PI-4

PROGRAMMED INSTRUCTION HANDBOOK

NONDESTRUCTIVE TESTING

Ultrasonic

VOLUME I - BASIC PRINCIPLES

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Publishing and Printing

Revision Editor: . . . . Dr. George Pherigo, ***PH D***iversified, Inc.

Production Editor . . Ms. Mary Lou Hollifield, ***PH D***iversified, Inc.

Proofreading . . . . Ms. Jean Pherigo, ***PH D***iversified, Inc.
Proofreading . . . . Ms. Dana Smilie

Technical Content Revision

Technical Editor . . . . Mr. Robert W. Smilie

This handbook was originally prepared by the Convair Division of General Dynamics Corporation under contract to NASA and was identified as N68-28781. This book is part of a series of books, commonly know as the General Dynamics Series, that has been the basis of many industrial NDT training programs for over 20 years.

Now, after several decades of widespread use, the entire series has undergone a major revision. The revised material no longer concentrates on applications in the aerospace industry, but instead, covers a wider range of industrial applications and discusses the newest techniques and applications.

Mr. Robert W. Smilie has been the principal author of the revised material in this text. Using his nondestructive testing experiences in several industries, including work at the EPRI NDE Center, he has updated the text to better suit the entry-level technician/engineer.

TABLE OF CONTENTS

PREFACE

Programmed Instruction Handbook - Ultrasonic Testing PI-4, (3 volumes) is one of a series of training handbooks designed for **self-study** applications. The programmed instruction format allows the student to learn the material when a formal classroom setting is not available.

This Programmed Instruction Handbook is also very helpful when used prior to, or in conjunction with, the **Classroom Training Handbook** CT-4, Ultrasonic Testing. The instructor can make assignments in the classroom handbook and, as a supplement, the student can read corresponding information in this self-study handbook to provide a more structured approach for individual learning.

This **Programmed Instruction** Handbook presents essentially the same entry-level material as in the Classroom Training Handbook. However, this **self-study format** provides self-evaluation quiz questions at the end of each chapter and at the end of the book. A score of 80% or better on the self-test will indicate the students understanding of the basic Level I concepts on this subject.

Other **Programmed Instruction Handbooks** in the series include:

PI-1	Introduction to Nondestructive Testing
PI-2	Liquid Penetrant Testing
PI-3	Magnetic Particle Testing
PI-5	Eddy Current Testing
PI-6	Radiographic Testing

INSTRUCTIONS

The pages in this book should **not** be read consecutively as in a conventional book. You will be guided through the book as you read. For example, after reading page 3-12, you may find an instruction similar to one of the following at the bottom of the page:

- Turn to the next page.
- Turn ahead to page 3-15.
- Turn back to page 3-8.

On many of the pages you will be faced with a choice. For instance, you may find a statement or question at the bottom of the page together with two or more possible answers. Each answer will indicate a page number. You should choose the answer you think is most correct and turn to the indicated page. If you happen to select an incorrect answer, continue to read, as the page will provide supplemental information to help you understand the concept.

We know that sometimes the information in this self-study format may seem oversimplified or repetitious. Bear with us; the reinforcement of basic Level I concepts is essential if you expect to retain the knowledge and apply it to Level II training or on-the-job NDT applications.

Do not rush through the volumes. Take whatever time you need to make sure you have a clear understanding of the material. Depending on your background knowledge, reading speed, etc., the time needed to complete this series of books may vary from **15 to 30 hours** or more. As you will soon see, this self-study handbook is easy to use - just follow instructions.

TURN TO THE NEXT PAGE.

CHAPTER 2

TRANSDUCERS AND THE GENERATION OF ULTRASOUND

In Chapter 1 you learned that ultrasound is a vibration which moves through a material as a series of small particle displacements. You also learned that something called a "transducer" can be used to inject sound into the material. Now let's define a transducer.

A transducer is a device that converts energy from one form to another (e.g., electrical energy to mechanical energy or mechanical energy to electrical energy).

A stereo speaker is one example of a transducer. In this case, electrical energy is applied to a coil surrounding a portion of the speaker and this causes the speaker cone to move back and forth (mechanical movement). The pickup on a turn table (or record player) is another example. In this instance, the record causes mechanical movement of a needle which exerts a pressure on a crystal (a part of the pickup). The crystal has the property of developing an electrical output (energy) when the pressure on the crystal is varied. This transducer is converting mechanical energy into electrical energy.

Turn to the next page.

Visualize that we have a crystal one inch (25 mm) square and that we are alternately applying and removing electrical energy through two wires connected to the crystal. As we do so, we notice that the crystal vibrates.

Under these conditions, could the crystal be a transducer?

No . . . . **Page 2-4**
Yes . . . . **Page 2-5**

A moment ago we mentioned that a record player pickup is a crystal which is vibrated by a record needle. As the needle moves, pressure changes are made on the crystal and the crystal generates an electrical charge. This is known as the "reverse piezoelectric effect." Mechanical energy is being converted to electrical energy.

Which of the following statements is true?

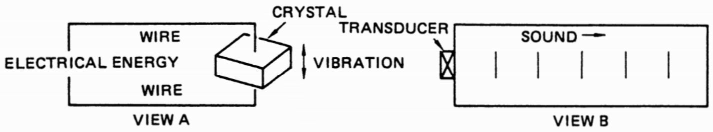
A piezoelectric transducer converts electrical energy to mechanical energy but does not convert mechanical energy to electrical energy . . . . Page 2-6
A piezoelectric transducer converts electrical energy to mechanical energy and converts mechanical energy to electrical energy . . . . Page 2-8

Your answer "no" is not correct. What we did was to apply electrical energy to a crystal. What we got was a mechanical vibration. Thus we went from electrical energy to mechanical energy.

Recall that a transducer is a device that *converts energy from one form to another form*. Since we converted electrical energy to mechanical energy (a vibration), we used a *transducer*.

Turn ahead to page 2-5.

You're right, of course. The crystal can be called a transducer.



View A above illustrates electrical energy being applied through two wires connected to a crystal. The ability of this crystal to convert electrical energy to mechanical energy is known as the "piezoelectric effect." Electrical energy causes a piezoelectric crystal to expand and contract forming mechanical vibrations.

View B above illustrates a piezoelectric crystal . . . let's call it a transducer . . . positioned against an article. From this illustration, we can see that a transducer is an ultrasonic generator which generates vibrations. Note that sound (from this point forward meaning ultrasound) is shown moving through the material. Recall that a vibration is energy in motion and ultrasonic energy moves through the material by a series of small particle displacements.

Turn back to page 2-3.

You're wrong when you say that the statement "A piezoelectric transducer converts electrical energy to mechanical energy but does not convert mechanical energy to electrical energy" is true. The statement is false because the transducer will also convert mechanical energy to electrical energy. Recall that the crystal in the record player made this conversion.

Perhaps we confused you by saying that the conversion of mechanical energy to electrical energy was known as "reverse piezoelectric effect." If so, we would like to correct the confusion. Either way the conversion is caused by the piezoelectric effect - one way is "forward" and the other way is "reverse."

Turn ahead to page 2-8.

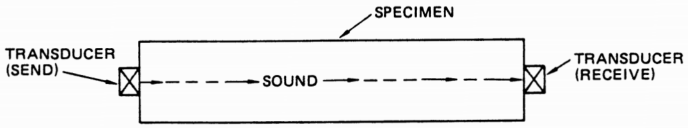
With one transducer, visualize that the transducer is momentarily energized (pulsed) by an electrical source. Under this condition, the transducer momentarily vibrates and sends a pulse of sound into the specimen. The transducer then stops vibrating.

If the sound within the specimen is reflected and returned to the transducer, will the transducer receive the sound, causing a vibration in the transducer?

Yes . . . . Page 2-9
No . . . . Page 2-10

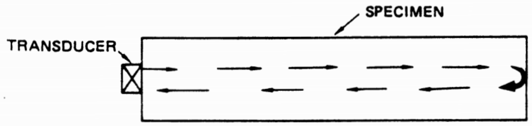
Good! You selected the statement that is true. A piezoelectric transducer converts electrical energy to mechanical energy (a vibration) and also converts mechanical energy to electrical energy.

Of course, this means that a transducer can send and receive energy. For example, if we locate transducers at opposite ends of a specimen as shown in View A below, we can use one transducer to send energy (sound) into the specimen and then use the other transducer to receive the sound.



VIEW A

View B illustrates the use of only one transducer on a test specimen.



NOTE:
SOUND IS REFLECTED WITHIN SPECIMEN AND RETURNS TO TRANSDUCER

VIEW B

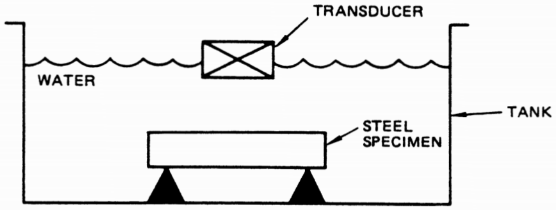
Return to the previous page.

Fine. You're right when you say that the transducer will receive the sound, causing a vibration in the transducer. In ultrasonic testing, it is a common practice to use the same transducer to send and receive the sound.

Ultrasonic testing of materials is based upon the fact that a transducer will inject a beam of energy into an article and the injected energy will be affected in some way by the material.

We are now going to introduce a new word . . . *medium*.

A medium, as used in ultrasonics, means the material through which the sound waves are passing. For example, when sound waves are traveling through steel, steel is the medium; when sound waves are passing through water, water is the medium.



Here we show a situation where the transducer is injecting a sound beam through water into and through steel.

Would you say that the sound beam is passing through more than one medium?

Yes . . . . **Page 2-11**
No . . . . **Page 2-12**

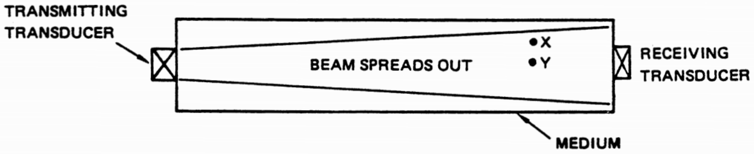
You are not correct when you say that the transducer will not receive the sound, causing a vibration in the transducer.

A piezoelectric transducer will work both ways. The same transducer can be used to send and to receive ultrasound. First, we can generate ultrasound by momentarily applying electrical energy to the transducer. When the electrical energy is removed, the transducer stops vibrating. Ultrasound returning to the transducer through the specimen will exert a pressure on the transducer and will cause the transducer to generate electrical energy. Thus, the same transducer can be used to send and receive ultrasound.

Turn back to page 2-9.

Exactly right. The sound beam is passing through two media. So far we have assumed that the sound beam does not spread out. In actual practice, it does to some extent.

Now let's find out what happens inside any medium. A transducer injects a beam of energy into the medium, and this beam will spread out (diverge) as it moves through the medium.



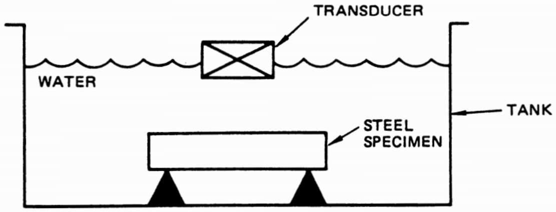
Now consider what this means in terms of energy (intensity) across the beam. The greatest concentration of energy is in the center of the beam, and this concentration decreases as you move away from the center. The beam intensity decreases as the distance from the center of the beam increases.

The illustration shows two points in a beam. Both points are the same distance from the transducer.

The intensity at point X will be:

less than at point Y . . . . Page 2-13
the same as at point Y . . . . Page 2-14

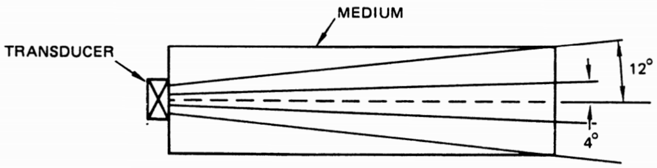
You feel that we cannot say the sound beam is passing through more than one medium. Look at the illustration again.



When the transducer is transmitting, the sound beam first passes through the water (the first medium) into and through the steel (the second medium). Transference of sound from one medium to another is an important factor in the science of ultrasonic testing.

Turn back to page 2-11.

Right! The intensity at point X will be less than the intensity at point Y. We can say that the intensity (energy) becomes less as we move away from the center of the beam.



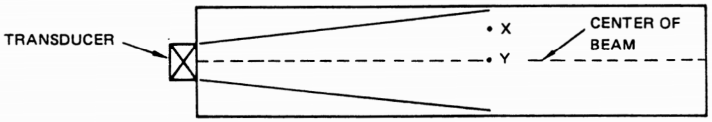
Shown above are two different beams within a medium. Note that one beam spreads only 4° from the center of the beam while the other spreads 12° in the same distance. The difference in beam spread is a function of two interrelated factors . . . the physical size of the transducer and its operating frequency. The larger the transducer, the narrower the beam spread; and the higher its operating frequency, the narrower the beam spread.

By using a transducer of the proper size and frequency, beam spread can be reduced to where the beam can be considered a straight beam. That is, the intensity across the beam can be considered almost constant.

If the proper transducer is selected so that the beam spread is small, we could say:

ultrasound travels through material as a straight beam of energy . . . . Page 2-15
ultrasound travels through material as an expanding beam of energy . . . . Page 2-17

You said the intensity at point X will be the same as at point Y. You're wrong.

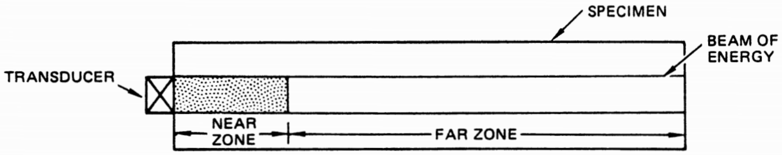


Recall that the intensity (energy) in the beam *decreases* as the distance from the center of the beam *increases*. This means that the intensity at point X is less than that at point Y. This also means that we can locate the center of the beam by locating the point where the intensity is highest.

Return to the previous page.

Correct. When using a transducer of the proper size at the proper frequency, ultrasound can be viewed as a straight beam of energy that is best for ultrasonic testing.

As shown below, the transducer injects a beam of energy into the material. This beam is divided into two zones: the "near zone" and the "far zone."



If we had a means of measuring the intensity of the beam at various distances from the transducer like we did at various distances from the center of the beam, we would learn two facts. In the *far zone*, the intensity (energy) would steadily decrease as the distance from the transducer increases. This is caused by the fact that the material absorbs and scatters some of the energy.

Turn to the next page.

In the *near zone* (also called the Fresnel zone) a different condition exists. Here we find that the intensity varies irregularly. Localized areas of high and low intensity exist within this area. Later we will learn that the near zone prevents the detection of discontinuities close to the surface on which the transducer is placed.

If you place a transducer against a specimen and excite the transducer, a beam of energy enters the specimen. This beam is divided into two zones.

The zone containing irregular intensities is called:

the far zone . . . . Page 2-18
the near zone . . . . Page 2-20

Of course some beam spreading occurs, but you have missed the point we are trying to make here!

When the beam spread is small, the intensity differences across the beam are very slight . . . slight enough so that we can ignore them. By using the *proper size* transducer and the *proper frequency*, this beam spreading can be minimized. This means we can think of the beam as a narrow, straight beam.

Turn back to page 2-15.

No, you have the zones reversed. You said that the zone containing irregular intensities is called the far zone. You should have said the near zone.

Recall that the far zone is the portion of the beam of energy where the intensity decreases as the distance from the transducer is increased. This decrease in intensity is caused by the absorption and scattering of energy by the material.

Turn ahead to page 2-20.

From page 2-20

You said that attenuation does not exist in the far zone. This is not correct. Attenuation *does* exist in the far zone.

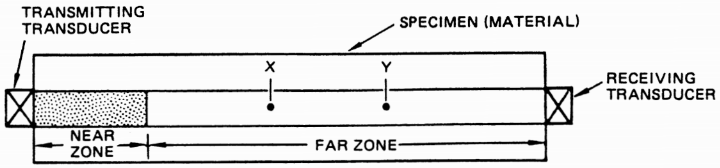
Attenuation, as applied to ultrasonic testing, means a loss of energy. Such a loss of energy occurs in the far zone; thus, attenuation does exist in the far zone.

Turn ahead to page 2-22.

From page 2-16

Yes, you're right. The zone containing irregular intensities is called the near zone. For our purposes, it is not important to know what causes this condition. All we need to remember is that it does exist.

Shown below is a transducer (transmitter) injecting ultrasound into a specimen (material). This sound is being sensed by a second transducer (receiver).



A moment ago, you learned that the intensity of the beam of energy decreases as the distance from the sending transducer increases. Again, *intensity refers to the relative strength of a sound beam at a certain point*. This means that the intensity at point Y, above, is less than at point X. It also means that the amount of energy delivered to the receiver transducer will be less than the amount injected into the material. The difference in energy represents an energy loss.

The term "attenuation" is used to describe this energy loss. Attenuation means "the process of lessening the amount." This is exactly what happens to ultrasound as it moves through a material. The physical properties of the medium cause attenuation.

Attenuation does:

not exist in the far zone . . . . Page 2-19
exist in the far zone . . . . Page 2-22

Your choice "No" is the wrong answer. The acoustical impedance of a given material *can* be determined if the material's density and sound velocity characteristics are known. Remember the definition? Acoustical impedance is the PRODUCT of the DENSITY and VELOCITY within the material (medium). In other words, IMPEDANCE = DENSITY X VELOCITY.

Turn ahead to page 2-32 and continue.

Correct! Attenuation exists in the far zone.

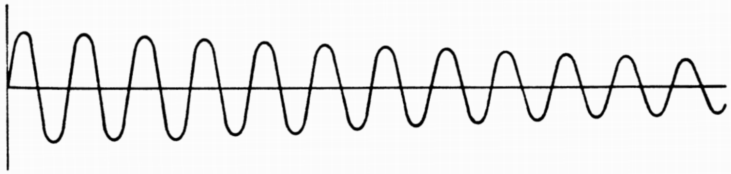
Okay, now let's take up a material characteristic that is used to relate one material to another ultrasonically. It is known as "acoustic impedance" (Z) and is a material property that is defined as the product of the density (ρ) and sound velocity (V) within the material. Impedance = density x velocity, or;

$$Z = \rho V$$

where:

Z = impedance
ρ = density
V = velocity

In fact, attenuation causes the wave to loose energy (wave amplitude) so that, if the wave were plotted, it would look like this:



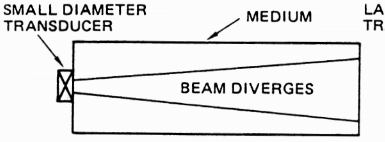
In other words, the energy peaks and valleys vary in height with the distance traveled into the medium. Velocity, frequency, and wavelength do not vary.

From what is stated above, could we determine the acoustical impedance of a material (medium) if we knew its density and sound velocity?

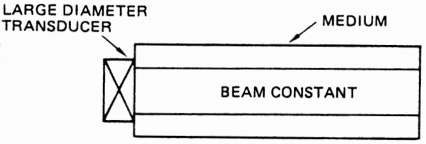
No . . . . **Page 2-21**
Yes . . . . **Page 2-32**

You are right. The secondary or side lobe effect does not increase the useful width of the transducer. Because of the secondary lobes, we find the useful width of a transducer is always less than the transducer's physical width.

In Views A and B below, we see two transducers of different sizes coupled to a medium. Notice how transducer diameter affects divergence (beam spread) within a medium.



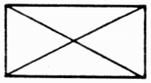
VIEW A



VIEW B

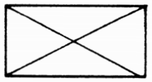
Recall that the frequency of the transducer has an effect on its beam spread. The higher the frequency, the less the beam spread.

A



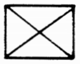
2-1/4 MHz
1 INCH

B



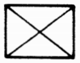
5 MHz
1 INCH

C



2-1/4 MHz
1/2 INCH

D

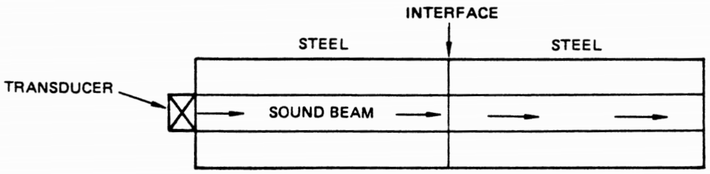


5 MHz
1/2 INCH

Here we show four transducers with their operating frequencies and their diameters given. Which transducer will have the least beam spread?

A . . . . **Page 2-38**
B . . . . **Page 2-34**
C . . . . **Page 2-39**
D . . . . **Page 2-41**

Now if we transmit sound energy into two pieces of identical steel, we find that the sound will move with the same velocity through both pieces. We can also say the two pieces of steel are matched and have an impedance ratio of 1 to 1.



VELOCITY REMAINS CONSTANT

Could we say the same thing is true if we place "water in touch with water?"

No . . . . **Page 2-26**
Yes . . . . **Page 2-28**

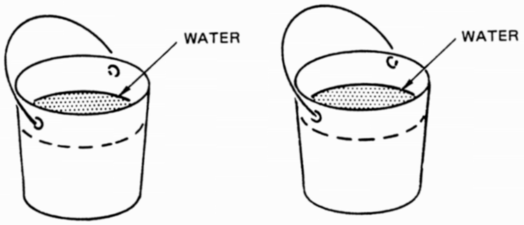
You're right. The impedance of water comes closer to the impedance of the steel; we have a smaller impedance ratio. Air is a very poor medium for transferring ultrasonic vibrations into liquids or solids.

Now let's examine the term "Impedance Ratio" a little more closely.

Turn ahead to page 2-27.

You apparently do not have the idea yet. You should have chosen "Yes." If we place water in contact with water, the sound velocity through the water remains constant and the impedance ratio is 1 to 1.

For example, say we have two identical buckets of water.

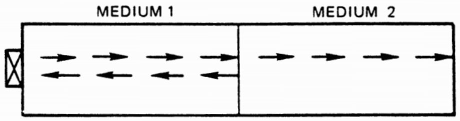


Doesn't the water in each bucket have the same density and sound velocity? Yes. Isn't the acoustical impedance the same for the water in both buckets? Yes.

Therefore the acoustical properties of the water in each bucket are the same. The impedance ratio is 1 to 1.

Turn ahead to page 2-28.

Here we show the transfer of sound from one medium to another (from medium 1 to medium 2) and the reflection of the sound at the interface between the two mediums.



The impedance ratio is defined as the impedance of medium 2 divided by the impedance of medium 1. That is:

$$\frac{Z_2}{Z_1} \quad \text{or:}$$

$$\textit{IMPEDANCE RATIO} = \frac{\textit{IMPEDANCE OF MEDIUM 2}}{\textit{IMPEDANCE OF MEDIUM 1}}$$

Note that although the sound is traveling from medium 1 to medium 2, the impedance ratio is Z_2 divided by Z_1.

In the case of a sound beam passing from water ($Z = 1.49 \times 10^5$ gm/cm^2-s) into steel ($Z = 45.6 \times 10^5$ gm/cm^2-s) the impedance ratio is equal to:

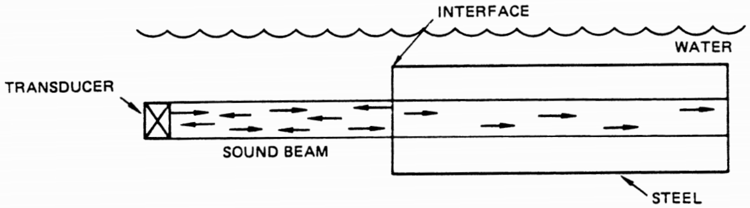
$\frac{1.49 \times 10^5}{45.6 \times 10^5}$ **. . . . . Page 2-29**

$\frac{45.6 \times 10^5}{1.49 \times 10^5}$ **. . . . . Page 2-31**

Fine. You're on the right track. "Yes" is the correct answer. The velocity will remain the same through "water in touch with water" and the impedance ratio will be 1 to 1.

In the preceding examples, we used steel versus steel and water versus water to show that when two media having the same acoustical impedance are placed together, the ultrasonic beam passing through them is unaffected.

Now let's place water in contact with steel and transmit a sound beam through both media. Note what happens.



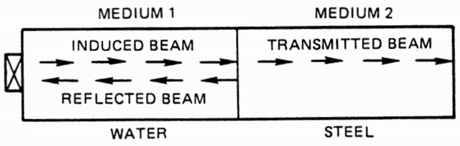
As the illustration shows, part of the sound passes from the water into the steel, and part of the sound is reflected at the interface.

The reflection of sound results because water has one impedance value and steel another. We now have an impedance mismatch. The ratio is no longer 1 to 1. Anything *greater* or *less* than a ratio of 1 to 1 is less than ideal. Therefore not all of the energy will transfer from the water to the steel. A portion of the sound beam will *reflect back* towards the transducer.

Which of the following conditions provides the smaller impedance ratio?

A water-to-steel impedance ratio . . . . Page 2-25
An air-to-steel impedance ratio . . . . Page 2-30

Sorry, you chose the wrong answer. We must have confused you somehow. Let's look at this again.



In the case cited, water is the first medium and steel is the second medium, since the sound is traveling from the water to the steel.

Now you *must* remember that the impedance ratio is *always* the impedance of the *second* medium divided by the impedance of the *first* medium. In this case, the impedance of the steel divided by the impedance of the water.

Now turn back to page 2-27, re-read the question and see if you don't get a different answer.

Wrong. You should have picked the water-to-steel impedance ratio as the smaller ratio. Air has a very low acoustical impedance (0.0003×10^5) in comparison with water (1.49×10^5) or steel (45.6×10^5). Remember that the closer the match of impedance values of the different media, the more sound will be transferred from one medium to another. The acoustical impedance of air is so low that it prevents the passage of sound waves from one medium to another.

Return to page 2-25.

Excellent choice! You have identified the correct impedance ratio for the case where water is the first medium and steel is the second medium. It is important to remember that, for impedance ratios greater than 1, part of the sound beam is reflected at the interface. The higher the ratio, the greater the amount of sound reflected.

Since air has a very small impedance, the impedance ratio between air and any liquid or solid material is very high. This indicates that most, if not all, of the sound beam will be reflected. Air is a very poor medium for transferring ultrasonic vibrations into liquids or solids.

A transducer is also considered a medium and has a characteristic acoustical impedance. Since the presence of air prevents the transfer of sound energy from the transducer to any other medium, we add something between the transducer and the test material. This something is called a "couplant." A couplant may be a solid, semisolid, or a liquid. The more common examples of couplants used are water, glycerin, oil, and grease. Sometimes foils, rubber, waxes, or cements are used.

When we use a couplant between the transducer and the surface of the test material, we are displacing air from between the transducer and the material so that transfer of the transducer vibrations to the test material will occur.

From this, could we say a couplant couples the transducer to the test material?

Yes . . . . **Page 2-33**
No . . . . **Page 2-36**

Good. "Yes" is the correct answer. The acoustical impedance of a material can be determined by multiplying the density of the material by the velocity of ultrasound through the material.

The impedance values for typical materials (media) are listed below along with velocity and density. A more comprehensive table can be found in most ultrasonic texts. Note the difference in impedance values for the media (materials) listed.

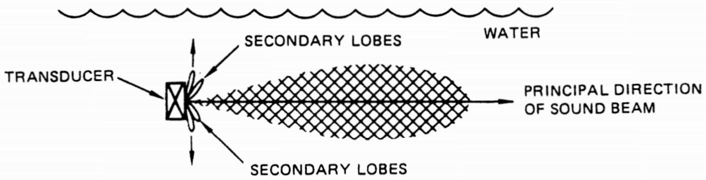
MATERIAL	IMPEDANCE (gram/cm^2-s)	VELOCITY (cm/s)	DENSITY (gram/cm^3)
AIR	0.00033×10^5	0.33×10^5	0.001
WATER	1.49×10^5	1.49×10^5	1.000
ALUMINUM	17.21×10^5	6.35×10^5	2.710
STEEL	45.63×10^5	5.85×10^5	7.800

As you can see, the acoustical impedance varies from one material (medium) to another, depending on the specific velocity and density characteristics of the material. Air has a very low impedance, with the impedance of water being relatively higher. Aluminum and steel have still higher impedances.

Turn back to page 2-24.

Right. You chose the correct answer. A couplant is used to couple the transducer to the test material. It provides a *sound path* and displaces *air* between the transducer and test material. We also find that the closer the couplant impedance matches that of the test material, the better the sound transfer.

Up until now, we have assumed that the useful width of the sound beam emitted from a transducer is the same width as the transducer. Well this is not quite true. For example, let's place a transducer under water and transmit a sound beam into the water as shown below.



The above illustration shows a typical example of how a sound beam radiates from a transducer. Note that most of the ultrasonic energy is bunched along the centerline of the beam. Also note that secondary or side lobes form at the transducer face and radiate away from the principal direction of sound travel. These secondary or side lobes represent areas of high and low intensities at the edge of the beam and close to the transducer.

Could we say that the secondary (or side) lobe effect increases the useful width of the transducer?

No . . . . **Page 2-23**
Yes . . . . **Page 2-37**

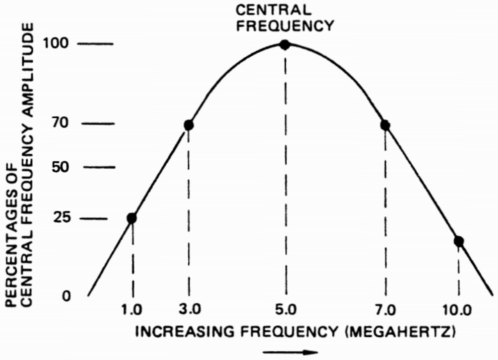
Correct! Transducer "B" has the largest diameter and the highest frequency so it has the least beam spread.

Each transducer has a rated, or central, frequency at which it is designed to vibrate; for example 5.0 megahertz, 10.0 megahertz, etc. A transducer will also respond over a band of frequencies on either side of the central frequency. Several factors affect the width of the frequency band. The design of the transducer governs the length of time it vibrates. The strength or amplitude of the central frequency plays a part in the bandwidth. Generally, a strong (high amplitude) central frequency will have a wider *bandwidth* than a transducer with a weaker central frequency.

Turn to the next page.

From page 2-34

The graph below illustrates a typical transducer's relationship between it's central frequency amplitude and bandwidth. In this case, the transducer's central frequency is 5.0 megahertz. Amplitude is expressed in percentages of the central frequency's amplitude.



All frequencies having an amplitude within 70% of the central frequency's amplitude are within the band. Therefore, in the example, the bandwidth includes:

all the frequencies between 3.0 and 5.0 megahertz . . . . . Page 2-40
all the frequencies between 5.0 and 7.0 megahertz . . . . . Page 2-42
all the frequencies between 3.0 and 7.0 megahertz . . . . . Page 2-43

From page 2-31

Your answer "no" is not correct. A couplant *does couple* the transducer to the test material. It removes air that would normally exist between the transducer and the test material. The couplant ensures maximum transfer of sound into the test material by coupling the transducer to the material.

Return to page 2-33.

Your answer "Yes" is not correct. The secondary or side lobes *do not* increase the useful width of the transducer.

Recall that the secondary or side lobes formed at the face of a transducer are areas of high and low intensities. For this reason, they tend to reduce the useful width of the transducer.

Return to page 2-23.

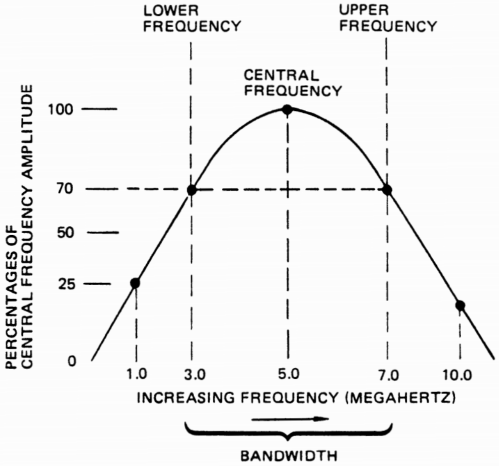
Your answer "A" is not correct. You did select one of the larger transducers, and it is true that the larger the transducer the less the beam spread for a given frequency but . . . beam spread is also dependent on frequency. The higher the frequency, the less the beam spread.

Keep this in mind and return to page 2-23 and select another answer.

Your answer "C" is not correct. First you selected one of the smaller transducers, in fact, the one with the smallest diameter. You must remember *the larger the transducer, the less the beam spread*. Then you also selected one of the transducers having the lowest frequency. This too is incorrect. Remember, *the higher the frequency, the less the beam spread*.

Keeping this in mind, return to page 2-23 and select another answer.

You're not quite right. Look at the graph again.



To determine the bandwidth, we must look for those frequencies that have amplitudes above 70% of the amplitude of the central frequency. To do this, we go up the left-hand side of the chart to 70% then draw a line (shown dashed) to the right to find the points where the line crosses the curve. Coming down from these points, we find the frequencies at the bottom of the chart. Aren't the frequencies between 5.0 and 7.0 megahertz also above the 70% minimum amplitude? Yes. Therefore, the bandwidth shown on the graph extends from 3.0 megahertz to 7.0 megahertz.

Turn ahead to page 2-43.

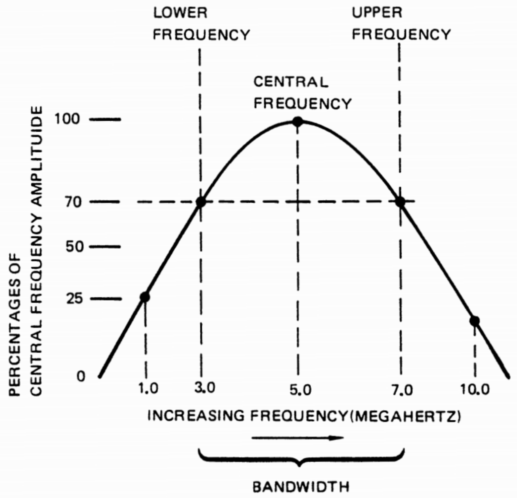
From page 2-23

Your answer "D" is not correct. You did select one of the transducers with the higher frequency and it is true that the higher the frequency the less the beam spread, but . . . beam spread is also dependent on transducer size. The larger the diameter, the less the beam spread.

Keep this in mind and return to page 2-23 and select another answer.

From page 2-35

You do not have the idea yet. "All frequencies between 5.0 and 7.0 megahertz" is not the correct answer.



To determine the bandwidth we must look for those frequencies that have amplitudes above 70% of the amplitude of the central frequency. To do this we go up the left-hand side of the chart to 70%, then we draw a line (shown dashed) to the right to find the points where the line crosses the curve. Coming down from these points, we find the frequencies at the bottom of the chart.

Don't the frequencies between 3.0 and 5.0 megahertz also have an amplitude above the 70% minimum? Yes. Therefore, the bandwidth shown on the graph extends from 3.0 to 7.0 megahertz.

Turn to the next page.

Excellent. The bandwidth shown on the graph is 3.0 to 7.0 megahertz. You learned that a transducer will vibrate over a band of frequencies and that bandwidth is determined by the transducer design and the amplitude or strength of the transducer's central frequency.

Turn to the next page for a review.

CHAPTER REVIEW

____ 1. A device which converts energy from one form to another is known as a:

A. medium.
B. converter.
C. pickup.
D. transducer.

____ 2. A ______ transducer (crystal) can convert electrical energy to mechanical energy; or mechanical energy to electrical energy.

A. piezoelectric
B. special
C. reversing
D. variable

____ 3. A piezoelectric crystal can both send and ______ energy.

A. capture
B. distort
C. receive
D. attenuate

_____ 4. An ultrasonic beam is a small, narrow beam of:

A. electrical energy.
B. mechanical energy.
C. injected atoms.
D. attenuated particles.

_____ 5. The tendency for a beam of sound to spread is known as:

A. divergence or beam restriction.
B. convergence or beam restriction.
C. convergence or beam spread.
D. divergence or beam spread.

_____ 6. Beam intensity ______ as the distance from the center of the beam increases.

A. increases
B. decreases
C. does not change

_____ 7. The ______ zone is that part of a sound beam closest to the transducer with the ______ zone beyond.

A. far, near
B. close, past
C. near, far
D. forward, reverse

_____ 8. The ______ zone is the zone of irregular intensities.

A. far
B. close
C. forward
D. near

_____ 9. The gradual loss of energy as a beam travels through a material (medium) is known as:

A. attenuation.
B. scatter.
C. impedance.
D. zoning.

____ 10. The ultrasonic characteristic of a medium defined by the product of density and velocity is:

A. impedance ratio.
B. ultrasonic attenuation.
C. acoustical impedance.
D. central frequency.

____ 11. Velocity of sound ______ from one medium to another.

A. changes
B. is constant

____ 12. Impedance mismatch between mediums is known as the:

A. near zone.
B. attenuation ratio.
C. sonic difference.
D. impedance ratio.

____ 13. The impedance ratio between mediums can be improved by using a(n):

A. bridge.
B. couplant.
C. injector.
D. attenuator.

____ 14. Water, glycerin, oil, and grease are the most common ______. Gaseous mediums, for example air, make very ______ couplants.

A. couplants, poor
B. attenuators, poor
C. couplants, good
D. attenuators, good

____ 15. Because of the secondary or side lobe effect at the face of a transducer, the useful width of the transducer is ______ than the transducer's physical width.

A. same
B. greater
C. less

____ 16. When comparing two transducers with the same frequency, the smaller diameter transducer has ______ beam divergence than the larger diameter transducer.

A. more
B. less
C. same

_____ 17. When comparing two transducers of the same size, the ______ frequency transducer has a spreading or divergent beam.

A. higher
B. lower

_____ 18. Couplants ensure maximum energy ______ between mediums.

A. impedance
B. restriction
C. attenuation
D. transfer or transmission

_____ 19. A transducer will produce (and receive) a band of frequencies near its central frequency ______. This band of frequencies is known as the ______.

A. bandwidth, divergence
B. bandwidth, convergence
C. amplitude, bandwidth
D. amplitude, divergence

_____ 20. A large, high-frequency transducer has a ______ beam spread.

A. large
B. small

Turn to the next page for answers to these review questions.

ANSWERS TO REVIEW QUESTIONS FOR CHAPTER 2

Question & Answer		Reference Page(s)
1.	D	2-1
2.	A	2-5
3.	C	2-8
4.	B	2-8
5.	D	2-11
6.	B	2-11
7.	C	2-15, 2-16
8.	D	2-16
9.	A	2-20
10.	C	2-22
11.	A	2-22
12.	D	2-27
13.	B	2-31
14.	A	2-31
15.	C	2-37
16.	A	2-23, 2-34
17.	B	2-23, 2-34
18.	D	2-31
19.	C	2-34, 35
20.	B	2-23, 2-34

Turn to Chapter 3 and continue your study of ultrasonics.