Using PhysLock with a chopped optical beam

User Manual

September 29, 2021, V 1.0

Scope

The theme of this manual is to introduce and test the functioning of an entry level lock-in amplifier, i.e., Qosain Scientific's (QS) PhysLock. We setup the discussion with a brief introduction of PhysLock and subsequently, test the features, capabilities, and effectiveness of PhysLock in a typical optics experiment. Many optical experiment employ lock-in amplifiers and are meant to detect and measure small signals embedded in noise. These experiments are enabled by an optical chopper that modulates the light beam at a certain frequency. The beam falls on a photodetector and the signal of interest, even though small and hidden in the overall photoresponse, possesses the frequency at which the beam is chopped. The purpose of any lock-in amplifier is to look for and measure the photoresponse at this frequency.

PhysLock. (Please note, the exact form of the product may vary slightly from this figure.)

Contents

1 Introduction

A lock-in amplifier is a device used to recover weak oscillating signals buried in overwhelming noise. The basic working principle of a lock-in amplifier is phase sensitive detection where an oscillating reference signal of frequency f_o is multiplied with the input signal that has been modulated at f_o and then passed through a low-pass filter. In this manual, a simple, entry level low-cost, stand-alone lock-in amplifier, called PhysLock is described. The technical specifications of PhysLock can be found in its technical manual [1].

2 Front Panel Control

The front panel of PhysLock is organized into distinct functional sections. Knowing this organization will help the user to become familiar with its operation. A diagram of the front panel is shown in Figure 2.1. A description of each section follows.

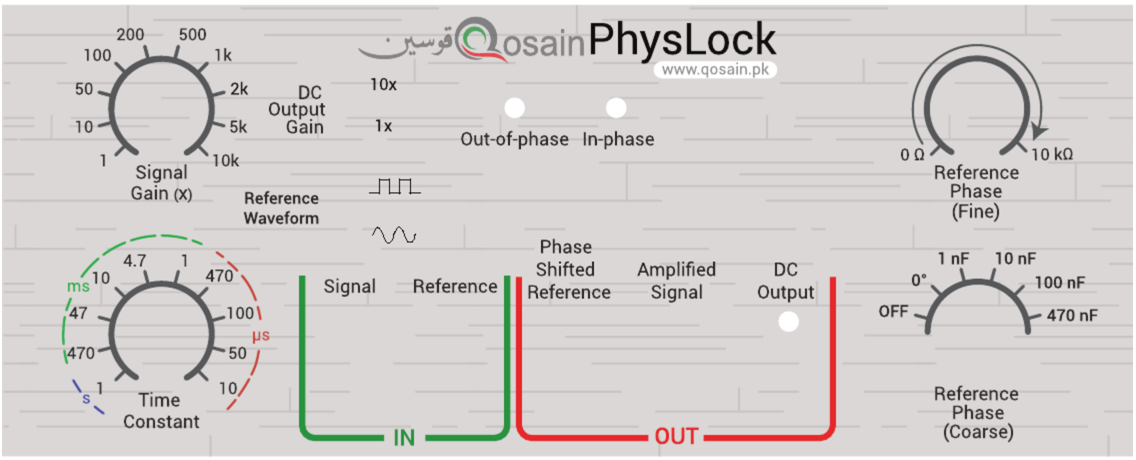


Figure 2.1: The front plate of PhysLock.

2.1 IN Section

"IN" section consists of BNC connectors for input and reference signals. These user input signals are applied to PhysLock through BNC cables.

2.1.1 Signal

The actual input signal to be analyzed is connected to this connector. This signal has been modulated at f_o.

2.1.2 Reference

A square or sinusoidal wave of known frequency f_o is fed through the BNC connector that is used as a reference signal for the lock-in amplifier. The reference waveform toggle switch allows the user to specify the kind of reference signal, be it a bipolar square wave or sinusoidal signal. The reference input must be a clean signal of amplitude $\gtrsim 1$ V.

2.2 Signal Gain

The top left-hand section of the instrument comprises of a variable switch labelled, “Signal Gain” to amplify the signal by factors of 10, up to 10k.

2.3 Time Constant

This changes the cut-off frequency of the low pass filter by connecting different capacitors through the selector switch. Effectively, a longer time constant τ would mean only frequencies really close to f_o will be allowed to pass, narrowing the bandwidth and improving the noise rejection of the lock-in amplifier. However, the DC output would require a time $\approx 5\tau$ to settle to a steady value.

2.4 OUT Section

The next section of the instrument is “OUT” that outputs phase shifted reference, the input signal amplified after the signal gain, and the DC output of the lock-in amplifier that is proportional to the locked input signal. All three of these ports are output BNC ports. The phase shifted reference and amplified signal can be used to monitor the waveforms at the intermediate points of the PhysLock circuit.

2.5 Reference Phase (coarse)

This is the coarse adjustment knob to change the reference phase. Internally, it changes the value of capacitance according to Equation 2.1.

$$\phi = \pi - 2\tan^{-1}(\omega RC) \tag{2.1}$$

2.6 Reference Phase (fine)

This is the fine adjustment knob that changes the value of R and shifts the phase according to Equation 2.1. Both, the coarse and fine reference phase controls, adjust the phase of reference $A_{ref}\cos(f_o t + \phi)$ prior to multiplication with the input signal; thus, changing the value of the DC output. In a typical experiment, ϕ is adjusted to maximize the DC output for a given input signal and calibrated against this benchmark as the input signal is subsequently varied.

2.7 DC Output Gain

This toggle switch allows the user to select and output the DC signal as it is or with a gain of 10×. The user ensures that all voltages are within measurable ranges.

3 PhysLock in a Typical Optics Experiment

The current section will test the functionality of PhysLock in an optical setup verifying Malus' law. According to the Malus' law, when plane polarized light is incident on an analyzer, the intensity of transmitted light varies as indicated in Equation 3.1.

$$I = I_o \cos^2\theta \tag{3.1}$$

where θ is the angle between the plane of polarized light and the analyzer's optic axis.

3.1 Apparatus Required

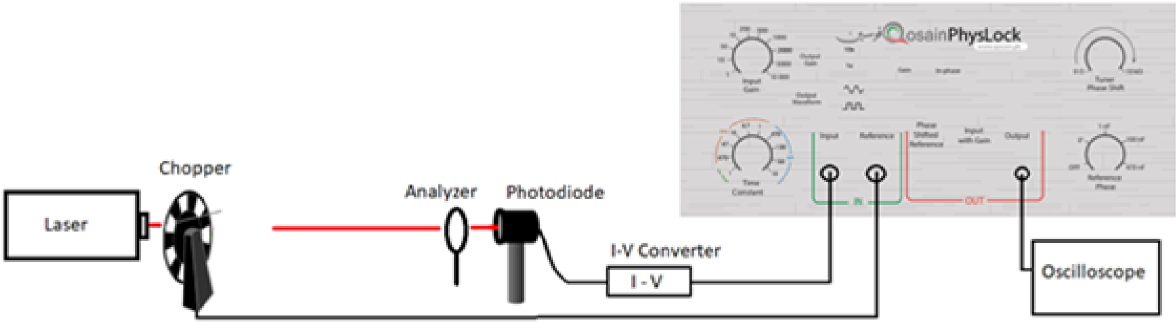
The user may have their own kind of equipment. We merely mention our equipment in Table 3.1 for the sake of completeness.

Equipment	Description
Laser	A solid state 405 nm laser is used.
Optical Chopper	An SR-540 (Stanford Research System) optical chopper with power ≈ 10 mW is used for optical modulation and it also provides a reference signal for the operation of PhysLock.
Analyzer	It is used to transmit the light with a plane of polarization parallel to its optic axis. It is mounted in a rotation stage that enables the angle θ to be changed from 0 to 360°.
Photodiode	The photodiode used in the setup is Newport (818-SL) and it converts light intensity to current. In another experiment, we used Thorlabs (DET-36) that directly outputs a voltage from a photodiode.
I-V Converter	It converts the current signal from a photodiode into the voltage to be used in PhysLock as an input signal.
PhysLock	This is our lock-in amplifier producing a DC output signal proportional to the input signal.

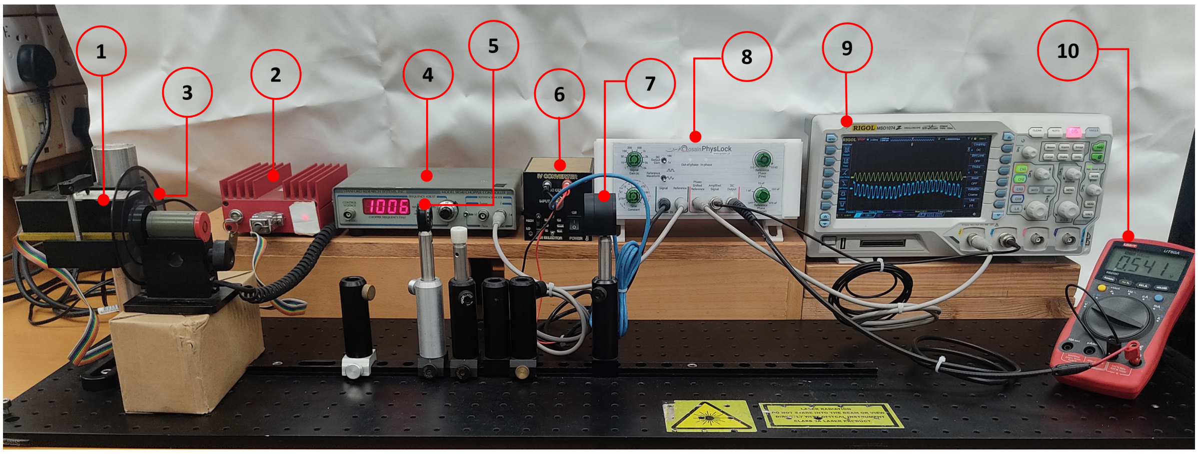
Table 3.1: Description of the equipment used by us in a typical optics experiment to verify Malus' law.

3.2 Experimental Setup

The experimental setup used to verify Malus' law incorporating PhysLock is shown in Figure 3.1.



(a) The schematic arrangement of optical elements in our test experiment. The oscilloscope is used to monitor or measure output signals. For measuring the DC output, one can also use a multimeter.



(b) Photograph of the experimental setup, showing the (1) laser, (2) laser power supply, (3) optical chopper, (4) optical chopper controller, (5) analyzer, (6) I-V converter, (7) photodiode, (8) PhysLock, (9) oscilloscope, and (10) voltmeter.

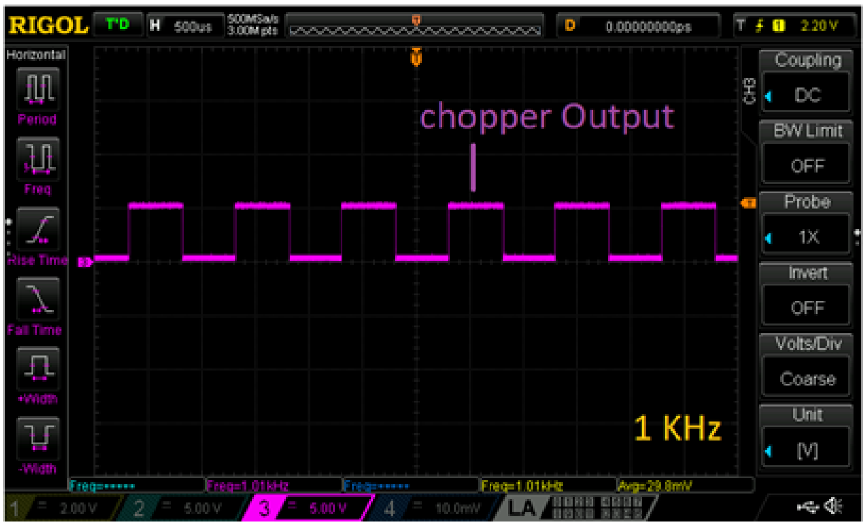
Figure 3.1: Experimental setup to verify Malus' law using PhysLock.

An optical beam from the laser is passed through an optical chopper that periodically interrupts the light. The frequency of interruption f_o is set by the chopper controller that also provides the reference signal to PhysLock. The reference signal waveform from the chopper is presented in Figure 3.2a.

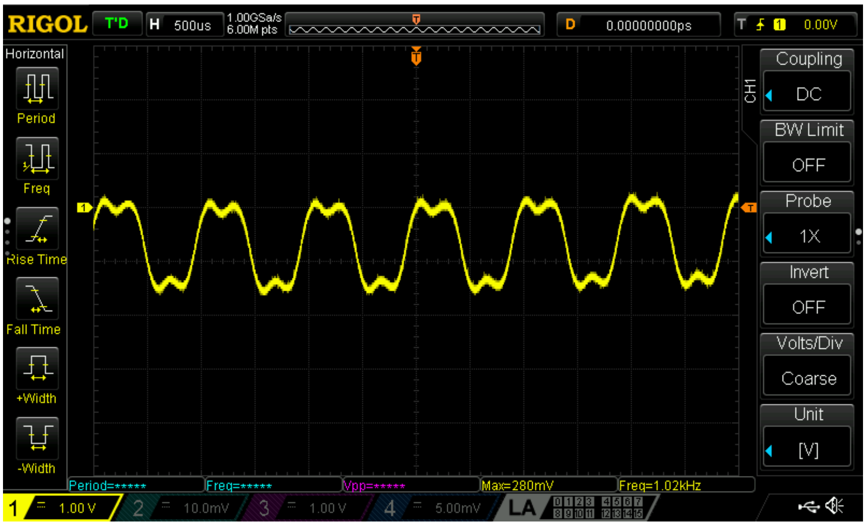
The interrupted beam then passes through the analyzer and the angle of analyzer is changed from 0 to 360° to vary the intensity of light. The expected output varies as per Equation 3.1. The output of photodiode is converted into voltage by means of an I-V converter and is subsequently fed into Phys-

Lock. The steps for conducting the experiment can be summarized as follows.

1. Place the analyzer in the path of laser beam.
2. Place the photodiode in the path of laser beam after the analyzer.
3. Connect the output of photodiode to the input of I-V converter. The I-V converter gain is selected as 1 M for this experiment. The output of I-V converter is observed on an oscilloscope and is shown in Figure 3.2b.
4. Connect the output of the I-V converter to "Signal" BNC inside the “IN” section of PhysLock.
5. Connect the output of the chopper to “Reference" BNC inside the “IN” section.
6. Set the “Time Constant” at 1 s for this experiment.
7. Select the “Input Gain” as 1× for this experiment.
8. Set “Reference Phase (coarse)” at 1 nF.
9. Connect the “Output” of the “OUT” section to a multimeter or oscilloscope to observe the output DC voltage.
10. Rotate the analyzer in small steps, say from 10° to 360° and note down the voltage measurements from the multimeter.



(a) Optical chopper reference signal between 0 to 5 V.

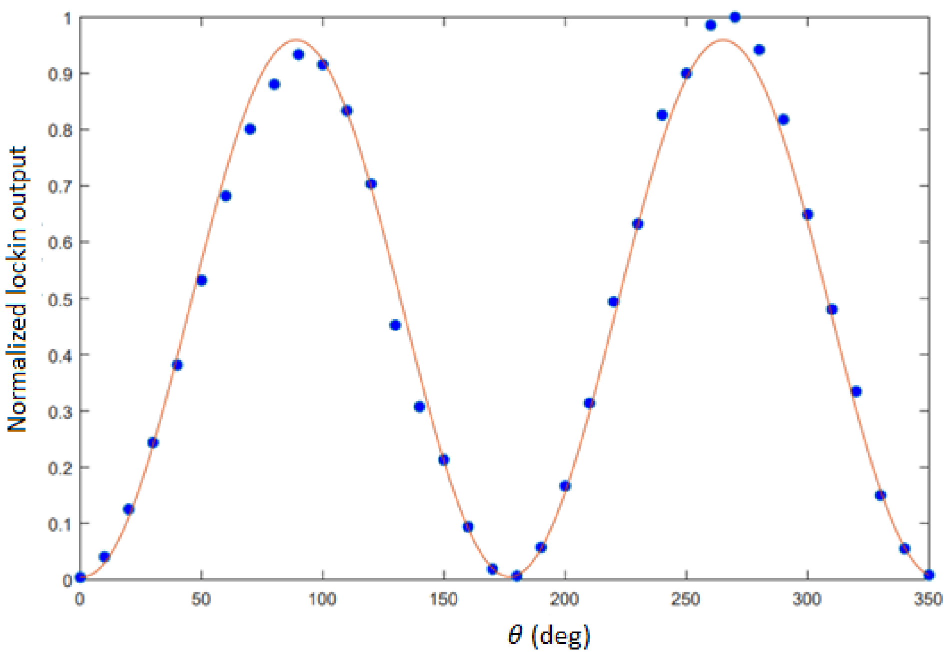


(b) Output of the I-V.

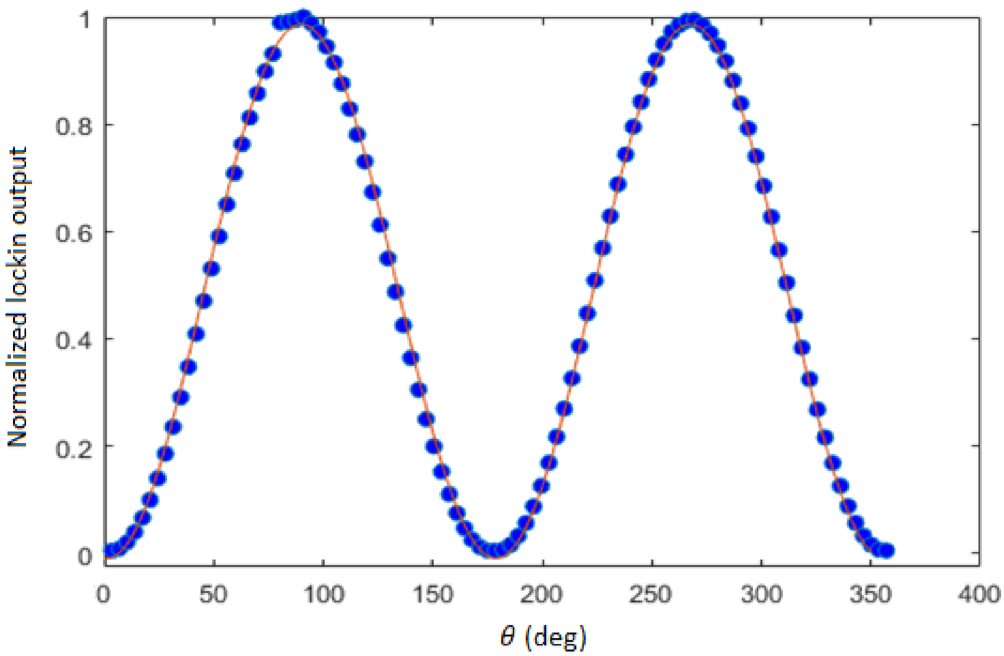
Figure 3.2: Signal waveforms, as observed at different stages of the experimental setup.

3.3 DC Output with Current and Voltage Type Photodiodes

Voltage is measured at the output of PhysLock while rotating the angle θ of the analyzer. The signal gain of the amplifier is set at $\times 10$ and the reference signal and input signal are in-phase. Figure 3.3a shows a plot of the DC output using a photodiode outputting a current that is converted to a voltage by an I-V converter with gain 1 M. Figure 3.3b shows a plot of the DC output when a voltage outputting photodiode is used.



(a) Intensity of an optical beam as a function of angle between laser source and analyzer. The photodiode outputs a current that is converted to voltage by an I-V converter. Data points are solid circles, whereas the solid line is a fit of the data to Equation 3.1.



(b) Intensity of an optical beam as a function of angle between laser source and analyzer. The curve fitted on square of cosine (Equation 3.1), satisfies Malus's law. A voltage type Photodiode is used.

Figure 3.3: DC output graphs.

3.4 Voltage Measurement in a Voltage Divider Circuit

Another simple test is performed using a function generator, setting the frequency at 500 Hz, and an output square wave voltage of 1 V_{p-p}. The voltage is fed into a voltage divider circuit as shown in Figure 3.4 with a fixed resistor R_2 of 1 kΩ and a small resistor R_2 in series. Voltage V_{out} given by,

$$V_{out} = V_{in} \frac{R_1}{R_1 + R_2} \approx V_{in} \frac{R_1}{R_2} \quad (R_2 >> R_1) \tag{3.2}$$

is tapped off and fed into PhysLock. Equation 3.2 shows a linear relationship is varied by changing the number of 1 Ω resistors in parallel. Figure 3.5 demonstrates the results of this test, confirming the linearity of PhysLock in this range.

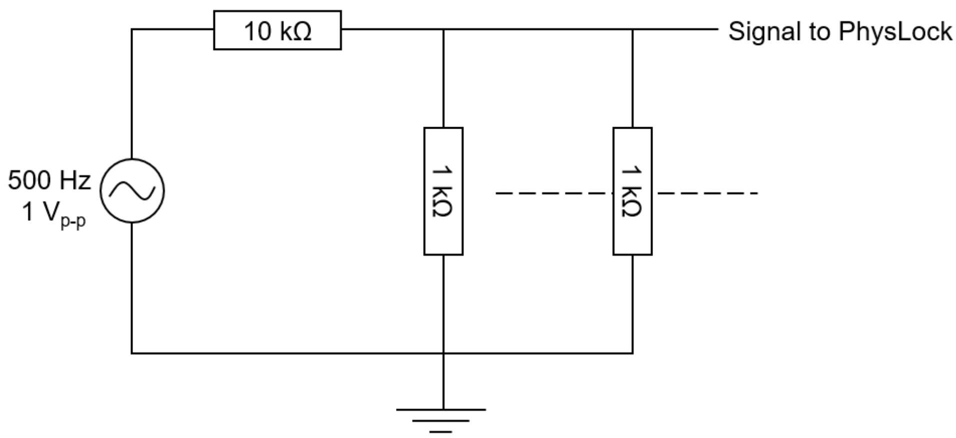


Figure 3.4: The circuit used to test signal variation using resistance test.

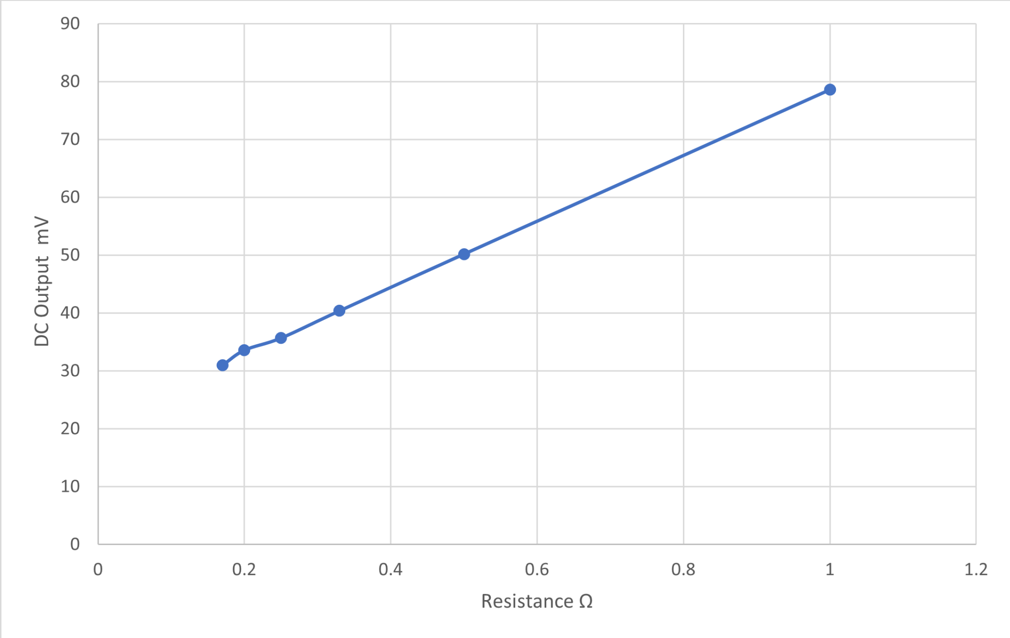


Figure 3.5: PhysLock output in mV when input signal is changed using Resistance.

References

[1] Physlab. *Physlock - an entry level lockin amplifier board*. URL: https://physlab.org/story/physlock-an-entry-level-lockin-amplifier-board/. (Accessed: 29.09.2021).