Using a Lock-in Amplifier

The Notes on Noise Reduction provide some background on experimental noise and briefly discuss the theory behind the lock-in amplifier. Here you will learn how to set up a lock-in for making measurements, using a simple instrument and simulated signal to follow the operation in detail. A later section describes a more sophisticated lock-in which is used for actual measurements in the lab.

The first lock-ins, sometimes referred to as synchronous detectors, were based on motor-driven mechanical switches. These implementations had obvious difficulties, motivating the development of purely electronic instruments. The first performed all operations in analog circuitry, with digital control of analog functions added soon thereafter. More recently, high-performance computer chips and sophisticated digital signal processing algorithms have made pure digital lock-ins feasible. Each variety has advantages and disadvantages in cost and capability.

A purely analog instrument is probably easiest to understand. The first section below leads you through the functions and set-up procedure for a Princeton Applied Research HR-8 lock-in. The remainder of the document describes the operation of the Stanford Research Systems SR 510, a modern hybrid design which is more flexible but somewhat trickier to control.

A. The PAR HR-8 with synthetic signal
1. General description and controls

Figure 1 is a simplified diagram of the PAR HR-8 lock-in, showing the principal functions, controls and monitoring points. The input signal plus noise is first amplified and then filtered to pass only a restricted band of frequencies to the phase sensitive detector. The reference voltage, usually from an external source, is also amplitude-adjusted and filtered to produce a pure sine wave.

Fig. 1 Block diagram of HR-8 functions.
at the reference frequency. The signal and reference voltages are then multiplied in the detector. The detector output is time-averaged by a low-pass filter to obtain an estimate of the signal amplitude with reduced fluctuation due to noise. The front panel meter and MONITOR output can be switched to observe the final output or any of several intermediate stages.

The instrument is controlled from the front panel, which is divided into several sections.

PREAMP: The installed module has two inputs, A and B. A switch selects the voltage to be amplified, either A, -B or the difference A-B.
SENSITIVITY: Sets the gain of the frequency-selective amplifier in the signal channel. The numbers indicate RMS voltage for full-scale deflection of the output meter.
FREQUENCY/FREQ RANGE: Set the center frequency of the signal channel and reference channel amplifiers. Must be set to the reference frequency.
SIG. Q: Adjusts bandwidth of signal tuned amplifier. Set at 10 for most applications.
FREQ. TRIM: Fine adjustment of amplifier frequency. Leave at 0 except when doing absolute calibration.
REF. IN/OUT: Input for reference signal from experiment, or output to control experiment.
REF. ATTEN.: Coarse and fine controls to adjust amplitude of reference input voltage.
MODE: Selects internal processing for reference signal. Default is SEL. EXT. to convert external reference to pure sine wave for detector.
PHASE: Coarse and fine controls to shift the phase of the reference to match signal phase.
TIME CONSTANT: Sets averaging time for final filter. Red switch selects slope of filter cut-off as 6 or 12 dB/octave.
METER/MONITOR: Selects quantity to be displayed on panel meter.
MONITOR: Voltage output proportional to meter reading for selected quantity.
ZERO OFFSET: Adds a constant voltage to the final output signal if needed.
CALIBRATE: Selectable amplitude square wave used to calibrate amplifier gains for high-precision measurements.

2. Testing with simulated signal

The circuit shown in Fig. 2 produces a sine-wave signal of controllable amplitude and adds noise when desired. There is a high-level output for scope display, and a much attenuated output for the lock-in. Check the operation of the circuit by connecting a signal generator (sine wave, about 1kHz) to the signal input of the simulator as indicated. Connect channel 1 of a scope to the simulator output and verify the presence of a sine wave signal and added noise. For later use, turn down the sine wave amplitude so that is it barely discernible under the noise. To maintain a stable display you will probably have to use the TTL output as an external trigger for the scope.
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Fig. 2 Circuitry and connections to generate a signal with noise for the lock-in. The components inside the dashed rectangle are already assembled in an enclosure.

Connect the simulator output to INPUT A of the lock-in, and set the switch to A to select that input. Connect the TTL output of the function generator (use a tee so you get signal to the scope and lock-in) to the REF IN/OUT connector. Finally, connect a cable from MONITOR to channel 2 of the scope, so you can see what various sections do to their inputs.

The next step is to adjust the lock-in operating frequency to match the reference frequency. Set the METER/MONITOR switch to REF and the MODE switch to SEL EXT. For a reference frequency of about 1 kHz, set FREQ RANGE to X10\(^2\), and adjust the FREQUENCY dial to maximize the meter reading. You may have to change the REF ATTEN setting to get the maximum to about half of full scale on the meter. The scope should now display a steady sine wave from the MONITOR output. This is the sine wave that goes to the phase sensitive detector. This process also centered the bandpass of the signal channel at the reference frequency. The frequency width of the filter can be changed with the SIG Q knob if necessary. A setting of 10 is good for general use. You can now see the effect of the bandpass filter on the noise. Switch the METER/MONITOR switch to SIG and increase the SENSITIVITY enough to make a sine wave visible on the scope. Note that there is still significant noise, but much less than at the input. (The OVLD light will probably come on, indicating saturation of later stages, but that is not a concern for now.)

Now complete the signal extraction by setting the relative phase of signal and reference to zero, thereby maximizing the output. Set the METER/MONITOR to OUT to look at the filtered output of the phase sensitive detector. Set the TIME CONSTANT to 1 SEC, and adjust the PHASE controls to maximize the meter reading. You can adjust the SENSITIVITY as needed to maintain a significant deflection without overload.
Try varying the TIME CONSTANT from 300 ms to 10s, to observe the effect of more or less averaging. Longer time constants should reduce the visible fluctuations in the meter reading and on the scope display. The disadvantage is that longer time constants bring longer response time when the signal level changes. You can demonstrate this by turning the signal on and off with the switch on the simulator box. The meter response will be very obviously slower for a 10s versus 1s time constant.

B. The SRS 510 Lock-in Detector

1. General description and controls

Figure 3 is a functional diagram of the Stanford Research Systems Model 510 showing most of the features. For our purposes, all the functions are controlled from the front panel through the embedded microprocessor.

Fig. 3 SRS Model 510 lock-in amplifier block diagram.

The SRS 510 has many bells and whistles that you will not need to use. Operation is actually quite easy once you figure out what to ignore. The front panel is divided into sections by function. The meter and digital display near the center of the panel both read a selected output voltage. The readout at the right side displays the frequency or relative phase of the reference, as desired. Most of the operating controls are push buttons, with corresponding settings shown by the lighted labels. The major controls and indicators you need to understand are:

SIGNAL FILTERS: These buttons insert bandpass, 60 Hz and 120 Hz filters between the preamplifiers and the phase sensitive detector. The bandpass filter is automatically tuned to the reference frequency. A filter which is "IN" is active and filtering the input.
SENSITIVITY: Can be decreased or increased with the buttons below the indicators. (Semantics: The illuminated number is the nominal full scale range in the units indicated. By increasing the number you are decreasing the sensitivity.)

DISPLAY: Connects the center meters to the filtered phase detector output, the added DC offset, or the RMS noise voltage at the input. Normal operation when set for X, the phase-detected output.

OUTPUT LCD: Shows the selected output parameter (signal, offset, or noise) in real units. The scale of the displayed quantity is indicated by the three LEDs to the right of the display.

ANALOG METER: Shows the selected output parameter (signal, offset, or noise) as a fraction of full scale.

OUTPUT BNC: Full-scale deflection of the meter corresponds to an analog output of ±10 V from this connector.

TIME CONSTANT: Switches set the time constants of two RC filters at the output of the phase detector. When the indicator is "NONE" the corresponding filter is not connected.

PHASE: This shifts the relative phase of reference and signal before they are combined in the phase detector. The buttons labeled "FINE" change the phase by 0.025° per toggle, or more rapidly if held down. The buttons labeled 90° will change the phase by ±90° steps.

OVLD indicator: If this is illuminated, the signal input is too large. Decrease the sensitivity until it goes out.

UNLK indicator: The reference signal is too small or missing. Be sure it is at least a volt or two and stable in frequency. The light will flash on briefly if you change the reference frequency, but that is not significant.

2. Connection and adjustment

Find the SIGNAL INPUTS section of the front panel and connect a cable from the experiment to the desired input. Input A is for signals referred to ground, A and B are used for differential signals, and I is for current inputs. Set the rocker switch to A for most uses, A-B for differential inputs and I for current inputs. If the OVLD indicator comes on, reduce the input signal and/or decrease the lock-in sensitivity until OVLD goes off. Be sure that you don't turn off the signal entirely, though.

Now find the REFERENCE section and connect the reference voltage from the experiment to reference input. Push the button labeled SELECT to get the Hz or kHz indicators to light. Push the button below the waveform symbols to select the correct type of reference signal: positive going square wave, negative going square wave, or symmetric input that crosses zero volts. The readout above the reference input should now show the frequency of the reference, and the UNLK
indicator should be off. If not, the lock-in is not getting a proper reference signal. Recheck your wiring and switch settings.

The optional bandpass filter in the signal channel is automatically set for the reference frequency, so manual adjustment is not needed.

The next adjustment is to internally phase shift the reference signal enough to bring it into phase with the input signal and thereby maximize the output. Adjust your experimental conditions to produce some signal at the input. Select a fairly short time constant to get a quick response, but still long enough to give a steady reading. Roughly maximize the signal output on the center meter with the phase buttons. Now change the phase by 90° and make further fine adjustments to the phase to get zero output. When you shift back by 90° again you will be at the maximum. (Positive deflection is usually preferable, but not required.) This procedure is more sensitive than trying to judge the maximum by eye. Note that the readout does not respond instantly because of the output filters.

Connect the OUTPUT BNC to a recording device if you wish to make a permanent record of your results.