Ultrasound Physics & Instrumentation
5th Edition

Companion Presentation

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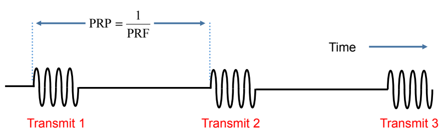
Chapter Outline

Chapter 4: Pulsed Wave - Level 2

We will begin by reviewing PW Definitions as learned in Level 1

Pulsed Wave Definitions

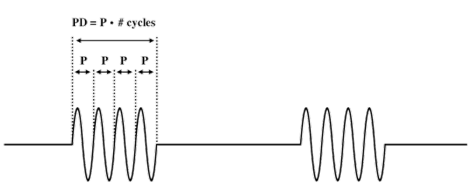
Each transmit burst or "pulse" represents the beginning of one acoustic line.



PRP = Pulse Repetition Period (time between repeating pulses)
PRF = Pulse Repetition Frequency (acoustic lines per time transmitted)

Pulse Duration

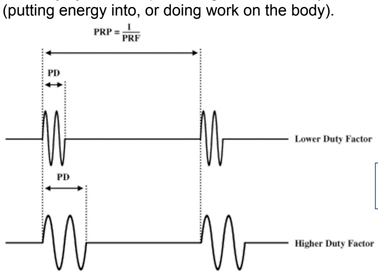
As the name suggests, the pulse duration refers to the time that the pulse lasts.



Pulse Duration (PD) = Period * # cycles

Duty Cycle Factor

The duty cycle is the percentage of time the system is transmitting (putting energy into, or doing work on the body).



$$Duty\ Cycle = \frac{PD}{PRP}$$

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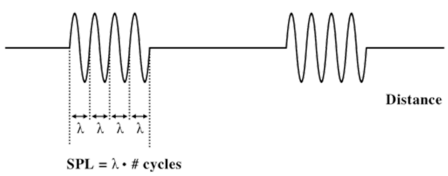
Spatial Pulse Length

As the name suggests, the spatial pulse length refers to the physical length of the pulse in the medium.



$$Spatial\ Pulse\ Length\ (SPL) = \lambda * \#\ cycles$$

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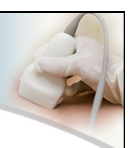
Pulsed Wave Related Terms



Make certain that you can define all of the following terms related to Pulsed Wave Operation (see page 82).

- Pulsed Wave
- Acoustic Line
- Receive Line
- Display Line
- Line
- Image
- Frame Time
- Frame Rate
- Sampling Rate

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Scanned vs. Non-scanned Modalities

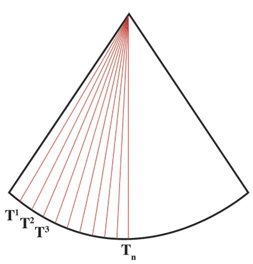
There are two fundamental types of ultrasound:

Scanned and Non-scanned.

The distinction is very important for three reasons:

1) Scanned modalities acquire information over a plane (or volume in 3D) whereas non-scanned modalities acquire information only along a line.
2) The temporal resolution is dramatically degraded with scanned modalities.
3) The risk of thermal bioeffects is usually much greater with non-scanned modalities than scanned modalities.

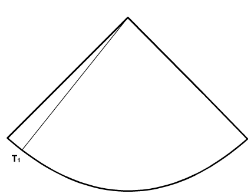
Scanned Modalities



For scanned modalities, the image is "built up" over time by transmitting and receiving in a specific direction and then sequentially moving over and repeating the process .

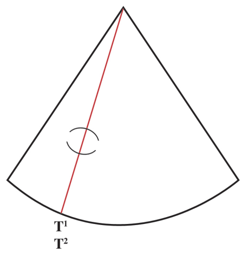
(As visualized in the animation of the next slide)

Scanned Modalities (Animation)



T_1 = depth • $\frac{13\ \mu sec}{cm}$

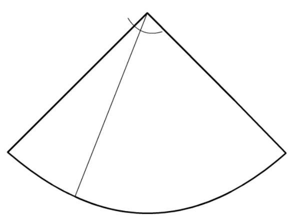
Non-Scanned Modalities



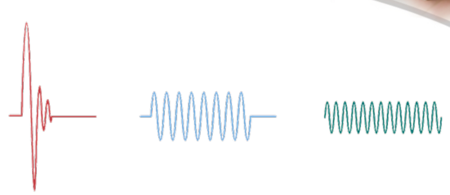
For non-scanned modalities, the data is acquired by repeatedly transmitting and receiving in the same direction over time.

(As visualized in the animation of the next slide)

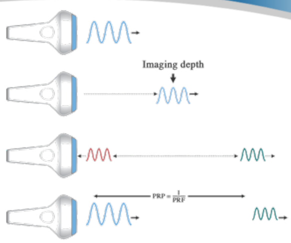
Non-Scanned Modalities (Animation)



Pulse Characteristics for Various Modes

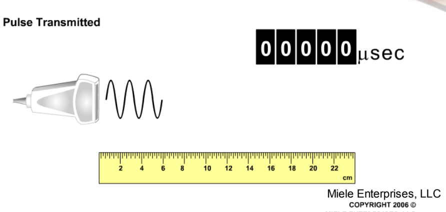


Imaging Depth and the PRF (PRP)



For 2-D imaging, the PRP (and hence PRF) are determined primarily by the imaging depth. The deeper the I.D., the longer the PRP and the lower the PRF.

Imaging Depth and the PRF (Animation)



Calculating the PRP and PRF

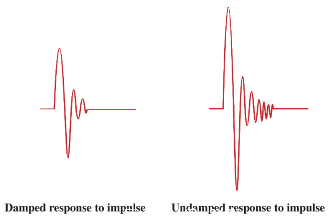
In Chapter 2 we calculated the time required to image 1 cm (by applying the distance equation) as 13 µsec.

To calculate the time required to image a line can therefore be calculated by scaling 13 µsec by the imaging depth as follows:

$$Acoustic\ Line\ Time\ (PRP) = \frac{13\ \mu sec}{cm} \times Imaging\ Depth\ (cm)$$

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

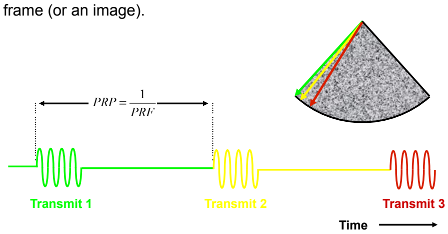
Damping and Ringdown



A single impulse causes multiple cycles of ringing from a transducer crystal. Having more cycles in a pulse results in a longer SPL and degraded axial resolution. By adding a "backing" or "damping" layer to the transducer crystal, the ringdown is decreased improving the axial resolution.

Creating a Frame & Acoustic Lines

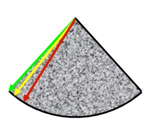
Each transmit burst or "pulse" represents the beginning of one acoustic line. Multiple acoustic lines constitute one frame (or an image).



Frame Time

The frame time is the time it takes to create a single frame or scan.

$$\text{frame time} = \frac{\text{time}}{\text{line}} * \frac{\text{lines}}{\text{frame}}$$



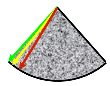
The frame time is clearly affected by the depth and the number of lines in the frame. For basic imaging, the number of lines in the frame is determined by the scan region. The scan region is set by the system user.

Frame Rate

The frame rate (frequency) is just the reciprocal of the frame time.

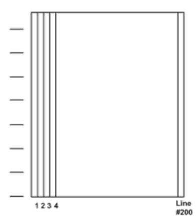
The scan frame rate tells how many images per second can be scanned.

$$\text{frame rate} \ (\text{frequency}) = \frac{1}{\text{frame time}}$$



The frame rate is clearly determined by the same parameters as the frame time, since the two are reciprocals. Higher frame rates are important when imaging structures which are moving or changing quickly in time.

Calculating the Frame Time



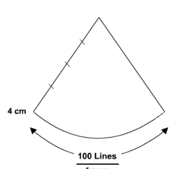
Acoustic Line Time:

$$(PRP) = \frac{13\ \mu\text{sec}}{1\ cm} \times \frac{8\ cm}{line} = \frac{104\ \mu\text{sec}}{line}$$

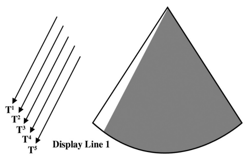
Time to Complete all Lines:

$$\text{Frame Time} = \frac{104\ \mu\text{sec}}{1\ line} \times 200\ \frac{lines}{frame} \approx \frac{20{,}000\ \mu\text{sec}}{frame} = \frac{20\ m\text{sec}}{frame}$$

Calculating the Frame Time (Animation)



Color Scans and Packets



Unlike Conventional 2-D imaging, there is not a 1 to 1 correspondence between acoustic lines and display lines in color Doppler. Each Color Display Line is comprised of multiple acoustic lines referred to as a "packet" or an "ensemble". As a result, the frame time is generally significantly greater for color images than 2-D images, degrading the temporal resolution. (As visualized in the animation of the next slide)

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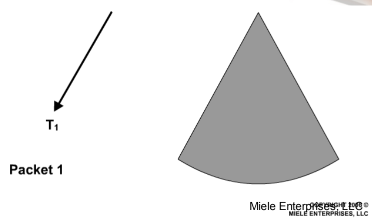
Color Scan (Animation)



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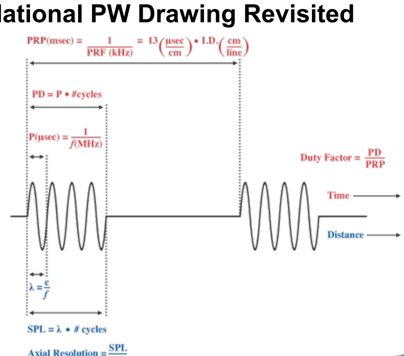
Foundational PW Drawing Revisited



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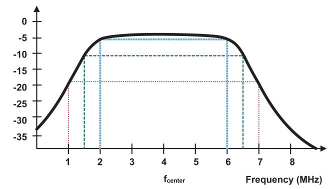
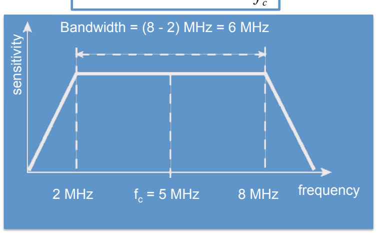
Bandwidth



Bandwidth is defined as the range of frequencies over which a device can operate.

Bandwidth Example and Fractional Bandwidth

$$Fractional\ Bandwidth = \frac{BW}{f_c}$$



Uses for Wide Bandwidth

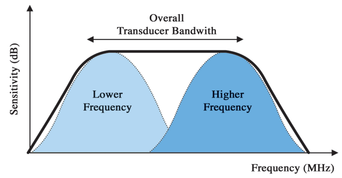
In the last 15 years, ultrasound has been revolutionized by the ability to produce “ultra-wide bandwidth” transducers.

Some advantages of wider bandwidth are:

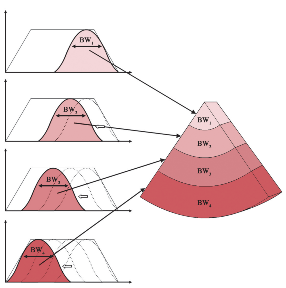
- Multi-Hertz operation
- Dynamic Frequency tuning
- Harmonic Imaging
- Frequency fusion (Frequency Compounding)

Multi-Hertz Operation

Multi-Hertz operation allows the user to change the transmit frequency while imaging a patient without switching transducers, or to image at a higher frequency and perform Doppler at a lower frequency.



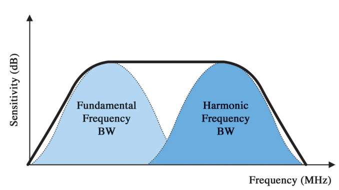
Dynamic Frequency Tuning



Dynamic Frequency Tuning (also referred to as "sliding receive filters") produces a wide bandwidth transmit and then selectively filters the receive frequency based on imaging depth. In the near field, high frequencies are received and processed. In the mid field, intermediate frequencies are received and processed. In the far field, only the lowest frequencies of the transmit bandwidth are received and processed.

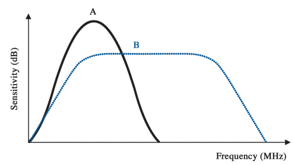
Harmonic Imaging

Harmonic Imaging allows the user to transmit at the lower "fundamental" frequency and receive at the higher "harmonic" frequency.



More Bandwidth is Not Always Better

Unlike 2-D imaging, Doppler does not require much bandwidth. Therefore a transducer with less bandwidth but greater sensitivity is better for Doppler than a transducer with wider bandwidth and less sensitivity.



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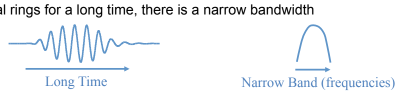
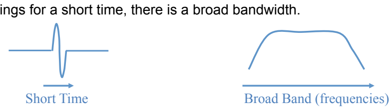
Pulse Width vs. Bandwidth

Recall that time and frequency are reciprocals.

If the signal rings for a long time, there is a narrow bandwidth



If the signal rings for a short time, there is a broad bandwidth.



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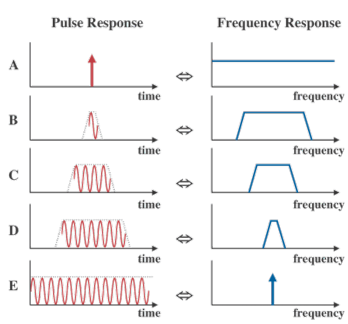
Pulse Duration vs. Bandwidth



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