UNIT 8 – ULTRASONIC TRANSDUCERS

UNIT OBJECTIVE

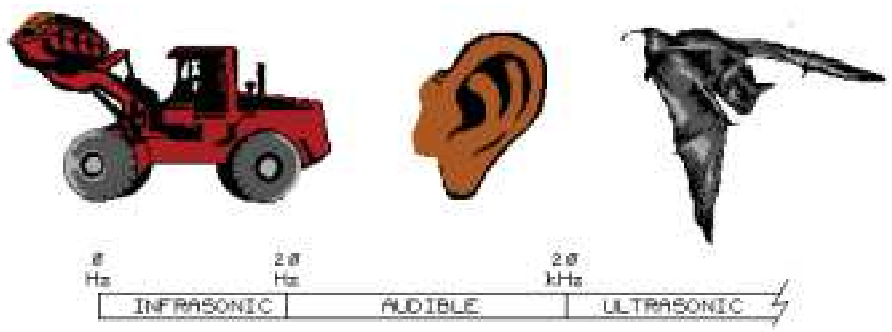
At the completion of this unit, you will be able to explain and demonstrate the principles of ultrasonic transducers and their practical application in distance measurement.

UNIT FUNDAMENTALS

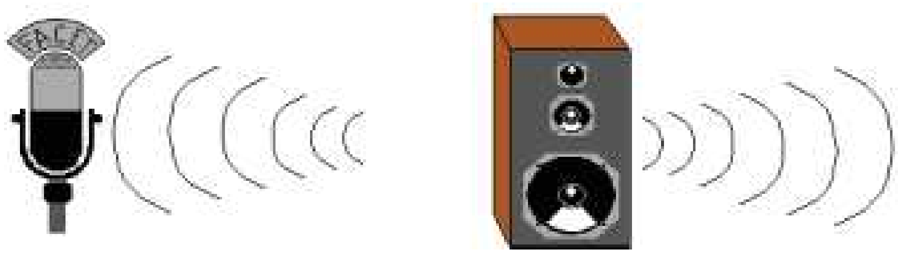
Ultrasonic transducers can utilize sound waves to detect the presence of an object or to measure the distance of the object from a reference point. Applications of ultrasonic transducers include motion sensors, automatic door openers, alarm systems, proximity sensors, level controls, range finders, and fish finders.

The sound spectrum is divided into three basic ranges, as shown here. The **infrasonic** range consists of very low frequencies (below 20 Hz) that we generally cannot hear. Examples of infrasonic sound sources include volcanoes, earthquakes, and vibrations from heavy machinery.

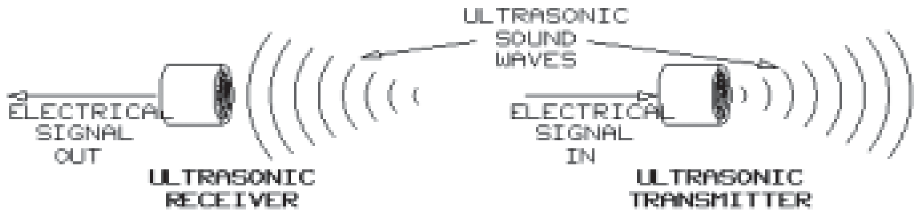
The audible range includes those frequencies that can be detected by the human ear. The audible range is typically from about 20 Hz to 20 kHz, but this can vary from person to person.



Frequencies above 20 kHz are in the **ultrasonic** range. You cannot hear these frequencies, but they can be detected by instruments and by some animals. Bats, for example, can hear frequencies up to 100 kHz.



Familiar examples of sound transducers are the loudspeaker and the microphone. The microphone converts sound energy (voice, music, etc.) into electrical energy that can be used by an amplifier or recording device. Conversely, the speaker converts electrical signals from an amplifier into sound energy we can hear.

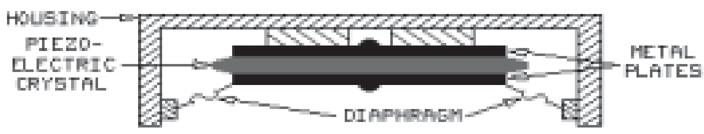


Ultrasonic transmitters and **ultrasonic receivers** are transducers that perform the same basic functions as the loudspeaker and microphone, but the sound waves are in the ultrasonic range.

	PIEZOELECTRIC	ELECTROSTATIC
transduction element	quartz or ceramic crystal	thin metal foil
bandwidth	narrow (high-Q)	wide (low-Q)
ringing	yes	no

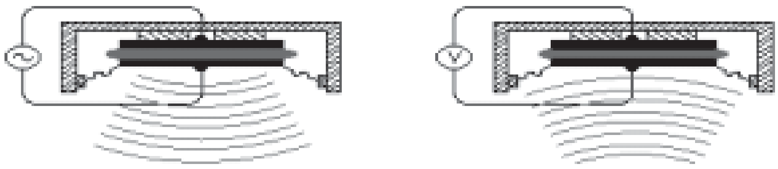
There are two basic types of ultrasonic transducers: the **electrostatic transducer** and the **piezoelectric transducer**. The two types differ in their internal construction and operating characteristics, as shown in the table.

The devices on your circuit board are ceramic piezoelectric transducers.



This is a cross-sectional view showing the construction of a piezoelectric transducer. The basic transducer element is a **piezoelectric crystal**, which is usually composed of quartz or a synthetic material.

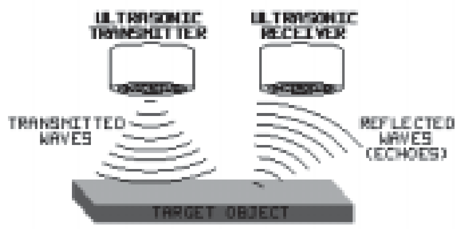
The crystal is sandwiched between two metal plates. The upper plate is mechanically anchored to the device's cylindrical housing, and the lower plate is attached to a vibrating diaphragm.



This figure shows that the transducer can be used as either an ultrasonic transmitter or an ultrasonic receiver, depending on how it is configured. The properties of a piezoelectric crystal are such that, when an ac voltage of ultrasonic frequency is applied (right figure), the crystal rapidly expands and contracts.

This vibration is transferred to the diaphragm, which, in turn, emits sound waves in the ultrasonic range.

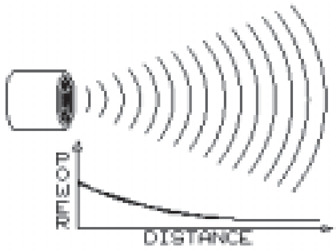
Conversely, if ultrasonic sound waves from an external source were to strike the diaphragm (left figure), the resulting vibrations are imparted to the crystal. The vibration of the crystal generates an ac voltage that can be detected by an ac voltmeter or a control circuit. In this case, the transducer is configured as an ultrasonic receiver.



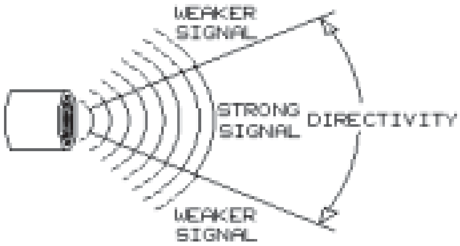
This figure shows how an ultrasonic transmitter and receiver pair can be used to detect the presence of an object. Ultrasonic waves from the transmitter are reflected, or echoed, off an object that lies in the path of the waves. The reflected waves are then detected by the receiver.

Ultrasonic transducers can be used to detect the presence or absence of an object in proximity sensing applications. However, it is also possible to measure the object's distance from the transducers.

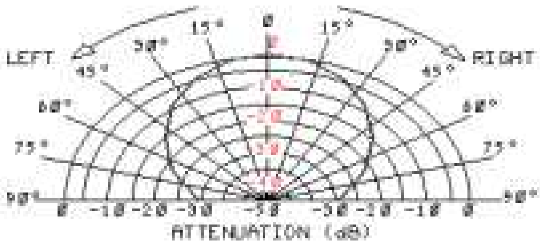
The velocity of sound waves depends on the medium through which they travel. For example, if the waves are transmitted through air, you can use the speed of sound in air and measure the **transmit time** to calculate the distance to the target. Transmit time is the time that the waves take to travel from the transmitter to the target object and back to the receiver.



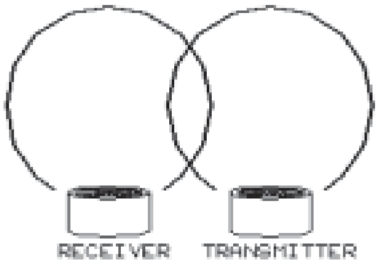
As with any form of radiant energy, transmitted ultrasonic waves grow weaker as they travel farther away from the transmitter.



Also, the signal is strongest in the area directly in front of the transmitter. As the angle increases outward, signal strength is attenuated. The angle in which the signal is strongest is called the angle of **directivity**.



The transducer manufacturer's data sheet often includes a directivity curve, such as the one shown here. At 0° (directly in front of the transducer), signal attenuation is 0 dB. As the angle increases, for example, to 30° left or right of center, attenuation increases to about -7.5 dB.



This figure shows the transmitter and receiver as they are positioned on your circuit board, along with their directivity patterns. Because the patterns overlap, the ultrasonic waves from the transmitter are picked up by the receiver, even without a target object.

You will see in Exercise 2 how this arrangement limits the measuring range of the transducers.

NEW TERMS AND WORDS

infrasonic - a sound frequency below the audible range (less than about 20 Hz).
ultrasonic - a sound frequency above the audible range (greater than 20 kHz).
ultrasonic transmitters - a transducer that converts electrical energy into ultrasonic sound energy.
ultrasonic receivers - a transducer that converts ultrasonic sound energy into electrical energy.
electrostatic transducer - a type of ultrasonic transducer that has a wide bandwidth, low Q, and a thin metal foil as a transduction element.
piezoelectric transducer - a type of transducer in which sound waves are converted to electrical signals or electrical signals are converted to sound waves.
piezoelectric crystal - the basic functioning element of a piezoelectric transducer.
transmit time - the time required for ultrasonic waves to travel from the transmitter to a target object and then to the receiver.
directivity - the property of an ultrasonic transducer that relates the angle of the ultrasonic waves to the signal strength.
resonant frequency - the frequency at which a circuit's inductive reactance and capacitive reactance are equal.
antiresonant frequency - the frequency at which a circuit has infinite impedance.

EQUIPMENT REQUIRED

F.A.C.E.T. base unit
TRANSDUCER FUNDAMENTALS circuit board
Multimeter
Oscilloscope, dual trace
Ruler

Exercise 1: Ultrasonic Principles

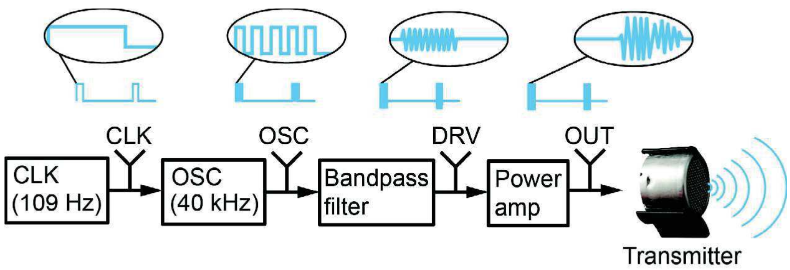
EXERCISE OBJECTIVE

When you have completed this exercise, you will be able to explain and demonstrate the principles of transmission and reception of ultrasonic sound waves by using the transducers and circuitry on your circuit board. You will verify your results by observing waveform characteristics and by taking measurements with an oscilloscope.

DISCUSSION

This is a block diagram of the TRANSMITTER section of the ULTRASONIC TRANSDUCERS circuit block.

NOTE: The waveform amplitudes are not necessarily to scale.



A clock circuit generates a 109 Hz pulse signal. What is the period (T) of the CLK signal?

T_{CLK} =_______________ ms (*Recall Value 1*)

The duty cycle of the CLK waveform is 2%. What is the on-time of the pulse?

The pulse on-time is 2% of the period: t_{on} = 0.02 x T

t_{on} =_________________µs (*Recall Value 2*)

The CLK pulse modulates a 40 kHz square wave oscillator. The output at the OSC test point is a ______________ µs (*Recall Value 2*) burst of 40 kHz pulses every ______________ ms (*Recall Value 1*).

A bandpass filter converts the OSC signal to the sine wave bursts seen at the driver (DRV) test point.

The output of the bandpass filter drives a power amplifier stage, which boosts the signal to the transmitter.

The resulting sine wave burst to the transmitter terminal is about 10 V_{pk-pk}, and directly drives the transducer.

What is the frequency of the ultrasonic sound waves transmitted by the transducer?

a. 109 Hz
b. 40 kHz
c. cannot be determined

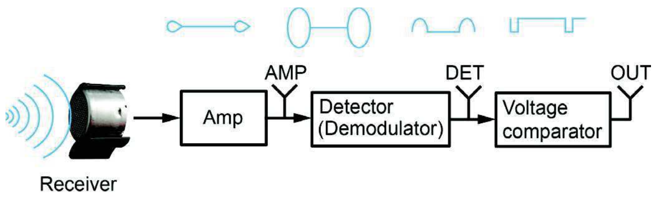
One disadvantage of piezoelectric transducers is the ringing that occurs after the tone burst ends. This happens because the diaphragm continues to vibrate for a short time after the signal oscillations stop.

The spacing of the tone bursts must be chosen to avoid interaction of adjacent bursts due to the ringing effect.

Figure A shows the normal spacing of the tone bursts.

You can see in Figure B that, as the tone burst spacing decreases, there is a possibility that the ringing from the first burst will interfere with the second.

This is a block diagram of the RECEIVER section of the ULTRASONIC TRANSDUCERS circuit block.

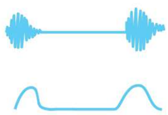


The signal at the transducer output shows the 40 kHz bursts that are picked up from the transmitter.

Because of the transducer’s low output level, an amplifier is used to boost the signal amplitude.

You can see that the ringing from the transmitter is also detected by the receiver.

The AMP output drives a DETECTOR circuit that demodulates the tone burst.



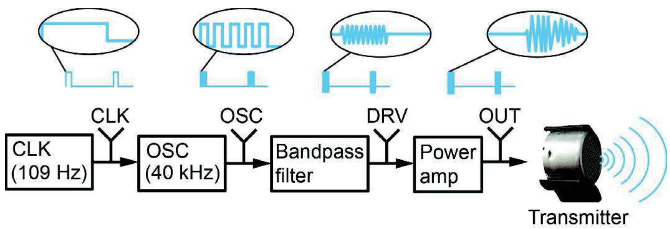
This figure shows the relationship of the 40 kHz AMP bursts to the demodulated DET output pulses.

One disadvantage of piezoelectric transducers is the ringing that occurs after the tone burst ends. This happens because the diaphragm continues to vibrate for a short time after the signal oscillations stop.

The spacing of the tone bursts must be chosen to avoid interaction of adjacent bursts due to the ringing effect.

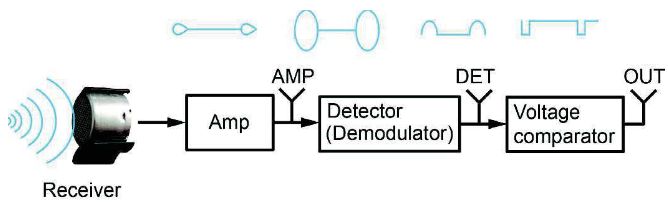
REVIEW QUESTIONS

1. What part of the TRANSMITTER section determines the time between ultrasonic tone bursts?
   a. CLK
   b. OSC
   c. BANDPASS FILTER
   d. POWER AMP



2. The ringing that occurs on the OUT waveform is due to
   a. an excessively high OSC frequency.
   b. an excessively low OSC frequency.
   c. the transducer's diaphragm.
   d. the power amplifier.

3. Which circuit in the RECEIVER section removes the 40 kHz signal?
   a. AMP
   b. DETECTOR
   c. VOLTAGE COMPARATOR
   d. None of the above



4. A low pulse from the RECEIVER section's output indicates
   a. a pulse picked up from the transmitter.
   b. an echo from a target object.
   c. Either of the above
   d. None of the above

5. In the procedure, you used a CM to insert an external signal at the DRV test point while monitoring the OUT signal. You can determine the resonant frequency of the ultrasonic transmitter by adjusting the DRV signal
   a. frequency for the maximum OUT signal amplitude.
   b. frequency for the minimum OUT signal amplitude.
   c. amplitude for the maximum OUT signal frequency.
   d. amplitude for the minimum OUT signal frequency.

Exercise 2: Distance Measurement

EXERCISE OBJECTIVE

At the completion of this exercise, you will be able to explain and demonstrate the operation of ultrasonic transducers in position sensing and range finding applications. You will verify your results with a tape measure or ruler and an oscilloscope.

DISCUSSION

Sound waves, including those in the ultrasonic range, can travel in virtually any medium (solid, liquid, or gas).

The velocity at which the waves travel depends on, among other things, temperature and the transmission medium.

A common reference for the velocity of sound in air is 331 meters per second (m/s) at 0°C. For each additional 1°C increase in temperature, the velocity increases by about 0.6 m/s.

You can therefore calculate the velocity at any temperature T (in C°) with the following formula:

$$v = (331 + 0.6T)\ \text{m/s}$$

A typical value for room temperature is 25°C. Calculate the velocity of sound waves at room temperature:

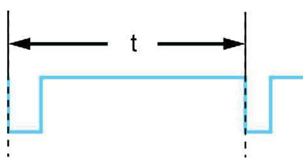
v =_________________ m/s (*Recall Value 1*)

Using the conversion factor 3.28 feet = 1 m, calculate the velocity of sound in air at 25°C in feet per second (f/s):

$$V_{fps} = \frac{346\ \text{m}}{\text{s}} \times \frac{3.28\ \text{ft}}{1\ \text{m}}$$

V_{fps}=________________ f/s (*Recall Value 2*)

You can measure the time between the transmitted and received pulses to determine the distance of a target object from the transducers.



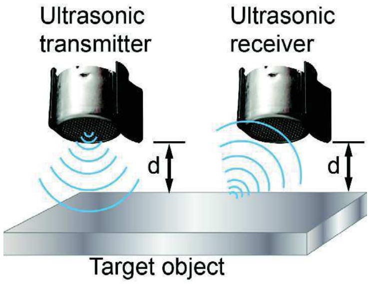
Since distance is the product of velocity and time (d = v x t), you can calculate the distance by using the velocity constant and the measured time.

For example, assume that you measure 2 ms between pulses. Using the velocity of sound in air, you can calculate the total distance (d_T) that the waves travel as follows:

$$d_T = v \times t$$

$$d_T = \frac{1135\ \text{ft} \times 0.002\ \text{second}}{\text{second}} = 2.27\ \text{feet}$$

With the transducer arrangement on your circuit board, the ultrasonic waves travel a distance d from the transmitter to the target.



The waves reflected from the target also travel the same distance back to the receiver.

What is the total distance (d_T) traveled by waves sent by the transmitter and detected by the receiver?

a. d
b. d/2
c. 2d

In the preceding example, the time between pulses represented a distance of 2.27 feet. This is the total distance that the ultrasonic waves travel from transmitter to receiver.

Since $d_T = 2d$, the actual distance (d) from the transmitter/receiver pair to the target is $d_T/2$, or 2.27/2 = 1.135 feet.

You can revise the basic equation to calculate the one-way distance to the target object as follows.

$d = v \times (t/2)$

The maximum measuring distance of the transducers on your circuit board is determined by the 9.17 ms CLK period. Calculate the maximum distance (v = 1,135 f/s).

$d_{max} = v \times (t/2)$

d_{max} =_______________ feet (*Recall Value 3*)

You can also rearrange the equation to calculate the transit time from a given target distance.

$d = v \times (t/2)$

$t/2 = d/v$

$t = 2 \times d/v$

$= 2 \times d/1{,}135$

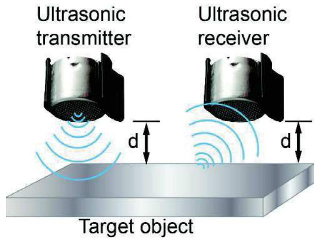
$= d/567.5$

Calculate the transit time for a distance of 1 foot.

$t = d/567.5$

t =__________________ ms (*Recall Value 4*)

3. Transit time is the time it takes for the ultrasonic waves to travel from the
   a. transmitter to the target object.
   b. target object to the receiver.
   c. target object to the transmitter
   d. transmitter to the target object and back to the receiver.



4. The maximum measuring range of the ultrasonic transmitter/receiver pair on your circuit board is determined by the transducer sensitivity and by
   a. the CLK period.
   b. the oscillator frequency.
   c. room temperature.
   d. All of the above

5. What is the velocity of sound waves in air at 20°C?

   $v = (331 + 0.6T)$ m/s

   a. 331 m/s
   b. 351 m/s
   c. 343 m/s
   d. 319 m/s

Desfășurarea lucrării

Asigurați-vă că osciloscopul are următoarele setări:

- CH1 și CH2: Coupling: DC
- TRIG: Source: CH1; Type: Edge; Slope: Rising; Mode: Auto, Coupling: DC

Plasați cutia cu accesorii sub marginea plăcii, pentru ca senzorii să fie paraleli cu masa.

I – Semnale emițător

1) Afișați semnalul **CLK**, pe CH1: 5V/div; 1ms/div; horiz. pos. 0,2

2) Măsurați perioada și frecvența semnalului CLK

3) Măsurați lățimea pulsului ON, al CLK: horiz. pos. 5; 25µs/div; horiz. pos. 0,2

4) Afișați semnalul **OSC**, pe CH2: 5V/div

5) Rețineți imaginea Fig. 1 – CLK + OSC

6) Măsurați frecvența semnalului OSC: 5µs/div

7) Ajustați: 1ms/div; horiz. pos. 0,2. Rețineți imaginea Fig. 2 – CLK + OSC

8) Treceți semnalul OSC pe CH1. Afișați semnalul **DRV**, pe CH2: 1V/div

9) Ajustați: horiz. pos. 5; 25µs /div; horiz. pos. 0,2. Rețineți imaginea Fig. 3 – OSC + DRV

10) Treceți semnalul DRV pe CH1. Afișați semnalul **XDCR**, pe CH2: 2V/div; 100µs/div.

11) Rețineți imaginea Fig. 4 – OSC + XDCR

II – Semnale receptor

1) Afișați semnalul **AMP**, pe CH1: 0,2V/div; 250µs/div; horiz. pos. 1

2) Afișați semnalul **DET**, pe CH2: 2V/div;

3) Suprapuneți cele două semnale. Rețineți imaginea Fig. 5 – AMP + DET

III – Măsurători de distanță

1) Afișați semnalul **DET**, pe CH1: 1V/div; 1ms/div; horiz. pos. 0,2

2) Plasați o hârtie albă la minim 30 cm de senzorii ultrasonici.

3) Măsurați timpul între două vârfuri ale semnalului DET și calculați distanța:

$$d = v \times t / 2 = 17300\ [cm/s] \times t\ [s] = 17,3\ [cm/ms] \times t\ [ms]$$

4) Repetați măsurătorile pentru alte două distanțe.