

SIGNAL PROCESSOR/LOCK-IN AMPLIFIER



Understanding Extraction of Signal from Noise

- Modular Architecture
- Multiple “Strategies” for Extracting Signal from Noise
- Compare Lock-In and Amplitude Detection
- Conceptually Transparent Modules
- Noise Generator and Test Signals Built-In
- Low-Noise Preamplifier, Single-Ended or Differential
- Appropriate for Real Physics Experiments

SIGNAL PROCESSING

THE INSTRUMENT

The Signal Processor / Lock-In Amplifier was developed to help students understand the process of extracting weak signals that are embedded in a noisy environment. It allows them to experiment with a variety of “electronic strategies,” as well as to become familiar with some of the uses of phase-sensitive detection. The SPLIA1-A is the antithesis of the modern commercial research lock-in amplifiers. These elegant devices are essentially “black boxes” to the user (student), since they automatically adjust almost all of their parameters to achieve optimum signal-to-noise. They are designed for ease of operation and to achieve optimal signal recovery, but not to make what we call the “electronic strategies” transparent to the user. In short, wonderful as they are, they were obviously *not designed for teaching*.

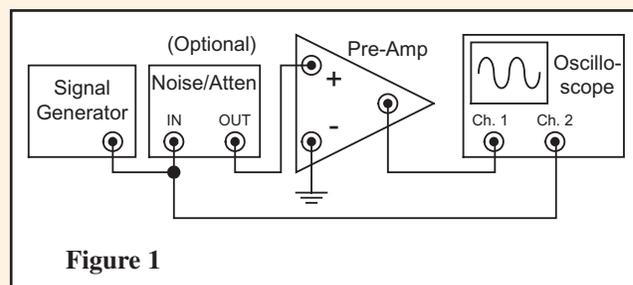
TeachSpin has designed the SPLIA1-A *specifically for teaching*. However, it can also function quite respectably as a “real” lock-in amplifier, for real physics experiments.

What makes this instrument unique and appropriate for teaching?

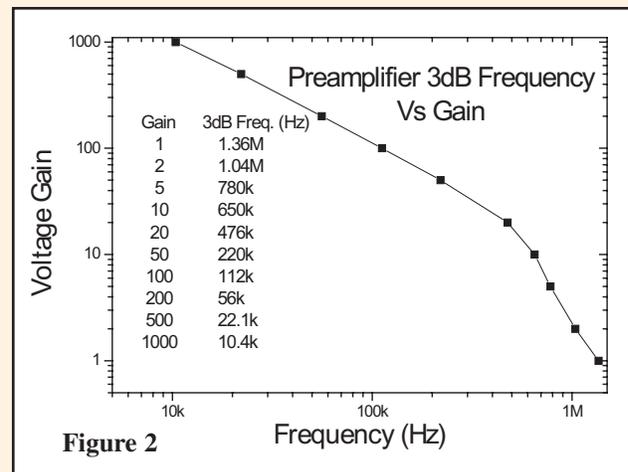
First of all, it has a modular layout, which electrically and spatially separates the preamplifier, filter, amplitude and lock-in detectors, low-pass amplifier, phase shifter, reference oscillator, noise generator, and attenuator. Students can configure these individual modules in a variety of ways to explore various “strategies” for enhancing the signal-to-noise of weak signals. This signal processor requires students to set the appropriate gain levels on various modules and to monitor the signal as it progresses through the instrument. With this instrument, the students can compare the signal-to-noise ratios for *both* lock-in and amplitude detection (precision rectifier) of the *same signal*.

Students must manually adjust all the controls on the SPLIA1-A. Nothing is automated! Additionally, all interconnections between the modules must be made by the operator. These are made with short BNC cables provided with the apparatus. This allows students to easily configure the modules for a variety of electronic enhancement strategies.

To give an example, students might study the frequency response of the preamplifier as a function of its gain. For this, the modules would be configured as shown in Figure 1.



The results of such measurements are shown in Figure 2. It may come as a surprise to some students that the frequency response of the preamplifier depends upon its gain. This is, however, a common characteristic of many amplifiers.



The SPLIA1-A has a sophisticated filter that has many applications. It can be used as a low-pass, high-pass, or bandpass filter with variable Q. The most common application of this filter is in bandpass mode, where it reduces the noise into the detector module.

Figure 3a shows the measured frequency response in the bandpass mode with two different values of Q . In Figure 3b, we show the measured phase shifts of the signal through this filter for the two values of Q . These measurements point to important phase stability considerations, which must be accounted for when using high Q filters and lock-in detection.

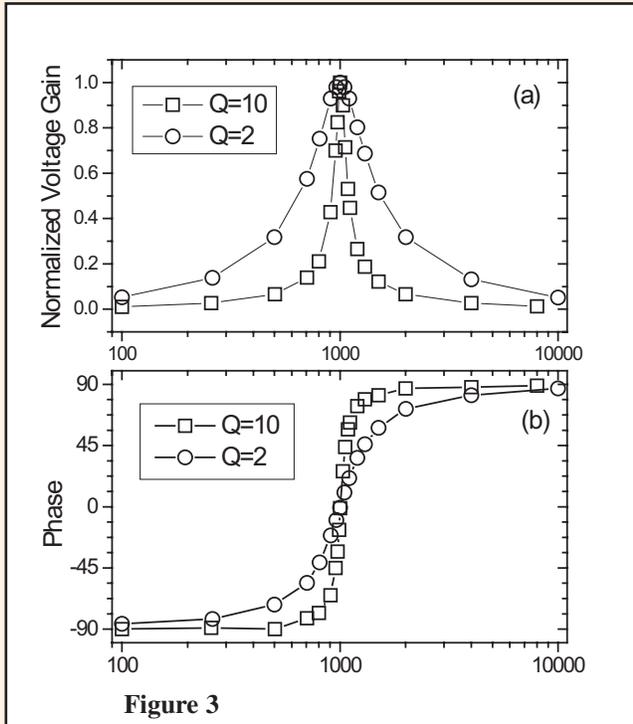


Figure 3

This module also has Chebyshev, Butterworth and Bessel types of filters. Examining the transient responses of these filters helps students to understand their function. Figure 4 shows the response of the Bessel filter (middle trace) and the Chebyshev filter (lower trace) to the square wave input shown on the upper trace.

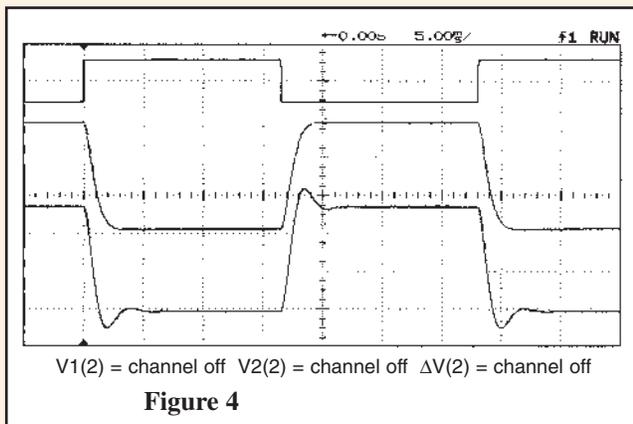


Figure 4

The low-pass amplifier module has both a 6db/oct and 12db/oct roll-off, with time constants varying from 0.3 to 10 seconds. The measured response curves for this output amplifier-filter are shown in Figure 5.

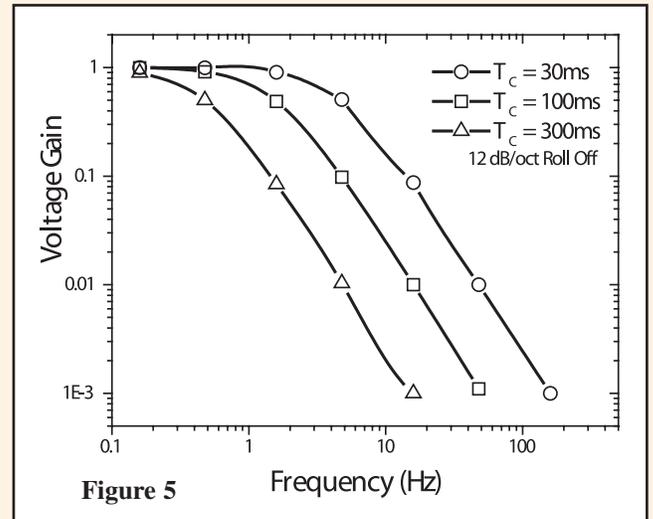


Figure 5

Students can study the effects of various time constants on signals that vary with time, such as when sweeping through a magnetic resonance signal. In that case, it is necessary to select a time constant compatible with the sweep rate, in order to optimize signal-to-noise enhancement, without distorting the signal. Students can also compare the effects of a 6db/oct and a 12db/oct roll-off filter on enhancement for time varying signals.

A unique feature of the SPLIA1-A is the ability to process a real physical signal (or a test signal) in different ways. In particular, it is useful to compare signal-to-noise enhancement using amplitude detection with lock-in or phase sensitive detection. Figure 6 shows the lock-in configuration of the modules while Figure 7 shows the amplitude detection architecture.

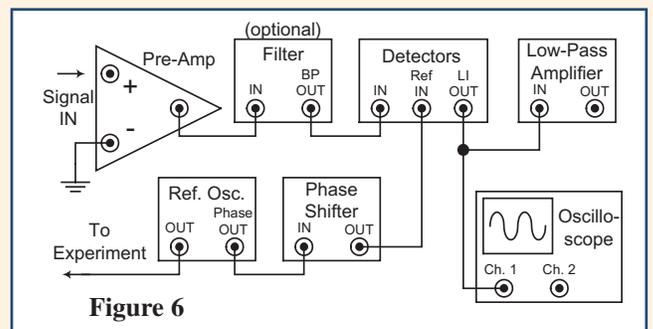


Figure 6

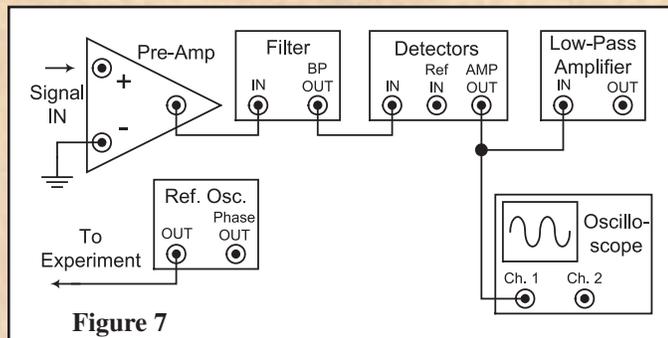


Figure 7

Figure 8 is a slow time scan of a test signal which is being detected both by the lock-in (lower trace) and the amplitude detector (upper trace) using the same overall signal bandwidth.

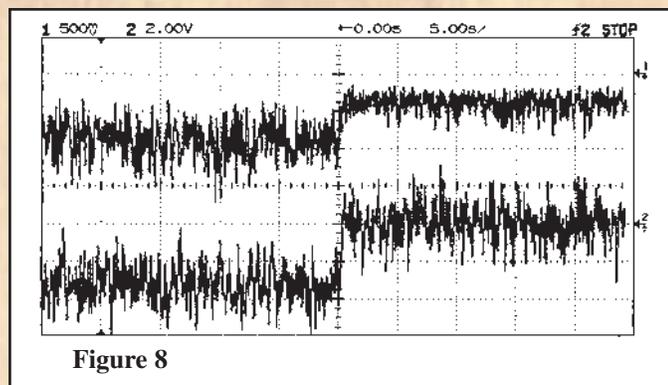


Figure 8

Teachspin's instrument even has a built-in noise source, which can be used to create a test signal with variable signal-to-noise ratios. This signal is created by connecting the reference oscillator through the signal attenuator. This allows students to experiment with signal processing before they use the instrument to process a weak signal from any number of real experiments.

This apparatus offers a wide variety of experiments to help students understand the nature of signal processing and develop a mastery of the lock-in detector. Considering the importance and omnipresence of the modern lock-in amplifier in the research labs of all kinds of experimental sciences, especially physics, it seems clear to us at TeachSpin that the SPLIA1-A belongs in every advanced lab. It is affordable; it is essential; it is ready for your advanced, electronics, or instrument laboratory course.

SPECIFICATIONS

Preamplifier

Input impedance 1 M Ω
 Noise @ 1kHz 9nV/ \sqrt{Hz}
 Common Mode Rejection 100 dB
 Max Output Voltage ± 10 V

Filter

Input Impedance 5 M Ω
 Max Input Voltage ± 12.5 V
 Frequency Range 3Hz - 3kHz
 Q Values .577, .707, 1, 2, 5, 10, 20, 50

Detectors

Input Impedance 100 k Ω
 Max Input Voltage ± 12.5 V
 Reference Switch Window ± 2 mV
 Reference Switching Spikes 50 mV pp. for .5 μ s

Low-Pass Filter / Amplifier (Output)

Input Impedance 1 M Ω
 Max Input Voltage ± 12.5 V
 Max Output Voltage ± 10 V
 Max Output Current ± 3.5 mA
 Time Constant .03, .1, .3, 1.0, 3.0, 10 seconds
 6 db/oct and 12 db/oct roll-off
 DC Offset ± 10 V
 Input Offset Voltage 100 μ V

Reference Oscillator

Frequency 2.6 to 3.2 kHz
 Harmonic Distortion .3% @ 3Hz, .03% > 30 Hz
 Max Output Voltage 4Vpp. (sine),
 8.8 Vpp. (Square)
 Max Output Current 35 mA
 Frequency Stability 200 ppm/ $^{\circ}$ C
 at HF, 800 ppm/ $^{\circ}$ C at LF end of range

Phase Shifter

Input Impedance 50 k Ω
 Frequency 3 Hz thru 3kHz
 Phase Shift 360 $^{\circ}$
 Quadrature Phase Accuracy $\pm 2^{\circ}$
 Max Input Voltage ± 12.5 V

Noise / Attenuator

Input Impedance 1.1 M Ω
 Attenuation 10 5
 Noise Voltage Output Max 1 V $_{rms}$

Minimum Detectable Signal 10 $^{-8}$ V $_{rms}$ @ 500Hz

BNC Cables 3-8", 4-6", 1-11"

Dimensions 12 9/16" x 8 7/16" x 8 1/2"

Instructor's Manual and Student Manual

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