

Experiments in the High-Tech Tools and Toys Laboratory

1. Propagation Velocity of Ultrasound Waves

The purpose of this exercise is to measure the propagation velocity of sound waves in air as a function of wave amplitude and frequency. We will be using pulses of sound at a frequency of 40 kHz. Sound at frequencies above the range of normal human hearing (usually taken to be 20 Hz – 20 kHz) is called *ultrasound*. The most familiar use of ultrasound is for medical diagnostic imaging where frequencies optimized for propagation and imaging through water or human tissue (1 MHz or higher) are used.

We will use a separate transmitter and receiver in a “pitch and catch” configuration illustrated in Figure 1 below. (Most medical ultrasound instruments use the same transducer both to transmit a pulse and receive the reflected pulse.)

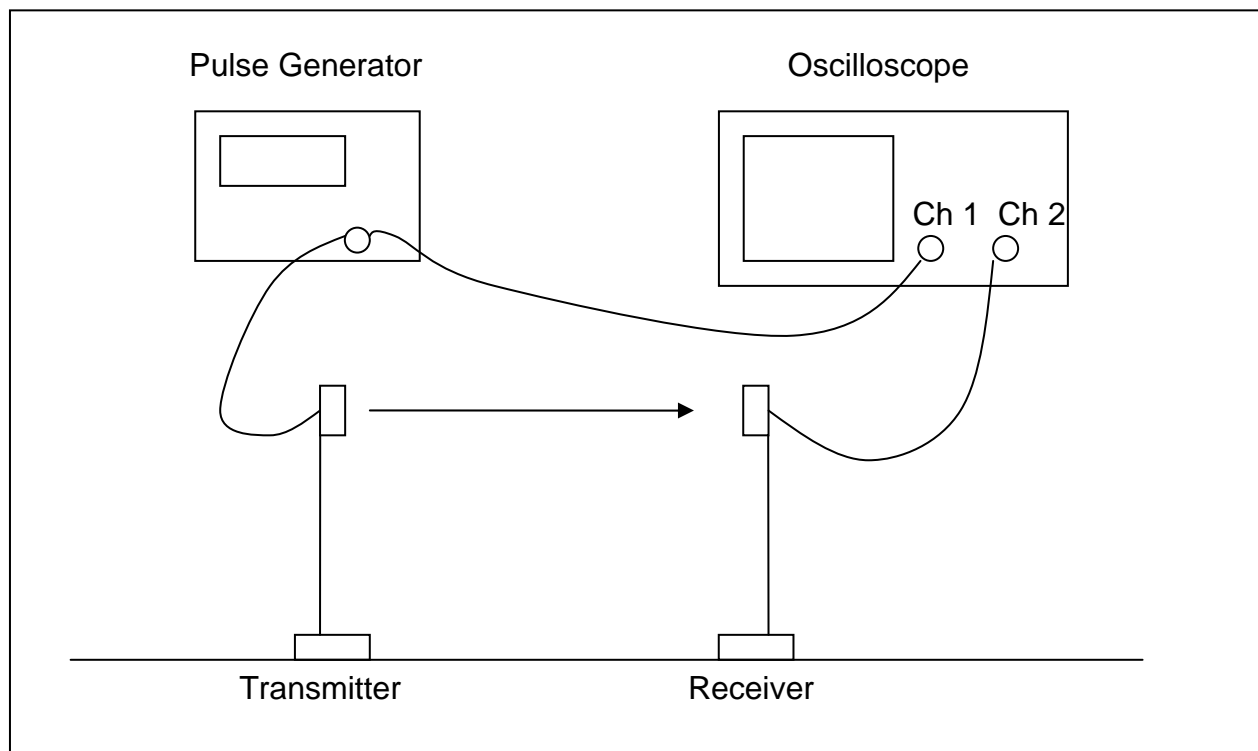


Figure 1: Ultrasound speed of sound in air setup.

The pulse generator creates a voltage pulse of 6-10 cycles of 40 kHz which the ultrasound transducer converts into a sound pulse. Channel 1 on the oscilloscope records the voltage on the transmitter and Channel 2 records the voltage produced by the receiver transducer which is proportional to the pressure of the sound wave.

The oscilloscope display should resemble Figure 2 below.

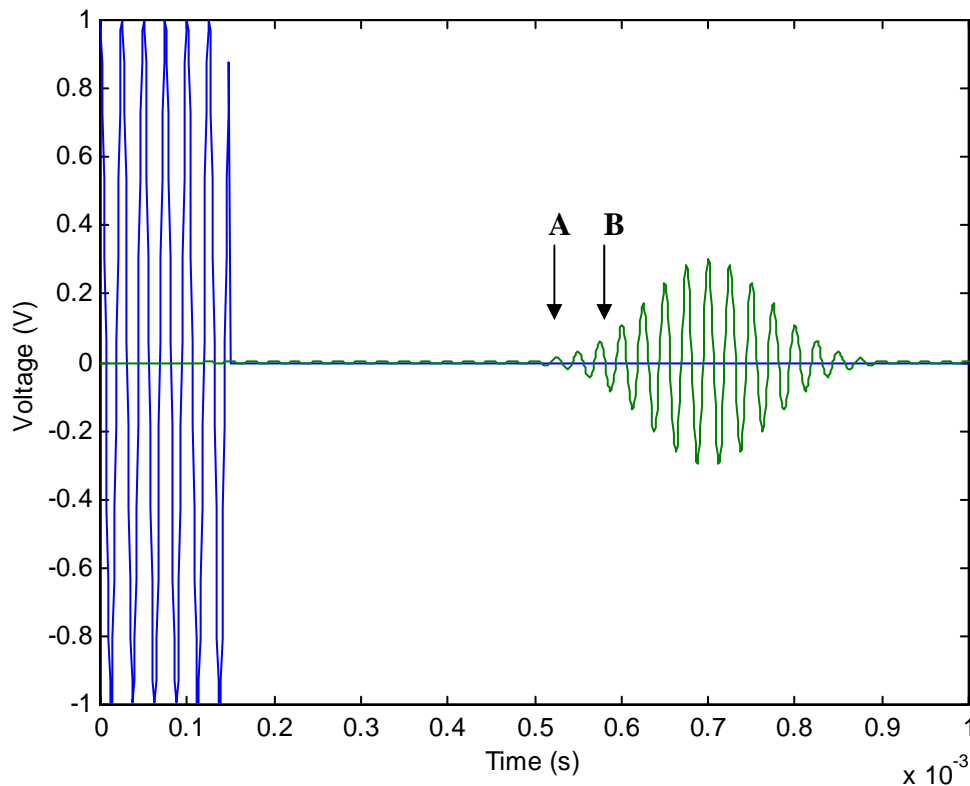


Figure 2. Oscilloscope display from Figure 1.

Put your hand in between the transmitter and receiver and see what happens. **Q1: Which is the transmitted pulse and which is the received pulse? How do you know?**

Try putting one finger or a pencil between the transmitter and receiver. **Q2: How large an obstacle do you need to effectively can you block the beam? Does it make any difference if the obstacle is near the transmitter or the receiver or midway between? What about if you move the transmitter and receiver farther apart? Does the ultrasound behave differently than if the beam were light from a laser pointer? How does the ultrasound get around or through a smaller obstacle?**

Instead of your hand, try using a piece of paper or cloth or tissue paper between the transmitter and receiver. **Q3: What can you say about how ultrasound transmits through different materials?**

The time delay between the initial transmitter pulse and the received pulse is a measure of the travel time of the sound pulse between the transmitter and the receiver. **Q4: What is the time delay between the two pulses in Figure 2 above? Where do you measure the beginning and the end of the time delay?**

A. Experiment: Finding the Speed of Sound in Air

1. Find the “Cursor” button on the oscilloscope and press it. At the bottom of the display you will see a menu which is keyed to the five grey buttons under the display screen. Push the buttons under the display until you have only the “t1” entry lighted. Then turn the “Entry” knob just below the “Cursor” button. What happens? Push the button under the display screen until only the “t2” entry is lighted and turn the “Entry” knob again. What happens now? You should see a display on the bottom of the screen indicating “ Δt .” This is the time difference between the vertical “t1” and “t2” lines. Use the cursor to adjust the two vertical lines to find the time delay between the transmitted and received pulse. If the display indicates “ms” the time difference is measured in milliseconds ($1 \text{ ms} = 1 \times 10^{-3} \text{ second}$). The display “ μs ” indicates microseconds, μs ($1 \mu\text{s} = 1 \times 10^{-6} \text{ second}$).
2. Open up an Excel spreadsheet and label one column “Time Delay” and another column “Distance.” Adjust the distance between the transmitter and receiver to several different values and for record each value of the distance and the corresponding time delay. To record microseconds or milliseconds in Excel, simply enter, e.g., 1.3e-3 (no space!) in the appropriate cell. You can measure the distance between the bases of the receiver and transmitter without having to determine exactly where the transducers are. **Q5: Why won't the offset between the base and the transducer affect your speed of sound value? (You might want to wait until you finish the next section to answer this.)**
3. When you have 5-10 different distance/time-delay pairs, do an Excel “Scatter Plot” of the Distance vs. Time Delay. You should get an approximate straight line plot like Figure 3 below. If not, check your data points to see if there is some error.

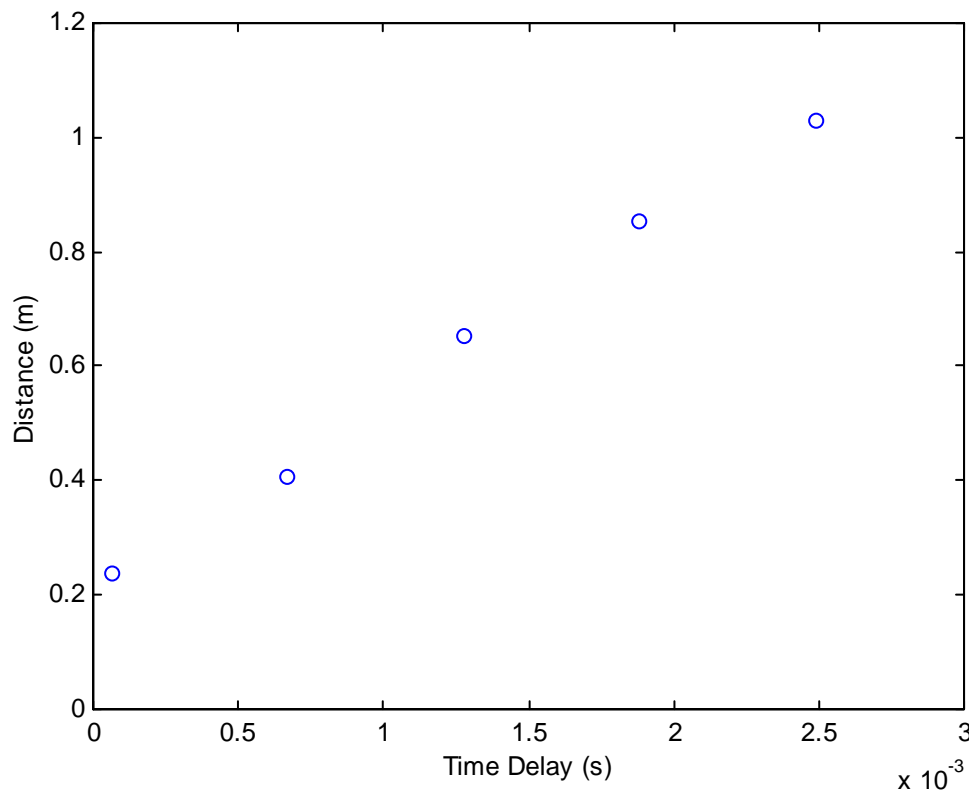


Figure 3: Distance vs. Time Delay for ultrasound propagation.

B. Analysis

The equation of a straight line is:

$$y = mx + b \quad (1)$$

Q6: What is the x in the graph of Figure 3? What is y ? What are m and b called? What does m represent physically? What does b represent physically? In Figure 3 estimate the values of m and b .

Right click on one of your data points and choose “Add Trendline.” If you select a “Linear” trendline, Excel will find the best straight-line fit through your data points by a technique known as “least-squares” fitting. If you check the “Display Equation on Chart” box on the “Options” tab, the equation similar to Eq. 1 above that best fits your data will be displayed on your plot.

Q7: How do you find the speed of sound from the Excel trendline? Why is this a better way than just picking one distance and dividing by the time? Can you think of three reasons why it is better?

Find the speed of sound in air from your data. What difference do you think it would make if you consistently measured the beginning of the receive pulse from point B rather than point A in Figure 2?

C. Experiment: Effect of Wave Amplitude on Sound Speed

Press the “Voltage” button on the signal generator and use the knob to adjust the pulse generator amplitude from 10V down to 5V. **Q8: How does this change the oscilloscope display? Is this what you expect?**

Measure the speed of sound as you did before by measuring the time delay for several distances and using the “Add Trendline” feature to find the slope of the Distance vs. Time Delay curve.

If you have time, reduce the pulse generator amplitude to 2.5 volt and repeat to find the speed of sound. **Q9: Does the speed of ultrasound in air depend on the wave amplitude?** (If you have any doubts, try plotting the Distance vs. Time Delay data for all three amplitudes on the same graph and see if there is any perceptible difference between the three measurements.)

D. Experiment: Effect of Wave Frequency on Sound Speed

The transducers we are using work best at 40kHz, but if you turn the pulse generator amplitude back up to 10 V you should be able to adjust the frequency to 30 kHz or 50 kHz and measure the speed of sound for these frequencies. (Press the “Frequency” button and use the dial to change the display to “30000” or “50000”.) **Q10: Does ultrasound velocity depend on the frequency of the transmitted wave?**

2. Extension: Effect of Propagation Distance on Wave Amplitude

You will have noticed that the amplitude of the received sound wave gets smaller as the distance between the transmitter and receiver increases. In this part of the lab, we will measure the mathematical relationship between the wave amplitude and the distance the wave travels.

A. Experiment: Wave Amplitude vs. Distance

In this experiment we will measure the amplitude of the received pulse and plot it against the distance between the transmitter and receiver. To measure the pulse amplitude, press the “Cursor” button again and use the menu buttons at the bottom of the display to select “V1” and then “V2.” When “V1” is selected the Entry knob controls one horizontal cursor line; when “V2” is selected you can move the other horizontal cursor line. The display on the chart will indicate the voltage difference ΔV . Make sure that the Channel 2 Input is selected – if you have selected Channel 2 the voltage values will be valid even if you expand the vertical scale to see the transmitted pulse better at large distance. Measure ΔV vs. Distance for 5-10 distances and record the Distance and ΔV in another area or page of your Excel spreadsheet.

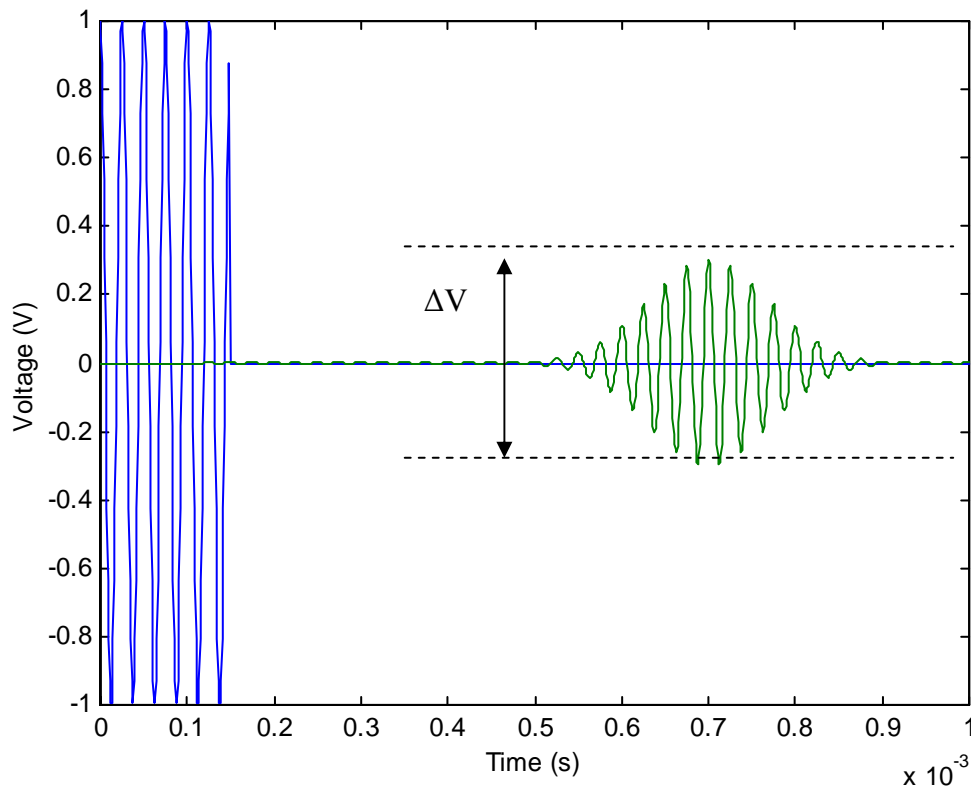


Figure 4: Measuring the amplitude of the received ultrasound pulse.

B. Analysis: Wave Spreading

The voltage measured by the transducers measures the *pressure* of the ultrasound wave. The energy in a sound wave is proportional to the square of the pressure:

$$\text{Energy} = \text{constant} \times (\text{pressure})^2 \quad (2)$$

Q11: How would you expect the energy of a wave to decrease as you get farther from the source and the wave spreads out? Consider a simple case where the source sends out sound in all directions. Assume that your receiver is a fixed area (say 1cm²). What fraction of the wave front does the receiver sample if the wave is 1 meter from the source? What if the wave is 2 meters from the source? Can you generalize this to a power law: $E_{\text{measured}} = \text{constant} / (\text{distance})^n$? What would the number n be?

Do an “XY Scatter Plot” of ΔV vs. Distance and click on one of your data points to add a trendline to your data. Select a “Power Law” fit and click the “Display Equation on Chart” option. Next try “Exponential” and “Linear” fits. Which gives you a better fit to the data? What is the equation of the best fit you get? You may get a better result if you correct your distances for the distance between the transducers when the transducer bases are touching before plotting.

Q12: What power relation do you find between Distance and Voltage from the Excel Trendline? Is this consistent with your answer to Q11? (Remember that $y = Ax^{-n}$ is the same as $y = A/x^n$ and that from Eq. 2 above wave *energy* is proportional to *Voltage*².)