Lock-In Amplifier

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Abstract

Two of the main objectives for the Lock-In Amplifier experiment were to gain an understanding of how a lock-in amplifier works, and how to use one. Upon completion of these tasks, the photodiode used for the experiment was determined to be operating in the linear range. This was completed by comparing the voltage reading from an oscilloscope to the wattage reading from a power meter. Once linearity was determined, the frequency response of the photodiode was measured to determine at what frequency of the chopper the photodiode could no longer record the light pattern precisely. Finally, observations were made to establish the relationship between the intensity of the laser and the frequency response of the photodiode.

The frequency response of the photodiode used in this experiment was measured to be below approximately 85 Hz.

Introduction

Lock-In Amplifiers are extremely important for the detection and measurement of tiny AC signals. What makes them so useful is their ability to discriminate between the signal and any noise associated with it. This is done by using Phase-Sensitive Detection (PSD), which takes advantage of a reference frequency. Since most experiments use a fixed frequency, a function generator or oscilloscope can be used to supply the Lock-In with such a reference. The lock-in multiplies the original signal by the reference frequency using PSD. Mathematically, this is expressed as follows:

$$V_{psd} = V_{sig}V_L\sin(\omega_r t + \theta_{sig})\sin(\omega_L t + \theta_{ref})$$

Which, by using trigonometric identities, results in two separate AC signals, one being the differences in the frequencies, and the other being the addition of the two.

$$= \tfrac{1}{2} V_{sig}V_L\cos([\omega_r - \omega_L]t + \theta_{sig} - \theta_{ref}) - \tfrac{1}{2} V_{sig}V_L\cos([\omega_r + \omega_L]t + \theta_{sig} + \theta_{ref})$$

The frequencies of the two signals are $(\omega_r - \omega_L)$, the difference frequency, and $(\omega_r - \omega_L)$, the sum frequency. However, when the frequency of the input signal and that of the reference are equal, the difference component becomes a very useful DC signal.

$$V_{psd} = \tfrac{1}{2} V_{sig}V_L\cos(\theta_{sig} - \theta_{ref})$$

At the output of the PSD, a low pass filter is used to block out all unwanted AC signals and noise components. When the input frequency and reference frequency are dissimilar, their resultant AC signals are among those blocked. The bandwidth of these low pass filters can be adjusted by setting the time constant. Increasing the time constant provides an output that is steadier and easier to measure dependably. The catch of this shows up when actual changes in the input signal take multiple time constants to be seen in the output.

Also with the output of the PSD comes the question of the amplitude of the DC signal. This is controlled by the dynamic reserve of the PSD. The dynamic reserve modifies the voltage of the noise signals both coming in and going out. The noise associated with a dynamic reserve of 60 dB can be 1000x (60 dB) higher than a full scale signal. With this dynamic reserve, the input signal can only be about 5 mV, and since a PSD does not normally have a gain, the output would also be just a few milli Volts. To boost this up to a 10V output, the DC gain needs to be approximately the same as the dynamic reserve. Any offset in the two can result in very large errors. To not affect measurements, it actually needs to be on the order of 10 μV. Because of this, analog lock-ins perform poorly when it comes to very high dynamic reserves. A digital DC amplifier, however, has no input offset, since amplification is just taking the input numbers and multiplying by the gain.

Apparatus

The primary equipment used in this experiment are listed below:

-HeNe Laser
-Mechanical chopper
-Photodiode
-Lock-In Amplifier
-Oscilloscope
-Light intensity power meter
-Light filters
-3M Scotch tape

I. Determination of Linearity range for the Photodiode

Method

The first thing done in this process was to position the equipment accordingly (see lab book). The location of the oscilloscope and the lock-in amplifier are not important, but the photodiode, chopper, filters, and laser must all be in line. Also, the power meter must be placed in line with the laser beam and all the rest, albeit for a short time. A small piece of 3M Scotch tape was place on the front of the tube for the photodiode to spread the laser beam in effort to prevent saturation.

Upon proper positioning, as can be seen in the diagram shown in the lab book, experimentation can begin. Data readings were taken from the power meter (wattage) and the photodiode (voltage), which was hooked up to the oscilloscope. For each pair of readings, different sets of filters were added or removed to compare changes. When a filter switch resulted in a linear change for the wattage and voltage, the photodiode is determined to be in its linear range.

Results

By using a combination of NG-9 and NG-5 filters, the intensity of the laser beam was reduced by a great enough factor to allow the photodiode to operate in the linear range. A table showing the recorded values for the wattage and voltage, and the corresponding filter sets is shown below.

Filters	Oscilloscope Voltage Reading (mV)	Power Meter Reading (mW)
NG-5 (1)	290	0.853
NG-5 (2)	270	0.420
NG-9 (1)	250	0.216
NG-9 (1) + NG-5 (1)	88	0.029
NG-9 (1) + NG-5 (2)	44	0.015

Table 1 – Recorded values for the voltage and wattage levels from the oscilloscope and power meter. The number in parentheses for filters represents the number of each used.

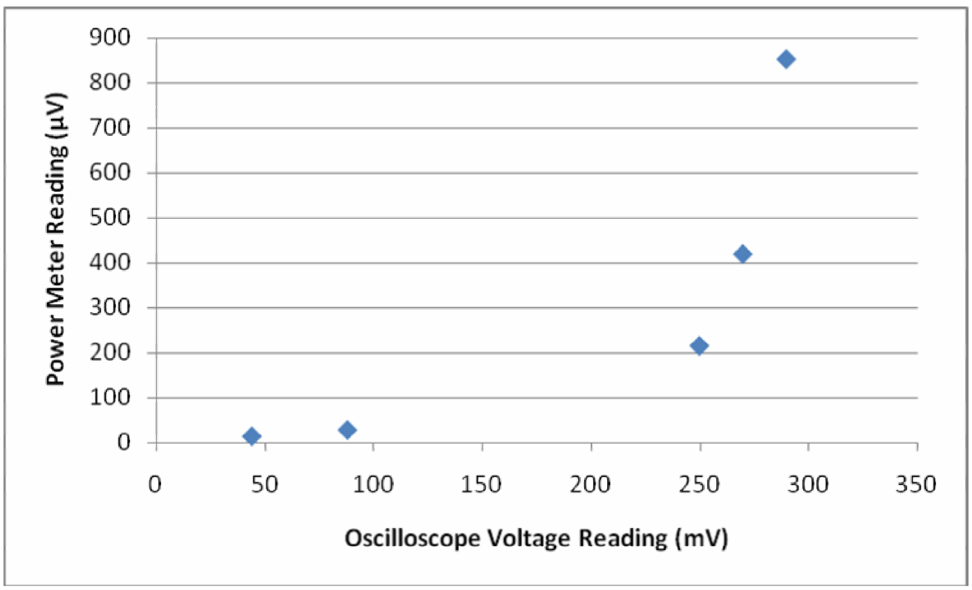

Chart 1 - The two data pairs farthest to the left on the chart, corresponding to the bottom two data pairs in Table 1, represent a linear change for both the wattage and voltage. The extra NG-5 filter creates a 50% decrease for both readings.

II. Determination of frequency response for photodiode

Method

The first thing required for this was to remove the power meter used in Part I. Now the position of the equipment was checked to ensure that the HeNe laser was firing through the chopper wheel, and hitting the photodiode. Once this was correctly prepared, the cables to the lock-in amplifier were attached. From the control box for the mechanical chopper, a line was run to the reference frequency input position on the lock-in. The photodiode was then connected to the signal input position.

With the setup completed, measurements were then taken. The frequency of the chopper was adjusted, and then the corresponding voltage on the lock-in was recorded. This was done for the full range of possible frequencies, running from 2000 Hz to 30 Hz. The former is the limit of the chopper, and the latter is the limit of the lock-in's ability to read voltage precisely.

Results

Based on the data obtained from the above process, shown in the table on the following page, there appears to be a noticeable roll-off at a frequency of approximately 85 Hz. After this point, the voltage drops quite drastically, and then begins dropping at a slow and steady pace that one would expect from increasing frequency in the chopper. This steady drop is indeed seen if one looks at the oscilloscope as the frequency increases.

Two significant dips are seen at both 60 Hz and at 120 Hz. These fluctuations are due to the large amounts of noise associated with the frequencies. The lock-in used had features set to block out these frequencies completely, resulting in the observed dips in voltage.

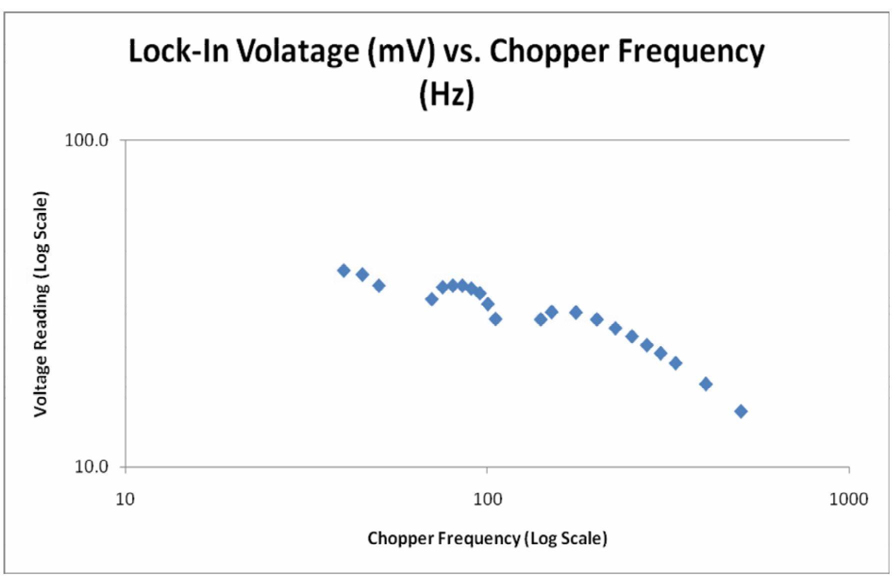

Chart 2 – Plot in log-log scale showing the roll off of the voltage with respect to frequency.

Chopper Frequency (Hz)	Lock-In Voltage Reading (mV)
2000	3.81
1750	4.35
1500	5.09
1250	6.02
1000	7.50
750	10.3
500	14.8
400	18.0
330	20.8
300	22.3
275	23.6
250	25.1
225	26.6
200	28.3
175	29.7
150	29.8
140	28.3
105	28.4
100	31.5
95	34.0
90	35.2
85	35.9
80	35.9
75	35.5
70	32.6
50	35.9
45	38.8
40	39.9

Table 3 – The recorded values for frequency and voltage determined from the Lock-In Amplifier

III. Determination of Frequency Response and its Dependence upon Intensity using LabVIEW

Method

The process for this experiment was much like that in Part II, except for the fact that the entire process was automated. First, a LabVIEW VI was created. This program was then used to change the frequency of the chopper, and record the amplitude of the voltage from the Lock-In Amplifier, and also the resultant phase.

The tests were run twice, using two significantly different powers for the laser. This was done in order to determine the effect of intensity on the Frequency response of the photodiode. Three data points were taken for each frequency, measuring both the amplitude and the phase.

Results

The tests were run with Power readings of 0.497 mW with the first run, and 0.048 mW for the second run. Due to apparent file corruption, the amplitude data for the 0.497 mW power has been lost, making it impossible to determine the correlation between frequency response and intensity of the laser beam on the photodiode.

However, the amplitude data that did survive corresponds to a power rating that is in the linear range, or at least very close for the photodiode used throughout this experiment. This knowledge is gained from the plot created in Part I. The large amounts of high quality amplitude data measured by using LabVIEW has only reinforced the conclusion from Part II, that the frequency response of the photodiode is approximately 85 Hz.

Chart 3 and Table 4 on the following page show the data for the 0.048 mW run. The frequency and phase data for the 0.497 mW run are shown in Table 3.

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Frequency (Hz)	Average Phase
25	176.8316667
35	173.712
45	171.774
55	169.9986667
65	168.5453333
75	166.8863333
85	166.42
95	164.173
110	162.4306667
130	160.652
150	158.5503333
175	156.407
200	155.0766667
250	151.9356667
300	149.634
500	143.457
750	139.061
1000	134.6

Table 3 – Results of the data taken with an intensity of 0.497 mW. Three data points were taken for each frequency for both amplitude and phase. Unfortunately, the file holding the amplitude data has been corrupted, leaving the information unusable. The phase data is intact, and the three data points per frequency have been averaged, and are shown here.

Frequency (Hz)	Average Amplitude (V)	Average Phase
25	0.053151667	-171.4176667
35	0.0528262	-175.743
45	0.0521548	-178.97
55	0.0514224	177.876
65	0.0506289	174.946
75	0.0497134	172.149
85	0.0487368	169.47
95	0.0476382	166.813
110	0.0459902	163.165
130	0.0437319	158.892
150	0.0414431	154.6986667
175	0.0387576	150.165
200	0.036173767	146.3393333
250	0.031647	140.035
300	0.0278932	135.1753333
500	0.0183717	125.2946667
750	0.0126649	119.378
1000	0.0096131	115.8076667

Table 4 – Results for the Voltage and Phase for each of eighteen frequencies. The values shown are an average of the three separate data points taken for each frequency

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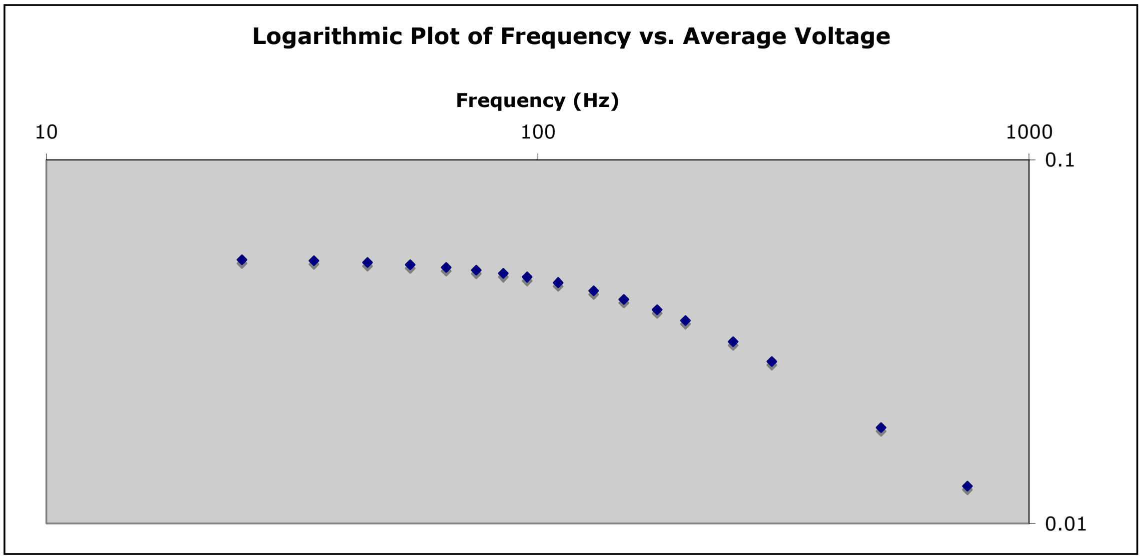

Chart 3 - Plot in log-log scale showing the roll off of the voltage with respect to frequency

Conclusions

Overall, this experiment proved to be highly successful. The only part in which the intended outcome was not met was in finding the intensity dependence for the frequency response of the photodiode. However, in using LabVIEW for this, more data was gathered in the linear range of the photodiode, ensuring a correct value for the frequency response range. The response appears to be limited to about 85 Hz. This was obscured in Part II of the lab, due to the interference from the 60 and 120 Hz bands. However, in using the LabVIEW program, and a different Lock-In Amplifier, these interference sections disappeared and the roll-off was much more noticeable.

This experiment has introduced Lock-In Amplifiers and the LabVIEW software. After using both for quite a bit of time throughout the process, much was learned about each. It has provided a very good base for using LabVIEW for future experimentation and data acquisition.