Low frequency noise mitigation by inter-platform control

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From 2nd to 3rd generation

- Noise must be lower by ~ six orders of magnitude
- Underground site and passive isolation by modified super-attenuator transmissibility is theoretically sufficient for length to length coupling
  - 17 m height
  - 6 magnetic anti-spring filters
  - Equally spaced
- **But**: Control noise of auxiliary control loops and scattered light has been a noise source in the detection band
- Filters cannot roll off arbitrarily steep

**Active isolation required below suspension resonances**

Figure 6.11: A comparison between the performance of the LIGO and Virgo instruments during the O3 observing run and the ET design sensitivity. The coloured windows show the important frequency regions, and the arrows show the regions where ET must have improved performance in order to reduce the corner-frequency of the ‘seismic wall’.

Sina Maria Köhlenbeck - 11th ET Symposium
Control noise dominates the ‘known’ noise below 50 Hz

LHO O3 noise budget, S. Dwyer LHO log 55755

Noise budget for GPS start time: 1268679618, duration: 600s

- Measured noise
- Sum of estimated noises
- Quantum noise
- Thermal noise
- Seismic and newtonian noise
- SRC length noise
- MICH length noise
- PRC length noise
- Alignment control noise
- Beam jitter
- Laser frequency noise
- Laser intensity noise
- Photo-detector dark noise
- OMC length noise
- Residual gas noise
- OSEM DAC noise
- PUM DAC noise

Research for aLIGO is ongoing to address noise below 50 Hz

Slide from: Brian Lantz
LVK meeting on Sept 15, 2020
LIGO DCC: G2001539
Active platform for mirror suspension

Pre-isolation platform at “Filter 0”
- Inertial sensors for active isolation
- Actuators for position control

Inertial isolation effective above ~ 100 mHz
- Tilt to horizontal coupling
- Suspension thermal noise

Underground seismic noise is lower, sensor sensitivity needs to scale with it!
Inertial isolation vs. differential control

Figure of merit:

**Interferometer displacement below GW band**

- Differential length control of main interferometer optics
  - Test masses
  - Beam splitter
  - Recycling cavities
- Can use interferometer signal during operation
- Use additional sensors for differential displacement of suspension points

Figure 6.3: Simplified sketch of the ET low and high frequency interferometers of a single ET-detector.
Suspension point stabilization

Arm cavities:
- No clear line of view
- Need to get near the beam line
- Periscope at inner structure, but:
  - Cryogenic-shield in the way
  - Tilt read-out required
- Angular stabilization to reduce control bandwidth on angular interferometer control loops

Stabilize at a platform supporting the suspension structure
Stabilization in central cavern

Interferometer between suspension points
- Additional tubes in central cavern are a possible
- Alternative: Platform at beam level

Suspension point control:
- Use Input test masses as virtual reference points
- Consecutively stabilize optics along the input beam line:
  - Folding periscopes
  - Power and signal recycling mirror
- Mode cleaner?
- Filter cavities?
Auxiliary optics

Auxiliary control loop can pollute interferometer output

- Unity gain frequency up in the 10\textsuperscript{th} of Hz, to provide sufficient suppression of low frequency motion
- Noise from modulated scattered light

Auxiliary optics on suspended benches:

- Use beamline level to stabilize between platform
- Tilt sensing for pitch and yaw control

Albert-Einstein-Institute (AEI) 10m-Prototype has tested a pre-stabilization scheme

Class. Quantum Grav. 36 (2019) 075007, J V van Heijningen et al
Technology demonstrator AEI 10m-Prototype

Large facility similar to gravitational wave detector and designed for prototyping

Passive and active seismic pre-isolation by AEI-SAS (similar to Virgo’s EIB-SAS)
- Passive filtering by Inverted-Pendulum legs and Geometric-Anti-Spring filter
- Active control with inertial sensors: geophones and accelerometers
Interferometer for active differential length control

Data acquisition and control

Phasemeter

Graph: Displacement (m/√Hz) vs. Frequency (Hz)
- Uncontrolled inter-platform displacement
- Controlled inter-platform displacement
- Out-of-loop inter-platform displacement
- Interferometer noise floor
Platform stability ≠ suspension point stability
Suspended cavity as sensor

Measure frequency noise

Match laser frequency to resonator length

Mode cleaner length must follow laser frequency
Demonstration of suspension point stabilization
Demonstration of suspension point stabilization

Noise mitigation depends on: geometry, sensor and actuator position!
Work closely with other groups.
What we want:

- Low noise due to high signal-to-noise of optical sensor array.
- No excess noise from auxiliary control loops and stray light.
- Angular interferometer control unity gain set by Sidles-Sigg instability.
- Active stabilization to assist lock acquisition and reduce dynamic range.

Focus on ET-LF but applicable to ET-HF as well.