Chapter 2 - Pulsed Ultrasound

Pulse

A pulse is a group of ultrasound waves that travel together.

Pulse Components

There are two components of a pulse:

1. Cycles
2. Dead time

- ***Cycles*** **–** also called "on" or "transmit" time. During this time short bursts of ultrasound pulses are produced and transmitted.
- ***Dead Time*** **–** also called "off" or "receive" time. During this time the returning echo signals are received by the transducer (listening time). No sound pulses are produced during this time.

❖ Important to Remember
In diagnostic ultrasound imaging, short pulses of ultrasound waves are used to produce an image.
A pulse must have a beginning and an end; otherwise it is a continuous wave.
Pulsed wave ultrasound is used to produce an ultrasound image.
Continuous wave ultrasound cannot be used to produce an ultrasound image.

Pulse Characteristics

1. Pulse Repetition Frequency
2. Pulse Repetition Period
3. Pulse Duration

4. Spatial Pulse Length

5. Duty Factor

Pulse Repetition Frequency (PRF)

Pulse Repetition Frequency is the number of pulses produced per second.

Pulse repetition frequency = lines per frame x frame rate

PRF = LPF x FR

$$pulse\ repetition\ frequency = \frac{1}{pulse\ repetition\ period}$$

$$PRF = \frac{1}{PRP}$$

- PRF is related to the imaging depth.
- There is an inverse relationship between the imaging depth and PRF.
- As imaging depth increases, the PRF decreases.
- As imaging depth decreases, the PRF increases.

- The sonographer can change the PRF by changing the image depth.

The unit of Pulse repetition frequency is Hertz (Hz).

In diagnostic ultrasound imaging, the PRF ranges from 1,000 Hz to 10,000 Hz (1-10 kHz)

Pulse Repetition Period (PRP)

Pulse repetition period is the time from the start of one pulse to the start of next pulse.

PRP includes the time when the pulse is on and the listening time when the pulse is off.

- ❖ Important to Remember
- **The imaging depth and pulse repetition period has a direct relationship.**
- As imaging depth increases, the PRP increases.
- As imaging depth decreases, the PRP decreases.
- Increasing the PRP increases the maximum depth that can be imaged.
- Decreasing the PRP decreases the maximum depth that can be imaged.
- **The pulse repetition period can be changed by changing the imaging depth.**

- $\text{Pulse Repetetion Period (PRP)} = \frac{1}{\text{Pulse Repetetion Frequency (PRF)}}$
- $PRP = \frac{1}{PRF}$

- ❖ **Pulse repetition frequency has inverse relationship with pulse repetition period.**
- As pulse repetition frequency increases, the pulse repetition period decreases.
- As pulse repetition frequency decreases, the pulse repetition period increases.

- As pulse repetition period increases, the pulse repetition frequency decreases.
- As pulse repetition period decreases, the pulse repetition frequency increases.
- ❖ **The pulse repetition period can be changed by changing the imaging depth.**

The unit of Pulse repetition period is same as units of time such as seconds, minutes.

- ❖ The sonographer can change the PRP indirectly.
- The sonographer cannot change the PRP directly, but he can change the listening time by increasing or decreasing the imaging depth, therefore sonographer can change the pulse repetition period indirectly by increasing or decreasing the imaging depth.
- Remember that the sonographer cannot change the pulse or length of the pulse, the sonographer can change only the listening time by increasing or decreasing the imaging depth.

In diagnostic ultrasound imaging, the PRP ranges from 100 µsec to 1 msec.

Pulse Duration

Pulse Duration is the time from the start of a pulse to the end of that pulse.

❖ Important to Remember
Pulse Duration is the actual time when the pulse is on.
Pulse duration is the actual time that an US machines is creating a pulse
In diagnostic ultrasound imaging, pulse duration is comprised of 2-4 cycles.
The sonographer cannot change the pulse duration (PD). The pulse duration is determined by the sound source.
In diagnostic ultrasound imaging, pulse duration ranges from .5 to 3 µsec.

Pulse duration is determined by the number of cycles in each pulse and the period of each cycle.

Pulse Duration (msec) = # cycles in pulse x period (msec)

$$\text{Pulse Duration (msec)} = \frac{\text{\# cycles in pulse}}{\text{frequency (kHz)}}$$

Spatial Pulse Length

Spatial Pulse Length is the distance from the start of a pulse to the end of that pulse. Spatial pulse length is the number of cycles in the pulse multiplied by wavelength.

❖ spatial pulse length = number of cycles x wavelength
If the wavelength increases, the spatial pulse length increases and if the wavelength decreases, the spatial pulse length decreases.

- If the numbers of cycles in the pulse increase, then the spatial pulse length also increases.

- The spatial pulse length decreases with higher frequency.
- Spatial Pulse Length determines the longitudinal resolution which determines the image quality.
- Shorter wavelengths result in shorter spatial pulse length which results in better axial resolution and better image quality.
- Shorter pulses create the higher quality images.
- Spatial Pulse Length is determined by the source and the medium.
- The unit of spatial pulse length (SPL) is same as unit of distance such as mm, meter.
- The spatial pulse length values range from .1 to 1 mm.

Duty Factor

Duty Factor is the percentage of time that the system transmits a pulse.

Duty Factor is the fraction of time that the system transmits a pulse.

- ❖ Duty Factor is unitless.
- Maximum value of Duty Factor is 1.0 or 100%
- Minimum value of Duty Factor is 0.0 or 0%

- If the duty factor is 1.0 or 100%, that means ultrasound system is producing sound waves continuously.
- The CW produces ultrasound pulses all the time and its duty factor is 1.0 or 100%.
- The CW cannot be used to make ultrasound images.

- When the duty factor is 0.0 or 0%, that means ultrasound machine is not producing any sound pulses.

$$\text{Duty factor }\% = \frac{\text{pulse duration (sec)}}{\text{pulse repetition period (sec)}} \text{ x } 100$$

The Duty Factor is determined by the sound source and cannot be changed by the sonographer.

- The sonographer can change directly or indirectly, the duty factor of an US machine.
- Duty Factor increases when:
  - Imaging depth decreases
  - Pulse repetition period decreases

- Duty Factor decreases when:
  - PRF increases
  - Pulse duration increases

Spatial Pulse Length

Spatial Pulse Length is the distance over which a pulse occurs.

Unit = mm, meters

Bandwidth

Bandwidth is the range of frequencies present within the sound beam.

Bandwidth can be increased by increasing damping.

Harmonic Imaging

Transmitted sound has a particular frequency which is called fundamental frequency, but the image is created from the sound reflected at twice the fundamental frequency also called the harmonic or second harmonic frequency.

For example the transducer transmits a sound pulse with a fundamental frequency of 2.5 MHz. In Harmonic mode an image will be produced with 5 MHz reflected frequency.

Fundamental Frequency – the frequency of the transmitted sound

Harmonic Frequency – is twice the fundamental or transmitted frequency

- When fundamental image is suboptimal, the second harmonic imaging can produce a better quality image.

Range Equation

Range Equation describes the time that it takes for an ultrasound pulse to travel from the transducer to the reflector (the body tissue), and return to the transducer (the go-return time).

The range equation relates distance from the reflector to time of flight, and propagation speed.

❖ The range equation is used to determine the reflector depth in the ultrasound system.
d = ½ ct
d = reflector Depth.
c = speed of sound in tissues 1.54 mm/µs
t = round-trip time.

distance to reflector = ½ propagation speed x go-return time

distance to reflector (mm) = ½ propagation speed (mm/µsec) x go-return time

distance to reflector (mm) = .77mm/µsec x go-return time

d = .77 x t

❖ **The 13 microsecond rule:**
In soft tissue, every 13 µsec of time means the reflector is 1cm deep.
When the total time of flight is:
13 µsec, the reflector is 1 cm deep in the body
26 µsec, the reflector is 2 cm deep in the body
39 µsec, the reflector is 3 cm deep in the body
52 µsec, the reflector is 4 cm deep in the body