

ANALYSIS OF DATA FROM INTERFEROMETRIC GRAVITATIONAL
WAVE DETECTORS

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ABSTRACT

Analysis of data from the interferometric gravitational wave detector prototype at Glasgow is discussed. Artificial signals in the form of coalescing binary chirps have been applied to the data by the Glasgow group. The advantage of using correlation techniques to detect these signals is discussed and it is shown how some non-white noise effects in the data can be removed.

1. INTRODUCTION

In a previous paper (Paper I), we presented preliminary results of an analysis of gravitational wave data from the Glasgow prototype interferometric detector¹. In the present paper, we report on a further investigation, and discuss how correlation techniques can increase the signal to noise ratio when searching for coalescing binary signals. We also describe ways in which non-white noise in the data, in the form of frequency biasing and mains interference, can be removed.

2. CORRELATION OF DATA WITH A COALESCING BINARY FILTER.

In paper I, we were able to detect artificial signals in the form of a coalescing binary chirp and we were able to accurately determine the mass parameter used in constructing these signals.

Figure 1 shows a time-series of data in which an artificial signal has been applied. The signal begins at point number 3233 (with data sampled at 6 kHz). It is important to point out that the peak at point 3232 is an

artefact of the equipment which generated the chirp. It is not part of the chirp and does not significantly affect our analysis. The chirp lies between points 3233 and 8103 and its frequency, f changes from 350Hz to 800Hz in this span. In figure 1, the standard deviation, σ , is 19.65, with a maximum amplitude of 3.87σ . This compares with a standard deviation of $\sigma_1 = 18.96$ and a maximum of 3.96σ , for the same number of points in nearby records in which a signal does not occur. These numbers indicate that the chirp lies below the level of the noise in figure 1.

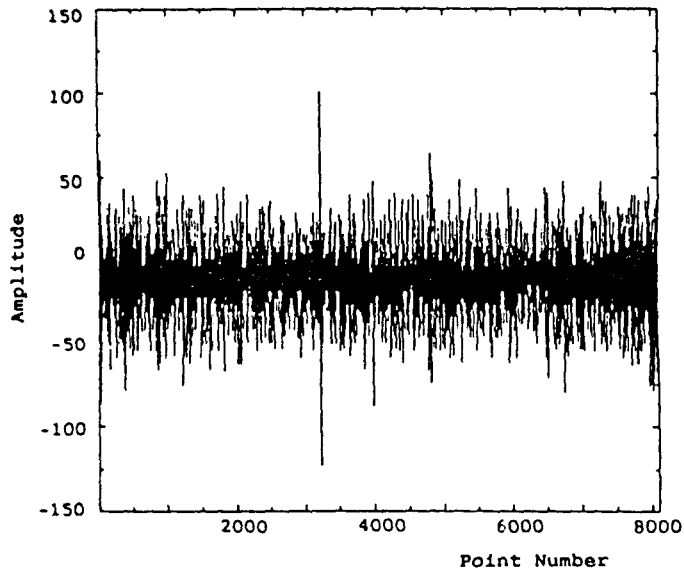


Figure 1: Record of data in which a chirp occurs. The horizontal axis is approximately $4/3$ seconds long and the vertical scale is arbitrary.

Figure 2 shows a cross-correlation of a coalescing binary template with the data of figure 1. The template uses the mass parameter which was estimated in paper I, with a frequency range $400\text{Hz} < f < 800\text{Hz}$. The large peak at point 2492 indicates the presence of the chirp in the data. The correlation has a maximum amplitude of $49.38 \sigma_1$, where σ_1 is the standard deviation of the noise, excluding points near to the maximum. We may conclude therefore that the correlation technique has enabled us to increase the signal to noise ratio by over forty-nine times the corresponding ratio in the time domain.

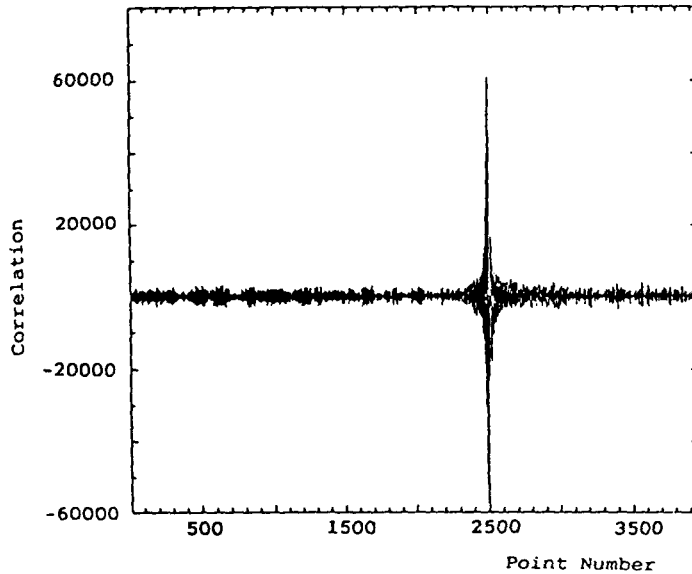


Figure 2: Correlation of a coalescing binary filter with the data in figure 1.

3. REMOVAL OF NON-WHITE NOISE

The two major sources of non-white noise in the Glasgow data are frequency biasing (i.e. stronger signal at particular frequencies) and mains interference. (i.e. interference in the time and frequency space due to the 50Hz electrical mains and its harmonics).

The frequency biasing may be removed using a calibration "comb" applied periodically to the data, consisting of peaks in the power spectrum at $f = (750, 1250, 1750, 2250, 2750)\text{Hz}$ which in unbiased data would have equal amplitudes. We interpolated between the comb frequencies to obtain a calibration signal for all $f \geq 750\text{Hz}$. Dividing each component of the Fourier transform by this interpolated calibration signal removes any biasing in frequency.

A more important problem to solve is that caused by interference from the mains supply. This interference makes it difficult or impossible to set limits on the sensitivity of laser interferometers to continuous wave sources and presents obstacles in analysing the detector's output noise. The problem

is that the mains fundamental frequency is difficult to ascertain accurately, due to several effects: the finite resolution of the frequency spacing, the fact that some of the harmonics appear to be split and that the fundamental frequency is in a region of high noise. We have had some success, however, by taking a long data set and studying the highest harmonics, these being cleaner than those at lower frequencies: because the frequency resolution is constant across the spectrum, the highest harmonics give the most accurate estimate of the fundamental. Using these higher harmonics, it was possible to determine the frequency of the fundamental within a narrower range than was possible by looking at the first few harmonics.

Figure 3 shows the log of the power spectrum of a record in which the mains and frequency biasing is still present. In contrast, figure 4 shows a similar plot in which these two effects have been reduced. Because the peak at $f \sim 340\text{Hz}$ is due to a wire resonance we have confined our analysis to frequencies above this.

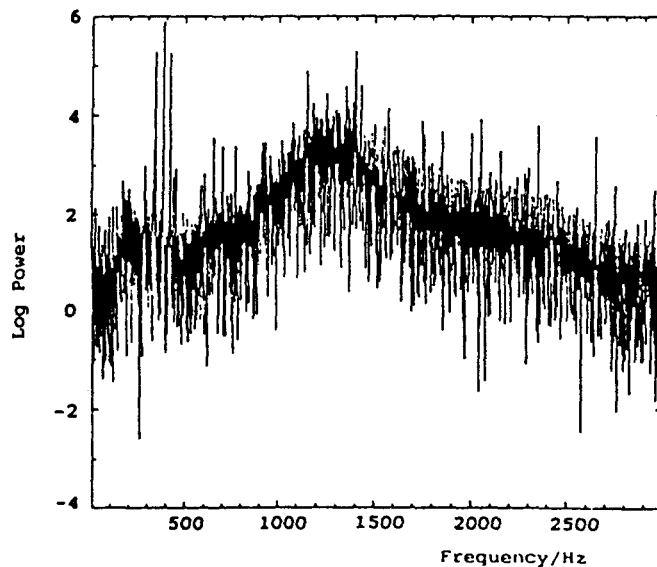


Figure 3: Log of power spectrum of sixty-five records of data showing mains interference and frequency biasing.

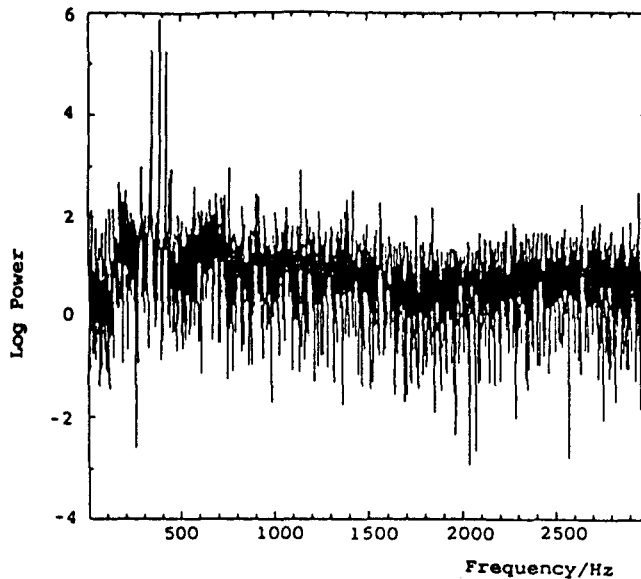


Figure 4: Log of power spectrum of same records as in figure 3, but with mains interference reduced, and frequency biasing removed.

4. CONCLUSIONS

We have shown that correlation techniques can dramatically increase the signal to noise ratio when searching for signals embedded in noise. Further, we have been able to reduce troublesome effects in the form of frequency biasing and mains interference, but it is clear that further work needs to be done on techniques for cleaning up the data in order to perform a complete noise analysis on the data.

ACKNOWLEDGEMENTS:

The authors would like to thank the Glasgow group (especially J. Hough, B. Meers and H. Ward) for supplying them with the data and for valuable discussions. The research was carried out with the aid of a DEC Microvax II, supplied under SERC grant GR/E46158.

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1. Lawrence, S.P.; Nahmad-Achar, E. and Schutz, B.F. in: *Gravitational Wave Data Analysis*, ed. B.F. Schutz (Reidel, Dordrecht, 1988) (Paper I).