Physics 480, Intro to Experimental Modern Physics---XI^th Friday!

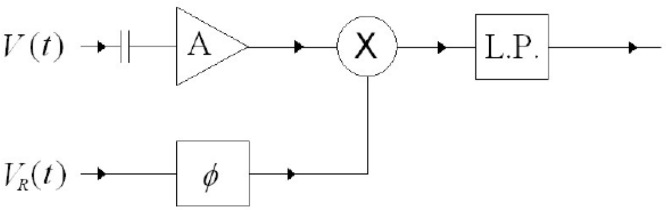
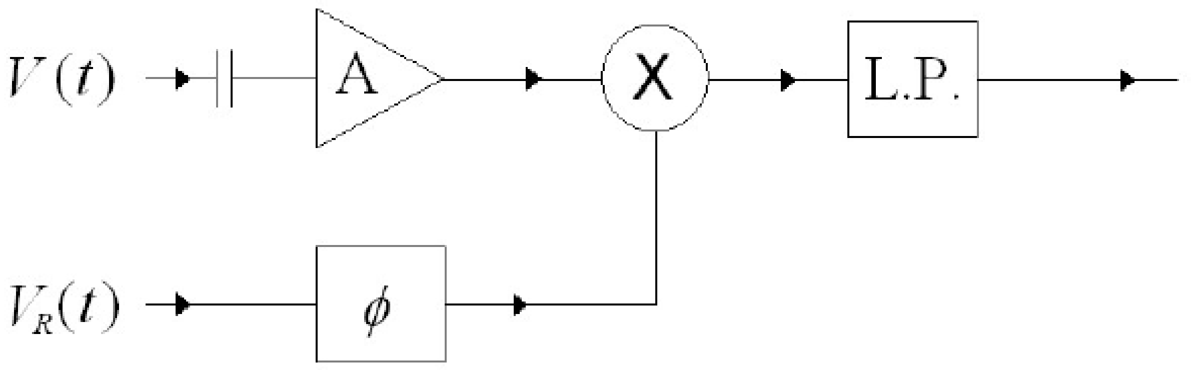


Fig. 1 Block diagram of phase-sensitive detection.

Goals for today:

G1 Diagnostics and experimental design….Noise reduction techniques (Lock-in Amplifiers)
E.g. listening for a humming bird in a hurricane

Experiments with lock-in amplifiers!!!



An introduction to phase-sensitive amplifiers: An inexpensive student instrument*

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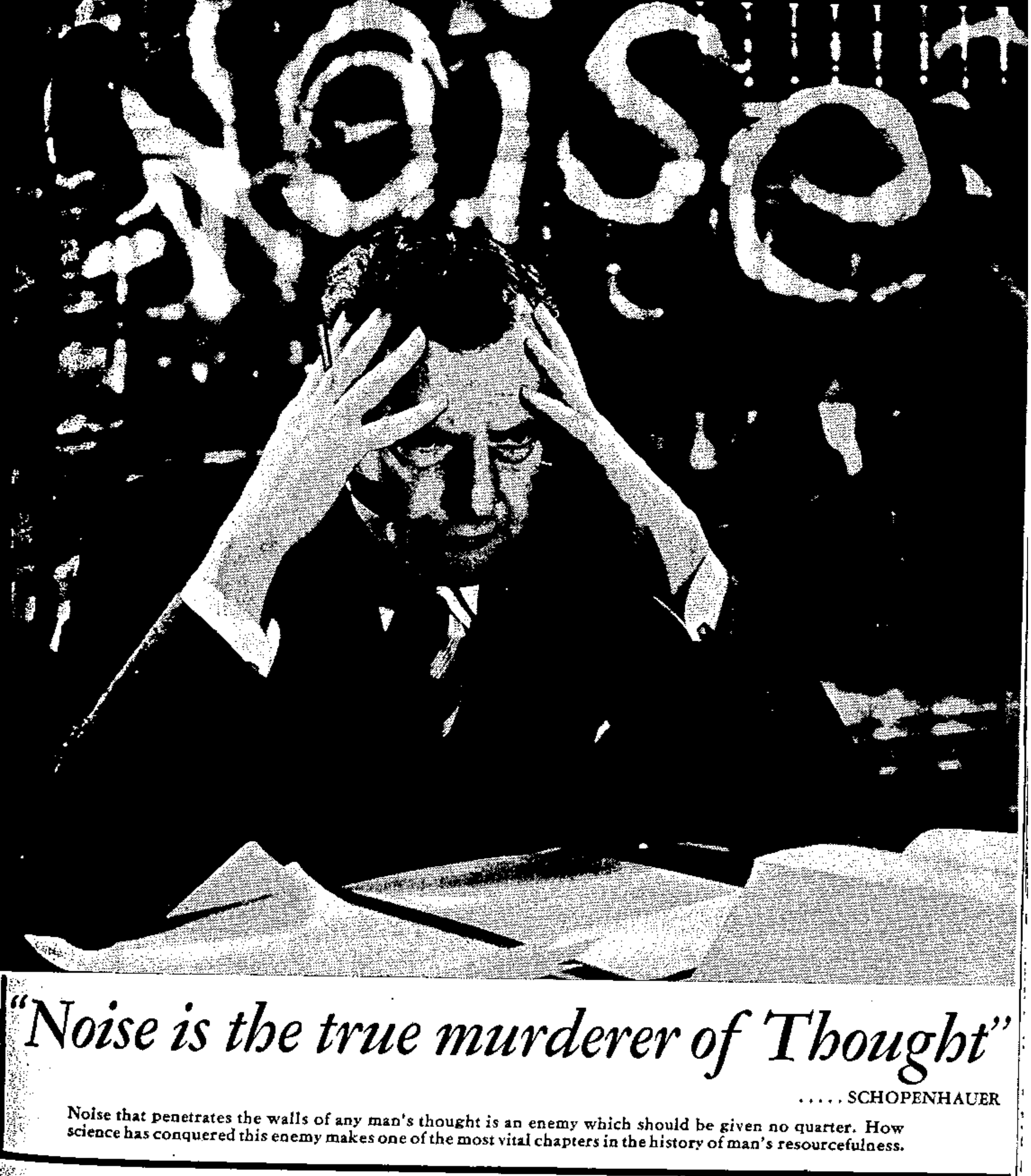
The principle of operation of phase-sensitive amplifiers is discussed. Three examples of the use of the phase-sensitive amplifier, or "lock-in," are given. The examples have been chosen to be suitable for undergraduate laboratory use. The paper is concluded with the description of an inexpensive "student" lock-in amplifier which has an overall voltage gain of 1000.

voltage. However, in addition to this small information signal, there will be present additional experimental output, called noise, which tends to obscure the desired information signal. The noise voltage may, in fact, be large compared to the information voltage. The problem confronting the experimentalist is that of extracting the information signal from the noise.

The information signal may be a slowly varying dc voltage or, in some cases, an ac voltage of fixed frequency with slowly varying amplitude. In general, it is just this slow variation, which represents the system's response to some slowly changing input parameter, that is of experimental interest. Noise, on the other hand, consists of a combination of voltage signals of random phase and more



To the Experimentalist:

NOISE is any signal that you don't care about,

Signal is any signal you DO care about

Signal is what your detector picks up

We are having this discussion because ALL detectors pick up MORE SIGNAL THAN YOU WANT…..

2 strategies:

1) Signal averaging
e.g.
(Boxcar integrator)

2) phase sensitive detection
(lockin amplifier)

"How to hear a humming bird in a Hurricane"

From one of our Lock-in Manuals…the heart of the Lock-in is the MIXER + LP filter……

3.3 Principles of Operation

3.3.01 Block Diagram

The model 7265 uses two digital signal processors (DSP), a microprocessor and a dedicated digital waveform synthesizer, together with very low-noise analog circuitry to achieve its specifications. A block diagram of the instrument is shown in figure 3-1. The sections that follow describe how each functional block operates and the effect it has on the instrument's performance.

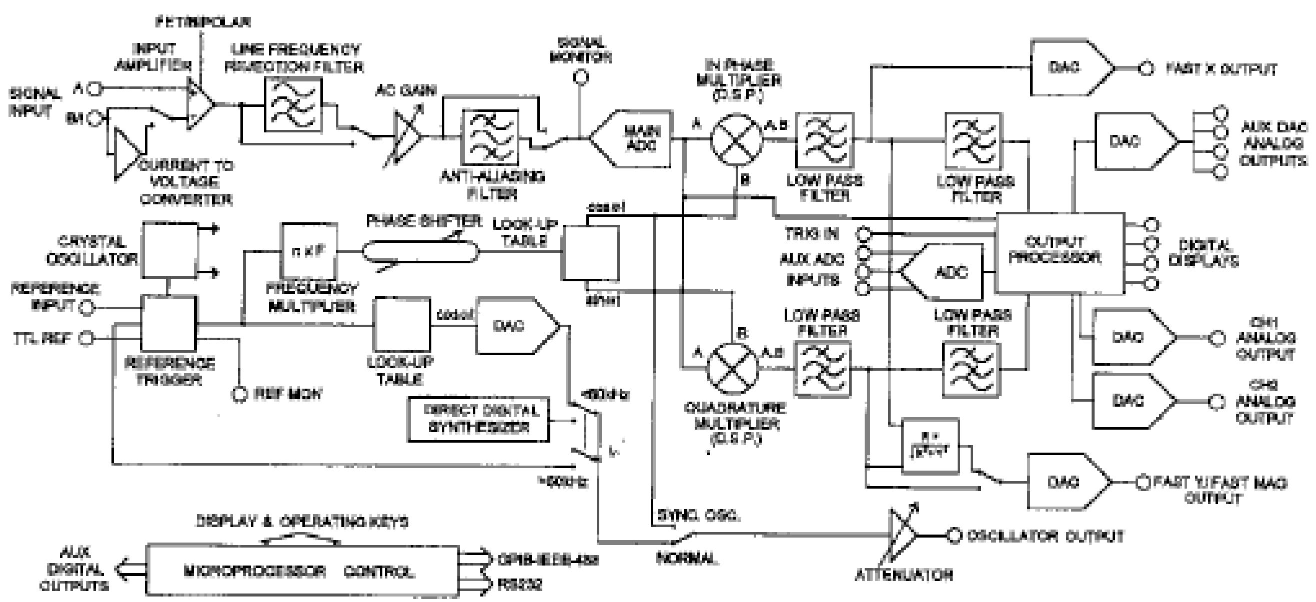


Figure 3-1, Model 7265 - Block Diagram

Generic Phase Sensitive Detection

A. Generic Phase Sensitive Detection

Let us assume that the input signal V_i and the reference V_r are given by

$$V_i = V_1 + V_1 \sin(\omega_s t - \phi_s), \\ V_r = V_2 \sin(\omega_r t - \phi_r), \tag{1}$$

A DC offset is included with V_i because Arduino, like most microcontrollers, only input or output positive voltage; therefore the Arduino outputs an offset reference voltage. This offset is removed during mixing, so V_r is centered on zero in what follows. Upon multiplication of the two signals in Eq. 1, and making use of a trig identity, the output of the mixing stage V_{mix} is

$$V_{\text{mix}} = V_1 V_2 \sin(\omega_2 t - \phi_2) + \frac{V_1 V_2}{2}\{\cos[(\omega_2 - \omega_1)t - (\phi_2 - \phi_1)] - \cos[(\omega_2 + \omega_1)t - (\phi_2 + \phi_1)]\} \tag{2}$$

At this stage Eq. 2 is nothing more than what we find in heterodyne detection in radio and optical engineering. The power of coherent detection is that small signals get amplified by a larger local oscillator signal is evident in Eq. 2. Upon mixing of the two signals there are contributions to the signal at the original frequencies and at the sum and difference frequencies. This is the heart of PSD; the output filter is set to reject all frequencies other than the difference frequency of the inputs. Furthermore, if V_i and V_r are made to oscillate at the same frequency before entering the PSD, the output V_o of the PSD simply depends on the phase difference between the two signals

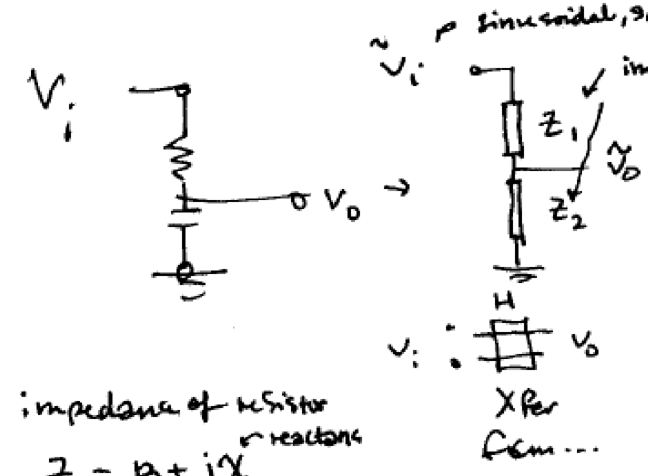
$$V_o = \frac{V_1 V_2}{2}\cos(\phi_o - \phi_1). \tag{3}$$

The final effect of this filtering is to move our output from $\omega_{1,2}$ to DC. The stronger the filtering, the more noise is rejected and the signal-to-noise increases. However, in effect, the PSD is performing signal averaging, so with each factor of two increase in the signal-to-noise, the collection time increases by a factor of four. The other disadvantage of PSD is that by making the measurements at DC we are placing our signal where $1/f$ noise dominates[10]. Once again we can see similarities with homodyne detection, and even though we have added no active amplification, the presence of a strong local oscillator can boost a weak experimental signal.

Hey Greg, make a worksheet for both this Mixer thing and the LP filter thing….

NOTES ON Lpfilters of the simplest kind….. (single – pole)

This is a "time domain" way of thinking about RC circuits, but there is also a frequency domain way, too and this is the speediest way of getting over the idea of "phase sensitive detection" . . . .



$H(\omega)$ = transfer function $\equiv \frac{\tilde{V}_o}{\tilde{V}_i}$;j

impedance of resistor or reactance

$Z = R + jX$, (impedance; resistance)

$= |\tilde{Z}|e^{j\theta}$ $\tan\theta = \frac{X}{R} = \frac{Im\{Z\}}{Re\{Z\}}$

Just a ______ High pass or low pass

$Z_1 = Z_R = R$ no imaginary part

$Z_2 = Z_c = -j\frac{1}{\omega C}$

$= \frac{1}{j\omega C}$

$\tilde{V}_o(\omega) = \tilde{I}Z_2$ but $\tilde{I} = \frac{\tilde{V}_i}{Z_1 + Z_2}$

$= \frac{\tilde{V}_i Z_2}{Z_1 + Z_2}$ ∴ $H(\omega) = \frac{Z_2}{Z_1 + Z_2}$

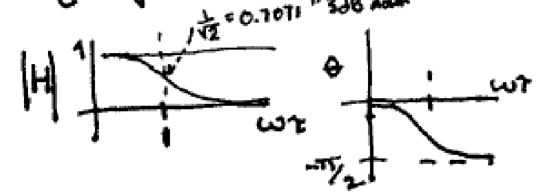
$= \frac{\frac{1}{j\omega C}}{\frac{1}{j\omega C} + R} = \frac{1}{1 + j\omega RC}$

$= \frac{1}{1 + j\omega\tau} = \frac{(1 - j\omega\tau)}{1 + \omega^2\tau^2}$

$= \frac{1}{\sqrt{1 + \omega^2\tau^2}} e^{-j\theta}$

$\tan\theta = -\omega\tau$ . . .

$e^{-j\theta} \cdot \sqrt{1 + \omega^2\tau^2} = 1 - j\omega\tau$



HOW DOES THIS WORK????

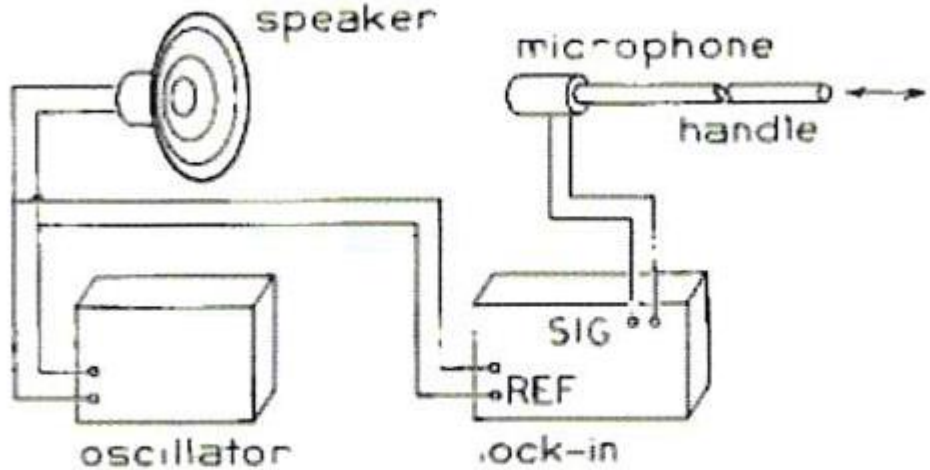


Fig. 5. Apparatus for the measurement of the speed of sound in a gas. Shown are an oscillator for driving a speaker, a microphone for measuring the instantaneous air pressure as a function of position, and a lock-in amplifier for measuring the phase relationship between the driving voltage and the instantaneous air pressure. The microphone is attached to a long rod to allow movement toward and away from the speaker. Not shown is a glass-wool-lined enclosure.

? Why would this be much harder even than this experiment
if the sample were obtained in hot filament discharge plasma
Such as this one….

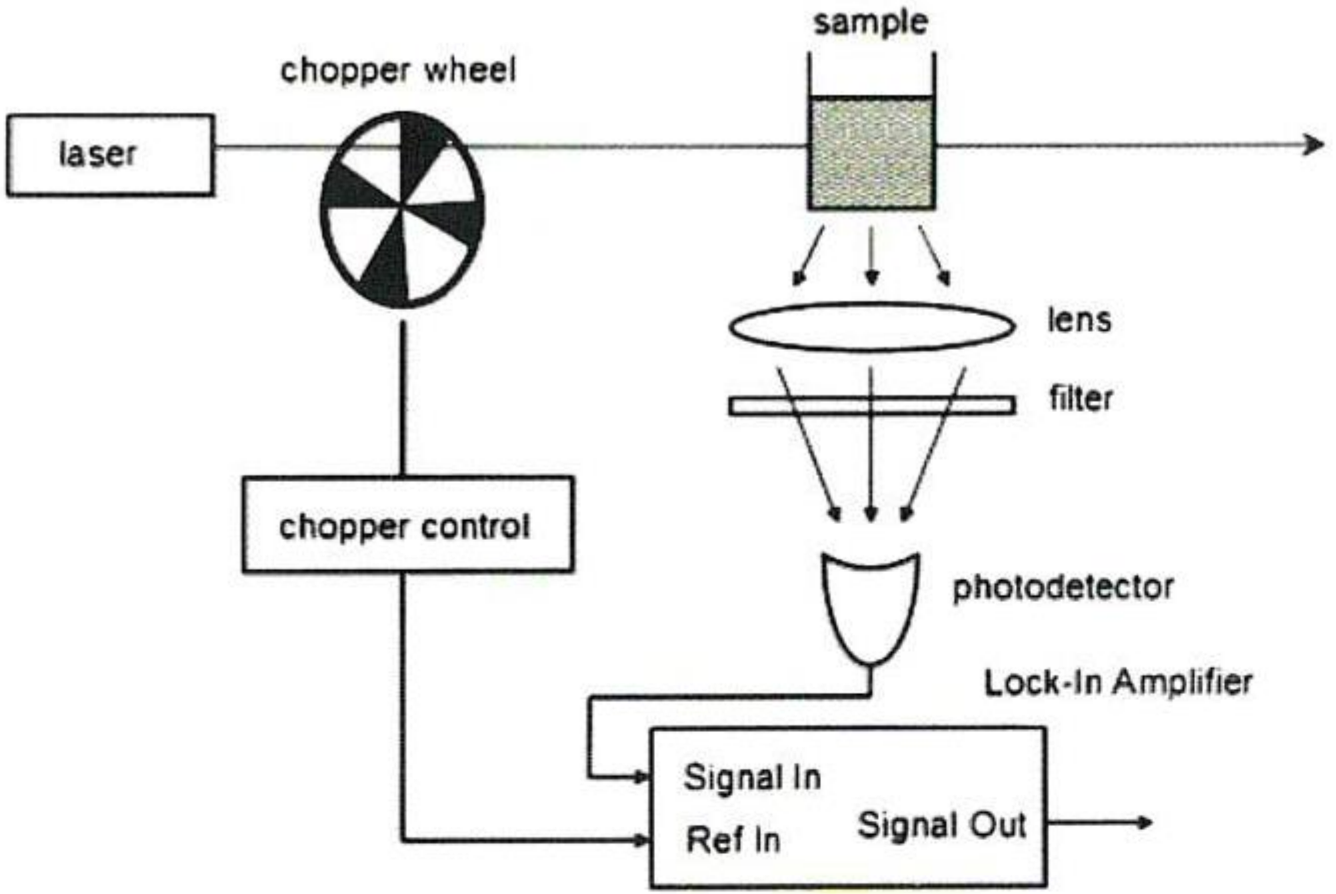
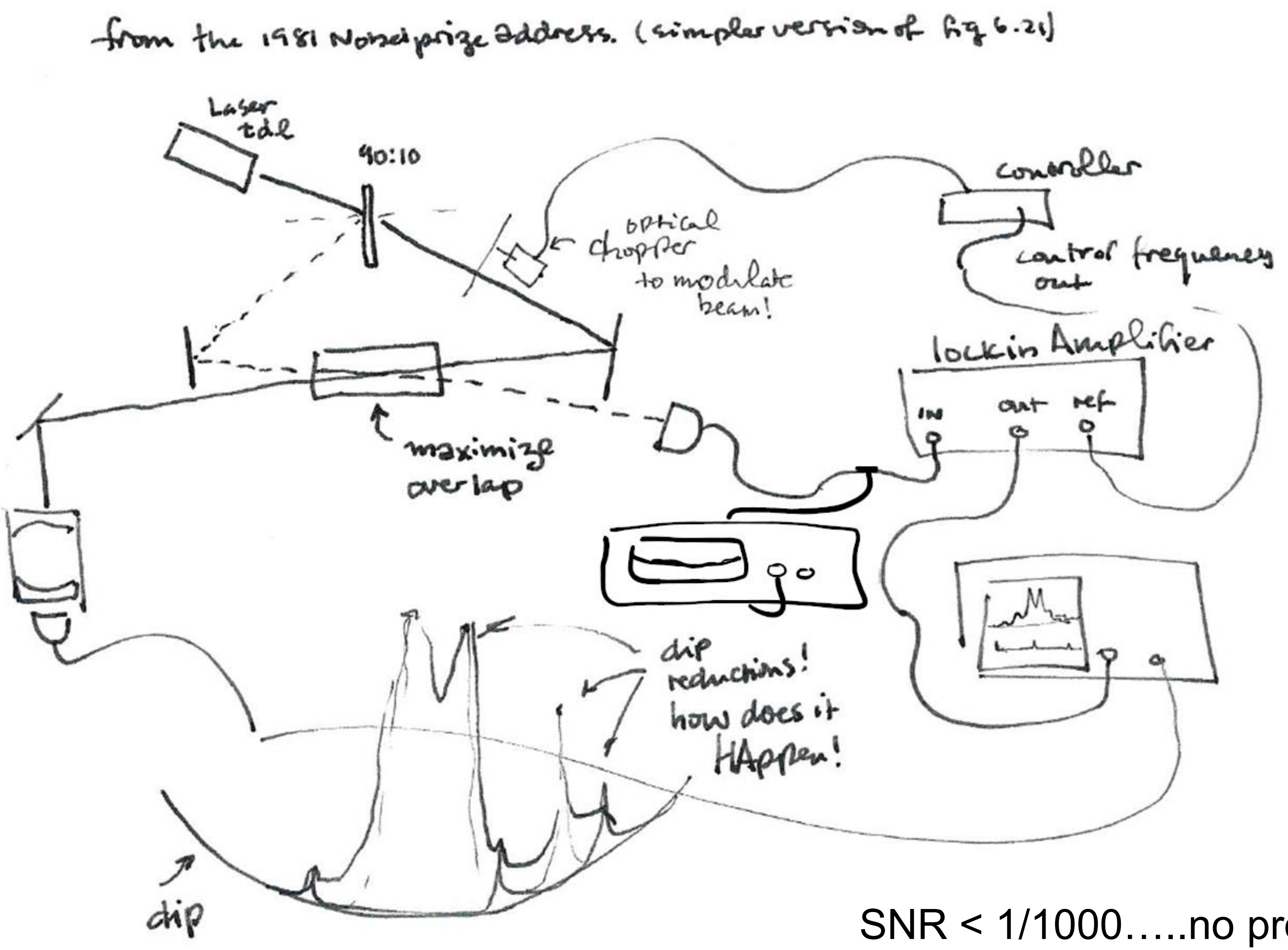


Fig. 2. A typical lock-in amplifier application in which one measures the fluorescence from a sample that is illuminated by a chopped laser beam—Ref. 5.

In our Laser Spectroscopy experiment, we use Lock-in ‘detection’ to observe hfs of excited state in Rb ($^2P_{3/2}$, ~ 780 nm, E1 transition)



SNR < 1/1000…..no problem
for Lock-in Amplifier!!!!