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A Laser Microphone

Utilizing the sensitivity of a Michelson interferometer to detect vibrations

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Introduction

The laser microphone is generally used as a surveillance device and is somewhat notorious for its supposed invention and implementation during the cold war period of the Soviet Union. It now serves more as a novelty. There exists many websites devoted to the construction and operation of these fairly simple devices. In our final project, we will attempt to build a laser microphone by first building a Michelson interferometer and measuring the amplitude modulation in the interference fringes that results from the vibrations induced by a sound wave.

Theory

The simplest embodiment of the laser microphone consists of a laser source which is reflected off of a vibrating object. The reflected beam is collected onto a photosensitive detector where the signal is amplitude modulated by the deflections induced in the beam by the vibrating object. This signal is converted into an electronic signal by the detector which can be amplified and transduced back into audio by way of a speaker (in the case of headphones) or recorded similar to a standard microphone. Figure 1 is a diagram illustrating this simplest embodiment.

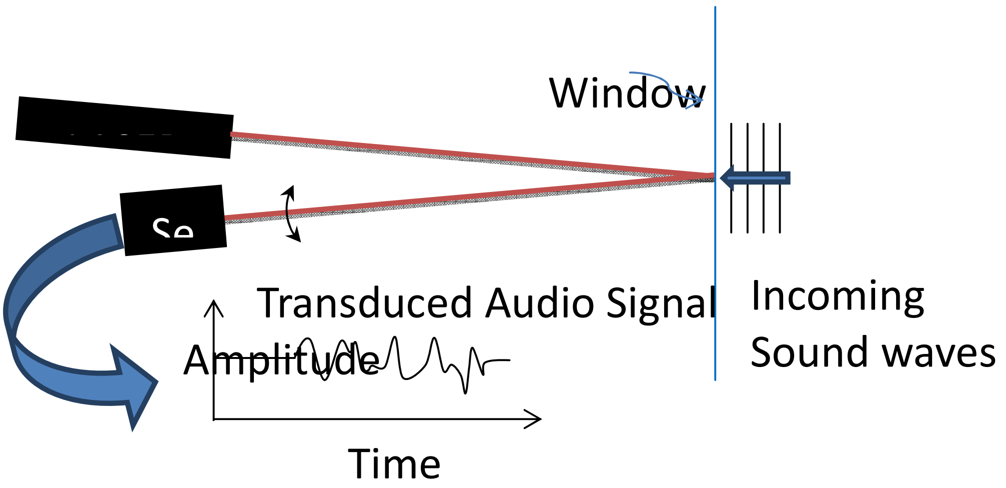

Figure 1 - Simple Laser Microphone

The limitation of this setup is that the sensor position is critical. The laser edge must be positioned such that the amplitude modulation is a result of the beam physically translating across sensor. In this case, the amplitude will increase if more of the beam overlaps the sensor and the amplitude will decrease if less of the beam overlaps. In order to improve upon this design, the signal can be gathered interferometrically. In this case the detector alignment is not as restricted and the sensitivity to vibration is greatly improved. This occurs because of the sensitive alignment of the interferometer where small deviations are easily detected.

The Michelson interferometer produces interference fringes by splitting a beam of monochromatic light so that one beam strikes a fixed mirror and the other a movable mirror. There are two paths from the light source to the detector (see Figure 1). One path reflects off the semi-transparent mirror onto a fixed mirror which retroreflects the path back through the semi-transparent mirror and into the detector plane. The other path is first transmitted through the semi-transparent mirror onto the translating mirror which retroreflects the path back to the semi-transparent mirror which then reflects the path into the detector plane. Small tilts in either mirror will result in added linear phase shifts which shorten the fringe period or degrades the fringe visibility completely. As a result the intensity along a particular cross section of this pattern will be modulated in amplitude in phase with any vibration in either mirror.

Interferometry can be broken down into homodyne and heterodyne detection. The difference is the number of carrier frequencies. For homodyne detection, the most common, the interference is from a single frequency, or monochromatic. For heterodyne, the detection uses the beating between two frequencies. While it is true the HeNe laser has more than one carrier frequency as a result of the many longitudinal modes in the laser, the optical system we will utilize is strictly homodyne detection. That is, the amplitude modulation is a result of the tilt vibrations in the mirror mounts which only requires a single carrier frequency. The beating between the other carrier frequencies is not contributing significantly to the signal.

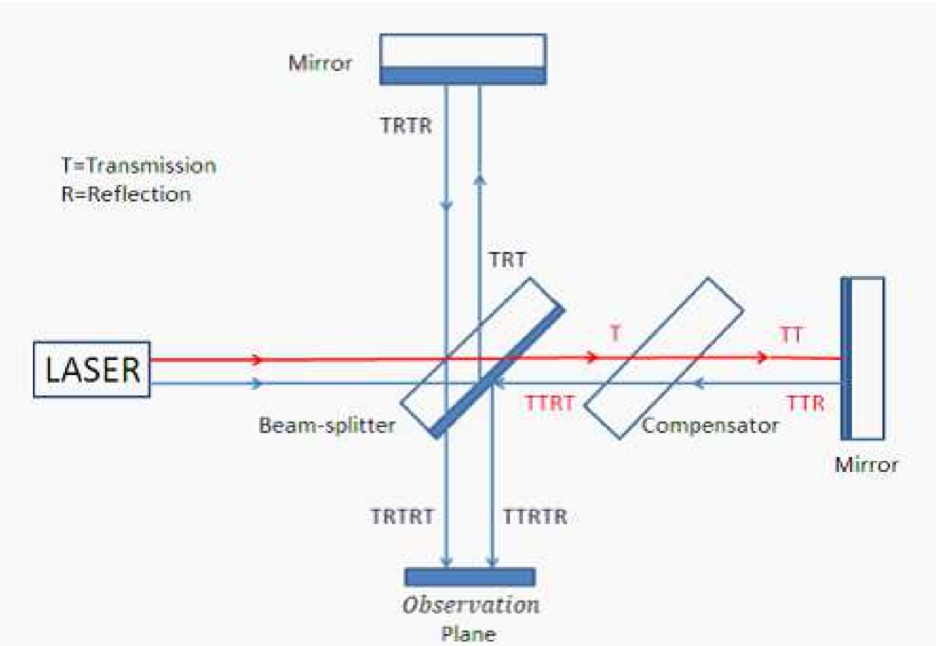

Figure 2 - Diagram of typical Michelson Interferometer

If the fringes are magnified such that detector area is small compared to the fringe period, the intensity of the light inside this area will fluctuate dramatically and proportionally to the induced vibrations on either mirror. This signal can be collected as a temporal waveform which carries the amplitude modulated signal. This signal is a superimposed collection of many frequencies. Each frequency also has a relative amplitude. The power spectrum plots the amplitude of each frequency in the signal. Figure 3 shows the power spectrum of a sample of the rock song “Your Touch” by the Black Keys for example. The waveform on the bottom is zoomed in to show the many frequencies superimposed on one another. This collection of frequencies can be transduced into sound waves by a speaker. If those sound waves fall in a frequency band between 20kHz to 20Hz, the sound can be interpreted by the human ear.

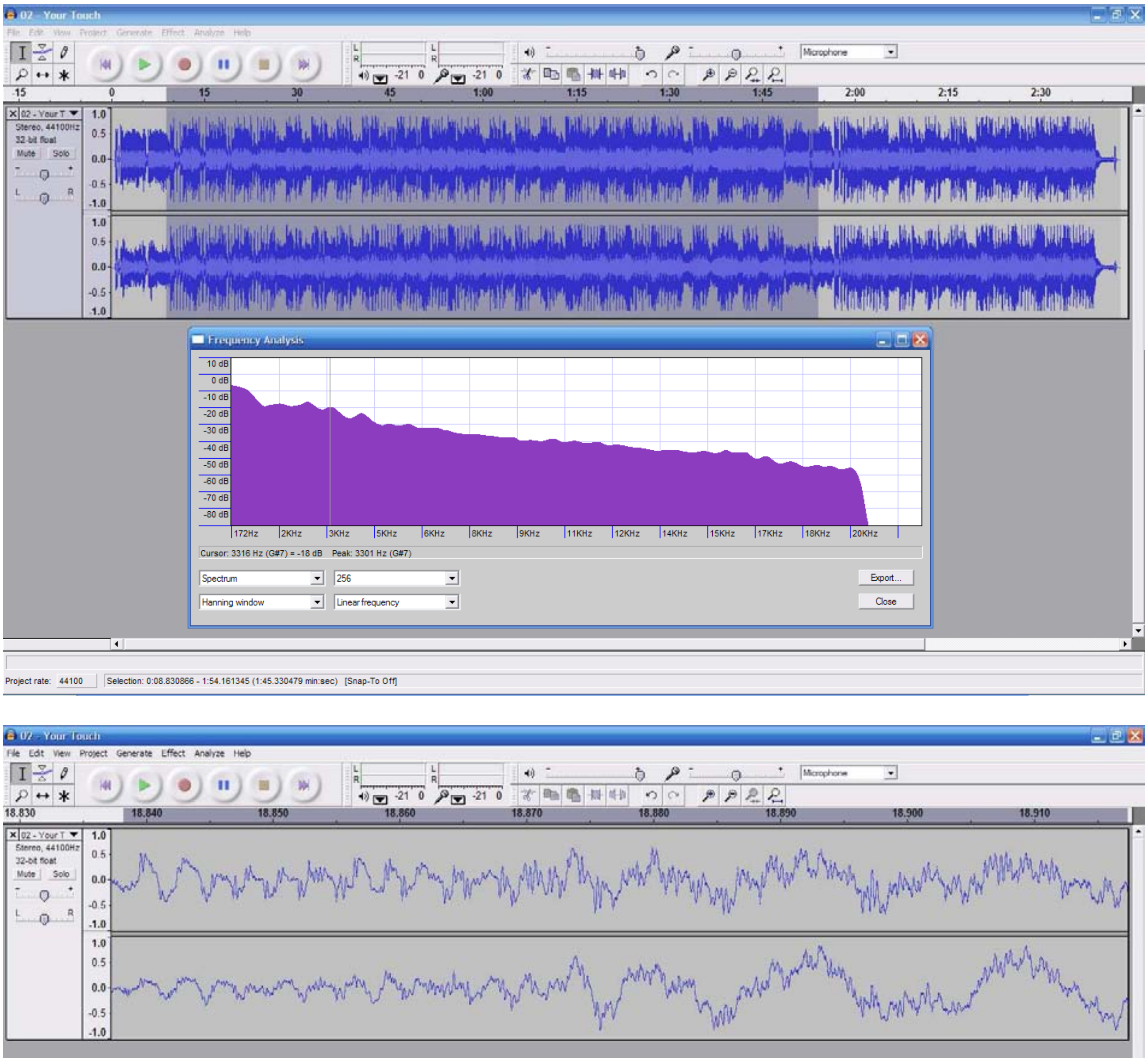

Figure 3 - Screenshot of audio power spectrum analysis

Procedure

Figure 4 illustrates the actual optical setup for our experiment. We were able to find a beamsplitting prism to split a HeNe beam into two beam paths in order to build a Michelson interferometer. Because the coherence length of the HeNe is very long (several meters) compared to the optical path difference in these two paths, the alignment is not overly critical. Interference fringes can be easily obtained with minimal attention to details. We placed a microscope objective in the observation plane to magnify the interference fringes to a size larger than the photoresistor we would be using for a detector. A simple amplifier circuit was acquired from lucidscience.com. The circuit and photo of the detector breadboard are shown in Figure 5. We replaced the headphones in this diagram with a 1/8" audio cable to connect to the 1/8" microphone input of a computer. This allowed us to record the amplitude modulation directly in Audacity, an open source audio manipulation software. Figure 6 shows the optical setup and the fringe visibility of the HeNe in the observation plane after the microscope objective.

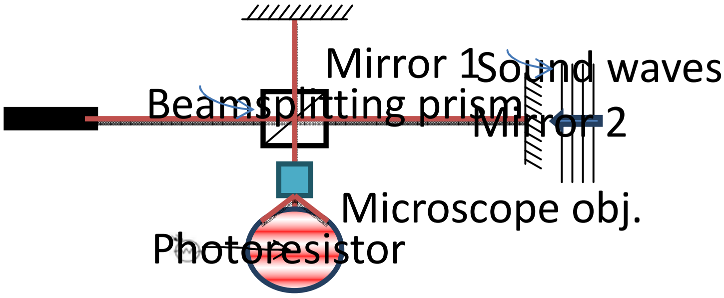

Figure 4 - Optical setup of experiment

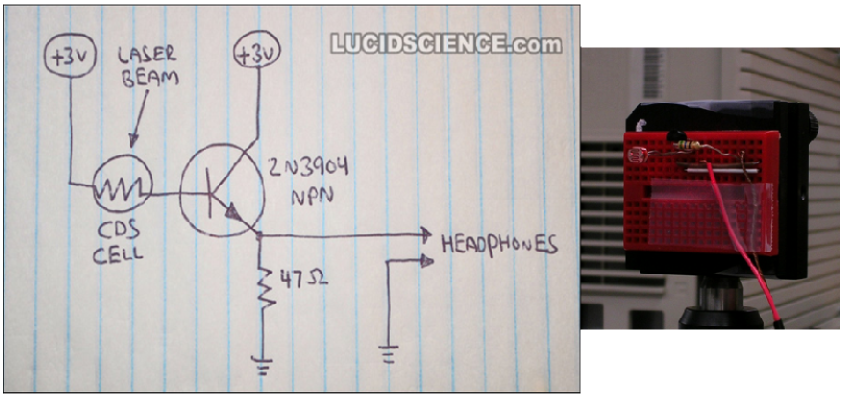

Figure 5 - Photoresistor circuit

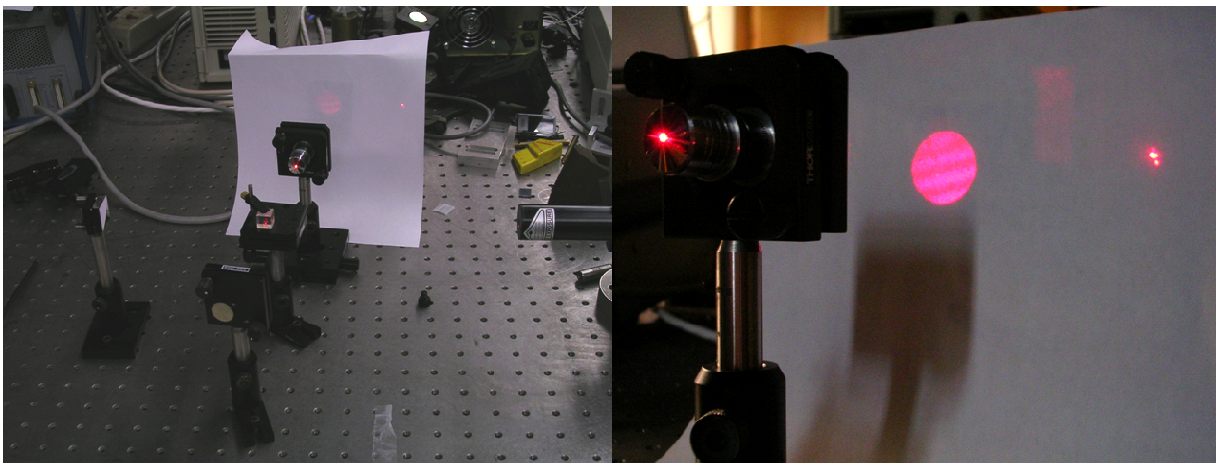

Figure 6 - Photos of experimental setup

Data Analysis

We were unable to collect any real audio with this optical system however, we were able to collect vibrations in the optical table by knocking. The raw data is shown in the top of Figure 7. The signal is very weak. Fortunately, Audacity allows you to amplify the signal in the software and apply bandpass filters. The middle waveform is the amplified signal and the bottom is the amplified signal with an audio frequency bandpass which removes some the DC “baseline” oscillations. These baseline oscillations were a result of the spatial drift in the interference fringes overtime. Audacity measures the difference from this baseline. This is why is it does not matter whether the sensor is located in the fringe null or peak.

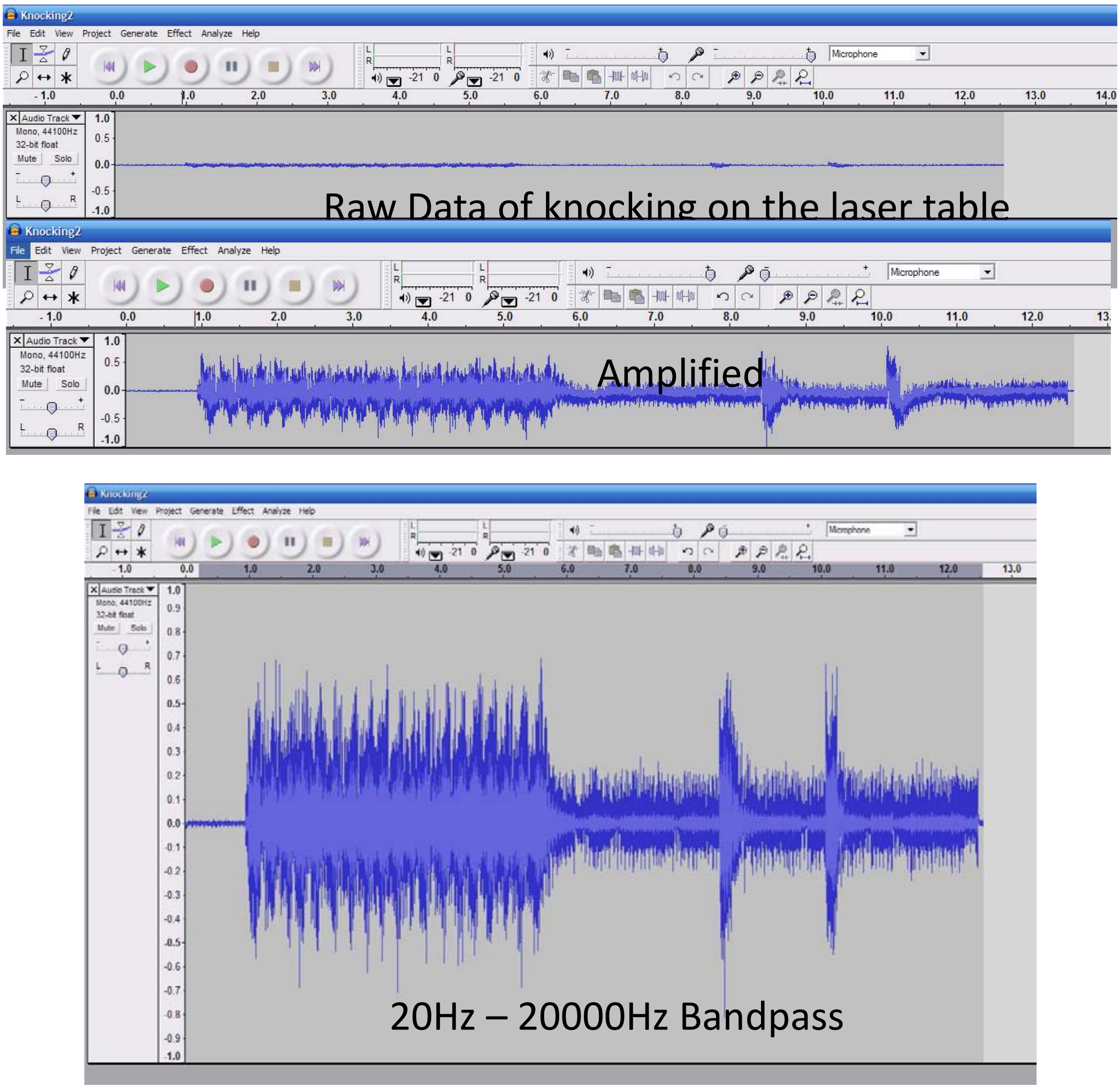

Figure 7 - Audacity screen shots of table knocking

Conclusions

While we were unable to measure music or conversation with this setup, we were somewhat successful in transducing vibration into sound by knocking on the laser table. We believe the most significant problem was due to the optical mounts themselves. These mirror mounts are specifically designed to absorb some vibrational energy. One significant improvement would be to replace one mirror with a pane of glass, or something that can actually vibrate more freely. A second and also significant improvement could be a more sensitive and faster detector such as an amplified photodiode.