In the first part of this lab you will simulate the behavior of a lockin amplifier on the computer.

1. **Simulation: signal vs. reference phase.** In Matlab, generate a sine wave with frequency ‘freq’, amplitude, ‘sigamp’, a sampling time ‘dt’ (so that the sampling frequency is \( f = 1/dt \)) and maximum time ‘tmax’. For now, choose \( tmax = 2 \) (seconds), \( freq = 10 \) (Hz), \( dt = 0.001 \), and some amplitude different than unity. “Lock in” to the signal by multiplying by a reference sinusoid of the same frequency and unit size, but with a variety of phase differences. The output of the lockin is the average of this product, times 2 to account for the average of a sinusoid. (Be sure you have the correct mathematics for the average – it is the integral, divided by the length of the signal).

First, just to get an idea, graph the signal and reference signals, and examine the lockin output for phase differences of, say, 0, \( \pi/2 \), \( \pi \), and \( 3\pi/2 \). Now, using a loop, scan the phase from 0 to \( 2\pi \) in 100 steps, and plot the output versus phase difference. Explain your graph.

2. **Simulation, signal vs. reference frequency.** Similar to the exercise above, now create a signal waveform, and loop over reference frequency from 5 to 15 Hz with steps of approximately 0.1 Hz. Plot the integrated signal as a function of the reference frequency. (Be careful to set the reference phase to the same value as your signal phase)!

Comment on your graph. Explore how it depends on the number of periods (i.e. length of time-stream) you integrate over, and comment on this in your lab notebook. Note that the lockin technique is related to the following representation of a Dirac delta function:

\[
\delta(\omega_2 - \omega_1) = \frac{1}{2\pi} \int_{-\infty}^{\infty} e^{-i(\omega_2 - \omega_1)t} dt
\]

3. **Photodiode exercise.**

Now you will use an actual lockin. Connect the two terminals of a mini-solar cell to your oscilloscope. Move the photodiode from light to dark (i.e. cover it, then uncover it) to see what the signal does.

Connect an LED to your function generator and drive it with a 5Vpp square wave at 100Hz. Shine the LED on the photodiode and see if you can detect that signal on the oscilloscope screen (you should).

Now, run the photodiode output to the input of the lockin amplifier, and use the “sync” output of the function generator as the lockin reference. Position the LED and photodiode so you get a good signal, in a stable way such that you won’t bump it. Set up your lockin (including the time constant) such that you see a stable (constant) output signal. Optimize the lock-in phase to maximize the signal.

a. Set the LED drive signal (and your reference) to 5000Hz. Set the time constant of the lockin to 100ms. **Change the amplitude to 0Vpp, and back to 5Vpp, and describe what happens to the lockin output after each change. Repeat with the lockin time constant set to 3 seconds. Why does this happen?**
b. Set the LED drive signal (and reference frequency) to 10Hz, and the time constant to 100ms. (Note that this is bad – you don’t want to use the lockin this way). Describe what occurs to the lockin output, and why. Why is this bad?

c. Set up a second LED driven from your other function generator, and position things so both LEDs are shining roughly equally on the solar cell. Set the frequency of one LED to 5000 Hz and the other to 5010 Hz. The signal on the oscilloscope should now be more complicated. Set up the lock-in so it only measures the signal from the LED at 5000 Hz – record how you set this up in your notebook. Verify that this works by changing the voltage level to either LED and only seeing a change on the lock-in when varying the 5000 Hz LED.