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LIGO Hanford Observatory SURF 2017 Noise Investigations: Interim Report 2

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 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 electronics 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 modifications 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

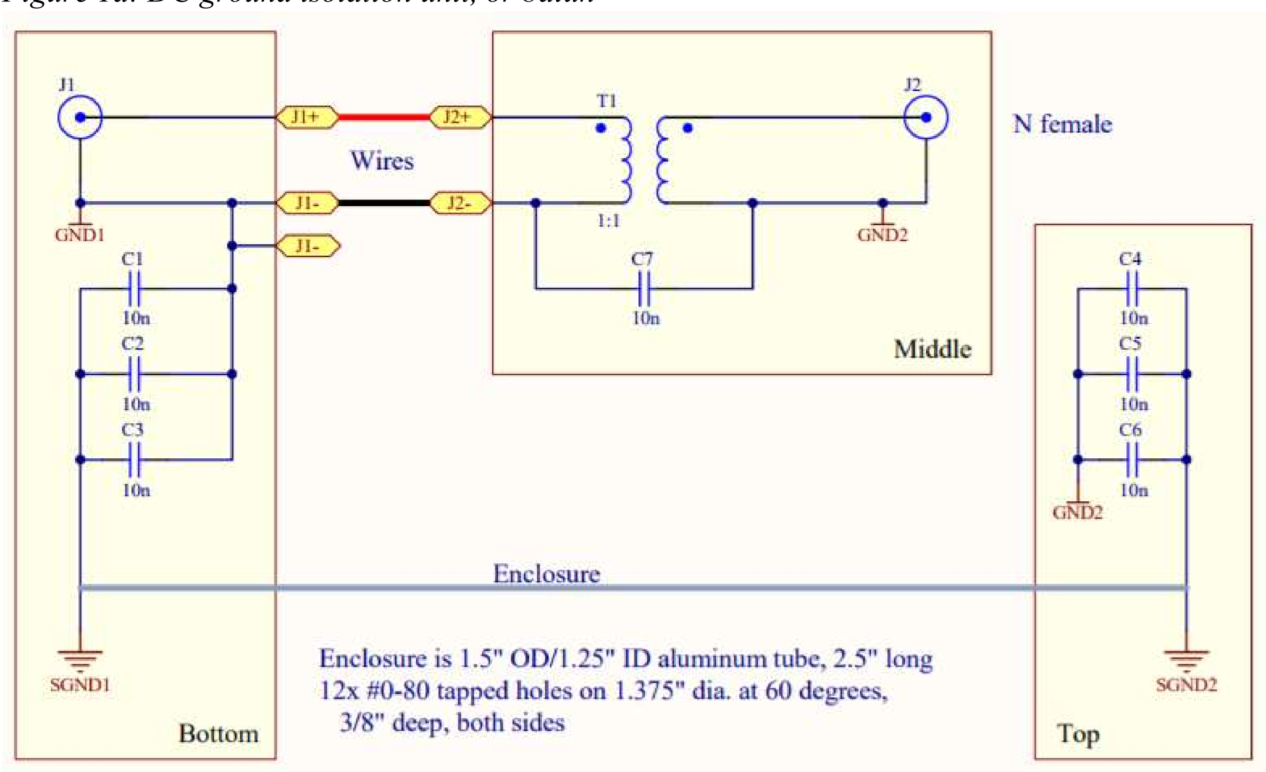

Figure 1b: Balun Circuit Diagram (LIGO-D1101077-v1)

The modifications made were ultimately due to the capacitance along the enclosure. 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. The latest version of this diagram does not have *any* capacitors on it. 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. The decrease in leakage mentioned above was the result of adding three ~1 μF capacitors in parallel with the existing 10 nF ones. So far, we have modified and tested baluns with three and five 47 μF (20% tolerance) capacitors. Each of the baluns, across the frequencies of 200 kHz to 100 MHz, had insertion losses of less than 3 dB and phase delay magnitudes of less than 5˚ as per the testing procedures (LIGO-E1100597-v1). Next, we will be testing these baluns on the electronics racks to see how RF leakage is mitigated in a contaminated environment.

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.

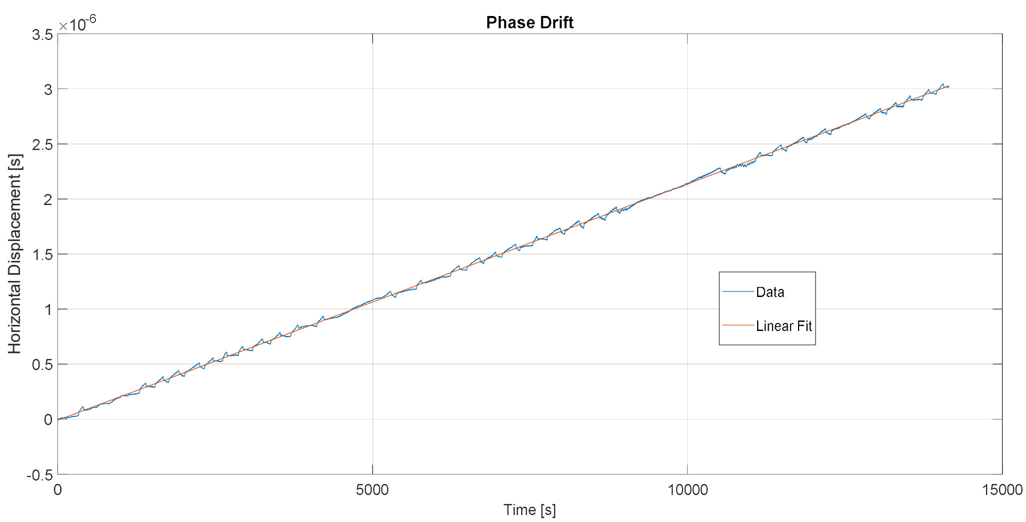

Figure 2: Phase Drift over Time

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. This is most likely due to the slight difference in frequency between the clock and GPS. The more interesting aspect of Figure 2 is the jitter in phase along the best fit line. We know that it is GPS that jitters because when we have several atomic clocks in tune with each other, they jitter in phase with each other against GPS.

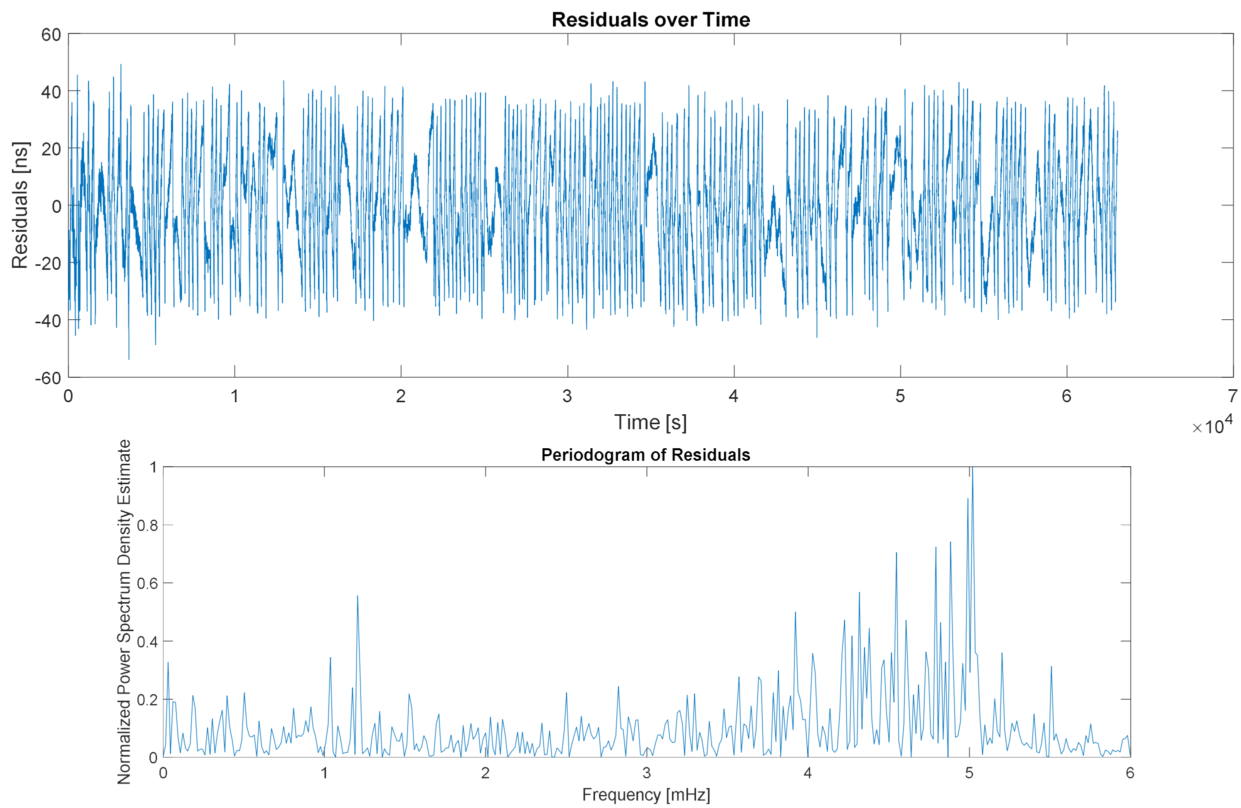

Figure 3: Phase Jitter Away from Linear Drift (above) and Periodogram (below)

From Figure 3, we can see that the jitter seems to be periodic. When plotting a periodogram of the jitter, we see that there are two distinguished peaks: at 5.02 mHz and 1.21 mHz. For the next couple of weeks, we intend to do more research on jitter analysis to find out whether it is deterministic or random. Furthermore, we will acquire two RF oscillator sources and have one disciplined by GPS and the other by an atomic clock. Then, the signals will be mixed so we can analyze the signals beating against each other to gain more insight. The only thing that is setting us back now has been trying to get an RF oscillator source to phase lock loop when disciplined by an atomic clock signal

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 electronics racks as well as having replaced some for testing. 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 tests will be done on baluns with larger capacitors installed. Moreover, the jitter in the seemingly linear phase drift of the atomic clock signal will be analyzed to determine if it is random or deterministic.