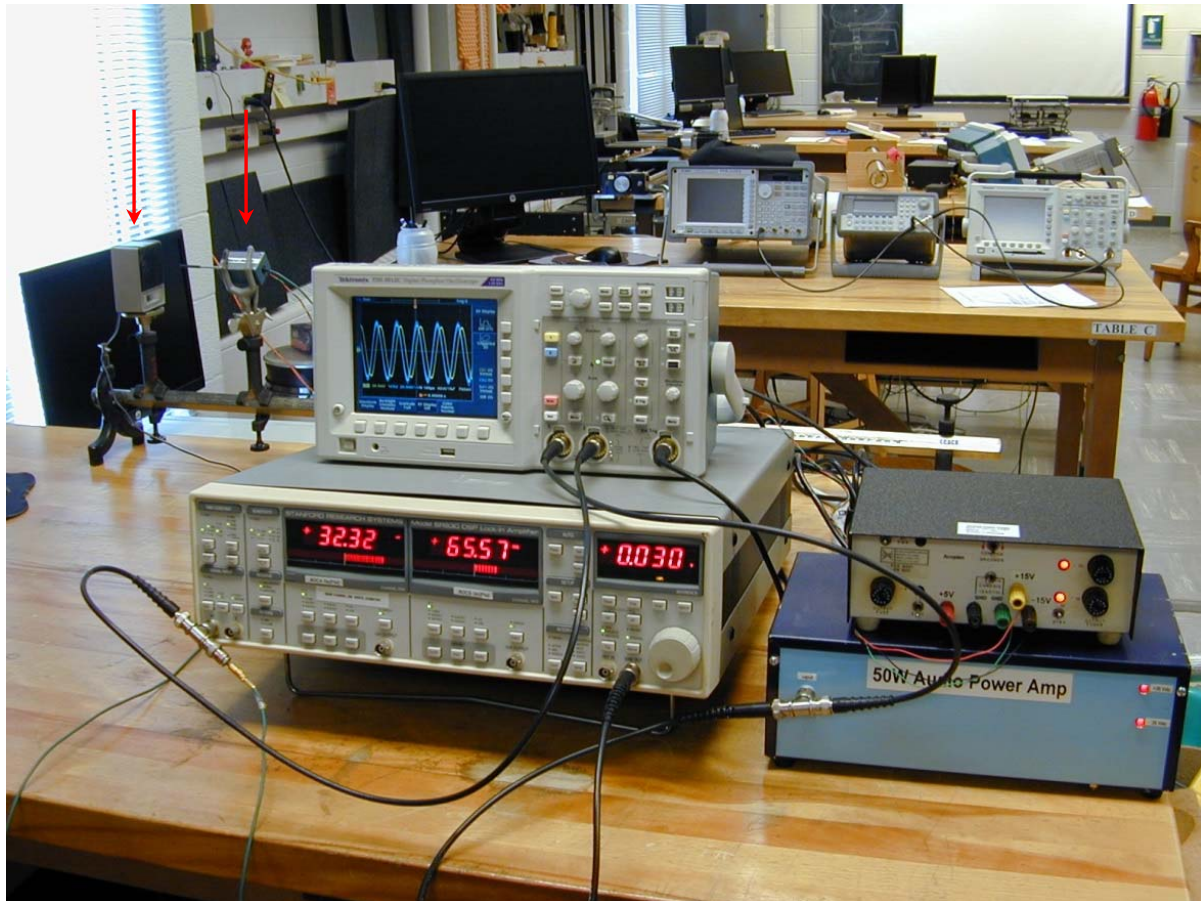


Measurement of the Phase Speed of Sound in “Free” Air

We have developed an experimental setup for the UIUC Physics of Music Lab that is specifically designed to measure the phase speed of sound $v_\phi = \omega/k = f\lambda$ in “free” air – *i.e.* air that is not physically confined/constrained in any manner – *e.g.* sound propagation in {still} air in the great outdoors. Measurement of the speed of sound propagation in air inside a {large} room is an approximation to this ideal situation.

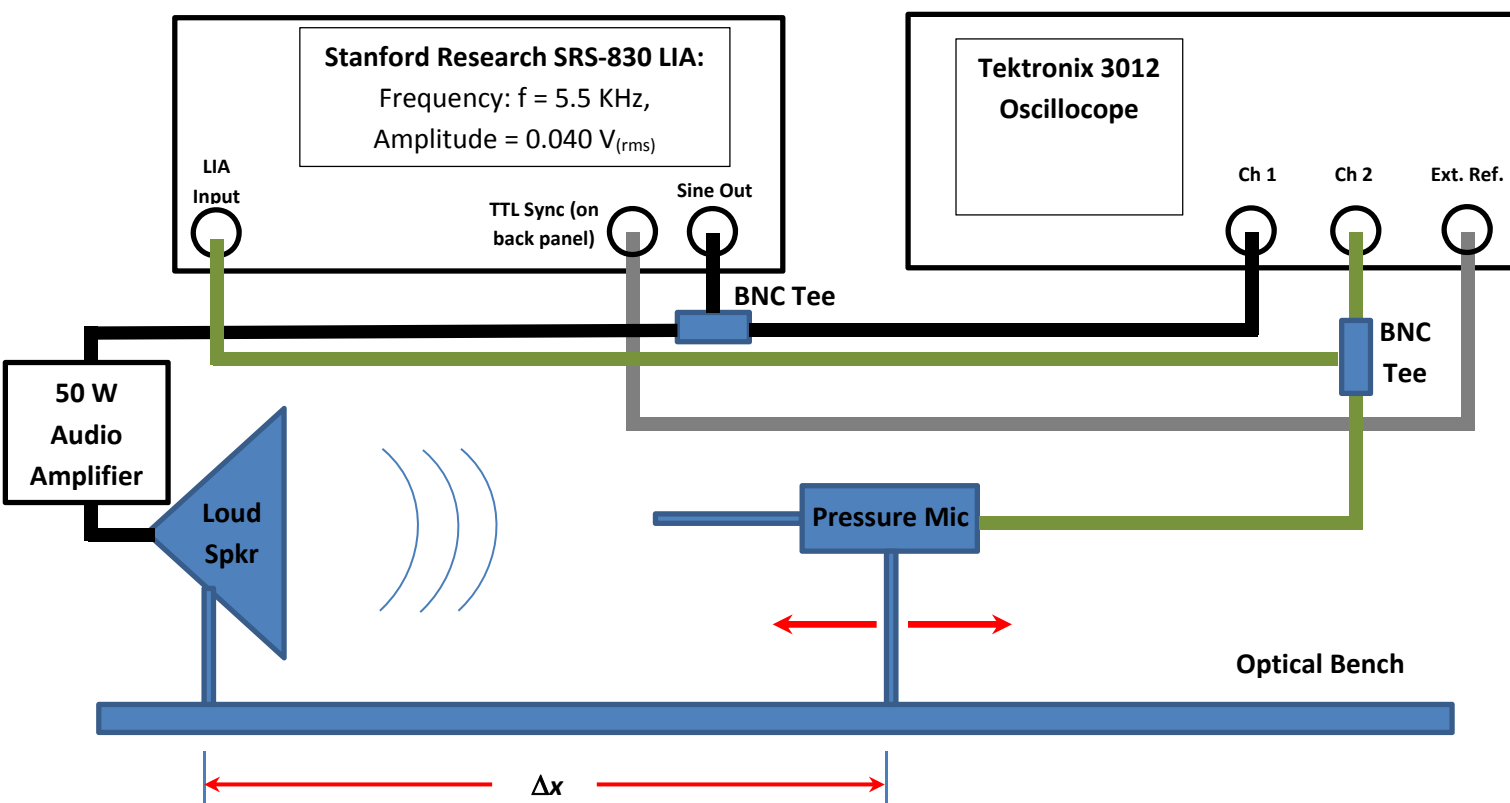
This experimental setup is shown in the pix below. The apparatus consists of using *e.g.* a 5.5 KHz sine wave output from a Stanford Research Dual Channel SRS-830 Lock-In Amplifier (LIA) to excite (via a solid-state 50 W audio power amplifier) a small loudspeaker mounted at the LHS end of an optical bench. We use one of our specially-developed pressure microphones, also mounted on the optical bench, to measure the acoustic pressure $p(x)$ at a distance Δx (m) from the loudspeaker. We use a dual-channel Tektronix 3012 Oscilloscope to simultaneously display both the exciting sine wave signal and the microphone signal. The signal output from the pressure mic is also simultaneously input to the SRS-830 LIA so that we can measure the phase of the pressure signal $\phi(\Delta x) = k\Delta x + \phi_o$ (radians) vs. loudspeaker-pressure mic separation distance Δx . The phase offset ϕ_o can be measured when $\Delta x = 0$. A ± 15 V_{DC} power supply is used to power the microphone’s preamplifier circuit.



Experimental Procedure:

A schematic diagram of the experimental setup – with cable connections indicated – is shown in the figure below. Switch on the 120V AC power to the SRS-830 LIA, the Tektronix 3012 ‘Scope, the ± 15 V_{DC} power supply for the microphone preamplifier and the 50W audio power amp.

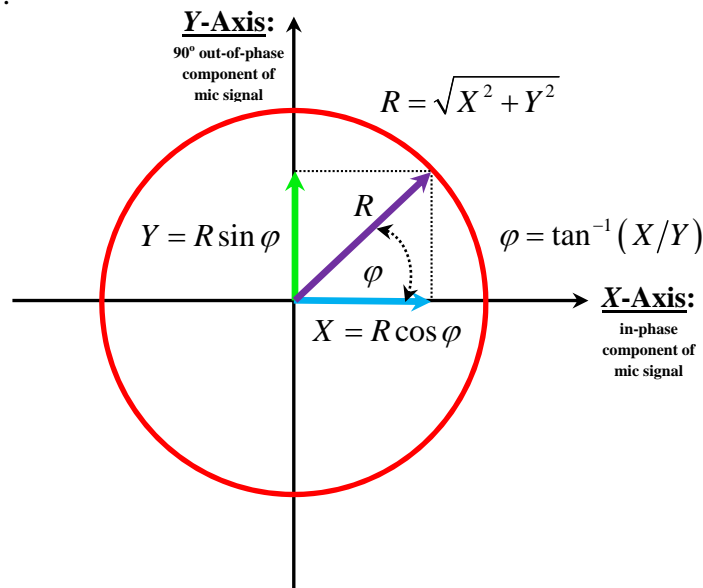
Experimental Setup for the Measurement of the Phase Speed of Sound in “Free” Air:



The sine wave signal output from the LIA’s internal oscillator and the pressure microphone signal should appear on Ch1 (Ch2) of the ‘Scope – yellow (blue) traces, respectively. Depending on whomever last used the experimental apparatus, the individual Ch1/Ch2 input sensitivities, the ‘Scope’s horizontal time base and trigger threshold, *etc.* may need to be adjusted to properly display these waveforms. The front panel controls of the SRS-830 LIA are shown in the photo below. The frequency and amplitude of the LIA’s internal oscillator can be adjusted/set using the red-box highlighted buttons and large wheel on the RHS of the LIA. The green LED for the internal oscillator (located just above the LIA’s *Sine Out*) should be lit. If it is not lit, use the *Source* button (also located just above the LIA’s *Sine Out*) to select this option. With the pressure mic in proximity to the loudspeaker (*n.b.* check that the axis of the pressure mic coincides with/is parallel to the speaker axis!), adjust the LIA’s sensitivity (light blue-highlighted box at top left of the LIA) until there is a reasonable signal detected by at least one of the two red LED bar displays and as per the numeric LED displays (green-highlighted box at top center of the LIA), *e.g.* as shown in the figure below, for LIA channels 1 (*aka* channel X) and 2 (*aka* channel Y). If any difficulties are encountered here, don’t hesitate to ask a POM TA for help/assistance!



The LIA's X-channel (Y-channel) respectively, measures the in-phase (90° out-of-phase) component of the mic signal input to the LIA relative to the reference sine wave signal {generated by the internal oscillator of the LIA}. The X- and Y-components of the mic signal input to the LIA can be graphically plotted in the X-Y plane – as shown in the figure below, and, using the Pythagorean theorem for a right triangle, it can be seen that the {total} amplitude R of the mic signal input to the LIA is $R = \sqrt{X^2 + Y^2}$; the phase of the mic signal input to the LIA – relative to the reference sine wave signal of the LIA's internal oscillator is: $\varphi = \tan^{-1}(Y/X)$. Hence, we also see that $X = R \cos \varphi$ and $Y = R \sin \varphi$.



The LIA's digital LED displays and the LED bar graph displays nominally show the X (in-phase) and Y (90° out-of-phase {aka "quadrature"}) components of the p -mic signal input to the LIA. However, very conveniently, the user can instead optionally select, using the X (Y) **Display** buttons (purple-highlighted boxes in the above pic of the front panel of the LIA) to display R and φ , respectively.

Slide the microphone towards/away from the loudspeaker – on the Oscilloscope, observe the change in the phase of the pressure mic signal (blue trace) relative to the reference sine wave signal (yellow trace) when the pressure microphone is moved towards/away from the loudspeaker.

Likewise, observe the changes in the readings of R and φ on the LIA's display for the microphone signal when the pressure microphone is moved towards/away from the loudspeaker.

You may notice/discover the extreme sensitivity of the LIA R and φ measurements *e.g.* to any motion(s) of your own body, when/if you make any movements – sound waves hitting you can/will scatter into the microphone and affect the results! Thus, insofar as possible, carry out such measurements with you located as far away as possible from the experimental setup!

Measure the phase offset φ_o by {carefully!} moving the microphone up to the loudspeaker. Then, slowly pull the microphone away from the loudspeaker. Determine the x -location where the phase first goes to zero. Call this point x_1 . Then, slowly pull the microphone further away from the loudspeaker, determine the 2nd x -location where the phase goes to zero again, call this point x_2 . Then, again slowly pull the microphone further away from the loudspeaker, determine the 3rd x -location where the phase goes to zero again, call this point x_3 , and so on. The distance between successive phase zeros is equal to one wavelength: $\Delta x = x_n - x_{n-1} = \lambda$. Since the frequency f is known, the phase velocity can then be calculated using the formula: $v_\varphi = \omega/k = f\lambda$. For free-field propagation of monochromatic sound waves, $v_\varphi = \text{constant}$, independent of position and/or frequency. Compare this result to that obtained *e.g.* using the pulse propagation time method!

Additionally, using the **Display** button on the Oscilloscope, by selecting the X - Y option (instead of the default Y - T option) it is possible to observe the phase relation between the pressure mic signal and the reference sine wave signal on the Oscilloscope – as a Lissajous figure – in this specific case, as an **ellipse**. For two signals with **equal** amplitudes, when two such signals are **exactly** in-phase, the Lissajous figure is a straight line with positive slope $m = +1$. When two such signals are **exactly** 180° out-of-phase, the Lissajous figure is a straight line with negative slope $m = -1$. When two such signals are **exactly** $\pm 90^\circ$ out-of-phase, the Lissajous figure is a perfect circle. For intermediate phase relations, the Lissajous figure is an ellipse. Try this out with the 'Scope, and observe what happens as the location of the pressure microphone is slowly moved back and forth – simultaneously observing what the LIA reports as the phase of the pressure mic signal, relative to the reference sine wave signal, output from the LIA's internal oscillator.

If interested, details of how the SRS-830 Dual-Channel LIA determines the in-phase and 90° out-of-phase components of an input signal are discussed in UIUC Physics 406 Lecture Notes XIII, as well as the SRS-830 User Manual – both are available on-line. The latter is also available as a POM Lab Handout.