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Effects of Transverse Shifts in the LIGO Beam

LIGO Progress Report

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Introduction

The Laser Interferometer Gravitational-Wave Observatory (LIGO) project is an on going effort to measure the gravitational radiation predicted by general relativity. According to Albert Einstein's theory of general relativity, gravity can be thought of as a curvature of space-time. Einstein's theory predicts that when massive stellar objects are accelerated in a sufficient manner, ripples of space time will be emitted from the motion, i.e. gravity waves. These waves should propagate across the universe at the speed of light, but with exceedingly small amplitude. In fact, the amplitude is so small Einstein thought that they would never be detected, and so far his prediction is correct. However, LIGO's sensitivity is becoming very close to the sensitivity needed to detect some of the larger gravitational waves thought to be detectable on Earth [1].

Potential sources for such gravitational waves include: compact binary systems with either neutron stars, black holes, or both; rotating neutron stars; supernovae; super massive black holes; the stochastic background from the early universe and big bang. Detection of gravitational waves from any of these sources would allow scientists a completely new look at these phenomena as well as the first look at a gravitational wave. As of now scientists have only viewed the universe through electromagnetic radiation, or light, and gravitational waves are a different form of radiation which can contain information that is unobtainable from light. In particular, gravitational waves from the big bang would give a first look at the early universe, one that is not possible with electromagnetic radiation [2].

However, the detection of gravitational waves is a very complex and difficult process with many physical hurdles. For example, it was necessary to build detectors at different sites, two in Hanford, Washington and the other in Livingston, Louisiana. Each of the detectors is essentially a large Michelson interferometer, which has two identical arms of 4 km or 2 km each in an L-shape. Each arm has a two mirror cavity, called a Fabry-Perot cavity. There is a laser beam that passes through each of the arms and resonates in the cavities. The idea behind the detector is that it can measure the length of each of the arms very precisely. If a gravitational wave passes through the detector, the arms will change length accordingly and this change can effectively detect the wave. This length change should be around 10^{-19} m to 10^{-17}m, which is about 1/1000 the size of an atom [3].

To measure a distance this small, it is necessary reduce the noise in the system to a value less than this. LIGO is set to detect waves in the frequency range of 100 Hz to 1000 Hz with the highest sensitivity at about 200 Hz [4]. Therefore all types of noise at these frequencies must be dealt with. Figure 1 shows a noise and sensitivity curve generated by SimLIGO for the LIGO detector in Hanford. The graph shows many different sources of noise in the detector between 10 Hz and 10000 Hz. The black curve is the actually sensitivity of the detector which is limited by seismic noise at low frequencies and shot noise at high frequencies. As one can see from the graph, the detector is most sensitive around 10^2 Hz to 10^3 Hz. [4].

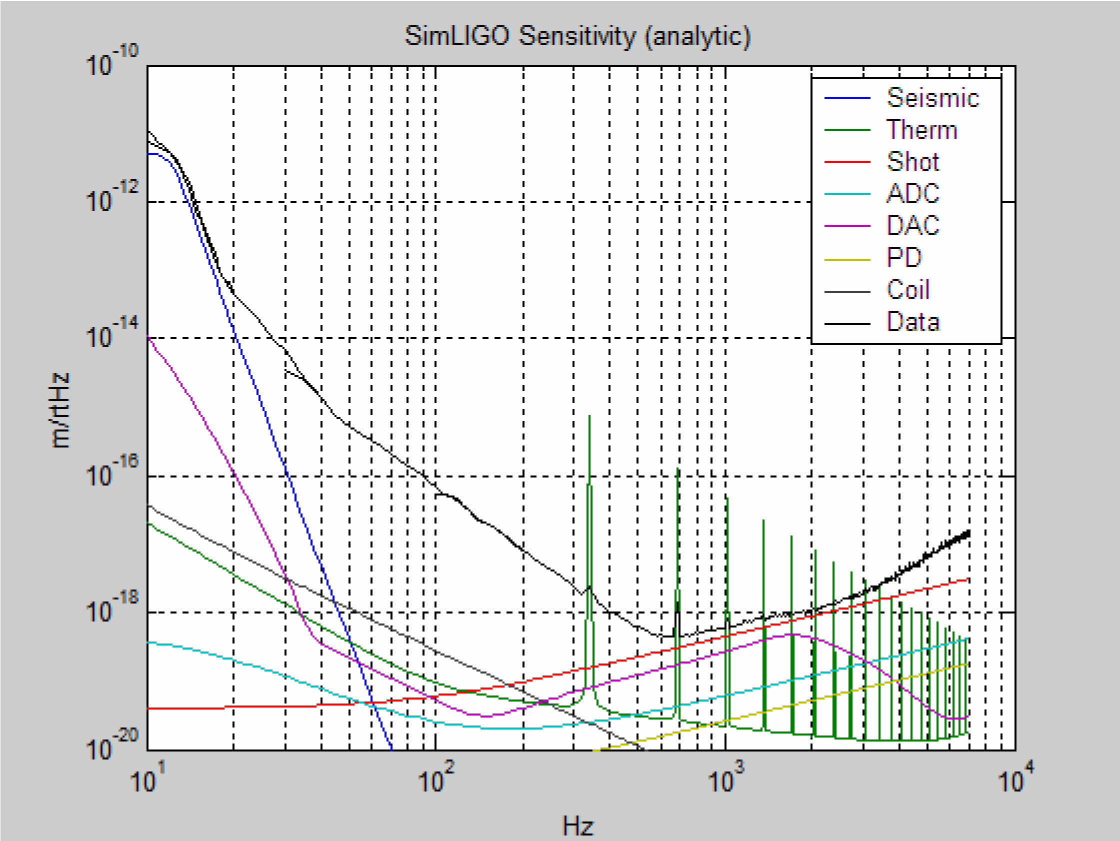

Figure 1: LIGO Hanford sensitivity curve generated by SimLIGO.

SimLIGO

Computer simulations are a convenient way to troubleshoot and test various issues in a detector as complex as LIGO. Thus a complete computer model of LIGO, called SimLIGO, was developed using the End-to-End simulation package. End-to-End, or e2e, is a time domain package which can simulate the spatial and time evolution of the field in the cavities. With SimLIGO I hope to determine the effects in the detector of transverse shifts on the laser beam [5].

Using a model of the Hanford detector, I ran several simulations. The first of which generated the noise curve in figure 1, which represents the unperturbed state since the beam was not shifted. Similarly, a simulation was ran in which the beam was effectively shifted by 1 cm off of the central axis. The sensitivity curve for this perturbed state is shown below in figure 2 and compared with the sensitivity curve for the unperturbed state. It appears from the simulation that such a perturbation would not significantly affect the sensitivity in the detector's frequency range. Also, a situation in which a mirror in one of the arms is shifted by 1 cm was simulated. Such a simulation may become useful because it is believed that one of the mirrors in the actual Hanford detector is misaligned by about 1 cm.

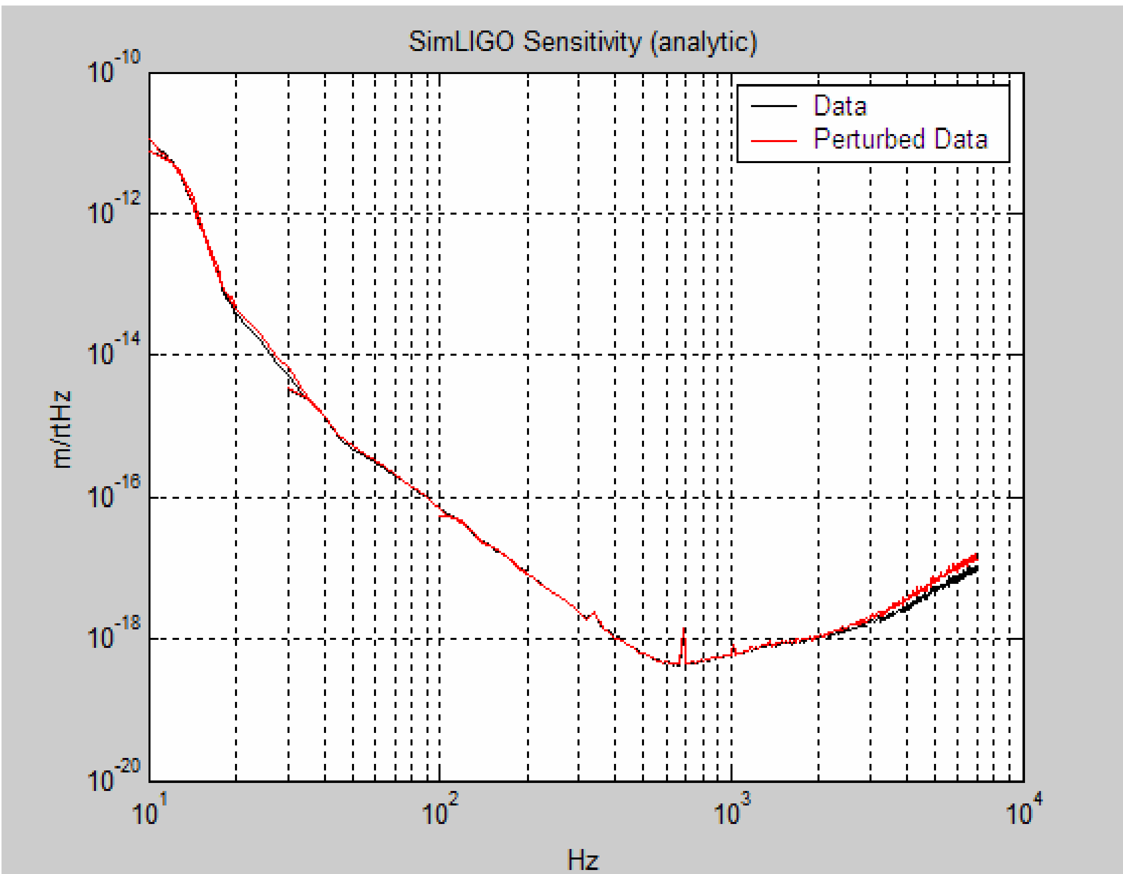

Figure 2: Comparison of perturbed and unperturbed sensitivity curves of LIGO Hanford.

Future Goals

The ultimate goal for my summer project is to determine the effects of shifts in the beam on the detector. If this can be achieved, then we can see if such transverse shifts are negatively affecting the sensitivity of LIGO. In such a case, we will explore ways to negate these effects and possibly improve the sensitivity slightly. To achieve this goal I will run several simulations and analyze the results. Currently I am running simulations in which various mirrors in the detector are shifted either horizontally or vertically. Once the data from these simulations are ready, I can analyze various properties including the beam position on each of the mirrors, the power in various beam modes on each of the mirrors, and the sensitivity curve. More simulations will be done to further explore any findings from these current simulations.

References

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[3] Bhawal, Biplab. *Physics of interferometric gravitational wave detectors*. Pramana, 647, 648 (2004).

[4] Bhawal, Biplab. *Physics of interferometric gravitational wave detectors*. Pramana, 646 (2004).

[5] Bhawal, Evans, Rakhmanov, and Yamamoto. *Time Domain Modal Model in End-to-End simulation package*. 4 (2004).