Spectral Line Tracking

Bria C. Storr

Summer Undergraduate Researcher

Mentor: Joseph Betzwieser

Abstract

The objectives are to track spectral lines and ultimately determine the strength of the lines by monitoring the modulation of narrow peaks visible in the gravitational wave data. We are using a test model that simulates what happens in the real controls model of the interferometer for testing methods of tracking these lines. The computer model is tested by injecting data streams which simulate those from an actual interferometer and then demodulating the signals. The model is tested. so that the coherence and uncertainty are consistent with the calculated values.The offline calculations of the line strength and phase are compared to the online values that came from the LIGO data stream. Future plans are to use finite impulse response, FIR filters in addition to the currently used infinite impulse response IIR filters The ultimate goal of the project is to improve tracking signals due to environmental noise and parametric instabilities.
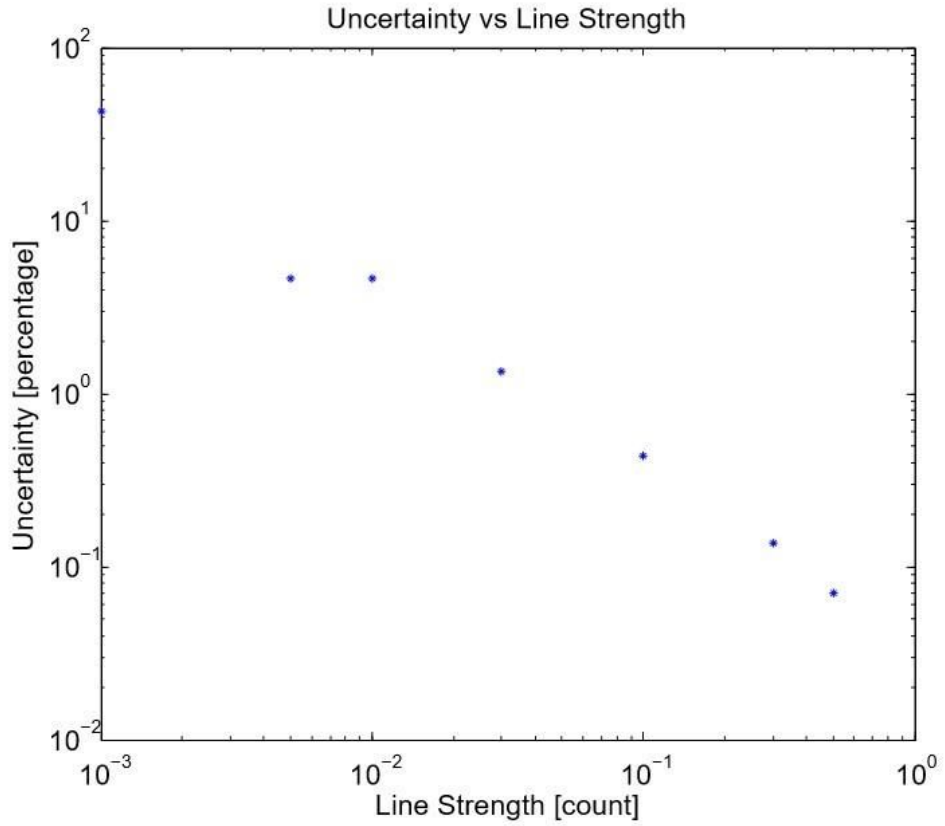
Background

Finding new innovative ways of tracking lines, will give us a better understanding of the behavior of gravitational waves. Observing gravitational wave help to detect things in the universe that does not emit light such as black holes.

The project will entail working on spectral line tracking and the properties to improve the performance of the interferometer over the ten week program at LIGO Livingston Observatory (LLO). The project's goal is to track the modulation of narrow peaks visible in the gravitational wave channel overtime and to address the limitations of different lines crossing in frequency or disappearing at times.

When observing the LIGO data stream there will be a focus on signals that are due to environmental noise. Some lines that modulate in size, large or small, due to environmental influences become undetectable, it is the project's goal to fix that. The detector noise is made up of a combination of broad-band noises and monochromatic features.
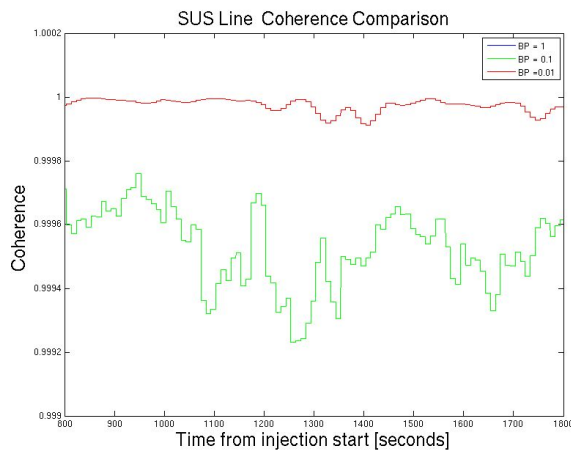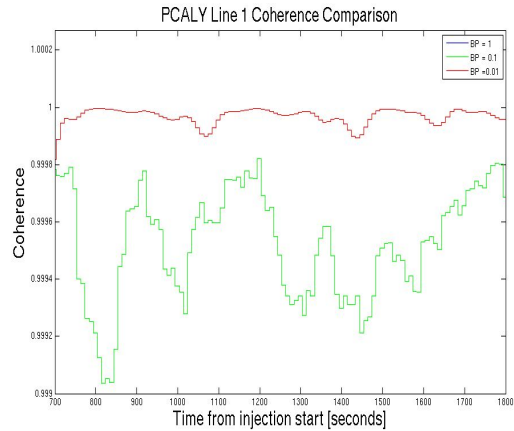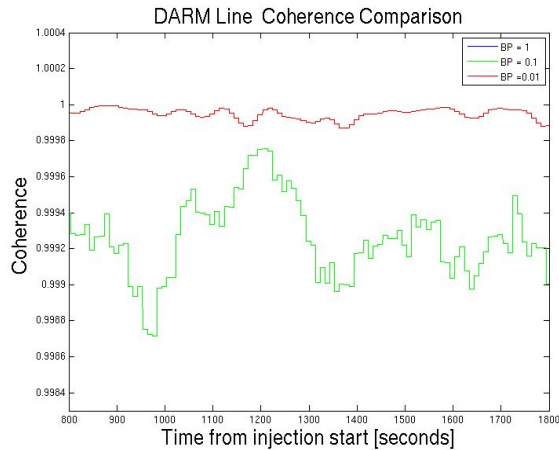
In researching the lines behaviour the uncertainty and coherence were looked at. [1]The coherence measures the power in the response channel (output) that is caused by the power in the reference channel (input). The coherence ranges from zero to one; zero being none of the output power at that frequency is caused by the input and one being the output power at that frequency is caused by the input. The uncertainty is the measure of the deviation of the outcome compared to the actual or predicted outcome.

Graph 1: A log-log graph of uncertainty vs line strength

Line Strength	Front End Coherence	DDT Coherence
0.001	0.266099	0.196279
0.005	0.913806	0.89421
0.01	0.971178	0.958412
0.03	0.993944	0.995268
0.1	0.999409	0.999572
0.3	0.999932	0.999959
0.5	0.999979	0.99999

Table 1: The coherence outcome for the front end and Diagnostic test tool (DDT)

Graphs 2a,b &c: Show the coherence comparison between at different bandpass.

Discussion

The coherence and uncertainty calculation were tested on the front end in real time, so that it can be used on the real time code running the actual interferometer. This helps to draw a conclusion about whether the calibration based on the line is consistent with the prediction or improvements to the models that need to be made.

The computer model that was set up by activating the low pass and bandpass manually. The low pass cuts high frequency and passes the lower proportion of the frequency. The low pass filter is in the sine and cosine bank, where 4th order butterworth filters cuts off frequency of .1 Hz. The band pass cuts out the low and high frequency allowing the mid-range to pass and focuses on the frequency of interest.

To test the calibration past LIGO data stream channel from the interferometer were made accessible, and filters, oscillators and white noise were added to the model that stimulated the interferometer. A test panel was made to change parameters to observe the coherence and uncertainty changes when the line strength was changed. The parameter of the added components were set for the PCAL line 2, where the frequency was set to 331.3 Hz. The PCAL oscillator for sine and cosine was set to 100.0 and the DARM_ERR oscillator line was manipulated overtime to find different plots and outcomes. A white noise generator was turned on in the computer model which was also controlled on the test panel.
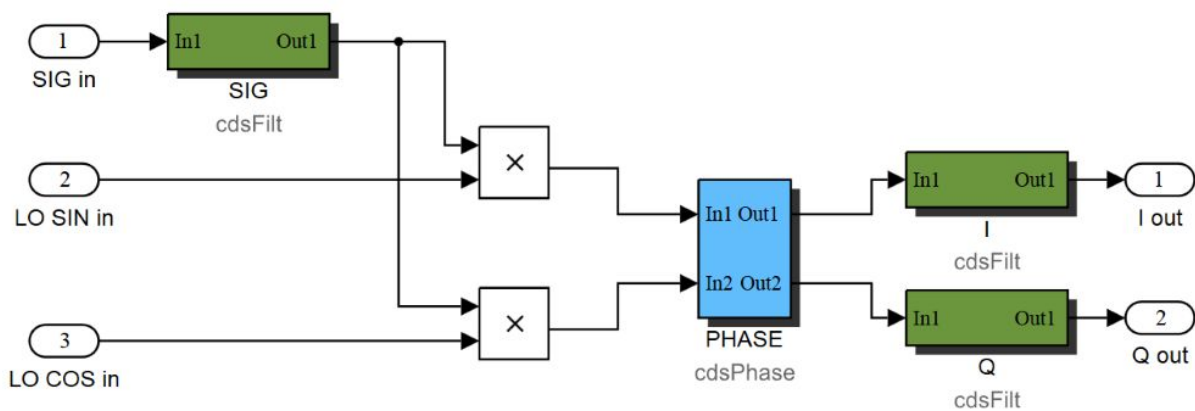

Figure 1: The process of demodulation

The demodulation progress is displayed in Figure 1. The signal goes through the bandpass filter. Then the oscillator sine and cosine multiple it, then they go through a phase filter, the outputs is represented as I and Q, they are low passed. This process demodulates the signal.

 The Diagnostic test tool (DDT), which used Fourier Transform, helped in determining the coherence graphically which was compared to the DARM_ERR/PCAL coherence to make sure they are consistent, this is confirmed when the coherence was approximately 1. This was done to check if the calculation was consistent with the output of the model. The relationship between the uncertainty and the line strength was observed in a log-log diagram which shows a relatively line plot in descending order representing the inversely proportional relationship.

 The second part of the project entailed observing the kappas calculation. This was done similarly to the first part of the project when observing the coherence and the uncertainty. The

new provisions were that three new injections were added. The injection comes from the LIGO interferometer data stream from December and are injected with awgstream. The kappa values and the real and image values observed will the injection is in the process and can be observed later using dataviewer.
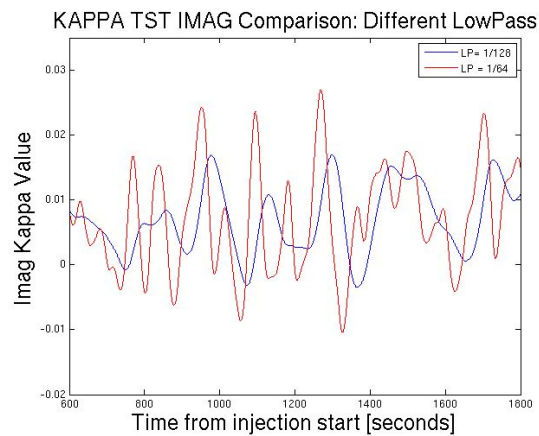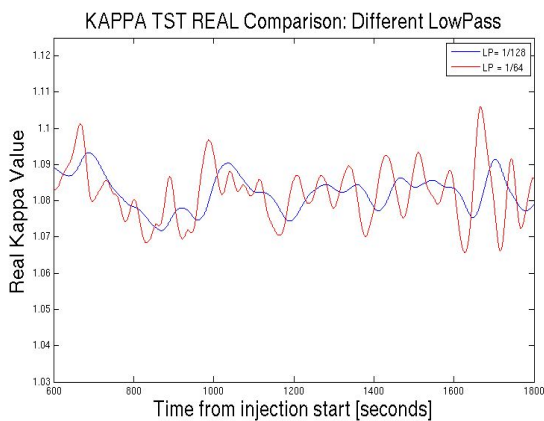
Calculation were done on matlab to compare the model outcomes with the expected values which came from the equation. The parameter of the equation comes from the DARM loop model. The two formulas used to check the kappa values is one for calculating the DARM control actuation.[2]The equation was used the determine the possible amplitude outcome using the DARM line and PCALY line 1 as the reference frequencies.

$$A(f_{ctrl}) = -\frac{\widetilde{d}_{err}(f_{ctrl})}{\widetilde{x}_{ctrl}(f_{ctrl})}\left(\frac{\widetilde{d}_{err}(f_{pcal})}{\widetilde{x}_{pcal}(f_{pcal})}\right)^{-1}\frac{C_0(f_{pcal})}{1+G_0(f_{pcal})}\left(\frac{C_0(f_{ctrl})}{1+G_0(f_{ctrl})}\right)^{-1}$$

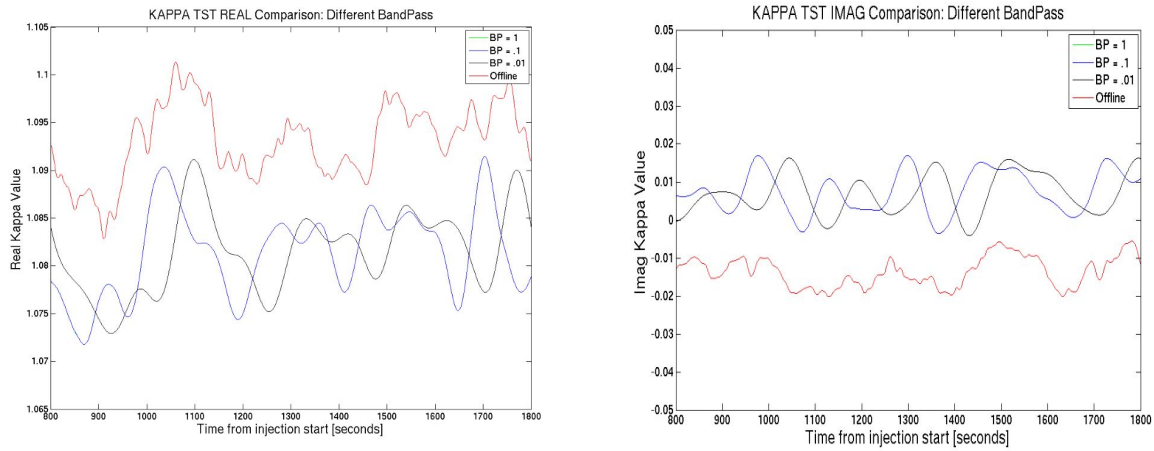**Equation:** Solve for the Amplitude of the DARM control actuation

After using the equation to predict the outcome of the kappa tst channel, the prediction was -2.9327e-16 + 1.4923e-16i. the actual outcome is approximately -3e-16 on the real channel.

The Kappa tst real and imaginary channel was tested at different band pass and different low pass. The comparison was made on a graph. By doing this and observing the different parameters, the effect of different bandpass and lowpass can be observed.
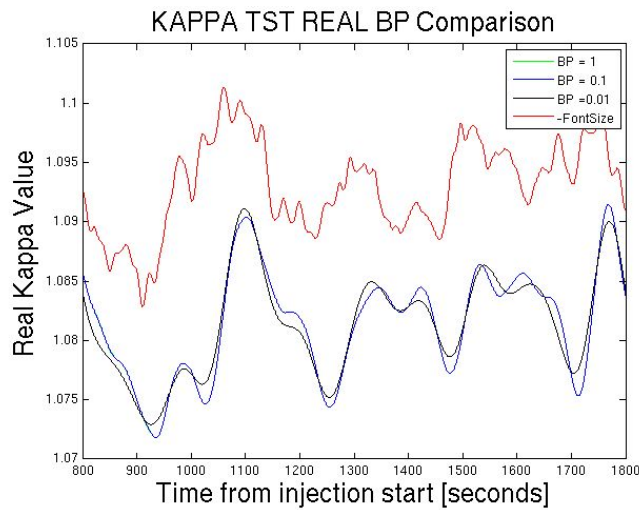

Graphs 3a & b: The kappa tst real and imaginary at different lowpass.

The final low pass change to observe if there is a difference in the kappa calculations . They appear to have consistent relationship with the higher low pass fluctuating more.

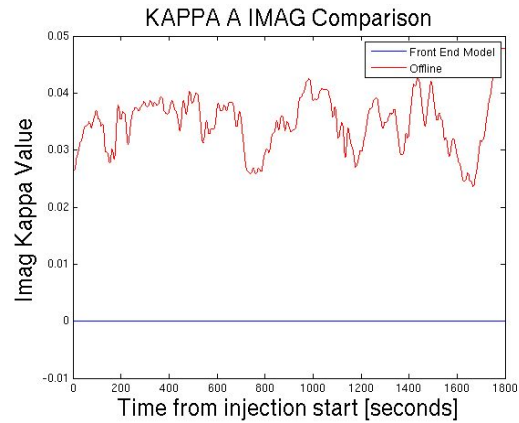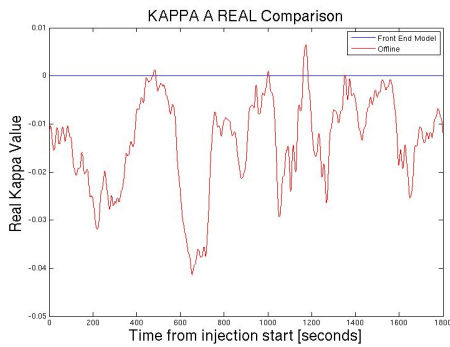**Graphs 4a & b:** The kappa tst real and imaginary channel at different bandpass.
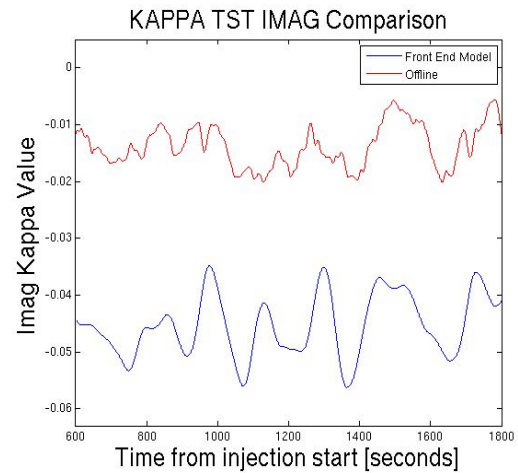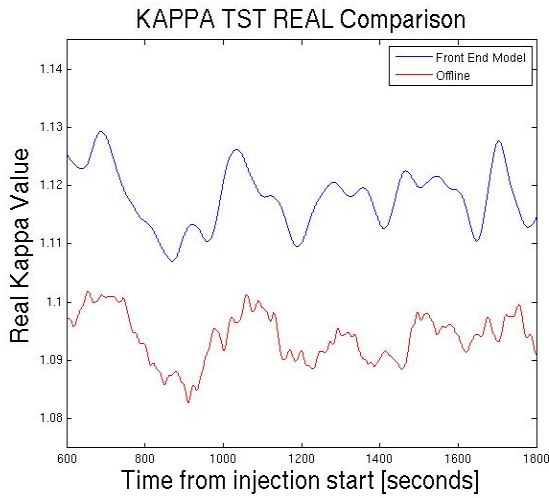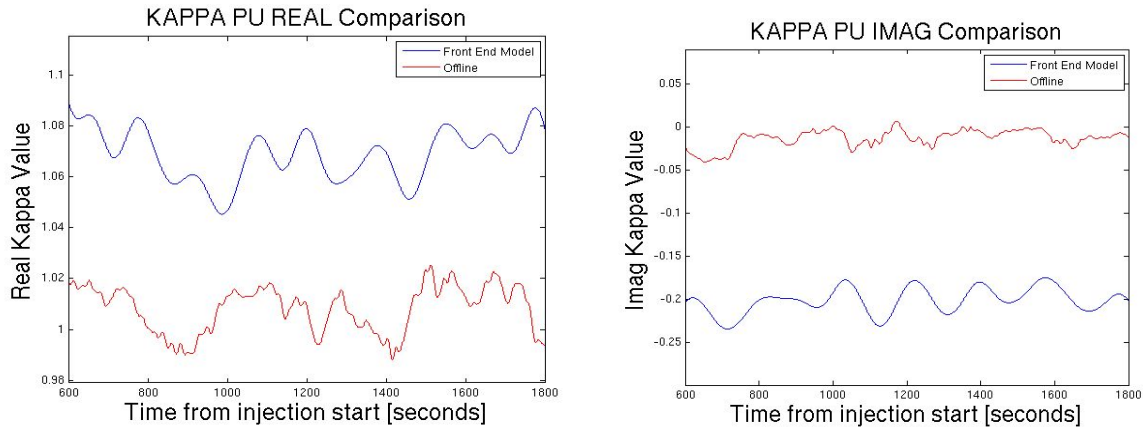

Graph 5: The kappa tst real channel different bandpass with a shift.

The bandpass is originally set to .1. The Bandpass parameter was set to .01, .1, and 1; this was done to observe the effect of the bandpass on the kappa tst calculations. The graph above does not show the line of the bandpass at 1 because it syncs with bandpass at .1. The bandpass of .1 and 1 and indistinguishable. Observing the graphs above there is a noticeable shift between the bandpass of .1 (along with bandpass of 1) and .01. This could be due to a phase difference. The KAPPA TST REAL BP Comparison is the graph were a time shift of 65 was added to the line of

bandpass .1 and 1. This shows that the different bandpasses are consistent with each other and with the offline value. The relationship is visible with a shift.

A bug was detected when testing the calcs model on the front end computer due to the phase between the injected calibration and the lines in calibrated DARM spectra..

Graph 6a,b,c,&d: The graphs show comparison between the front end model and offline kappa values.

The figures above, it shows that the online and offline has a proportional relationship. However they seem to be off by a few percentage points due to the amplitude difference and a phase difference. Red representing the offline value and blue representing the values from the Front end model. However the offline value for the KAPPA_A real and imaginary are expected to wrong, thus giving off false values.

To collect the kappa values from the generated interferometer and compare it to kappa offline values. The online kappa values are collected from the L1-DCS channels. This is a way to confirm that the computer generated interferometer is consistent with actual. The offline data is enough to run for thirty minutes which can be found/retrieved after the injection using dataviewer and the GPS of injection. The model also had missing lowpass over the the kappa values that was added as an accessible button on the model.

With the Front end model that was setup, it now open opportunity to test various line configurations. The model makes it easier test different filter settings and find the best way to monitor the calibration lines. The object is to track lines and improve the output of the interferometer. A similar test will be done on parametric instability lines as done, codes will be tested what track them to determine if the output is consistent with predictions. Observing lines, seeing if the model focuses on a specific line/peak or if switch to another one that is in close proximity and ways to improve the test model.

Future Plan

After finding the correct parameter for filters and correct phases the for the Front end model. The plan is to to use finite impulse response, FIR filters in addition to the currently used infinite impulse response IIR filters. The ultimate goal of the project is to improve tracking signals due to environmental noise and parametric instabilities.

References.

[1] The Fundamentals of Signal Analysis by *Agilent Technology

[2] Tracking temporal variations in the DARM calibration parameters by D. Tuyenbayev and the LSC Calibration Team LIGO-T1500377-v8