5. Experimental Contents

1) Measure the speed of sound wave propagating in the air by the method of resonant interference.
2) Measure the speed of sound wave propagating in the air by the method of phase comparison.
3) Measure the speed of sound wave propagating in the air by the method of time difference.
4) Measure the distance of a barrier board by the method of reflection.

6. Experimental Procedure

A. Find the resonance frequency of the experiment system

Dismount the baffle. Use a BNC cable to connect one of the two transmitting signal output ports and the ultrasonic generator; connect the ultrasonic receiver A to the input port of the signal amplifier; connect the other transmitting signal output port to X channel of the oscilloscope; and connect the amplifier output to Y channel of the oscilloscope.

Set the frequency of the sine wave to 40 kHz. Move receiver A as close as possible to the transmitter (the maximum signal is observed on the oscilloscope). Then, increase the distance between the transmitter and receiver A to approximately 6-7 cm until a maximum signal is observed on the oscilloscope (now the receiver A is at a wave node position).

Adjust frequency again to maximize the signal on the oscilloscope. Finally, finely tune frequency to make the output signal of the receiver A and the signal of the signal generator in phase. Now, the output frequency of the signal generator equals the natural frequency of the two transducers. At this frequency, the transmitter outputs strong ultrasonic waves.

B. Measure speed of sound at resonance frequency using resonance and phase methods

Select the "Frequency-Phase Method" mode on the menu. Based on the previous experiment, the system has been adjusted to work at resonance frequency.

Place the receiver A at 20 different locations (L_i) where maximum signals are observed on the oscilloscope. Then calculate the ultrasonic wavelength.

To use the phase method, locate the receiver A at a distance > 30 mm from the transmitter. Connect the outputs of the receiver A to the Y-axis and the other transmitting signal output port to X-axis of the oscilloscope, respectively. The phase difference between the received wave and the emitted wave can be observed on a Lissajous graph. Properly adjust sensitivities of X axis and Y axis to achieve a satisfied Lissajous graph.

For the synthesis of two perpendicular simple-harmonic motion of equal frequency, the Lissajous graph changes from a straight line with a positive slope to an oval, and then from an oval to a straight line with a negative slope, as their phase difference changes from 0 to π.

Shift the receiver A along the caliper, record the reading of the digital caliper each time when the Lissajous graph becomes a straight line. If the distance between the transmitter and the receiver changes by a half of the wavelength, the Lissajous graph changes between straight lines of alternative slopes. This way, the speed of sound can be derived.

The temperature and humidity in the lab should be measured accurately, and the p_w value can be found under this condition. Next, measure the air pressure value p in the lab. Use Eq. (7) to calculate the speed of sound. **Note**: p_w and p do not need to be measured in dry climate.

Compare the results between the two methods, and calculate their errors relative to the recognized value.

C. Measure speed of sound using time difference method

Select “Time Difference Method” mode on the menu.

Move the receiver A step by step, record the position L of the receiver A, and record the corresponding time t displayed on the LCD screen. Take multiple data and make a linear fit, the slope of which is the measured speed of sound V.

D. Measure distance using reflection method

Select “Ultrasonic Ranging” mode on the menu.

Use the magnetic steel to attract the baffle to front of the receiver A. Disconnect the cable of the receiver A, and then connect it to receiver B. Move the baffle while recording the position L of the baffle and the distance l displayed on the LCD screen. Compare the two values and analyze the cause of the error from related factors such as temperature and distance.

7. Examples of Data Recording and Processing

Note: the following data are for reference purposes only, not the criteria for apparatus performance.

1. Measure sound speed using resonant interference method

Table 1 Data of resonant interference method (*T = 26.1 °C, f = 40.070 KHz*)

No. (i)	*Li (mm)*	No. (*i*)	*Li (mm)*	□*Li (mm)*	$\overline{\Delta L_i}$*(mm)*
1	3.60	11	47.41	43.81	
2	8.03	12	51.78	43.75	
3	12.32	13	56.02	43.70	
4	16.83	14	60.03	43.20	
5	21.09	15	64.35	43.26	43.31
6	25.63	16	68.74	43.11	
7	29.95	17	73.08	43.13	
8	34.42	18	77.47	43.05	
9	38.72	19	81.77	43.05	
10	43.11	20	86.17	43.06	

Average $\overline{\lambda} = 43.31 \times \frac{1}{5} = 8.662mm$

Sound speed: $V = 40.070 \times 8.662 = 347.1m/s$.

At temperature T = 26.1 °C, sound speed in dry air is V_0*=347.3 m/s*. The experimental result has an error 0.06%.

2. Measure sound speed using phase method

Table 2 Results of phase method (*T = 26.0 °C, f = 40.070 KHz*)

No. (i)	*Li (mm)*	No. (*i*)	*Li (mm)*	□*Li (mm)*	$\overline{\Delta L_i}$*(mm)*

1	29.95	11	73.28	43.33	43.29
2	34.30	12	77.63	43.33	
3	38.64	13	81.91	43.27	
4	42.97	14	86.25	43.28	
5	47.32	15	90.65	43.33	
6	51.66	16	94.92	43.26	
7	55.96	17	99.23	43.27	
8	60.28	18	103.57	43.29	
9	64.61	19	107.90	43.29	
10	68.98	20	112.22	43.24	

Average $\overline{\lambda} = 43.29 \times \frac{1}{5} = 8.658mm$

Sound speed $\mathrm{V} = 40.070 \times 8.658 = 346.9m/s$.

At temperature T =26.0 °C, sound speed in dry air is V_0*=347.2 m/s*. The experimental result has an error 0.09%.

3. Measure sound speed using time difference method

Table 3 Results of time difference method (*T =23.8 °C*)

L (mm)	0	10.08	20.20	30.10	40.29	50.19	60.52	70.23	80.21
t (us)	160	196	229	256	284	311	341	368	395
L (mm)	90.29	100.07	110.19	120.27	130.42	140.3	150.15	160.29	170.32
t (us)	424	451	480	518	547	575	602	630	659

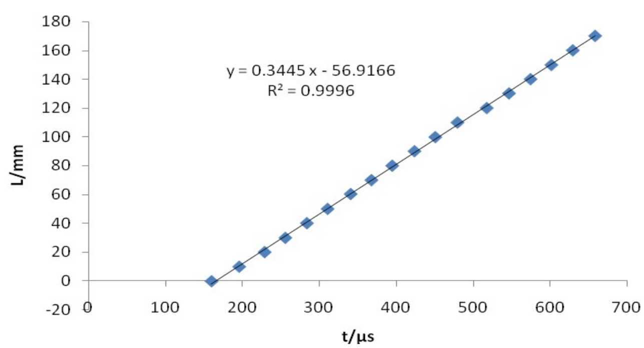

Figure 3 Plot of relationship between distance (L) and time difference (t)

By straight line fitting, we got slope, it is sound speed $V = 0.345mm/\mu s = 345m/s$.

At temperature T = 23.8 °C, sound speed in dry air is V_0*=345.9 m/s*. The experimental result has an error 0.26%.

4. Measure barrier board distance by reflection method

Since the transmitting and receiving ends of the ultrasonic probe are separated by a certain distance, as shown in Figure 2, the measured distance $L=x/\cos(\theta)$ is larger than the actual distance x. The error reduces with x increasing. For ultrasonic ranging of close distance, the measurement results must be corrected.

Table 4 Comparison of measured and actual distances

L (mm)	0	10.23	20.07	30.37	40.03	50.16	60.18	70.26	80.27
x (mm)	-1	9	19	30	39	49	60	69	79
L (mm)	90.18	100.05	110.3	120.07	130.42	140.62	150.49	160.1	170.29
x (mm)	89	100	109	119	129	140	150	160	170

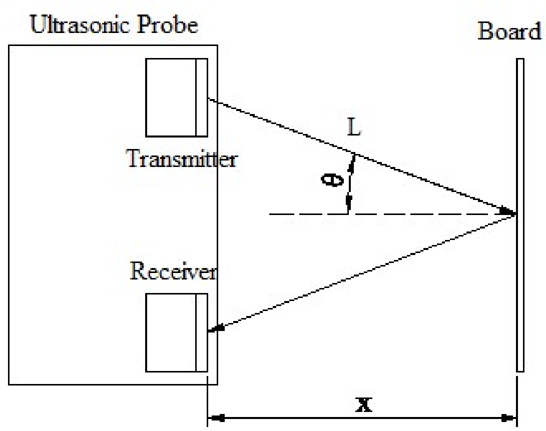

Figure 2 Schematic of the actual distance of ultrasonic ranging