UNIT 8
ULTRASONIC TRANSDUCERS

UNIT OBJECTIVE

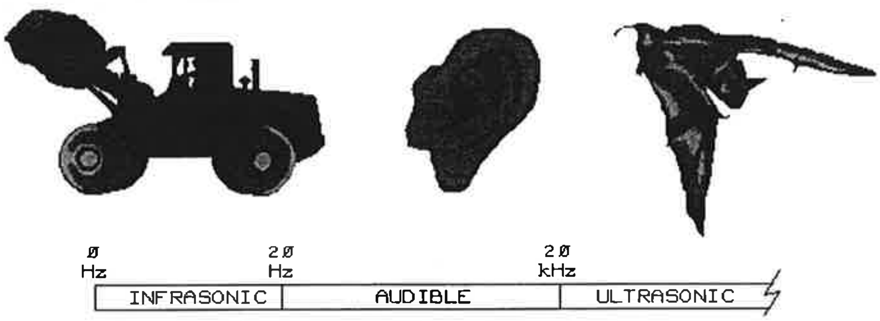
Explain and demonstrate the principles of ultrasonic transducers and their practical application in distance measurement.

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.

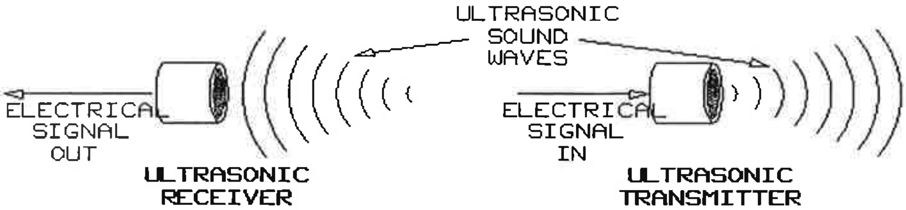
The audible range includes those frequencies that can be detected by the human ear. The audible range is typically from about 20 Hz to 20 kHz, but this can vary from person to person.



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.

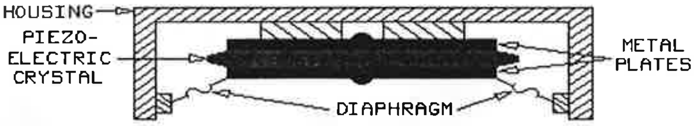


Ultrasonic transmitters and **ultrasonic receivers** are transducers that perform the same basic functions as the loudspeaker and microphone, but the sound waves are in the ultrasonic range.

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

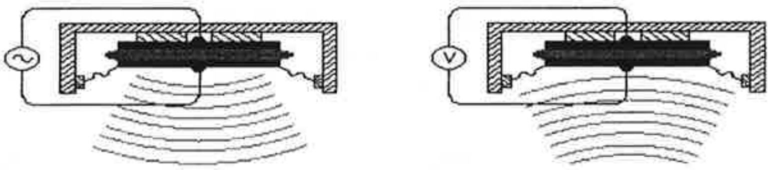
There are two basic types of ultrasonic transducers: the **electrostatic transducer** and the **piezoelectric transducer**. The two types differ in their internal construction and operating characteristics, as shown in the table.

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.

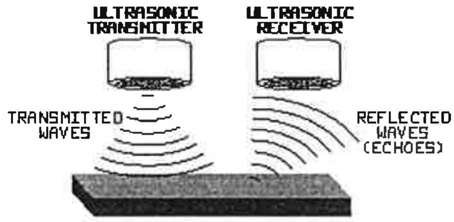
The crystal is sandwiched between two metal plates. The upper plate is mechanically anchored to the device's cylindrical housing, and the lower plate is attached to a vibrating diaphragm.



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 (left figure), the crystal rapidly expands and contracts. This vibration is transferred to the diaphragm, which, in turn, emits sound waves in the ultrasonic range.

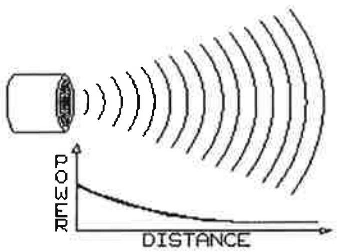
Conversely, if ultrasonic sound waves from an external source were to strike the diaphragm (right figure), the resulting vibrations are imparted to the crystal. The vibration of the crystal generates an ac voltage that can be detected by an ac voltmeter or a control circuit. In this case, the transducer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



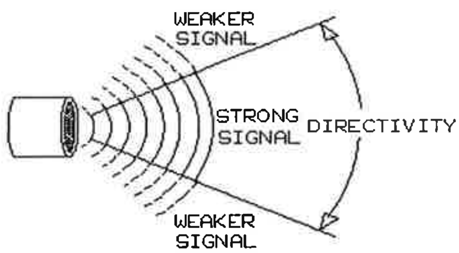
This figure shows how an ultrasonic transmitter and receiver pair can be used to detect the presence of an object. Ultrasonic waves from the transmitter are reflected, or echoed, off an object that lies in the path of the waves. The reflected waves are then detected by the receiver.

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.

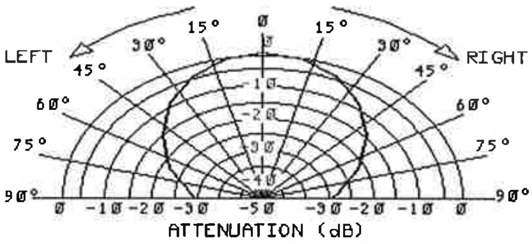
The velocity of sound waves depends on the medium through which they travel. For example, if the waves are transmitted through air, you can use the speed of sound in air and measure the **transmit time** to calculate the distance to the target. Transmit time is the time that the waves take to travel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



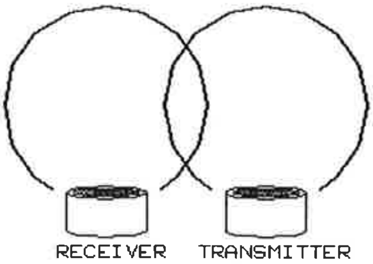
As with any form of radiant energy, transmitted ultrasonic waves grow weaker as they travel farther away from the transmitter.



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 tranducers.

UNIT FUNDAMENTALS ANSWERS

	Number	Correct Answer
FUNDAMENTALS	1	b
	2	b
	3	a
	4	b
	5	a
	6	–12.5 dB±20%

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)

piezoelectric - a property by which sound waves are converted to electrical signals or electrical signals are converted to sound waves.

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.

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.

ultrasonic transmitter - a transducer that converts electrical energy into ultrasonic sound energy.

ultrasonic receiver - 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.

transit 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.

SCHEMATIC, CMs AND FAULTS

SCHEMATIC SWITCH NUMBER	CM NUMBER	FAULT NUMBER	CIRCUIT CHANGE WHEN ACTIVE
S6	CM6		reduces the transmit power by reducing the value of R56
S7	CM7		opens the connection from the bandpass filter to the DRV test point and the power amplifier
S9	CM9		changes the maximum measuring range of the ultrasonic transducer
S14	CM14		decreases the receiver's sensitivity by reducing the value of R110
S20	CM20		allows the oscillator to run continuously
S29		F9	diode (D6) is shorted
S30		F10	Q3 (base - emitter) shorted

Refer to the schematic at the end of this volume.

EXERCISE 8-1 Ultrasonic Prinicples

EXERCISE OBJECTIVE

Explain and demonstrate the principles of transmission and reception of ultrasonic sound waves by using the transducers and circuitry on this circuit board.

DISCUSSION

- The ULTRASONIC TRANSDUCER circuit block contains a clock circuit which generates a 109 Hz pulse signal.

- The CLK pulse modulates a 40 kHz square wave oscillator. The output at the OSC test point is a 180 μs burst of 40 kHz pulses every 9.0 ms.
- 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 at the OUT terminal is about 10 $V_{pk\text{-}to\text{-}pk}$, and directly drives the transducer.
- 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.
- The ultrasonic receiver boosts the signal amplitude it receives from the transmitter.
- The ringing from the transmitter is also detected by the receiver.
- The AMP output drives a DETECTOR circuit that demodulates the tone burst.
- The DETECTOR output drives a voltage comparator that inverts the pulses, squares the edges, and removes the effects of the ringing.
- The frequencies at which the impedance is resistive are the resonant frequency (f_r) and the antiresonant frequency (f_a).
- The magnitude of the transducer impedance is minimum at resonance and maximum at antiresonance.
- A transmitter should be operated at resonance to maximize mechanical to electrical efficiency.
- A receiver should be operated at antiresonance to maximize electrical to mechanical efficiency.
- For optimum sensitivity, it is common in a two-transducer system for the transmitter's resonant frequency to match the receiver's antiresonant frequency.
- The transducer on this circuit board has a resonant frequency of about 40 kHz.

CMs AVAILABLE

CM6 - reduces the transmit power by reducing the value of R56.
CM7 - opens the connection from the bandpass filter to the DRV test point and the power amplifier
CM20 - allows the oscillator to run continuously

FAULTS AVAILABLE

F10 - Q3 (base - emitter) is shorted.

PROCEDURE

The 49 procedure steps in this exercise include the following:

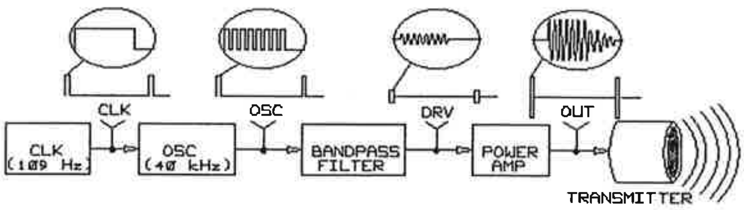
- locate the ULTRASONIC TRANSDUCER circuit block
- adjust potentiometers
- use an oscilloscope to observe waveforms
- use an oscilloscope to measure the period of waveforms
- use an oscilloscope to measure the amplitude of waveforms
- use an oscilloscope to measure the pulse width of waveforms
- verify that the bandpass filter converts the square OSC pulses into the sine wave bursts needed to drive the ultrasonic transducer
- calculate voltage gain of the amplifier
- connect a signal generator and adjust it for a specific signal
- measure the resonant frequency
- measure the antiresonant frequency

EXERCISE DISCUSSION AND PROCEDURE ANSWERS

	Number	Correct Answer
DISCUSSION	1	9.17 ms±10%
	2	*
	3	b
	4	a
	5	b
PROCEDURE	6	9.17 ms±30%
	7	165.0 μs±30%
	10	a
	11	b
	12	40 kHz±20%
	17	15.0 V_{pk-pk}±20%
	18	2.0 V_{pk-pk}±20%
	22	10.0 V_{pk-pk}±20%, b
	28	200.0 mV_{pk-pk}±30%
	32	*
	33	37.4 ±10%
	38	a
	41	c
	47	c
	48	40.0 kHz±10%
	49	42.2 kHz±10%

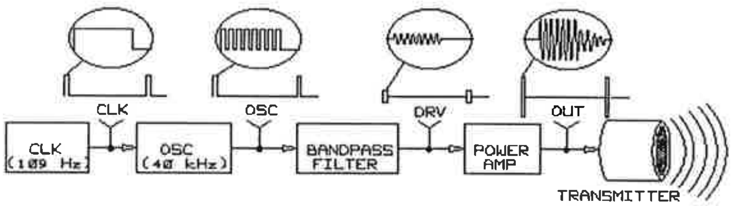
* calculations based on the students measured and/or calculated values

REVIEW QUESTIONS AND ANSWERS



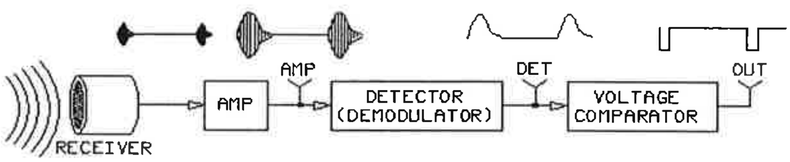
1. What part of the TRANSMITTER section determines the time between ultrasonic tone bursts?

   a. CLK
   b. OSC
   c. BANDPASS FILTER
   d. POWER AMP



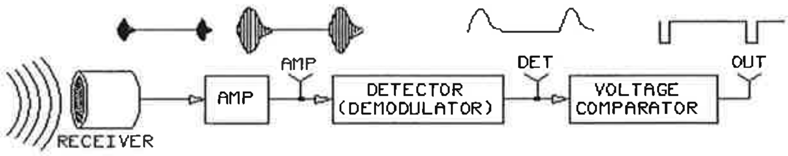
2. The ringing that occurs on the OUT waveform is due to

   a. an excessively high OSC frequency.
   b. an excessively low OSC frequency.
   c. the transducer's diaphragm.
   d. the power amplifier.



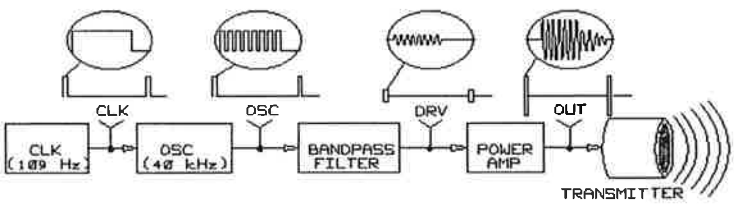
3. Which circuit in the RECEIVER section removes the 40 kHz signal?

   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 8-2 Distance Measurement

EXERCISE OBJECTIVE

Explain and demonstrate the operation of ultrasonic transducers in position sensing and range finding applications.

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 the temperature and the transmission medium.
- The most common reference for the velocity of sound in air is 331 meters per second (m/s) at 0°C. For each degree increase in temperature the velocity increases by about 0.6 m/s.

- This formula allows you to calculate the velocity at any temperature (T), in °C:

  $v = (331 + 0.6T)$ m/s
- The time between the transmitted and received pulses can be measured to determine the distance of a target object from the transducer.
- Distance is the product of velocity and time ($d = v \times t$); using the velocity constant and the measured time, the distance between the object and the transducer can be determined.
- The arrangement of the ultrasonic transducer requires that the pulse travel an equal distance to and from the object. Therefore, the measured time is for twice the distance, or 2d. This leads to the modified equation, $d = v \times (t/2)$, which represents the actual distance from the transducer to the object.

CMs AVAILABLE

CM9 - changes the maximum measuring range of the ultrasonic transducer.
CM14 - decreases the receiver's sensitivity by reducing the value of R110.

FAULTS AVAILABLE

F9 - diode (D6) is shorted.

PROCEDURE

The 32 procedure steps in this exercise include the following:

- locate the ULTRASONIC TRANSDUCER circuit block
- use an oscilloscope to view waveforms
- use an oscilloscope to measure waveform parameters
- adjust the FREQ pot for the maximum amplitude
- verify that there is a clear transmission path between the circuit board and the object
- verify that an increased measuring range is achievable
- measure the time between output pulses for various distances
- calculate the distance for each sample by converting the transmit times into distances
- tabulate the measured and calculated distances

EXERCISE DISCUSSION AND PROCEDURE ANSWERS

	Number	Correct Answer
DISCUSSION	1	346.0 m/s±2%
	2	1135.0 f/s±5%
	3	c
	4	5.204 feet±2%
	5	1.762 ms±2%
PROCEDURE	11	a
	17	b
	18	4.673 ms±30%
	19	*
	22	1.74 ms±20%, a
	25	3.48 ms±20%

EXERCISE DISCUSSION AND PROCEDURE ANSWERS (CONTINUED)

Number	Correct Answer
26	2.0 feet±20%
29	5.22 ms±20%
30	3.9 feet ±20%, a
32	b

* calculations based on the students measured and/or calculated values

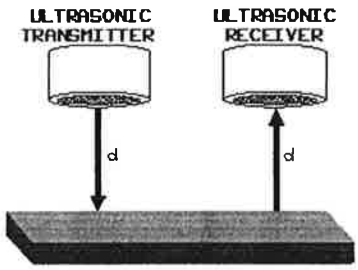
REVIEW QUESTIONS AND ANSWERS

1. A book is placed 2 feet, 6 inches from the front of your F.A.C.E.T. base unit. How long does it take for ultrasonic waves generated by the transmitter to echo off the book and be detected by the receiver?

   a. 3.5 ms
   b. 4.4 ms
   c. 45.8 ms
   d. 4.4 s

2. If you measure a transit time of 7 ms for the transducers on your circuit board to detect an object, what is the approximate distance of the object from the front of the base unit?

   a. 1 foot
   b. 2 feet
   c. 3 feet
   d. 4 feet



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

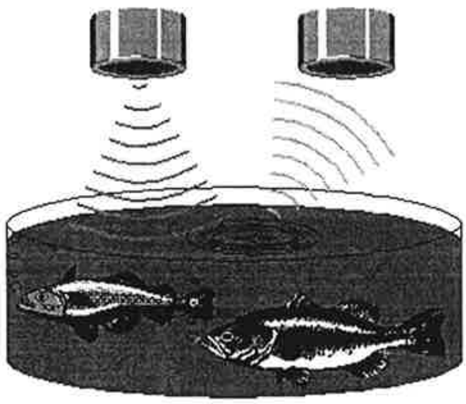
   a. the CLK period.
   b. the oscillator frequency.
   c. room temperature.
   d. All of the above.

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

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

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

UNIT 8 TEST QUESTIONS AND ANSWERS

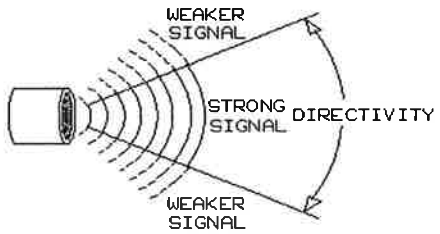


1. An ultrasonic transmitter/receiver pair is used to monitor the liquid level in a tank by using echoes off the liquid's surface as shown. What information can the receiver provide to a control circuit?

   a. full tank detection
   b. empty tank detection
   c. amount of liquid in the tank
   d. All of the above.

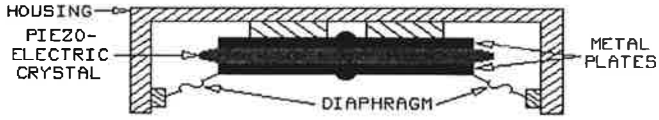
2. Ultrasonic frequencies are all sound frequencies which are

   a. detectable by the human ear.
   b. not detectable by the human ear.
   c. above the audible frequency range.
   d. below the audible frequency range.



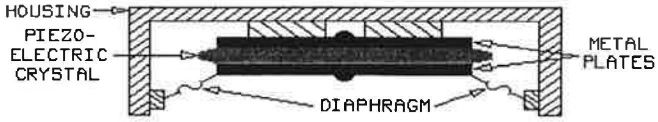
3. The signal directly in front of an ultrasonic transducer is stronger than the signal at the sides because of the transducer's

   a. directivity.
   b. voltage gain.
   c. current gain.
   d. transmission medium.



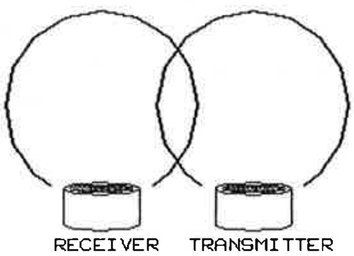
4. What is the function of the diaphragm in a piezoelectric transmitter?

   a. provides a means of making electrical connections
   b. converts the vibrations of the crystal to ultrasonic sound waves
   c. converts an ac voltage into a mechanical vibration
   d. detects ultrasonic sound waves



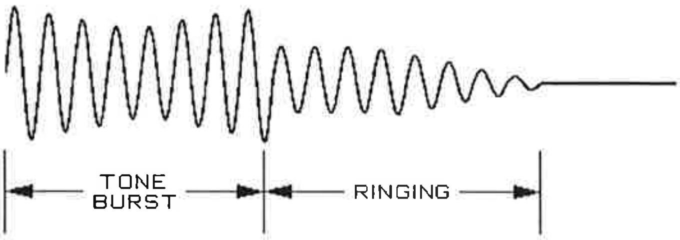
5. The piezoelectric transducer shown can be used as an ultrasonic

   a. receiver.
   b. transmitter.
   c. transceiver.
   d. All of the above.



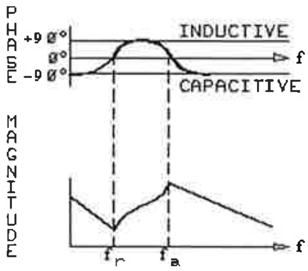
6. When an ultrasonic receiver and transmitter are positioned side-by-side with intersecting directivity curves as shown, what effect does directivity have on the transducer operation?

   a. Transmitter tone bursts are picked up by the receiver.
   b. Receiver tone bursts are picked up by the transmitter.
   c. Both a. and b.
   d. None.



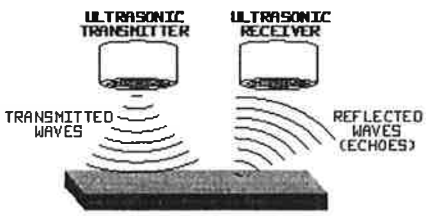
7. The ringing that occurs in a piezoelectric transmitter is due to

   a. increased amplitude in the applied ac signal.
   b. decreased amplitude in the applied ac signal.
   c. additional vibration of the diaphragm.
   d. an improperly mounted diaphragm.



8. These are impedance phase and magnitude curves for a typical ultrasonic transducer. For best performance, what type of impedance should the transducer have?

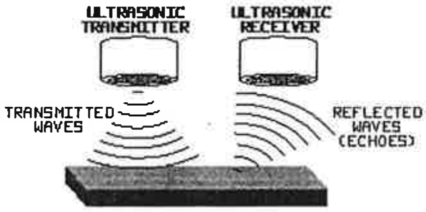
   a. purely inductive
   b. purely capacitive
   c. purely resistive
   d. Depends on whether the transducer is used as a transmitter or a receiver.



9. Ultrasonic waves travel from the transmitter to the target object in t milliseconds. What is the transit time of the waves?

   a. t

b. t/2
c. 2t
d. 4t



10. In an ultrasonic transducer system, what parameter can you measure to determine the distance to an object?

a. ultrasonic frequency
b. transit time of the ultrasonic waves
c. time between transmitter tone bursts
d. amplitude of the receiver output pulses