Vacation Scholarship Report - Equipment noise at AIGO

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Introduction

The Australian International Gravitational Observatory (AIGO) is an interferometric gravitational wave detector located in the Shire of Gingin, about 70 km north of Perth, Western Australia. The equipment at the site produces vibrations which may interfere with measurements, so this noise needs to be minimised. To prevent noise from being transferred to sensitive equipment, there are isolation systems in place, which should sufficiently attenuate high frequency noise (above approximately 20Hz). Previous studies have focussed on characterizing weather-induced seismic noise [1], vehicle-induced noise [2], and noise in the 2-20 Hz band (including equipment noise) [3]. This investigation seeks to characterize equipment noise in the 5-25 Hz range, and find ways to minimise its effect. HEPA filters, vacuum pumps, air compressors and air conditioners all produce noise which is measurable with a geophone or seismometer, and which, if it is strong enough, may transfer through the isolation systems.

Method

Seismic data were collected from November 2006 to January 2007, using a Güralp Seismometer, model CMG-6TD. Sampling was done at 50Hz (allowing observation of frequencies up to 25Hz). The seismometer measures velocity in 3 axes: North-South (n), East-West (e) and up-down (z). Most analysis was done on the z channel, because equipment noise was often most obvious in the vertical axis. The seismometer connects to the serial port of a laptop running SCREAM! (Seismometer Configuration and REal time Acquisition and Monitoring), which can display a spectrogram of the data in real time, or record them in GCF format. GCF files can be merged with the program GCFinfo, and converted to ASCII format (for importing into MATLAB) with the command-line program gcf2asc. SCREAM! and related utilities are available from http://www.guralp.net/download/ for Windows and Linux (gcf2asc and GCFinfo available only for Windows). Once the data are loaded into MATLAB, the power spectral density can be estimated via the Welch method with the pwelch command, and the specgram command can be used to make a spectrogram.

Several methods were used to identify the source of noise. Most equipment noise is fairly monochromatic, so one piece of equipment usually produces a straight line on a spectrogram. Turning off the equipment then results in the line disappearing, so turning of pieces of equipment one by one can identify the source of a line. Sometimes there is equipment that is not easily turned off, so other methods must be used. If the equipment has a speed control (as do most of the air filters and some vacuum pumps), then adjusting it will change the frequency of the line that the equipment is producing. Another method is to take measurements with the seismometer at different distances from the piece of equipment. If the magnitude of the vibration is greater closer to the equipment, then it is likely to be the source of the noise. This method is not always reliable as the magnitudes of vibrations can fluctuate depending on location, possibly due to the formation of standing waves. Yet another method is to observe the spectrogram from a horizontal channel for different orientations of the seismometer. It is possible to determine in which direction the vibration is strongest; this is likely to be in the direction of the equipment. The measurements can be taken at another location, and then the location of the equipment can be approximately determined by triangulation.

Sources of Noise

Figure 1 shows a typical spectrogram taken in the main lab. The various horizontal lines are each from a particular piece of equipment. The vertical lines come from things such as doors closing. You will notice that the frequency of some of the lines fluctuates, and that all lines which fluctuate do so in unison (see for example the 2 lines around 11 and 12 Hz at time 4000 seconds). We suspect that this is due to voltage fluctuations in the mains power supply.

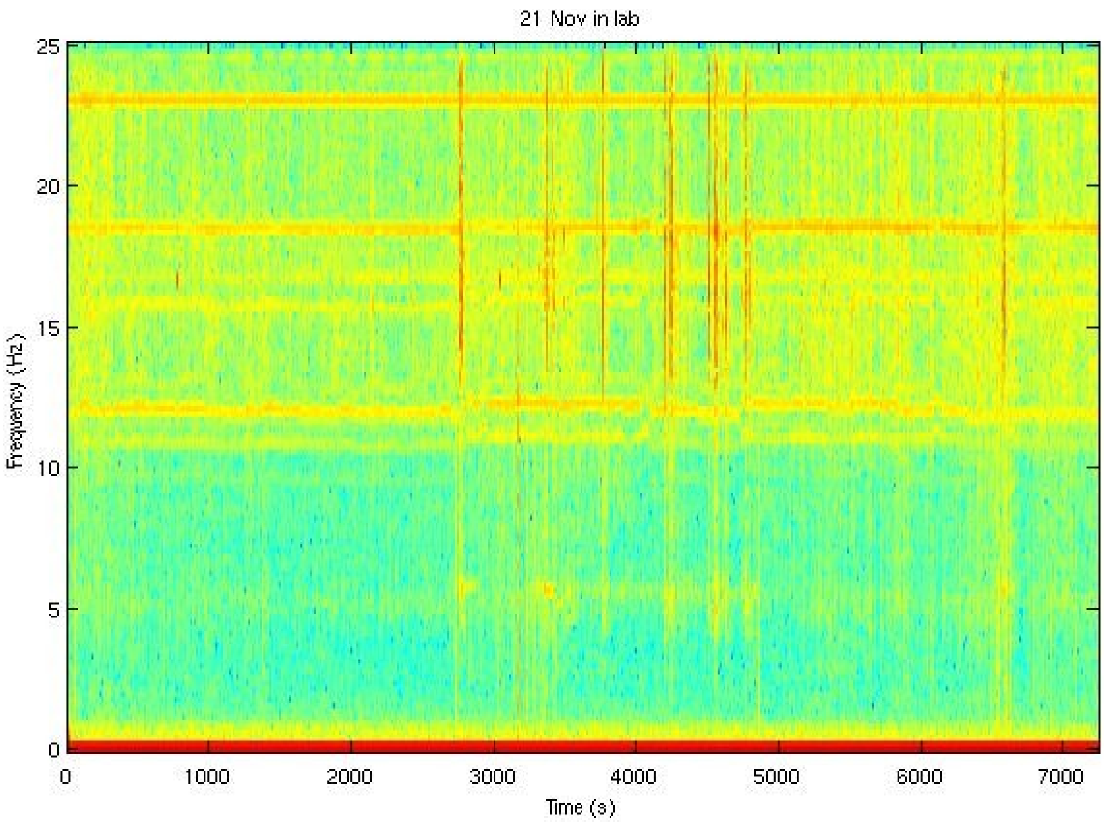

Figure 1: Spectrogram of seismic noise taken on 21st November 2006 in main lab.

Source	Frequency (Hz)
Main Lab Air Conditioning System:	
SAF Hi	11.2, 11.6, 16.8, 22.4
SAF Lo	12.3, 13.6, 17.5
OAF	21
Meeting Room Air Conditioner:	
	15.4 (goes on for 5-10 minutes, off for 3 minutes, cycles)
Vacuum Pumps:	
P1	24.1
P2	has speed control, 20.2 (14/12/06)
HEPA Filters:	
Tent 2 Filter 4	18.5 ±0.5
Main Lab Air Compressor:	
	11.1, 16.7, 22.2 (for about 13s approximately once an hour)

Table 1: Major sources of noise in main lab. Most HEPA filters not listed because of variable frequencies.

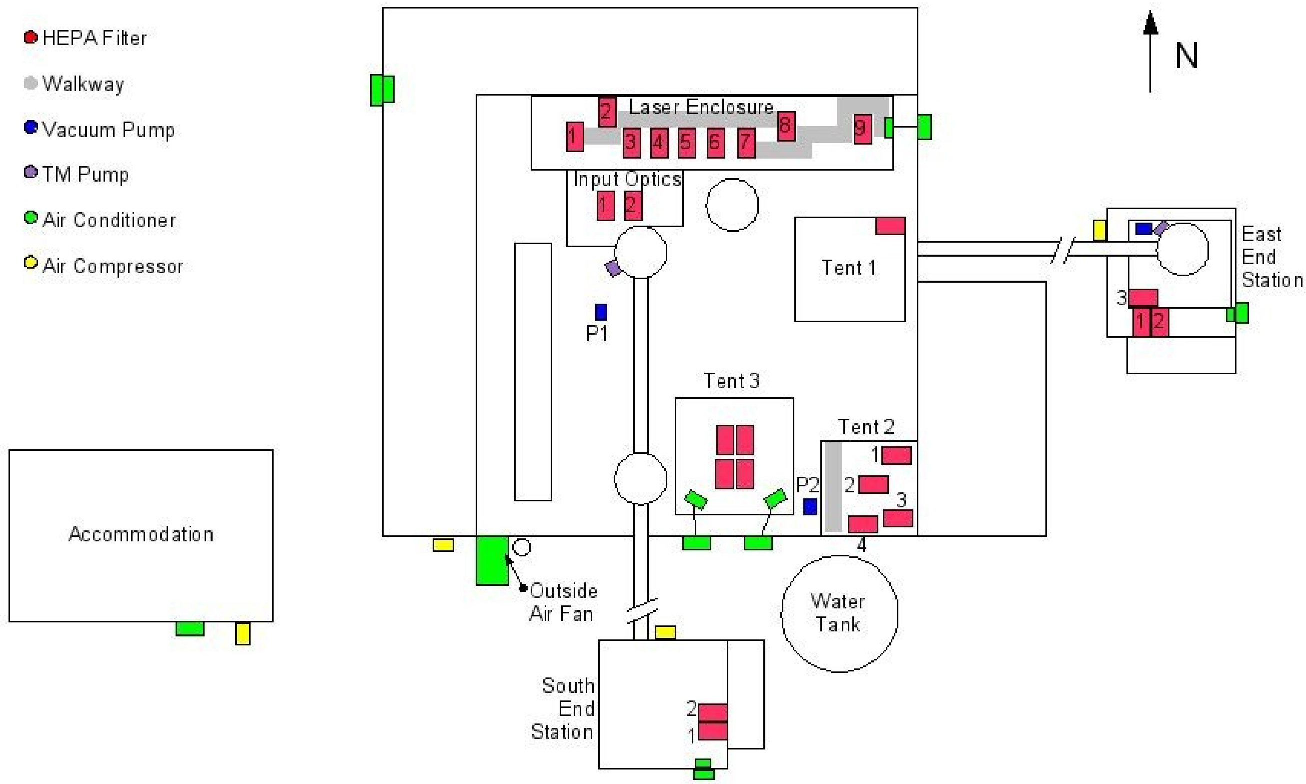

Figure 2: Map of AIGO buildings (not drawn to scale).

Vacuum Pumps

P1 and P2 (see Figure 2) both produced vibrations that were easily detectable in the main lab. P1 does not have a speed control, and produced monochromatic 24.1Hz vibrations. P2 has a speed control, so the noise it produced was easily identified by changing its speed slightly, and noting any changes of frequency on the spectrogram. P2 produced the line around 23Hz visible in Figure 1. Its last known speed is 20.2Hz. The vacuum pumps in the end stations were not switched on when I was taking measurements, so the nature of their vibrations is not known. P1 and P2 produce very strong noise (P2's line is one of the reddest in Figure 1), but their higher frequency is probably better attenuated by the isolation systems; although I didn't get a chance to look at the geophone output to confirm this. Perhaps the vacuum pumps should be placed on thicker foam to help reduce the vibrations.

Air Conditioning

The air conditioning systems tend to produce weak, monochromatic lines. The main lab air conditioning system had a "supply air fan" (SAF) with 2 speed settings and an "outside air fan" (OAF). The lines these fans produce (see Table 1) were quite hard to observe; the best way to see them was through a horizontal channel of the seismometer, with the device correctly rotated. These fans can be controlled via the control panel in the southwestern corner of the main lab. The meeting room air conditioner produced a monochromatic, 15.4Hz line, observable in the main lab, which would come on for several minutes, then disappear for about 3 minutes, then come on again. The air conditioners on Tent 3 and in the East end station didn't produce any observable vibrations. The rest of the air conditioners were not thoroughly tested for vibrations. In any case, the air conditioning systems are very quiet (difficult to detect against the background noise in the main lab).

HEPA Filters

Noise originating from an air filter is easily recognised by its fluctuating frequency, see for example the 12Hz line in Figure 1. All HEPA filers at AIGO bar one have speed controls, and some only produce significant noise at certain speed settings (probably due to resonance in the structures they are attached to). The air filters are made by ESCO [4], except the one without a speed control (filter 4 on tent 2 - see Figures 2 and 5).

Figure 3: Air filters on laser enclosure; filter 9 at front.

Figure 4: Filter 1 on the laser enclosure

Most of the HEPA filters on the laser enclosure weren't producing detectable vibrations, with the exceptions of filters 1 and 5 (see Figure 2), which make strong noise at some speed settings. Filter 1 was producing the line around 12Hz visible in Figure 1. It is now set to a different speed which doesn't make any noise detectable with the seismometer. Filter 1 has a blue prefilter (Figure 4), while the rest of the laser enclosure filters have white prefilters (Figure 3).

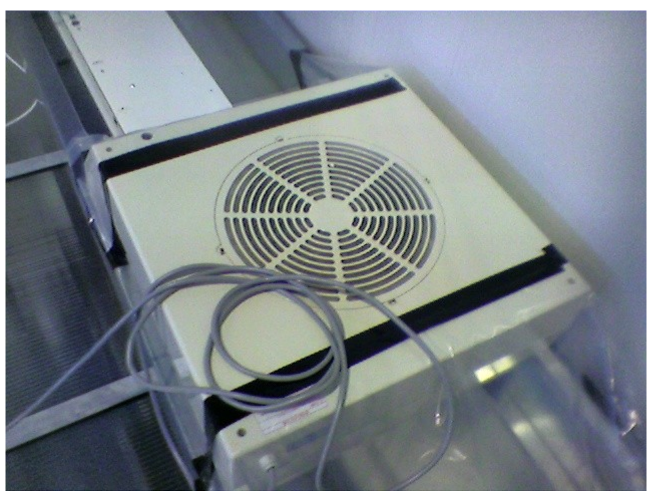

Figure 5: Filter 4 on tent 2, producing strong 18.5Hz line.

The HEPA filters on tents 1 and 3 produce no detectable noise. Filter 4 on tent 2 produced a strong vibration around 18.5Hz (visible in Figure 1). It is now switched off, and the other filters on tent 2 make no detectable vibrations.

The air filters on the input optics table show the most dramatic amplitude changes for varying frequency. These two filters were originally producing the lines around 16 and 17Hz in Figure 1. Figure 6 shows the amplitude measured with the seismometer placed on the ground next to the input optics table. If filter 1 is set to a speed corresponding to about 13Hz, and filter 2 to 12 or 16Hz, then the noise is minimised; although due to frequency fluctuations, this is not completely reliable.

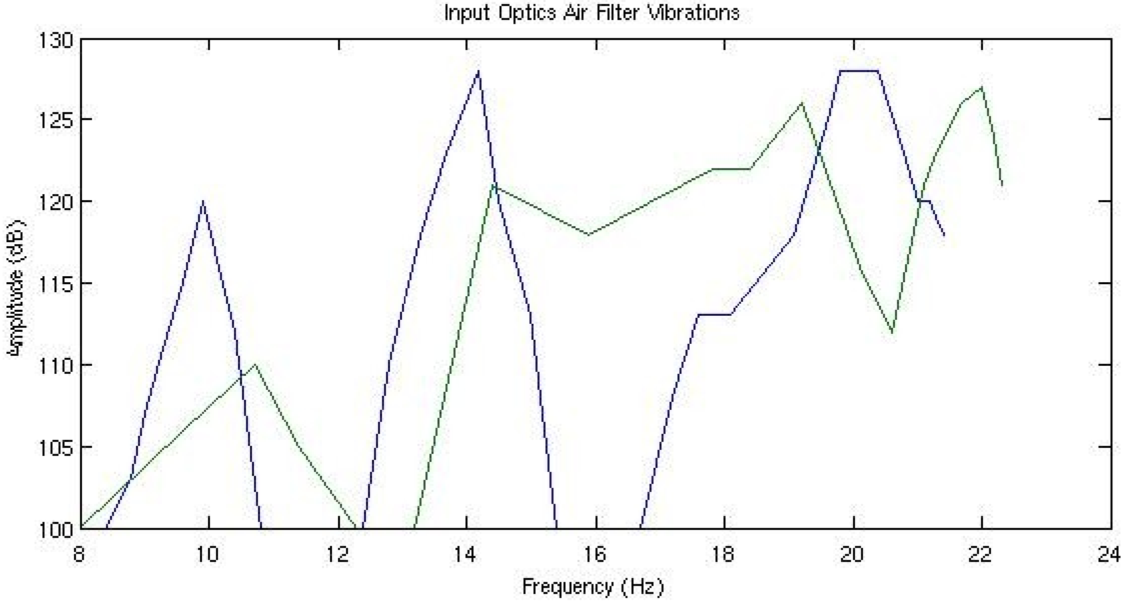

Figure 6: Input optics filters 1 (green) and 2 (blue) amplitude of vibration versus frequency.

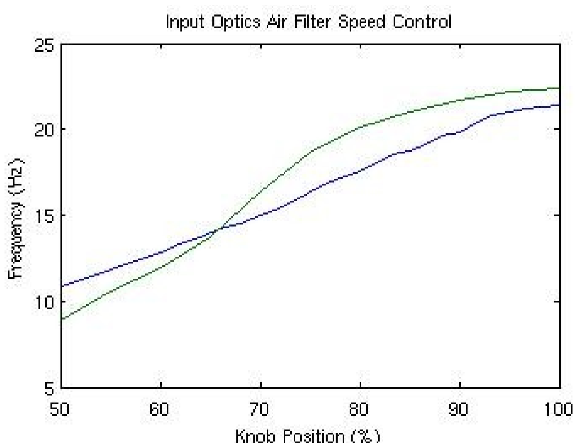

Figure 7: Measurements of frequency produced for given speed settings of input optics filters 1 (green) and 2 (blue).

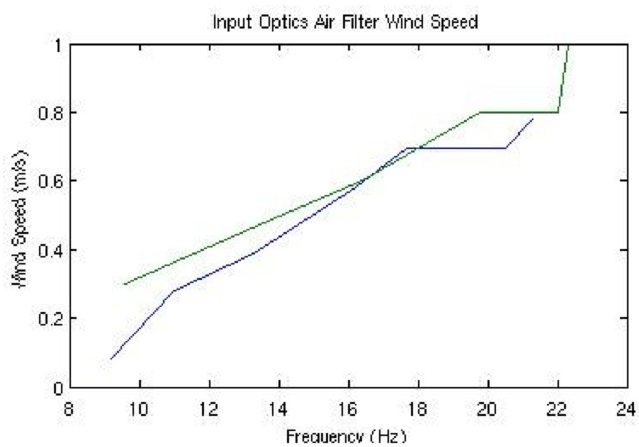

Figure 8: Wind speed measurements for input optics filters 1 (green) and 2 (blue).

The HEPA filters mounted on the walls of the end stations make strong vibrations which are suspected to be visible in the main lab (this is hard to prove with certainty because the vibrations they supposedly produce in the main lab are faint and often disappear due to frequency fluctuations). We tried putting a layer of foam underneath filter 2 in the east end station to see if it would reduce the vibrations' amplitude, but the foam had no noticeable effect. Figure 9 shows the amplitude measured for filter 1 at various frequencies. The filter is quite quiet at 20-21Hz, but this band may be too narrow as the HEPA filters' frequencies fluctuate widely. For all filters that I have investigated thoroughly, their vibrations are not noticeable (i.e. they are weaker than the background noise) for frequencies below about 9Hz. Experiments with the input optics air filters suggest that 9Hz corresponds to a wind speed of about 0.1Hz, and a speed setting of slightly less than half. The filters have a surface area of 0.7m^2 each

(1.21m × 0.6m) [4], and the east end station has a volume of $224m^3$ (5.7m × 5.7m × 6.9m). If the two wall-mounted air filters in the east end were set to 9Hz, they would replace the air in about half an hour ($224m^3$ / ($0.7m^2$ × 2) / (0.1m/s) / (60s/minute) = 27 minutes).

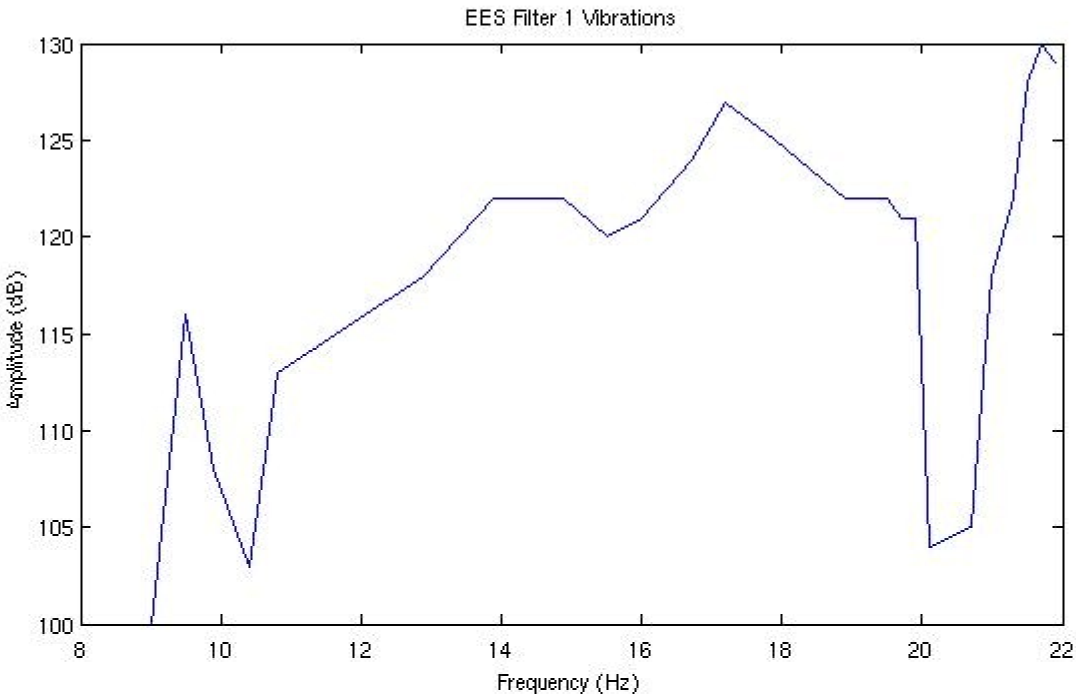

Figure 9: Frequency response for east end station filter 1, measured from floor of east end.

Air Compressors

The air compressor by the main lab makes a vibration consisting of several frequencies (see Table 1); the strongest one below 25Hz is 16.7Hz. The vibration lasts for about 13s and comes about once an hour (this varies). It is visible in Figure 1, at 800 and 3000s. There is a similar noise at 14.4Hz which is suspected to be an air compressor, and all compressors bar the one at the east end station have been ruled out as sources of this noise. The south end air compressor's vibrations are not detectable from the main lab, but are clearly audible around the accommodation building.

Conclusion

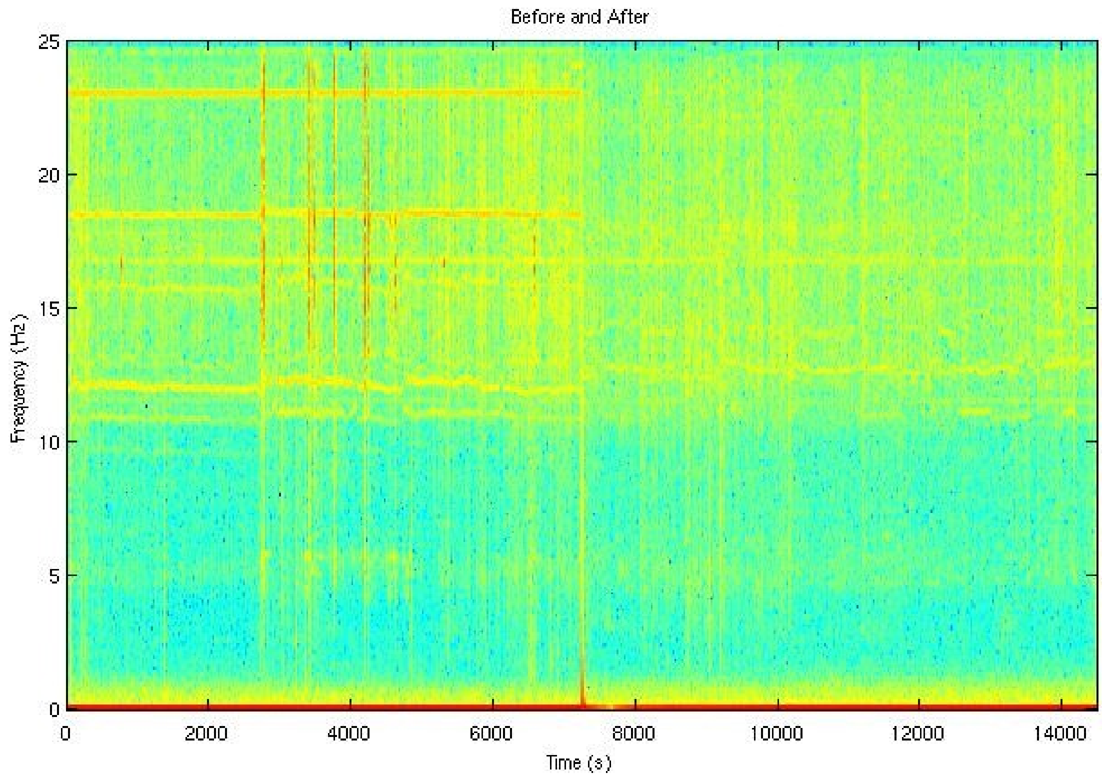

Figure 10: Comparison of noise on 21/11/06 (time 0 to 7200s) and 15/02/07 (time 7200 to 14400s) taken at same location in main lab.

The most significant sources of equipment-induced seismic noise at the AIGO site are the HEPA filters and vacuum pumps. More investigation into ways to minimise vibrations from the vacuum pumps is required. The HEPA filters' noise can be reduced by changing the speed setting. Figure 10 shows the progress made in reducing vibrations from the filters. Note that the 23Hz line is from a vacuum pump which by chance was off on 15/02/07, so perhaps the change is not as dramatic as it seems. The wall-mounted filters in the end stations still produce strong seismic noise despite our efforts.

References

[1] Turner J., 2005, *A Study of Microseismic Noise at the Australian Gravitational Observatory*, dissertation presented for Bachelor of Science (Honours), University of Western Australia, School of Physics.

[2] Coward D., Blair D., Burman R., Zhao C. 2003, 'Vehicle-induced Seismic Effects at a Gravitational Wave Observatory', *Rev. Sci. Instrum.*, vol. 74, no. 11, pp. 4846-4854.

[3] Coward D., Turner J., Blair D., Galybin K. 2005, 'Characterizing Seismic Noise in the 2-20Hz Band at a Gravitational Wave Observatory', *Rev. Sci. Instrum.*, vol. 76, no. 4, 044501.

[4] ESCO. (2006), *ESCO Airstream Fan Filter Units*, [Online], Available from: <http://www.escoglobal.com/cleanroom/product_2.asp> [19/02/07].