

Ultrasound Physics Vocabulary Reference

Chapters 1–8 | Edelman, *Understanding Ultrasound Physics*, 4th Ed.

An In-Depth Review by Dr. Alice Matthews

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Chapters 1–2: Introduction to Sound & Wave Parameters

Term	Definition	Analogy / Example
Acoustic Variables	The three factors used to distinguish sound waves from other wave types: pressure (pascals), density (kg/cm^3), and distance (cm or mm).	If a variable like pressure oscillates rhythmically, the wave is a sound wave.
Amplitude	The maximum variation of an acoustic variable from the undisturbed (resting) value; relates to the strength or loudness of the wave.	The height of an ocean wave from the calm water line to the peak. A bigger amplitude = louder/stronger signal.
Compression	A region in a sound wave where molecules are squeezed together, creating high pressure and density.	When you push a Slinky, the coils bunch up at the push point--that crowded region is compression.
Constructive Interference	When a pair of in-phase waves combine to form a single wave with greater amplitude than either component.	Two people pushing a swing at the same time in the same direction--the swing goes higher.
Destructive Interference	When out-of-phase waves combine to form a wave with lesser amplitude.	Noise-canceling headphones use this principle to “cancel out” background sound.
Directly Proportional (Directly Related)	A relationship between two variables where an increase in one leads to a simultaneous increase in the other.	Clothing size is directly proportional to weight--as weight increases, clothing size increases.
Frequency	The number of complete cycles of a wave that occur in one second; measured in Hertz (Hz). In clinical imaging, frequency ranges from 2 to 15 MHz.	A hummingbird’s wings beat 80 times/sec = 80 Hz. Diagnostic ultrasound operates at 2--10 million Hz (MHz)--far above human hearing.
Intensity	The concentration of power (energy) over a given area; measured in W/cm^2 . Calculated as power divided by beam cross-sectional area.	A garden hose: put your thumb over the end to narrow the stream. Same power, smaller area = higher intensity.
Inversely Proportional (Inversely Related)	A relationship where an increase in one variable leads to a decrease in the other.	Golf score is inversely related to skill--as skill increases, score decreases.
Longitudinal Wave	A wave in which the particle motion is along the same direction as the propagation of the wave energy.	Imagine a Slinky on a table: when you push one end, the coils compress and expand along the same axis the wave travels.
Peak Intensity	The highest value of intensity within the ultrasound beam, typically found at the spatial peak.	The bullseye center of a flashlight beam where the light (energy) is most concentrated.
Peak-to-Peak Amplitude	The total variation from the maximum positive value to the maximum negative value of a wave cycle.	Measuring from the top of a wave crest down to the bottom of the trough--the full “swing” of the wave.
Period	The time required for one complete cycle of a wave to occur; measured in seconds or microseconds. Period is the reciprocal of frequency.	If frequency is “how many laps per hour,” period is “how long each lap takes.” High frequency → short period.

Term	Definition	Analogy / Example
Power	The rate at which energy is transferred by the sound wave; measured in Watts (W).	A lightbulb's wattage: a 100-watt bulb has more energy output than a 40-watt bulb.
Rarefaction	A region in a sound wave where molecules are stretched apart, resulting in low pressure and density.	The opposite of compression--like the spread-out coils behind the pushed section of a Slinky.
Reciprocal Relationship	A special form of inverse relationship where two numbers multiplied together equal one. Example: period and frequency are reciprocals.	10 and 1/10 are reciprocals ($10 \times 0.1 = 1$). If frequency doubles, period is cut in half.
Scientific Notation	A shorthand method for writing very large or very small numbers using powers of ten.	1,000,000 is written as 1.0×10^6 . This makes it easier to work with MHz and μ s values in ultrasound.
Sound (Sound Wave)	A mechanical, longitudinal wave that requires a medium to travel through. It cannot propagate in a vacuum. Sound carries energy by causing molecules to vibrate (compress and rarefy).	Think of dominoes falling in a line: each domino bumps the next, but the dominoes themselves don't travel--only the energy does.
Units	Standardized measurements used to make numerical values comprehensive and meaningful.	If someone asks how old you are and you say "6," it is incomplete without "years" or "decades."
Wavelength	The distance (length) that one complete cycle of a wave occupies in space; measured in millimeters.	Imagine a sound wave as a train; wavelength is the length of a single boxcar. Higher frequency = shorter wavelength = better resolution.

Chapter 3: Propagation of Sound Through Tissue

Term	Definition	Analogy / Example
Acoustic Impedance	The resistance of a tissue to the passage of sound; equal to the product of tissue density $\times$ propagation speed ($Z = \rho \times c$). Measured in Rayls.	Think of acoustic impedance as a tissue's "personality" regarding sound--it determines how much sound is reflected or transmitted at boundaries.
Density	The concentration of mass (matter) in a material; measured in kg/m^3 . Density and speed are inversely related.	A lead brick has higher density than a sponge of the same size--more "stuff" packed in. Mnemonic: Density and Speed start with different letters, so they go in different directions.
Medium	Any material through which sound can travel (e.g., soft tissue, bone, fluid, air). A vacuum is NOT a medium.	Water, muscle, liver, blood--all are media. Sound cannot travel through the vacuum of outer space.
Propagation Speed	The speed at which a sound wave travels through a medium; determined by the density and stiffness of the medium, NOT by the sound source. In soft tissue, approximately 1,540 m/s.	Sound travels faster through bone (4,080 m/s) than through soft tissue (1,540 m/s)--like how your voice carries differently through a wall vs. open air.
Stiffness (Bulk Modulus / Elasticity)	The ability of a material to resist compression. Stiffer materials have higher propagation speeds. Stiffness is the dominant factor affecting propagation speed.	A ping-pong ball is stiff and retains its shape, whereas a marshmallow compresses easily. Sound zips through steel much faster than through rubber. Mnemonic: Stiffness and Speed both start with "S" and go in the same direction.

Chapter 4: Pulsed Ultrasound

Term	Definition	Analogy / Example
Continuous Wave (CW)	Sound that is produced without interruption--the transducer transmits and receives simultaneously. Requires two separate crystals.	Like a referee blowing a whistle nonstop--no pauses. One crystal sends while the other listens.
Duty Factor	The fraction (percentage) of time that the transducer is actively transmitting sound. Duty factor = pulse duration / PRP. Diagnostic imaging has a very low duty factor (0.1--1%).	If you speak for 1 second and then listen for 99 seconds, your duty factor is 1%.
Pulse Duration	The actual "on" time or transmit time of a single pulse; the time from the start to the end of one pulse.	The time it takes for a train to roll past a railroad crossing--just the active transit time.
Pulse Repetition Frequency (PRF)	The number of pulses emitted by the transducer per second; measured in Hz or kHz.	If a lighthouse flashes 10 times per second, its PRF is 10 Hz. Shallow imaging = short wait = high PRF.
Pulse Repetition Period (PRP)	The time from the start of one pulse to the start of the next; the reciprocal of PRF. Includes both "on" and "off" time.	The time from the moment one train engine passes a crossing until the next train's engine arrives.
Pulsed Wave (PW)	Ultrasound that is transmitted in short bursts (pulses), with "listening" periods between transmissions. Used in diagnostic imaging.	Like clapping your hands (transmit), then cupping your ear to listen for an echo (receive), then clapping again.
Spatial Peak Intensity	The beam's intensity at the location where it is at its maximum value.	The very center of a flashlight beam where the light is brightest and most concentrated.
Spatial Pulse Length (SPL)	The physical length (in mm) of a pulse in space; equals the number of cycles in the pulse $\times$ wavelength. Determines axial resolution.	The physical length of a train from the locomotive to the caboose. A shorter SPL gives a more precise "bang" location = better axial resolution.

Chapter 5: Interactions of Ultrasound with Tissue

Term	Definition	Analogy / Example
Absorption	The process whereby sound energy is dissipated in a medium, primarily in the form of heat. The dominant cause of attenuation.	Friction: rubbing your hands together converts motion into heat. Sound energy is similarly "absorbed" by tissue and converted to thermal energy.
Attenuation	The progressive weakening of a sound wave as it travels through tissue; caused by absorption, reflection, and scattering. Measured in decibels (dB).	Like shouting across a field--the farther away you are, the quieter the sound gets. Or a light beam dimming as it passes through fog.
Decibel (dB)	A logarithmic unit used to report relative changes in signal strength (e.g., attenuation or amplification). A 3 dB change means intensity has doubled; -10 dB means one-tenth of the original.	The Richter scale for earthquakes is logarithmic similarly: a magnitude 7 quake is 100 times stronger than magnitude 5.
Half-Value Layer (HVL)	The thickness of tissue required to reduce the intensity of the ultrasound beam to half its original value.	If you stack blankets over a speaker, the HVL is however many blankets it takes for the sound to be half as loud.

Term	Definition	Analogy / Example
Logarithm	A mathematical method of rating numbers; the log of a number represents how many 10s are multiplied together to create that number.	$\log(100) = 2$ because $10 \times 10 = 100$. Decibels use logarithms to compress huge intensity ranges into manageable numbers.
Normal Incidence	When the sound beam strikes a tissue boundary at exactly 90 degrees (perpendicular). At normal incidence, no refraction occurs.	Throwing a ball straight at a wall (90°)--it bounces straight back. Angled throws cause the ball to deflect sideways.
Reflection	The return (bouncing back) of a portion of the sound wave when it strikes a boundary between two tissues with different acoustic impedances.	A mirror reflects light; a tissue boundary reflects sound. The greater the impedance mismatch, the stronger the reflection.
Refraction	The change in direction (bending) of a sound wave as it passes from one medium to another at an oblique angle, due to a change in propagation speed.	A straw appears “bent” in a glass of water--that’s light refracting. Sound bends similarly at tissue boundaries.
Scattering	The redirection of sound in multiple directions when the wave encounters a structure smaller than or comparable in size to the wavelength.	Throwing a tennis ball into a room full of pinball bumpers--the ball bounces unpredictably in many directions. This is how we image red blood cells and organ parenchyma.
Spatial Peak Intensity	The beam’s intensity at the location where it is at its maximum value.	The very center of a flashlight beam where the light is brightest and most concentrated.
Specular Reflection	Reflection from a large, smooth surface (relative to wavelength) that produces a strong, organized echo in one direction.	A calm lake acting as a mirror--smooth surface, clean reflection. Clinical examples: diaphragm, pericardium.
Temporal Average Intensity	The intensity averaged over the entire pulse repetition period (both transmit and receive time).	Like averaging your speed over an entire road trip, including stops--not just while driving.

Chapters 6–7: Transducers & Beam Characteristics

Term	Definition	Analogy / Example
Axial Resolution	The ability to distinguish two structures lying along the beam’s path (one in front of the other); determined by spatial pulse length. Shorter SPL = better axial resolution.	Two cars driving in the same lane, one behind the other--can you tell them apart? Shorter pulse = better axial resolution.
Backing Material (Damping Material)	Material placed behind the piezoelectric crystal to absorb rearward-directed sound energy and shorten the pulse length, thereby improving axial resolution.	A pillow behind a drum--it dampens the ringing so each “hit” is short and distinct.
Bandwidth	The range of frequencies contained within a transducer’s ultrasound pulse (highest minus lowest frequency). A short pulse = wide bandwidth.	A choir singing many notes at once has a “wide bandwidth” vs. one singer holding a single note (narrow bandwidth).
Far Field (Fraunhofer Zone)	The region of the beam beyond the near field where the beam diverges (spreads out). Lateral resolution degrades in this zone.	Past the flashlight’s focal point, the beam fans out and gets dimmer and less focused.
Focal Point / Focal Zone	The narrowest point of the ultrasound beam, where lateral resolution is best. Located at the transition from near field to far field.	The waist of an hourglass--the narrowest part, right where the near field transitions to the far field.
Lateral Resolution	The ability to distinguish two structures lying side by side, perpendicular to the beam; determined by beam width. Narrower beam = better lateral resolution.	Two cars driving side by side in adjacent lanes--can you tell them apart? Narrower beam = better lateral resolution.

Term	Definition	Analogy / Example
Matching Layer	A layer of material placed on the face of the transducer to reduce the acoustic impedance mismatch between the crystal and the skin, improving sound transmission into the body.	Like a translator between two people who speak different languages--the matching layer bridges the impedance gap so more sound enters the body.
Near Field (Fresnel Zone)	The region of the beam closest to the transducer where the beam converges (narrows). Best lateral resolution occurs at the end of the near field.	A flashlight beam that starts wide and narrows to a tight spot--that tight spot is the end of the near field.
Piezoelectric Effect	The property of certain crystals (e.g., PZT) to generate an electrical voltage when mechanically deformed, and to vibrate when an electrical signal is applied.	Squeezing a stress ball that lights up when compressed--mechanical force creates an electrical response, and vice versa.
Quality Factor (Q-Factor)	A unitless number representing the degree of damping; inversely related to bandwidth. Imaging transducers are "low-Q" because they use backing material to produce short pulses.	A bell with a long ring has a high Q-factor. Imaging probes are designed to ring briefly (low Q) for better resolution.
Transducer	A device that converts one form of energy into another. In ultrasound, it converts electrical energy into mechanical (sound) energy and vice versa via the piezoelectric effect.	A microphone (sound → electrical) and a speaker (electrical → sound) combined into one device.

Chapter 8: Range Equation & Image Display

Term	Definition	Analogy / Example
13-Microsecond Rule	In soft tissue (propagation speed $\approx 1,540$ m/s), it takes 13 μ s for sound to travel 1 cm round trip (go-and-return). This is the ultrasound machine's built-in "ruler."	If the go-return time is 26 μ s, the reflector is 2 cm deep. Every 13 μ s of delay = 1 cm of depth on the image.
B-Mode (Brightness Mode) / Gray-Scale Imaging	A display method in which returning echo amplitudes are represented as varying shades of gray, from black (no echo) to white (strongest echo). The basis for all gray-scale imaging.	Like a black-and-white photograph--different tissue "brightnesses" correspond to how strongly they reflect sound.
Color Doppler	A display mode that assigns colors (typically red and blue) to represent the direction and velocity of blood flow relative to the transducer.	A weather radar map: red = storms moving toward you, blue = moving away. Same concept applied to blood flow.
Range Equation	Distance to reflector = (propagation speed $\times$ time) / 2. The division by 2 accounts for the round-trip travel of the pulse.	If you shout at a cliff and the echo returns in 2 seconds, and sound travels 340 m/s: distance = $(340 \times 2) / 2 = 340$ meters.
Time-of-Flight (Go-Return Time)	The elapsed time from pulse creation to pulse reception; used in the range equation to determine the depth of a reflector.	Clap near a canyon wall and time the echo--the round-trip time is the go-return time.