Using a Lock In Amplifier to Convert an AC Power Source to a DC Signal While Taking a Spectrum

sical Sciences, CSU Stanislaus, 2014, Spectroscopy Final Report

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This experiment demonstrates the usefulness of a lock in amplifier as a Phase Sensitive Detector in producing a spectrum with a monochromator from an alternating current light source. A monochromator was used to produce a spectrum of sodium and mercury lamps powered by an AC power source. Spectra were produced both with and without the use of a lock in amplifier to show the difference. In the spectra produced without the use of the lock in amplifier, there was observed inconsistencies in the lines. Using the lock in amplifier in conjunction with the monochromator allowed spectra to be produced without the inconsistencies produced by the AC power source.

Introduction

A specialized light source can be produced by construction of a sealed glass tube containing a small amount of a specific gas. When an electric current is passed through this gas the atomic and/or molecular electronic emissions will produce light at specific wavelengths. A monochromator can separate out these specific wavelengths and display them in what is called the spectrum of the gas. This can be achieved with the use of a prism, diffraction grating, etalon, etc.

What is the problem?

It is important that when measuring a spectrum with a momochromator, the signal being measured is a direct current (DC). Problems arise when the signal being measured is an alternating current (AC). The problem with AC power sources starts with the sampling rate. The sampling rate of the monochromator is finite. The monochromator samples the signal at defined increments while the lines in the spectrum are varying in intensity continuously. For example, if the source signal is alternating at a frequency of 60Hz (a typical North American household electrical frequency), then the spectrum that is varying continuously, is switching on and off 60 times a second. The monochromator will then, could be, taking a measurement when the AC signal is a maximum, or other times, when it is a minimum and, sometimes, somewhere in between. If the scan is slow enough, this AC signal can be seen in the lines of the spectrum as "noise". If the scan is too fast to detect the actual fluctuations of the AC signal, problems can arise from inconsistent line height and entire lines could even be missed if the scan crosses over when the AC signal is at a minimum.

How to solve the problem

Ensuring that a DC signal is measured by a monochromator can easily be achieved by simply using a DC power source (i.e. use a DC power source to power your lamp). However if it is not possible to use a DC light source, a lock in amplifier can be used as a Phase Sensitive Detector (PSD), this will produce a measurable DC signal from an AC signal. In the experiment, this is achieved by using a reference signal of the same frequency as the lamp power source.

The lock in amplifier uses this reference signal to produce a measurable DC signal. A more detailed explanation of how the lock in amplifier does this is discussed further on in the report.

Theoretical Model

The basic idea behind a lock in amplifier as a PSD is to use a reference that is generally AC, except under certain circumstances where it is DC, and produce a signal that is measurable. We can use a simple example to illustrate this idea.

An experiment can be run at a certain AC frequency (ω_{exp}). In this case, a 60Hz AC power supply is used to power the gas lamp. This same frequency can be directly connected to the input of the lock in amplifier as the reference frequency (ω_{ref}). In this case, the experiment signal and reference signal are:

Experiment: $V_{exp}\left[\sin\left(\omega_{exp}t + \theta_{exp}\right)\right]$

Reference: $V_{ref}\left[\sin\left(\omega_{ref}t + \theta_{ref}\right)\right]$

Where θ is the phase shift of the experimental and reference signal respectively.

Multiplying these signals we achieve:

$$V_{exp}\left[\sin\left(\omega_{exp}t + \theta_{exp}\right)\right]V_{ref}\left[\sin\left(\omega_{ref}t + \theta_{ref}\right)\right]$$

Simplifying:

$$\frac{1}{2}V_{exp}V_{ref}\left[\cos\left(\left(\omega_{exp} - \omega_{ref}\right)t + \theta_{exp} + \theta_{ref}\right) - \cos\left(\left(\omega_{exp} + \omega_{ref}\right)t + \theta_{exp} + \theta_{ref}\right)\right]$$

If ω_{ref} is not equal to ω_{exp}, then the signal is an AC signal and it can be passed through a low pass filter and be eliminated. However when ω_{ref} is equal to ω_{exp} the cos $\left[\left(\omega_{exp} - \omega_{ref}\right)t + \theta_{exp} - \theta_{ref}\right]$ term becomes independent of time and is therefore a DC signal. When this signal is passed through a low pass filter, the θ components, or phase shift components, survive and the output is:

$$\frac{1}{2}V_{exp}V_{ref}\left(\cos\left(\theta_{exp} - \theta_{ref}\right)\right)$$

If θ_{exp} is set equal to θ_{ref}, as can be done with the lock in amplifier, then the output simply becomes,

$$\frac{1}{2}V_{exp}V_{ref}$$

With no time dependence, this is now a DC signal as desired.[1]

Experiment/Method

Figure 11.1 is a basic schematic illustration of how the experiment was set up. As you can see, the AC power source that runs the gas lamp is also the reference signal, that is the input, to the lock-in amplifier. The light emitting from the gas lamp travels through the monochromator as it normally would, and the output light is measured by the photomultiplier and electrometer, respectively.

Now, instead of the results recording straight to the computer, first the measurements are sent to the lock-in amplifier where only the signals in-sync with the reference signal will be recorded and displayed on the computer (the CPU).

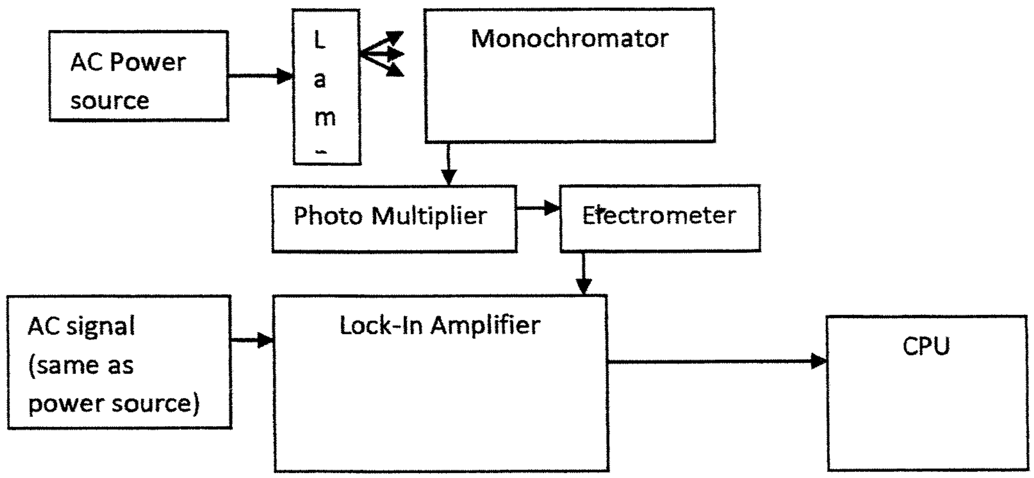
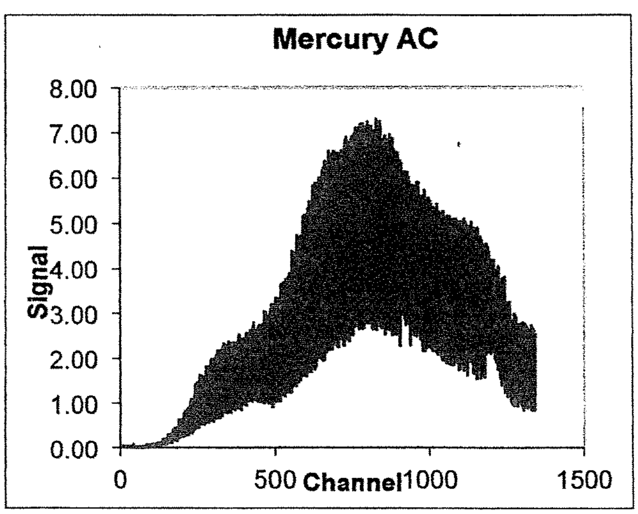


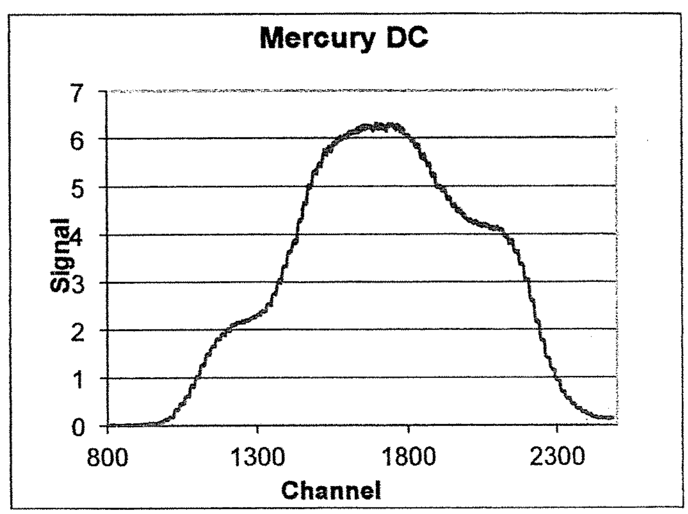
Figure 11.1: A schematic illustration of the experimental set up. Note that the AC power source is the signal powering the lamp and is the reference signal for the lock-in amplifier.

Data

A major difference can be seen in the spectrum produced without the PSD versus the spectrum taken with the PSD. The actual fluctuation in the mercury spectra caused by the AC lamp can be seen in *Graph 11.1*, where the fluctuation in the signal can be seen in the peaks. *Graph 11.2* shows the mercury spectra taken ***with*** the use of the lock-in amplifier. A notable difference can clearly be seen. The spectra taken with the PSD is noticeable clearer and more defined than the spectra taken without the lock-in amplifier. When using the lock-in amplifier, as a PSD, these fluctuations are eliminated.

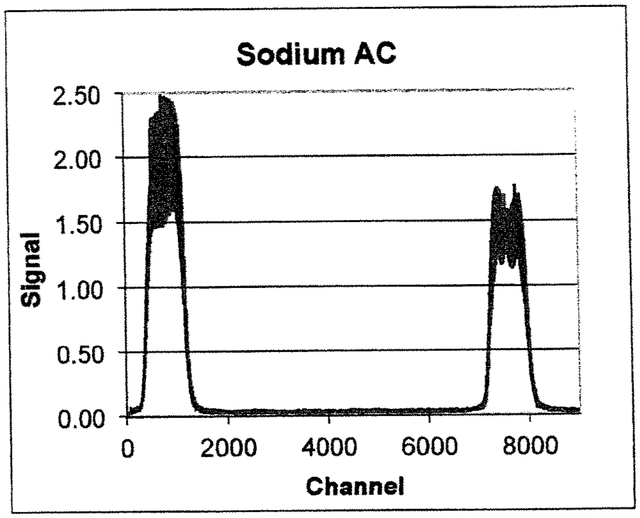


Graph 11.1 Mercury spectrum taken without the use of the lock-in amplifier

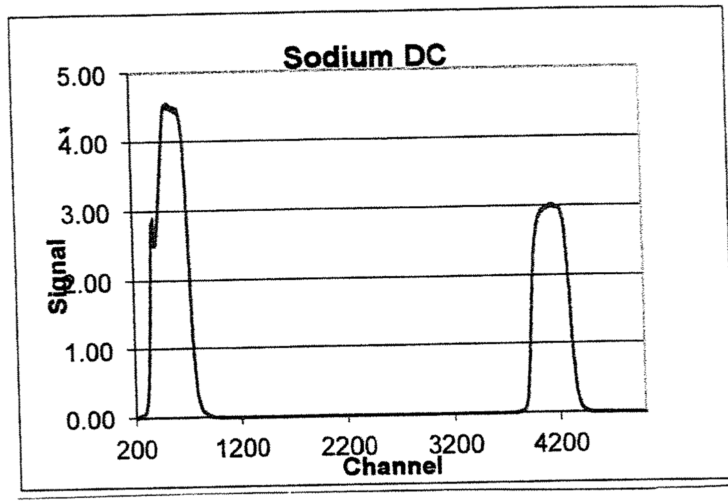


Graph 11.2 Mercury spectrum take with the lock-in amplifier as a PSD

A spectrum was taken with a sodium lamp, both with and without the use of the lock-in amplifier. As with the mercury spectra, the sodium lines are much more distinguishable in *Graph 11.4* where the aid of the lock-in amplifier ***was*** used.



Graph 11.3 Sodium spectrum taken without the use of the lock-in amplifier.



Graph 11.4 Sodium spectrum taken with the use of the lock-in amplifier as a PSD.

Analysis

We expected to see some effect on the data caused by the AC power source of the lamps used. Because the power source has a frequency of 60 Hz the lamp will go through a minimum intensity 120 times a second. The program used to produce the spectrum was set at a maximum data acquisition rate of 20 per second. This means that the spectrum will not follow every intensity minimum that the lamp goes through. However, on occasion the program will acquire a data point at or near a lamp intensity minimum. This was seen in spectrum of the mercury lamps in *Graphs 11.1* where the signal has fluctuations. When the lock-in amplifier was used these fluctuations in the spectra were eliminated as was seen in *Graphs 11.2*.

Another effect that can be seen in the spectra acquired with an AC power source, is reduced peak height. If the lamp happens to be at an intensity minimum when the scan is acquiring data that corresponds to the peak of a line then the true height of the line will not be recorded. This effect occurs when a fast scan is taken.

Conclusion

From this experiment, we see the usefulness of using a lock-in amplifier as a phase sensitive detector. By using a lock-in amplifier, we can take an AC power source and get more accurate mearsurements that would other wise be fluxuating greatly. The lock-in amplifier accumulates data that is close to the reference signal and therefore has fewer more precise points of data.

1. **About Lock-In Amplifiers,** http://www.thinksrs.com/downloads/PDFs/ApplicationNotes/AboutLIAs.pdf.
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