ULTRASOUND Physic 2025-2026

3.st Stage

Lecture 4 - Practical

ULTRASOUND CHARACTRISTICS

Lecturer

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References: **المصادر:**

Thayalan, K., and Ramamoorthy Ravichandran. *The physics of radiology and imaging*. JP Medical Ltd, 2014.

2.10 Ultrasound Characteristics

Ultrasound pulses have several physical characteristics that should be considered by the user in order to adjust the imaging procedure for specific diagnostic applications.

The most significant characteristics are illustrated here.

2.10.1 Frequency

Frequency (*f*) is the number of wavelengths that pass per unit time. It is measured as cycles (or wavelengths) per second and the unit is hertz (Hz). It is a specific feature of the crystal used in the ultrasound transducer. It can be varied by the operator within set limits - the higher the frequency, the better the resolution but the lower the penetration. Ultrasound Pulse Frequency:

- The range (2- 20 MHz)
- Determined by the transducer
- Affects Absorption and Penetration
- Affects image Detail

The frequency of ultrasound pulses must be carefully selected to provide a proper balance between image detail and depth of penetration. In general, high frequency pulses produce higher quality images but cannot penetrate very far into the body.

The frequency of sound is determined by the source. In diagnostic ultrasound equipment, the source of sound is the transducer. The major element within the transducer is a crystal designed to vibrate with the desired frequency. A special property of the crystal material is that it is piezoelectric. This means that the crystal will deform if electricity is applied to it. Therefore, if an electrical pulse is applied to the crystal, it will have essentially the same effect as the striking of a piano string: the crystal will vibrate. If the transducer is activated by a single electrical pulse, the transducer will vibrate, or "ring," for a short period of time. This creates an ultrasound pulse as opposed to a continuous ultrasound wave. The ultrasound pulse travels into the tissue in contact with the transducer and moves away from the transducer surface. A given transducer is often designed to vibrate with only one frequency, called its resonant frequency. Therefore, the only way to change ultrasound frequency is to change transducers. This is a factor that must be considered when selecting a transducer for a specific clinical procedure. Certain frequencies are more appropriate for certain types of examinations than others. Some transducers are capable of producing different frequencies. For these the ultrasound frequency is determined by the electrical pulses applied to the transducer.

2.10.2 Velocity

Propagation Velocity (v) is the speed that sound waves propagate through a medium and depends on tissue density and compressibility. The relationship between these variables is expressed by the Wave Equation (Eq. 2.1). In soft tissue propagation velocity is relatively constant at 1540m/s and this is the value assumed by ultrasound machines for all human tissue. Hence wavelength is inversely proportional to frequency.

Factors Related to Ultrasound Pulse Velocity:

- ✓ Determined by the material
- ✓ Affects the depth dimension in the image
- ✓ Average for soft tissue: 1540 m/s, for air: 330 m/s

The importance of the speed of ultrasound is that it is used to locate the depth of the structures in the body. The speed is determined with which sound travels through a medium by the characteristics of the medium and not characteristics of the sound. The velocity of longitudinal, or compression, sound waves in which the particles of the medium vibrate in the direction of wave propagation, can propagate in liquids like tissue and gases, is given by:

$$(velocity)\ v = \sqrt{(Stiffness/Density)} \quad \ldots\ldots (2.2)$$

where "stiffness" is a factor related to the elastic properties of the medium or the bulk modulus. The velocities of sound through several materials of interest are given in the table 2.1.

Most ultrasound systems are set up to determine distances using an assumed velocity of 1540 m/sec. This means that displayed depths will not be completely accurate in materials that produce other ultrasound velocities such as fat and fluid.

Table 2.1: Approximate Velocity of Sound in Various Materials

Material	Velocity (m/sec)
Fat	1450
Water	1480
Soft tissue (average)	1540
Bone	4100

2.10.3 Wavelength

Wavelength (λ) is the distance sound travel during the period of one vibration which is the distance between two areas of maximal compression (or rarefaction) (see figure 8.10). The importance of wavelength is that the penetration of the ultrasound wave is proportional to wavelength and image resolution is no more than 1-2 wavelengths. It is typically measured between two easily identifiable points, such as two adjacent crests or troughs in a waveform. Wavelength is inversely proportional to frequency. That means if two waves are traveling at the same speed, the wave with a higher frequency will have a shorter wavelength. Likewise, if one wave has a longer wavelength than another wave, it will also have a lower frequency if both waves are traveling at the same speed.

Although wavelength is not a unique property of a given ultrasound pulse, it is of some significance because it determines the size (length) of the ultrasound pulse.

This has an effect on image quality, as we will see later.

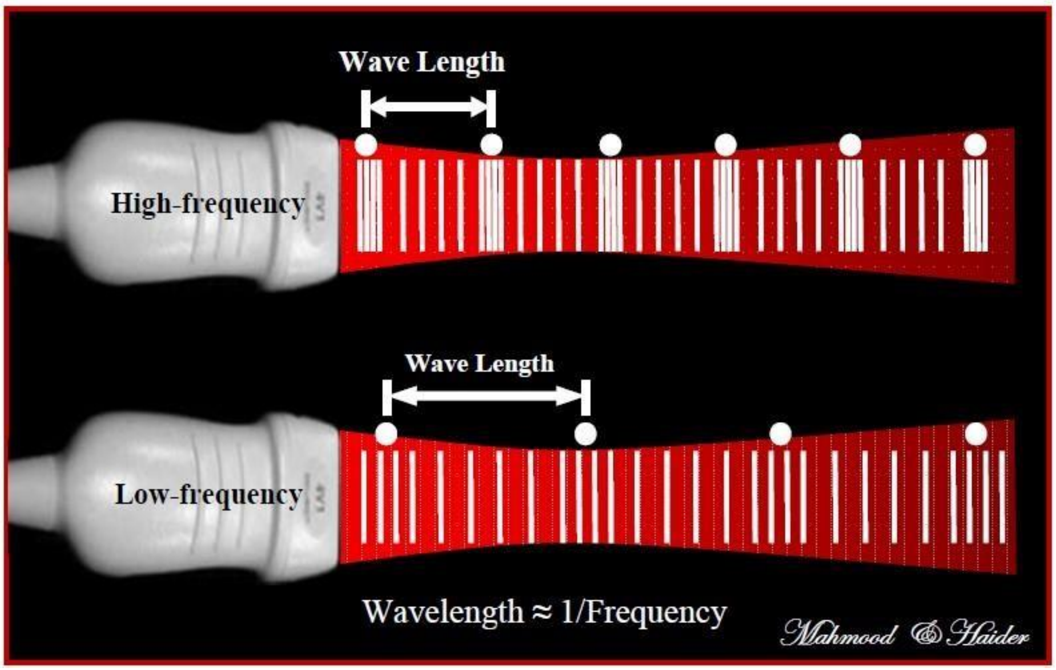

Figure 10: Dependence of Pulse Length on Wavelength and Frequency.

The illustration Figure 11 shows both temporal and spatial (length) characteristics related to the wavelength. A typical ultrasound pulse consists of several wavelengths or vibration cycles. The number of cycles within a pulse is determined by the damping characteristics of the transducer. Damping is what keeps the transducer element from continuing to vibrate and produce a long pulse.

The period is the time required for one vibration cycle. It is the reciprocal of the frequency. Increasing the frequency decreases the period. In other words, wavelength is simply the ratio of velocity to frequency or the product of velocity and the period. This means that the wavelength of ultrasound is determined by the characteristics of both the transducer (**frequency**) and the material through which the sound is passing (**velocity**).

The pressure is related to the degree of tissue displacement caused by the vibration. The amplitude is related to the energy content, or "loudness," of the ultrasound pulse. The amplitude of the pulse as it leaves the transducer is generally determined by how hard the crystal is "struck" by the electrical pulse.

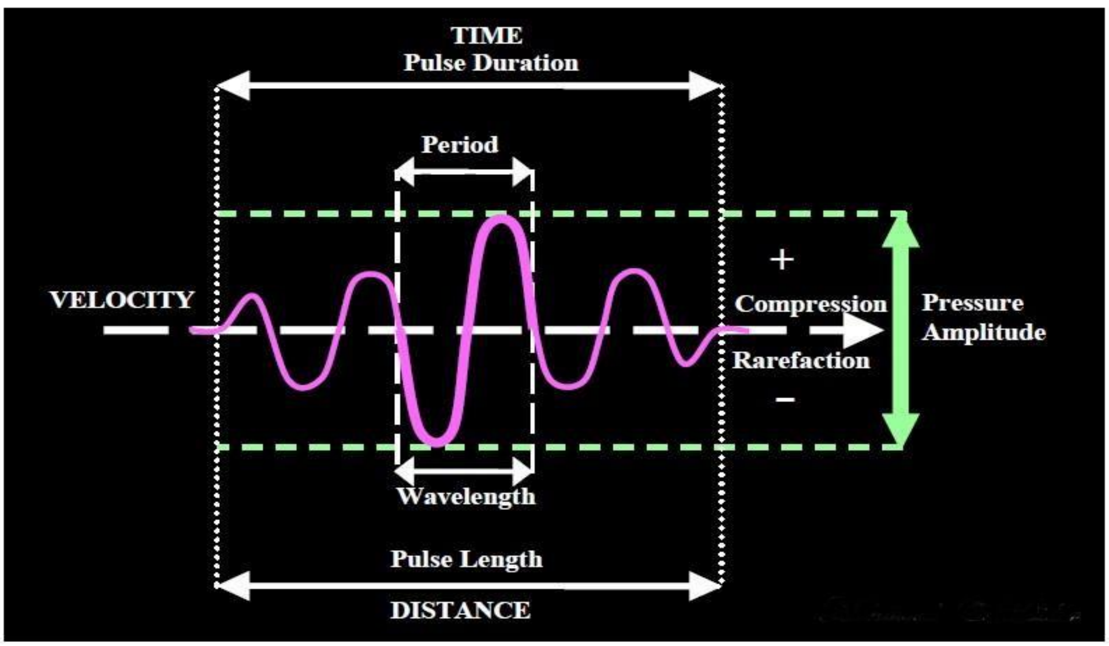

Figure 11: The Temporal and Length Characteristics of an Ultrasound Pulse.

In ultrasound imaging the significance of wavelength is that short wavelengths are required to produce short pulses for good anatomical detail (in the depth direction) and this requires higher frequencies as illustrated below.

2.10.4 Amplitude

Amplitude is the height above the baseline and represents maximal compression. It is expressed in a decibel which is a logarithmic scale (see figure 12). Most systems have a control on the pulse generator that changes the size of the electrical pulse and the ultrasound pulse amplitude. We designate this as the intensity control, although different names are used by various equipment manufacturers. In diagnostic applications, it is usually necessary to know only the relative amplitude of ultrasound pulses. For example, it is necessary to know how much the amplitude, A, of a pulse decreases as it passes through a given thickness of tissue. The relative amplitude of two ultrasound pulses, or of one pulse after it has undergone an amplitude change, can be expressed by means of a ratio as follows:

$$\textbf{Relative amplitude (ratio)} = A_2/A_1$$

There are advantages in expressing relative pulse amplitude in terms of the logarithm of the amplitude ratio. When this is done the relative amplitude is specified in units of decibels (dB). The relative pulse amplitude, in decibels, is related to the actual amplitude ratio by:

$$\textbf{Relative amplitude (dB)} = {}_{20}\log A_2/A_1$$

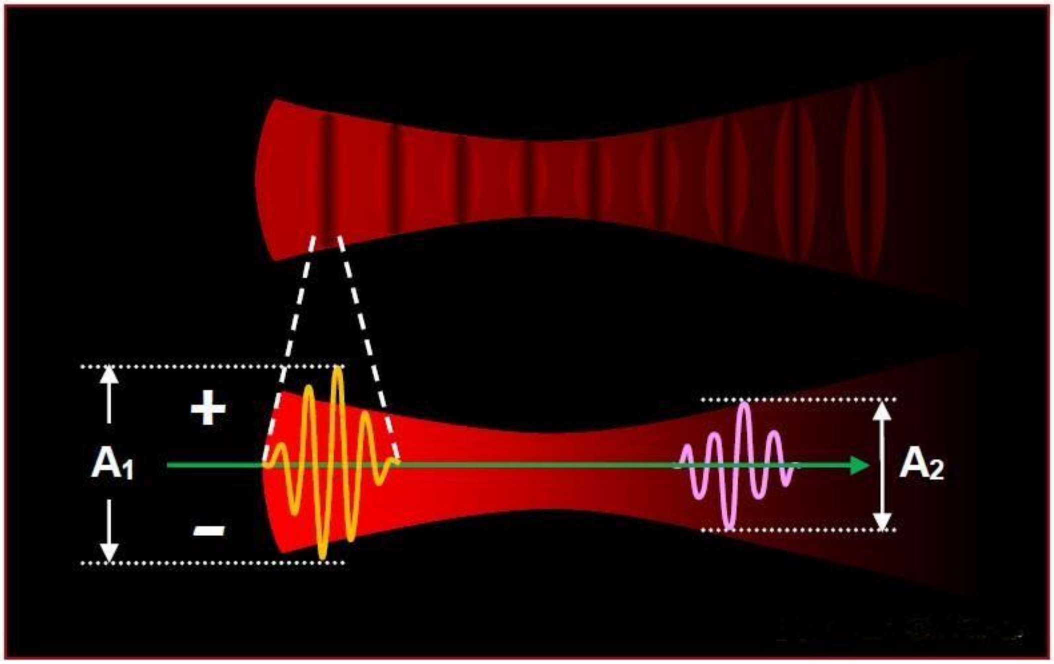

Figure 12: Ultrasound Pulse Amplitude, Intensity, and Energy.

When the amplitude ratio is greater than 1 (comparing a large pulse to a smaller one), the relative pulse amplitude has a positive decibel value; when the ratio is less than 1, the decibel value is negative. In other words, if the amplitude of a pulse is increased by some means, it will gain decibels, and if it is reduced, it will lose decibels.

The figure 13, compares decibel values to pulse amplitude ratios and percent values. The first two pulses differ in amplitude by 1 dB. In comparing the second pulse to the first, this corresponds to an amplitude ratio of 0.89, or a reduction of approximately 11%. If the pulse is reduced in amplitude by another 11%, it will be 2 dB smaller than the original pulse. If the pulse is once again reduced in amplitude by 11 % (of 79%), it will have an amplitude ratio (with respect to the first pulse) of

0.71:1, or will be 3 dB smaller.

Perhaps the best way to establish a "feel" for the relationship between pulse amplitude expressed in decibels and in percentage is to notice that amplitudes that differ by a factor of 2. differ by 6 dB. A reduction in amplitude of -6 dB divides the amplitude by a factor of 2, or 50%. The doubling of pulse amplitude increases it by +6 dB.

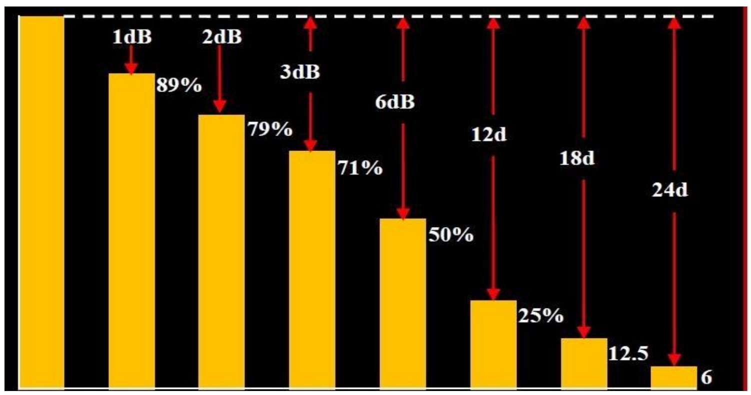

Figure 13: Pulse Amplitudes Expressed in Decibels and Percentages.

- During its lifetime, an ultrasound pulse undergoes many reductions in amplitude as it passes through tissue because of absorption. If the amount of each reduction is known in decibels, the total reduction can be found by simply adding all of the decibel losses. This is much easier than multiplying the various amplitude ratios.