# Lab 6: Arduino Demonstration of a Digital Lock-In Amplifier

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## 1 Abstract

This report demonstrates a simple implementation of a lock-in amplifier using an Arduino and LED/photoresistor pair. The results show that the device is able to reliably reproduce the desired signal. The effects of the sample rate on the response time and output oscillation are explored. The lock-in amplifier was also tested using a strobe light to simulate noise at different frequencies, and results show that the device is able to remove noise outside of the 3dB range.

## 2 Introduction

The basic operation of the lock-in amplifier takes advantage of the orthogonality of sine waves to precisely isolate a chosen frequency component from the signal. The signal is multiplied by a provided reference frequency and integrated/averaged to obtain the output.

In the implementation described in this report, the reference signal is applied by multiplying the photoresistor reading by 1 or -1 when the LED is on or off, respectively. This amounts to multiplying the input signal by a square wave oscillating in sync with the LED. When the LED–photoresistor path is obstructed, the input signal is roughly constant, and the output of the multiplication is a square wave centered around 0V. When the low-pass filter is applied to isolate the DC component, the result is nearly 0V. A similar result is obtained when a flashing light shines on the photoresistor at a frequency different from $f_{ref}$, provided it is well outside the 3dB range of the amplifier.

However, when the light path from the LED to the photoresistor is clear, the input signal oscillates between high and low values at the same rate as the reference. As a result, when the two signals are multiplied, the high readings (when the LED is on) line up with the positive portions of the reference signal, and the low readings (when the LED is off) line up with the negative portions, producing a waveform with a positive voltage offset. When the low-pass filter is applied, the amplifier outputs a non-zero DC voltage.

## 3 Results

The input signals from the photoresistor, under dark and bright ambient lighting, are shown below in Figures 1 and 2. Both plots show rough square waves due to the flashing LED, but under bright ambient lighting, the signal amplitude is over 20 times smaller. The offset is increased by 165%, and the amplitude is reduced by about 96%. Due to the increased sensitivity of the photoresistor under darker conditions, ambient light was kept to a minimum for the remainder of the experiment.

With the parameters $f_{ref}$ and $f_{sample}$ set to 5Hz and 100Hz, respectively, the plot shows approximately 10 data points for each peak and each trough.

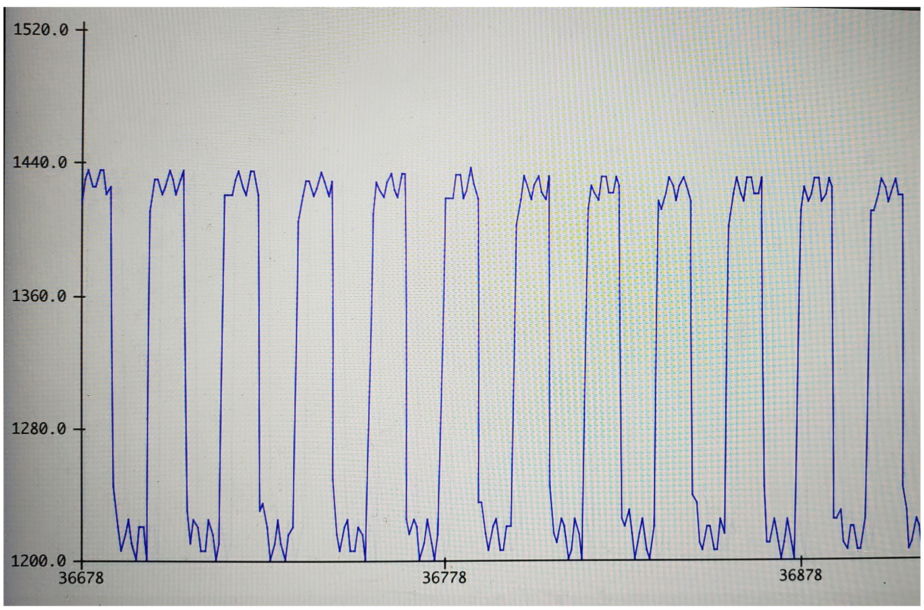


Figure 1: Input signal from photoresistor with low ambient light. The waveform is centered near 1320mV with an amplitude of about 240mV. Parameters $f_{ref}$ and $f_{sample}$ set to 5Hz and 100Hz, respectively.

Figure 3 shows the result of multiplying the input signal with the reference signal, with the path between the LED and photoresistor open. The waveform is offset by around 250mV, indicating that the signal from the photoresistor is oscillating in step with the reference frequency.

Figure 4 shows the output after passing the multiplied signals through a low-pass filter. The reference frequency is set to 10Hz, and the sample frequency is set to 30Hz. The low point in the center, where the output drops from about 200mV to near 0mV, corresponds to the light path being manually obstructed. There is some oscillation in the output signal, likely due to the 20Hz frequency introduced by the multiplication of the 10Hz signal and reference waveforms,

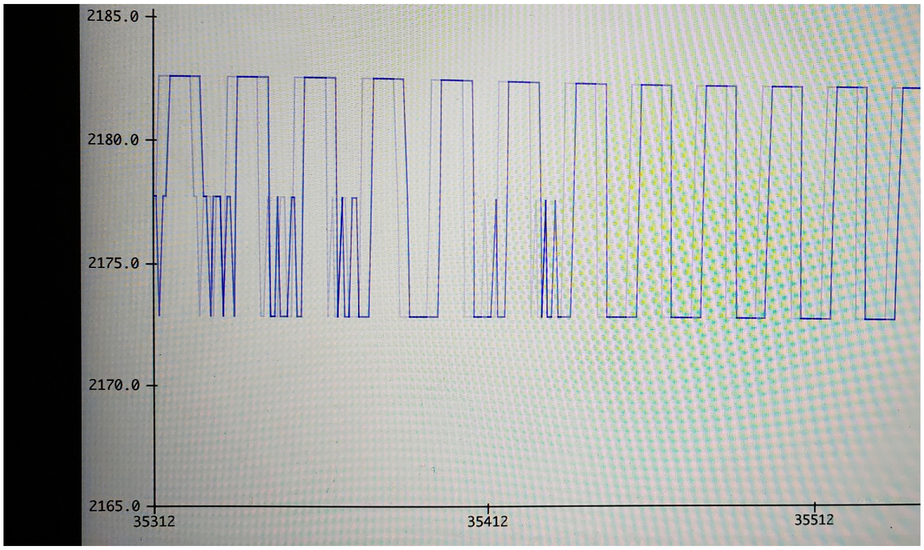


Figure 2: Input signal from photoresistor with high ambient light. The waveform is centered near 2178mV with an amplitude of about 10mV, over 20 times smaller than under dark conditions. Parameters $f_{ref}$ and $f_{sample}$ set to 5Hz and 100Hz, respectively.

but it is small enough that the desired signal is clearly visible.

Figure 5 shows the same process performed with a 20Hz sample frequency. In this case, the 20Hz oscillation from the multiplication process is nearly imperceptible, and while the signal is slightly distorted, it is still clearly visible.

Figure 6 shows that same process with a 90Hz sample frequency. Now the settling time is reduced, but the 20Hz oscillation is much more apparent. The signal from the obstructed light path is still visible, but sample frequencies much larger than this will likely obscure it.

Setting the sample frequency below the reference frequency was expected to disrupt the amplifier's functioning, but it appeared to continue functioning normally when set to 5Hz, with a noticeably longer settling time.

Finally, the sensor was briefly exposed to a strobe light at different frequencies to test its response. With strobe frequencies outside the 3dB range, the lock-in amplifier was able to reliably reproduce the desired signal, while frequencies near the reference obscured it. Plots of this behavior were not saved, and future work should include a closer examination of this behavior.

# 4 Conclusion

This report demonstrates the principle of the lock-in amplifier using a simple Arduino implementation, with and LED and a photoresistor providing the signal. The results show that the system is able to reliably detect the experimenter

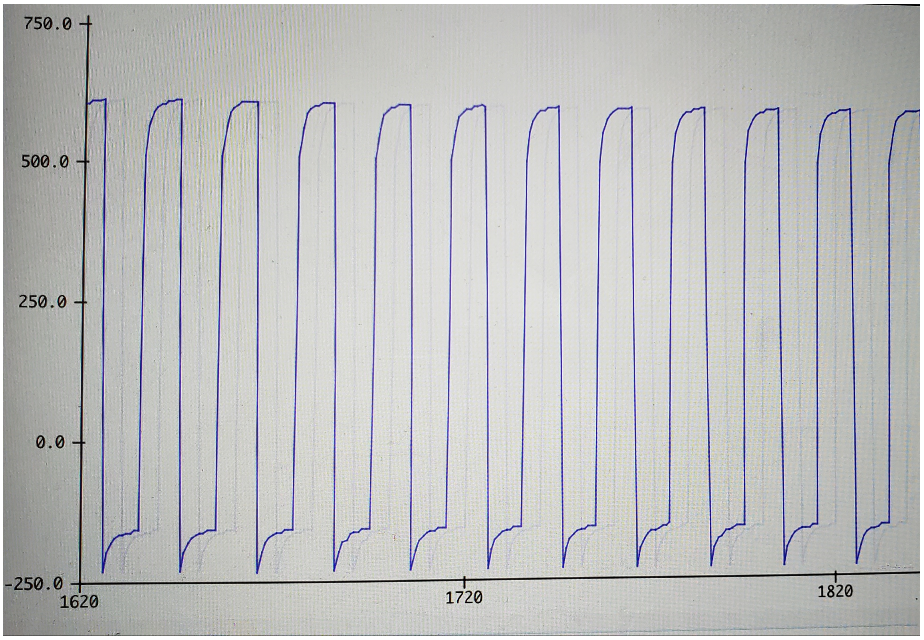


Figure 3: Result of multiplication of input and reference signals, with LED–photoresistor path open.

blocking and unblocking the signal path, with the choice of sample rate affecting both the response time and the amplitude of oscillation in the output.

Exposing the sensor to a strobe light at different frequencies was briefly tested, and revealed that the amplifier was able to reliably detect the signal when the strobe frequency was outside the 3dB range. Future work should involve investigating this effect in more detail and comparing the response curves at different frequencies.

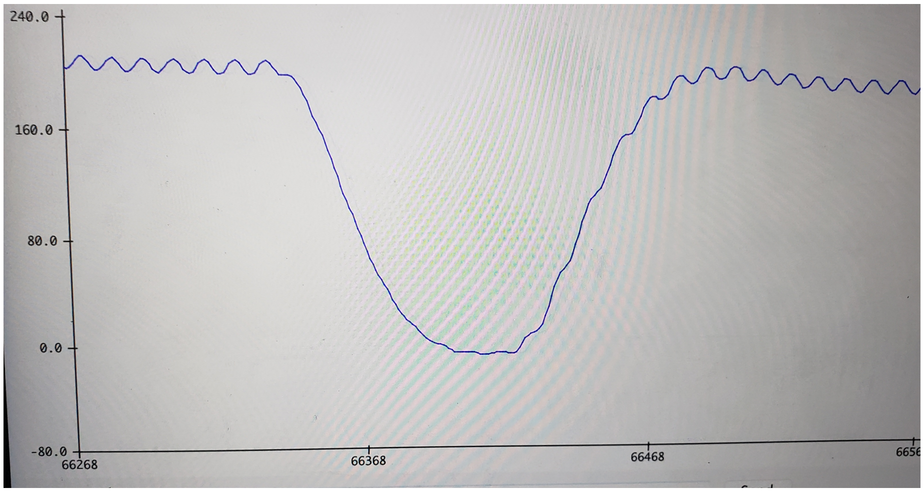


Figure 4: Output after passing the multiplied signals through a low-pass filter with a reference frequency of 10Hz and a sample frequency of 30Hz.

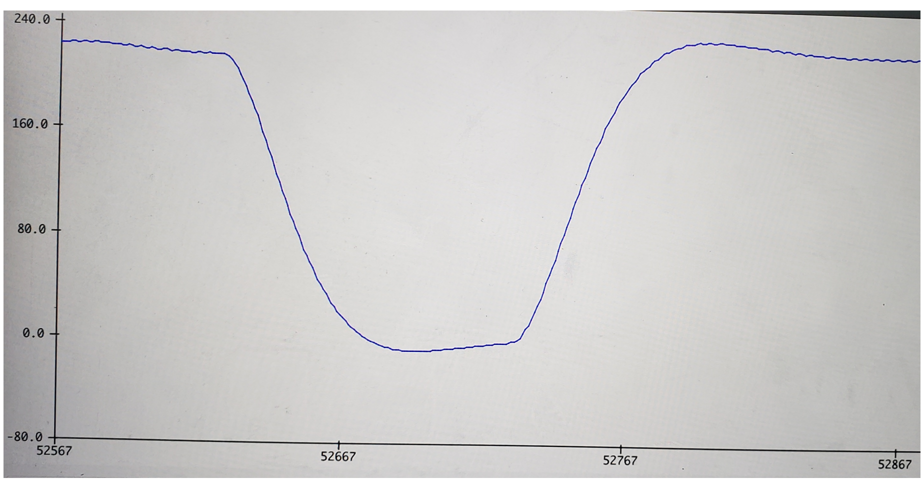


Figure 5: Output after passing the multiplied signals through a low-pass filter with a reference frequency of 10Hz and a sample frequency of 20Hz.

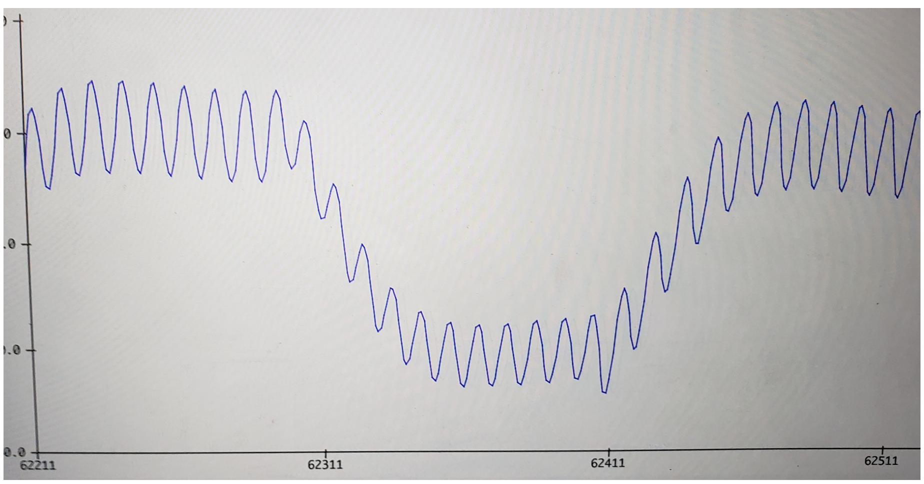


Figure 6: Output after passing the multiplied signals through a low-pass filter with a reference frequency of 10Hz and a sample frequency of 90Hz.