Measurements of Environmental Coupling to the Gravitational Wave Channel (PEM Injections)

Robert Schofield (Oregon)

Aleksandr Ageyev (Syracuse)
Masahiro Ito (Oregon)
Brian O'Reiley (LLO)

PURPOSE:

Get a rough idea of the coupling between environmental signals and the GW channels using PEM sensors in the data system. This coupling changes with interferometer configuration so inject during run.

Collect data for setting veto thresholds based on PEM channels

PROGRAM:

Inject magnetic, RF, acoustic, and seismic signals loud enough to be seen on GW channels.

Inject lines and bursts

Simulate potential environmental siganls

Inject at multiple locations

LIMITATIONS:

About 4 hours of good interferometer running time

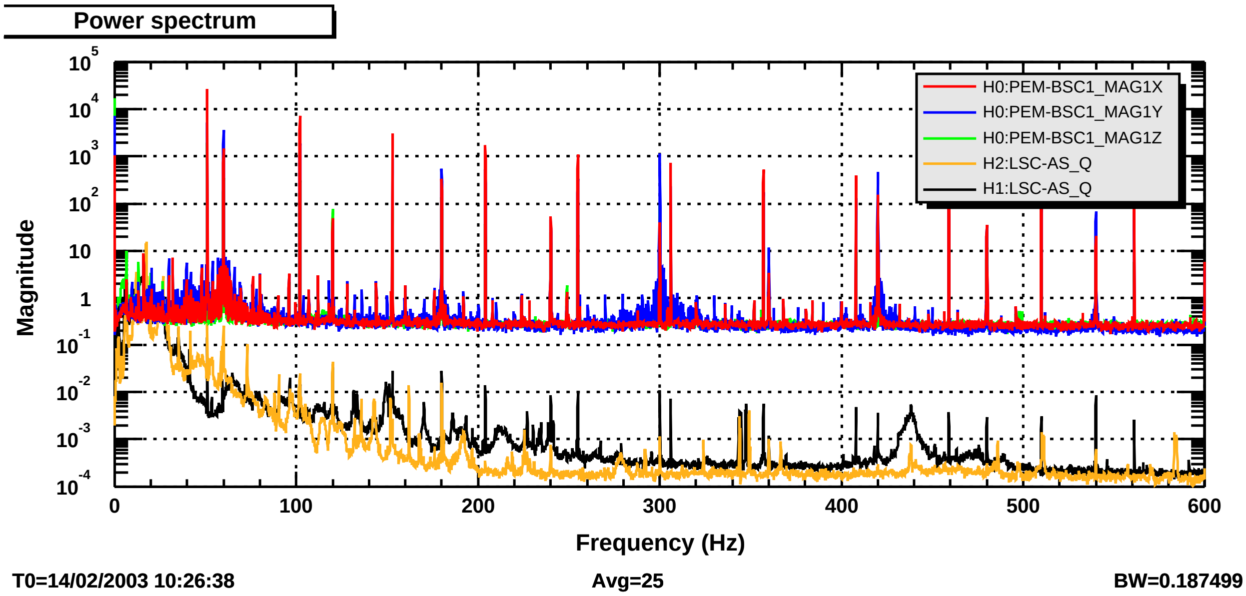
Nothing invasive; no connections to the data acquisition system (no AWG); not even connections to mains power for DAQ.

Magnetic Field Injections

Generating coil

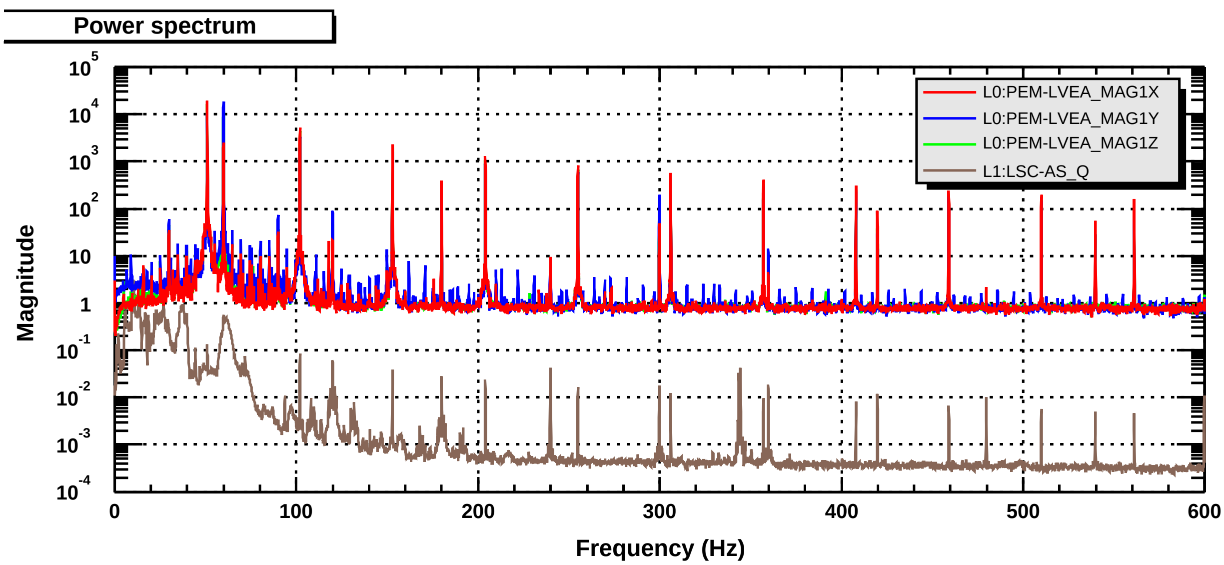
Fluxgate magnetometer

Coil generating 51Hz sawtooth near Hanford HAM2



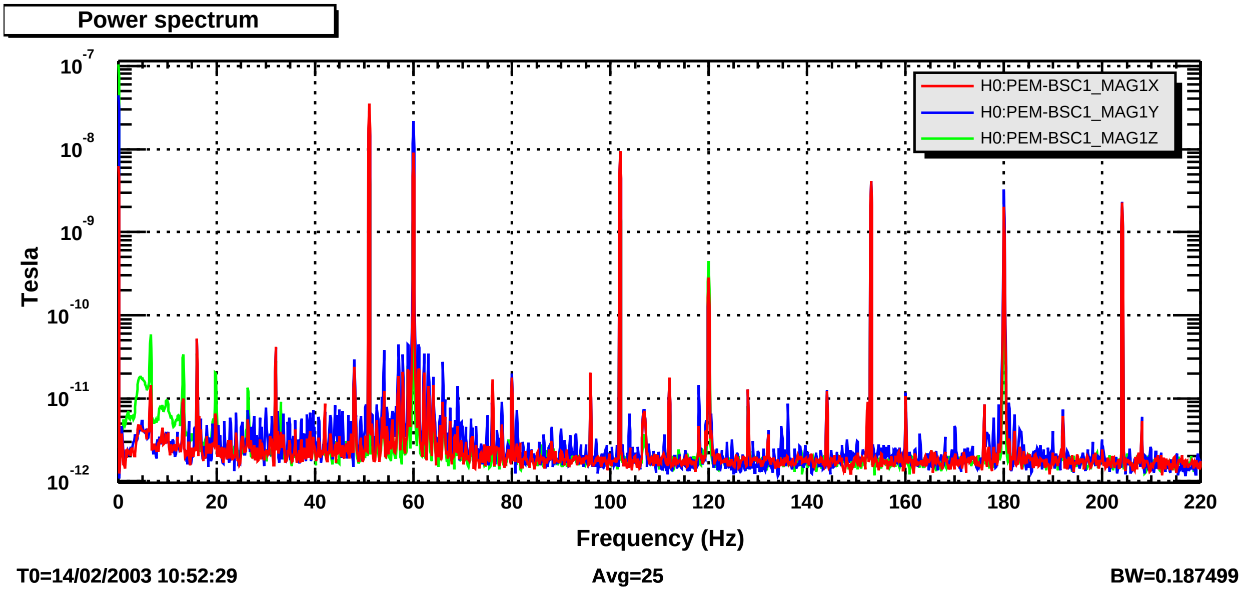
Magnetometer signal: 6e-12 Tesla/count

Same coil current and position but at Livingston

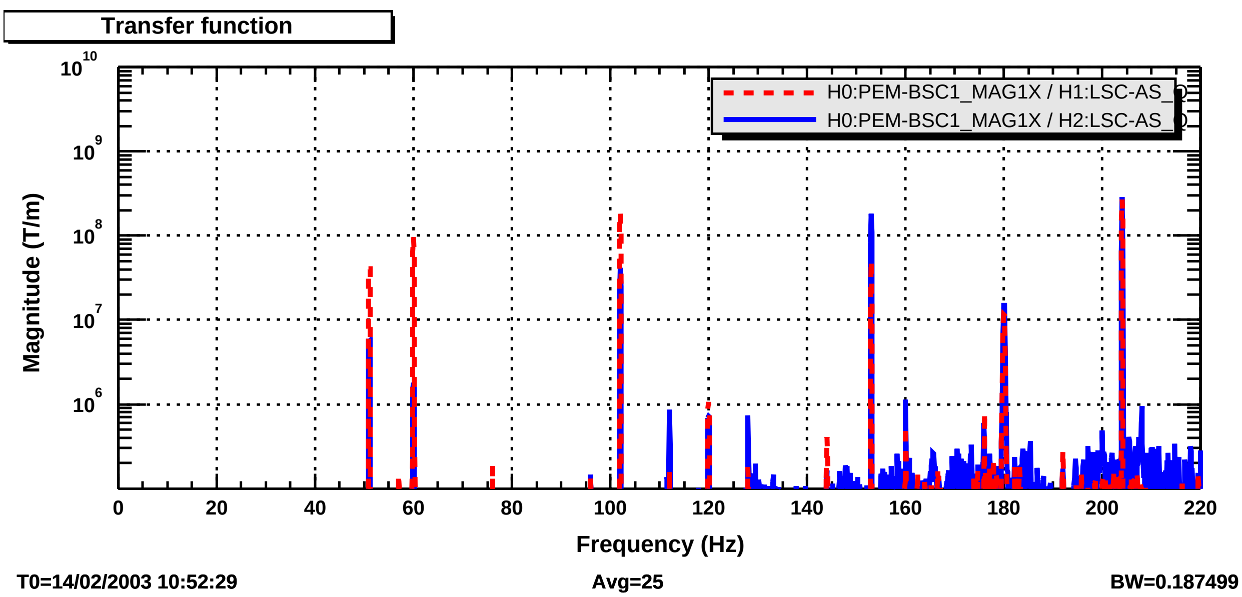


Coupling at LHO and LLO similar; reduction of 60 Hz lines in AS_Q close to being limited by magnetic field coupling.

Injection from a more distant Hanford LVEA location

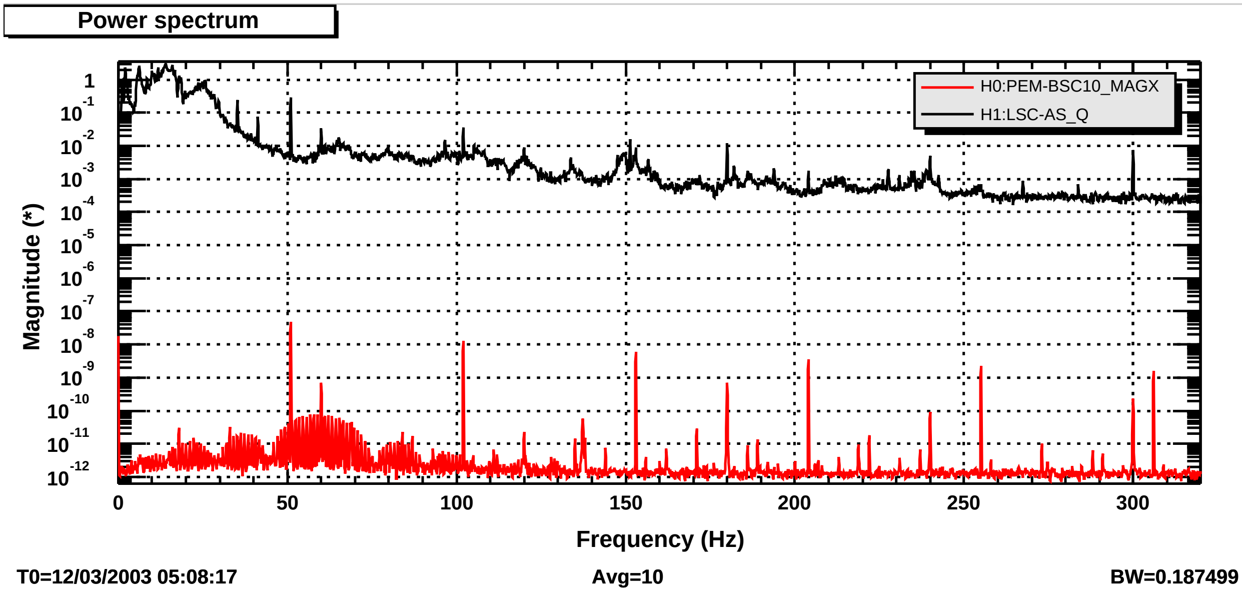


B field to displacement t-function for 51 Hz and harmonics

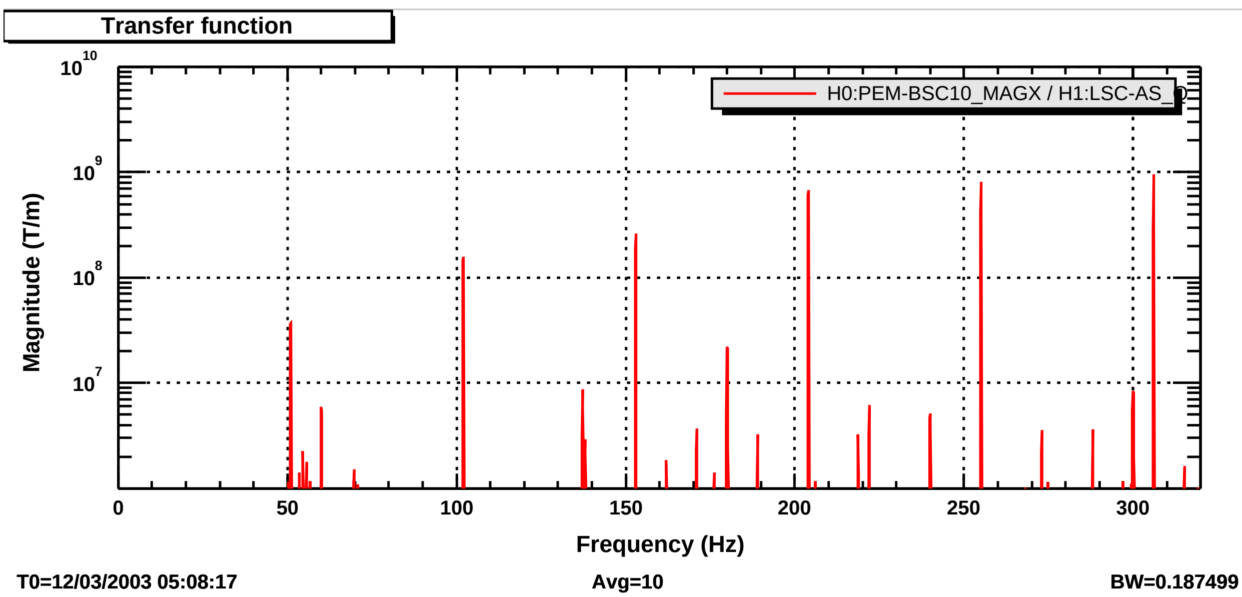


Prediction from test mass magnets (60 Hz): 2e9; measured: ~1e8 (bigger is better). Electronic coupling?

Coupling at Hanford Y-end



Magnetometer spectrum in T/sqrt(Hz)



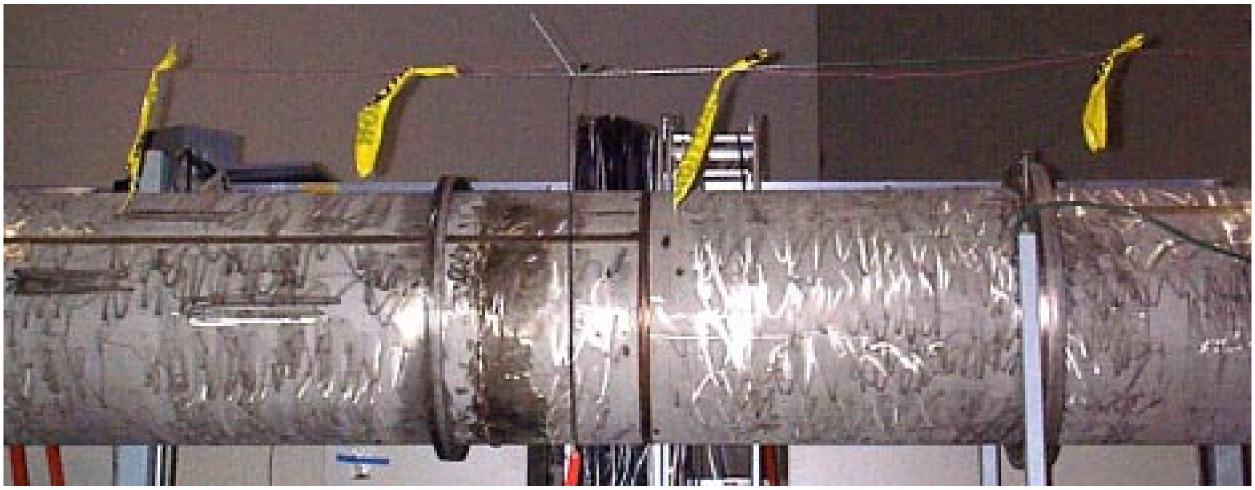
Similar to coupling at corner station.

Conclusion: 60 Hz peaks likely to show up at full sensitivity but background floor is not.

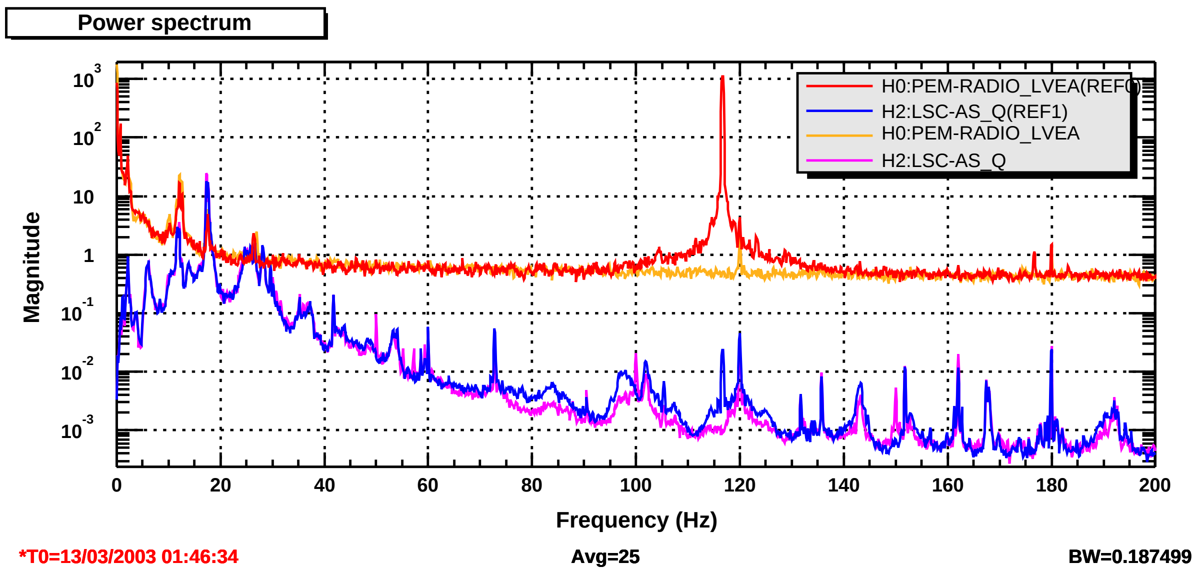
Radio Frequency Injections

Transmitter set to about 100 Hz above the H2 26 MHz laser light modulation frequency

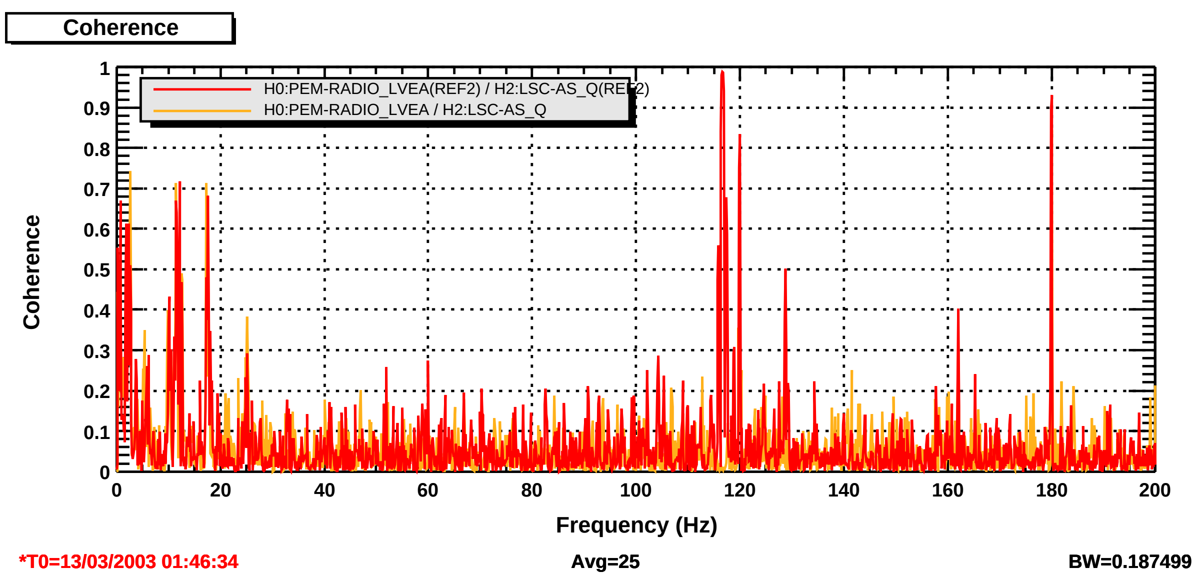
Receiver antenna signal mixed with laser light modulation signal



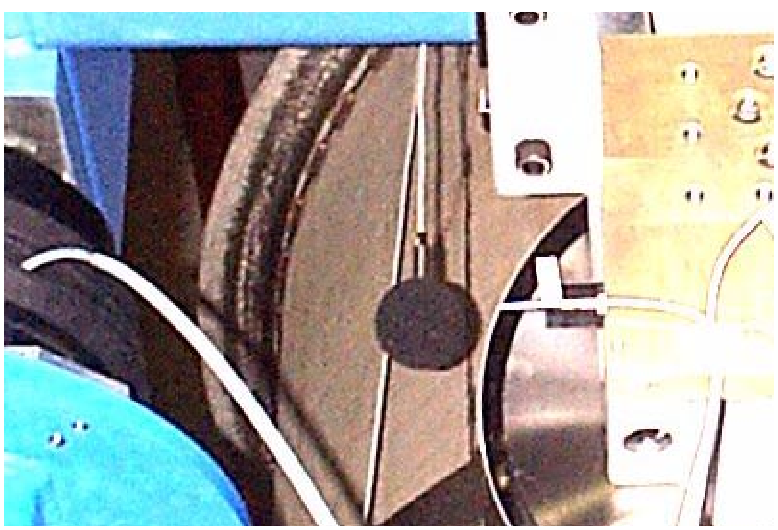
Radio and GW channels; transmitter on and off
Peak at about 117 Hz



Coherence

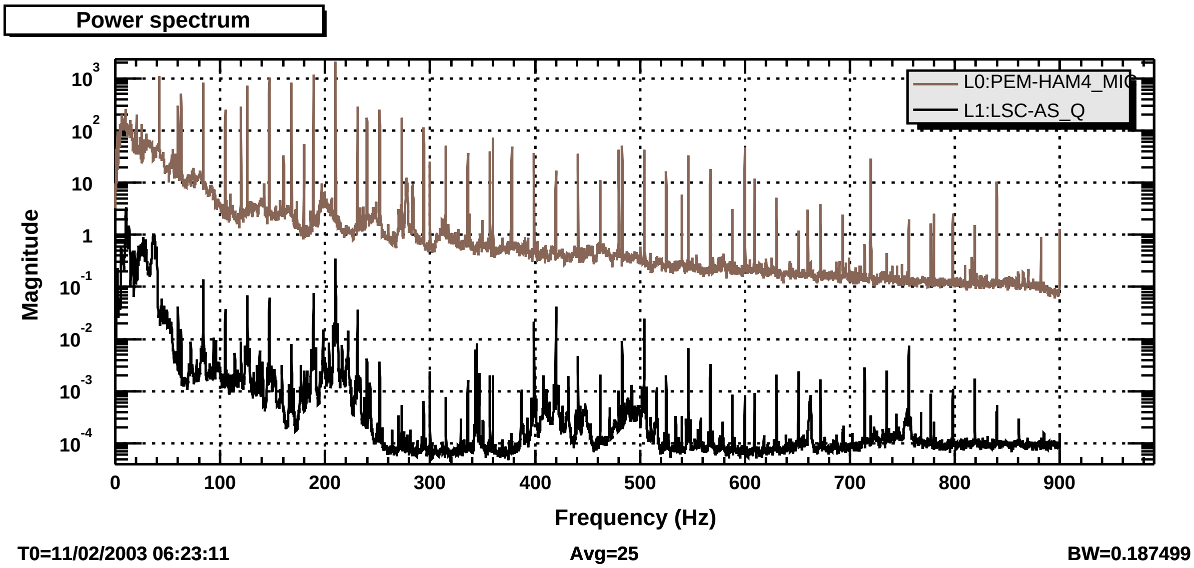


Mainly Acoustic Injections



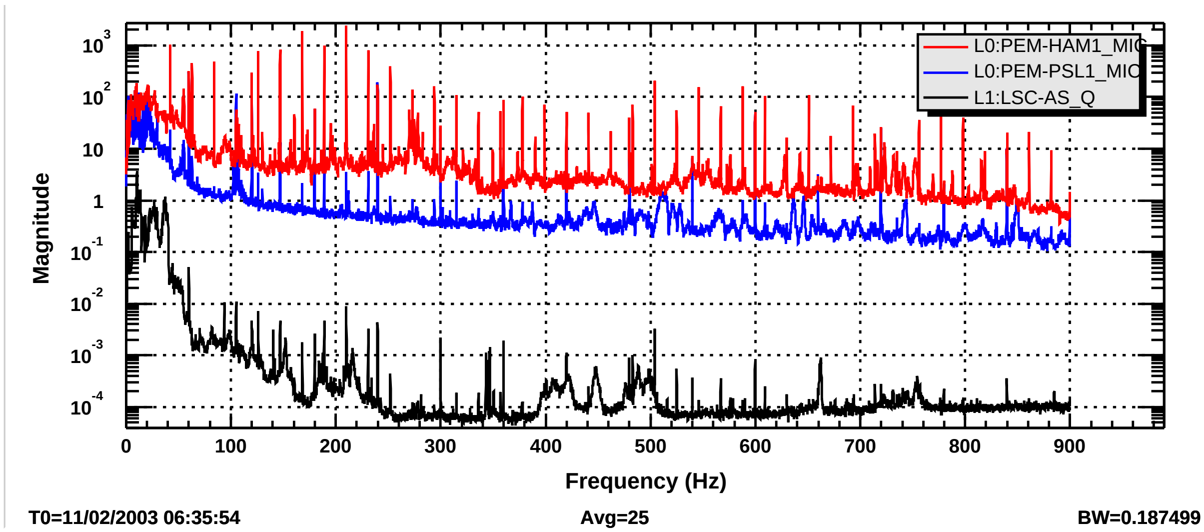
21 Hz sawtooth played through speaker at Livingston

Near dark port (ISCT4)



Microphone: 3e-5 P/count

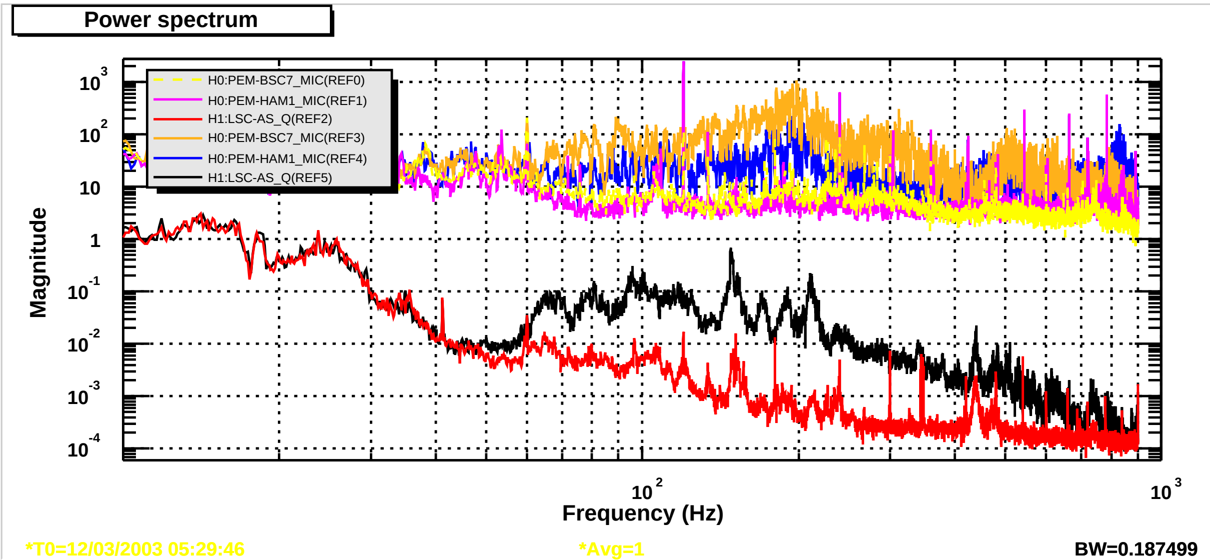
Near reflected port (ISCT1)



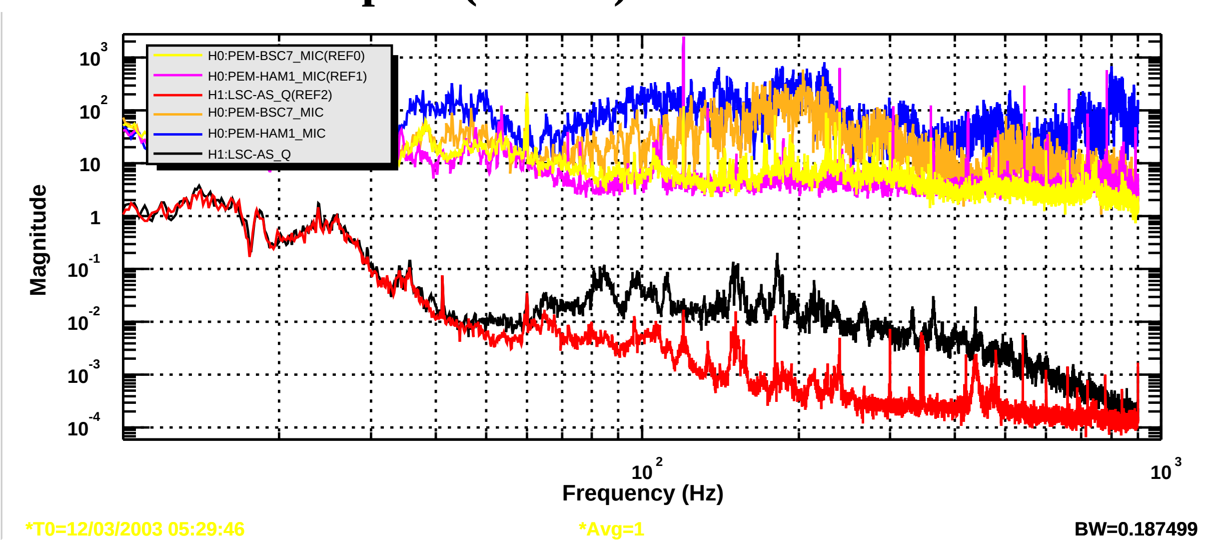
GW sensitivity close to acoustically limited; greater coupling near ISCT4

Noise played through speaker at Hanford

Near H1 dark port (ISCT4); Black: AS_Q with noise; Red: normal



Near H1 reflected port (ISCT1)

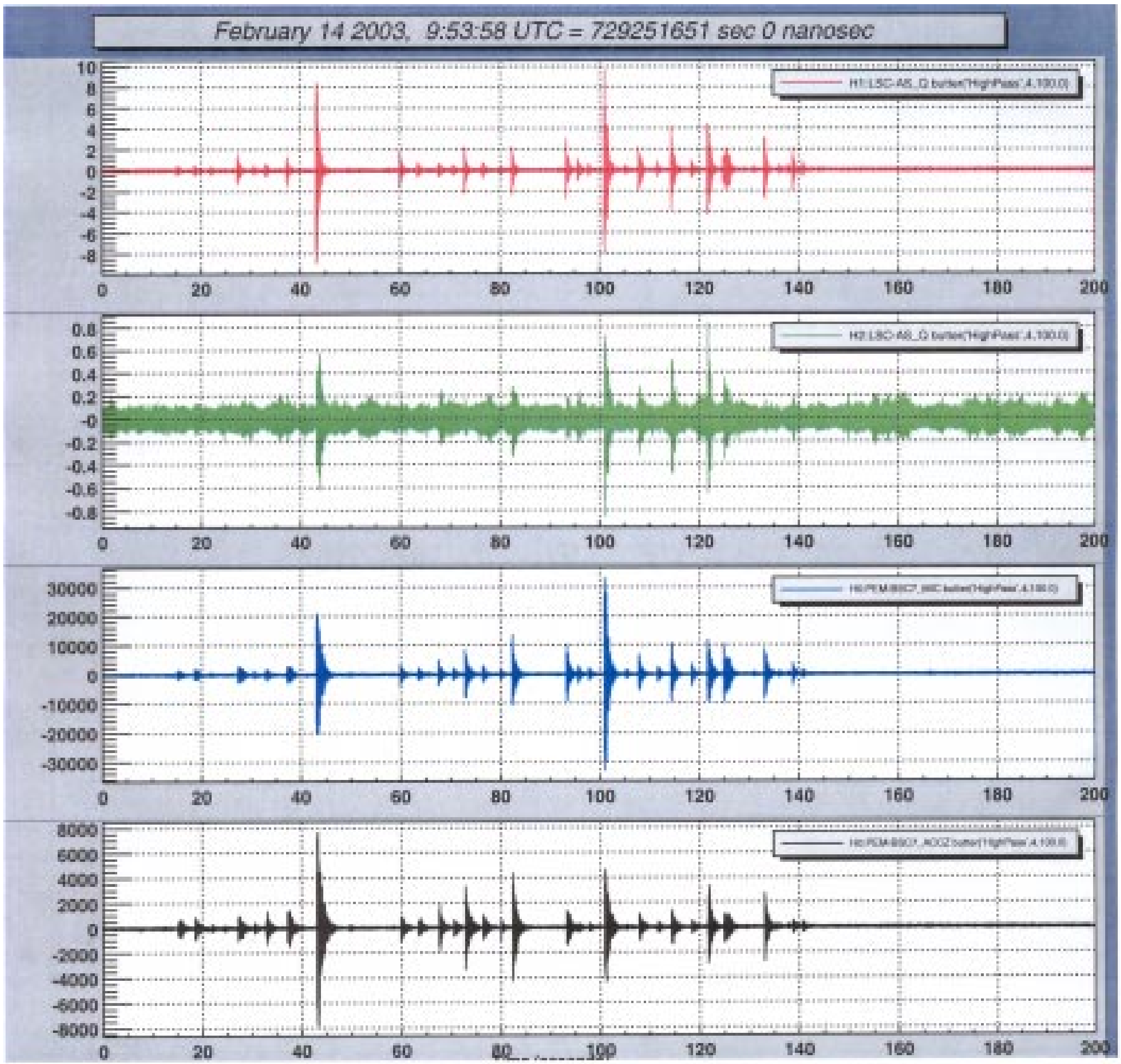


Resonances at coupling site get excited by noise

We must reduce acoustic contribution by 100 - 1000 to reach design sensitivity.

Burst Parade in LHO LVEA

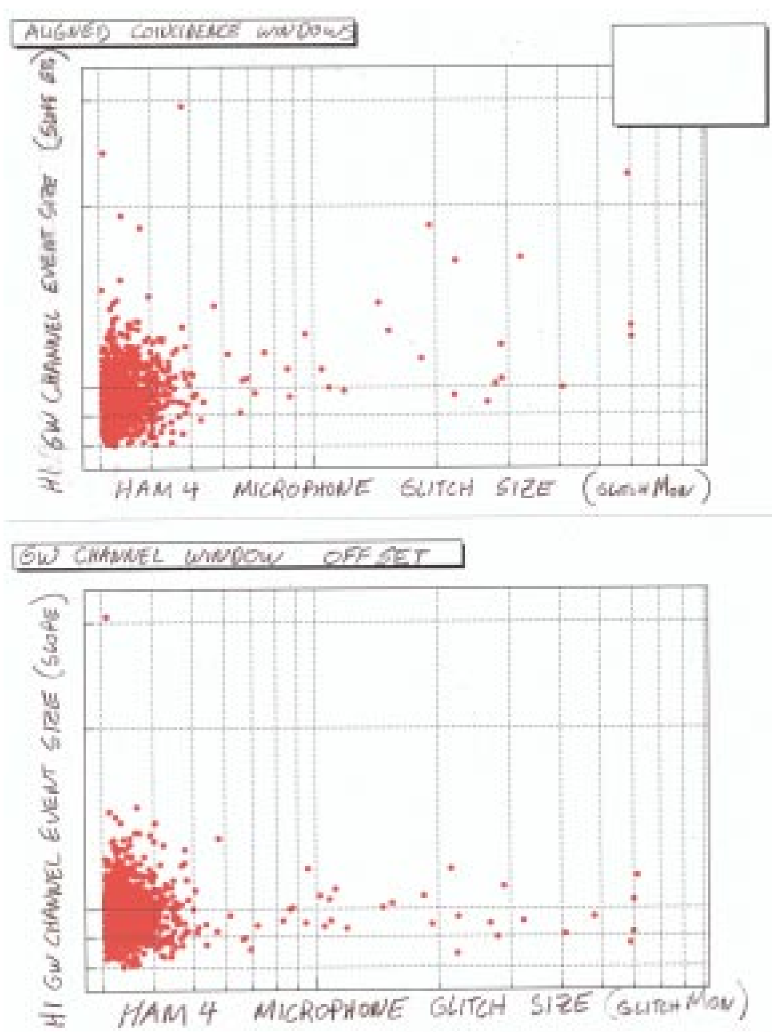
Traces 1&2: H1 & H2 GW channels; 3: mic; 4: accelerometer



Thanks to Stephan Ballmer for display code

Setting PEM veto thresholds for GW burst search

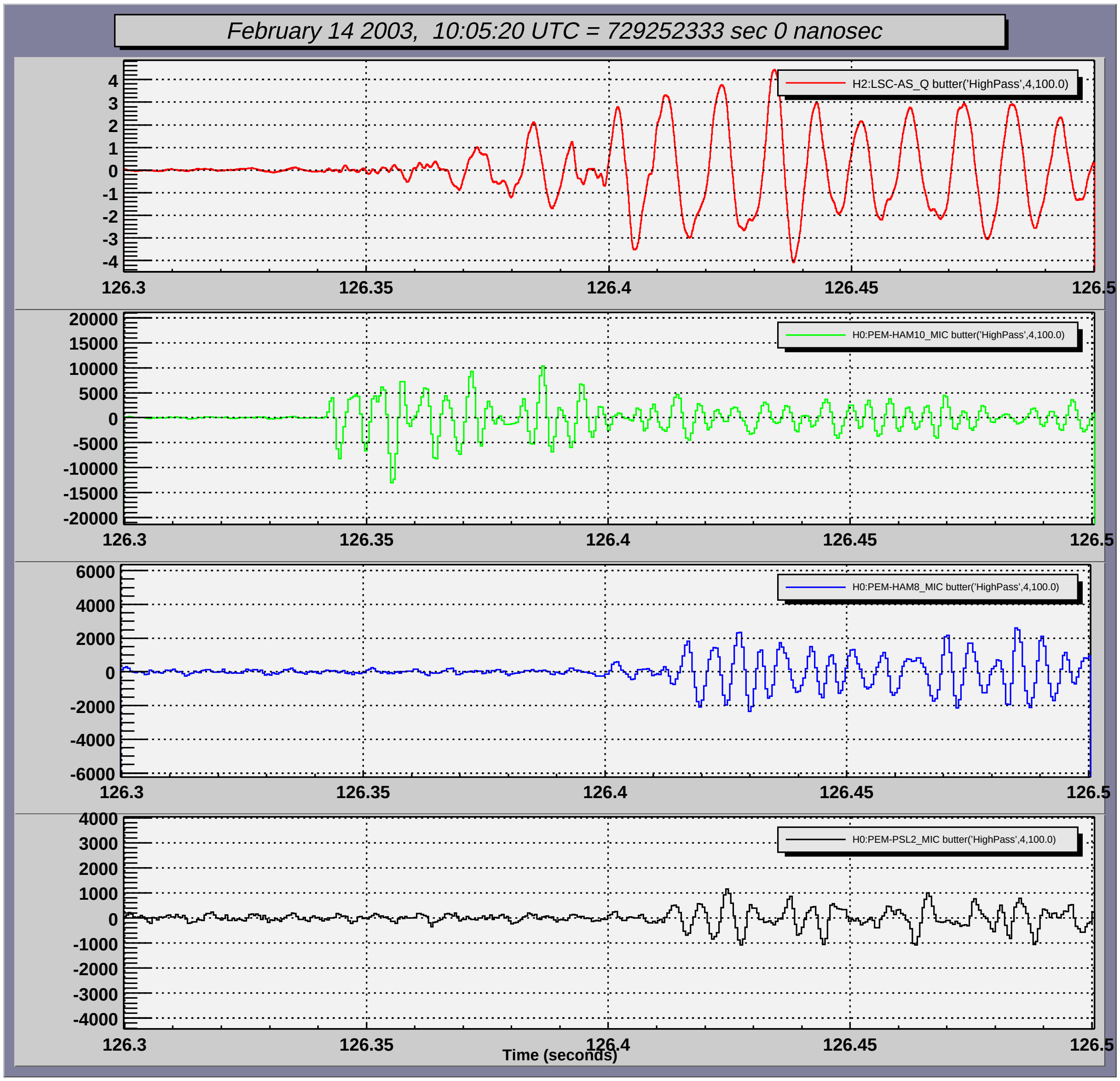
Plot size of GW channel event vs. size of PEM channel event. To set threshold, compare aligned and misaligned coincidence windows.



S1 data; glitchMon bandpass 256 - 577 Hz

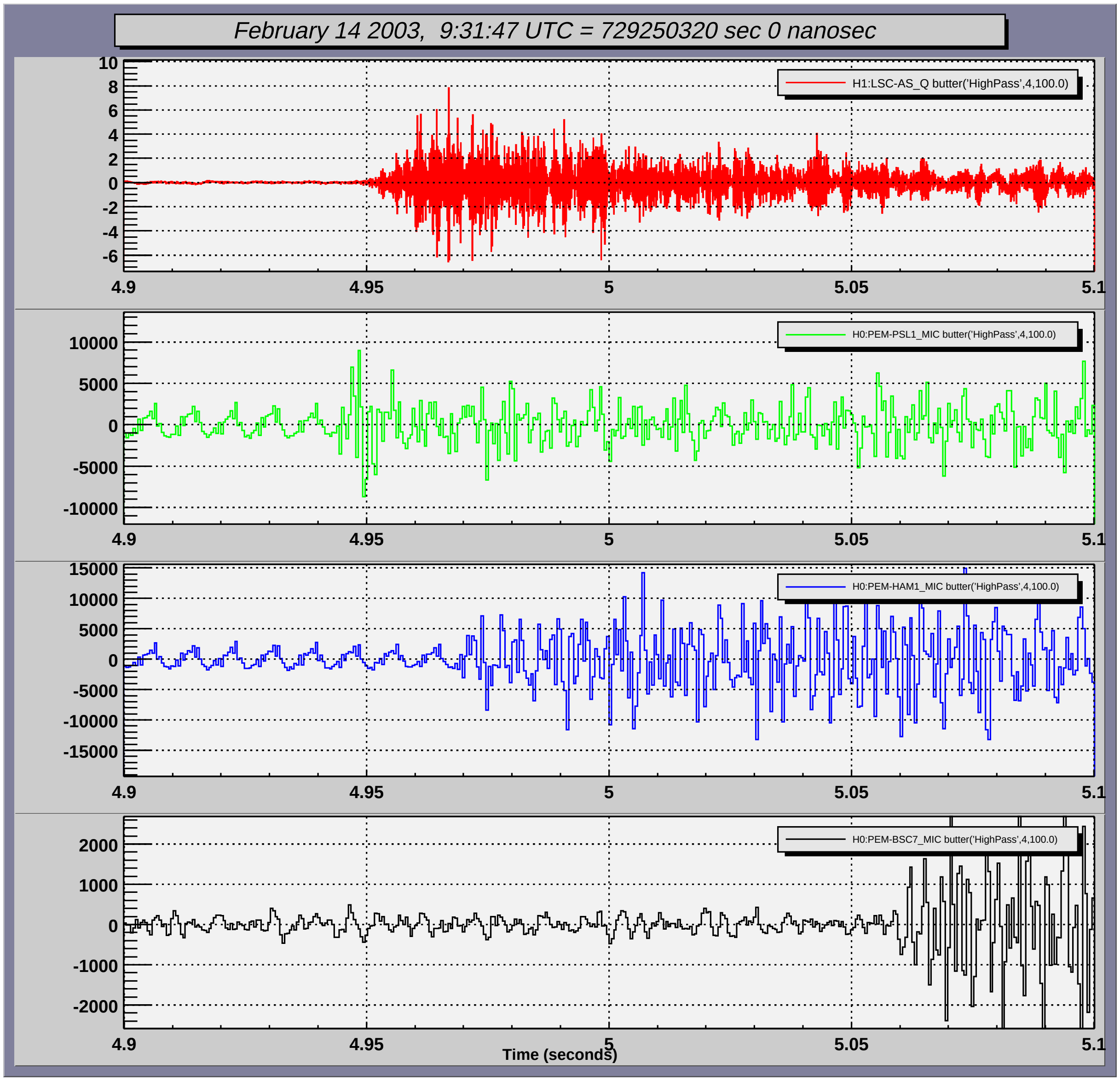
Burst propagation delays localize coupling sites

Top trace: Hanford 2k GW channel; lower 3, microphones
Burst generated near top trace microphone at 2k dark port



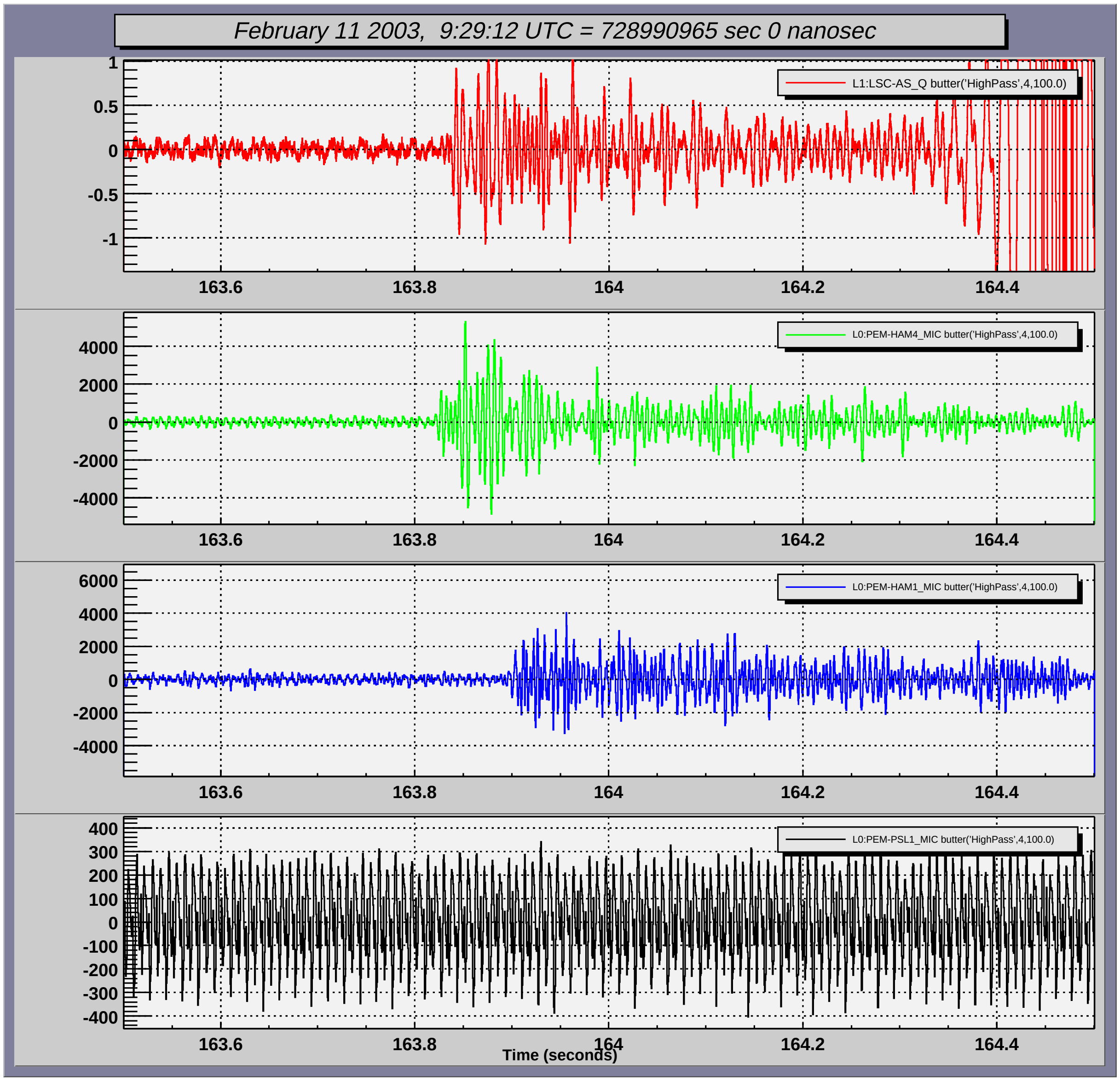
Conclusion: acoustic coupling at or near 2k dark port

Top trace: Hanford 4k gravitational wave channel
Second trace: 4k laser table (PSL) mic., burst nearby.
Third trace: HAM 1 mic (near other potential coupling sites)



Coupling before sound reaches HAM1 mic, likely at PSL

Top trace: Livingston 4k gravitational wave channel
Lower three traces: mics; lowest trace PSL mic



Acoustic driven lock loss not seen at Hanford.
Coupling near dark port; PSL enclosure effective.

Most evident S2 acoustic coupling at Hanford:

2k dark port
4k dark port
4k laser table (PSL)

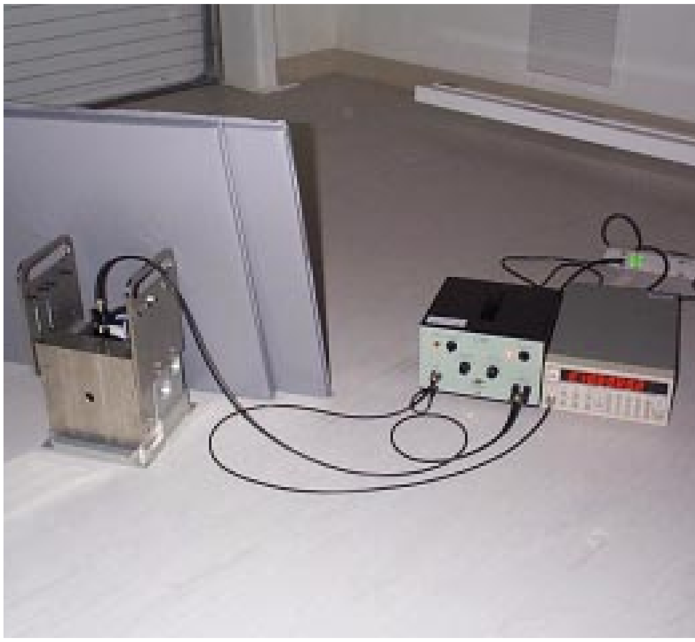
Most evident S2 acoustic coupling at Livingston:

dark port

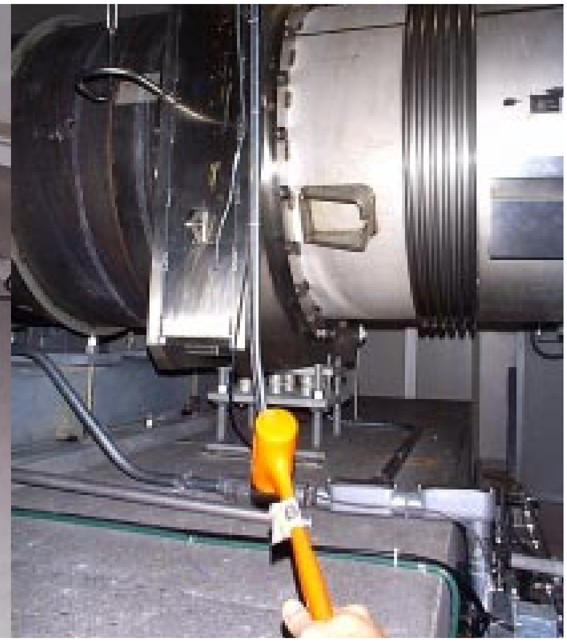
More measurements needed to determine level of coupling at Livingston reflected port and input optics port.

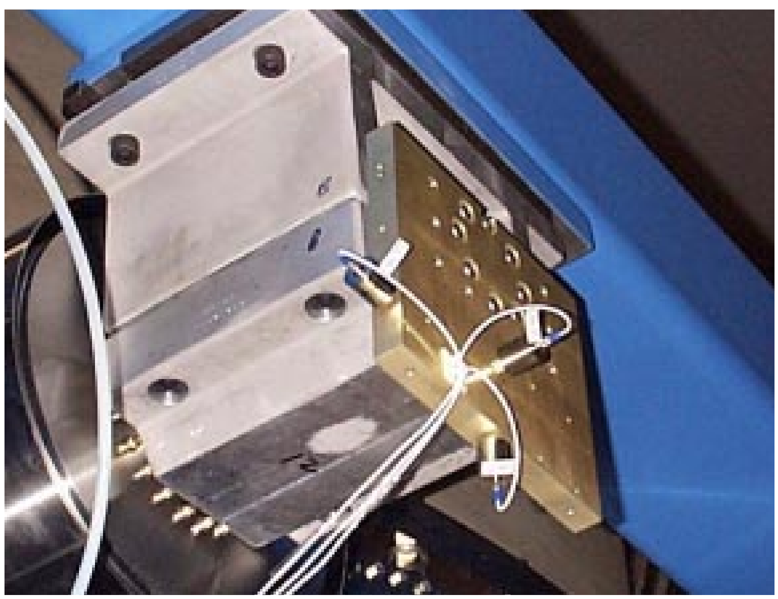
Seismic and Acoustic Injections

Coil Shaker



Hammer



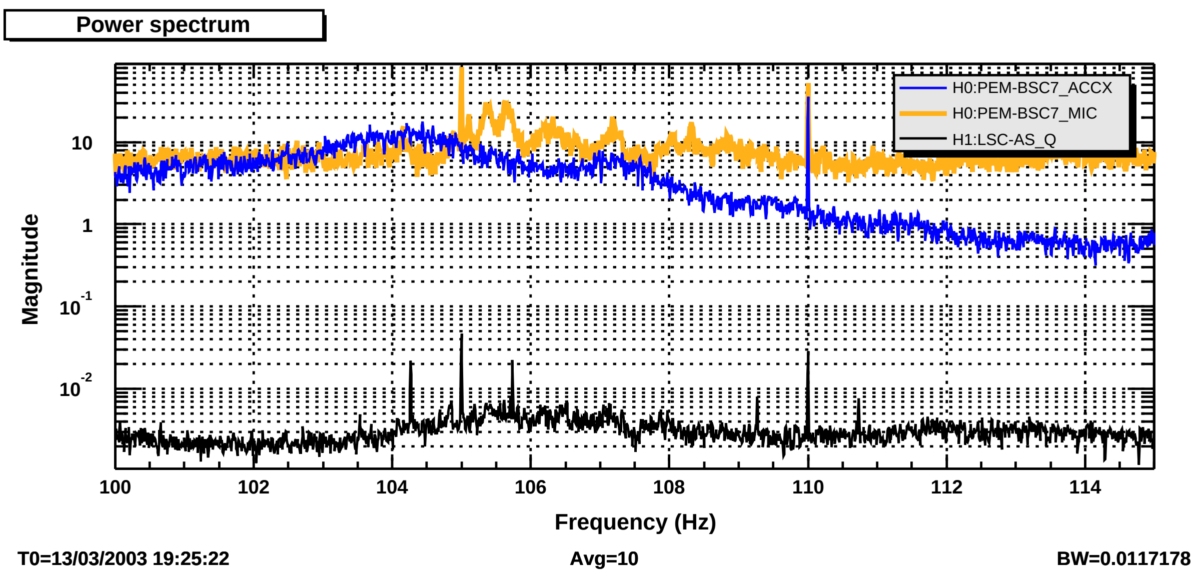


Accelerometers

Suspended speaker generating signal at 105

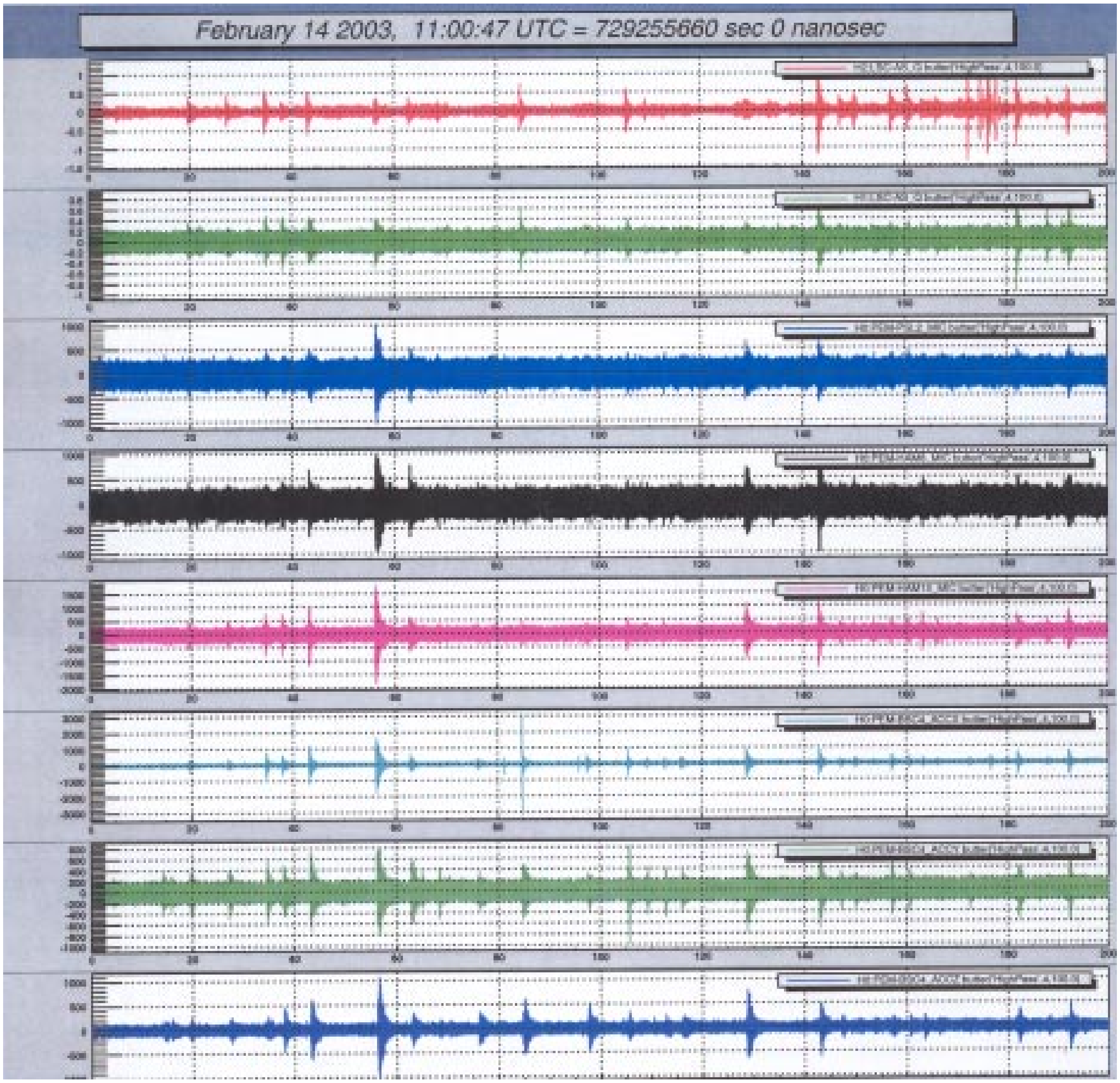
Shaker on ground generating signal at 110

Blue: Accelerometer; Orange: Mic; Black: GW channel



Acoustic signal couples locally at table; cant tell whether shaker coupling is through ground or acoustic.

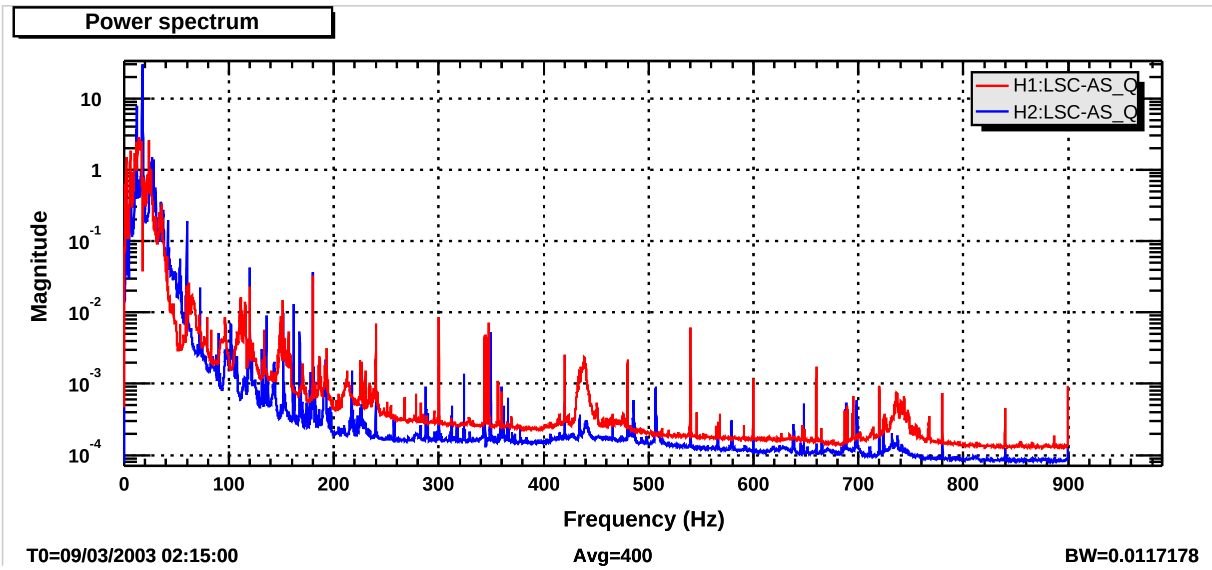
Top two traces: H1 and H2 gravity wave channels
Next three traces: mics in input and output enclosures
Last three traces: periscope accelerometers in enclosures



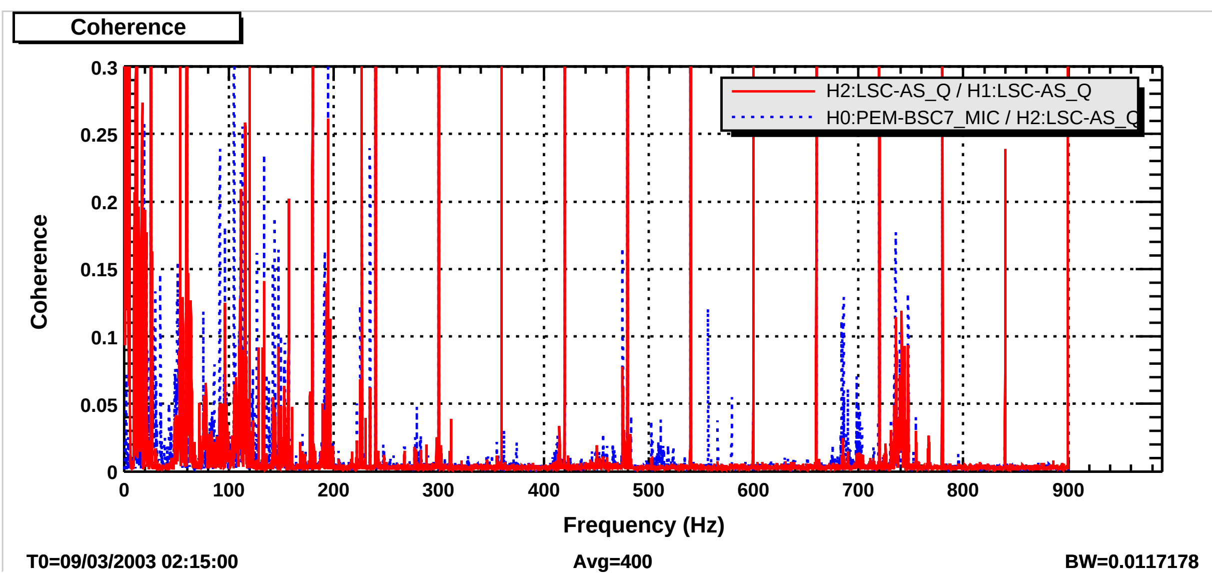
Wide range of coupling factors

Coherence Between H1 & H2 GW Channels

About 12 Hours of data



Coherence



Probably due to acoustic coupling

Types of Acousto-seismic Coupling

1) Doppler Shift - seen at H2 PSL table for seismic coupling
2) Backscatter - seen at H2 POX port - perhaps at Livingston?
3) Clipping - on H2 AS port, PD was the limiting aperture
4) Index of refraction modulation - seen in H2 PMC
5) Microphonics (electronic coupling)

Possible Mitigation Schemes

1) Isolation of coupling center

   a. Acoustic enclosure around tables - e.g. Livingston PSL
   b. Float tables on the legs we have tested at LHO

2) Isolation and reduction of sources

   a. Acoustic enclosures and panelling around sources
   b. Seismic isolation of sources
   c. Reduce reverb time in LVEA to reduce "recycling gain"
   d. Remove unneeded cooling fans or replace with quiet fans

3) Reduction of coupling

   a. Float table: may help 1, 2, and 3
   b. Improve beam dumping: helps 2
   c. Damp or move resonances of optic support structures: 1, 2, 3
   d. Smaller beams, larger apertures: 2,3
   e. Wide angle lenses in front of limiting apertures (e.g. short focal length lens in front of photo diode to reduce effect of upstream mirror jitter) - helps 3

Needed Measurements and Issues

1) Evaluate efficiency of LLO PSL enclosure, particularly with regard to the seismic part of acousto-seismic

2) Can LLO type enclosures fit around tables and accomodate access

3) How do we bring the beam into an enclosure without compromising air tightness

4) Reverb time at LLO LHO as a function of frequency

5) Test new electronics racks

6) Determine worst coupling centers

7) Identify worst types of coupling (1,2,3,4,5)

8) Compare Hanford and Livingston PSL accelerometers and mics

9) Pinpointing coupling sites on tables using small speaker and headphones

10) Tighten or modify kinematic mounts on periscope mirrors