Requirements

- Environment and constraints
- Performance requirements
- Functional requirements
Environment

- Seismic spectra at observatories somewhat quieter than anticipated at GW frequencies
- In excess by factor 3-10 at lower frequencies
- Steady-state spectrum noisier by ~10x at LLO
- Highly non-stationary
‘Standard’ seismic spectrum
Daily variability

red = Livingston, green = Hanford
Impulsive nature

LHO  LLO

Seismic Noise at Hanford during E4 – Saturday 12–May–2001

Seismic Noise at Livingston during E4 – Saturday 12–May–2001
Top-level performance requirements

● **Objective:**
  » To reach the SRD sensitivity,
  » With the prescribed interferometer duty cycle,
  » Given the present seismic environment and detector components.

● **Constraints**
  » The transfer function, and especially the resonant character, of the initial LIGO seismic isolation system.
  » The pendulum transfer function – assume $1/f^2$
  » The finite dynamic range of the suspension controller coil drivers –
    – 100 micron pk-pk range in “acquisition mode”; in “run mode” 20 micron pk-pk authority below the pendulum resonant frequency; and $5e-20$ m/$\sqrt{\text{Hz}}$ noise performance at 40 Hz on the optical axis (local longitudinal damping turned off)

● **Need:**
  » Significant reduction in the uncontrolled velocity of the suspended optics in the ‘control’ band (frequencies less than 40 Hz)
Science Requirements Document

Sensitivity

![Sensitivity Graph](image)

- Initial LIGO Target (SRD)
- Frequency (Hz)
- $x (m/\text{Hz}^{1/2})$
- $x (m/\text{Hz}^{1/2})$ vs Frequency (Hz)
- Seismic
- Thermal
- Shot
Functions

● The external pre-isolator will
  » Provide coarse positioning of the seismic load
  » Compensate for tidal motions (6 and 12 hour periods) and quasi-static alignment offsets (replacing this function of the original initial LIGO PZT fine actuator)
  » Compensate for the ~6 second period microseismic motion (replacing this function of the original initial LIGO PZT fine actuator)
  » Reduce the input seismic motion in the region of the stack solid-body resonances, especially 1-3 Hz to a level permitting performance according to the SRD

● The internal damping system will
  » Damp the solid-body resonances of the initial LIGO seismic isolation system, in particular from 1-3 Hz
External Pre-Isolator performance requirements

- **Basic tenets:**
  - The pre-isolator must not increase the present noise in the GW-band, and
  - Must bring the day LLO environment to the level of the LHO night environment.

<table>
<thead>
<tr>
<th>Frequency Range</th>
<th>Stability Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 month 100 seconds</td>
<td>10 microns pk-pk 1 micron pk-pk</td>
</tr>
<tr>
<td>0.16 Hz</td>
<td>4e-7 m/√Hz</td>
</tr>
<tr>
<td>1 Hz</td>
<td>1e-9 m/√Hz</td>
</tr>
<tr>
<td>10 Hz</td>
<td>4e-10 m/√Hz</td>
</tr>
<tr>
<td>15 Hz 30 Hz 50 Hz and higher</td>
<td>2e-10 m/√Hz 6e-11 m/√Hz 2e-11 m/√Hz</td>
</tr>
</tbody>
</table>
Daily variability – and requirement
Internal Stack Damping performance requirements

- **Basic tenets:**
  - The internal stack damping system must not contribute more than 1/10 of the seismic noise in the GW band, and
  - Must reduce the targeted stack mode peaks by a factor of 10 (from ~30 to ~3)

- **BSC noise requirements:**
  - Horizontal: $1.2 \times 10^{-13} \text{ m/} \sqrt{\text{Hz}}$ at 20 Hz, $2.5 \times 10^{-17} \text{ m/} \sqrt{\text{Hz}}$, $\geq 50 \text{ Hz}$
  - Vertical: $5 \times 10^{-13} \text{ m/} \sqrt{\text{Hz}}$ at 20 Hz, $1 \times 10^{-16} \text{ m/} \sqrt{\text{Hz}}$, $\geq 50 \text{ Hz}$

- **HAM noise requirements:**
  - Horizontal: $4 \times 10^{-12} \text{ m/} \sqrt{\text{Hz}}$ at 20 Hz, $2.5 \times 10^{-16} \text{ m/} \sqrt{\text{Hz}}$, $\geq 50 \text{ Hz}$
  - Vertical: $2 \times 10^{-11} \text{ m/} \sqrt{\text{Hz}}$ at 20 Hz, $1 \times 10^{-15} \text{ m/} \sqrt{\text{Hz}}$, $\geq 50 \text{ Hz}$
Pre-Isolator: Notes

- Dynamic range: to handle microseismic and tidal input
  - 260 µm tidal differential, 40 µm microseismic, 300 µm total
  - Must be able to perform all correction from End Mass
  - Goal of 1 mm
  - Coarse positioning through shimming, etc.
- 6 DOF to allow pitch, yaw correction
- Must survive moderate earthquakes
- Installation:
  - The BSC EPI is to fit into the space between the support piers and the spherical knuckle attached to the crossbeam
  - Must allow installation without disturbing optic alignment
- The design must assure that no oils or lubricants will be released in the vicinity of the vacuum equipment
- The design must not create magnetic fields at a level which leads to noticeable test mass disturbance
- The EPI must interface via the observatory installed data acquisition system and EPICS control system
Internal Stack Damping: Notes

- Dynamic range: guarantee of no interference
  - Normal motion
  - Moderate earthquakes
- Must be capable of 6 DOF; but will target specific modes (e.g., 1.2, 2.1 Hz in BSC)
- Installation:
  - Must use existing structures and points of attachment
  - Must allow installation without disturbing optic alignment
- In-vacuum components:
  - Must obey (the usual) strict Class-A vacuum requirements (materials and preparation)
  - Must protect against overheating (outgassing)
  - Reliability requirements: 10 years MTBF
- The design must not create magnetic fields at a level which leads to noticeable test mass disturbance
- No interference with installed optical systems (main, ghost, optical lever)
Requirements: to be done

- Characterization of initial LIGO stacks
- More complete statistical analysis of noise at both sites
- Interpretation in terms of gain profile, availability

- Anticipated that this information will refine design, loop parameters, not change the conceptual design