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LIGO Hanford Observatory SURF 2017 Noise Investigations: Interim Report 1

The Laser Interferometer Gravitational-Wave Observatory (LIGO) is an experiment dedicated to the detection of gravitational waves. LIGO utilizes large-scale Michelson interferometers (IFOs) located in Hanford, Washington and Livingston, Louisiana. These IFOs have arms that are 4 km long that are oriented at right angles from each other. With a laser beam split to travel down the two arms and back, the interference pattern created by the rejoined beams tells us whether there are any differences in lengths between the two arms. In the presence of a gravitational wave, one the arms with contract and the other will extend due to the perturbation in space-time. Due to the nature of gravitational waves, even some of the universe's strongest waves (from binary black hole mergers) can only create differences in length on the order of 10^{-19} m. This is about one ten-thousandth the size of a proton.

Detecting such an incredibly small fractional change requires an incredible amount of noise reduction. Sources of noise that are accounted for include seismic activity, building tilt due to wind, and vibrations in the fibers that suspend test masses. My two projects for the summer have also focused on noise reduction at the LIGO Hanford Observatory. The first of these projects focuses on investigations of radio frequency (RF) leakage in the Interferometer Sensing and Control (ISC) RF source cabling. These leakages have been suspected to be an underlying cause of frequent losses of laser lock. The second of these projects is investigation into the wandering in one of our atomic clocks in relation to a GPS 1 pulse per second (PPS) control system. So far investigations in both projects have yielded interesting results.

There have been several trips to the Laser and Vacuum Equipment Area with the purpose of investigating RF leakages. The suspect for such leakages have been DC ground isolation units, or baluns. Using an Agilent 4396B RF Analyzer, spectrum analyses were performed on baluns mounted on the ISC racks. Measuring cabling ground to cabling ground across the balun, rather large RF leakages were observed with the largest peaks seen at frequencies supplied by the voltage control oscillator (VCO) that respective baluns were mounted on. One of the highest peaks observed was about -22 dBV at 80 MHz. By making basic modification to these baluns, the peak on the 80 MHz balun was reduced from about -22 dBV to about -42 dBV. This is equal to about an order of magnitude decrease in voltage difference between cabling grounds.

Figure 1a: DC ground isolation unit, or balun

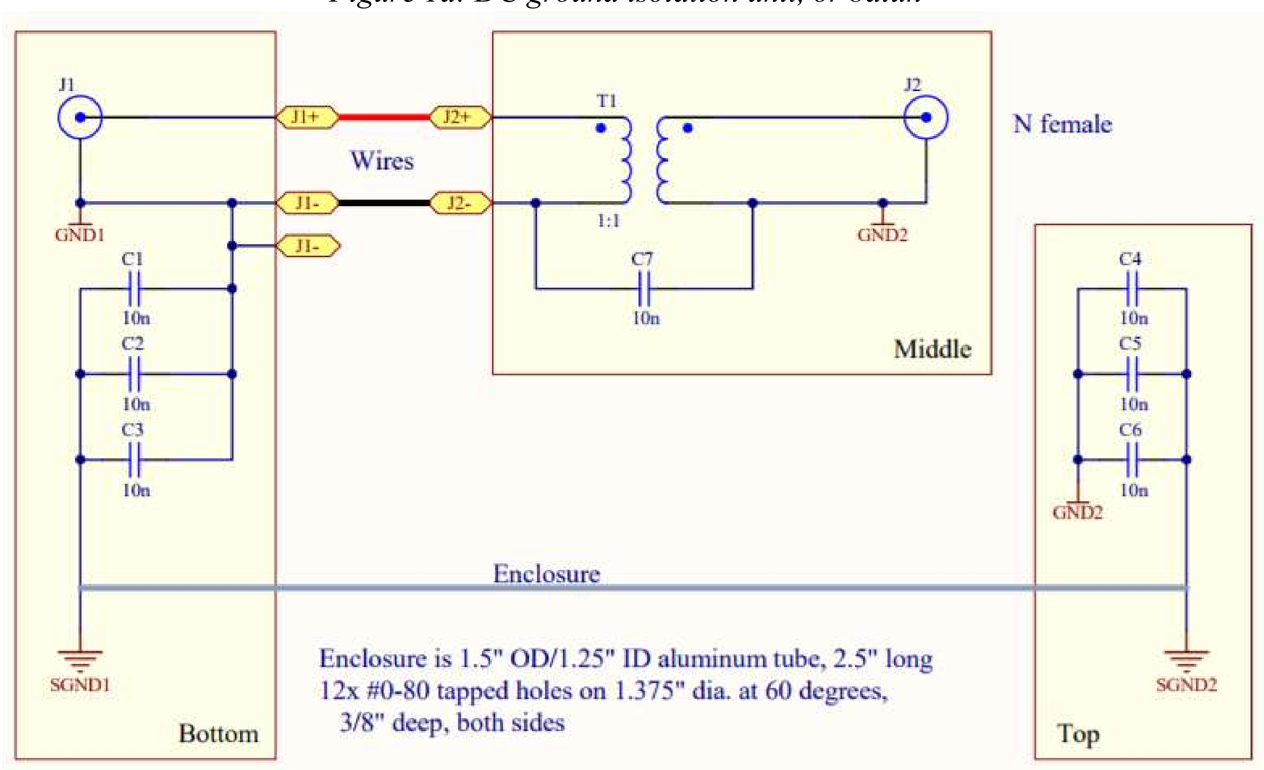

Figure 1b: Balun Circuit Diagram (LIGO-D1101077-v1)

From Figure 1b, we can see that there are two groups of three 10 nF capacitors on either end of the balun. The individual groups are in parallel with each other giving an effective capacitance of 30 nF on each side. The problem is that the two groups are in series giving an overall effective capacitance of 15 nF. We want a large capacitance so that the voltage difference between the cabling grounds on either side of the balun becomes minute, reducing the RF leakage.

This comes from the fact that the impedance Z of a capacitor in an AC circuit is $Z = 1/(i\omega C)$ where ω is the angular frequency of the oscillating voltage supply and C is the capacitance. The higher C is, the smaller Z is. And thus, the voltage difference is decreased as well by Ohm's Law. The modifications made includes replacing one of the plates of three capacitors with a copper plate, a conducting material. This alone increases the effective capacitance to 60 nF. Then, the remaining plate was loaded with more capacitors placed in parallel with the existing ones, thereby increasing the capacitance even more. For the next couple weeks, we intend to improve upon and create more modified baluns, and then identify more baluns on other electronics racks that need to be replaced. Challenges may include unforeseen limits to how much capacitance can be added to the balun.

As for the other project, we are measuring the signal produced by a Model FS725 Rubidium Frequency Standard when triggered using a 1 PPS Timing Master (LIGO-D070011). This is being measured using a Tektronix TDS 3034C Digital Phosphor Oscilloscope controlled using the Instrument Control Toolbox from MatLab run by a computer connected via ethernet cable. Given the slow timescale, it initially appeared as if the phase of the signal oscillated. However, when the horizontal shift of the signal is measured once per second in the long run, it turns out that the signal drifts at a mostly constant rate with some small perturbations.

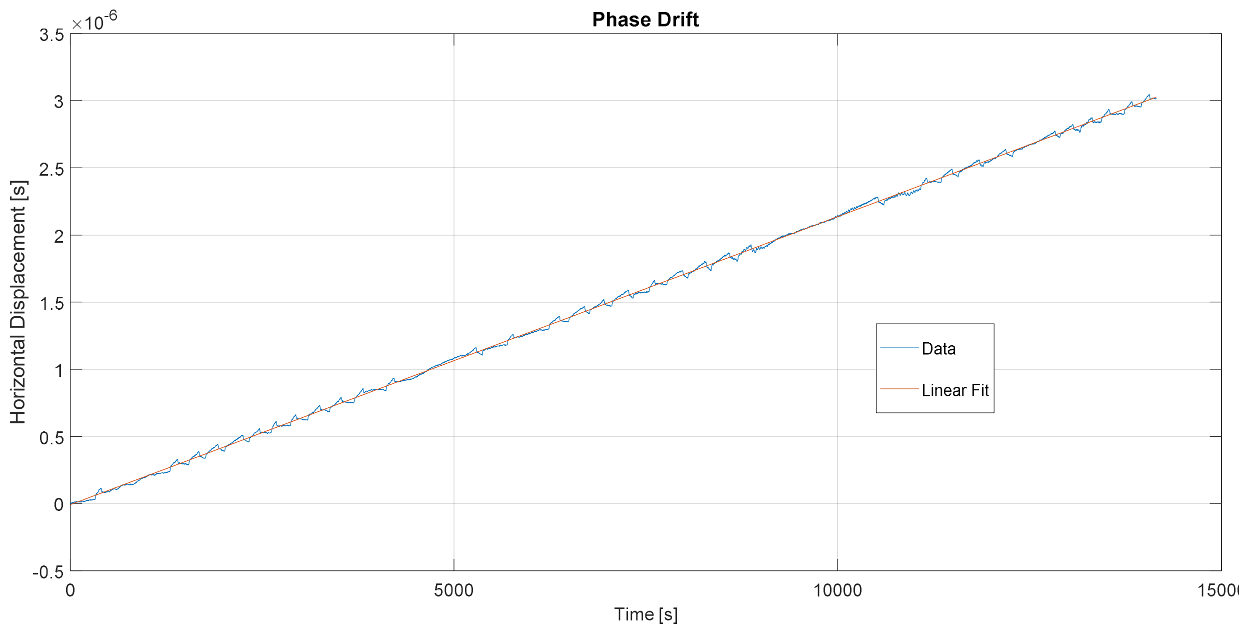

Figure 2: Phase Drift over Time

From Figure 2, we can see that the mean drift speed with time is approximately constant. With a simple linear fit, we have that signal drifts by about 214.48 picoseconds every second. In the next couple of weeks, we intend to perform further data analysis to determine if these movements are random or not. Better insight can be seen by looking at the seemingly periodic residuals of the fit. Further consultation will be needed to determine what the best approach is for analyzing this data.

In both of my summer projects, my mentor Dick Gustafson and I have come to the point to where we can investigate our problems. In the RF leakage project, we have made our own modifications to baluns used on the ISC electronics racks as well as having replaced some. This has resulted in measured decreases in RF leakage. Also, I have finished setting up a data acquisition system for looking at the phase drift of our atomic clock signal. With further research in the next couple weeks, more modified baluns will be created and more candidates for replacement will be identified. Moreover, the noise in the seemingly linear phase drift of the atomic clock signal will be analyzed to determine if it is random.