Lab Lecture #4

Revisiting Lab #1 Results, Introduction to Lock-In Detection

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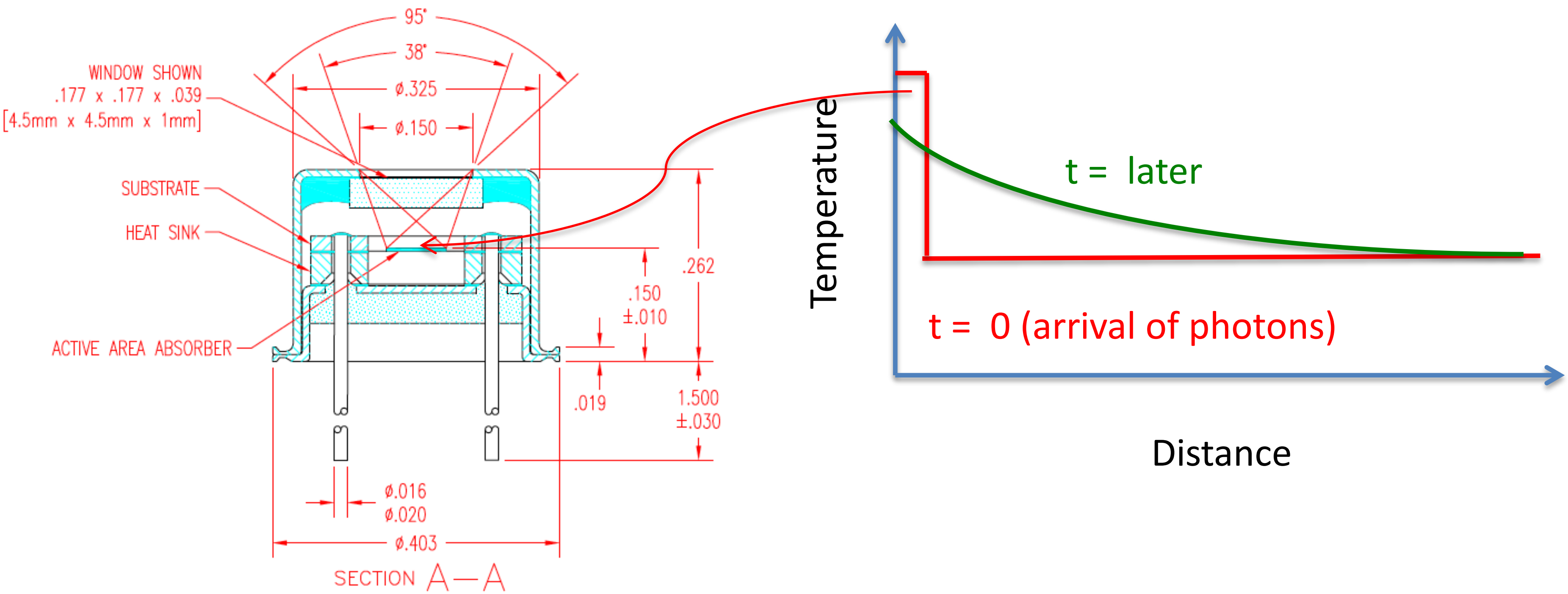
PHYS 4580, 6280, and 7280

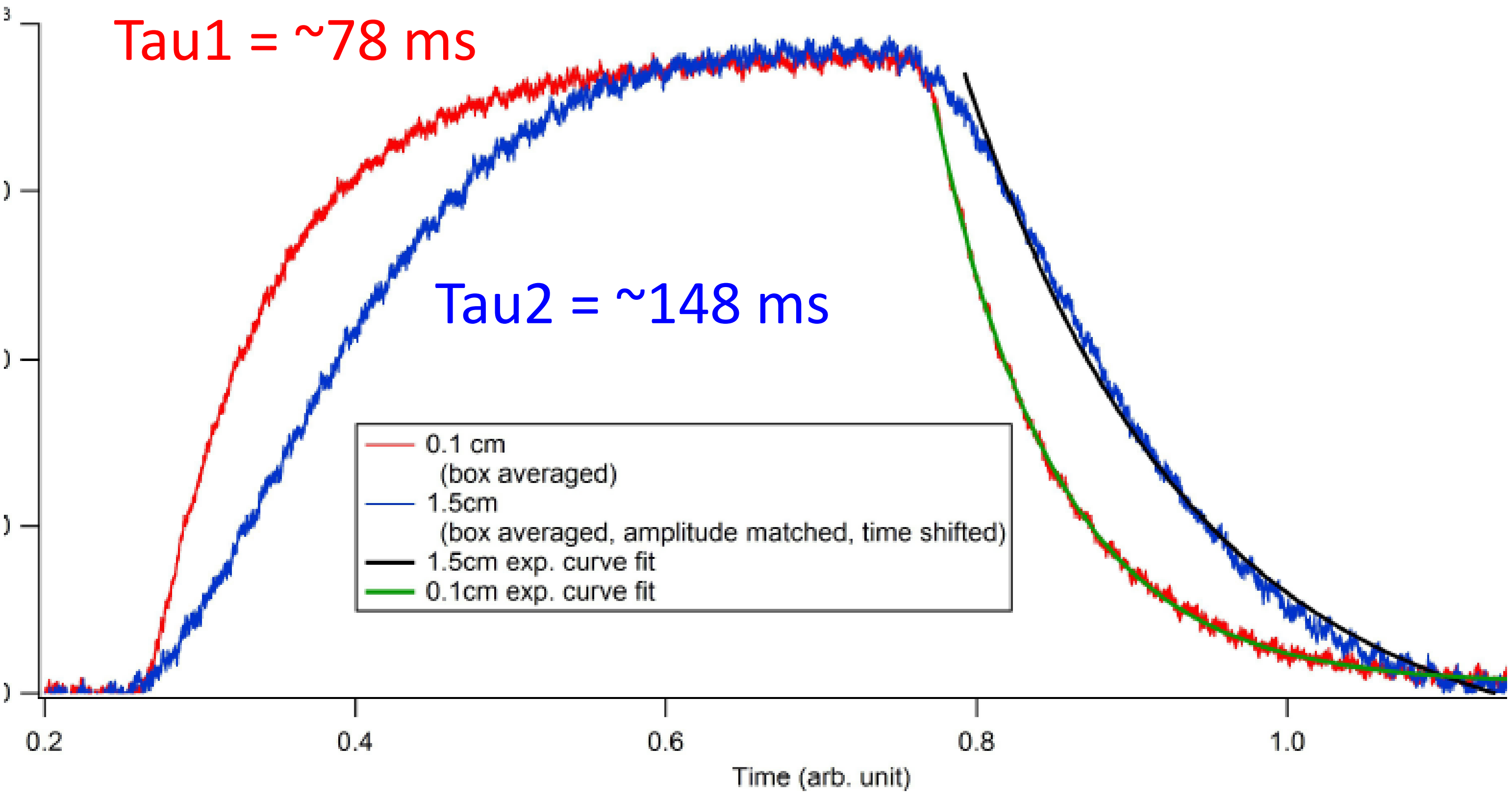
1 D Temperature Model for the Thermopile Detector



Newton's Law of Cooling: $\Delta T(t) = \Delta T(t_0)e^{-rt}$

1/r is the "time constant"

Effect of Effective Shuttering Rate

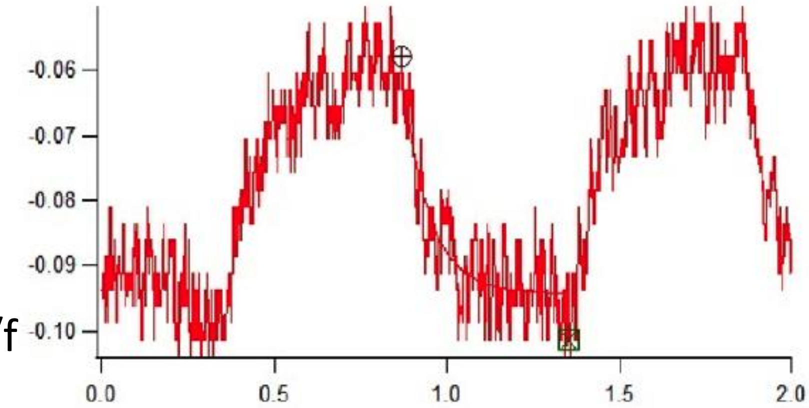


From Bean and Maltby Lab Report

Discriminating the Signal from the Noise

Intrinsic Sources of Electrical Noise (some):

From Eric Ha Lab Report



- Thermal Noise – random motion of electrons in conductor at any non-zero temperature (white noise, i.e. little frequency dependence).
- Shot Noise – discreet transfer of electron packets across junctions in, e.g. vacuum tubes.
- Flicker noise – due to a variety of effects, has a 1/f power spectrum.

Extrinsic Sources of Electrical Noise (some):

- Cross-talk – Unwanted coupling of signals in the experiment.
- Interference – Introduction of unwanted noise/signals into the experiment.
- Unintended/uncontrolled/unknown variation of experimental parameter.

Small Signals ((in the raw data, and in the processed data)

- Unoptimized alignment of optical set-up and problems with signal generation.
- Unoptimized signal acquisition.
- Unoptimized data manipulation.

http://en.wikipedia.org/wiki/Noise_(electronics)#Crosstalk

Techniques to Improve Signal to Noise Ratio

Compromise between time, effort, and quality of data

Maximize the signal:

- Can alignment be improved, slit-width be increased?

Minimize introduced variations:

- Is the output of the bulb constant, or varying?
- Are there vibrations, or stray light being introduced?
- Can sources of electrical noise be identified and/or shielded against?

Data acquisition techniques:

- Point averaging, dwell time, step size
- Spectrum averaging

Post-acquisition Data Processing:

- Smoothing, filtering (Igor Pro)

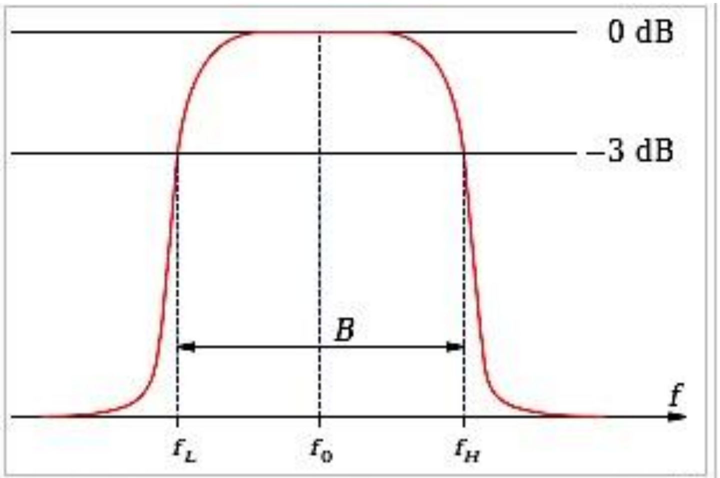
Signal Filtering and Lock-In Detection

The Lock-in technique allows for a signal of a given to be detected with a very good electrical filter that rejects (does not pass) all other frequencies.

Q of a filter – inverse of the fractional bandwidth passed at the half power point.

$$Q = f_0/\Delta f$$

From wikipedia



Bandwidth measured at half-power points (gain -3 dB, √2/2, or about 0.707 relative to peak) on a diagram showing magnitude transfer function versus frequency for a band-pass filter.

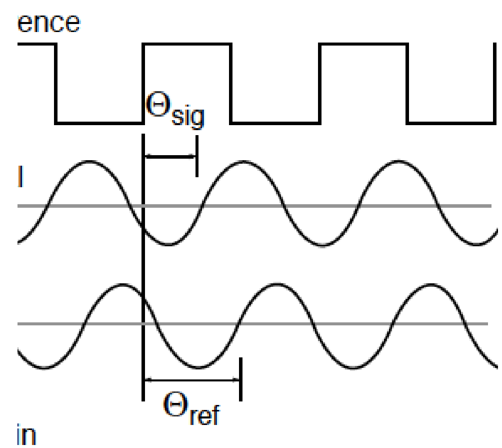
Example:

- Suppose you have a very good electrical filter that passes 10 kHz signals with a Q = 100.
- In addition to 10 kHz data, this filter would also pass signals that were 10 kHz +/- 50 Hz

By using Phase Sensitive Detection (PSD), Lock-in amplifiers can allow filtering with Qs as high as 500,000, which allows much higher noise rejection.

PSD: Driving the experiment at a particular *frequency*

The lock-in amplifies the signal and then multiplies it by the lock-in reference using a phase-sensitive detector or multiplier. The output of the PSD is simply the product of two sine waves.



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

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

The PSD output is two AC signals, one at the difference frequency ($\omega_r - \omega_L$) and the other at the sum frequency ($\omega_r +$

$$\sin x \cdot \sin y = \frac{1}{2}\left[\cos(x - y) - \cos(x + y)\right]$$

If the PSD output is passed through a low pass filter, the AC signals are removed. What will be left? In the general case, nothing. However, if ω_r equals ω_L, the difference frequency component will be a DC signal. In this case, the filtered PSD output will be:

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

This is a very nice signal—it is a DC signal proportional to the signal amplitude.

http://astro1.panet.utoledo.edu/~relling2/teach/4580.6280.2014/About_LIAs.pdf