SCPY 394: Advanced Physics Laboratory II
Lab 4: Lock-In Amplification

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1 Objective

To study basic Lock-In detection technique, working principle of Lock-In Amplifier, and its application.

2 Theories

The Lock-In detection technique is phase-sensitive detection; the signal component in phase with a reference signal is measured by using an input signal

$$V_{sig}(t) = V_{sig}^{0} \sin(2\pi f t + \theta) \tag{1}$$

,same frequency f as the reference signal

$$V_{ref}(t) = V_{ref}^{0} \sin(2\pi f t) \tag{2}$$

but with phase difference θ.

For the Lock-In Amplifier used in the experiment, DSP Lock-In Amplifier Model SR830, the signal voltage is measured in in-phase component $X(t) = V_{sig}^{0}\cos(\theta)$ and quadrature component $Y(t) = V_{sig}^{0}\sin(\theta)$ with amplitude $R(t) = \sqrt{X^2(t) + Y^2(t)} = V_{sig}^{0}$ and phase difference from the reference signal $\theta = \arctan \frac{Y(t)}{X(t)}$

3 Capacitance measurement using Lock-In Amplifier

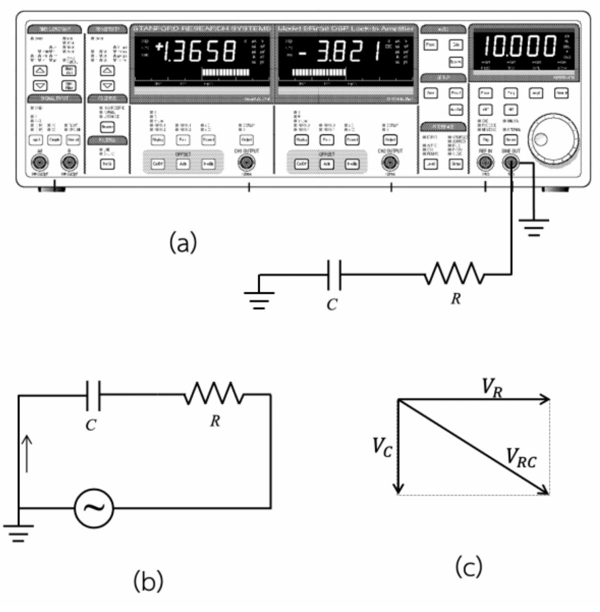

Figure 1: Circuit representation for using Lock-In Amplifier to measure capacitance

The sub-experiment is to measure capacitance by using the Lock-In Amplifier instead of an ordinary method using a multimeter. We connect a sine-wave source to an R-C circuit as shown in figure 1. The voltage between a capacitor is used as an input of the Lock-In Amplifier. The complete setup is shown in figure 2.

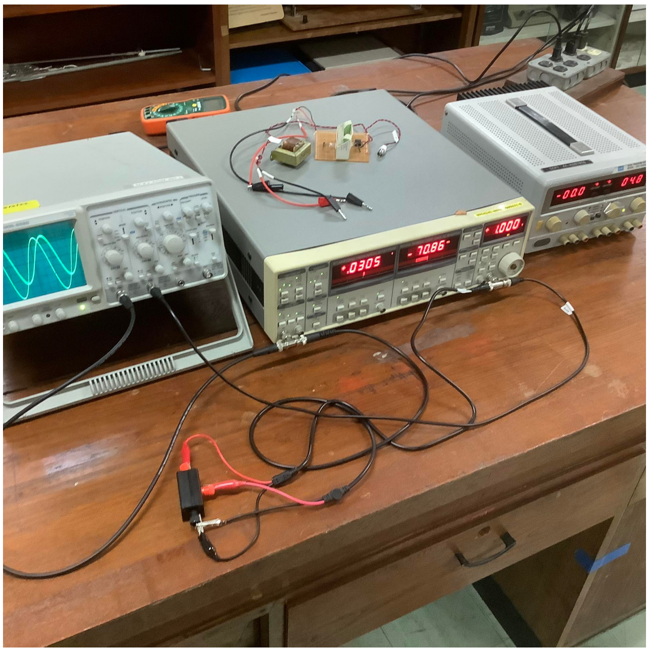

Figure 2: The experimental setup for using Lock-In Amplifier to measure capacitance

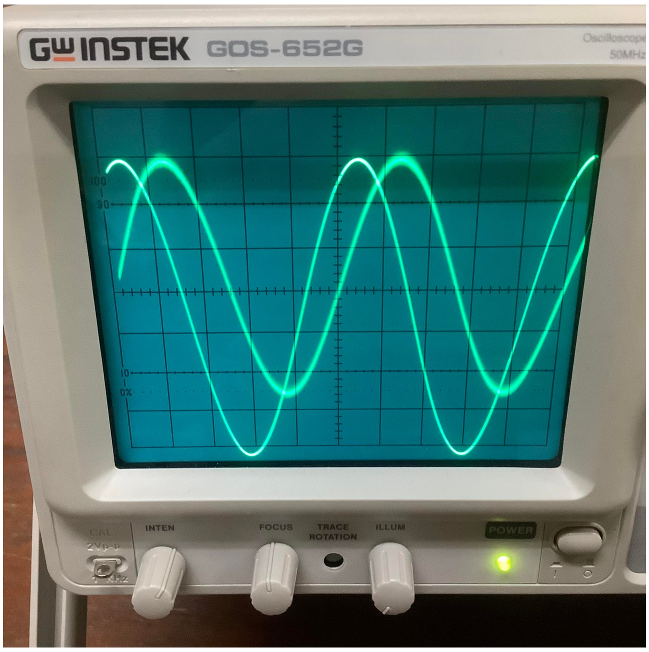

Figure 3: The result signals from the R-C circuit

From the setup, the result signals are shown in figure 3
From figure 1, measured quantities from the Lock-in Amplifier are shown in the below table.

Quantities from Lock-In Amplifier	**Quantities from phasor diagram**
X	voltage between capacitor V_C
Y	voltage between resistor V_R
R	source voltage V_{RC}
θ	phase difference between V_C and V_{RC}

Table 1: Comparison of quantities from Lock-In Amplifier and quantities from phasor diagram

Using a frequency range of 1 to 10 kHz, the obtained data is represented in the below graph.

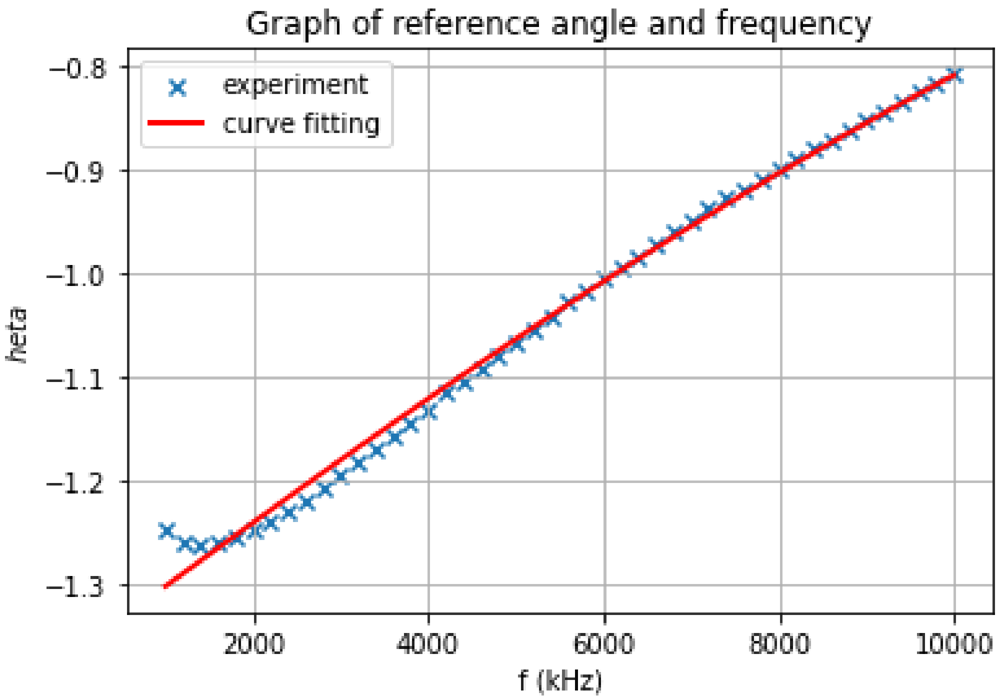

Figure 4: Graph of θ and frequency of the R-C circuit

From the prior knowledge of AC circuits, θ can be obtained from frequency.

$$\theta(f) = \arctan(2\pi RCf) + \theta_0 \tag{3}$$

where θ_0 is the reference phase, different for a unique system.

In the sub-experiment, $R = 47\ \Omega$. With curve fitting, the capacitance is

$$\boxed{C = 209 \pm 3\ \text{nF}}$$

4 Lock-In detection technique to measure noise-rich signal

The sub-experiment is to modulate the noise-rich signal. We compare using a multimeter with using a Lock-In Amplifier to examine both efficiencies.

4.1 Multimeter

We connect an electric source to a circuit (+5V). A non-zero output voltage, called **offset voltage** V_{off}, is expected even if electricity is unavailable in the system. In the sub-experiment, the offset voltage

$$V_{\text{off}} = 4.7 \pm 0.1\ \text{mV} \tag{4}$$

Then the source is connected to the 2.0 V LED. From the observation, the voltage is 251 ± 1 mV and it increases from V_{off} for

$$V_0 - V_{\text{off}} = 246 \pm 1\ \text{mV} \tag{5}$$

In the sub-experiment, a light-attenuated sheet is added to the system. The expected measured voltage must decrease when the number of sheets increases. For the number of sheets, the output voltage V_{out} is in the same order as the offset voltage, so the multimeter will be inapplicable.

From the sub-experiment, a graph of $V_{\text{out}} = V - V_{\text{off}}$ with a different number of sheets is shown below.

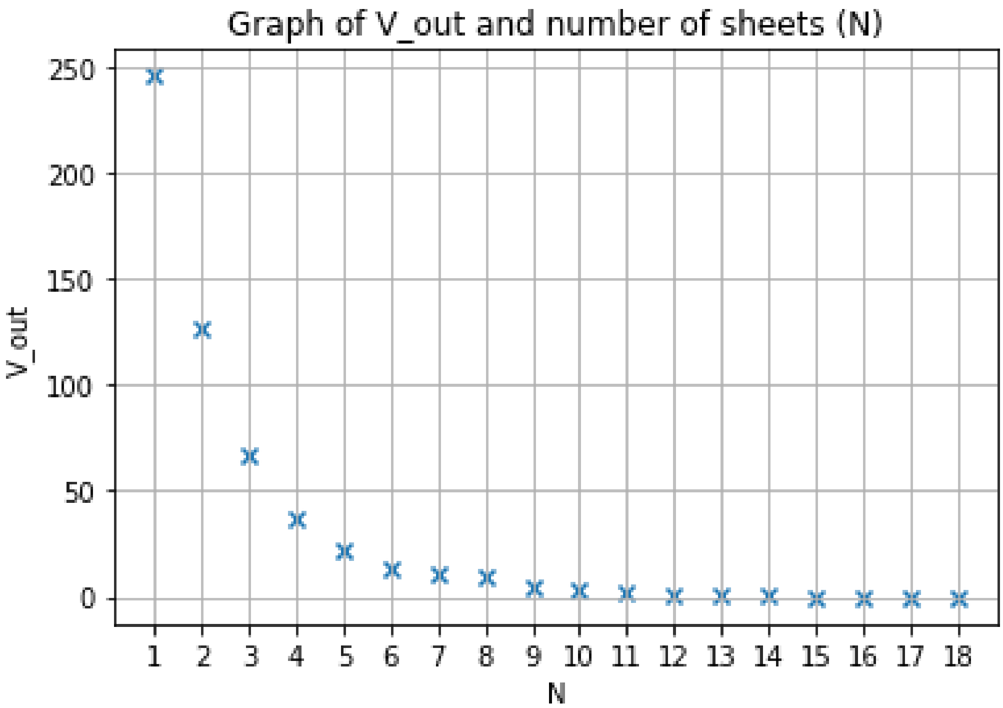

Figure 5: graph of V_{out} and number of sheets

From the graph 5, the multimeter measurement is inapplicable when the number of sheets exceeds $N = 14$.

4.2 Lock-In Amplifier

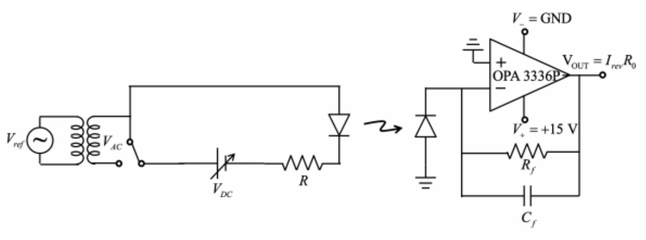

Figure 6: Circuit representation for noise-rich signal modulation in LED circuit

Figure 7: The experimental setup for noise-rich signal modulation in LED circuit

With the setup 7, with a change of output voltage from the multimeter to the Lock-In Amplifier input, the same output voltage can be observed with a different number of sheets. The corresponding output from the Lock-In amplifier to analyze further is Y.

The graph of Y and the number of sheets is shown below

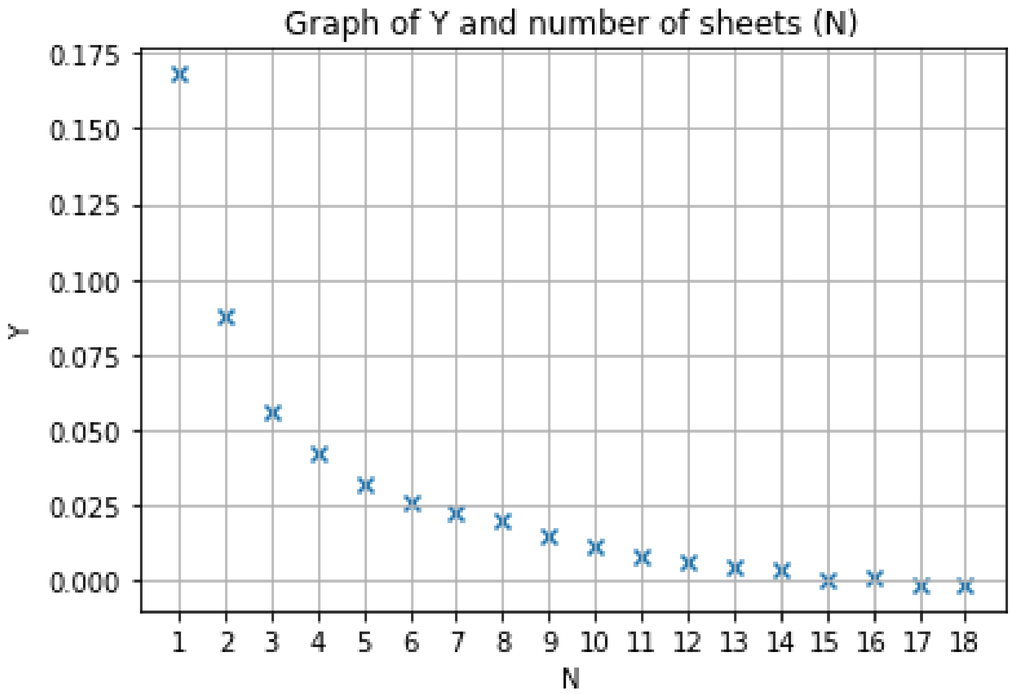

Figure 8: graph of Y and the number of sheets using the Lock-In Amplifier

From graph 8, the Lock-In Amplifier measurement is inapplicable when the number of sheets exceeds $N = 16$.

5 Conclusion

The experiment is to use a Lock-In Amplifier in various scenarios. In a resistor-capacitor system, we can obtain the capacitor by using the Lock-In Amplifier $C = 209 \pm 3$ nF. With measuring a noise-rich signal of an LED circuit, the comparison using a multimeter and a Lock-In Amplifier is conducted. The resulting number of sheets that the voltage measurement is inapplicable from the multimeter is $N \geq 14$ whereas one from the Lock-In Amplifier is $N \geq 16$