The VIRGO Suspensions Control System

Alberto Gennai

The VIRGO Collaboration

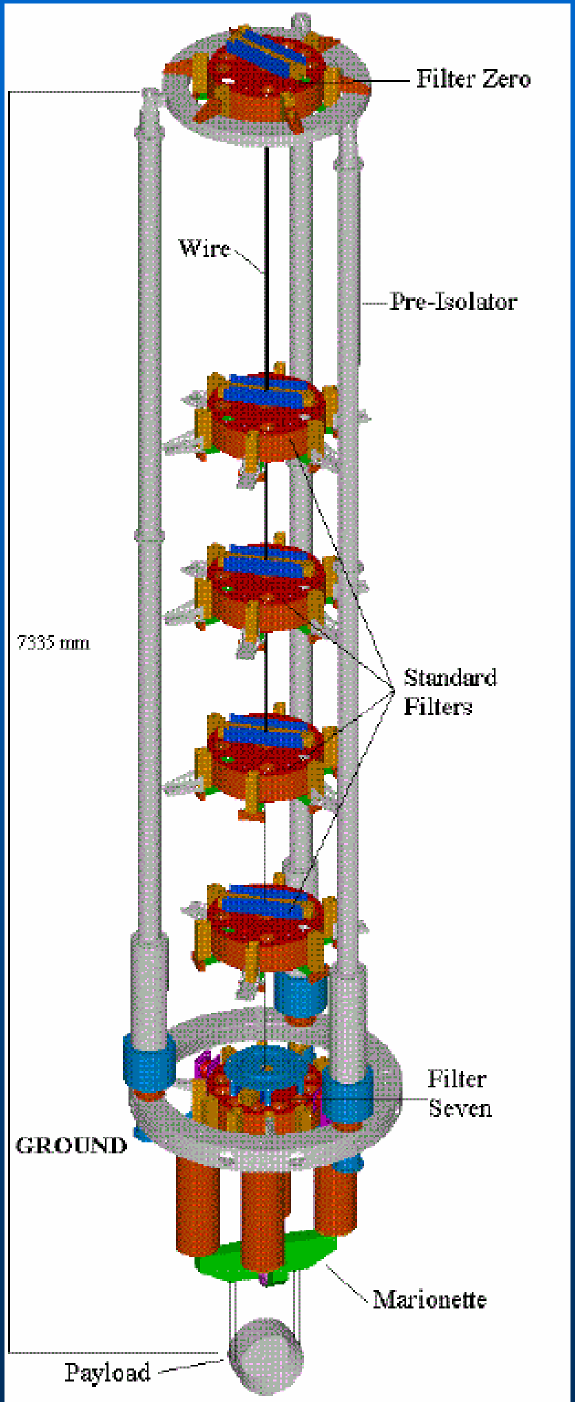
LIGO-G050527-00-Z

Summary

- Superattenuator
- Local Controls
  - Inertial Damping
  - Payload Control
- Global Control
  - Hierarchical Control
  - Lock Acquisition

Superattenuator

- Passive seismic isolation for optical elements
- 18 coil-magnet pair actuators distributed in 3 actuation point:
  - Filter zero (top stage)
  - Filter #7 – Marionette
  - Recoil Mass – Mirror
- Several sensors distributed along the whole chain:
  - 5 accelerometers on top stage
  - 14 position sensors
  - Payload coarse local position readout via CCD camera
  - Marionette and mirrors fine local position readout via optical levers
- Digital control system using DSP processors



Local Controls

- **Feedback loops using measurements provided by local sensors**
  - **Top stage inertial control (Inertial Damping)**
    - **Reduction of payload free motion**
    - **Always active**
  - **Payload local control**
    - **Positioning along a local reference frame**
    - **Damping of payload modes**
    - **Active only with interferometer unlocked**

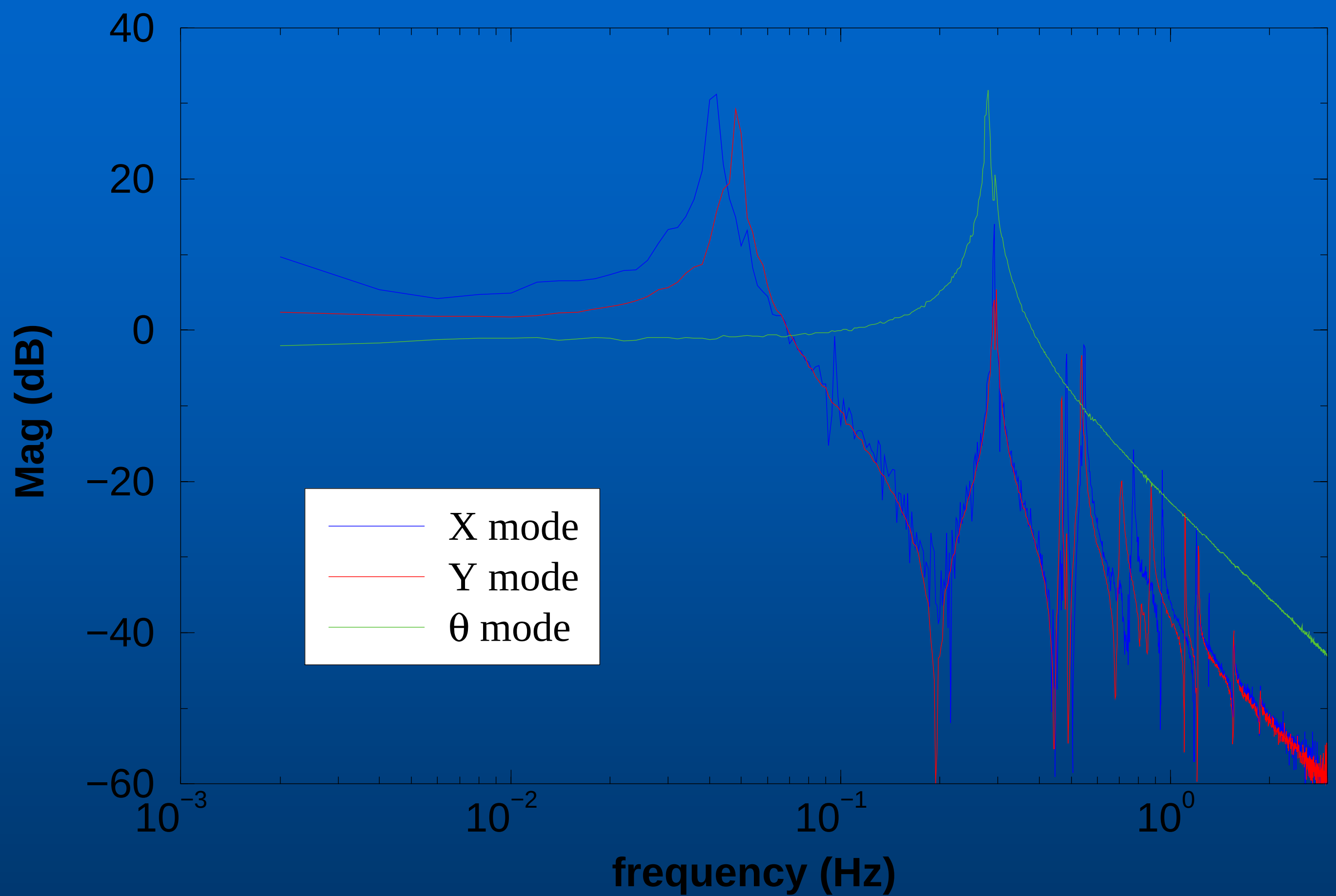
Global Controls

- **Feedback loops using measurements provided by photodiodes readout system**
  - **Active when interferometer is locked**
  - **Payloads longitudinal position control (Locking)**
  - **Payloads angular position control (Automatic Alignment)**
  - **Position error signals computed by a single processing unit and distributed to suspensions using fiber optics connections**

Local Controls: Inertial Damping

- **Inertial sensors (accelerometers):**
  - **DC-100 Hz bandwidth**
  - **Equivalent displacement sensitivity: 10^{-11} m/sqrt(Hz)**
- **Displacement sensors LVDT-like:**
  - **Used for DC-0.1 Hz control**
  - **Sensitivity: 10^{-8} m/sqrt(Hz)**
  - **Linear range: ± 2 cm**
- **Coil magnet actuators:**
  - **Linear range: ± 2 cm**
  - **0.5 N for 1 cm displacement**
- **Loop unity gain frequency:**
  - **5 Hz**
- **Sampling rate:**
  - **10 kHz**

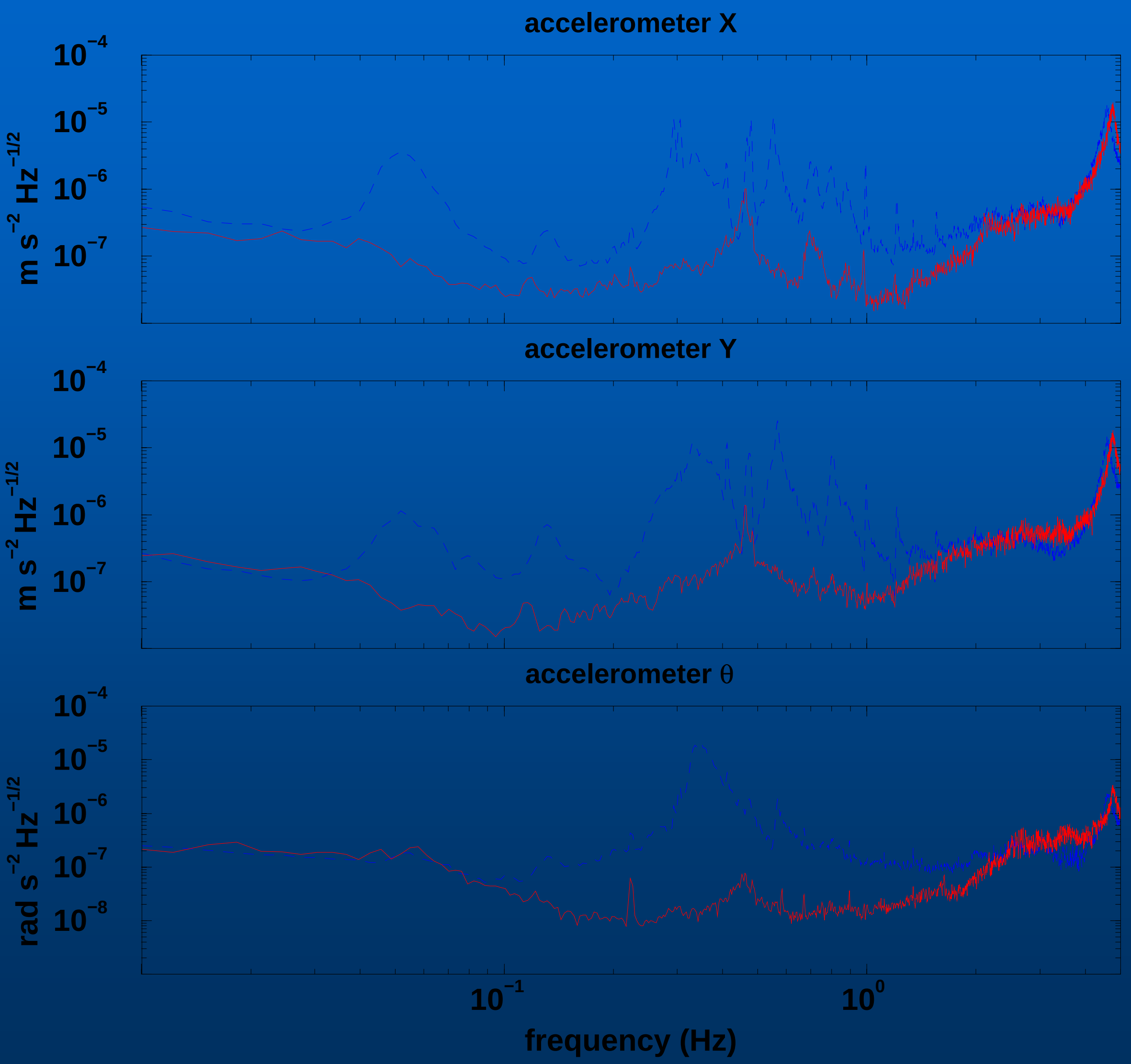
Inertial Damping (II)

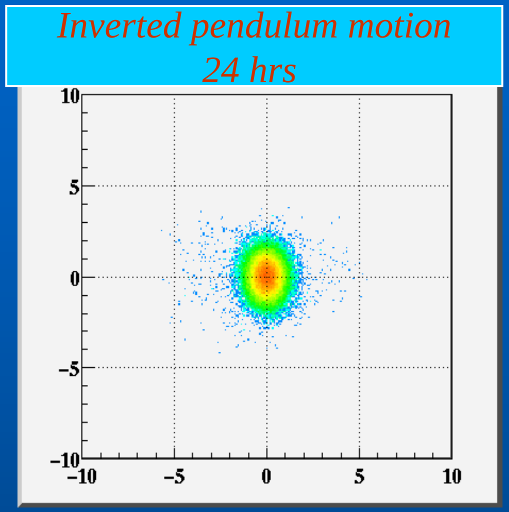


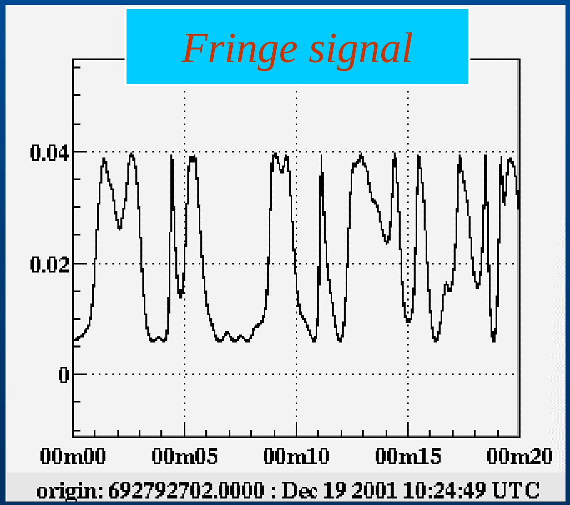
- **Complex transfer functions**
- **Diagonal dominance achieved using static sensing and driving matricies**

I.D. Performances

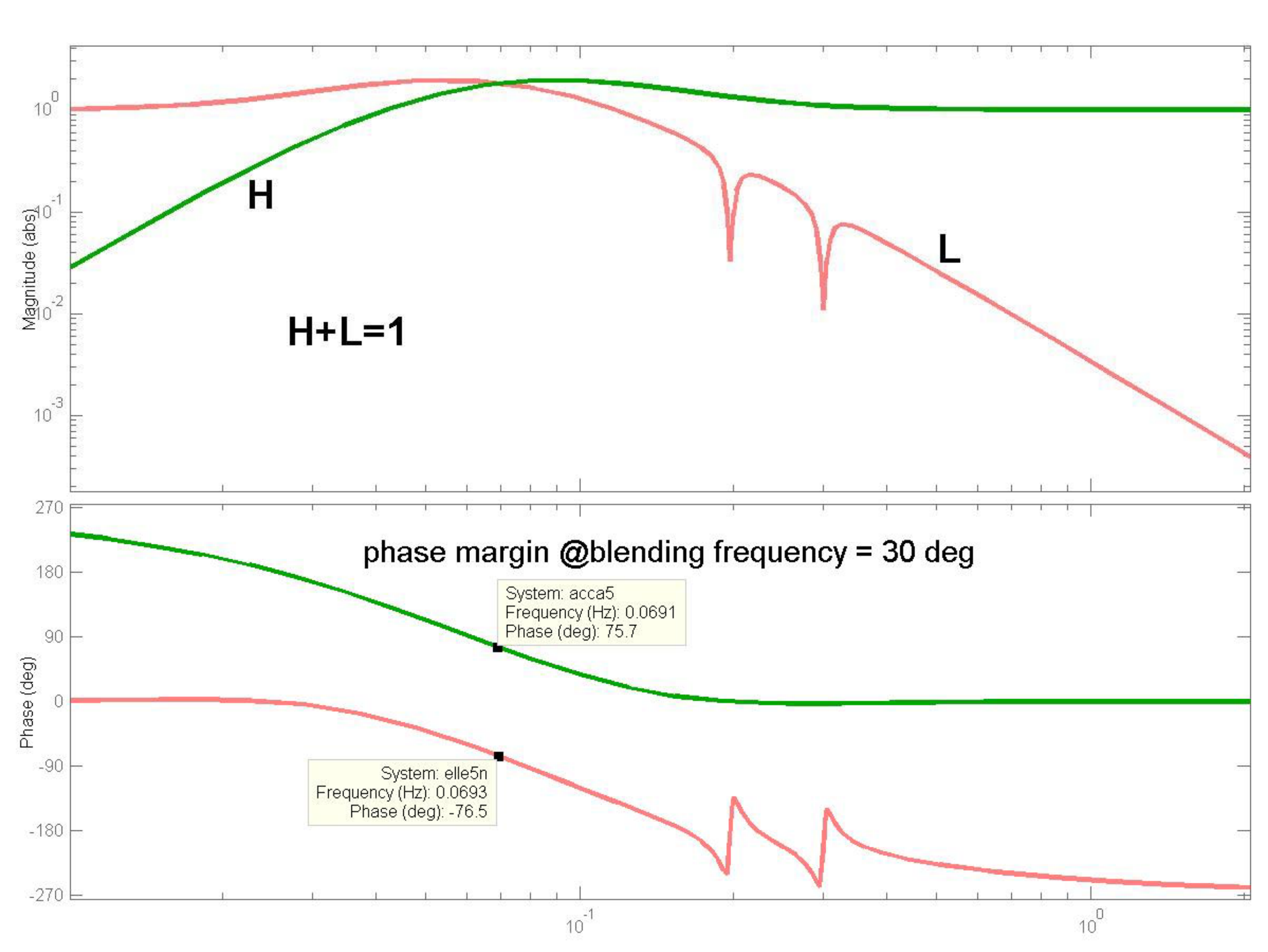
- 1 um relative displacement
- 0.25 um/sec relative speed







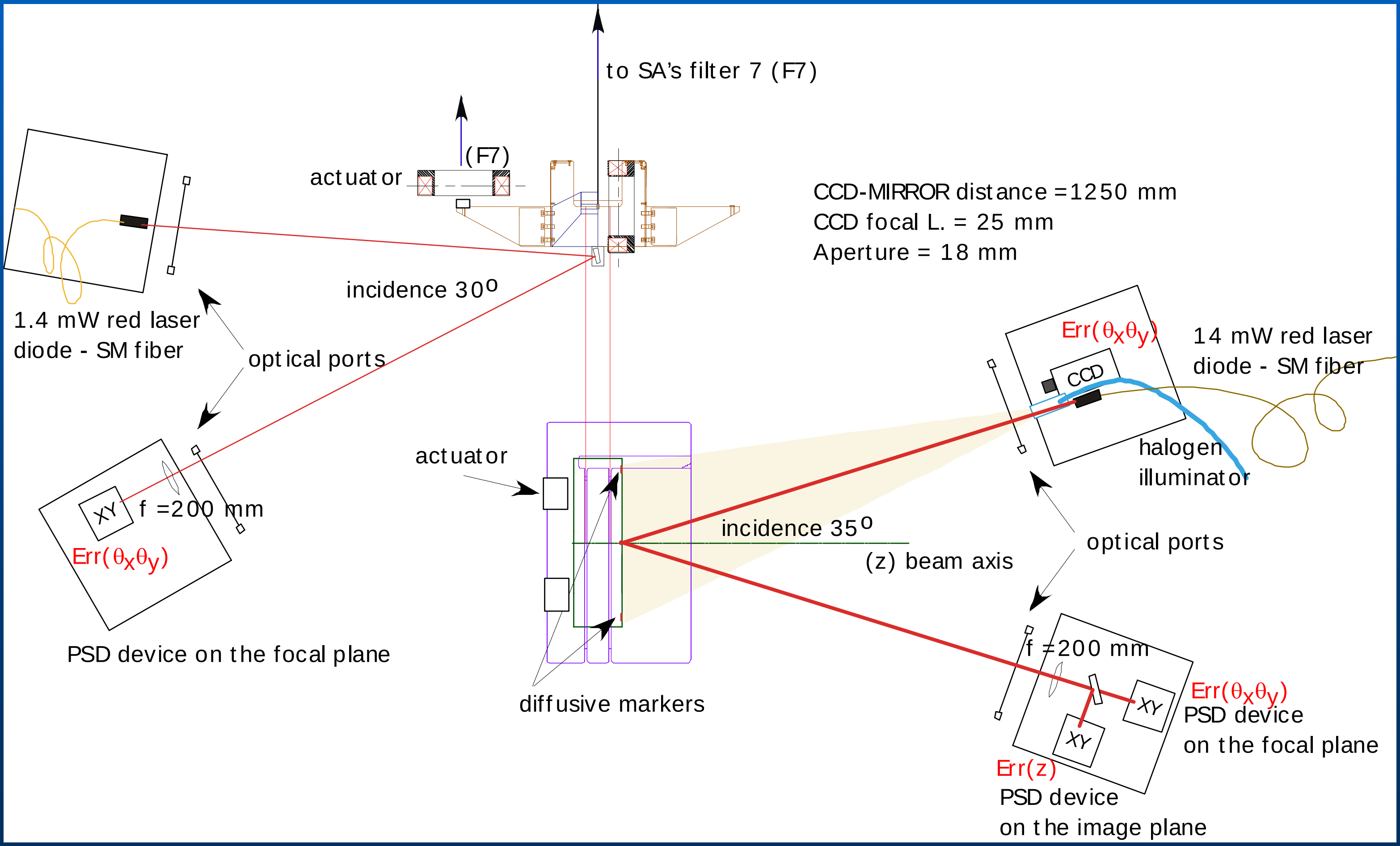
I.D. Blending Filters



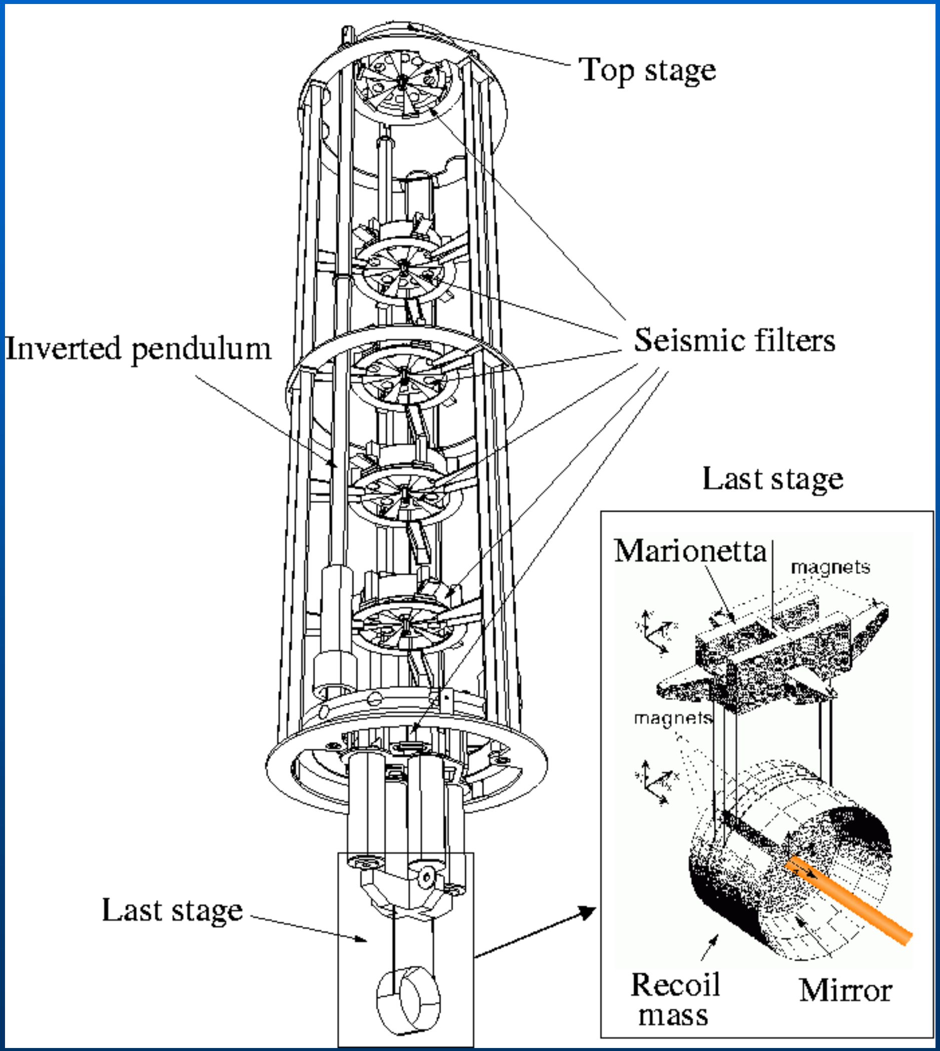
$$\frac{a}{s^2}\cdot H + l\cdot L \;=\; x - L\cdot x_0$$

Local Control: Payload

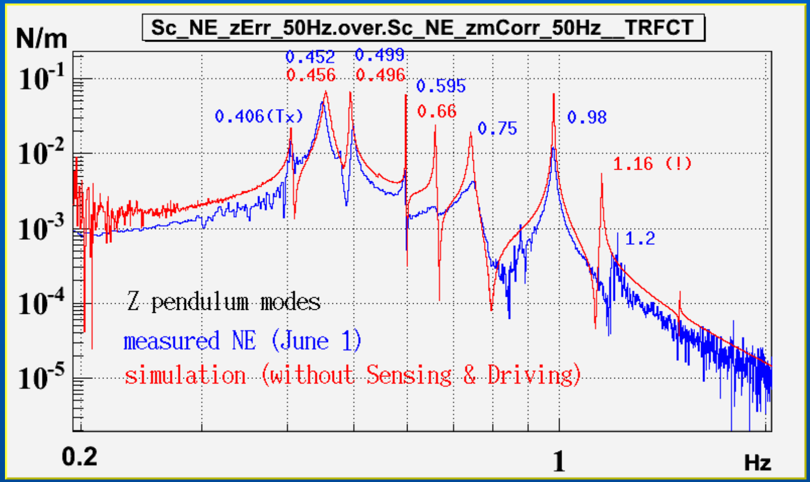
- **Optical levers read both the mirror and the marionette**
- **Marionette position readout allows larger bandwidth control loops**

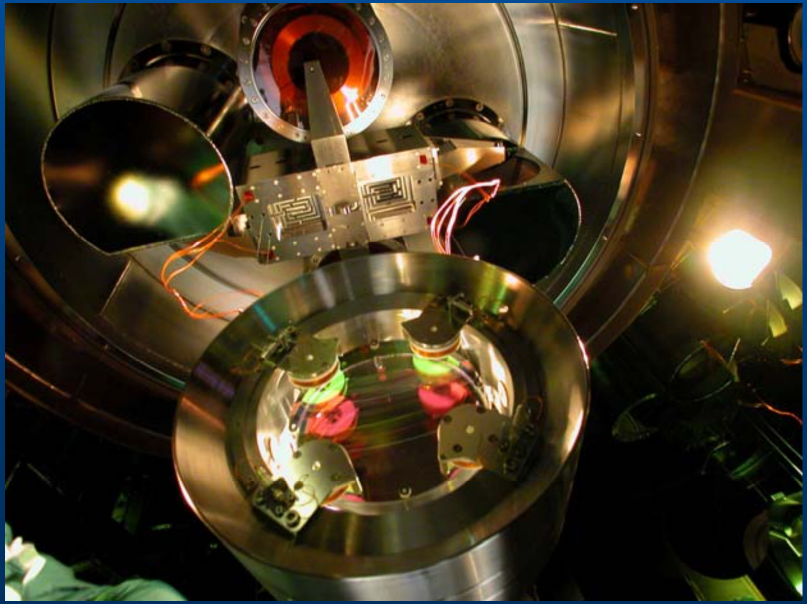


Payload Local Control



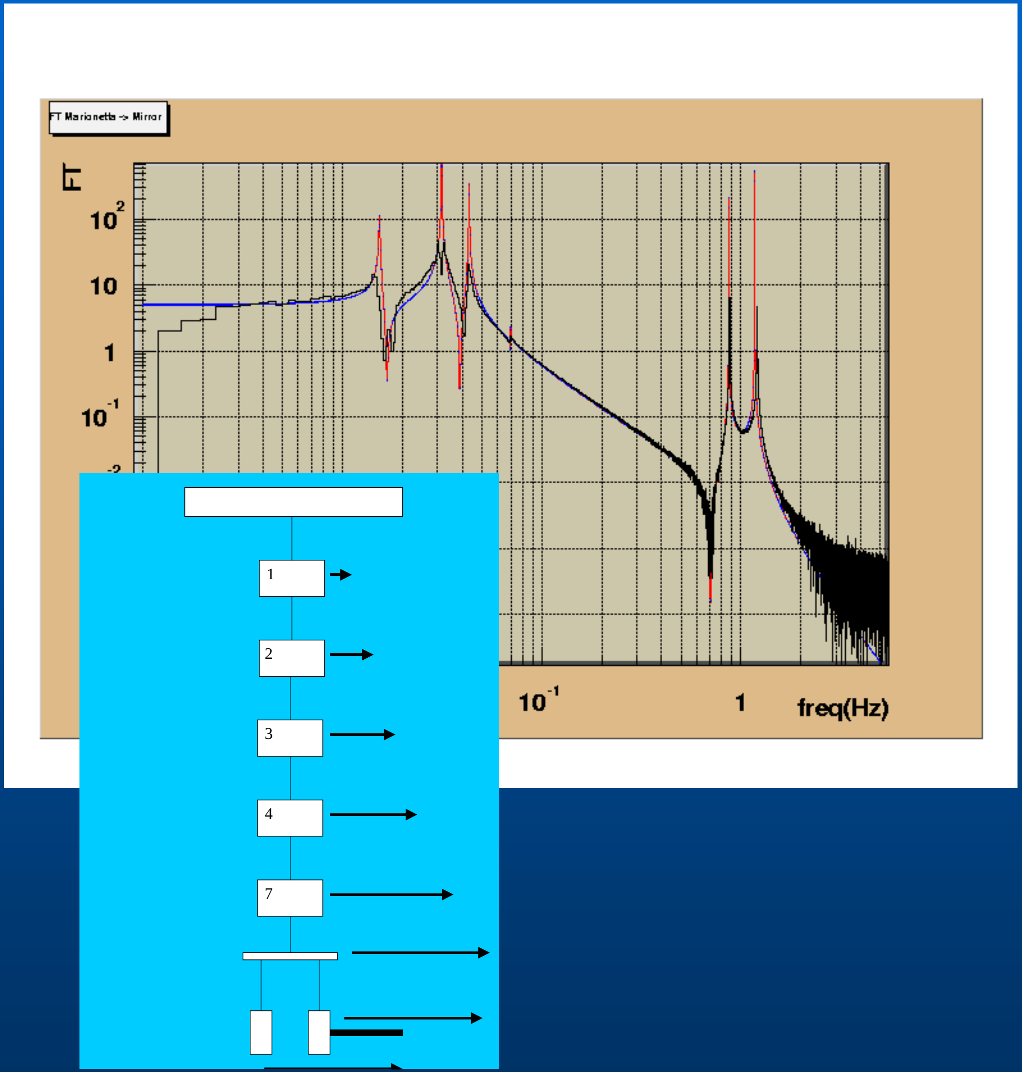
- Very complex dynamics



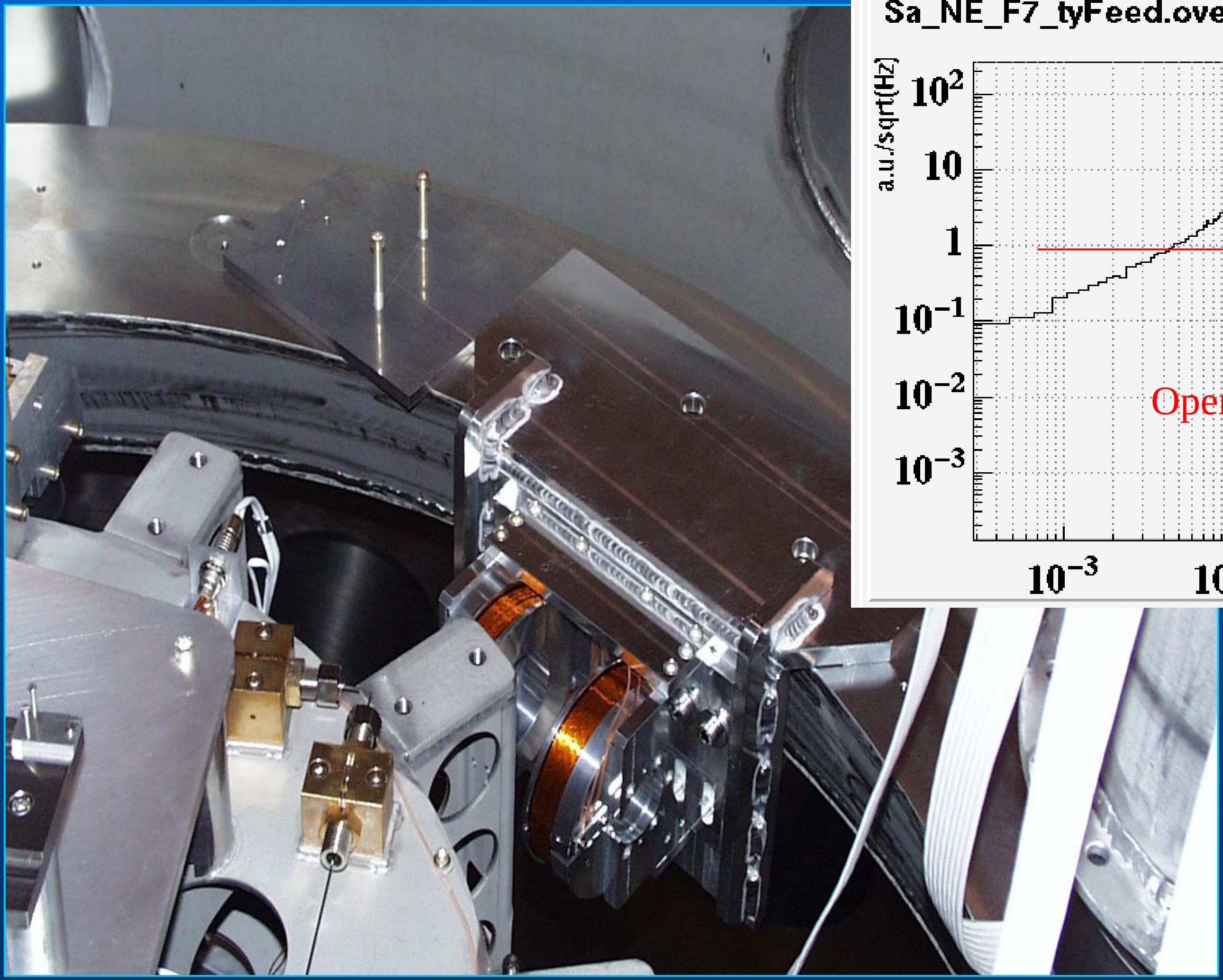


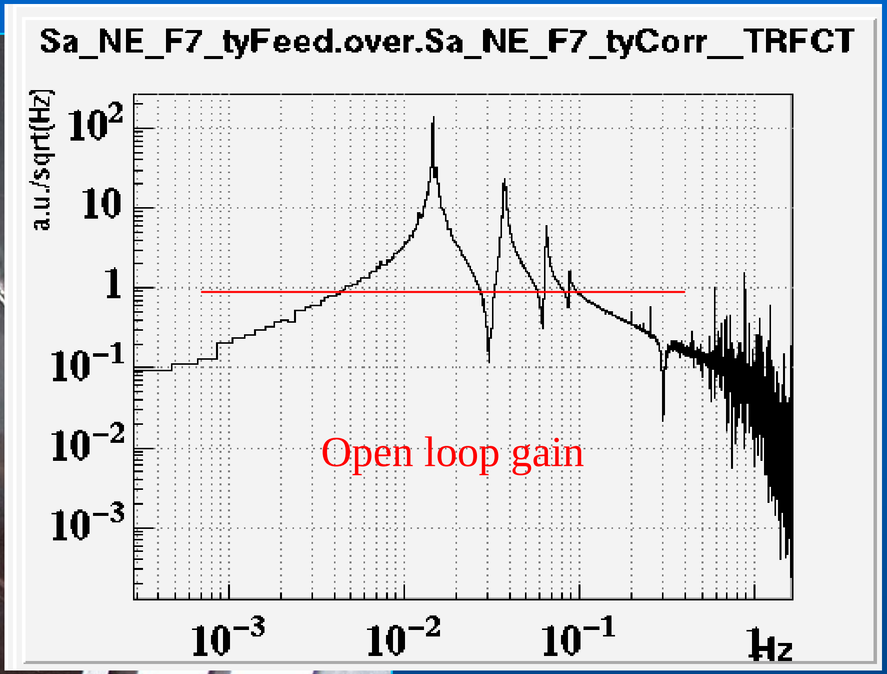
Local Controls: Filter #7

- 16 mHz “chain” mode gets excited when marionette horizontal coils are involved.
- Long decay time, large elongation.
- Impossible to damp it from top stage
- It can be damped acting on Filter #7



Filter #7 Damping





Velocity feedback

Global Control

- **Required locking accuracy:**
  $dL \approx 10^{-12}$ m
- **Tidal strain over 3 km:**
  $dL \approx 10^{-4}$ m
- **Wide dynamic range to be covered without injecting actuation noise.**
- **Hierarchical Control**
  - **3 actuation points**

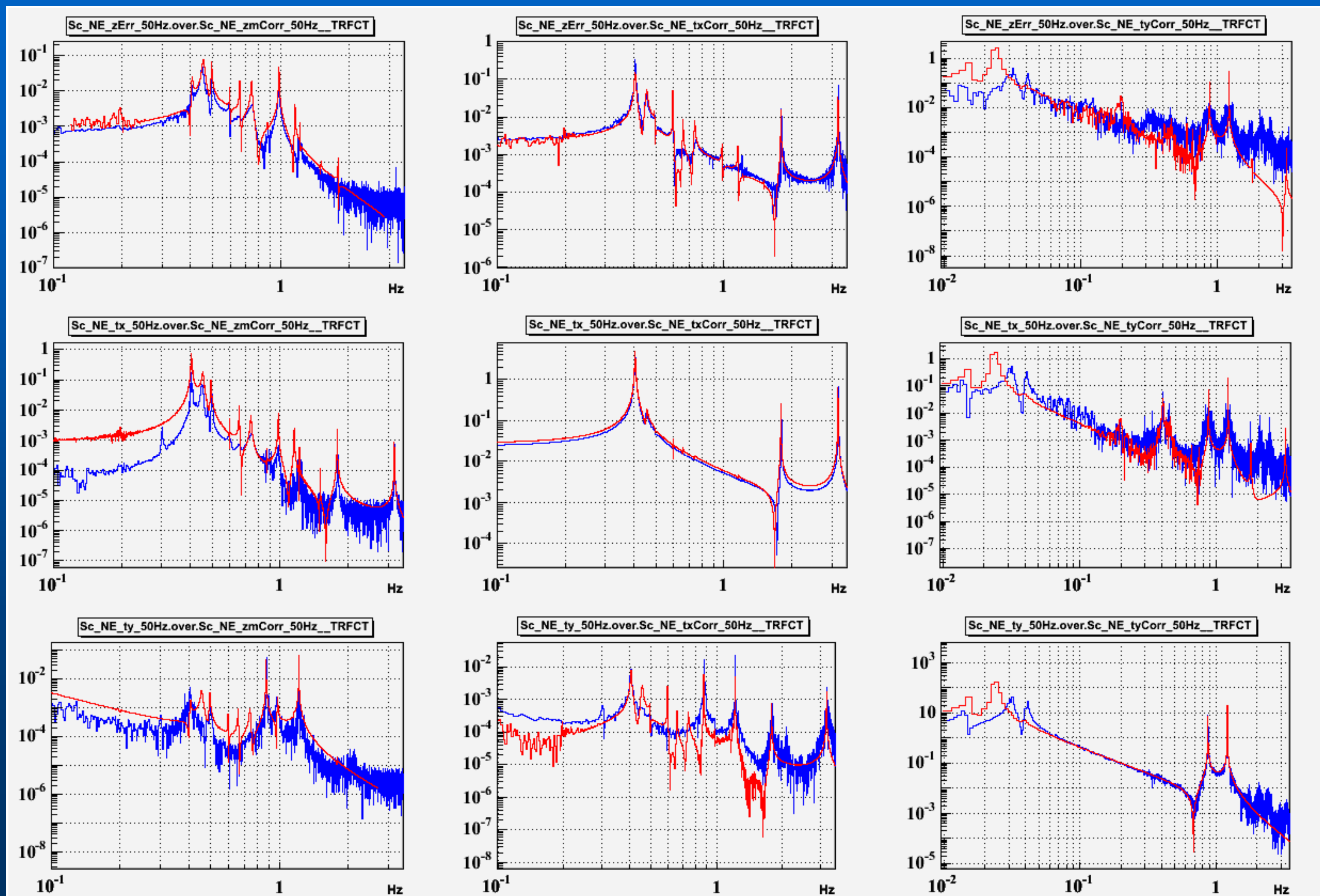
Marionette Transfer Functions

F_z M_x M_y

z

θ_x

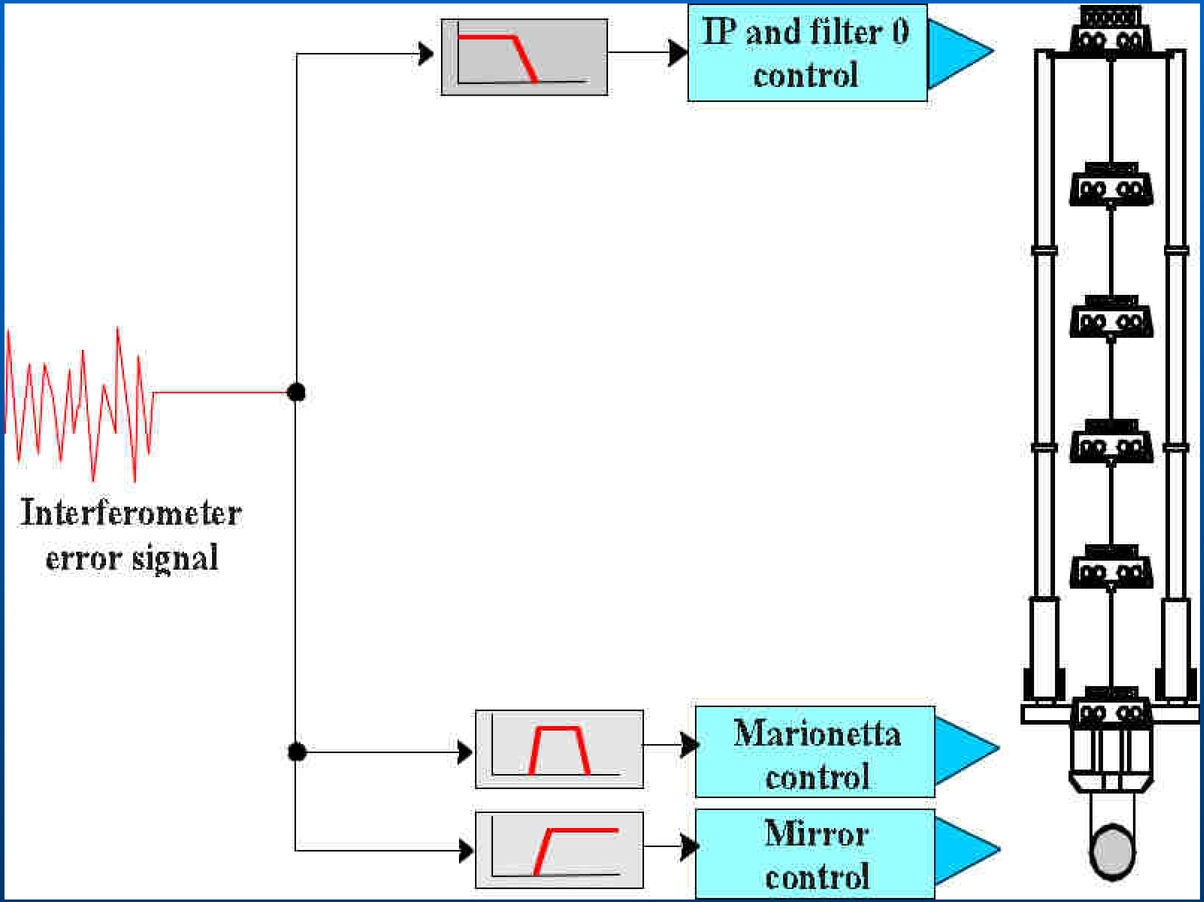
θ_x



Lock Acquisition

- **Coil-magnet pair actuators steering VIRGO optical elements need a wide dynamical range due to the big force impulse required for acquiring the lock of VIRGO optical cavities→**
  - **The DAC dynamical range (17.5 effective bits, 105 dB SNR) is not large enough.**
- **Solution**
  - **Use of 2 DAC channels**
    - **DAC #1 for lock acquisition when the large force impulse is required**
    - **DAC #2 for linear regime when low noise is required**
  - **Use of two different coil drivers for the two DAC channels**
    - **HighPower (up to 2A output current)**
    - **LowNoise (programmable max output current)**

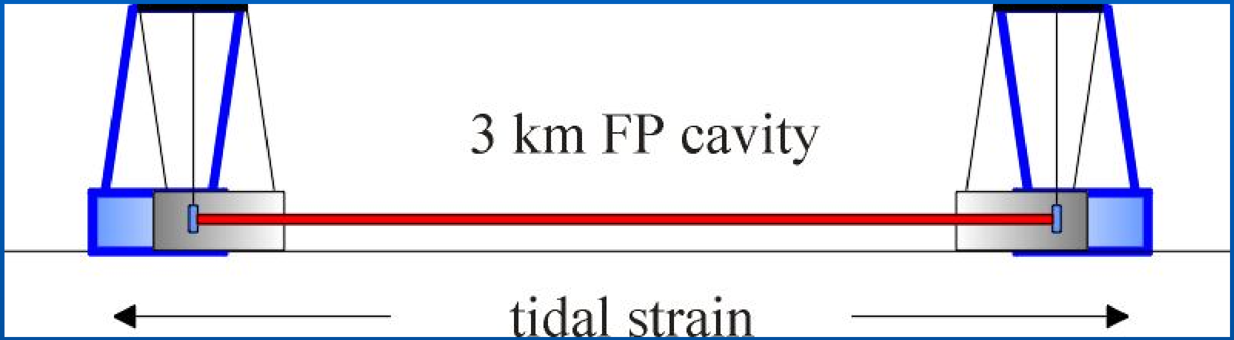
Hierarchical Control

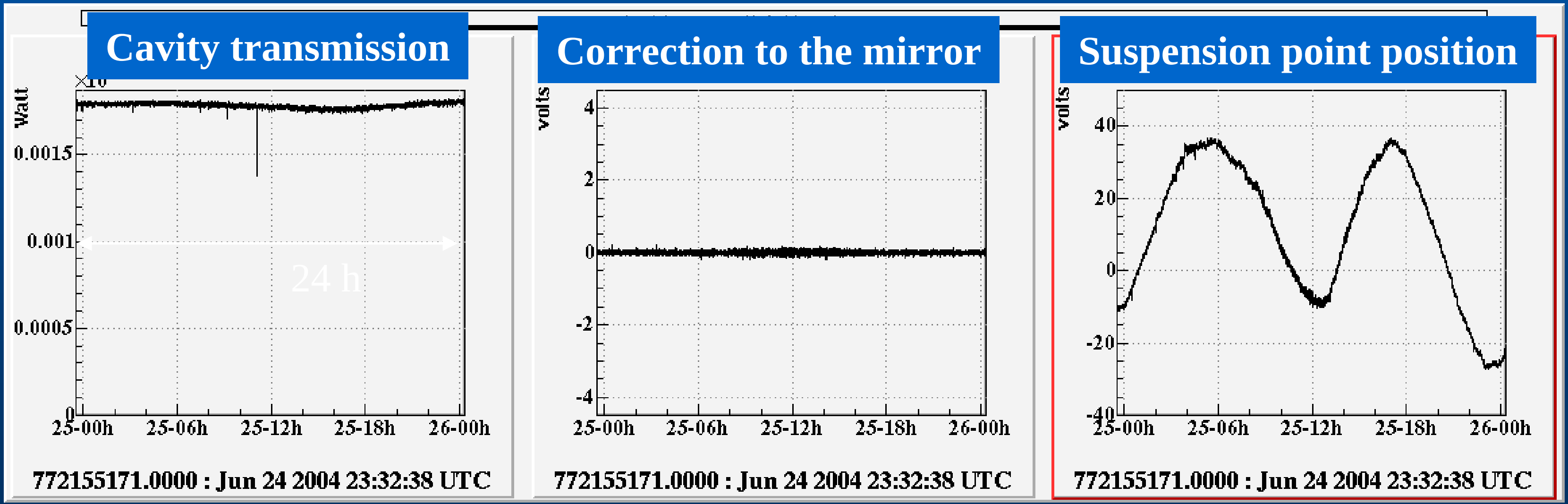


- Tide compensation (low frequency drifts) is applied on Superattenuator top stage
- Marionetta and mirror actuation controls payload normal modes

Tide Control

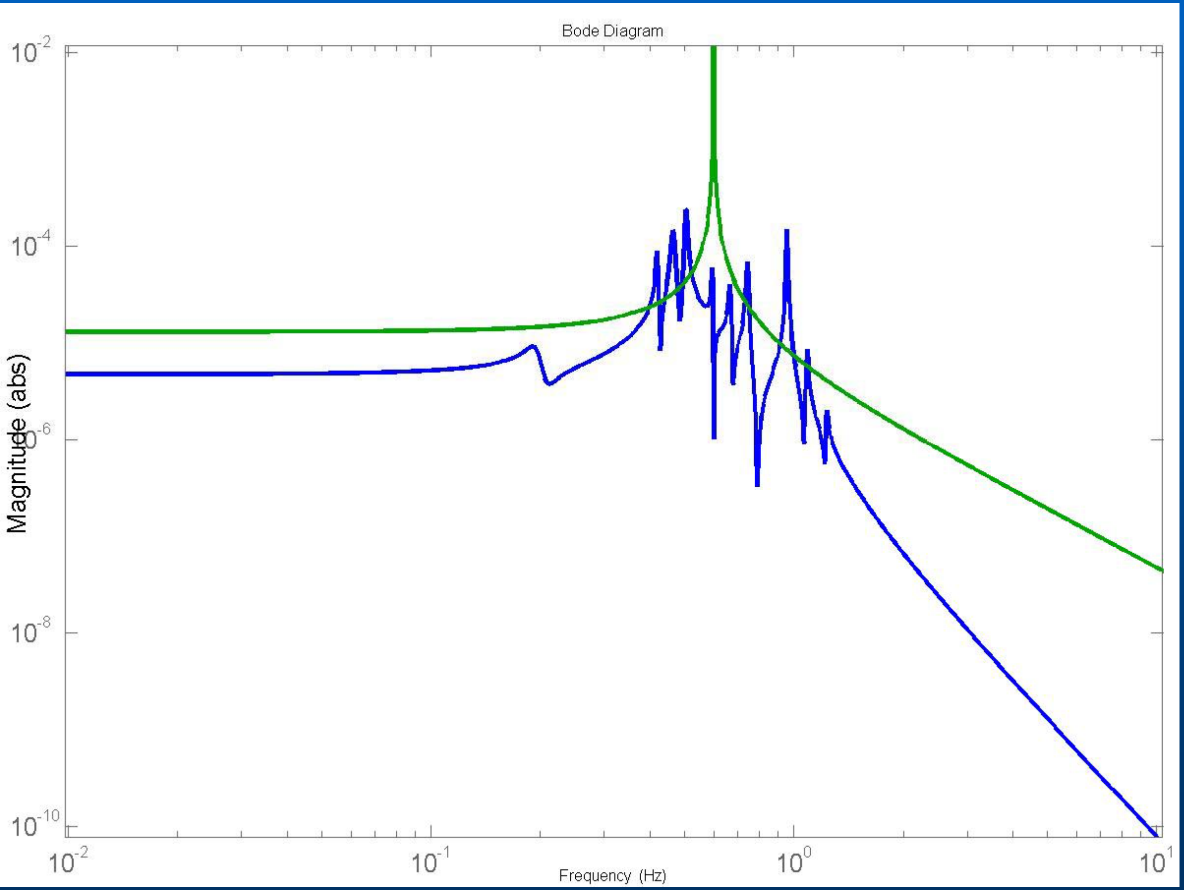
- **Low frequency (< 10 mHz) part of z error signal is sent to top stage (IP) actuators**



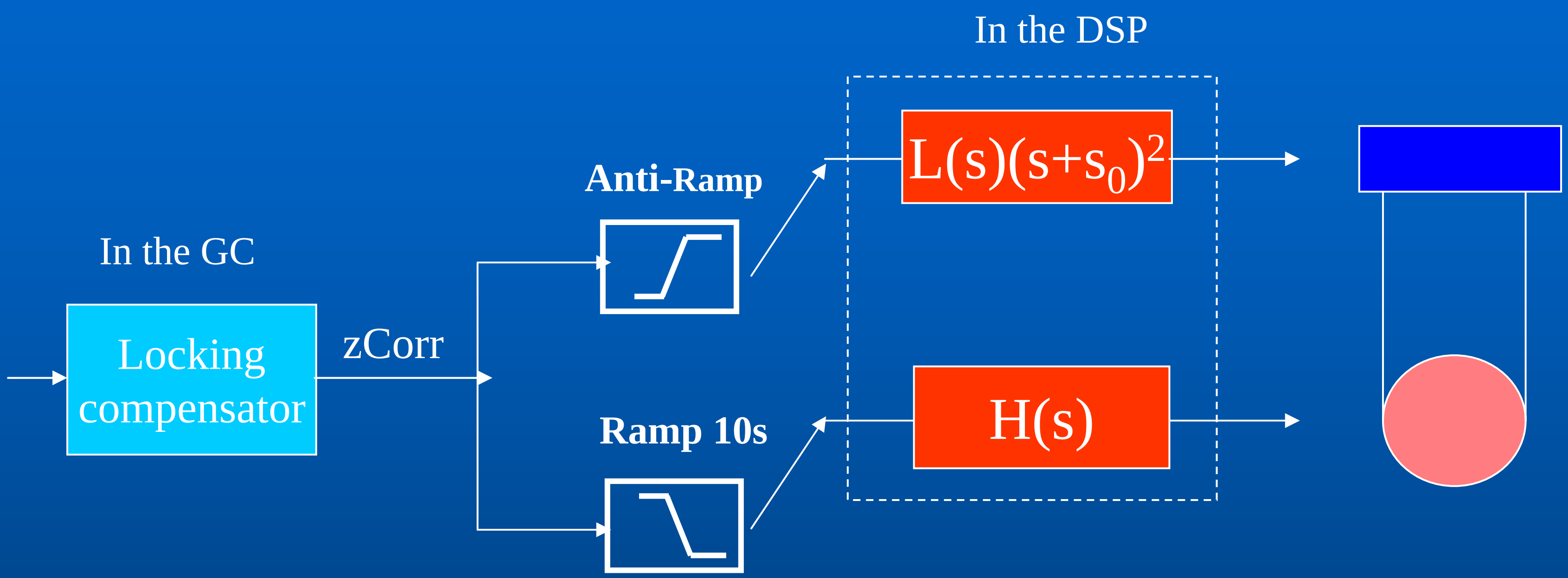


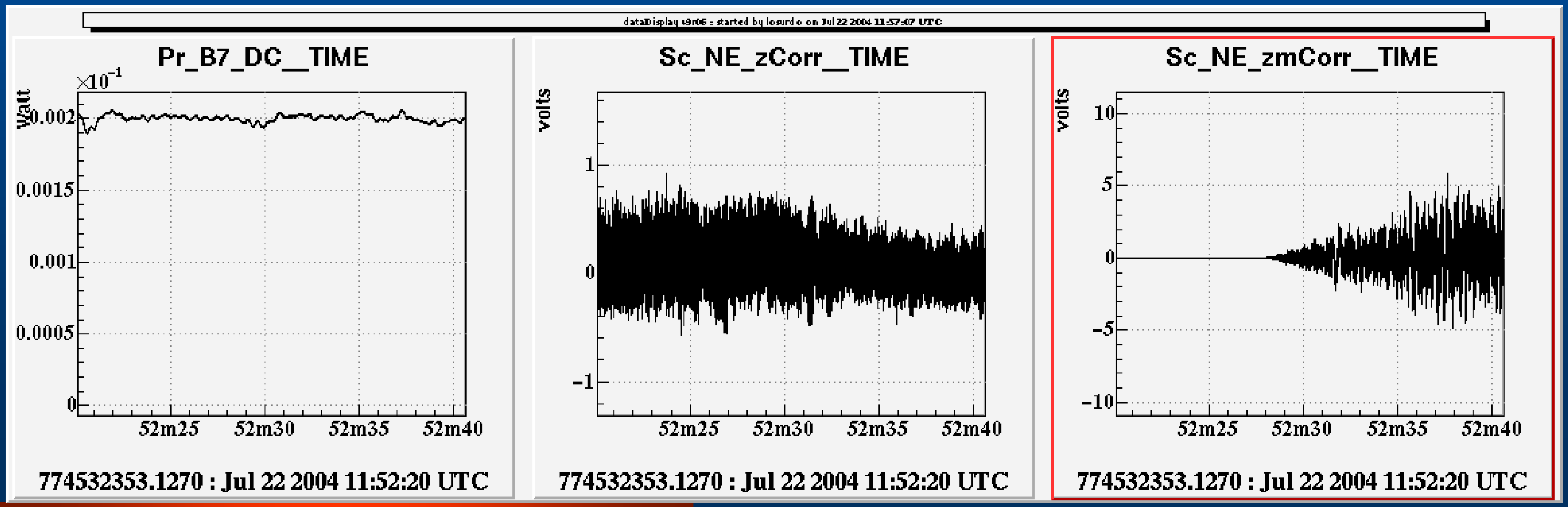
Marionette and Reference Mass – Mirror TF

- **Acting on Marionette from Filter #7, Superattenuators modes are excited**
- **Acting on Mirror from Reference Mass only one longitudinal mode is excited.**



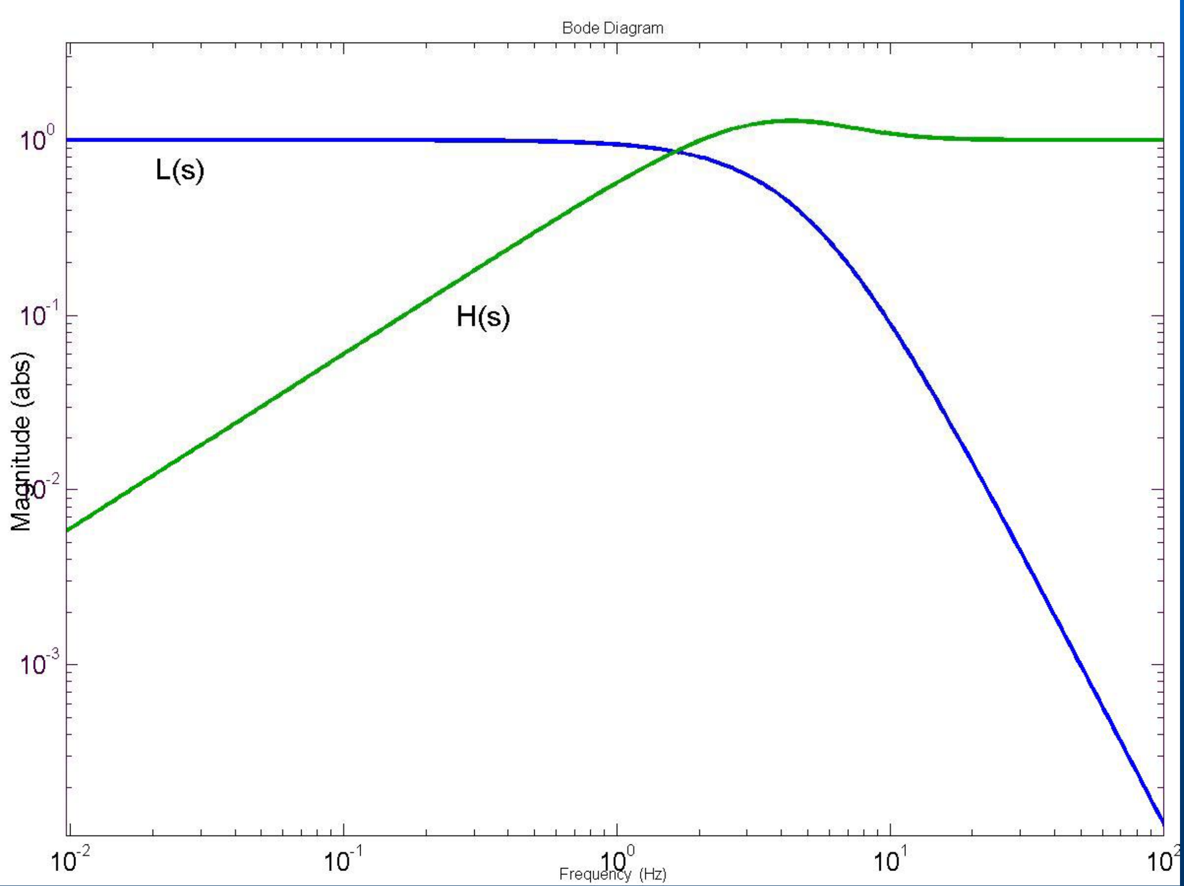
Force re-allocation





Marionette – Mirror Blending

- L(s) = 3rd order low pass filter, H(s) = 1-L(s)
- Force applied on mirror from reference mass is high-pass filtered while force applied on marionette from filter #7 is lowpass filtered

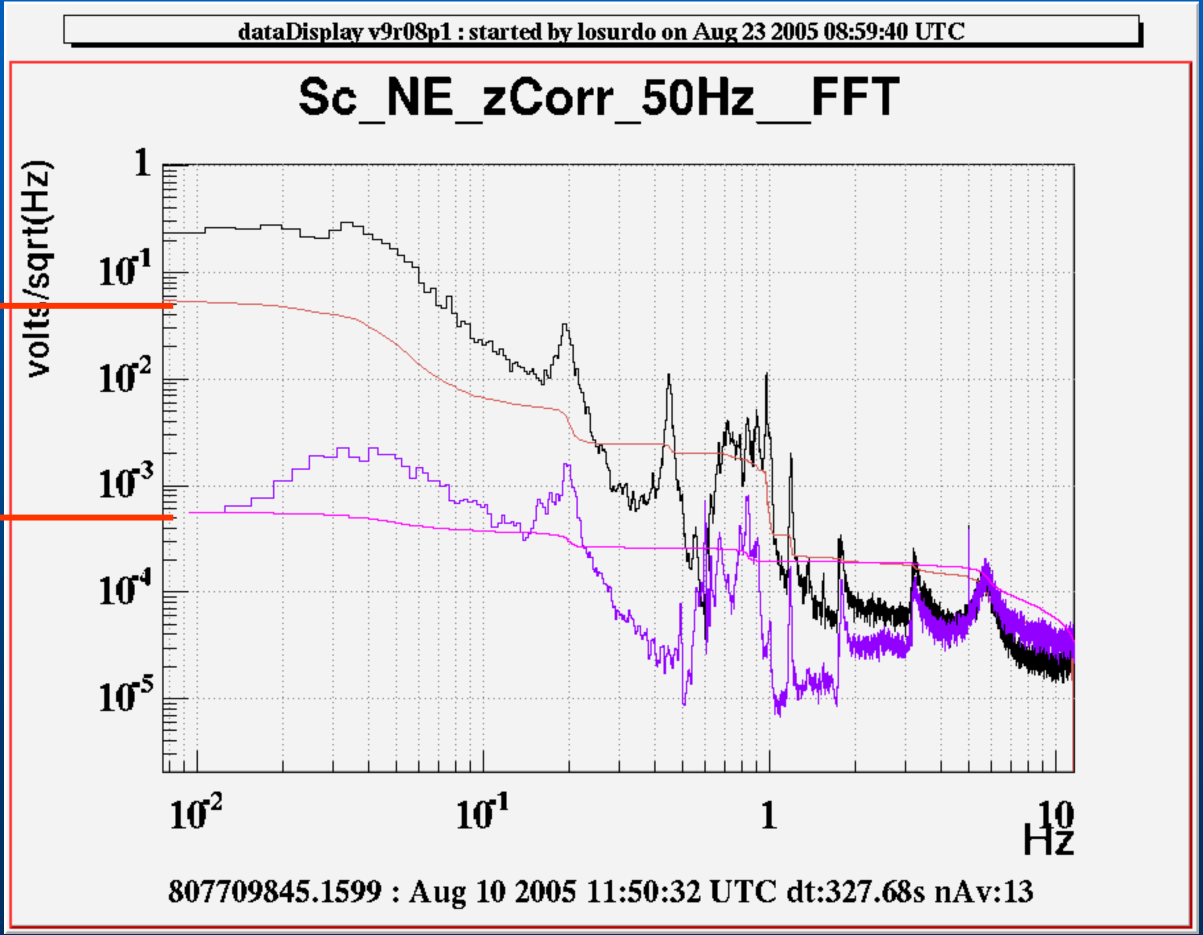


Force on Mirror

- Marionette/RM crossover @5 Hz
- After reallocation zCorr rms reduced by a factor 100

Without marionette
700 nm rms

Without marionette
7 nm rms



Conclusion

- **Superattenuator Controls**
  - **Even if basic control strategies has not change during the last few years, feedback loops compensators are keeping on changinng to improve controls performances.**
  - **Possibility to adapt compensator to specific states of the interferometer has shown to be a key feature. Re-allocation of forces along the chain allows easy lock acquisition and good performances in linear regime.**
  - **Control strategies, expecially for lower stage, are continuosly upgraded.**
  - **Powerful and flexible digital control system is a must. (See next talk)**