# Ultrasonic waves

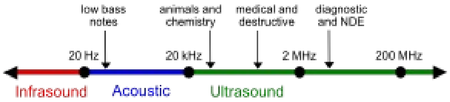
## Ultrasonic waves

Ultrasound is a **mechanical wave** with a frequency **greater than 20 kHz** , i.e. exceeding the upper level of audibility. It is therefore inaudible to humans. However, it is audible to a number of animals (e.g. dogs, dolphins, bats). They do not differ in properties from audible sound and infrasound.

### Perception of ultrasound

#### With people

The human ear is unable to perceive ultrasound, which is caused by the anatomical-physical limitations of the middle and inner ear. The upper limit of audibility generally decreases with increasing age. In children, it can rarely even exceed the 20 kHz limit. An auditory sensation from an ultrasound wave can arise in the cochlea when the wave passes directly through the bone ( bone conduction ) without passing through the external auditory canal or middle ear cavity.



Approximate distribution of ultrasonic waves

#### In animals

Generally speaking, there are many species of animals, mostly nocturnal, that use ultrasonic waves for orientation in reduced visibility (echolocation). Some species have an upper limit of audibility of almost 180 kHz (i.e. in the ultrasonic range). Ultrasonic, **high-frequency whistles** are used, for example, in dog training.

### Physical essence

From the source, ultrasound propagates through the environment as a wave, which is divided into longitudinal waves, when the particles move in the direction of wave propagation, and transverse waves, when the particles oscillate perpendicular to the direction of wave propagation , according to the direction of oscillation of the particles of the given medium. In the soft tissues and fluids of the human body, ultrasound propagates in the form of longitudinal waves. Only in bones does ultrasound also propagate in the form of transverse waves.

Similar to sound, **ultrasound propagates best in solids** - speed about 3000 m/s, worse in liquids - speed 1000 m/s, the worst propagation of ultrasound is in air - speed about 350 m/s. The dependence of wave speed on the environment can be a potential source of inaccuracy when ultrasound is used to measure distances. For biomedical measurement purposes, this error is usually negligible.

### Use of ultrasound

**Ultrasonic waves** have a wide range of uses not only in the military, technology industry, pharmacy and medicine. The advantages of using ultrasound are mainly simple and **non-contact** detection and measurement inside spaces that would be difficult to map using other means. Both continuous and interrupted (pulsating) waves are used. The principle of using pulse waves consists in sending short pulses of ultrasound energy. After each pulse, the signal receiver receives the reflected wave in a short time window. The signal is then evaluated. These methods are used, for example, to measure the flow through a tube.

There are several ultrasound generators:

- **Mechanical generators**, i.e. special whistles and sirens, have a rather historical significance.
- **Magnetostrictive generators** create ultrasonic waves using a ferromagnetic rod that is placed in the magnetic field of an electromagnet powered by alternating current. They have great power, but they can only generate ultrasound with a frequency of up to about 60 kHz. The maximum frequency is limited primarily by the fact that the impedance of the excitation coil increases with increasing frequency . They are used in dentistry to remove tartar and caries, and to a limited extent in physical medicine.
- **Piezoelectric generators** are the most commonly used ultrasound generators in medicine. Their physical essence is the piezoelectric phenomenon, i.e. the change of shape of some materials in an electric field. A plate of suitable material (quartz, some ceramic materials, etc.) is connected to the electrodes with alternating voltage. The plate thus oscillates with the same frequency as the applied voltage and thus changes electrical energy into mechanical wave energy. Piezoelectric generators can generate ultrasound up to tens of megahertz.

The frequency band 2−40 MHz is the most suitable for application in medicine, while it is possible to distinguish:

- **low-frequency ultrasound** (20−100 kHz) used mainly in ultrasound surgery during surgical procedures and for cleaning instruments,
- **high-frequency ultrasound** used in physical therapy (1−3 MHz) and in diagnostics (2−40 MHz).

#### Ultrasound in medicine

The most important applications of ultrasound are medical ultrasonography and acoustic microscopy . The theoretical use of these methods was obvious to scientists a long time ago, but the practical use came only later with more advanced technology. Mechanical waves with frequencies higher than 2 MHz and intensity less than 1 W/cm 2 are used to image objects in medicine using ultrasound. A shorter wavelength is more suitable for higher resolution , but the disadvantage is smaller perforation. With a longer wavelength, the wave penetrates deeper, but does not capture such details.

With increasing frequency, i.e. with decreasing wavelength, ultrasound waves are more significantly "absorbed" in the tissues, more precisely, there is a more significant **transformation** of the mechanical energy of the **mechanical waves** into thermal energy , i.e. the heating of the tissues. The practical consequence is that ultrasound at a very high frequency (tens to hundreds of megahertz) can only be used to examine the skin. If sufficient intensities were used so that even the echo could be reliably measured, there would be significant heating of the tissues just below the probe. In practice, it is said that ultrasound with higher frequencies has a **lower penetration depth**. On the other hand, the higher the ultrasound frequency, the better the resolution of the examination. Even hundreds of megahertz ultrasounds are being used, albeit experimentally rather than in clinical practice, to image tissue structure at the level of almost histological detail.

#### Principle of ultrasound examination

1. The impulse-reflection method — the **probe** is placed on the surface and emits waves in the form of short pulses that pass through the tested material, reflect from the interface with another environment that has a different acoustic impedance than the studied tissue, and return to the probe, where they are registered. The advantage is the use of only one probe and the possibility of measuring inaccessible bodies and spaces.
2. Through-impulse method — probes placed on opposite surfaces of the tested object — transmitter and receiver are used. We measure the amount of energy that reaches the transmitting probe through the material to the receiving probe.

**Ultrasonic waves** are almost completely reflected at the solid-gas interface. Even a very thin layer of gas between the probe and the tissue will practically prevent the penetration of waves into the material. Therefore, the space between the probe and the surface of the tested substance is filled with a liquid or semi-solid material, which we call **acoustic coupling**.

The binding agent can be vaseline, oil, glycerin, water or special agents for acoustic binding.

#### Medical ultrasonography

It is a technique based on the properties of ultrasound waves. Using ultrasonography, we visualize muscles, organs, bones, body cavities and other structures. Using modern technologies, the computer can conjugate many two-dimensional images to create a 3D image in real time. This diagnostic technology is relatively affordable and easily portable. It is most often used when **imaging the fetus in the** prenatal period. Compared to other diagnostic devices, ultrasonography is one of the gentlest methods and poses no threat to the patient. Ultrasound examination has a wide range of uses — from the localization of trauma to the detection of abnormalities and lesions in various tissues.

Other uses of ultrasound include, for example, ultrasound cleaning, veterinary diagnostics, ultrasonic air humidification, therapeutic use — treatment of connective tissue inflammation, breaking of urinary stones and other obstructive bodies, sonochemistry.

### Safety

Frequent exposure to ultrasound at a volume level greater than 120 dB can lead to hearing loss or impairment. Exposure to 155 dB can already cause thermal heating of tissues, and a level of around 180 dB is thought to be lethal. The limit in public spaces should ideally be 70 dB at 20 kHz.

## Properties

Ultrasound has a very high frequency and therefore a very short wavelength. Its wavelength is smaller than the wavelength of sound, so the propagation of ultrasound is less affected by bending. However, its reflection from obstacles and the fact that it is less absorbed in liquids and solids are significant.

At the interface of two tissues with different acoustic impedances, there is a partial change in the direction of wave propagation and their reflection. The intensity ratio R of the reflected wave to the incident ultrasonic wave can be calculated according to the relation:

$$R = \left(\frac{Z_1 - Z_2}{Z_1 + Z_2}\right)^2$$

Applies to:

- R = 0, if Z1 = Z2
- R → 0, if Z1 ≈ Z2
- R → 1, if Z1 ›› Z2 o Z2 ›› Z1

The ratio of the intensities T passing through to the incident ultrasound wave can be found from the relation

$T = (1 - R)$.

In general, the same rules and regularities apply to ultrasound as to other types of mechanical waves.

# Resources

## Links

- http://fyzika.jreichl.com/main.article/view/203-ultrazvuk
- https://is.muni.cz/th/t0bcj/?so=nx
- https://referaty.aktuality.sk/ultrazvuk/referat-3154http://www.amapro.cz/datove_zdroje/knihy/fyzika/fyzika_171.php
- https://cs.wikipedia.org/wiki/Ultrazvuk

## Related articles

- Ultrasound
- Effects of Ultrasound
- Ultrasound in various media and tissues

## References


- NAVRÁTIL, Leoš. Biofyzika v medicíně. 1. vydání. Praha : Manus, 2003. ISBN 80-86571-03-3

VŠB - TUO, Ultrazvukové vlny. Ostrava

20.11.