Noise Budget Development for the LIGO 40 Meter Prototype
Progress Report

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Introduction

The Laser Interferometer Gravitational-wave Observatory (LIGO) is the largest observatory in a world wide network of gravitational wave detectors. LIGO is a Michelson interferometer with Fabry-Perot cavities in its 4 km long arms. When a gravitational wave (GW) passes through the detector, it induces a strain, a fractional change in the lengths of the two arms, that is detected by the presence of light in the anti-symmetric port photo-detector. The anti-symmetric port is dark in the absence of any strain because the light along that path has undergone destructive interference. Currently, there are two GW antennae, comprising one observatory, near Hanford, Washington and a single GW antenna near Livingston, Louisiana. These detectors have a detection band of 40 Hz to 5 kHz for an induced strain of approximately 10^{-20} rms and a few hundred Hz band centered near 200 Hz for a strain of 10^{-21} rms. This corresponds to a displacement of only 10^{-18} m rms or 1/1000th the diameter of the nucleus of an atom over the 4 km baseline.

Due to the ambitious sensitivity goal of LIGO, all possible sources of noise must be identified and understood. Noise sources are divided into two categories: technical and fundamental. Technical noise sources arise due to imperfections in laboratory equipment, e.g. misaligned sensing and control devices and electronics noise. These noise sources can be reduced by incorporating innovative engineering, better equipment, and more precise construction techniques. Fundamental noise sources are those sources that are intrinsic to the detection method. For LIGO, these sources are seismic noise, the interferometer is on the ground; thermal noise, the optics are heated by the laser light; and shot noise, due to the quantum nature of light. To increase LIGO's sensitivity, a second generation of LIGO, Advanced LIGO, is being planned and will be an enhancement of the current design incorporating a more complex optical configuration, e.g. a signal recycling mirror and output mode cleaner, and control system. At the California Institute of Technology, a 1/100th scale interferometer, the 40m IFO, is used as a test platform for the design, testing, and refinement of these new optical configurations and control systems that will be incorporated into Advanced LIGO. As with LIGO, the 40m IFO must identify its experienced noise if it is to meet its design requirements.

The process that determines the amount of signal that a noise source contributes to the gravitational wave data signal is known as noise budgeting. A noise budget is developed by first locating and measuring the noise as it first enters the system (the interferometer and its control and data readout superstructure). Using seismic noise as an example, the locations are the ground support points and the noise measurements can be made by seismometers, accelerometers, or geophones. The next step involves developing a transfer function between the noise input point and the data output point. For the example, the transfer function goes between the motion of the ground to the resulting motion of the optics incorporates the various seismic isolation techniques implemented by the 40m. The final step involves multiplying the transfer function by the measured noise spectra and plotting the result against the data output channel.

Progress

The first noise source considered for the 40m IFO noise budget was seismic noise. The ground noise during the periodic seismically active, the day time, and inactive, the night time, periods were measured using a Wilcoxon 731A accelerometer. The seismic noise spectra were then calibrated and multiplied by the appropriate transfer functions (incorporating the seismic isolation stack and pendulum test mass) to produce a final seismic noise budget. A more detailed description can be found in the attached paper (a first draft of the final paper).

Since the installation of the Input Test Mass X (ITMX), the X arm of the interferometer has experience a larger amount of noise than the Y arm. It has been determined that part of this noise is due to different seismic environments between the X and Y arms. This determination was made after dozen of measurements using the accelerometers and comparing the results of the X and Y arms and expected results. The cause of this difference is still under investigation.

The LIGO sites have a collection of bash scripts and MATLAB programs that automatically produce a noise budget for the detectors. This collection has been modified to run at the 40m IFO.

Problems

The primary problem that I have encountered was learning the complexities of the 40m control system. I have begun to resolve this problem by constantly participating in the daily operations of the 40m IFO, i.e. trying to help resolve problems that arise and assist in the nightly locking efforts. Currently I am able to resolve minor problems and can lock the interferometer using the auto-locking scripts.

The second problem consists of learning MATLAB. I have begun to resolve this by writing MATLAB scripts and using the help option.

Goals

My research goals for the remained of the SURF program include:

- Calibrate the noise budget scripts
- Develop the transfer functions for the noise budget scripts
- Determine the seismic noise difference between the X and Y arms
- Operate the 40m via the control system

Interaction

I have daily interaction with my primary mentor, Dr. Weinstein, that consists of a short update session and have longer (1 to 2 hours) discussion sessions once a week typically around or over lunch. I have constant daily contact with my co-mentors, which consist of post-docs and a graduate student. These are my main sources of assistance in dealing with very specific questions in regards to my project.