Ultrasonic sensors are in available for the past many decades and these devices continue to hold huge space in the sensing market because of their specifications, affordability, and flexibility. As the automation industry has been progressing, the employment of ultrasonic sensors in multiple domains such as drones, EV vehicles is emerging. In the year 1914, Fessenden developed the first modern transducer employed in sonar where it can be able to find the items in water but not the direction of items. And then in the year, 1915 Langevin introduced the contemporary model of ultrasonic which resolved the problem of Fessenden. ultrasonic sensor definition, how it works, it's specifications, its integration with Arduino, and its advantages are explained clearly in this article. What is Ultrasonic Sensor? Ultrasonic sensors are electronic devices that calculate the target's distance by emission of ultrasonic sound waves and convert those waves into electrical signals. The speed of emitted ultrasonic waves traveling speed is faster than the audible sound. There are mainly two essential elements which are the transmitter and receiver. Using the piezoelectric crystals, the transmitter generates sound, and from there it travels to the target and gets back to the receiver component. To know the distance between the target and the sensor, the sensor calculates the amount of time required for sound emission to travel from transmitter to receiver. The calculation is done as follows: $D = 1/2\ T * C$ Where 'T' corresponds to time measured in seconds 'C' corresponds to sound speed = 343 measured in mts/sec Ultrasonic sensor working principle is either similar to sonar or radar which evaluates the target/object attributes by understanding the received echoes from sound/radio waves correspondingly. These sensors produce high-frequency sound waves and analyze the echo which is received from the sensor. The sensors measure the time interval between transmitted and received echoes so that the distance to the target is known. Ultrasonic Sensor Specifications Knowing the specifications of an ultrasonic sensor helps in understanding the reliable approximations of distance measurements. The sensing range lies between 40 cm to 300 cm. The response time is between 50 milliseconds to 200 milliseconds. The Beam angle is around 50. It operates within the voltage range of 20 VDC to 30 VDC Preciseness is ±5% The frequency of the ultrasound wave is 120 kHz Resolution is 1mm The voltage of sensor output is between 0 VDC – 10 VDC The ultrasonic sensor weight nearly 150 grams Ambient temperature is -250C to +700C The target dimensions to measure maximum distance is 5 cm × 5 cm Ultrasonic Sensor Arduino This section explains the interfacing of the ultrasonic sensor with an Arduino by considering HC-SR-04 where it explains the ultrasonic sensor pinout, its specifications, wiring diagram, and how the sensor with Arduino connection. The ultrasonic sensor pin diagram is: Ultrasonic Sensor Pin Diagram Vcc – This pin has to be connected to a power supply +5V. TRIG – This pin is used to receive controlling signals from the Arduino board. This is the triggering input pin of the sensor ECHO – This pin is used for sending signals to the Arduino board where the Arduino calculates the pulse duration to know the distance. This pin is the ECHO output of the sensor. GND – This pin has to be connected to the ground. The below picture shows the ultrasonic sensor block diagram for distance measurement. Ultrasonic Sensor Block Diagram The target's distance is calculated using an ultrasonic distance sensor and the output from the sensor is provided to the signal conditioning section and then is processed using an Arduino microcontroller. The results from the microcontroller are fed to the LCD display and then moved to a personal computer. The ultrasonic sensor can be connected to the servo motor to know the polar distance of the sensor up to 1800 rotations approximately. Working In general, an ultrasonic sensor has two sections which are the transmitter and receiver. These sections are closely placed so that the sound travel in a straight line from the transmitter to the target and travels back to the receiver. Making sure to have minimal distance between transmitter and receiver section delivers minimal errors while calculations. These devices are also termed ultrasonic transceivers because both the transmitter and receiver sections are combined in a single unit which considerably minimizes the PCB footprint. Here, the sensor operates as a burst signal and it is transmitted for some period. Later the transmission, there exists a silent period and this period is termed response time. The response time indicates that it is waiting for the reflected waves. The shape of the acoustic waves that leave the transmitter section resembles the same shape of the light emitted from a laser so beam angle and spread have to be measured. When the sound waves move away from the transmitter, the detection area increases vertically and sideways too. Because of the varying detection area, the coverage specification is considered either as beam angle/beamwidth other than the standard area of detection. It is more recommended to observe the beam angle pattern for the sensor whether it is the complete angle of the beam or the angle of variation corresponding to the straight line that forms a transducer. Mostly, a thin beam angle results in a higher detection range, and a broader beam angle corresponds to a lesser detection range. The transmitted/acoustic signals might find a hindrance or not. When there is any hindrance, the acoustic wave bounces back from the hindrance. This bounced signal is termed ECHO. This echo travels to the receiver. Then the received signal is either filtered or amplified and then transformed into a digital signal. With the time between transmission and reception of acoustic waves, the distance between the ultrasonic system and hindrance can be known. Let us consider an example to know the Ultrasonic sensor timing diagram. Consider HC-SR-04 ultrasonic sensor where we should provide trigger pulse. It produces a sound wave with a frequency of 40 kHz (corresponds to 8 pulses). This makes the ECHO pin to the HIGH state. The echo pin will stay in a HIGH state until and unless it receives the ECHO sound. Therefore, the echo pin width is calculated as the time for the sound to travel from an object and get back. From the time, the distance is measured and this is termed sound speed. The rangeability of HC-SR-04 is 2 cm – 400 cm. The below picture shows the timing diagram of HC-SR-04. Ultrasonic Sensor Timing Diagram Procedure to analyze the timing diagram: To the Trig pin, the trigger pulse should be supplied for at least 10 µsec. Then the device automatically transmits eight pulses of 40 kHz and waits for the rising edge to appear on the output pin. When the echo pin observed a rising edge, start the timer and observe the time required to appear falling edge at the echo pin. When the echo pin shows a falling edge, observe the timer count. The count of the timer indicates the time taken by the sensor for object detection and getting back from the object. As we know that $D = S * T$ D = Distance S = Speed T = Time Total distance is measured as = (343* Time at HIGH ECHO)/2 Note: '343' in the above formula indicates the sound speed in air medium considered at room temperature. The total distance is divided by 2 because the sound wave travels from the source to the object and then returns back to the source. The code for ultrasonic sensor with Arduino is explained as follows: Code to Measure Distance //defining pin numbers int trig = 9; // trigger pin connected to 9th pin in Arduino board int echo = 8; // echo pin connected to 10th pin in Arduino board // defining variables long timetaken; int distance; void setup() { pinMode (trig, OUTPUT); // sets the trigger pin as output mode pinMode(echo, INPUT); // sets the echo pin as input mode // initiating the serial communication Serial.begin(9600); } Void loop () { digitalWrite (trig, LOW); // clearing the trigger pin delayMS (2); digitalWrite (trig, HIGH); // sets the trigger pin to HIGH state for 10 µsec delayMS (10); digitalWrite (trig, LOW); timetaken = pulseIN(echo, HIGH); // calculates the time taken by pulse from echo pin distance = timetaken * 0.034/2; // measures the distance serial.print ("Timetaken:….") // prints the value on LCD display serial.println(timetaken); } Code to Filter Noise in Ultrasonic Sensor The result measured from the ultrasonic sensor comes with noise. In most situations, the noisy output causes unnecessary functionality in the device and shows errors too. The noise can be filtered out from output through the below approach. Try with multiple calculations (consider 2 trails) and sort the result in an array. Sort the stored array in ascending format. Filter the noise levels (the smallest and biggest 5 samples are termed to be noise and we can ignore those) Observe the average value of middle sample from 5th trial to 14th trial int trig = 9; int echo = 8; float filter_Array[20]; // defining array to store multiple data sample received from the sensor float distance; // stores the distance from ultrasonic sensor long timetaken; int distance; void setup() { pinMode (trig, OUTPUT); pinMode(echo, INPUT); } Void loop(); { for (int trial =0, trial < 20; trial++) { filter_Array[trial] = ultrasonicMeasure(); delay(30); // to eliminate } // initiating the serial communication Serial.begin(9600); } void loop () { digitalWrite (trig, LOW); // clearing the trigger pin delayMS (2); digitalWrite (trig, HIGH); // sets the trigger pin to HIGH state for 10 µsec delayMS (10); digitalWrite (trig, LOW); timetaken = pulseIN(echo, HIGH); // calculates the time taken by pulse from echo pin distance = timetaken * 0.034/2; // measures the distance serial.print ("Timetaken:….") // prints the value on LCD display serial.println(timetaken); } The above explains the functionality of the ultrasonic sensor with Arduino. Factors Influencing Ultrasonic Sensor A radar cross-section helps to know how well a target holds the ability to reflect ultrasonic waves and transmit them back. Slanting/curved objects scatter most of the ultrasonic signals those are transmitted towards the target and result in minimal echo response. Whereas the surfaces like smooth, flat, dense, and large provide strong echo responses. Minor targets or targets that moderately deflect sound such as human beings, animals and plants result in minimal sensing responses. In order to generate a higher sensing response, a flat target should be towards the sensor at a 900 angle. But, rigid/rough surfaces show larger angular deviations. The below picture shows the reflection pattern of ultrasonic waves depending on the shape of the target. Reflection Pattern As Per The Target Shape Advantages and Disadvantages of Ultrasonic Sensor In most of the domains, ultrasonic sensors are widely employed because of their advantages which are as follows: Advantages These devices are not impacted by the target's color. The device shows flexibility in its distance measurement range where it holds the capability of measuring in the range of a few centimeters to five meters. It provides consistent outcomes and shows high reliability. High precision device. The measurements can be made every second thus showing rapid refresh rates. Disadvantages Even though ultrasonic sensors employ versatile technology, there are a few limitations to be considered and those are: As sound speed is based on humidity and temperature, environmental circumstances might show an impact on the accuracy while measuring the distance. For minimal and embedded projects, ultrasonic sensors seem to be a not good option because these devices are large to integrate with small projects. These sensors will not function in a vacuum. The sensors will get dirt, wet and frozen which results in errors while measuring or the functionality gets impacted. Applications The applications of ultrasonic sensors are: Used in robotic sensing for positioning of robotic arms. Employed in washdown design for constantly noticing the filling level of objects on a conveyor belt. Used to detect objects. The diameter of the coil/roll can be known by ultrasonic sensors. Used to avoid a collision. Proximity detection. know more about PCB Design MCQs. Know more about MB1240 Ultrasonic Sensor Datasheet. Where are ultrasonic sensors used? The primary usage of ultrasonic sensors is proximity sensors where we can find these sensors in the anti-collision safeguarding domain and vehicle self-parking technologies. What is the range of the ultrasonic sensors? The operating frequency range of ultrasonic sensors is between 30 kHz – 500 kHz. Can ultrasonic waves hurt humans? When there is a long time of exposure to ultrasound waves, it results in symptoms such as headache, dizziness, and a few hearing problems. People can come across these symptoms when the ultrasound wave's frequency crosses 20 kHz. What can an Ultrasonic sensor detect? Ultrasonic sensors are used for the detection of distance for an extended range of targets irrespective of the target's surface, color, and shape. This is all the concept of ultrasonic sensors. Here the article has explained the ultrasonic sensor working principle, its specifications, integration with Arduino, and its applications. Know how the ultrasonic sensor gained prominence in IoT? Cross-section ultrasound image of a fetus Source: Phillips Health Care- iu22xMATRIX system Medical ultrasound falls into two distinct categories: diagnostic and therapeutic. Diagnostic ultrasound is a non-invasive diagnostic technique used to image inside the body. Ultrasound probes, called transducers, produce sound waves that have frequencies above the threshold of human hearing (above 20KHz), but most transducers in current use operate at much higher frequencies (in the megahertz (MHz) range). Most diagnostic ultrasound probes are placed on the skin. However, to optimize image quality, probes may be placed inside the body via the gastrointestinal tract, vagina, or blood vessels. In addition, ultrasound is sometimes used during surgery by placing a sterile probe into the area being operated on. Diagnostic ultrasound can be further sub-divided into anatomical and functional ultrasound. Anatomical ultrasound produces images of internal organs or other structures. Functional ultrasound combines information such as the movement and velocity of tissue or blood, softness or hardness of tissue, and other physical characteristics, with anatomical images to create "information maps." These maps help doctors visualize changes/differences in function within a structure or organ. Therapeutic ultrasound also uses sound waves above the range of human hearing but does not produce images. Its purpose is to interact with tissues in the body such that they are either modified or destroyed. Among the modifications possible are: moving or pushing tissue, heating tissue, dissolving blood clots, or delivering drugs to specific locations in the body. These destructive, or ablative, functions are made possible by use of very high-intensity beams that can destroy diseased or abnormal tissues such as tumors. The advantage of using ultrasound therapies is that, in most cases, they are non-invasive. No incisions or cuts need to be made to the skin, leaving no wounds or scars. Source: Terese Winslow Ultrasound waves are produced by a transducer, which can both emit ultrasound waves, as well as detect the ultrasound echoes reflected back. In most cases, the active elements in ultrasound transducers are made of special ceramic crystal materials called piezoelectrics. These materials are able to produce sound waves when an electric field is applied to them, but can also work in reverse, producing an electric field when a sound wave hits them. When used in an ultrasound scanner, the transducer sends out a beam of sound waves into the body. The sound waves are reflected back to the transducer by boundaries between tissues in the path of the beam (e.g. the boundary between fluid and soft tissue or tissue and bone). When these echoes hit the transducer, they generate electrical signals that are sent to the ultrasound scanner. Using the speed of sound and the time of each echo's return, the scanner calculates the distance from the transducer to the tissue boundary. These distances are then used to generate two-dimensional images of tissues and organs. An ultrasound transducer. During an ultrasound exam, the technician will apply a gel to the skin. This keeps air pockets from forming between the transducer and the skin, which can block ultrasound waves from passing into the body. Click here to watch a short video about how ultrasound works. Diagnostic ultrasound. Diagnostic ultrasound is able to non-invasively image internal organs within the body. However, it is not good for imaging bones or any tissues that contain air, like the lungs. Under some conditions, ultrasound can image bones (such as in a fetus or in small babies) or the lungs and lining around the lungs, when they are filled or partially filled with fluid. One of the most common uses of ultrasound is during pregnancy, to monitor the growth and development of the fetus, but there are many other uses, including imaging the heart, blood vessels, eyes, thyroid, brain, breast, abdominal organs, skin, and muscles. Ultrasound images are displayed in either 2D, 3D, or 4D (which is 3D in motion). The ultrasound probe (transducer) is placed over the carotid artery (top). A color ultrasound image (bottom, left) shows blood flow (the red color in the image) in the carotid artery. Waveform image (bottom right) shows the sound of flowing blood in the carotid artery. Functional ultrasound. Functional ultrasound applications include Doppler and color Doppler ultrasound for measuring and visualizing blood flow in vessels within the body or in the heart. It can also measure the speed of the blood flow and direction of movement. This is done using color-coded maps called color Doppler imaging. Doppler ultrasound is commonly used to determine whether plaque build-up inside the carotid arteries is blocking blood flow to the brain. Another functional form of ultrasound is elastography, a method for measuring and displaying the relative stiffness of tissues, which can be used to differentiate tumors from healthy tissue. This information can be displayed as either color-coded maps of the relative stiffness; black-and white maps that display high-contrast images of tumors compared with anatomical images; or color-coded maps that are overlayed on the anatomical image. Elastography can be used to test for liver fibrosis, a condition in which excessive scar tissue builds up in the liver due to inflammation. Ultrasound is also an important method for imaging interventions in the body. For example, ultrasound-guided needle biopsy helps physicians see the position of a needle while it is being guided to a selected target, such as a mass or a tumor in the breast. Also, ultrasound is used for real-time imaging of the location of the tip of a catheter as it is inserted in a blood vessel and guided along the length of the vessel. It can also be used for minimally invasive surgery to guide the surgeon with real-time images of the inside of the body. Therapeutic or interventional ultrasound. Therapeutic ultrasound produces high levels of acoustic output that can be focused on specific targets for the purpose of heating, ablating, or breaking up tissue. One type of therapeutic ultrasound uses high-intensity beams of sound that are highly targeted, and is called High Intensity Focused Ultrasound (HIFU). HIFU is being investigated as a method for modifying or destroying diseased or abnormal tissues inside the body (e.g. tumors) without having to open or tear the skin or cause damage to the surrounding tissue. Either ultrasound or MRI is used to identify and target the tissue to be treated, guide and control the treatment in real time, and confirm the effectiveness of the treatment. HIFU is currently FDA approved for the treatment of uterine fibroids, to alleviate pain from bone metastases, and most recently for the ablation of prostate tissue. HIFU is also being investigated as a way to close wounds and stop bleeding, to break up clots in blood vessels, and to temporarily open the blood brain barrier so that medications can pass through. Diagnostic ultrasound is generally regarded as safe and does not produce ionizing radiation like that produced by x-rays. Still, ultrasound is capable of producing some biological effects in the body under specific settings and conditions. For this reason, the FDA requires that diagnostic ultrasound devices operate within acceptable limits. The FDA, as well as many professional societies, discourage the casual use of ultrasound (e.g. for keepsake videos) and recommend that it be used only when there is a true medical need. The following are examples of current research projects funded by NIBIB that are developing new applications of ultrasound that are already in use or that will be in use in the future: 3D printing through the skin: Researchers at Duke University have developed a method to 3D print biocompatible structures through thick, multi-layered tissues. The approach entails using focused ultrasound to solidify a special ink that has been injected into the body to repair bone or repair soft tissues, for example. Initial experiments in animal tissue suggest the method could turn highly invasive surgical procedures into safer, less invasive ones. (Image on left courtesy of Junjie Yao (Duke University) and Yu Shrike Zhang (Harvard Medical School and Brigham and Women's Hospital)). Inducing a hibernation-like state: Researchers at Washington University in St. Louis used ultrasound waves directed into the brain to lower the body temperature and metabolic rates of mice, inducing a hibernation-like state, called torpor. The researchers replicated some of these results in rats, which, like humans, don't naturally enter torpor. Inducing torpor could help minimize damage from stroke or heart attack and buy precious time for patients in critical care. (Image on right courtesy of Yang et al./Washington University in St. Louis). A wireless, wearable ultrasound patch: A fully wireless ultrasound patch that can continuously track critical vital signals such as heart rate and blood pressure has shown promise in a small study in humans. Developed by researchers at the University of California San Diego, the patch could facilitate the remote monitoring of critical physiological functions in the comfort of a patient's home. (Image on left courtesy of Xu lab at UC San Diego.) High-quality imaging at home: Brigham and Women's Hospital researchers compared ultrasound scans acquired by experts with those taken by inexperienced volunteers, finding little difference in the image quality of the two groups. The unconventional approach of having patients take ultrasound images of themselves at home and share them with healthcare professionals could allow for remote monitoring and reduce the need for hospitalization. (Image on right courtesy of Duggan et al./Brigham and Women's Hospital). Reviewed December 2023 Bats use ultrasonic sound for navigation. Their ability to catch flying insects while flying full speed in pitch darkness is astounding. Their sophisticated echolocation permits them to distinguish between a moth (supper) and a falling leaf. About 800 species of bats grouped into 17 families. The ultrasonic signals utilized by these bats fall into three main categories. 1. short clicks, 2. Frequency-swept pulses, and 3. constant frequency pulses. There are two suborders, Megachiroptera and Microchiroptera. Megas use short clicks, Micros use the other two. Tongue clicks produce click pairs separated by about 30ms, with 140-430 ms between pairs. (Sales and Pye, Ultrasonic Communication by Animals). 10-60 kHz in frequency swept clicks. One kind of bat, the verspertilionidae, have frequency swept pulses 78 kHz to 39 kHz in 2.3 ms. Emits pulses 8 to 15 times a second, but can increase to 150-200/s when there is a tricky maneuver to be made. Waves can be categorized by their frequency and speed relative to the speed of sound. In acoustics and aerodynamics, terms such as infrasonic, subsonic, supersonic, hypersonic, and ultrasonic are used to describe different regimes of wave motion. Infrasonic and ultrasonic pertain primarily to sound waves outside the range of human hearing, while subsonic, supersonic, and hypersonic describe regimes of airflow relative to the speed of sound. In this article, we will explore each term in detail, discussing their definitions, physical characteristics, and practical implications in scientific and engineering contexts.Infrasonic, Subsonic, Supersonic, Hypersonic and Ultrasonic 1. Introduction: Infrasonic, Subsonic, Supersonic, Hypersonic and UltrasonicSound and fluid flows are governed by properties such as frequency, speed, and energy. In many scientific fields, the classification of waves into infrasonic, subsonic, supersonic, hypersonic, and ultrasonic helps define operational regimes and design constraints. These terms are used in disciplines ranging from acoustical engineering and seismology to aerospace and mechanical engineering. Understanding the differences between these regimes is essential for applications like earthquake detection, aircraft design, medical imaging, and industrial testing. 2. Definitions and Frequency Ranges 2.1 What Are Infrasonic Waves?Infrasonic waves are sound waves with frequencies below the range of human hearing, typically defined as waves with frequencies less than 20 Hz. While humans cannot perceive them, many animals, such as elephants and whales, use infrasonic communication. These waves can travel long distances with minimal attenuation, making them useful for monitoring natural and artificial phenomena. Sources of Infrasonic WavesNatural SourcesEarthquakes – Seismic activity generates low-frequency vibrations that travel through the Earth.Volcanic Eruptions – Erupting volcanoes release infrasonic waves that can be detected from thousands of kilometers away.Ocean Waves – Large waves produce infrasound, which propagates through the atmosphere.Severe Weather – Hurricanes, tornadoes, and thunderstorms generate infrasonic waves due to strong air pressure fluctuations.Animal Communication – Some animals, including elephants and whales, use infrasound to communicate over long distances.Man-Made SourcesExplosions – Nuclear tests, mining detonations, and industrial blasts produce infrasound.Machinery – Large turbines, engines, and industrial equipment emit low-frequency vibrations.Buildings and Bridges – Structural oscillations can generate infrasonic waves during movement or strong winds. Properties and CharacteristicsLong Wavelengths: Infrasonic waves have large wavelengths, allowing them to travel vast distances without significant energy loss.Low Attenuation: They penetrate obstacles more effectively than higher-frequency waves.Impact on Humans: Prolonged exposure to high-intensity infrasonic waves can cause discomfort, nausea, dizziness, or anxiety. 2.2 What Are Subsonic Waves/Flows?Subsonic waves refer to sound waves traveling at speeds below the speed of sound in a given medium. In aerodynamics, subsonic flow describes the movement of a fluid (usually air) around an object when the flow velocity is less than the speed of sound, which is approximately 343 m/s (1,235 km/h or 767 mph) in air at sea level.Subsonic flows are characterized by smooth, predictable motion with minimal shockwave formation, making them fundamental in aircraft design, weather patterns, and engineering applications. Characteristics of Subsonic FlowMach Number Less Than 0.8 – The Mach number (M) is the ratio of the object's speed to the speed of sound. Subsonic flow occurs when $M < 0.8$.Streamlined Airflow – Air moves smoothly around objects, with minimal turbulence.No Shockwaves – Unlike supersonic and hypersonic flow, subsonic movement does not produce shockwaves.Significant Viscous Effects – The effects of viscosity (fluid friction) are more pronounced, impacting boundary layers and drag. Subsonic Flow in AerodynamicsSubsonic aerodynamics plays a key role in aviation and vehicle design. Most commercial aircraft operate within the subsonic regime for efficiency and stability. Airfoil Design in Subsonic FlowRounded Leading Edge: Reduces air resistance and promotes smooth airflow.Cambered Shape: Enhances lift generation by directing airflow efficiently.Thicker Cross-Section: Helps maintain laminar flow, reducing drag. Subsonic Waves in AcousticsSubsonic waves in sound refer to low-frequency vibrations that move slower than the speed of sound. These waves are commonly used in:Structural Engineering: Detecting material fatigue and vibrations.Medical Imaging: Certain ultrasound applications use subsonic frequencies for diagnostics.Noise Control: Understanding and mitigating low-frequency noise in buildings and vehicles.Subsonic waves and flow are integral to fields ranging from aerodynamics to acoustics. Their smooth, predictable nature makes them essential in aviation, engineering, and environmental studies. Understanding subsonic behavior helps optimize aircraft design, enhance efficiency, and improve sound wave applications in various industries. 2.3 What Are Supersonic Waves/ Flows?Supersonic waves refer to sound waves or disturbances traveling faster than the speed of sound in a given medium. In aerodynamics, supersonic flow occurs when a fluid (usually air) moves at a speed greater than Mach 1 (the speed of sound, ~343 m/s or 1,235 km/h at sea level).Supersonic flows are commonly encountered in high-speed aircraft, missiles, and spacecraft. Unlike subsonic flow, supersonic flow generates shockwaves, significantly impacting aerodynamics and engineering design. Characteristics of Supersonic FlowMach Number Between 1 and 5 – Supersonic flow occurs at speeds between Mach 1 and Mach 5.Shockwaves Formation – When an object moves faster than sound, it compresses air, creating shockwaves that lead to sonic booms.Compressibility Effects – Air behaves as a compressible fluid, leading to changes in pressure, temperature, and density.Thin Shock Layers – A bow shock forms in front of a supersonic object, while expansion fans occur at certain points to adjust pressure differences.Flow Separation & Drag – Supersonic speeds cause an increase in wave drag, requiring specialized aircraft designs.Supersonic waves and flow play a crucial role in aerospace engineering, defense, and medical technology. Their high-speed nature requires specialized design considerations, from shockwave management to aerodynamic shaping. As technology advances, supersonic travel is expected to become more efficient and accessible. 2.4 What Are Hypersonic Waves/ Flows?Hypersonic waves refer to disturbances traveling at speeds greater than Mach 5 (five times the speed of sound). Similarly, hypersonic flow describes the movement of air or any fluid around an object traveling at extreme speeds, typically above Mach 5 (~6,175 km/h or 3,836 mph at sea level).At these speeds, air behaves differently than in subsonic or supersonic conditions, undergoing extreme compression, high-temperature effects, and chemical reactions. This makes hypersonic aerodynamics crucial in space exploration, military defense, and high-speed travel. Characteristics of Hypersonic FlowMach Number Greater Than 5 – Hypersonic flow occurs when an object's speed exceeds Mach 5.Intense Shockwaves – Shock layers become thinner and stronger, significantly affecting aerodynamic forces.High-Temperature Effects – Air molecules dissociate (break apart), leading to ionization and plasma formation.Extreme Drag and Heat Generation – Friction and shockwaves generate immense heat, requiring thermal protection systems (TPS).Air Chemistry Changes – Unlike supersonic flow, where air is relatively stable, oxygen and nitrogen molecules dissociate at hypersonic speeds, altering aerodynamic behavior.Hypersonic flow is a critical field in aerospace and defense, with applications in weapons, space exploration, and future air travel. While challenges like extreme heating and plasma formation exist, technological advancements continue to push the boundaries of hypersonic innovation.Read Here: Supersonic vs Hypersonic Flow 2.5 What Are Ultrasonic Waves?Ultrasonic waves are sound waves with frequencies above 20 kHz, which is beyond the hearing range of humans. Unlike infrasonic waves, which have low frequencies, ultrasonic waves are characterized by short wavelengths and high energy, making them useful in various industrial, medical, and scientific applications. Characteristics of Ultrasonic WavesHigh Frequency: Ultrasonic waves typically range from 20 kHz to several gigahertz (GHz).Short Wavelengths: Due to their high frequency, they have shorter wavelengths, allowing them to interact with small objects.Directional Propagation: Ultrasonic waves can be focused into narrow beams, making them useful for imaging and non-destructive testing.Reflection and Refraction: They exhibit strong echo effects, which is useful in sonar and medical ultrasound.Non-Audible to Humans: While humans cannot hear ultrasound, animals like bats, dolphins, and whales use it for navigation and communication. Types of Ultrasonic WavesLongitudinal Waves: Particles in the medium move parallel to the direction of wave propagation (used in medical ultrasound and industrial applications).Transverse Waves: Particles move perpendicular to wave propagation (occur in solids but not in fluids).Surface Waves: Travel along the surface of solids and are used in certain industrial applications.Ultrasonic waves have revolutionized multiple industries, from medicine and navigation to industrial quality control. Their high-frequency, non-invasive nature makes them an indispensable tool in modern technology. With advancements in ultrasonic imaging, sensing, and material testing, these waves will continue to drive innovation across multiple fields. 3. Physical Principles and Propagation 3.1 Sound Propagation in AirSound waves are longitudinal waves that propagate through a medium via pressure variations. The speed of sound in air depends on the temperature and composition of the air. At standard conditions (20°C), the speed of sound in air is approximately 343 m/s. 3.2 Wave Behavior in Different RegimesInfrasonic Waves: With very low frequencies, infrasonic waves are less affected by obstacles and can travel long distances. They often have lower attenuation in the atmosphere and can diffract around obstacles.Ultrasonic Waves: High frequencies lead to very short wavelengths, which means they can provide fine resolution in imaging but are more readily absorbed by the medium. They tend to have a limited propagation range in air compared to lower frequency sounds.Subsonic Flow: In fluid dynamics, subsonic flows involve speeds below the speed of sound, where compressibility effects are minimal. The flow is generally smooth and predictable.Supersonic Flow: Once an object exceeds the speed of sound, disturbances (such as pressure waves) cannot travel upstream, leading to shock waves. These shock waves cause abrupt changes in pressure, temperature, and density.Hypersonic Flow: At even higher speeds, the energy of the flow is high enough to cause significant heating and chemical reactions in the air. The shock wave stands very close to the vehicle, creating extreme conditions that influence both the aerodynamics and the structural integrity of the object. 4. Applications and Examples 4.1 Infrasonic ApplicationsEarthquake and Tsunami Detection: Seismologists use infrasound sensors to detect early warning signs of earthquakes and tsunamis. This helps in disaster preparedness and mitigation.Volcano Monitoring: Scientists track volcanic activity using infrasonic signals, which help predict eruptions.Military and Defense: Governments use infrasound detectors to monitor nuclear tests and missile launches.Medical Applications: Some researchers explore the effects of infrasound on the human body to diagnose conditions related to low-frequency vibrations.Animal Communication Studies: Biologists study how large animals, such as elephants, use infrasound to communicate and navigate. 4.2 Subsonic ApplicationsCommercial Aviation: Most commercial aircraft operate at subsonic speeds (e.g., cruising at Mach 0.8) for fuel efficiency and comfort.Wind Engineering: Understanding subsonic flows is essential in designing buildings and bridges.Automotive Aerodynamics: Car design often focuses on subsonic airflow to reduce drag and improve fuel efficiency.Drones and UAVs: Unmanned aerial vehicles (UAVs) designed for surveillance and reconnaissance often operate at subsonic speeds.Propeller-Driven Aircraft: Many military and civilian aircraft use subsonic flow principles for efficient propulsion. 4.3 Supersonic ApplicationsMilitary Aircraft: Fighters and bombers are designed to operate in the supersonic regime to intercept targets quickly.Supersonic Transport: The Concorde is a classic example of a supersonic airliner, despite its economic and operational challenges.Missiles: Many missiles travel at supersonic speeds to reduce interception time and increase effectiveness.Research Vehicles: Experimental aircraft like the X-15 have provided valuable data on supersonic aerodynamics.Medical Imaging: Shockwaves are used in extracorporeal shock wave lithotripsy (ESWL) to break kidney stones. 4.4 Hypersonic ApplicationsRe-entry Vehicles: Spacecraft re-entering Earth's atmosphere experience hypersonic flow and require robust thermal protection systems. For example, Space Shuttles & Capsules like the Apollo reentry module and SpaceX's Starship experience hypersonic flow upon atmospheric entry.Hypersonic Missiles: Next-generation weapons are being designed to travel at hypersonic speeds to evade current defense systems. For example, Hypersonic Cruise Missiles such as the U.S. ARRW (Air-Launched Rapid Response Weapon) are designed for precision strikes.Hypersonic Glide Vehicles (HGVs): Weapons like Russia's Avangard and China's DF-ZF travel at Mach 20, making them nearly impossible to intercept.Experimental Aircraft: Programs like NASA's X-43 and scramjet research explore hypersonic propulsion and aerodynamics.Future Commercial Travel: Although still experimental, hypersonic airliners are being researched for ultra-fast global travel. Companies like Venus Aerospace and Hermeus are developing hypersonic passenger planes to cut intercontinental travel to under an hour. 4.5 Ultrasonic ApplicationsMedical Imaging: Ultrasound technology is widely used in diagnostic imaging, such as fetal ultrasound scans.Nondestructive Testing: Industrial ultrasonic testing is used to detect flaws in materials and structures.Cleaning: Ultrasonic cleaners use high-frequency sound waves to remove contaminants from objects.Sensors: Ultrasonic sensors are common in robotics and automotive systems for distance measurement and object detection.Scientific Research: Ultrasound helps in biochemical and medical research by detecting molecular interactions. It is used in laboratories to study the elastic properties of materials.Infographics: Infrasonic, Subsonic, Supersonic, Hypersonic and Ultrasonic Waves The classification of waves and flows into infrasonic, subsonic, supersonic, hypersonic, and ultrasonic categories helps engineers and scientists tailor their designs and measurement techniques to the specific challenges of each regime. Infrasonic and ultrasonic waves describe sounds outside the human hearing range, with unique applications in environmental monitoring and medical imaging, respectively. Meanwhile, subsonic, supersonic, and hypersonic flows relate to how objects move through a medium like air, each presenting increasing levels of complexity in terms of shock waves, aerodynamic heating, and material demands.Understanding these distinctions is critical for developing safe and efficient technologies, whether it's designing a commercial jet, a stealth fighter, or a spacecraft re-entering Earth's atmosphere. As research continues to advance in these fields, the boundaries between these regimes will become even more important in pushing the limits of high-speed travel and innovative engineering solutions. Science Physics Matter & Energy ultrasonics, vibrations of frequencies greater than the upper limit of the audible range for humans—that is, greater than about 20 kilohertz. The term sonic is applied to ultrasound waves of very high amplitudes. Hypersound, sometimes called praetersound or microsound, is sound waves of frequencies greater than 1013 hertz. At such high frequencies it is very difficult for a sound wave to propagate efficiently; indeed, above a frequency of about 1.25 × 1013 hertz it is impossible for longitudinal waves to propagate at all, even in a liquid or a solid, because the molecules of the material in which the waves are traveling cannot pass the vibration along rapidly enough.Many animals have the ability to hear sounds in the human ultrasonic frequency range. A presumed sensitivity of roaches and rodents to frequencies in the 40 kilohertz region has led to the manufacture of "pest controllers" that emit loud sounds in that frequency range to drive the pests away, but they do not appear to work as advertised.Some ranges of hearing for mammals and insects are compared with those of humans in the table.Frequency range of hearing for humans and other selected animalsanimal frequency (hertz) low high humans 20 20,000 cats 100 32,000 dogs 40 46,000 horses 31 40,000 elephants 16 12,000 cattle 16 40,000 bats 1,000 150,000 grasshoppers and locusts 100 50,000 rodents 1,000 100,000 whales and dolphins 70 150,000 seals and sea lions 200 55,000 An ultrasonic transducer is a device used to convert some other type of energy into an ultrasonic vibration. There are several basic types, classified by the energy source and by the medium into which the waves are being generated. Mechanical devices include gas-driven, or pneumatic, transducers such as whistles as well as liquid-driven transducers such as hydrodynamic oscillators and vibrating blades. These devices, limited to low ultrasonic frequencies, have a number of industrial applications, including drying, ultrasonic cleaning, and injection of fuel oil into burners. Electromechanical transducers are far more versatile and include piezoelectric and magnetostrictive devices. A magnetostrictive transducer makes use of a type of magnetic material in which an applied oscillating magnetic field squeezes the atoms of the material together, creating a periodic change in the length of the material and thus producing a high-frequency mechanical vibration. Magnetostrictive transducers are used primarily in the lower frequency ranges and are common in ultrasonic cleaners and ultrasonic machining applications. By far the most popular and versatile type of ultrasonic transducer is the piezoelectric crystal, which converts an oscillating electric field applied to the crystal into a mechanical vibration. Piezoelectric crystals include quartz, Rochelle salt, and certain types of ceramic. Piezoelectric transducers are readily employed over the entire frequency range and at all output levels. Particular shapes can be chosen for particular applications. For example, a disc shape provides a plane ultrasonic wave, while curving the radiating surface in a slightly concave or bowl shape creates an ultrasonic wave that will focus at a specific point. Piezoelectric and magnetostrictive transducers also are employed as ultrasonic receivers, picking up an ultrasonic vibration and converting it into an electrical oscillation. One of the important areas of scientific study in which ultrasonics has had an enormous impact is cavitation. When water is boiled, bubbles form at the bottom of the container, rise in the water, and then collapse, leading to the sound of the boiling water. The boiling process and the resulting sounds have intrigued people since they were first observed, and they were the object of considerable research and calculation by the British physicists Osborne Reynolds and Lord Rayleigh, who applied the term cavitation to the process of formation of bubbles. Because an ultrasonic wave can be used carefully to control cavitation, ultrasound has been a useful tool in the investigation of the process. The study of cavitation has also provided important information on intermolecular forces. Understand the concept of sonoluminescence which is a phenomenon of turning sound into lightLearn how collapsing bubbles with sound can create sonoluminescence.See all videos for this articleResearch is being carried out on aspects of the cavitation process and its applications. A contemporary subject of research involves emission of light as the cavity produced by a high-intensity ultrasonic wave collapses. This effect, called sonoluminescence, can create instantaneous temperatures hotter than the surface of the Sun. The speed of propagation of an ultrasonic wave is strongly dependent on the viscosity of the medium. This property can be a useful tool in investigating the viscosity of materials. Because the various parts of a living cell are distinguished by differing viscosities, acoustical microscopy can make use of this property of cells to "see" into living cells, as will be discussed below in Medical applications. After reviewing this chapter, you should be able to do the following: Define ultrasound and describe its characteristics as a form of energy. Explain the principles of sound wave propagation, including frequency, wavelength, amplitude, and velocity. Describe the piezoelectric effect and how it is used in ultrasound transducers. Explain the difference between longitudinal and transverse waves and how they relate to ultrasound. Understand the concept of acoustic impedance and its effect on ultrasound imaging. Describe the interaction of ultrasound with tissue, including absorption, reflection, and scattering. This chapter introduces the fundamental principles of sound wave propagation, including frequency, wavelength, amplitude, and velocity and how these relate to ultrasound imaging. The chapter also covers the interaction of ultrasound with tissue, including absorption, reflection, and scattering. 1.3 Why Study Ultrasound? Ultrasound has a wide range of medical applications. These include its use in obstetrics (monitoring the progress of pregnancy), oncology (monitoring the growth of tumors), cardiology (visualizing heart function and physiology), and biopsy (guiding needles in various procedures) and as a rehabilitation modality. For example, today, an estimated 60–70% of pregnant women in the United States undergo ultrasound examinations during pregnancy. An estimated 250 million fetal ultrasound examinations are performed annually in the United States. The examination aims to assess fetal abnormalities, confirm the site of pregnancy within the uterus, and determine gestational age. Due to the increasing use of ultrasound in health care, most medical schools are transforming curricula to include medical ultrasound applications. In addition, most medical professions require successful completion of a Sonography Principles and Instrumentation (SPI) examination and some specialty examinations administered by the American Registry for Diagnostic Medical Sonography (ARDMS). The SPI examination requires a sound knowledge of the physical principles of ultrasound and imaging, which includes an understanding of the physics of ultrasound and imaging techniques. This requirement is appalling to most clinicians with no physics background. On the other hand, depending on the individual's interest, a specialty examination will be given in one or more of the following areas: abdomen, breast, echocardiography, obstetrics, gynecology, pediatric, vascular technology, or musculoskeletal ultrasound. Most hospitals recognize ARDMS credentials as requirements for clinical sonographers and physicians. Ultrasound images in medical imaging are generated from sound waves reflected from different tissues and organs and converted into electrical signals, which a computer processes to create an image displayed on a screen. This technology helps health care professionals visualize internal structures and diagnose medical conditions. To make it easier to understand the operation of a medical ultrasound machine, we will first discuss some basic physics principles. 1.4 Mechanical Vibrations and Waves A mechanical vibration is a back-and-forth motion. When vibrations affect the media around them, waves are generated. These waves transport energy from one point to another. If a single vibratory disturbance moves from one point to the other, it is called a pulse. A back-and-forth motion that occurs repeatedly is called a periodic motion. A mechanical wave requires a material medium (such as a solid, liquid, or gas) to propagate through; its speed depends on the properties of that medium. Mechanical waves fall into two classes: longitudinal and transverse waves. For a transverse wave, the displacement of the medium is perpendicular to the direction of the motion of the wave. In a longitudinal wave, the displacement of the medium is in the same direction as wave motion. One example of a longitudinal wave is sound. These waves are similar to the motion of a pulse on a slinky, as illustrated in Figure 1-1. Figure 1-1: Characteristics of a longitudinal wave on a slinky. 1.5 Characteristics of Sound Waves A sound wave comprises alternating regions of low and high pressures. The waveform is a sinusoidal wave function in which the crests and troughs represent high- and low-pressure regions, respectively, as shown in Figure 1-2. Figure 1-2: Characteristics of a longitudinal wave. 1.5.1 Amplitude and Wavelength The maximum displacement or height from the horizontal axis, the equilibrium position, is the amplitude (A) of the wave. The distance between two successive points in the same phase is the wavelength (λ). For example, the wavelength is the distance between neighboring peaks, neighboring troughs, or any two points where the wave returns to the same shape, as shown in Figure 1-3. Figure 1-3: Transverse wave characteristics. 1.5.2 Period and Frequency The time for one complete cycle is the period (T); it is related to the number of oscillations (complete cycles) per unit time, called the frequency (f), as follows: $T = 1/f$. The unit of frequency is the cycle/second = 1/s or s-1. One cycle per second = 1 hertz (Hz). 1.5.3 Wave Velocity The rate at which the waveform changes position with respect to time is called the velocity (v) of the wave. In mathematical form, $v = f\lambda$. The wave velocity depends on the characteristics of the medium in which it travels. The velocity has a unit of meters per second if the frequency (f) is in hertz and the wavelength (λ) is in meters. The speed of sound is fastest in solids, slower in liquids, and slowest in air. Sound does not travel through free space or vacuums due to the lack of a medium. 1.6 Audible and Ultrasound Waves Sound waves are classified into three categories based on their frequency: infrasonic, audible, and ultrasonic waves. Infrasonic waves: These are waves with frequencies of less than 20 Hz; they are not audible to the human ear. Various natural and man-made sources produce them, including earthquakes, volcanoes, thunderstorms, and industrial machinery. Animals such as elephants, whales, and alligators also produce these waves to communicate over long distances. Audible waves: These are sound waves with frequencies that the human ear can hear. The audible frequencies fall in the range of about 20 Hz to 20 kHz. The audible range of sound can vary between individuals due to various factors. Age is one factor that can affect a person's ability to hear some frequencies, as the ear's sensitivity decreases with age. For example, younger people are likely to hear sounds of up to 20 kHz, while older people mostly hear frequencies of far less than 20 kHz. Certain diseases and medical conditions, such as otitis media, otosclerosis, or Meniere's disease, can also affect a person's hearing ability. Additionally, individuals with hearing impairments or disabilities may have a reduced hearing range due to damage to the ear or nerve pathways involved in hearing. Ultrasonic waves (also called ultrasound): These are waves with a frequency of more than 20 kHz. Humans cannot hear ultrasound, but bats use these waves for navigation. However, medical professionals use these waves to examine or image the different parts of the human body, a practice also known as sonography. Medical ultrasound imaging typically uses the 3.5 to 20 MHz frequency range. 1.7 Quantifying Ultrasound The amount of sound energy flux per unit of time is called the sound intensity (I). For a point source generating sound with acoustic power (P), the intensity (I) at distance (r) from the source obeys the inverse square law: The acoustic power of an ultrasound wave is the quantity of energy generated per unit of time. The standard unit of acoustic power is the watt (W), and 1 watt = 1 joule per second. Therefore, the unit of sound intensity is W/m2. The intensity equation shows that sound intensity decreases as the square of the distance from the point source. We all know that sound loudness (ear perception of sound intensity level) decreases as we move away from the source, as illustrated in Figure 1-4. Figure 1-4: The intensity of a wave decreases inversely with the square of the distance from its source. The sound intensity level (also called the sound acoustic level) is commonly measured relative to the standard threshold of hearing intensity (Io) in decibels. A decibel is a dimensionless quantity (no units) represented as dB, which is based on the logarithmic scale. In mathematical form, the sound intensity level (ß) is expressed as where Io = 10-12 W/m2, which is the faintest audible sound intensity. 1.8 Propagation of Ultrasound Through Tissues Clinicians examine body tissue structures using ultrasound waves with 2 to 20 MHz frequencies. Inside the tissue structures, the waves propagate through the medium by vibrating molecules of the medium. In soft tissues, the propagation velocity is relatively constant at 1540 m/s. This velocity value is used by ultrasound machines for all human tissue. Ultrasound waves propagating through tissue undergo reflection, refraction, attenuation, scattering, and diffraction. 1.8.1 Reflection Like any wave, ultrasound waves are reflected at tissue boundaries and interfaces. The transducer detects these reflected waves, and piezoelectric signals are generated and processed into an image form via a computerized processing unit. These signals form the basis of all ultrasound imaging. The number of reflected waves detected by the transducer depends on the angle of incidence at the band boundary and the difference in acoustic impedance between the two tissues traversed by the beam. More details about the acoustic impedance will be discussed later. However, it represents the resistance of a tissue to the passage of ultrasound. Typically, a propagating ultrasound wave is split into two components, as Figure 1-5 illustrates. If the wave traverses from medium 1 (with acoustic impedance Z1) to medium 2 (with acoustic impedance Z2), the reflection coefficient is where θi is the angle of incidence, θr is the reflected angle, and θt is the angle of transmission. Pr and Pi represent the reflection and incident probability amplitudes, respectively. Figure 1-5. Ultrasound reflection at the boundary between two tissues with different acoustic impedances. Reflections can also be classified into two categories: specular and diffuse, as illustrated in Figure 1-6. Figure 1-6: Different types of ultrasound reflections. The ultrasound beam that succeeds in penetrating the boundary layers or interface is called the transmitted wave. The transmission coefficient is mathematically expressed in the following form (refer to Figures 1-5 and 1-7): where Pt represents the transmission probability amplitude. The ratio of the speed of the transmitted wave (v2) to that of the incident wave (v1) is related to the ratio of the sines of the angles of transmission and incidence, a relationship called Snell's law: When the waves are reflected from a perfectly flat surface or boundary, the reflected waves tend to be uniformly parallel to each other. In contrast, they tend to be diffuse for rough surfaces. This phenomenon is commonly observed as a "mirage" when driving on a hot summer day, and the road appears to have a wet surface that disappears as one gets closer. This leads to two different kinds of reflections, specular and diffuse, which are illustrated in Figure 1-6. The transducer picks up the reflected waves and converts the echoes into images. The strength of the echoes depends on the acoustic impedance between the two tissues through which the waves pass. Typically, boundary reflections occur on blood vessel walls and organ boundaries. Figure 1-7: The ultrasound beam from the transducer undergoes reflection, refraction, and absorption as the beam penetrates the tissue. 1.8.2 Refraction When an ultrasound beam strikes a tissue boundary obliquely, the transmitted component of the beam undergoes a change in direction. This change is due to the differences in the velocities of the incident and transmitted beams. This bending process, called refraction, is illustrated in Figure 1-8 and is often related to the formation of artifacts during ultrasound image acquisition. Figure 1-8: Ultrasound refraction at surface boundaries. In ultrasound imaging, refraction can result in the formation of artifacts such as double image artifacts, as shown in Figure 1-9. This artifact is caused by the differential refraction of the ultrasound beam while passing through the relatively different echogenic tissues, such as muscle and fat tissues, and the difference in velocities in those tissues. Figure 1-9: The figure on the left illustrates how a double image artifact is formed, and the one on the right is the actual double image artifact of an aorta on an ultrasound image. Aorta duplication artifact by Nevit Dilmen licensed under CC BY-SA 3.0 1.8.3 Scattering Inside the human body, scattering is mostly a result of small changes in the density, compressibility, and absorption properties of the tissues. Ultrasound scanners detect these scattered waves to show the backscattered signal in the form of images. Scattered waves are primarily caused by red blood cells, or erythrocytes, due to their relatively small diameter of 6–8 µm, compared to the commonly used ultrasound wavelength of about 0.8 mm. For ultrasound frequencies below 20 MHz, the backscattering signal from blood is about 10 to 27 dB lower than from the surrounding tissue. This difference makes it possible to image the blood flow inside the tissue. 1.8.4 Absorption As the ultrasound beam traverses the tissue structures, it also loses energy through absorption. The lost energy varies depending on the tissue's characteristics and the ultrasound wave's frequency. For example, bones absorb more ultrasound energy than soft tissue does. Absorption of ultrasound in tissue is frequency dependent—it increases with increasing frequency. 1.8.5 Attenuation As the ultrasound moves through tissues, some of the ultrasound energy is lost due to absorption through heat, reflection, refraction, and scattering. The beam weakens with increased depth into the tissue, increasing acoustic impedance mismatch. Another factor is the presence of air bubbles inside the tissue, which tend to form virtually impenetrable barriers to ultrasound. Attenuation becomes higher not only with increasing distance from the transducer but also because of the heterogeneity caused by acoustic impedance mismatch as well as the higher frequency of the transducer, as illustrated in Figure 1-10. This is because air has a higher resistance to ultrasound propagation than fluids. The intensity (Ix) of an ultrasound beam at tissue depth x can be estimated using Beer's law: where Io is the incident intensity at the tissue surface and µ is the intensity attenuation coefficient. Of this attenuation, absorption contributes about 60–80%. Figure 1-10: An illustration of attenuation at multiple tissue boundaries. Attenuation increases with increasing gas and fat. The higher the tissue density (or impedance), the lower the reflection. For example, blood has an attenuation coefficient value closer to 0.20 dB/MHz.cm, while the typical value for bone is around 20.0 dB/MHz.cm.2 Attenuation generally increases linearly with increasing frequency among different body tissues. Fluid-filled structures have much lower attenuation than solid structures. Hence the transmitted pulse from a fluid-filled structure is usually more substantial than that from passing through an equivalent amount of solid tissue. 1.8.6 Diffraction The ultrasound beam spreads out with distance from the transducer as it passes through the tissue, causing diffraction, as shown in Figure 1-11. This results in the reduction of beam intensity. This diffraction pattern is highly dependent on the shape and size of the transducer relative to the wavelength of ultrasound. This phenomenon causes a decrease in the intensity of the ultrasound beam. To achieve a parallel beam, the diameter of the crystal face is designed to be approximately 10 to 20 times the wavelength of ultrasound. Figure 1-11:

Schematic of an ultrasound diffraction. 1.8.7 Acoustic Impedance Acoustic impedance (Z) is the resistance of a tissue to the passage of ultrasound. It depends on the density of the tissue (ρ) and the velocity of propagation (v) of the ultrasound through the tissue: $Z = \rho v$. If the density is in kg/m3 and the velocity is in m/s, then the specific acoustic impedance is expressed in the unit of rayl (Ry), which is equivalent to 1 kg/(m2s). A typical value of acoustic impedance is 0.0004 rayls for air, 1.65 rayls for the liver and blood, and around 5 rayls for the bone. The greater the difference between two tissues (media), the more the ultrasound is reflected and the lesser the transmission through the tissue. For example, more ultrasound beams will be reflected at soft tissue / bone and soft tissue / air interfaces than at soft tissue / blood interfaces. The difference in acoustic impedance is called acoustic impedance mismatch. A greater acoustic mismatch results in a greater reflection and a lower transmission. What are the three different classifications of sound waves? To which frequencies do each classification of sound waves correspond? What different processes can ultrasound waves undergo as they pass through the body and tissues? How is acoustic impedance defined? Nelson TR, Fowlkes JB, Abramowicz JS, Church CC. Ultrasound biosafety considerations for the practicing sonographer and sonologist. J Ultrasound Med. 2009 Feb;28(2):139–50. doi: 10.7863/jum.2009.28.2.139. PMID: 19168764. Jensen JA. Estimation of blood velocities using ultrasound: A signal processing approach. New York: Cambridge University Press; 1996. 317 p. Ter Haar G. Ultrasonic imaging: Safety considerations. Interface Focus. 2011 Aug 6;1(4):686–97. doi: 10.1098/rsfs.2011.0029. Epub 2011 May 25. PMID: 22866238; PMCID: PMC3262273. Goss SA, Johnston RL, Dunn F. Comprehensive compilation of empirical ultrasonic properties of mammalian tissues. J Acoust Soc Am. 1978 Aug;64(2):423–57. doi: 10.1121/1.382016. PMID: 361793. An ultrasound scan is used to see images of the inside of your body, such as muscles, organs, or a baby in your womb. It's usually done in hospitals or clinics. You might be referred for an ultrasound scan to:investigate symptoms you've had, such as pain or a lumpmonitor a condition, such as a problem with your thyroidhelp a health professional see inside your body during a procedure, such as injecting a steroid into a jointcheck your baby's development during your pregnancy Find out more about ultrasound scans in pregnancy The hospital or clinic should tell you if there's anything you need to do before having an ultrasound scan.For example, a short time before the test you might need to:drink a few glasses of water, without going to the toilet, so you have a full bladderremove jewellery or piercings from the area being scanned Let the person doing the ultrasound scan know if you'd like someone else to be in the room with you (a chaperone). This could be someone you know, or a member of staff. An ultrasound scan can take around 10 to 45 minutes, but it might take longer.A healthcare professional will do the scan. There might also be a nurse or healthcare assistant in the room.2 common ways an ultrasound scan is done are:an external ultrasound, where a device called a probe is moved across your skin on the part of your body being scannedan internal ultrasound, where a tube-shaped probe is put inside your vagina (this is sometimes called a pelvic or transvaginal ultrasound) or your bottomAn ultrasound probe can also be attached to an endoscope, which is a thin tube that's passed into your food pipe (oesophagus) to give your doctor a clearer picture of things such as your heart or stomach.Before the ultrasound scanYou might need to undress behind a screen or in a changing room and put on a hospital gown. Sometimes you can just move your clothing out of the way for the scan.During the ultrasound scanYou might be asked to lie or sit on a flat bed next to a machine with a screen.The healthcare professional will put a slippery gel on your skin on the part of your body being scanned. Paper towel might be put around the area, to soak up excess gel.The lights might be dimmed to help them see images on the screen.The healthcare professional will move the probe over the area covered in gel. You might need to change position during the test.They might stop to make notes or take measurements on the screen.When the scan is finished, you can wipe off the gel with paper towel and get dressed. An external ultrasound scan involves a probe being moved over your skin. During an internal ultrasound scanYou might be asked to lie on a bed with your knees apart or lie on your side. You might need to change position during the test.You may have a sheet or paper towel to cover yourself.The healthcare professional will gently put a smooth, tube-shaped probe with a latex cover into your vagina or bottom. Tell them if you have a latex allergy so they can use an alternative for you. Lubricant is used to make this more comfortable. You can ask to insert the probe yourself if you want to.The lights might be dimmed to help them see images on the screen.The healthcare professional will gently move the probe and might need to press on your tummy.They might stop to make notes or take measurements on the screen.When the scan is finished, you can wipe off the lubricant with paper towel and get dressed. You're in control of the scan and can ask the person doing your scan to stop at any time. An internal or pelvic ultrasound scan involves a probe being put inside your vagina or bottom. You may get the results of your ultrasound scan at the end of your appointment, or it can take a few weeks, depending on why you had the scan.Your result will be sent to the doctor who referred you for the ultrasound scan. You might need a follow-up appointment with your doctor to discuss your results.If you have not heard anything after a few weeks, contact the specialist or your GP surgery about your results and what happens next.Sometimes you might need other tests, depending on why you had the ultrasound scan.If you had a routine ultrasound during pregnancy, a report about the scan will usually be added to your maternity notes.Talk to a healthcare professional if you have questions about your results or do not understand them. The sound waves used in ultrasound scans are safe. Ultrasound scans do not use any radiation, unlike in X-rays or CT scans.The probe used for an external ultrasound scan does not usually cause any pain as it's moved across your skin. But it might be uncomfortable if it's pressed on an area that's already painful, such as a swollen joint.Internal ultrasound probes can be uncomfortable when they're put inside your body or moved during the test. Tell the person doing the scan if you feel pain and they will help you feel more comfortable. Page last reviewed: 25 February 2025 Next review due: 25 February 2028 Ultrasound refers to sound waves with frequencies higher than the upper limit of human hearing, above 20,000 hertz. It is widely used in medical imaging to visualize internal structures of the body. On the other hand, ultrasonic pertains to any sound wave beyond the range of human hearing, encompassing both audible and inaudible frequencies.Ultrasound refers to using sound waves above the range of human hearing to produce images of internal body structures. In contrast, ultrasonic refers to using high-frequency sound waves for various applications, including medical imaging, cleaning, and welding.Ultrasound is commonly used for medical diagnosis and monitoring, while ultrasonic is used in various industrial and scientific applications.Ultrasound requires specialized equipment and training, while ultrasonic applications vary widely in complexity and accessibility.Ultrasound is used to describe a medical imaging technique that uses high-frequency sound waves to produce images of internal organs and tissues. Ultrasonic is a term which means the use of high-frequency sound waves in applications such as cleaning, measuring distance, and detecting objects.Diagnostic ultrasound, known as sonography as well as diagnostic and interventional sonography, is a type of scanning that employs high-frequency sound waves to create images of things inside the body. The images can be used to help diagnose and treat a wide range of diseases and disorders.Ultrasonic testing (UT) refers to a class of non-destructive testing (NDT) methods, including the passage of ultrasonic waves through such an object or surface. Very high-frequency sound vibrations are delivered into components to evaluate the substance or find flaws.FeatureUltrasoundUltrasonicMeaning1. Sound waves with frequencies higher than the upper limit of human hearing (above 20 kHz). 2. The application of these sound waves for various purposes (e.g., medical imaging, cleaning)Refers to anything related to sound waves with frequencies above 20 kHzFrequency RangeAbove 20 kHz (can vary depending on application)Above 20 kHzApplications– Medical imaging (ultrasound scans) – Cleaning (ultrasonic cleaners) – Material testing (NDT) – Animal communication (e.g., bats)– All applications of ultrasound (listed above) – Additional applications like welding, humidification, and pest control (may use different frequencies)FocusCan refer to the sound waves themselves or their applicationRefers specifically to the sound wavesPin This Now to Remember It Later Pin This Ultrasound, also known as sonography, is a medical imaging technique that utilizes high-frequency sound waves to produce images of the internal structures of the human body. This non-invasive and radiation-free imaging method has a wide range of applications, ranging from diagnostic purposes to monitoring fetal development during pregnancy.Also Read: kVA vs kW: Difference and ComparisonUltrasound imaging involves the use of a transducer, a device that emits high-frequency sound waves. These waves are inaudible to the human ear, with frequencies above 20,000 hertz. The transducer converts electrical energy into sound waves, which are then directed into the body.When these sound waves encounter tissues and organs within the body, they are partially reflected back to the transducer. The reflected waves, or echoes, are then converted into electrical signals by the transducer. The system analyzes the time taken for the echoes to return, and this information is used to create detailed images of the internal structures.Ultrasound is widely employed for diagnostic purposes in various medical specialties. It is commonly used to visualize the organs in the abdomen, such as the liver, kidneys, and gallbladder. Additionally, ultrasound is valuable in assessing the cardiovascular system, muscles, joints, and soft tissues.One of the most well-known applications of ultrasound is in obstetrics and gynecology. It plays a crucial role in monitoring fetal development during pregnancy, providing detailed images of the fetus and the uterus. Ultrasound is also utilized for evaluating the female reproductive system, detecting abnormalities, and assisting in fertility treatments.In some cases, ultrasound is used in conjunction with medical procedures. This includes guiding needle biopsies, draining fluid from cysts, and aiding in the placement of catheters or drainage tubes. The real-time imaging capabilities of ultrasound make it a valuable tool in minimally invasive interventions.Also Read: Leeks vs Shallots: Difference and ComparisonNon-Invasiveness: Ultrasound imaging is non-invasive, avoiding the need for surgical procedures or radiation exposure.Real-Time Imaging: The ability to provide real-time images allows for dynamic observations during medical procedures.Cost-Effective: Compared to other imaging modalities, ultrasound is more cost-effective.Limited Penetration: Ultrasound waves have limited penetration through bone and air, which may hinder imaging in certain areas.Operator Dependency: The quality of ultrasound images can be operator-dependent, relying on the skill and experience of the sonographer.Limited Resolution in Obese Patients: Images may be of lower resolution in patients with excessive body weight.Ultrasonics refers to a branch of science and technology that deals with the study and application of ultrasound waves. Ultrasound is a form of acoustic wave with a frequency higher than the upper limit of human hearing, above 20,000 hertz (Hz). This technology finds widespread use in various fields, ranging from medical diagnostics and imaging to industrial applications and cleaning processes.At its core, ultrasonics relies on the principles of sound wave propagation. Ultrasonic waves are mechanical vibrations that travel through a medium, air or water. The key characteristic of ultrasound is its high frequency, allowing for shorter wavelengths and more precise interactions with materials. The wave propagation involves the creation of compressions and rarefactions, leading to the generation of pressure waves.In the realm of medicine, ultrasonics plays a pivotal role in diagnostic imaging. Ultrasound devices use high-frequency sound waves to produce real-time images of internal structures within the human body. This non-invasive technique is widely employed for imaging organs, monitoring fetal development during pregnancy, and guiding minimally invasive procedures.Also Read: Croup vs Whooping Cough: Difference and ComparisonUltrasonic technology finds extensive use in various industrial applications. One notable area is non-destructive testing (NDT), where ultrasonic waves are utilized to inspect the integrity of materials without causing damage. Additionally, ultrasonic cleaners employ high-frequency waves to remove contaminants from surfaces, making them effective in industries such as electronics and precision manufacturing.Ultrasonic sensors are devices that use the principles of ultrasonics for distance measurement and object detection. These sensors emit ultrasonic waves and measure the time it takes for the waves to bounce back after hitting an object. The information is then used to calculate the distance to the object, making ultrasonic sensors valuable in robotics, automotive parking systems, and industrial automation.In ultrasonics, cavitation refers to the formation, oscillation, and collapse of microscopic bubbles in a liquid. This phenomenon is harnessed for ultrasonic cleaning processes. Ultrasonic cleaners use the energy generated by cavitation to remove dirt and contaminants from various surfaces, making them efficient tools in cleaning delicate items like jewelry, surgical instruments, and electronic components.While ultrasonics offer numerous advantages, there are limitations and considerations to keep in mind. The effectiveness of ultrasound waves can be influenced by factors such as the medium through which they travel, temperature, and the presence of obstacles. Additionally, the potential for tissue heating in medical applications requires careful monitoring and control to ensure patient safety.Main Differences Between Ultrasound and UltrasonicUltrasound:Refers to sound waves with frequencies higher than the upper limit of human hearing (above 20,000 Hz).Used in medical imaging, industrial testing, and cleaning applications.Can be audible or inaudible, depending on the frequency.Human ears cannot detect ultrasound waves.Ultrasonic:Specifically pertains to sound waves with frequencies above the audible range, above 20,000 Hz.Primarily used for medical imaging, industrial cleaning, pest control, and various sensing applications.Commonly employed in non-destructive testing and measurement.Ultrasonic waves are beyond the hearing range of humans.References