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Lock-In Amplifier

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Abstract

This experiment involved signal detection in the noisy environment with an amplitude detection method. We studied three different setup for an amplitude detection: DC Lab Amplifier, Precision Rectifier, Lock-In Detector. For each setup, we found the maximum distance at which we could detect LED-blinking light with a photodiode. Maximum distances for DC Lab Amplifier and Precision Rectifier were only 5cm and 25cm, while Lock-in Detector gave us a great result in the maximum distance of 5 meters.

Introduction

When the scientists are performing experiments in the laboratories, very often they have to study the signal that they receive. Unfortunately, sometimes signal is not clear and comes with a lot of unwanted noise. In almost all the laboratories one can find a lock-in amplifier, which is an electronic instrument that can extract even small signal from the unwanted noise or background interference. Lock-in amplifier enhances the signal-to-noise ratio by decreasing the unwanted noise, which allows us to get more precise measurement of the signals [1].

To know what happens to the signal as we feed it thought the setup it is important to know how each component of the setup affects the signal. Preamplifier amplifies voltage of the signal to a level where noise voltage does not significantly affect the final output of the signal-to-noise ratio [2]. In the bandpass filter, we can select specific range frequencies that will pass on to the output. If we select a higher quality factor Q we decrease the band, therefore we decrease the range of frequencies that are passed on. Filter increases signal-to-noise ratio by cutting of the unwanted noise in the frequencies outside that range. Amplitude detector, which is also known as a precision rectifier, simply converts AC signal to a DC signal. Lock-in detector also acts as a rectifier but it output depends on the phase of the reference signal with respect to the input signal [2]. We use phase shifter to adjust the phase of the reference signal.

In this experiment, we studied three different types of a signal processing setups for amplitude detection: DC lab amplifier, Precision rectifier and lock-in detection. For all the setups, we get an output from the Low-pass amplifier, which averages the signal coming into the amplifier. However, each setup does different signal processing before passing the signal through the Low-pass amplifier. DC lab amplifier just feeds signal through preamplifier. In Precision rectifier and Lock-in detector, signal goes through preamplifier, Filter and Detector prior entering low-pass amplifier. The difference between those setups is that Precision rectifier uses amplitude detector, while lock-in detection uses lock-in detector. We observed the averaged signal on the oscilloscope and detected how amplitude of the signal changes as we switch the signal on or off. In this experiment for each setup, we were investigating what is the maximum distance in between LED and photodiode, for which we can detect the signal with a lock-in amplifier.

Procedure

The main equipment for this experiment are Tektronix TDS 1002B Dual Trace Oscilloscope and TeachSpin SPLIA1-A Signal Processor Lock-in Amplifier. We used regular RG-58 BNC cables and BNC connectors for the signal transmission. Our signal for this experiment was a green LED blinking at the constant frequency. We used a square wave signal from the reference oscillator to power the LED, which essentially powers it up only 50% of the time. We choose the amplitude to be high enough to make LED bright. The noise of this experiment was the room light, which comes from the windows and lamps, as well as the shades that are produces by the experimenters moving around the setup. The photodiode was connected to the preamplifier positive input to receive the LED signal.

As it was mentioned in the introduction, each of the amplitude detectors requires different setup. The block diagram on Figure 1 is the schematic for the DC Lab Amplifier setup. For this setup one just has to assemble the setup, feed the signal to the photodiode and observe the output on the oscilloscope screen.

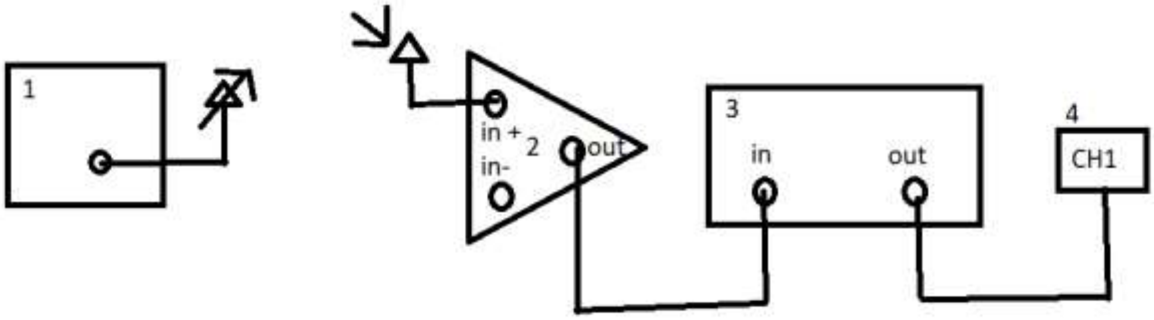

Figure 1: Block diagram for DC Lab Amplifier amplitude detector. 1 – Reference Oscillator, 2 – Preamplifier, 3 - Low-Pass Amplifier, 4 – Oscilloscope.

Precision Rectifier setup has more complicated configuration and it is shown on Figure 2. Before assembling the setup, we had to tune the filter to the signal frequency. To do so, we used BNC tee on the output of the reference oscillator and fed the signal to the filter as well as to the Ch2 of the scope. We connected the output of the filter to Ch1 of the scope. While observing both signals on the scope we adjusted the filter frequency until the phase on both signals on the scope matches. It is better to do filter tuning on high Q values for a better precision. We did out tuning for Q=20 because on the higher Q values we observed clipping on the output signal. We also checked the value of the detector to make sure the signal is rectified. Only after all the preparation and checking we assembled the setup and started taking our data.

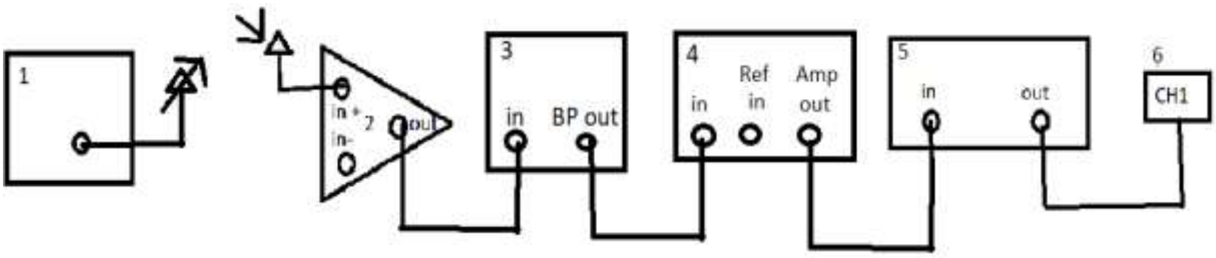

Figure 2: Block diagram for Precision Rectifier amplitude detector. 1 – Reference Oscillator, 2 – Preamplifier, 3 – Filter, 4 – Detector (Amplitude detector), 5 - Low-Pass Amplifier, 6 – Oscilloscope.

Lock-in detection setup is very much like the Precision Rectifier except we are using lock-in detector instead of the amplitude detector. In addition, Lock-in detection required a phase shifter to make sure that the reference signal that is passed to the detector is of the same phase as the input of the detector.

The setup for Lock-in detection amplitude detector is shown in Figure 3. Before connecting the phase shifter into our setup, we tuned it with the filter output signal. Our filter was already tuned from the previous setup. Phase shifter takes signal from the reference oscillator phase output. We connected phase shifter output to the Ch2 of the scope, while connecting filter output to the Ch1 of the scope, and adjusted the phase knob to match the phases of the two observed signals on the scope. As soon as we were done with tuning, we assembled the setup and started taking our data.

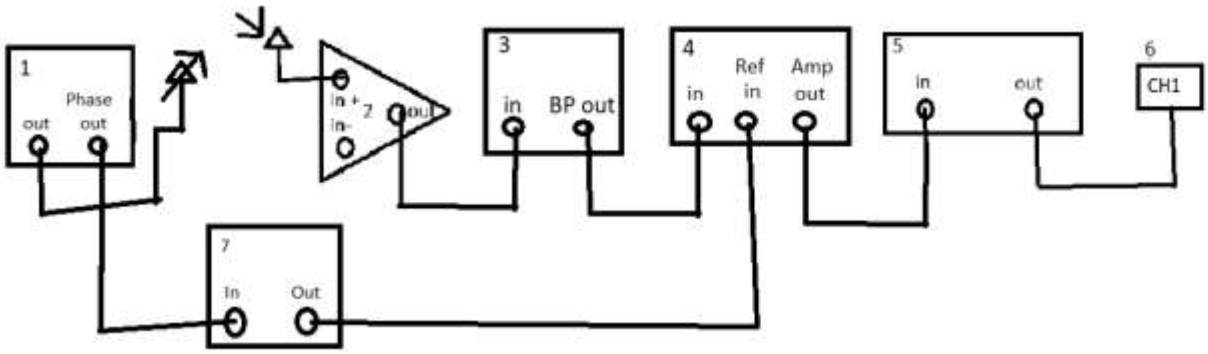

Figure 3: Block diagram for Lock-in detection amplitude detector. 1 – Reference Oscillator, 2 – Preamplifier, 3 – Filter, 4 – Detector (Amplitude detector), 5 - Low-Pass Amplifier, 6 – Oscilloscope, 7 – Phase Shifter.

For each of the setup described above we performed the same experiment. My partner was aiming the LED directly to the detector and measuring the distance between them, while I was observing the signal on the scope. As we turn the signal on/off by using the attenuation toggle switch, we could observe the amplitude change on the scope. If amplitude does not change, that means that signal is too weak comparing to the noise, so we cannot detect it. We performed this experiment for each setup and recorded the maximum distance at which we could detect the signal for each of the amplitude detection setups. For the higher distances, I had to increase gain on the Lock-in amplifier as well as significantly zoom in the signal on the oscilloscope to observe the amplitude change.

Results

First setup that we tested was DC Lab amplifier and we perform experiments for 1cm and 5cm distances between the LED and photodiode. With DC Lab Amplifier setup, we could not observe amplitude change in the signal on the oscilloscope beyond 5cm. For the Precision Rectifier we performed five measurements with distances 1, 5 10, 20 and 25 cm. We could not extract a signal on the distances above 25cm; therefore, we stated that this is the maximum distance for DC Lab Amplifier that we could achieve. Lock in Amplifier was the most challenging and most successful. We got data for many distances starting with 1cm and ending with the maximum distance of 5 meters. Extracting the signal on the high distances was harder because we had to increase the gain of a lock-in amplifier, which also increased the noise level along with the signal strength.

Conclusion

The results of this experiment show that the simple DC Lab Amplifier is not effective for a signal detection in the noisy environment. Precision rectifier can be used to detect the signal on the distances that do not exceed 25cm. The application of the Precision rectifier might include signal detection at the doorway. The best setup for signal detection is a Lock-in amplifier that allowed us to detect LED signal up to 5 meters distance in the noisy environment. The results for this experiment show that Lock-in amplitude detection is a very powerful tool for extracting signal in the noisy environment.

References

[1] “Lock –In Amplifier Tutorial” for PHY-431 Advanced Physics Laboratory (Le Moyne College, Physics Department, Syracuse, 2009).

[2] “TechSpin SPLIA1-A Lock-In Amplifier: Specifications and Reference Document” (Le Moyne College, Physics Department, Syracuse, 2009).