Pre-Lab Notes: Waves, Phase, and Speed of Sound

Traveling waves

You should study the following concepts associated with oscillations and traveling harmonic waves:

- Period T, frequency $f = 1/T$ (units s, Hz = 1/s); sinusoidal oscillation at a point in space.
- Wavelength λ: The distance for which wave pattern repeats.
- Wave speed v:the speed at which the wave propagates; in this lab we are concerned with pressure waves in air, or sound, with speed approximately 330 m/s. The wave speed, frequency (or period), and wavelength are simply related:

$$v = \lambda f = \lambda/T$$

- The formula for a harmonic traveling wave:

$$y(x,t) = A\cos\left(\frac{2\pi}{\lambda}x - \frac{2\pi}{T}t + \phi\right) = A\cos\left(\frac{2\pi}{\lambda}(x - vt) + \phi\right)$$

Notice how this is a function of both position x and time t. The entire argument in parentheses of the cosine function is known as the *phase* of the wave (usually expressed in radians). The meaning of the letter ϕ in the equation is the value of the phase at $x = 0$ and $t = 0$. It may be used to designate the phase difference between two harmonic waves that have the same wavelength. You should learn to spot when two waves have a phase difference of 90 degrees ($\pi/2$ radians) and 180 degrees (π radians).

Phase

This lab emphasizes interpreting the difference in phase $\Delta\phi$ of two signals, and relating that to the period or wavelength. If the two signals line up, they are *in phase*: the phase difference is zero. If the peak of one is over the trough of the other, and the phase difference is 180 degrees, or π radians. In this case, the waves are *completely out of phase*: if you were to add them together, they could cancel each other if they have the amplitude A.

For other cases, one can measure the (smallest) difference in time between the same feature in each wave (like the positive peak of each), call it Δt, and divide by the period T to get the fraction of a period between each wave. Then multiply this by the number of degrees or radians in a full period. Thus,

$$\Delta\phi = \frac{\Delta t}{T}360 \text{ (degrees)} = \frac{\Delta t}{T}2\pi \text{ (radians)}$$

Beats

When two harmonic waves of nearly the same amplitude and slightly different frequency are added together, the result is a composite wave whose main frequency is the average of the two original frequencies, but whose amplitude varies in time at a frequency equal to the difference of the two original frequencies. In sound waves, this produces the phenomenon of *beats.* Musicians learn to listen for beat frequencies when they play or tune their instrument: when the beat frequency goes to zero, the two notes are in tune. You will use this trick to match the sound of a tuning fork with the sound produced by an electronic function generator.

Apparatus

Function Generator

A function generator is an electronic instrument designed to produce a well-defined signal that can be used for testing purposes. Most function generators will produce at least three different kinds of signals, “square waves” in which the output voltage oscillates between only two values, “triangle waves” in which the output varies in a linear way between two extremes, and “sine waves” in which the output oscillates sinusoidally, i.e., according to the mathematical function $\sin(2\pi f t)$, where f is the frequency. A sine wave is a *pure tone* or a single frequency; it would sound like a flute. The other waves would have a noticeably more complex sound, like a horn. In this lab you will connect the function generator to a speaker and use the sine wave to create a pure tone. The *amplitude* controls the volume of the sound as created by a speaker. The *frequency* controls the pitch.

Oscilloscope

An oscilloscope is a complex instrument with many measurement capabilities. It is one of the most useful instruments in physics research laboratories. Oscilloscopes allow you to study signals that are too rapid to sense in other ways. They provide a visual representation of electrical signals over time. The names of the signals produced by function generators–square waves, triangle waves and sine waves–come from the way that they look on the oscilloscope screen.

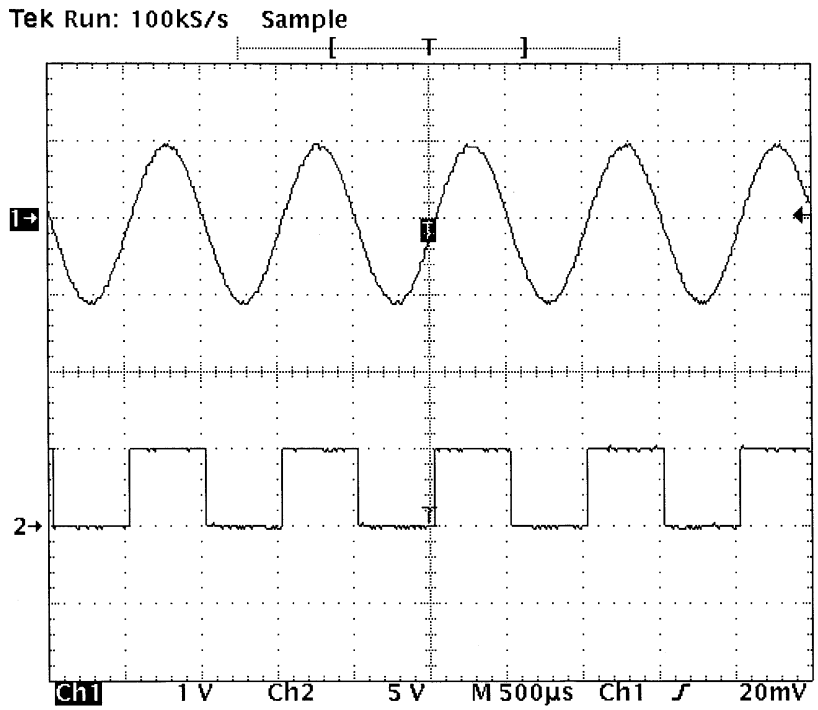
The screen of an oscilloscope displays a graph of an electrical signal, with *time* on the x-axis and *voltage* on the y-axis. One of the features of the oscilloscope that you will use in this lab is to measure the time between similar features of two different signals created by two different microphones that are sensing the sound made by a speaker. The time difference between the two sine waves along with the time duration of one cycle will allow you to determine the phase difference between the waves. Later, you can track the shift in time of a peak of one sine wave as you move the microphone, and this relationship will give you the speed of the wave: the speed of sound.

There are three most-important controls on an oscilloscope:

VOLTS/DIV: This is the amount of vertical amplification applied to the incoming signal. The smaller the number, the larger the amplification. Each division is about 1 cm in size, and the setting means that one vertical division is equal to the voltage increment specified. For example, 1V/DIV would be one volt change for each vertical division change. Each signal input (Channel 1 or Channel 2, i.e., “CH1” or “CH2”) has its own amplifier.

SEC/DIV: This is the amount of time change per horizontal division. The smaller the number, the more rapid the signal that can be displayed. The SEC/DIV setting is the same for both channels.

TRIGGER: The “trigger” circuit is comprised of a number of controls, and learning to use this part of the oscilloscope takes some practice. The trigger allows the oscilloscope display to synchronize to the incoming signal. The image will appear stable only when the trigger is set to respond to the same part of the signal for each repetition (also called “sweep”) of the display.



The picture at right shows a typical screen on a digital oscilloscope, similar to what you will use in the lab. Along the bottom are the settings in use: CH1 is set to 1V/DIV, CH2 is set to 5V/DIV, the SEC/DIV is set to 500 microseconds/DIV, and the trigger circuit is set to respond to CH1 and to sweep when the input signal reaches 20mV, increasing (positive slope).

In this example, the upper signal is a sine wave with amplitude of 2 volts "peak-to-peak" (that is, top-to-bottom). The lower signal is a square wave with amplitude of 5 volts peak-to-peak. The numbers and arrows at the left side indicate where zero volts is for each channel. You can see that the sine wave (CH1) oscillates between positive and negative voltages of ±1V, but that the square wave (CH2) oscillates between 0V and +5V. The period of both signals is 1000µs, corresponding to a frequency of 1000 Hz.