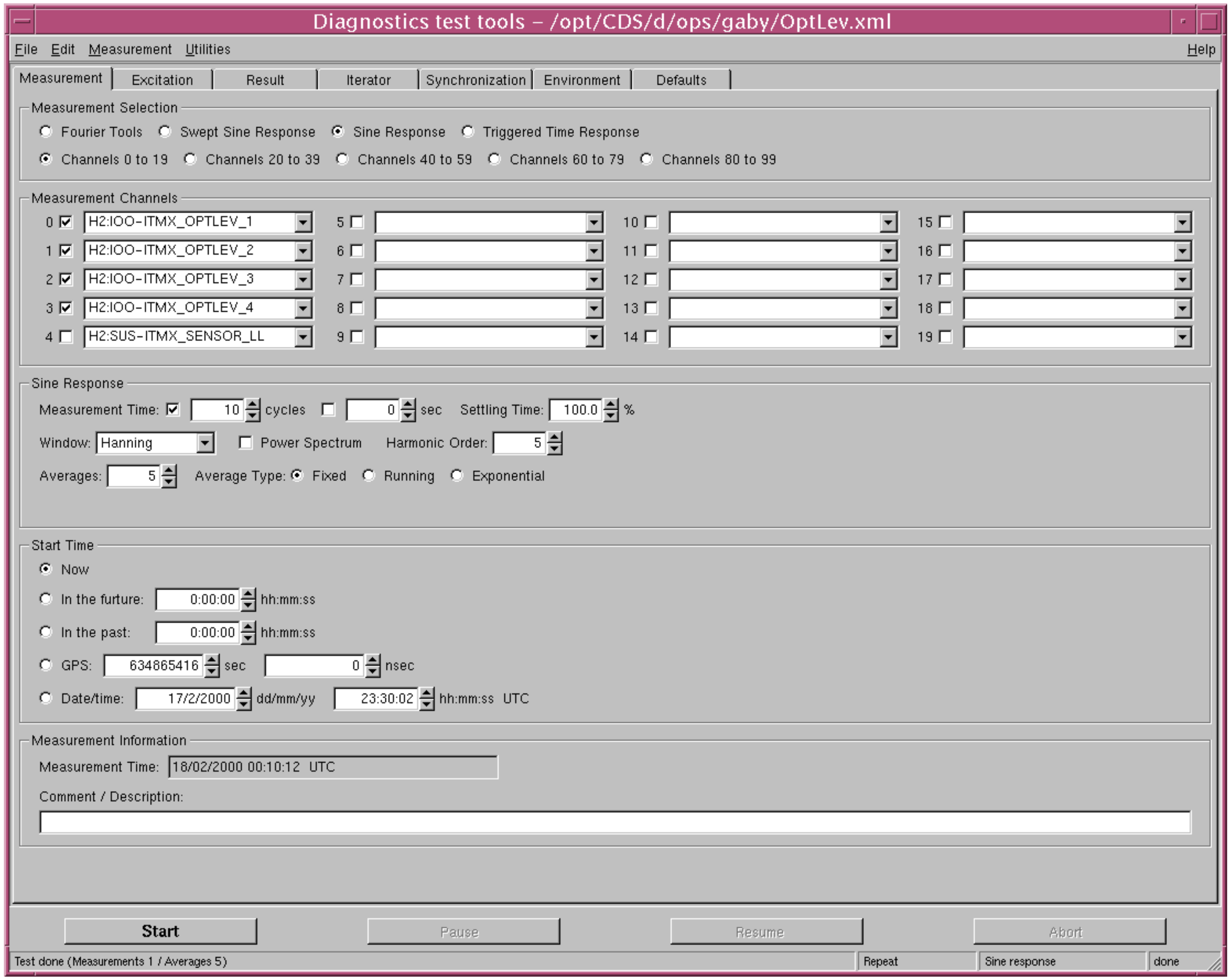
Output Matrix Tuning

- Two methods:
  - Using optical levers as a reference
    - requires an optical lever (special setup for most SOS, not possible for some SOS)
    - only suitable for position component of output matrix
  - Using tuned input matrix as a reference
    - requires accurately tuned input matrix
    - suitable for all optics
    - suitable for whole output matrix

Output Matrix Tuning Procedure

- Repeat for each of POS, PIT, YAW component:
  - Choose measurement frequency ("low": 0.2 Hz, "high": 1.85 Hz)
  - Hookup GDS output to appropriate controller test input
  - Apply excitation using GDS Tools software
  - Measure response with 100% gain to each actuator
  - Measure response with perturbations to gain of particular actuators
  - Calculate cross-couplings
    - use either input matrix or optical levers
  - Interpolate to find improved gain settings
    - custom software does this automatically
  - Repeat using perturbations about the improved gain settings

GDS Tools Software

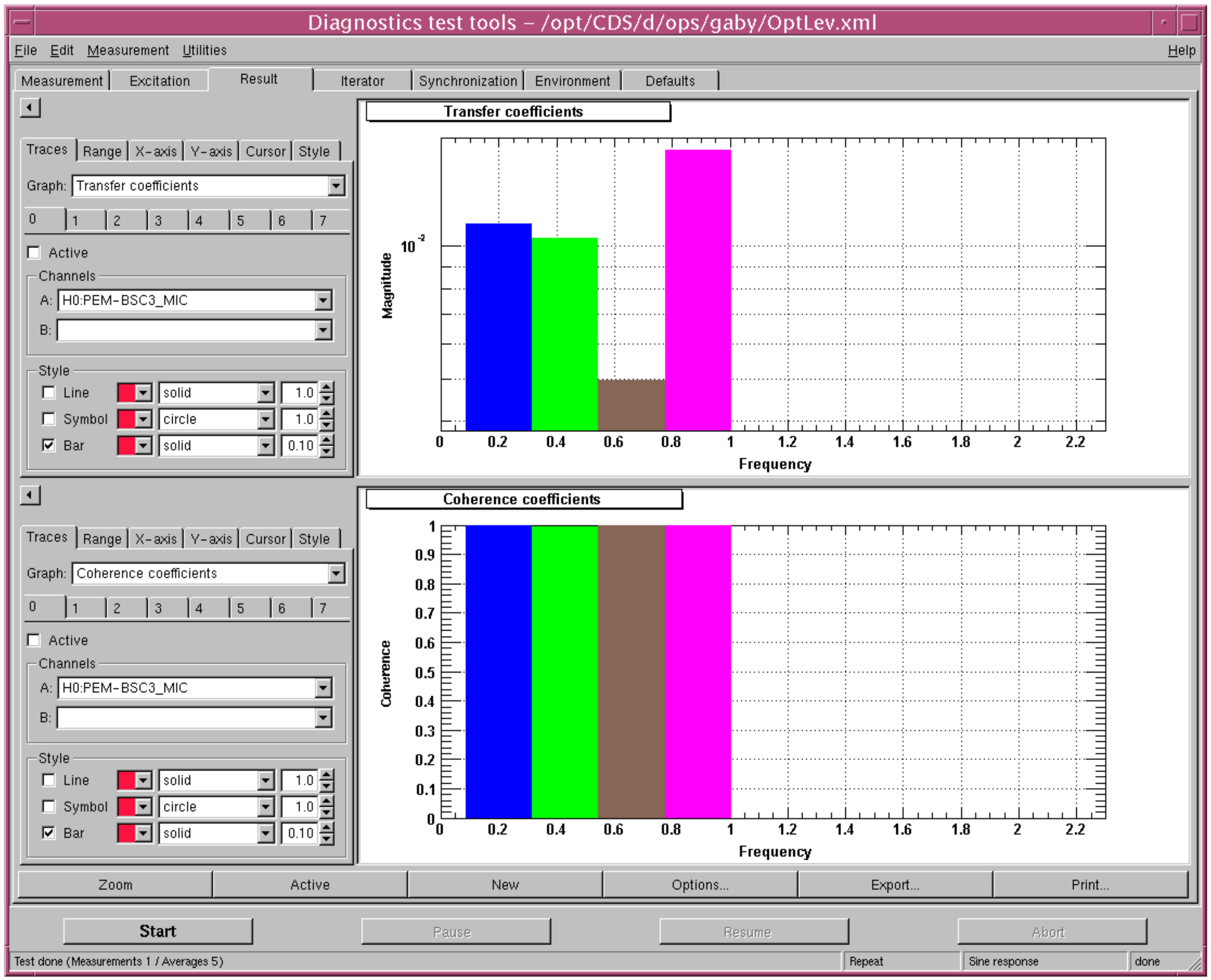


Measurement Program

Table 1: Measurement program for Round 1 of tuning for the position, pitch and yaw components of the output matrix using the sensors as reference

Position		*Pitch*		*Yaw*	
UL UR *LL LR*	*Filename*	*UL UR* *LL LR*	*Filename*	*UL UR* *LL LR*	*Filename*
100 100 100 100	`SensorPosInit.xml`	100 100 100 100	`SensorPitInit.xml`	100 100 100 100	`SensorYawInit.xml`
90 90 100 100	`SensorPosUp.xml`	90 90 100 100	`SensorPitUp.xml`	90 100 100 90	`SensorYawMain.xml`
100 100 90 90	`SensorPosDown.xml`	100 100 90 90	`SensorPitDown.xml`	100 90 90 100	`SensorYawOff.xml`
90 100 90 100	`SensorPosLeft.xml`	90 100 100 90	`SensorPitMain.xml`	90 100 90 100	`SensorYawLeft.xml`
100 90 100 90	`SensorPosRight.xml`	100 90 90 100	`SensorPitOff.xml`	100 90 100 90	`SensorYawRight.xml`

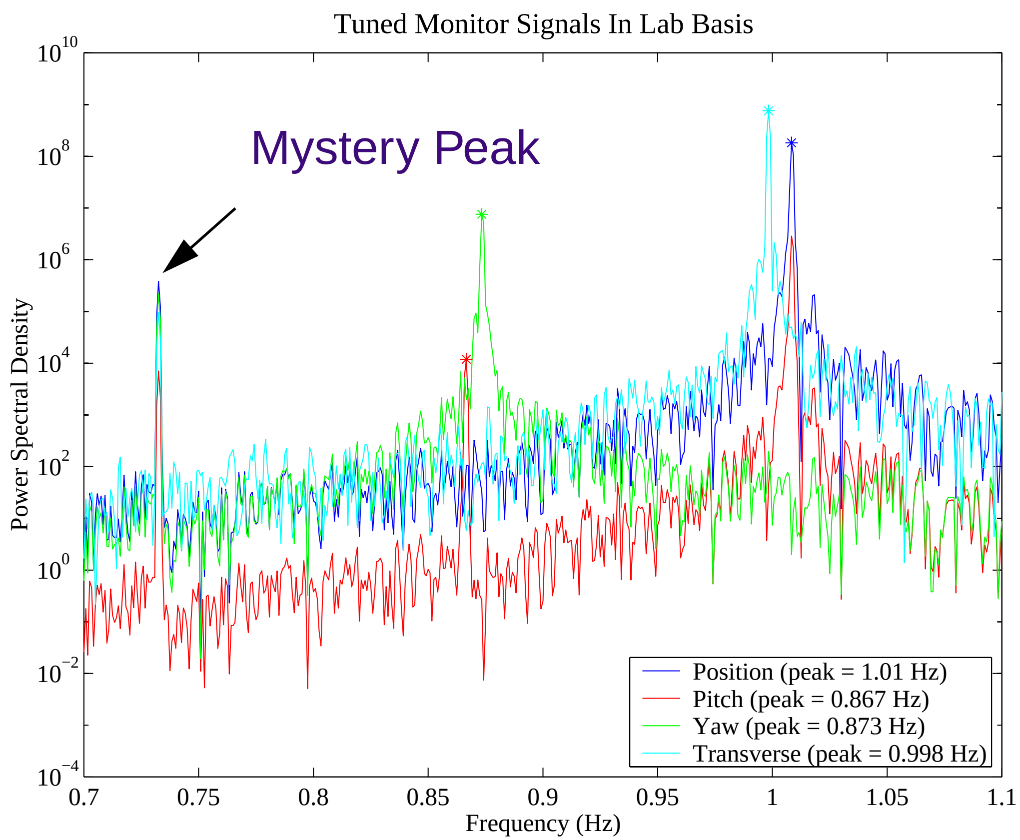
Typical Results



Status

- Software for all combinations written
  - Position component, optical lever method
  - Position, pitch yaw components, OSEM method
- Consistent results across runs for each method separately
- Discrepancy between optical lever and OSEM methods
  - corresponding to ≈5% imbalance in sensors for SOS, 10% for LOS
- The discrepancy is being investigated. Probably in input matrix tuning procedure. Suspects include
  - PAM magnets (LOS only)
  - improper FFT windowing
  - improper modelling

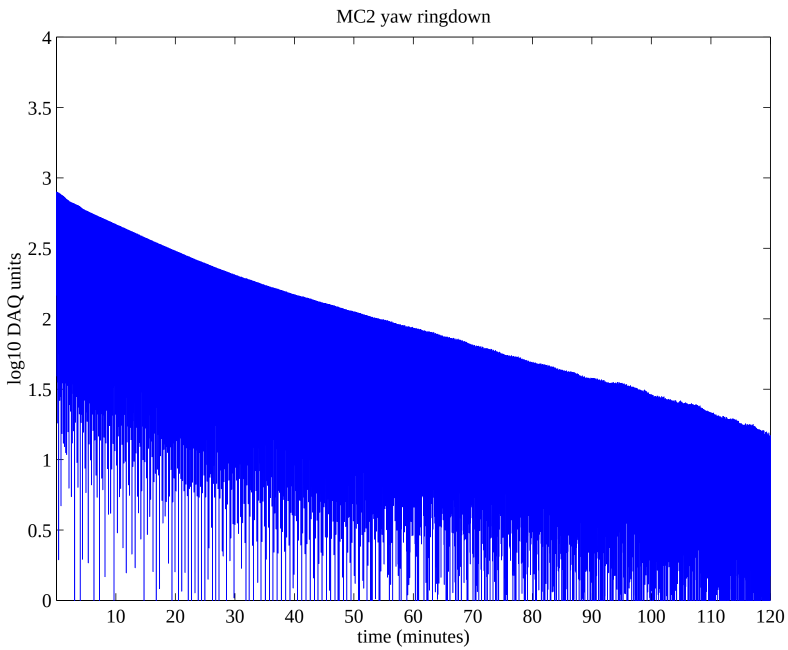
Puzzles (i)



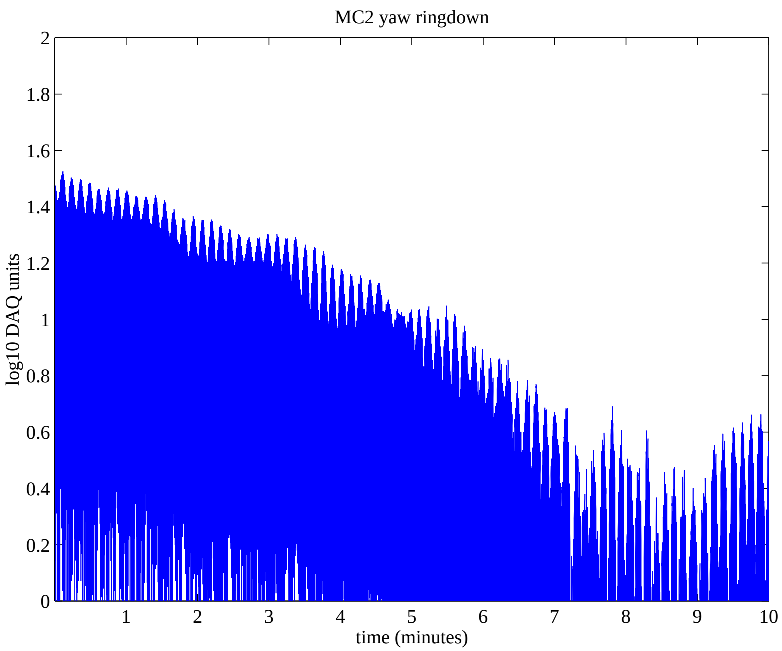
- Mysterious peak in LLO electronics
  - Very well-defined frequency (0.77345 Hz) -> electronic

Puzzles (ii)

- Poor, somewhat amplitude dependent Q on some optics



Large amplitude Q ≈ 5500



Small amplitude Q ≈ 600

Conclusions

- More debugging of existing procedure required
  - some data taken last week but not yet fully analysed
- Some debugging of LLO electronics and optic installation required
  - Sany Yoshida, Warren Johnson investigating Q issue
- LHO status check required
- Forthcoming digital suspension controller will be a major improvement
  - arbitrary signs in I/O matrices (useful for extreme cases, e.g., dead sensor or actuator)
  - side signal can be included in the diagonalization
  - frequency dependent I/O matrices possible