Sononerds
in the classroom

13 μs

ARDMS Topic:
Ultrasound Physical Principles

Unit 7: Calculating Reflector Depth

Sononerds Ultrasound Physics
Workbook & Lectures

Unit 7: Calculating Reflector Depth

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Unit 7: Calculating Reflector Depth

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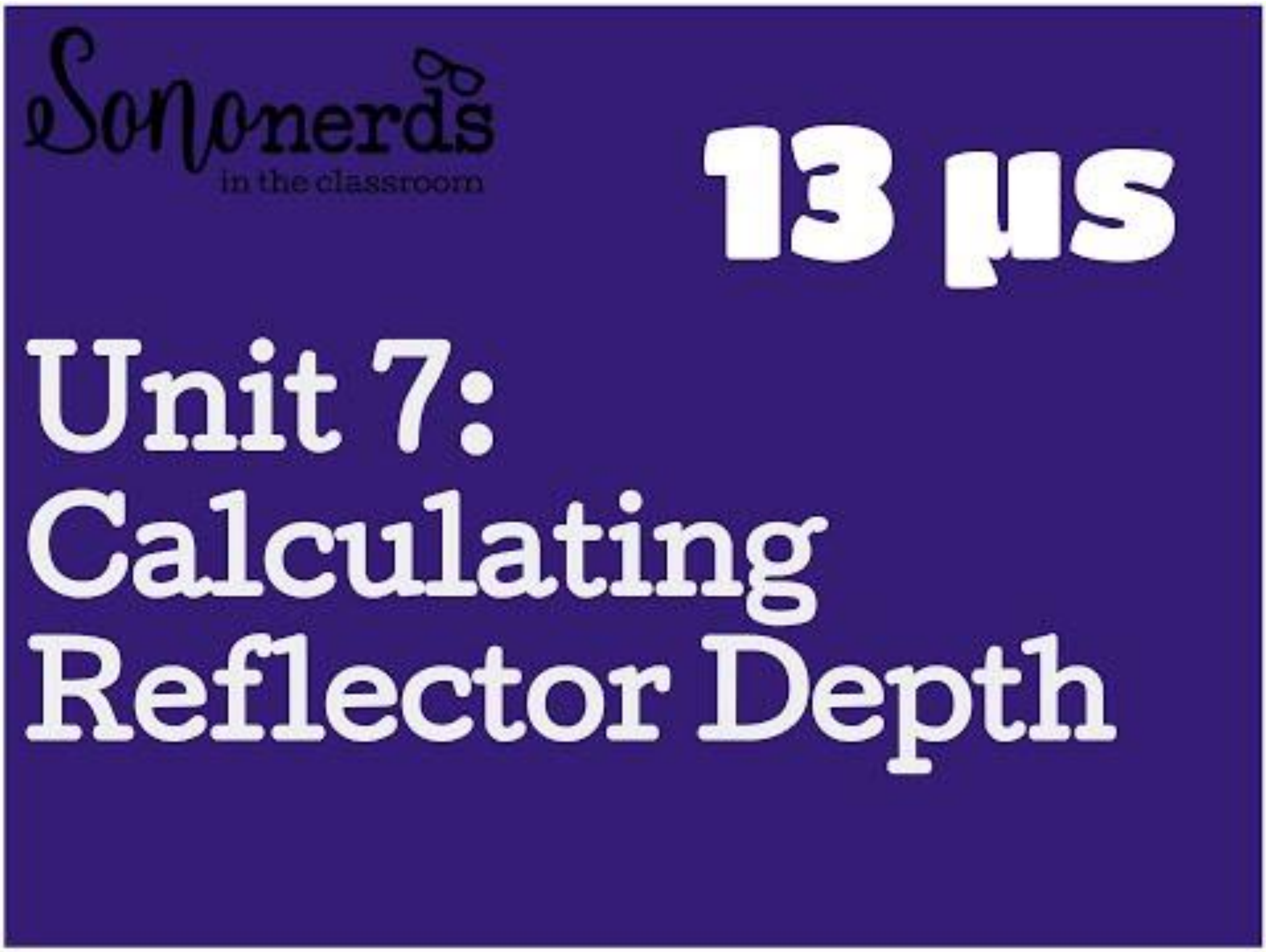
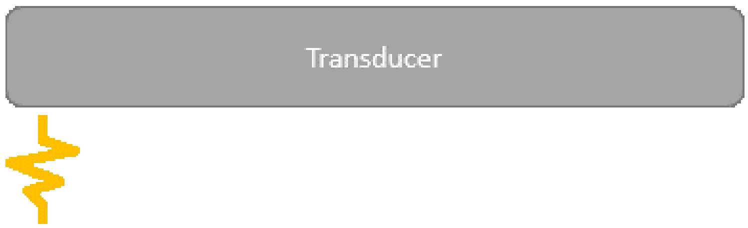
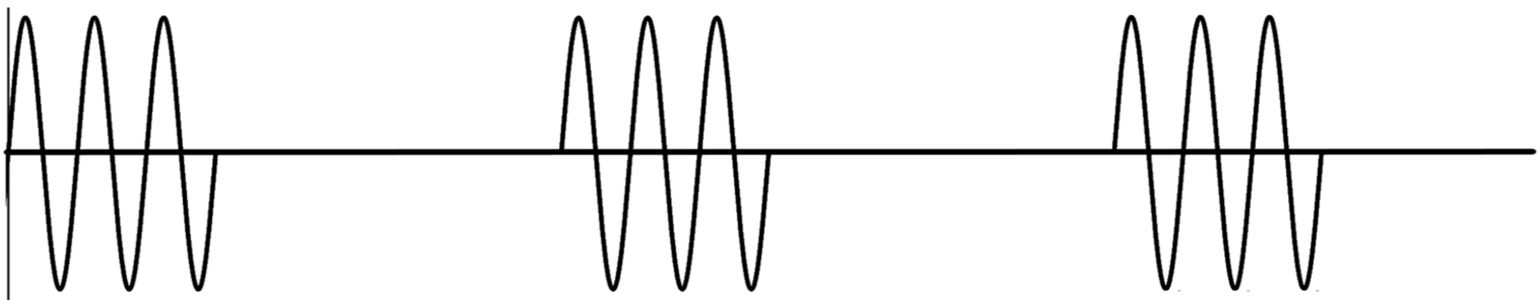


Section 7.1 Creating the Image

In Unit 4, we talked about how the machine sent a pulse out and then waited for that pulse to travel ALL the way to the max depth and return before it would send another pulse.

That one pulse created one scan line, the next pulse the next scan line and so on until a whole image was created. The amount of time it takes to create a whole frame is based on the maximum imaging depth **and the speed of sound.**





The pulse propagates into the body will interact with reflectors along its path.

As the pulse's sound energy interacts with a reflector:

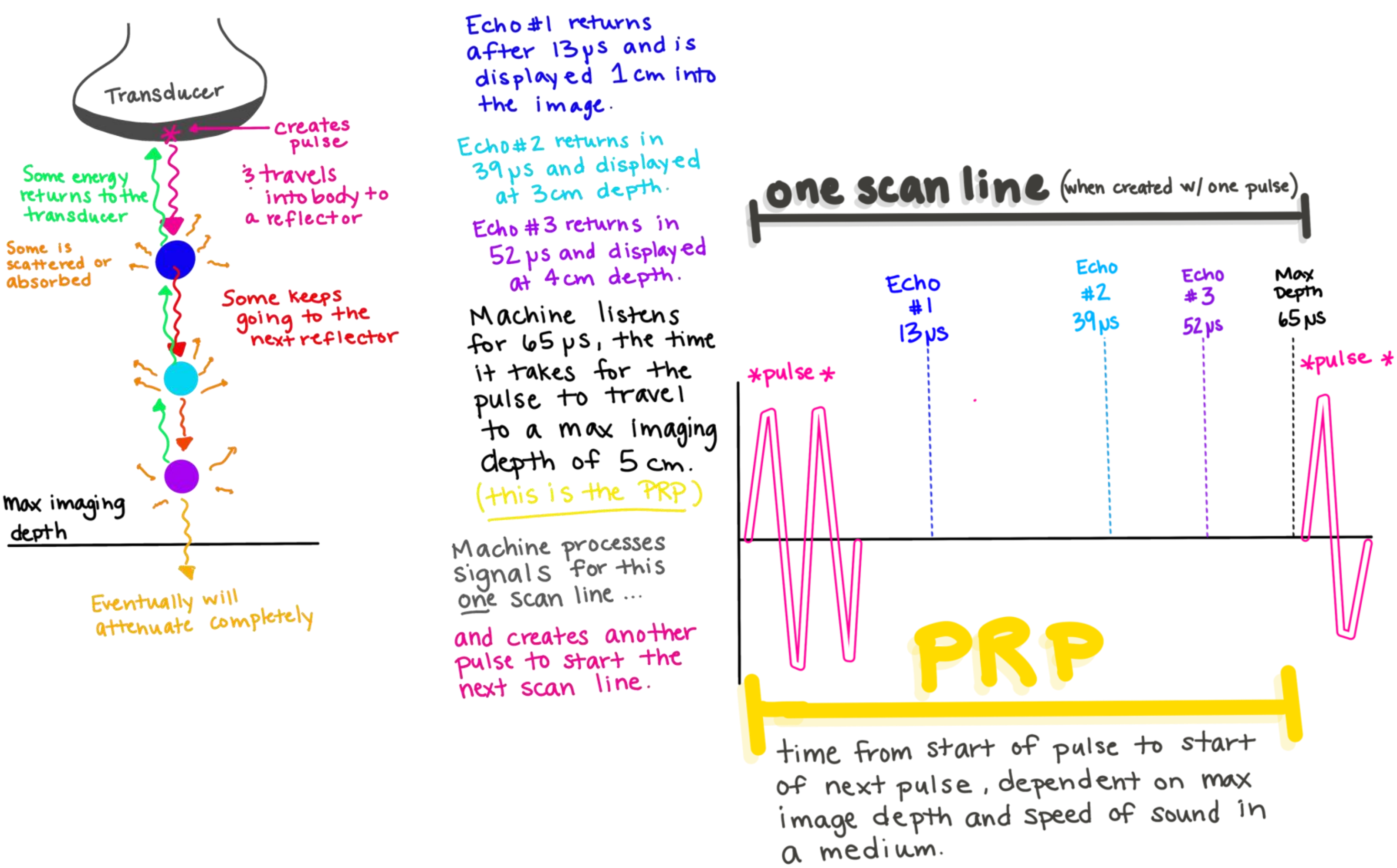
- some of that energy is sent back to the transducer
- some gets sent in a different direction
- some continues forward

The forward moving energy will go until it interacts with another reflector and the cycle keeps happening until sound attenuates or weakens enough that echoes are no longer being returned.

The machine will "listen" for echoes from the initial pulse until pulses that have traveled to the max depth have returned.

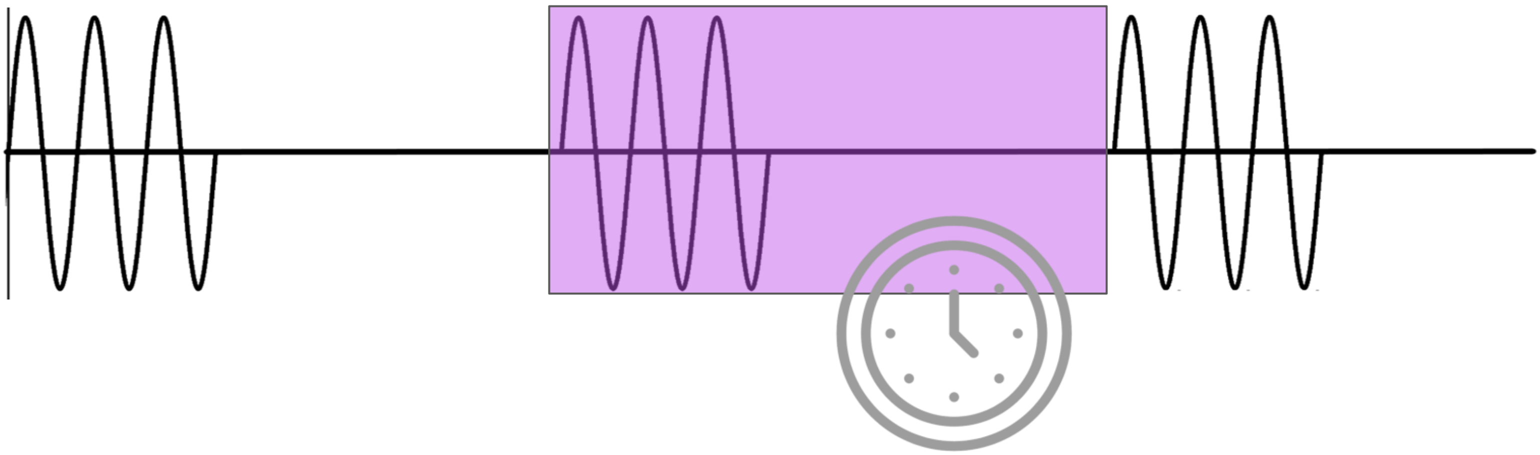
When the echo sound energy comes back to the transducer, it is brought into the machine for processing. The **time** it took for reflector echoes to return are used to calculated where the echo information is placed in the scan line.

The machine is like a big stopwatch that uses sound and echoes to map the body.

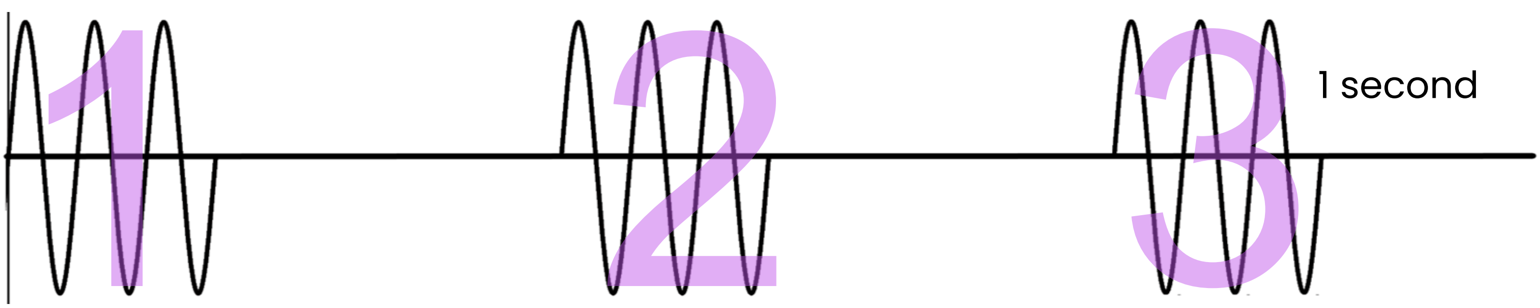


Section 7.2 PRP & PRF (again)

The name we gave the time it took to make the pulse + the waiting for the pulse to return was the **Pulse Repetition Period.**



The amount of times a pulse could be sent per second was the **Pulse Repetition Frequency.**



When we as the sonographer adjust the **max imaging depth:**

Shallow Imaging	Deep Imaging
Less off-time	More off-time
Short PRP	Long PRP
High PRF	Low PRF
High DF	Low DF

7.2.1 PRP & PRF New Formulas

We also learned that PRP and PRF are reciprocals of each other, which gives us the very basic formulas:

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

And when we had a graphical representation of pulse in 1 second, it was pretty easy to calculate PRF and PRP. We just needed to count the pulses and use our knowledge of reciprocals.

What if we aren't given the graphical representation though? Maybe we only know maximum imaging depth, which we (and the machine) can get from our settings. How are we supposed to figure out the **time** it takes for the pulse to travel to max depth and back (which is PRP)?

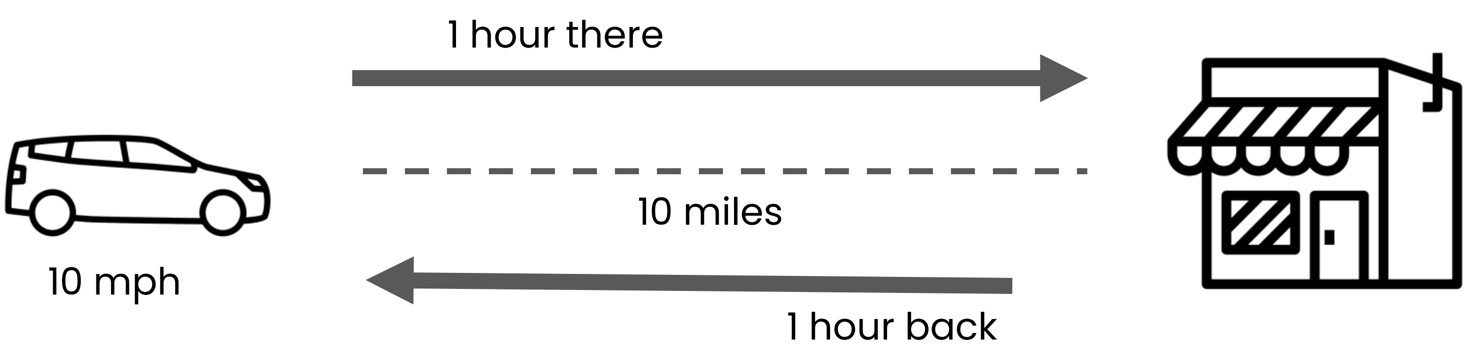
Remember that sound can only travel as fast the medium allows it to! Since propagation speed is a constant, we ***know*** how long it takes for the sound pulse to travel to the max depth and back regardless of the other factors.

For example....if the ONLY speed any car (color, model doesn't matter) could drive was 10 mph, no more, no less, you would know exactly how long it would take you to get anywhere.

10 miles away? 1 hour. 5 miles away? 30 minutes to go a one way distance.

What about getting back though?

Back in our car, if it was 10 miles there and 10 miles back our total travel time would be 2 hours for a total of 20 miles distance.



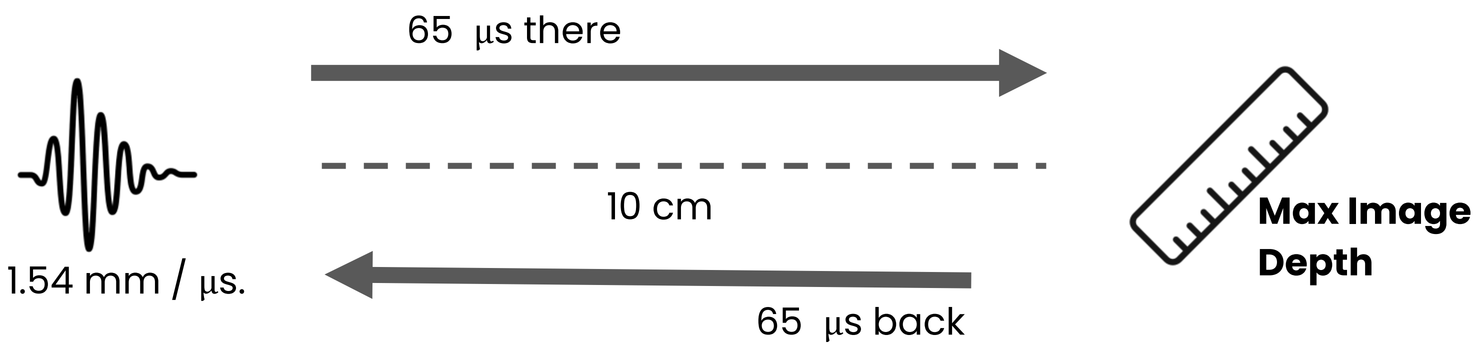
One way distance = 10 miles

One way travel time = 1 hour

There and back distance = 20 miles

Total travel time = 2 hours

We know that the speed limit in **soft tissue is 1.54 mm / µs.** So we can calculate distance and time just the same way as we would in our car. Let's say our max depth is set to 10 cm. How long does it take to for the pulse to travel to 10 cm and back? (The time that we calculate is the PRP.)



One way distance = 10 cm

One way travel time = 65 µs.

There and back distance = 20 cm

Total travel time = 130 µs.

The PRP of *any* transducer being used to image to 10 cm depth is 130 µs. The PRF is the reciprocal of PRP and is 7,700 Hz (7.7 kHz)

Based on the speed limit, we can form new formulas to help us calculate PRP and PRF based on the imaging depth:

$$PRP(\mu s) = 13\ \mu s \times depth\ (cm)$$

$$PRF(hz) = \frac{77{,}000\ cm/s}{depth\ (cm)}$$

7.2.1 Practice

What are the PRP and PRFs for a 5 MHz ultrasound beam in soft tissue set to the imaging depths below?

Max imaging Depth	PRP	PRF
5 cm		
8 cm		
13 cm		
20 cm		

What happens to PRP and PRF if the sonographer changes to a 3 MHz transducer?

Bonus Practice! In Unit 4, we were given an image of a wave and could calculate a lot of the parameters based on that image. Let's try another one knowing our new PRP & PRF formulas:

Sonographer is imaging to a max depth of 9 cm using a 12 MHz transducer that produces pulses with 3 cycles each. Calculate the following:

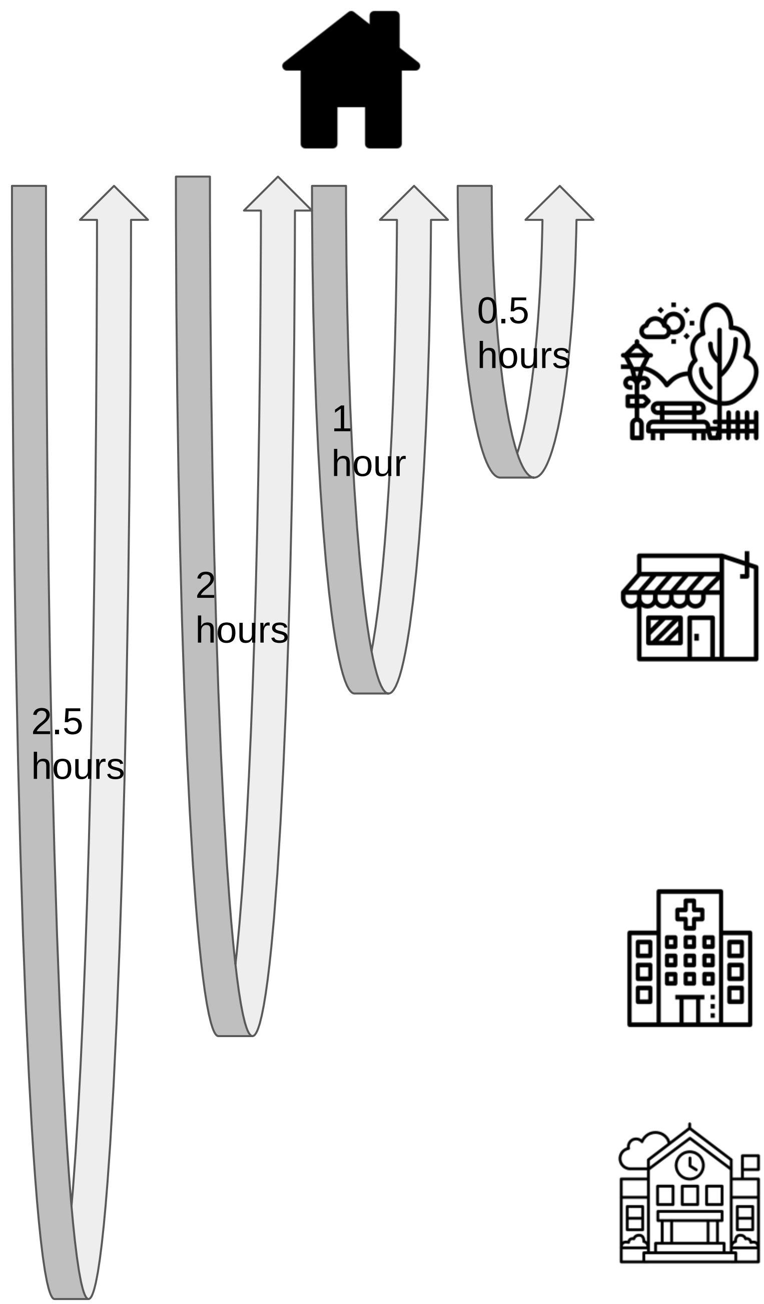
Parameter	**At 9 cm max depth**
Frequency	12 MHz
Period	
Speed in Soft Tissue	
Wavelength	
# of cycles / pulse	3
PRF	
PRP	
PD	
SPL	
DF	

Section 7.3 The 13 µs Rule

Our new PRP and PRF formulas help the machine to know when echoes have reached max imaging depth and they can send a new pulse out. But this unit is called calculating reflector depth, so let's get into that a little more.

The speed limit also helps that machine to calculate how deep reflectors are so they are displayed correctly on the image.

Let's say we're back in our 10 mph cars. You just moved to a new area with 3 friends and there is no internet. The 4 of you get into your cars to go explore the area. You make the deal that you're all driving down one road, in one direction and as soon as you see an interesting location you'll turn around and head home, recording the total time you drove. Agreeing not to drive more than 3 hours total.



You all leave at the same time and here it was you found:

- Friend #1 drove for a total of 30 minutes and saw a park.
- Friend #2 drove for 1 hour and saw a store.
- Friend #3 drove for 2 hours and saw a hospital.
- You drove for 2.5 hours and saw a school.

Because there is no internet, you all decide it would be a good idea to make a map of the new town.

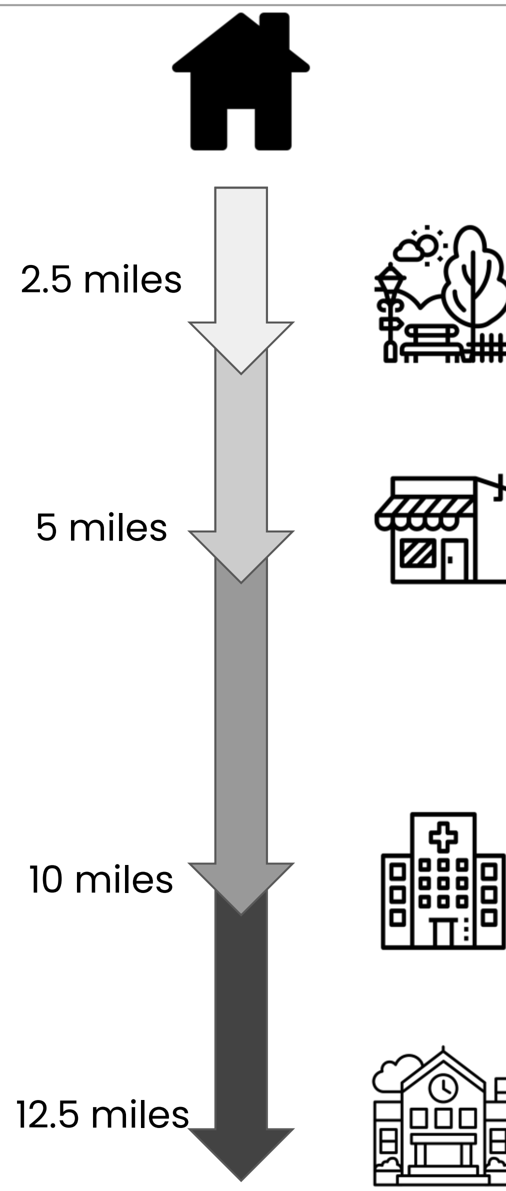
The total time traveled by each driver from home to location and back is called **the time of flight or go-return-time.**

If each car is going 10 mph then we need to multiply the speed x the go-return time and divide that answer by 2 to get the location's distance from home. If we don't divide by two, then we get the entire distance traveled, not just the distance to the location.

Park	10 mph x	0.5 hours =	5 miles / 2 =	2.5 miles from home
Store	10 mph x	1 hour =	10 miles / 2 =	5 miles from home
Hospital	10 mph x	2 hours =	20 miles / 2 =	10 miles from home
School	10 mph x	2.5 hours=	25 miles / 2 =	12.5 miles from home
Max	10 mph x	3 hours =	30 miles / 2	15 miles from home

Just like our 4 friends mapping the town using go-return-time at a constant speed, the ultrasound machine can map the body using similar information.

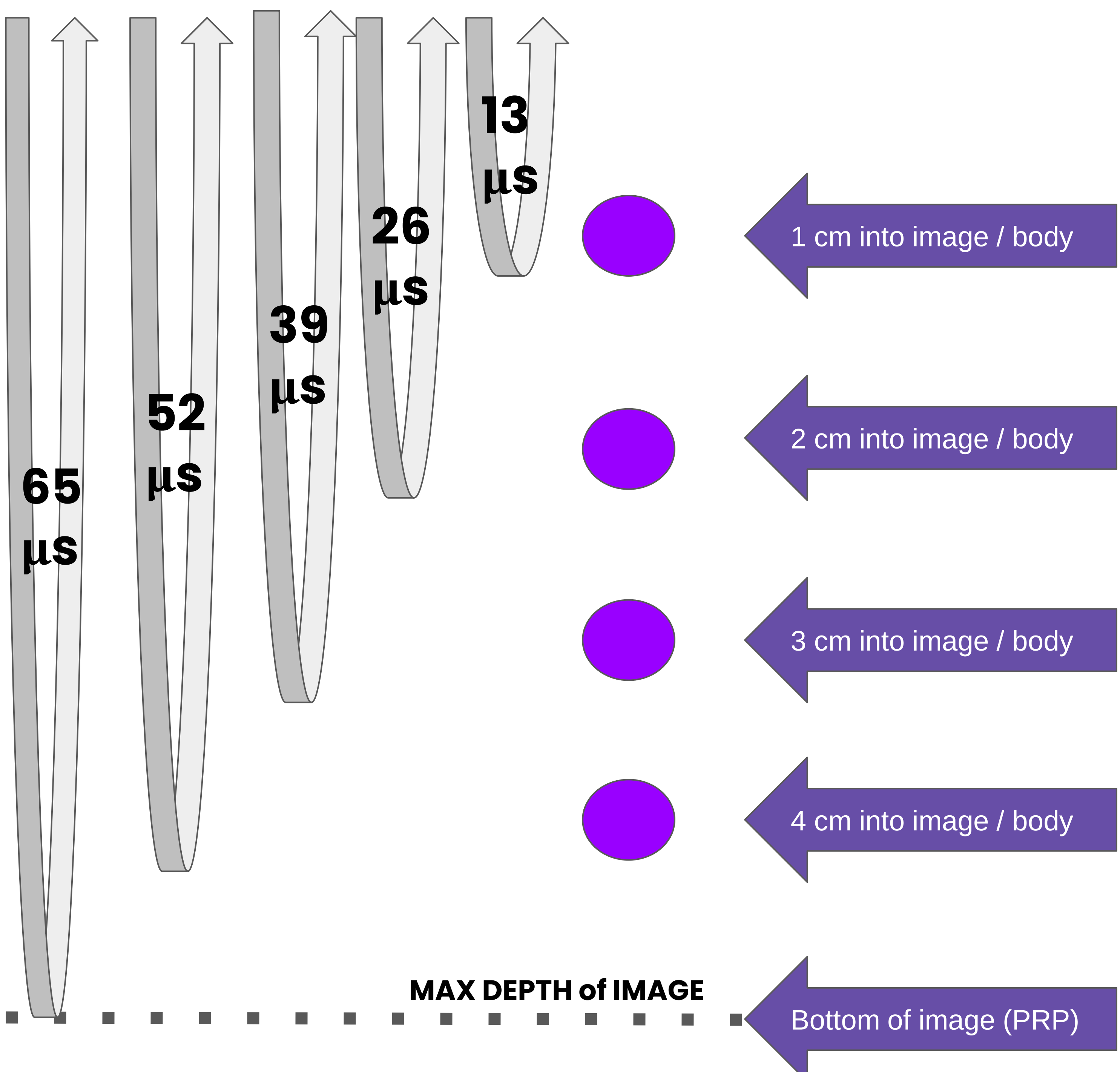
- ➔ One pulse creates information for one scan line.
- ➔ The machine records go-return-time from the start of a pulse to the return of each individual echo of the pulse
- ➔ Machine stops listening for returning echoes from pulse when max depth time has occured
- ➔ Machine calculates depth of reflector based on go-return-time
- ➔ Gray level of reflector is determined by the strength of the echo



To calculate the depth of a reflector, the machine uses this formula:

$$depth\ (mm) = \frac{1.54\,\frac{mm}{\mu s} \times go\ return\ time\ (\mu s)}{2}$$

Note that it is the speed limit x time of flight, all divided by two to calculate the distance from transducer to reflector ***not** the total distance the pulse & echo travel.*



Looking at the math, we can see a pattern emerge, and this gives us:

The 13 microsecond rule:

A sound pulse entering the body returns from a depth of 1 cm for every

13 microseconds of go-return-time.

If it takes a sound pulse to enter the body and return from a reflector a total of 156 μs, the reflector is 12 cm deep. (156 / 13 = 12). If it takes a sound pulse echo 78 μs to return, its reflector is 6 cm deep (78/13 =6).

It is important to note that the 13 μs rule has already taken the division by 2 into account from this formula

$$depth\ (mm) = \frac{1.54\frac{mm}{\mu s} \times go\ return\ time\ (\mu s)}{2}$$

Because if we plugged numbers in it would look like this:

$$10(mm) = \frac{1.54\frac{mm}{\mu s} \times 13(\mu s)}{2}$$

The 13 μs will tell us the depth of a reflector, doubling the depth tells us the total distance the pulse/echo traveled (into body and back).

The machine is calculating much more minute values, as it might get echoes back in 17.3, 17.6 and 18.1 μs, which would require reflectors being displayed at 1.33 cm, 1.35 cm and 1.39 cm respectively, but this is beyond the scope of what you would need to know or calculate.

- **For the 13 μs rule, focus on:**
    - **Whole cm values**
    - **Knowing the difference between depth of reflector and total distance traveled**

Section 7.4 Activities ← Answer Link

1. Fill in the chart - try to do the math in your head or on scratch paper.

Time of Flight	Reflector Depth	TOTAL distance traveled
13 μs		
	10 cm	
		24 cm
52 μs		
	2 cm	
		6 cm

2. Fill in the chart.

Imaging Depth	PRP	PRF
10 cm		
	52 µs	
		5,133 Hz
13 cm		
	26 µs	
		3,850 Hz

3. Looking back on problem #2, what did you notice:
(Increased, decreased, no change)

When the imaging depth increased...

PRP:	

PRF:	

When PRF increased...

PRP:	

Depth:	

When PRP increased...

PRF:	

Depth:	

7.5 Nerd Check!

1. Describe how an image is created.
2. What two things is the time needed to complete a frame based on?
3. How long will the machine listen for echoes from any one pulse?
4. What is PRP?
5. What is PRF?
6. How does imaging depth affect PRP and PRF?
7. What relationship do PRP and PRF have?
8. If a car can only travel 10 miles per hour:
    a. How long would it take to go 30 miles one way?
    b. How long would it take to complete a round trip of 30 miles and back?
    c. How far did the car travel it was driven for 6 hours?
9. If you have a pulse traveling in soft tissue, at 1.54 mm per microsecond:
    a. How long would it take for it to go 5 cm one way?
    b. How long would it take for a round trip of 5 cm and back?
    c. How far did the pulse travel if it propagated for 52 microseconds?
10. What is the PRP of a 5 MHz transducer traveling to max image depth of 10 cm?
11. What is the PRP of a 10 MHz transducer traveling to max image depth of 10 cm?
12. What is the PRP of a 7 MHz transducer traveling to max image depth of 10 cm?
13. Based on propagation speed, what are the two new formulas from PRP and PRF?
14. In general, how does the machine calculate a reflector depth?
15. What does the phrase "time of flight" and go-return-time mean?
16. In more detail, describe the process for displaying a reflector.
17. What causes the reflector to be bright or dark?
18. What is the formula for reflector depth?
19. Why do we need to divide by 2?
20. What is the 13 microsecond rule?
21. List the reflector depth and total distance traveled for these values:
    a. 13 microseconds
    b. 26 microseconds
    c. 39 microseconds
    d. 52 microseconds
    e. 65 microseconds
    f. 78 microseconds
    g. 91 microseconds
    h. 104 microseconds
    i. 117 microseconds
    j. 130 microseconds
    k. 260 microseconds