

# Ultrasonic Transducers Technical Notes

Olympus is a global technology leader, crafting innovative optical and digital solutions in medical technologies; life sciences; industrial solutions; and cameras and audio products. Throughout our 100-year history, Olympus has focused on being true to society and making people's lives healthier, safer, and more fulfilling.

Our Scientific Solutions Division is committed to the safety and betterment of society through the pioneering, development, and manufacture of world-leading test and measurement solutions. These solutions are used in industrial and research applications ranging from aerospace, power generation, petrochemical, civil infrastructure, automotive, and consumer products.

These ultrasonic transducer Technical Notes provide an overview of the ultrasonic principles that impact the design and functioning of ultrasonic transducers. The Technical Notes cover topics ranging from basic ultrasonic principles through the different cable styles used with transducers.

<b>Basic Ultrasonic Principles</b> . . . . .	<b>2</b>
What Is Ultrasound? . . . . .	2
Frequency, Period, and Wavelength . . . . .	2
Velocity of Ultrasound and Wavelength . . . . .	2
Wave Propagation and Particle Motion . . . . .	2
Applying Ultrasound . . . . .	3
Sensitivity and Resolution . . . . .	3
<b>Advanced Definitions and Formulas</b> . . . . .	<b>3</b>
Transducer Waveform and Spectrum . . . . .	3
Acoustic Impedance, Reflectivity, and Attenuation . . . . .	4
Sound Field . . . . .	4
Other Parameters of a Sound Beam . . . . .	4
<b>Design Characteristics of Transducers</b> . . . . .	<b>5</b>
What Is an Ultrasonic Transducer? . . . . .	5
The Active Element . . . . .	5
Backing . . . . .	5
Wear Plate . . . . .	5
<b>Transducer-Specific Principles</b> . . . . .	<b>6</b>
Dual Element Transducers . . . . .	6
Angle Beam Transducers . . . . .	6
Delay Line Transducers . . . . .	7
Immersion Transducers . . . . .	7
Normal Incidence Shear Wave Transducers . . . . .	8
<b>Transducer Excitation Guidelines</b> . . . . .	<b>9</b>
<b>Cables</b> . . . . .	<b>9</b>
<b>Near-Field Distances of Flat Transducers in Water</b> . . . . .	<b>10</b>
<b>Acoustic Properties of Materials</b> . . . . .	<b>11</b>



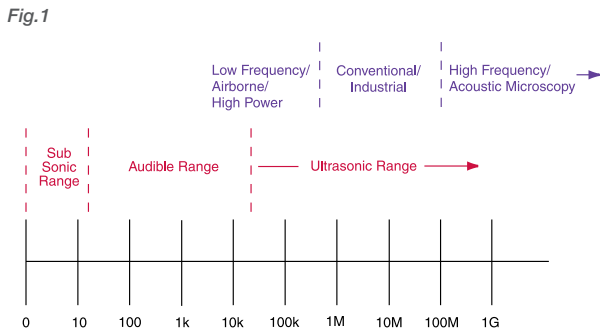
# Technical Notes

## 1. Basic Ultrasonic Principles

### a. What Is Ultrasound?

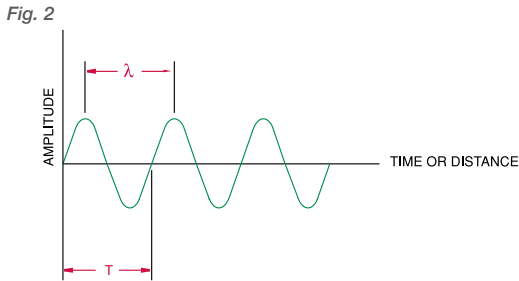
Sound generated above the human hearing range (typically 20 kHz) is called ultrasound. However, the frequency range normally employed in ultrasonic nondestructive testing and thickness gaging is 100 kHz to 50 MHz. Although ultrasound behaves in a similar manner to audible sound, it has a much shorter wavelength. This means it can be reflected off very small surfaces such as defects inside materials. It is this property that makes ultrasound useful for nondestructive testing of materials.

The acoustic spectrum in Figure 1 breaks down sound into three ranges of frequencies. The ultrasonic range is then broken down further into three sub-sections.



### b. Frequency, Period, and Wavelength

Ultrasonic vibrations travel in the form of a wave, similar to the way light travels. However, unlike light waves, which can travel in a vacuum (empty space), ultrasound requires an elastic medium such as a liquid or a solid. Shown in Figure 2 are the basic parameters of a continuous wave (cw). These parameters include the wavelength ( $\lambda$ ) and the period (T) of a complete cycle.



The number of cycles completed in one second is called frequency (f) and is measured in hertz (Hz), with multiples as follows;

- 1 cycle/second = 1 Hz
- 1,000 cycles/second = 1 kHz
- 1,000,000 cycles/second = 1 MHz

The time required to complete a full cycle is the period (T), measured in seconds. The relation between frequency and period in a continuous wave is given in Equation 1.

Eqn. 1

$$f = 1/T$$

### c. Velocity of Ultrasound and Wavelength

The velocity of ultrasound (c) in a perfectly elastic material at a given temperature and pressure is constant. The relation between c, f,  $\lambda$ , and T is given by Equations 2 and 3:

Eqn. 2

$$\lambda = c/f$$

Eqn. 3

$$\lambda = cT$$

- $\lambda$  = Wavelength
- c = Material Sound Velocity
- f = Frequency
- T = Period of time

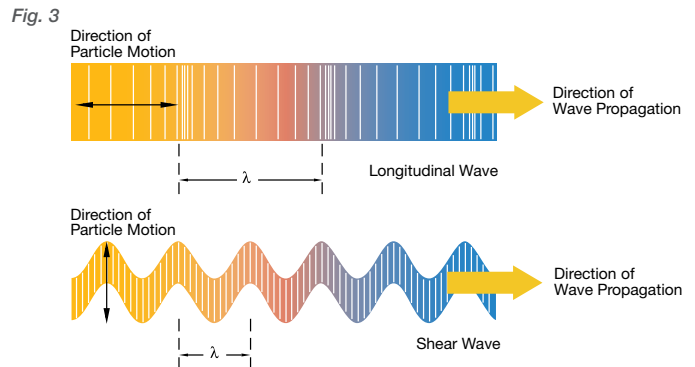
"Table 2 - Acoustic Properties of Materials" on page 11 lists the longitudinal and shear wave velocities of materials that are commonly tested with ultrasonics.

### d. Wave Propagation and Particle Motion

The most common methods of ultrasonic examination use either longitudinal waves or shear waves. Other forms of sound propagation exist, including surface waves and Lamb waves.

- A longitudinal wave is a compressional wave in which the particle motion is in the same direction as the propagation of the wave.
- A shear wave is a wave motion in which the particle motion is perpendicular to the direction of the propagation.
- Surface (Rayleigh) waves have an elliptical particle motion and travel across the surface of a material. Their velocity is approximately 90% of the shear wave velocity of the material and their depth of penetration is approximately equal to one wavelength.
- Plate (Lamb) waves have a complex vibration occurring in materials where thickness is less than the wavelength of ultrasound introduced into it.

Figure 3 provides an illustration of the particle motion versus the direction of wave propagation for longitudinal waves and shear waves.



# Technical Notes

## e. Applying Ultrasound

Ultrasonic nondestructive testing introduces high-frequency sound waves into a test object to obtain information about the object without altering or damaging it in any way. Two basic quantities are measured in ultrasonic testing; they are time of flight, or the amount of time for the sound to travel through the sample, and the amplitude of the received signal. Based on velocity and round trip time of flight through the material, the material's thickness can be calculated as follows:

Eqn. 4

$$T = \frac{ct}{2}$$

T = Material Thickness  
 c = Material Sound Velocity  
 t = Time of Flight

Measurements of the relative change in signal amplitude can be used in sizing flaws or measuring the attenuation of a material. The relative change in signal amplitude is commonly measured in decibels. Decibel values are the logarithmic value of the ratio of two signal amplitudes. This can be calculated using the following equation. Some useful relationships are also displayed in the table below;

Eqn. 5

$$dB = 20 \log_{10} (A_1/A_2)$$

dB = Decibels  
 A<sub>1</sub> = Amplitude of signal 1  
 A<sub>2</sub> = Amplitude of signal 2

A <sub>1</sub>	A <sub>2</sub>	Ratio	dB
100%	70.71%	1.4142	3
100%	50%	2	6
100%	25%	4	12
100%	10%	10	20
100%	1%	100	40

## f. Sensitivity and Resolution

- Sensitivity is the ability of an ultrasonic system to detect reflectors (or defects) at a given depth in a test material. The greater the signal that is received from a given reflector, the more sensitive the transducer system.
- Axial resolution is the ability of an ultrasonic system to produce simultaneous and distinct indications from reflectors located at nearly the same position with respect to the sound beam.
- Near-surface resolution is the ability of the ultrasonic system to detect reflectors located close to the surface of the test piece.

## 2. Advanced Definitions and Formulas

### a. Transducer Waveform and Spectrum

Transducer waveform and spectrum analysis is done according to test conditions and definitions of ASTM E1065. Typical units are MHz for frequency analysis, microseconds for waveform analysis, and dB down from peak amplitude. Figure 4 illustrates waveform duration at the -14 dB level or 20% amplitude of peak. The -40 dB waveform duration corresponds to 1% amplitude of peak.

Fig. 4

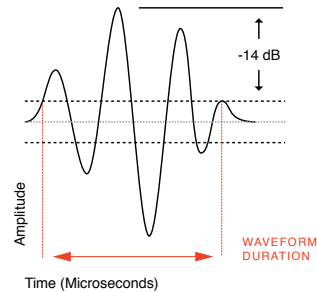
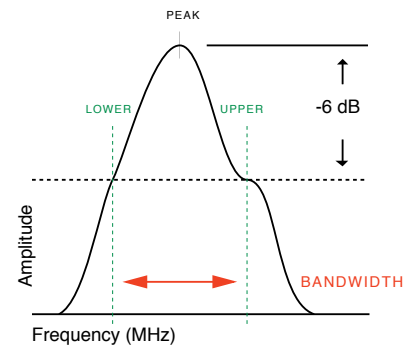


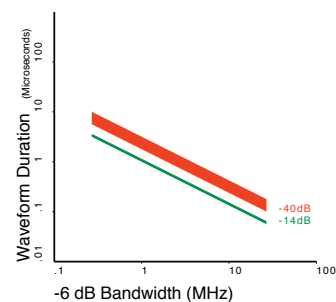
Figure 5 illustrates peak frequency, upper and lower -6 dB frequencies, and MHz bandwidth measurements.

Fig. 5



The relationship between MHz bandwidth and waveform duration is shown in Figure 6. The scatter is wider at -40 dB because the 1% trailing end of the waveform contains very little energy and has very little effect on the analysis of bandwidth. Because of the scatter, it is most appropriate to specify waveforms in the time domain (microseconds) and spectra in the frequency domain.

Fig. 6



The approximate relations shown in Figure (6) can be used to assist in transducer selection. For example, if a -14 dB waveform duration of one microsecond is needed, what frequency transducer should be selected? From the graph, a bandwidth of approximately 1 to 1.2 MHz corresponds to approximately 1 microsecond -14 dB waveform duration. Assuming a nominal 50% fractional bandwidth transducer, this calculates to a nominal center frequency of 2 to 2.4 MHz. Therefore, a transducer of 2.25 MHz or 3.5 MHz may be applicable.

### b. Acoustic Impedance, Reflectivity, and Attenuation

The acoustic impedance of a material is the opposition to displacement of its particles by sound and occurs in many equations. Acoustic impedance is calculated as follows:

$$\text{Eqn. 6} \quad Z = \rho c$$

- Z = Acoustic Impedance
- c = Material Sound Velocity
- $\rho$  = Material Density

The boundary between two materials of different acoustic impedances is called an acoustic interface. When sound strikes an acoustic interface at normal incidence, some amount of sound energy is reflected and some amount is transmitted across the boundary. The dB loss of energy on transmitting a signal from medium 1 into medium 2 is given by:

$$\text{Eqn. 7a} \quad \text{dB loss} = 10 \text{Log}_{10} [4Z_1Z_2 / (Z_1 + Z_2)^2]$$

- Z<sub>1</sub> = Acoustic Impedance of First Material
- Z<sub>2</sub> = Acoustic Impedance of Second Material

The dB loss of energy of the echo signal in medium 1 reflecting from an interface boundary with medium 2 is given by:

$$\text{Eqn. 7b} \quad \text{dB loss} = 10 \text{Log}_{10} [(Z_2 - Z_1)^2 / (Z_1 + Z_2)^2]$$

For example, the dB loss on transmitting from water (Z = 1.48) into 1020 steel (Z = 45.41) is -9.13 dB; this also is the loss transmitting from 1020 steel into water. The dB loss of the backwall echo in 1020 steel in water is -0.57 dB; this also is the dB loss of the echo off 1020 steel in water. The waveform of the echo is inverted when Z<sub>2</sub> < Z<sub>1</sub>.

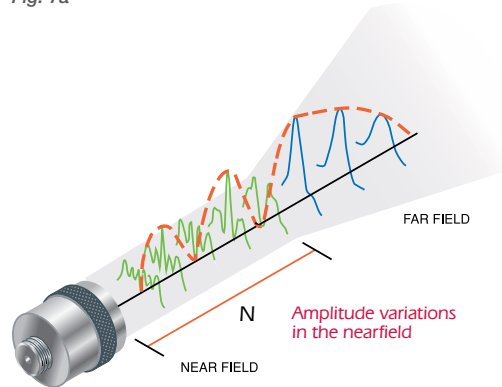
Finally, ultrasound attenuates as it progresses through a medium. Assuming no major reflections, there are three causes of attenuation: diffraction, scattering, and absorption. The amount of attenuation through a material can play an important role in the selection of a transducer for an application.

### c. Sound Field

The sound field of a transducer is divided into two zones (figure 7a); the near field and the far field. The near field is the region directly in front of the transducer where the echo amplitude goes through a series of maxima and minima and ends at the last maximum at distance N from the transducer. In the beam profile below, figure 7, red represents areas of highest energy, while green and blue represent lower energy.



Fig. 7a



The location of the last maximum is known as the near field distance (N or Y<sub>0</sub><sup>+</sup>) and is the natural focus of the transducer. The far field is the area beyond N where the sound field pressure gradually drops to zero. Because of the variations within the near field, it can be difficult to accurately evaluate flaws using amplitude-based techniques. The near field distance is a function of the transducer frequency, element diameter, and the sound velocity of the test material, as shown by Equation 8:

$$\text{Eqn. 8} \quad N = D^2 / 4c \quad \text{Eqn. 8a} \quad N = D^2 / 4\lambda$$

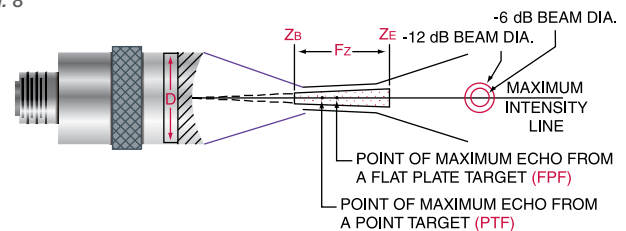
- N = Near Field Distance
- D = Element Diameter
- f = Frequency
- c = Material Sound Velocity
- $\lambda$  = Wavelength

("Table 1 - Near Field Distance of Flat Transducers in Water" on page 10 lists the near field distances in water for many combinations of transducer frequency and element diameter.)

### d. Other Parameters of a Sound Beam

There are a number of sound field parameters that are useful in describing the characteristics of a transducer. In addition to the near field, knowledge of the beam width and focal zone may be necessary in order to determine whether a particular transducer is appropriate for a given inspection. Figure (8) gives a graphical representation of these parameters:

Fig. 8



- Z<sub>B</sub> = Beginning of the Focal Zone
- F<sub>Z</sub> = Focal Zone
- Z<sub>E</sub> = End of the Focal Zone
- D = Element Diameter

Note that the distance to the maximum echo from a flat plate target and the maximum echo from the point target are not the same, although both will occur within the calculated -6 dB focal zone.

# Technical Notes

## Beam Diameter

A transducer's sensitivity is affected by the beam diameter at the point of interest. The smaller the beam diameter, the greater the amount of energy is reflected by a flaw. The -6 dB pulse-echo beam diameter at the focus can be calculated with Equation 9 or 9a. For a flat transducer, use Equation 9a with  $S_F = 1$ .

Eqn. 9  $BD(-6\text{ dB}) = 1.02Fc/fD$

Eqn. 9a  $BD(-6\text{ dB}) = .2568DS_F$

- BD = Beam Diameter
- F = Focal Length
- c = Material Sound Velocity
- f = Frequency
- D = Element Diameter
- $S_F$  = Normalized Focal Length (Eqn. 14)

## Focal Zone

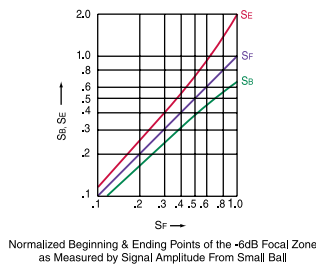
The starting and ending points of the focal zone are located where the on-axis pulse-echo signal amplitude drops to -6 dB of the amplitude at the focal point. The length of the focal zone is given by Equation 10:

Eqn. 10  $F_Z = N \cdot S_F^2 [2 / (1 + .5S_F)]$

- $F_Z$  = Focal Zone
- $N$  = Near Field
- $S_F$  = Normalized Focal Length (Eqn. 14)

Figure 9 shows the normalized beginning ( $S_B$ ) and ending ( $S_E$ ) point of the -6 dB focal zone versus the focusing factor.

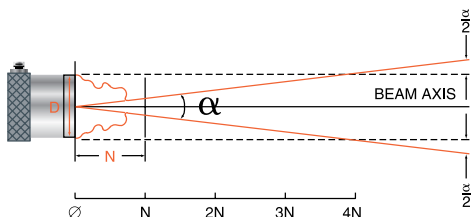
Fig. 9  
-6 dB Focal Zone



## Beam Spread and Half Angle

All ultrasonic beams diverge. In other words, all transducers have beam spread. Figure 10 gives a simplified view of a sound beam for a flat transducer. In the near field, the beam has a complex shape that narrows. In the far field, the beam diverges.

Fig. 10



For flat transducers as shown in Figure 10, the -6 dB pulse-echo beam

spread angle is given by Equation 11:

Eqn. 11  $\sin(\alpha/2) = .514c/fD$

$\alpha/2$  = Half Angle Spread between -6 dB points

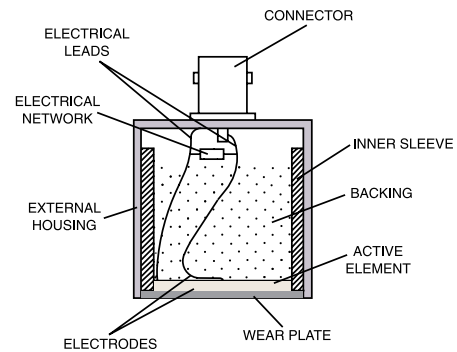
It can be seen from this equation that beam spread from a transducer can be reduced by selecting a transducer with a higher frequency or a larger element diameter or both.

## 3. Design Characteristics of Transducers

### a. What Is an Ultrasonic Transducer?

A transducer is any device that converts one form of energy to another. An ultrasonic transducer converts electrical energy to mechanical energy in the form of sound, and vice versa. The main components are the active element, backing, and wear plate.

Fig. 11



### b. The Active Element

The active element, which is piezo or ferroelectric material, converts electrical energy, such as an excitation pulse from a flaw detector, into ultrasonic energy. The most commonly used materials are polarized ceramics that can be cut in a variety of manners to produce different wave modes. New materials, such as piezo polymers and composites, are also being employed for applications where they provide benefit to transducer and system performance.

### c. Backing

The backing is usually a highly attenuative, high-density material that is used to control the vibration of the transducer by absorbing the energy radiating from the back face of the active element. When the acoustic impedance of the backing matches the acoustic impedance of the active element, the result will be a heavily damped transducer that displays good range resolution but may be lower in signal amplitude. If there is a mismatch in acoustic impedance between the element and the backing, more sound energy will be reflected forward into the test material. The end result is a transducer that is lower in resolution due to a longer waveform duration, but may be higher in signal amplitude or greater in sensitivity.

### d. Wear Plate

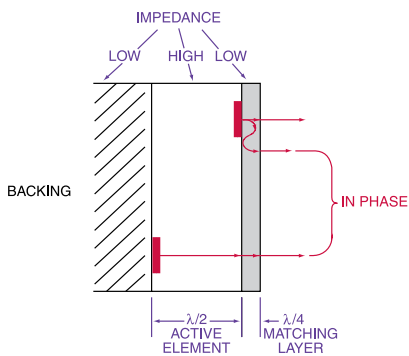
The basic purpose of the transducer wear plate is to protect the transducer element from the testing environment. In the case of contact transducers, the wear plate must be a durable and corrosion-resistant material in order to withstand the wear caused by use on materials such as steel.

For immersion, angle beam, and delay line transducers, the wear plate has the additional purpose of serving as an acoustic transformer or matching

layer between the high acoustic impedance of the active element and the water, the wedge, or the delay line, all of which are of lower acoustic impedance. This is accomplished by selecting a matching layer that is  $\frac{1}{4}$  wavelength thick ( $\lambda/4$ ) and of the desired acoustic impedance (the active element is nominally  $\frac{1}{2}$  wavelength). The choice of the wear surface thickness is based on the idea of superposition that allows waves generated by the active element to be in phase with the wave reverberating in the matching layer as shown in Figure 4.

When signals are in phase, their amplitudes are additive, thus a greater amplitude wave enters the test piece. Figure 12 shows the active element and the wear plate and when they are in phase. If a transducer is not tightly controlled or designed with care and the proper materials, and the sound waves are not in phase, it causes a disruption in the wavefront.

Fig. 12



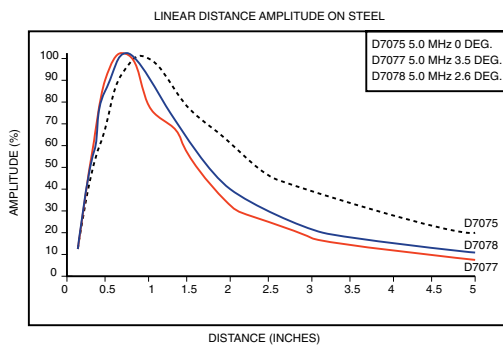
## 4. Transducer-Specific Principles

### a. Dual Element Transducers

Dual element transducers use separate transmitting and receiving elements mounted on delay lines that are usually cut at an angle. This configuration improves near-surface resolution by eliminating main bang recovery problems. In addition, the crossed beam design provides a pseudo focus that makes duals more sensitive to echoes from irregular reflectors such as corrosion and pitting.

One consequence of the dual element design is a sharply defined distance/amplitude curve. In general, a decrease in the roof angle or an increase in the transducer element size will result in a longer pseudo-focal distance and an increase in useful range, as shown in Figure 13.

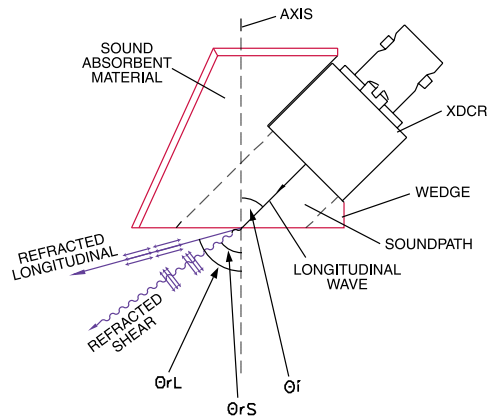
Fig. 13



### b. Angle Beam Transducers

Angle beam transducers use the principles of refraction and mode conversion to produce refracted shear or longitudinal waves in the test material as shown in Figure 14.

Fig. 14



The incident angle necessary to produce a desired refracted wave (i.e. a 45° shear wave in steel) can be calculated from Snell's law as shown in Equation 12. Because of the effects of beam spread, this equation doesn't hold at low frequency and small active element size. Contact us for details concerning these phenomena.

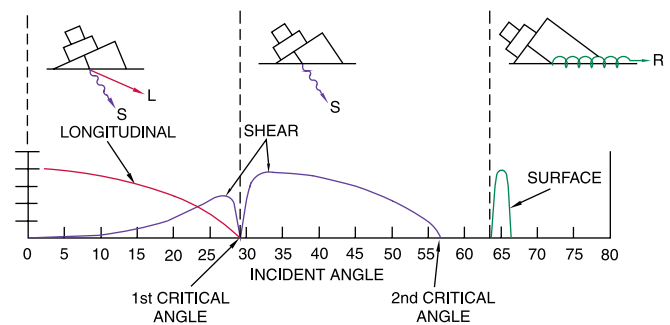
Eqn. 12

$$\sin\theta_i/c_i = \sin\theta_{rl}/c_{rl} = \sin\theta_{rs}/c_{rs}$$

$\theta_i$	=	Incident Angle of the Wedge
$\theta_{rl}$	=	Angle of the Refracted Longitudinal Wave
$\theta_{rs}$	=	Angle of the Refracted Shear Wave
$c_i$	=	Velocity of the Incident Material (Longitudinal)
$c_{rl}$	=	Material Sound Velocity (Longitudinal)
$c_{rs}$	=	Velocity of the Test Material (Shear)

Figure 15 shows the relationship between the incident angle and the relative amplitudes of the refracted or mode converted longitudinal, shear, and surface waves that can be produced from a plastic wedge into steel.

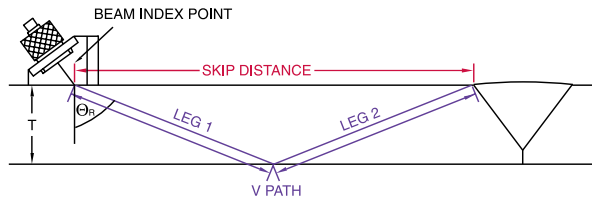
Fig. 15



Angle beam transducers are typically used to locate and/or size flaws that are oriented non-parallel to the test surface. The following are some of the common terms and formulas used to determine the location of a flaw.

# Technical Notes

Fig. 16

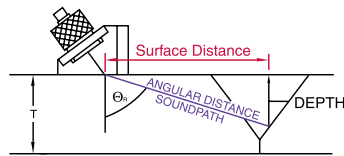


$\Theta_R$  = Refracted Angle  
 T = Thickness

$$\text{Leg} = \frac{T}{\cos \Theta_R}$$

$$\text{V-PATH} = \frac{2T}{\cos \Theta_R}$$

$$\text{Skip Distance} = 2T \times \tan \Theta_R$$



$$\text{Surface Distance} = \sin \Theta_R \times \text{Soundpath}$$

$$\text{Depth (1st Leg)} = \cos \Theta_R \times \text{Soundpath}$$

$$\text{Depth (2nd Leg)} = 2T - [\cos \Theta_R \times \text{Soundpath}]$$

Many AWS inspections are performed using refracted shear waves. However, grainy materials, such as austenitic stainless steel, may require refracted longitudinal waves or other angle beam techniques for successful inspections.

## c. Delay Line Transducers

Delay line transducers are single element longitudinal wave transducers used in conjunction with a replaceable delay line.

One of the reasons for choosing a delay line transducer is that near-surface resolution can be improved. The delay allows the element to stop vibrating before a return signal from the reflector can be received. When using a delay line transducer, there will be multiple echoes from end of the delay line, and it is important to take these into account.

Another use of delay line transducers is in applications in which the test material is at an elevated temperature. The high-temperature delay line options offered by Olympus are not intended for continuous contact; they are meant for intermittent contact only.

## d. Immersion Transducers

Immersion transducers offer three major advantages over contact transducers:

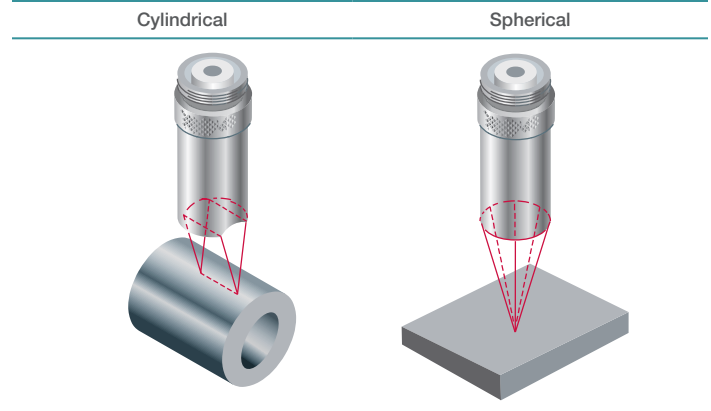
- Uniform coupling reduces sensitivity variations.
- Reduction in scan time due to automated scanning.
- Focusing of immersion transducers increases sensitivity to small reflectors.

## Focusing Configurations

Immersion transducers are available in three different configurations: unfocused ("flat"), spherically ("spot") focused, and cylindrically ("line") focused. Focusing is accomplished by either the addition of a lens or by curving the element itself. The addition of a lens is the most common way to focus a transducer.

An unfocused transducer may be used in general applications or for penetration of thick materials. A spherically focused transducer is commonly used to improve sensitivity to small flaws and a cylindrical focus is typically used in the inspection of tubing or bar stock. Examples of spherical and cylindrical focusing are shown in Figure 17.

Fig. 17



By definition, the focal length of a transducer is the distance from the face of the transducer to the point in the sound field where the signal with the maximum amplitude is located. In an unfocused transducer, this occurs at a distance from the face of the transducer, which is approximately equivalent to the transducer's near field length. Because the last signal maximum occurs at a distance equivalent to the near field, a transducer, by definition, can not be acoustically focused at a distance greater than its near field.

### Focus may be designated in three ways:

**FPF (Flat Plate Focus)** — For an FPF, the lens is designed to produce a maximum pulse/echo response from a flat plate target at the distance indicated by the focal length.

**PTF (Point Target Focus)** — For a PTF, the lens is designed to produce a maximum pulse/echo response from a small ball target at the distance indicated by the focal length.

**OLF (Optical Limit Focus)** — The OLF designation indicates that the lens is designed according to the lens maker's formula from physical optics and without reference to any operational definition of focal length. The OLF designation describes the lens and ignores diffraction effects.

When focusing a transducer, the type of focus (spherical or cylindrical), focal length, and the focal target (point or flat surface) need to be specified. Based on this information, the radius of curvature of the lens for the transducer, which varies based on the above parameters, can be calculated. When tested, the measured focal length will be off of the target specified.

There are limitations on focal lengths for transducers of a given frequency and element diameter for a particular focal designation. The maximum practical focal length for a flat plate focus (FPF) is 0.6 times the near field length, and for a point target focus (PTF), the maximum practical focal length is 0.8 times the near field length. Optical limit focus (OLF) focal length is not specifically constrained, but it should be understood that the actual maximum response point from a given target may not correspond to the distance indicated by the OLF focal length.

FPF and PTF transducers with focal lengths beyond these maximums, but less than the near field length, will usually be weakly focused units with only a small increase in sensitivity at the focal point. As a practical matter, there may be no functional advantage to a weakly focused transducer over a flat, unfocused transducer. In addition to acoustic limitations on maximum focal lengths, there are mechanical limitations on minimum focal lengths. Consult us for detailed information on focusing parameters.

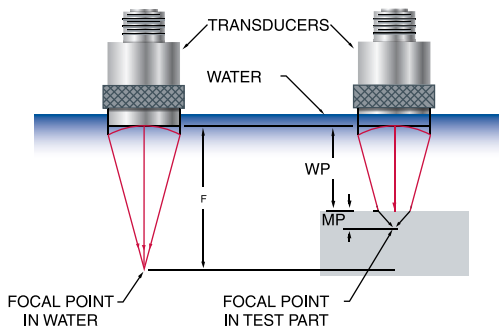
"Table 1 - Near Field Distance of Flat Transducers in Water" on page 10 lists the near field distances as well as the minimum and maximum practical focal lengths for common frequency-element diameter combinations.

Consult us for detailed information in focusing parameters.

## Focal Length Variations Due to Acoustic Velocity and Geometry of the Test Part

The measured focal length of a transducer is dependent on the material in which it is being measured. This is due to the fact that different materials have different sound velocities. When specifying a transducer's focal length, it is typically specified for water. Since most materials have a higher velocity than water, the focal length is effectively shortened. This effect is caused by refraction (according to Snell's law) and is illustrated in Figure 18.

Fig. 18



This change in the focal length can be predicted by Equation 13.

For example, given a particular focal length and material path, this equation can be used to determine the appropriate water path to compensate for the focusing effect in the test material.

$$\text{Eqn. 13} \quad WP = F - MP(c_{tm}/c_w)$$

WP =	Water Path
MP =	Material Depth
F =	Focal Length in Water
$c_{tm}$ =	Sound Velocity in the Test Material
$c_w$ =	Sound Velocity in Water

In addition, the curvature of the surface of the test piece can affect focusing. Depending on whether the entry surface is concave or convex, the sound beam may converge more rapidly than it would in a flat sample, or it may spread and actually defocus.

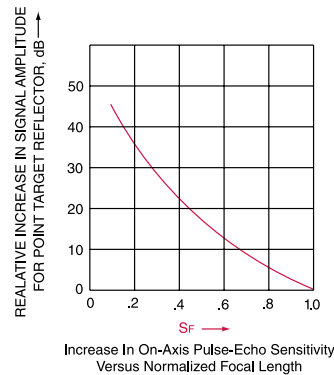
## Focusing Gain

Focused immersion transducers use an acoustic lens to effectively shift the location of the  $Y_0^+$  point toward the transducer face. The end result can be a dramatic increase in sensitivity. Figure 19 illustrates the relative increase in signal amplitude from small defects due to focusing where  $S_F$  is the normalized focal length and is given by Equation 14. The amplitude from a small defect cannot exceed the echo amplitude from a flat plate.

$$\text{Eqn. 14} \quad S_F = F/N$$

$S_F$ =	Normalized Focal Length
F =	Focal Length
N =	Near Field

Fig. 19



For example, the chart can be used to determine the increase in on-axis pulse-echo sensitivity of a 2.25 MHz, 1.0 in. element diameter transducer that is focused at 4 inches. The near field length of this transducer is 9.55 in., and the normalized focal length is 0.42 (4.0 in./9.55 in.). From the chart, it can be seen that this will result in an increase in sensitivity of approximately 21 dB.

Focusing gain (dB) for cylindrical focuses can be estimated as being  $\frac{3}{4}$  of the gain for spherical focuses.

## e. Normal Incidence Shear Wave Transducers

Normal Incidence Shear Wave transducers incorporate a shear wave crystal in a contact transducer case. Rather than using the principles of refraction, as with the angle beam transducers, to produce shear waves in a material, the crystal itself produces the shear wave.

Typically, these transducers are used to make shear velocity measurements of materials. This measurement, along with a longitudinal velocity measurement, can be used in the calculation of Poisson's Ratio, Young's Modulus, and Shear Modulus. These formulas are listed below for reference.

$$\text{Eqn. 15} \quad \sigma = \frac{1 - 2(V_T/V_L)^2}{2 - 2(V_T/V_L)^2}$$

$$\text{Eqn. 16} \quad E = \frac{VL^2\rho(1 + \sigma)(1 - 2\sigma)}{(1 - \sigma)}$$

$$\text{Eqn. 17} \quad G = V_T^2\rho$$

$\sigma$ =	Poisson's Ratio
$V_L$ =	Longitudinal Velocity
$V_T$ =	Shear (Transverse) Velocity
$\rho$ =	Material Density
E =	Young's Modulus
G =	Shear Modulus

Because shear waves do not propagate in liquids, it is necessary to use a very viscous couplant when making measurements with these. When using this type of transducer in a through-transmission mode application, it is important that direction of polarity of each of the transducers is in line with the other. If the polarities are 90° off, the receiver may not receive the signal from the transmitter.



# Technical Notes

## 5. Transducer Excitation Guidelines

As a general rule, all of our ultrasonic transducers are designed for single pulse negative spike or square wave excitation. The maximum spike and square excitation voltages should be limited to approximately 50 volts per mil of piezoelectric transducer thickness. Low-frequency elements are thick, and high-frequency elements are thin. A negative-going 600 volt fast rise time, short duration, spike excitation can be used across the terminals on transducers 5.0 MHz and lower in frequency. For 10 MHz transducers, the voltage used across the terminals should be halved to about 300 V as measured across the terminals. Normal incidence shear wave and very high-frequency transducers are special cases; they must be excited more gently to avoid damage.

Although negative spike excitation is recommended, continuous wave or tone burst excitations may be used. However, there are limitations to consider when using these types of excitation. First, the average power dissipation to the transducer should not exceed 125 mW to avoid overheating the transducer and depoling the crystal.

Since total average power depends on a number of factors such as voltage, duty cycle, and transducer electrical impedance, the following equations can be used to estimate the maximum excitation duration as well as the number of cycles in a burst to stay within the total power limitation:

$$\text{Eqn. 18} \quad V_{\text{rms}} = 1/2(0.707)V_{\text{p-p}}$$

$$\text{Eqn. 19} \quad P_{\text{tot}} = \frac{(\text{Duty Cycle})(V_{\text{rms}})^2 \cos(\text{phase angle})}{Z}$$

$$\text{Eqn. 20} \quad \text{No. of Cycles in a Burst} = \frac{(\text{Freq.})(\text{Duty Cycle})}{\text{Rep Rate}}$$

The following is an example of how to use the above equations to calculate a duty cycle and number of cycles for a V310-SU transducer.

**V310-SU Assuming:** 5.0M Hz, 0.25 in. element diameter, unfocused  
100 V peak-to-peak  
50 ohm nominal impedance at the transducer input impedance (Note: This value will vary from transducer to transducer and should be measured. An impedance plot can be ordered at the time of purchase if necessary.)  
-45° Phase Angle  
5 kHz Rep Rate

**Step 1:** Calculate  $V_{\text{rms}}$

$$V_{\text{rms}} = \frac{1}{2}(0.707)V_{\text{p-p}}$$

$$V_{\text{rms}} = \frac{1}{2}(0.707)(100) = 35.35 \text{ V}$$

Rearrange Equation 19 to solve for the Duty Cycle. Use 0.125 W as  $P_{\text{tot}}$ , as this is the maximum recommended for any transducer.

**Step 2:** Duty Cycle =  $Z \cdot P_{\text{tot}} / (V_{\text{rms}})^2 \cdot \cos(\text{phase angle})$   
 $= (50)(0.125) / (35.35)^2 \cdot \cos(-45^\circ)$   
 $= 0.007 \text{ s/s}$

This means 7 milliseconds of excitation in every 1000 milliseconds.

**Step 3:** Number of cycles in the burst can now be calculated from Equation 20.

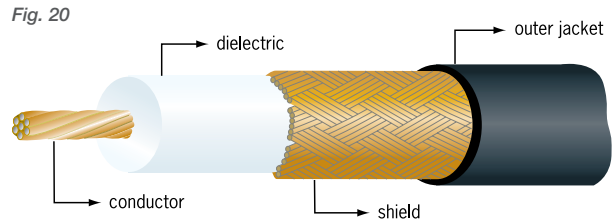
$$\text{No. Of Cycles in Burst} = (\text{Freq.})(\text{Duty Cycle}) \text{ Rep Rate}$$

$$= (5 \cdot 10^3) \cdot (0.007) / (5 \cdot 10^3)$$

$$= 7$$

## 6. Cables

The inside of a cable is made of three main components. They are the conductor, the dielectric, and shield/braid. These components are then surrounded by an outer protective jacket. Figure 20 shows a cross-sectional view of a typical cable. The conductor acts as the positive connection of the cable while the shield acts as the ground. The dielectric isolates the conductor from the shield.



Most cables have one shielding/braided layer. However, to better prevent electrical interference from the environment, double-shielded cables have an additional shielding/braided layer in contact with the other.

The following is a list of standard cable grades we offer:

Type	Grade	Impedance	Nominal Diameter
			in.
15	Low Impedance	15 ohms	0.11
25	Low Impedance	25 ohms	0.10
58	RG58/U	50 ohms	0.20
62	RG62/U	93 ohms	0.24
74	RG174/U	50 ohms	0.11
188	RG188/U	50 ohms	0.11
316	RG316/U	50 ohms	N/A

RG/U is the abbreviation for “radio guide, universal” in the military, “RG” is the designation for coaxial cable, and “U” stands for “general utility”. Most of the cables used in ultrasonic NDT have military RG numbers that define the materials, dimensions, and electrical characteristics of the cables.

The characteristic impedance of a coaxial cable is determined by the ratio for the inner diameter of the outer conductor (D) to the outer diameter of the inner conductor (d) and by the dielectric constant (E) of the insulating material between the conductors.

$$\text{Eqn. 21} \quad \text{Impedance } (Z_0) = \frac{138}{\sqrt{E}} \log(D/d) \Omega$$

The characteristic impedance can also be calculated from the capacitance (C) and the inductance (L) per unit length of cable.

$$\text{Eqn. 22} \quad \text{Impedance } (Z_0) = \sqrt{\frac{L}{C}}$$

The most common values for coaxial cables are 50 ohm, 75 ohm, and 95 ohm. Note that the actual input impedance at a particular frequency may be quite different from the characteristics impedance of the cable due to the impedance of the source and load. In ultrasonics, on transmit, the source is the pulser and the load is the transducer; on receive, the source is the transducer and the load is the receiver. The complex impedance of the pulser and the transducers will reflect some of the electrical energy at each end of the cable. The amount of reflection is determined by the length of the cable, the frequency of the RF signal, and the electrical impedance of the cable and its termination. In ultrasonic NDT, the effect of the cable is most practically determined by experimenting with the shorter and longer cables, with cables of differing impedance, and by placing a 50 ohm feed-through attenuator at the pulser/receiver jack.

## Near Field Distances of Flat Transducers in Water

Table 1 — Near Field Distance of Flat Transducers in Water

Frequency	Element Diameter	N	Focal Length (PTF)**	
			Min.	Max.
(MHz)	(in.)	(in.)	(in.)	(in.)
0.5	1.50	4.757	2.15	3.80
	1.125	2.661	1.50	2.10
	1.00	2.095	1.25	1.65
	0.75	1.164	0.78	0.93
1.0	1.50	9.559	2.50	7.65
	1.125	5.366	1.90	4.30
	1.00	4.235	1.625	3.38
	0.75	2.372	1.00	1.90
2.25	0.50	1.043	0.60	0.80
	1.50	21.534	2.70	14.50
	1.125	12.099	2.15	9.50
	1.00	9.554	1.875	7.60
	0.75	5.364	1.00	4.30
	0.50	2.374	0.80	1.90
	0.375	1.329	0.50	1.06
3.5	0.25	0.584	0.35	0.45
	1.00	14.868	1.95	11.5
	0.75	8.350	1.00	6.65
	0.50	3.699	0.83	2.95
	0.375	2.073	0.60	1.65
5.0	0.25	0.914	0.385	0.70
	1.00	21.243	1.95	14.40‡
	0.75	11.932	1.00	9.50
	0.50	5.287	0.75	4.20
	0.375	2.965	0.60	2.35
7.5	0.25	1.309	0.43	1.00
	0.75	17.900	1.00	12.75‡
	0.50	7.933	0.75	6.30‡
10	1.00	42.490	2.00	20.00‡
	0.75	23.868	1.00	15.375‡
	0.50	10.579	0.75	8.40‡
	0.375	5.934	0.60	4.75‡
	0.25	2.622	0.46	2.10
15	0.50	15.870	0.75	11.75‡
	0.375	8.902	0.60	7.10‡
	0.25	3.935	0.50	3.15‡
20	0.25	5.247	0.50	4.20‡
	0.125	1.290	0.25	1.00‡
25	-	6.559	0.50	5.25‡

\*\*Standard Case Style, Large-Diameter Case Style, Slim-Line Case Style, and Pencil Case Style Immersion Transducers with straight connectors (see "Immersion Transducers" in the Transducer Catalog) can be focused between the Minimum and Maximum Point Target Focal (PTF) distance limits listed in Table 1. Please consult Olympus before ordering a transducer focused outside these limits.

‡ Consideration should be given to attenuation effects that increase linearity and with the square of frequency and the square of bandwidth. In applications where long water paths are required, the effects of frequency-dependent attenuation should be checked per ASTM E 1065 Annex A7. It is advisable to consider the effects of frequency dependent attenuation if the focal distance equals or exceeds the following values:

The near field values in this table have been determined using the following equation:

$$N = \frac{D^2}{4\lambda} \left[1 - \left(\frac{\lambda}{D}\right)^2\right]$$

Note that equations 8 and 8a on page 4 were derived from this expression. The calculations were carried out assuming an ultrasonic velocity in water of  $0.586 \times 10^5$  in./s at 22 °C (71.6 °F) and using the actual transducer element diameters. It should be noted that the actual transducer element diameters are slightly smaller than the nominal element diameters listed in the tables in the catalog .

The minimum and maximum practical focal lengths have been calculated by considering the acoustic and mechanical limitations of each configuration. These limitations are a function of transducer frequency, element diameter, and case dimensions. There may be exceptions to the limits listed in the table.

Frequency	Focal Length
MHz	in.
5.0	13
7.5	6
10	3.5
15	1.5
20	0.8
25	0.5
30	0.4

# Acoustic Properties of Materials

Table 2 – Acoustic Properties of Materials

Material	Longitudinal Velocity		Shear Velocity		Acoustic Impedance (kg/m <sup>2</sup> s × 10 <sup>9</sup> )
	(in./μs)*	(m/s)	(in./μs)*	(m/s)	
Acrylic resin (Perspex)	0.107	2,730	0.056	1,430	3.22
Aluminum	0.249	6,320	0.123	3,130	17.06
Beryllium	0.508	12,900	0.350	8,880	23.5
Brass, naval	0.174	4,430	0.083	2,120	37.30
Cadmium	0.109	2,780	0.059	1,500	24.02
Columbium	0.194	4,920	0.083	2,100	42.16
Copper	0.183	4,660	0.089	2,260	41.61
Glycerine	0.076	1,920	—	—	2.42
Gold	0.128	3,240	0.047	1,200	62.60
Inconel	0.29	5,820	0.119	3,020	49.47
Iron	0.232	5,900	0.127	3,230	45.43
Iron, cast					
(slow)	0.138	3,500	0.087	2,200	25.00
(fast)	0.220	5,600	0.126	3,220	40.00
Lead	0.085	2,160	0.028	700	24.49
Manganese	0.183	4,660	0.093	2,350	34.44
Mercury	0.057	1,450	—	—	19.66
Molybdenum	0.246	6,250	0.132	3,350	63.75
Motor oil (SAE 20 or 30)	0.069	1,740	—	—	1.51
Nickel, pure	0.222	5,630	0.117	2,960	49.99
Platinum	0.156	3,960	0.066	1,670	84.74
Polyamide, (nylon, Perlon)					
(slow)	0.087	2,200	0.043	1,100	.40
(fast)	0.102	2,600	0.047	1,200	3.10
Polystyrene	0.092	2,340	—	—	2.47
Polyvinylchloride, PVC, hard	0.094	2,395	0.042	1,060	3.35
Silver	0.142	3,600	0.063	1,590	37.76
Steel, 1020	0.232	5,890	0.128	3,240	45.63
Steel, 4340	0.230	5,850	0.128	3,240	45.63
Steel, 302	0.223	5,660	0.123	3,120	45.45
Austenitic stainless steel, 347	0.226	5,740	0.122	3,090	45.40
Austenitic stainless Tin	0.131	3,320	0.066	1,670	24.20
Titanium, Ti 150A	0.240	6,100	0.123	3,120	27.69
Tungsten	0.204	5,180	0.113	2,870	99.72
Uranium	0.133	3,370	0.078	1,980	63.02
Water (20 °C)	0.058	1,480	—	—	1.48
Zinc	0.164	4,170	0.095	2,410	29.61
Zirconium	0.183	4,650	0.089	2,250	30.13

\* Conversion Factor: 1 m/s = 3.937 × 10<sup>-5</sup> in/μs  
 Source: Nondestructive Testing Handbook 2<sup>nd</sup> Edition Volume 7  
 Ultrasonic Testing ASNT 1991 ed Paul McIntire

**OLYMPUS SCIENTIFIC SOLUTIONS AMERICAS CORP.**  
**is certified to ISO 9001, ISO 14001, and OHSAS 18001.**

\*All specifications are subject to change without notice.  
 All brands are trademarks or registered trademarks of their respective owners and third party entities.  
 Olympus, Centrascan, Videoscanner, Sonopen, THRU-COAT, 38DL PLUS, and Atlas are registered trademarks, and OmniPC is a trademark of Olympus Corporation.  
 Microdot™ is a trademark of Tyco Electronics Corporation.  
 LEMO is a registered trademark of LEMO SA.  
 Copyright © 2019 by Olympus.

[www.olympus-ims.com](http://www.olympus-ims.com)

**OLYMPUS**<sup>®</sup>

**OLYMPUS CORPORATION OF THE AMERICAS**  
 48 Woerd Avenue, Waltham, MA 02453, USA, Tel.: (1) 781-419-3900  
 110 Magellan Circle, Webster TX, 77598, USA, Tel.: (1) 281-922-9300  
**OLYMPUS NDT CANADA INC.**  
 505, boul. du Parc-Technologique, Québec (Québec) G1P 4S9, Tel.: (1) 418-872-1155  
 1109 78 Ave, Edmonton (Alberta) T6P 1L8

For inquiries - contact  
[www.olympus-ims.com/contact-us](http://www.olympus-ims.com/contact-us)