Sononerds
in the classroom

ARDMS Topic:
Doppler Imaging Concepts

Unit 19: Doppler Physics & Instrumentation

Sononerds Ultrasound Physics
Workbook & Lectures

Unit 19: Doppler Physics & Instrumentation

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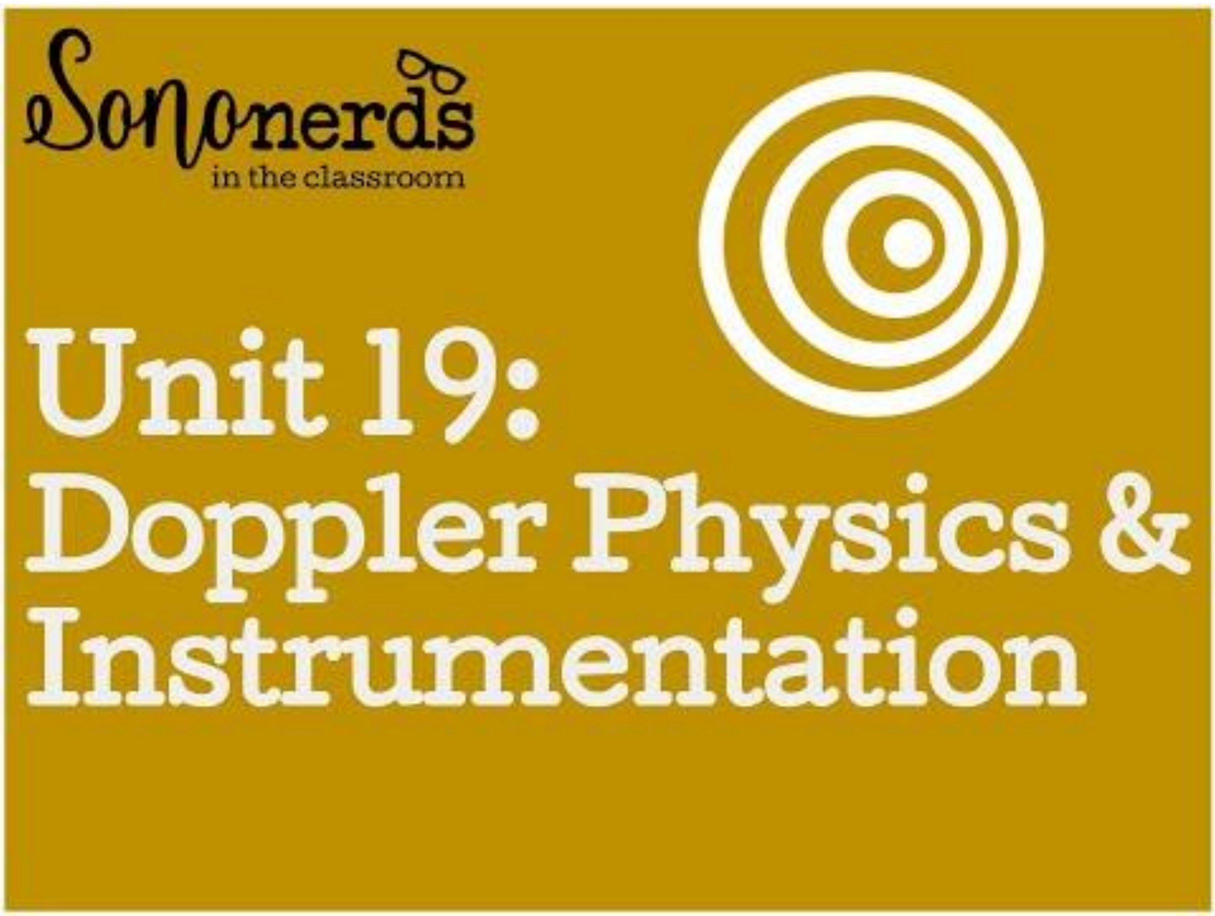


Did you know you can time jump to each section by using the “chapters” in the YouTube video playbar OR timestamps in the video description?

Unit 19: Doppler Physics & Instrumentation

Outside of ultrasound, most of us have experienced a Doppler shift. If you have ever heard an emergency vehicle with their siren active, you may have noticed that the pitch of the siren changed in regards to the vehicles location and you.

The pitch getting higher as the vehicle comes towards you and then sounding lower as it drives away is the called the Doppler effect.

Learning about Doppler as it applies to ultrasound doesn't need to alarm you. We're going to break this down into sections. Unit 19 is going to be the math and physics behind Doppler and unit 20 will be the clinical application of Doppler.

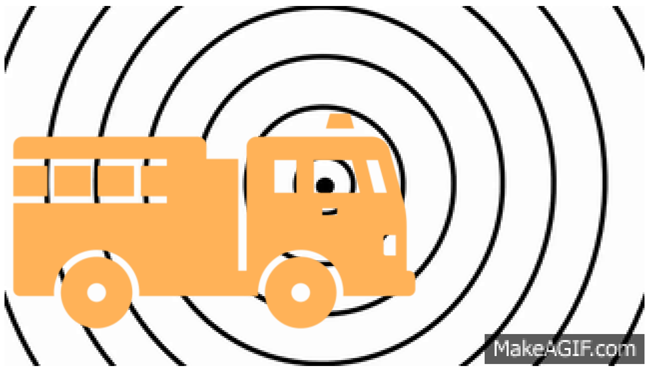
In unit 19 we will cover the Doppler Effect, Doppler shift, the Doppler equation, Continuous wave Doppler, Pulsed Wave Doppler, Color Doppler and the instrumentation.

Section 19.1 Doppler Effect

→ **The Doppler effect is the change in frequency and wavelength caused by the motion of one of 3 things:**
  - **The sound source**
  - **The receiver**
  - **The reflector**

Let's use the siren on a moving vehicle as our example,

The fire truck's siren produces a sound with a frequency of **800 Hz.**



If the truck is stationary, you perceive the siren's sound, to also be **800 Hz.**

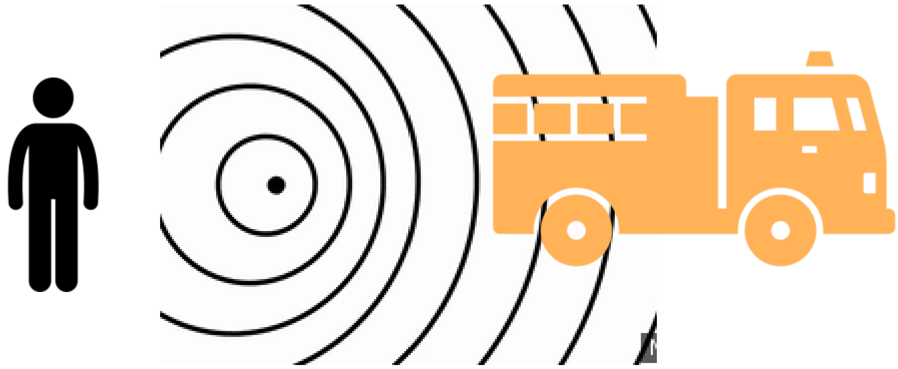
Note that the wavelengths are equal and true to the 800 Hz.

If the fire truck is moving towards you, the siren is still producing a sound with a frequency of **800 Hz.**

Now the soundwaves are being compressed faster, causing shorter wavelengths, short wavelengths = higher frequency.

As the truck moves towards you, the particles begin to oscillate faster. The shorter wavelengths increases the frequency you can hear. You perceive the the siren's sound, to also be **820 Hz.**

As the truck moves away from you, the particles oscillate slower. The longer wavelengths decreases the frequency you can hear. You perceive the the siren's sound, to also be **780 Hz.**



If the fire truck is moving away from you, the siren is still producing a sound with a frequency of **800 Hz.**

Now the soundwaves are being stretched out, causing longer wavelengths,
Long wavelengths =
Lower frequency.

In this example the Doppler effect is the physical phenomenon that the sound pitch changed as the sound source moved due to the frequency and wavelength changes perceived by the receiver.

In short:

- ➔ A sound source or reflector moving towards the receiver causes:
  - ◆ Short wavelengths
  - ◆ Higher frequency
  - ◆ Higher pitch
- ➔ A sound source or reflector moving away from the receiver causes:
  - ◆ Longer wavelengths
  - ◆ Lower frequency
  - ◆ Lower pitch

- ➔ **The change in frequency due to motion is the Doppler shift.**

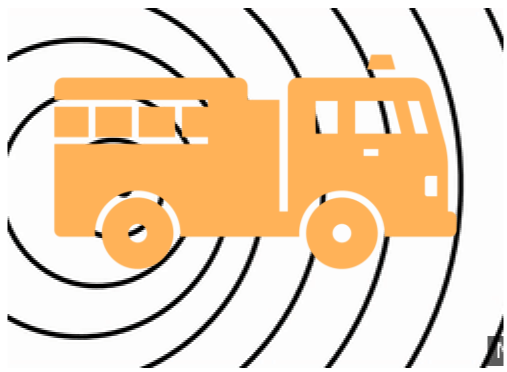
Section 19.2 Doppler Shift

→ **The change in frequency due to motion is the Doppler shift.**

The Doppler shift can be calculated by taking the received frequency and subtracting the transmitted frequency.

$$Doppler\ Shift\ (Hz) = Frequency_R - Frequency_T$$

Let's use the fire truck again:



780 Hz

800 Hz

820 Hz

The transmitted frequency of the siren is 800 Hz.

When stationary, the received frequency is 800 Hz, this makes the Doppler shift 0 Hz. There is no change because there is no motion.

$$800\ Hz - 800\ Hz = 0\ Hz$$

When the truck is moving towards the receiver, the receiver perceives a frequency of 820 Hz. This makes the Doppler shift 20 Hz.

$$820\ Hz - 800\ Hz = 20\ Hz$$

When the truck is moving away from the receiver, the receiver perceives a frequency of 7800 Hz. This makes the Doppler shift -20 Hz.

$$780\ Hz - 800\ Hz = -20\ Hz$$

Notice that when the received frequency was greater than the transmitted, we got a **positive** Doppler shift and when the received frequency was less than the transmitted, we got a **negative** Doppler shift.

- **Positive Doppler Shift**
  - **Object is moving towards the receiver**
  - **Received frequency is greater than transmitted**

- **Negative Doppler Shift**
  - **Object is moving away from the receiver**
  - **Received frequency is less than transmitted**

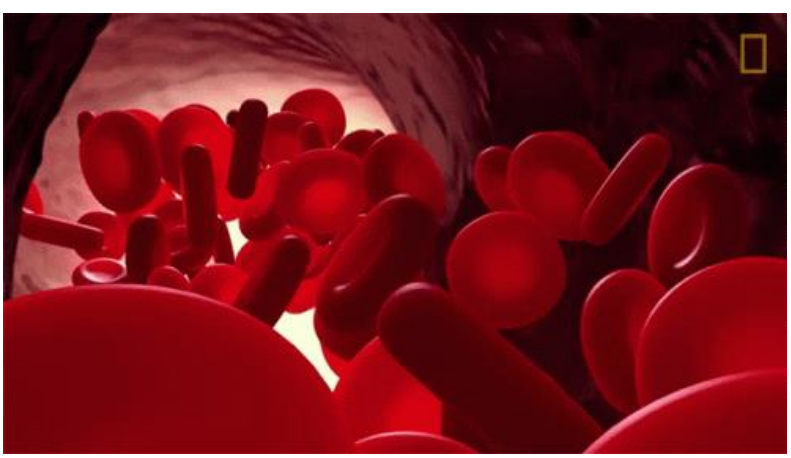
19.2.1 Doppler Shift & Blood Cells

A Doppler shift can be detected by the machine when it evaluates the frequency of the echoes being returned off of the moving reflectors, which are the red blood cells.

When red blood cells are moving towards the transducer location, they will reflect back **higher** frequencies than what the transducer is producing.

When red blood cells are moving away from the transducer location, they will reflect back **lower** frequencies than what the transducer is producing.

The RBCs moving towards the transducer produce a positive shift, where the RBCs moving away from the transducer produce a negative shift.



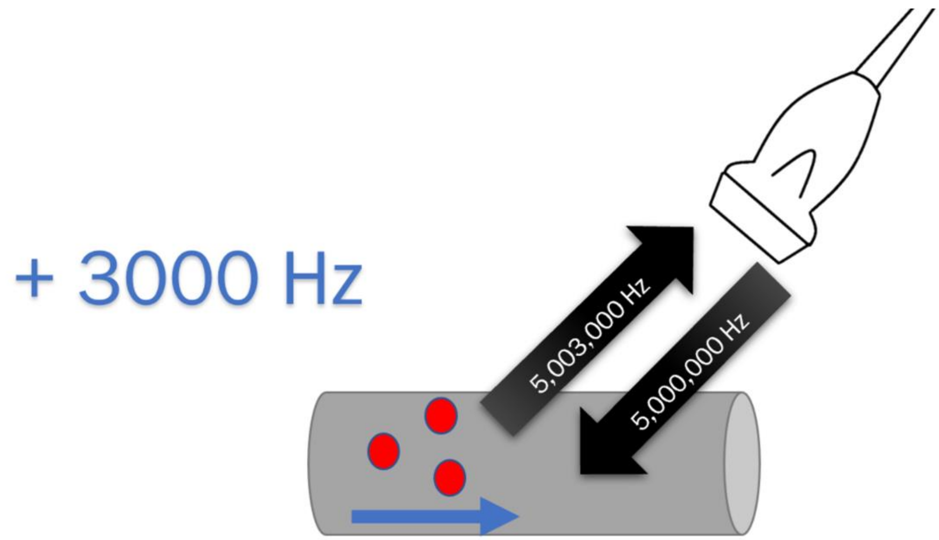
Let's look at an example of what how a Doppler shift might look using ultrasound numbers. Remember the Doppler shift is calculated:

$$Doppler\ Shift\ (Hz) = Frequency_R - Frequency_T$$

Let's use a 5 MHz transducer - remember this is the same as 5,000,000 Hz.

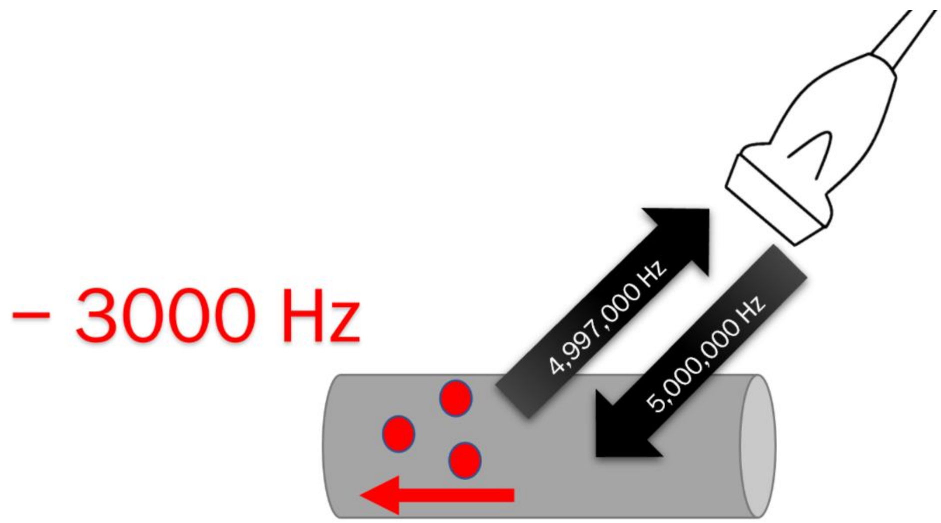
The transducer transmits a frequency of 5,000,000 Hz.
The sound wave strikes a red blood cell.

If the RBC is moving **towards** the transducer, (depending on how fast it is going) will reflect a sound wave with a frequency **greater** than 5,000,000. For this examples, let's say it reflected a 5,003,000 Hz frequency.



$$5{,}003{,}000\ Hz - 5{,}000{,}000\ Hz = 3{,}000\ Hz$$

If the RBC is moving **away from** the transducer, (depending on how fast it is going) will reflect a sound wave with a frequency **less** than 5,000,000. For this examples, let's say it reflected a 4,997,000 Hz frequency.



$$4{,}997{,}000\ Hz - 5{,}000{,}000\ Hz = -3{,}000\ Hz$$

The machine receives the reflected frequency along with a lot of other frequencies. When Doppler instrumentation is being used, the machine uses the demodulator to **demodulate or** identify those small frequency shifts and extract them from the high ultrasound frequencies for further processing.

There are some key facts that you need to know about Doppler shifts and their relationship to ultrasound:

- ➔ Doppler shift is a shift in **frequencies**, not amplitude, intensity or speed

- ➔ Since Doppler shift is a frequency, the unit for Doppler shift is **Hertz**

- ➔ In ultrasound the Doppler shifts we can detect range between **20 Hz to 20,000 Hz. (-20 Hz to -20,000 Hz depending on direction)**

- ➔ Since ultrasound Doppler shifts range between 20 Hz to 20 kHz, this makes the Doppler shift **audible.**

- ➔ The Doppler shift is what is detected and calculated by the machine using a complex formula. BUT, Doppler shift is not diagnostic, we want velocities. By rearranging the formula and performing calculations, the machine can display the velocity of blood.

Section 19.3 Doppler Equation

The Doppler equation is truly how the Doppler Shift is calculated. Our machines can detect a difference of frequencies, using the very simple Doppler shift equation.

$$Doppler\ Shift\ (Hz) = Frequency_R - Frequency_T$$

It can take the Doppler shift value and then calculate the velocity of the blood flowing through the sampled area.

The velocity of the blood is much more important to sonographers.

But we need to know the Doppler Equation, so we can rearrange it to solve for velocity.

In its expanded form:

$$Frequency_{Doppler\ Shift}(kHz) = \frac{2 \times Frequency_{operating}(kHz) \times Velocity\left(\frac{cm}{s}\right) \times cos\theta}{propagation\ speed\left(\frac{cm}{s}\right)}$$

Shortened:

$$f_D(kHz) = \frac{2 \times f_O(kHz) \times v\left(\frac{cm}{s}\right) \times cos\theta}{c\left(\frac{cm}{s}\right)}$$

Even shorter:

$$f_D = \frac{2 \times f_O \times v \times cos\theta}{c}$$

All of these formulas are the same, they just have extra information in them.

- ➔ **You need to know the Doppler equation.**

Start with the shortened form so you know the components of the Doppler Equation and how they are related. We will use the expanded forms to demonstrate the math which is why we need the units. The units are VERY important to our calculations.

19.3.1 Doppler Shift (kHz)

$$f_D(kHz) = \frac{2 \times f_O(kHz) \times v\left(\frac{cm}{s}\right) \times cos\theta}{c\left(\frac{cm}{s}\right)}$$

The whole equation allows us to calculate the Doppler shift. We need to know all of the variables to be able to do this.

However, the machine is able to determine this variable using the demodulator.

We will see later how this play a role into calculating the velocity, but for now remember that Doppler shift is the change in frequencies because of moving objects.

19.3.2 2

$$f_D(kHz) = \frac{2 \times f_O(kHz) \times v\left(\frac{cm}{s}\right) \times cos\theta}{c\left(\frac{cm}{s}\right)}$$

The “2” in the equation is a constant and will always be there.

The 2 represents the fact that there will be a Doppler shift when the transmitted beam strikes the RBC and another Doppler shift when the RBC reflects the sound.

19.3.3 Operating Frequency (kHz)

$$f_D(kHz) = \frac{2 \times f_O(kHz) \times v\left(\frac{cm}{s}\right) \times cos\theta}{c\left(\frac{cm}{s}\right)}$$

The operating frequency is the frequency that is transmitted by the ultrasound transducer.

Pay attention to the units. If we are using a 5 MHz transducer, we would want to use 5,000 kHz, in the equation.

This variable is known by the machine as it is determined by the machine.

19.3.4 Velocity (cm/s)

$$f_D(kHz) = \frac{2 \times f_O(kHz) \times v\left(\frac{cm}{s}\right) \times cos\theta}{c\left(\frac{cm}{s}\right)}$$

For the Doppler equation as it is, velocity needs to be a known variable. However, in the case of ultrasound we do not know velocity. We'll see later how to rearrange the formula to solve for velocity.

In the meantime though let's define what velocity is.

➔ **Velocity is the speed and direction of a moving object.**

Speed is **distance / time.** In ultrasound we often look at speed in the unit of "centimeters per second" or cm/s. To translate this into a velocity, we need to know a direction. In ultrasound the direction is as simple as toward the transducer (positive) or away from the transducer (negative). However, it is calculated by knowing the angle of flow in relation to the sound beam.

19.3.5 cos**θ**

$$f_D(kHz) = \frac{2 \times f_O(kHz) \times v\left(\frac{cm}{s}\right) \times cos\theta}{c\left(\frac{cm}{s}\right)}$$

The last sentence of velocity read:

[Direction] is calculated by knowing the angle of flow in relation to the sound beam.

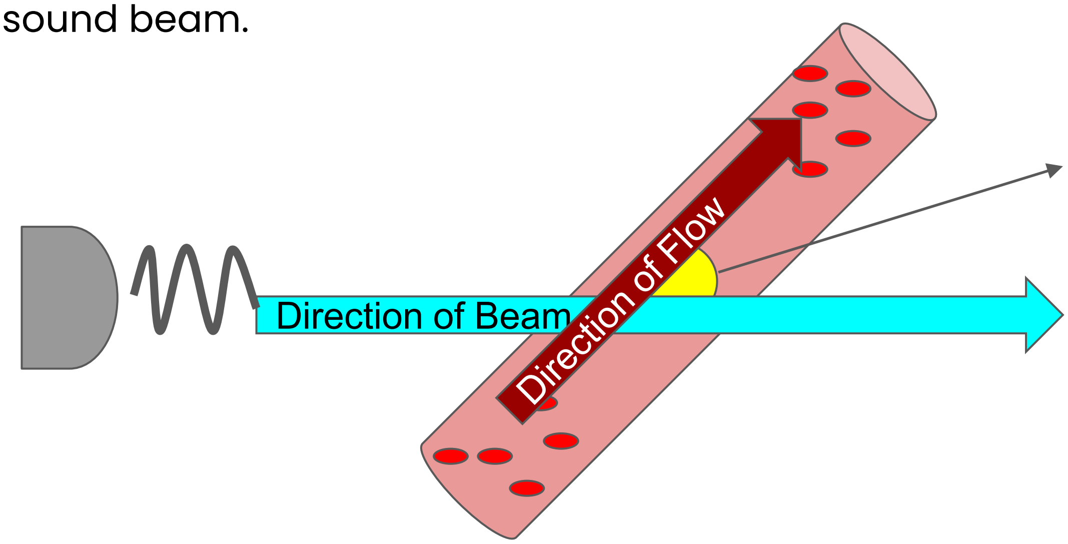
This is where the "cosine of theta" - cos**θ** applies.

➔ **To accurately calculate Doppler shift & velocity the angle of flow to the the scan line must be known.**

We can think of the cos**θ** as a modifier for velocity. It will tell us if flow is away or towards the transducer (negative or positive). This is important to know as well, because if the sound beam is not parallel with the flow, only a fraction of the Doppler shift is reported.

The symbol **θ** is the greek letter theta, and is used to represent an angle.

In ultrasound, the angle is between the direction of flow and the direction of the sound beam.



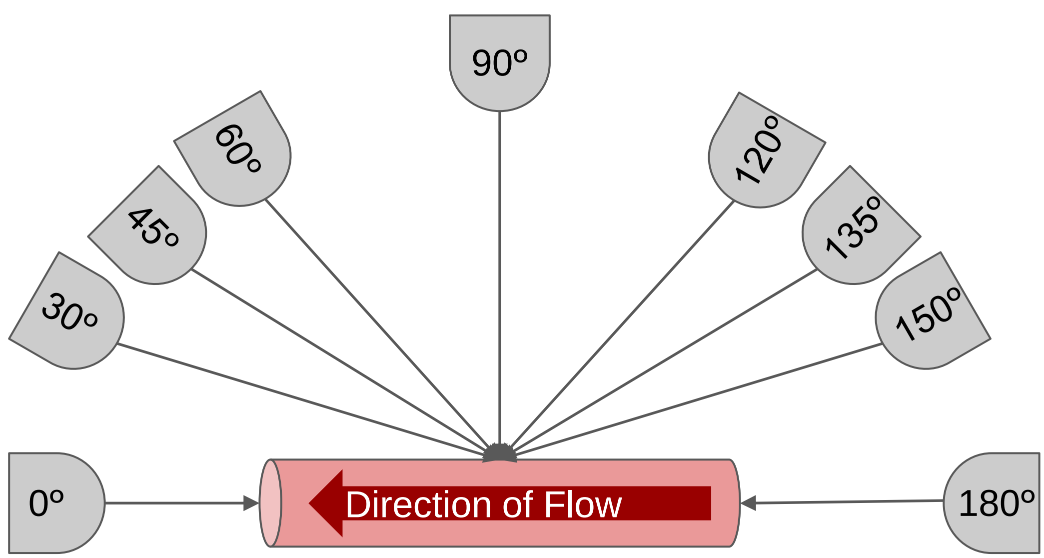
This is theta or the angle of blood flow to the direction of the sound beam.

There are a few theta degrees that are super important to ultrasound to know.

- When the beam is **parallel** to the flow:
  - θ = 0° when flow is toward the transducer
  - θ = 180° when flow is away from the transducer
  - **This provides the most accurate and greatest Doppler Shifts**
  - **This provides the most accurate and lowest velocity information**

- Changing theta to other degrees changes the accuracy of the measured velocity
  - If θ = 30° or 150° it is less accurate
  - If θ = 45° or 135° it is even less accurate
  - If θ = 60° or 120° it is the threshold of inaccuracy that we allow in ultrasound
- **Theta should NEVER exceed 60° (120°)**

- **No Doppler Shift (or velocity) can be detected when θ = 90°**
  - Doppler should never be attempted when the sound beam is **perpendicular** to flow of blood
  - The machine cannot tell if blood if flowing away or towards the transducer when the angle is 90 degrees.



Once we know what theta is, then cosine can be applied. Cosine is a trigonometry function that gives us a ratio. We don't really need to know much more of the math than these charts.

θ	cosθ
0°	1
30°	0.87
45°	0.7
60°	0.5
90°	0

θ	cosθ
180°	-1
150°	-0.87
135°	-0.7
120°	-0.5
90°	0

Thinking about these cosine values and positive and negative shifts, here are some key takeaways:

- ➔ When cosθ is positive, a positive Doppler shift is calculated
- ➔ When cosθ is negative, a negative Doppler shift is calculated
- ➔ When cosθ = 1 or -1, this is the most accurate velocity we are getting a true velocity calculated. Using a 0 degree angle is best when possible.
- ➔ When cosθ is anything other 1 or -1 only a portion of the Doppler shift is measured. The closer to 1 cosθ is, the more accurate it is.
- ➔ When theta is 60 degrees, cosθ = 0.5. Theta should never exceed 60 (120) degrees when Dopplering a vessel.
- ➔ When theta is 90 degrees, cosθ = 0. When used in the Doppler equation, we end up with 0/c. Zero divided by anything is zero. Therefore, no Doppler shift can be detected. Never Doppler at 90 degrees to blood flow.

19.3.6 c (cm/s)

$$f_D(kHz) = \frac{2 \times f_O(kHz) \times v\left(\frac{cm}{s}\right) \times cos\theta}{c\left(\frac{cm}{s}\right)}$$

Lastly, is variable "c" or propagation speed. Remember that propagation speed is determined by the medium. So for ultrasound we default to the soft tissue propagation speed of 1540 m/s,

BUT this formula requires propagation speed to be in cm/s, so to be accurate for the formula, we would use **154000 cm/s.**

This is also a constant when we look at Doppler shift from an ultrasound perspective.

19.3.7 Doppler Equation Relationships

$$f_D(kHz) = \frac{2 \times f_O(kHz) \times v\left(\frac{cm}{s}\right) \times cos\theta}{c\left(\frac{cm}{s}\right)}$$

As with all of our formulas that we learn, we want to spend some time looking at the relationships that we can see.   Since propagation speed is a constant in ultrasound, we really only need to focus on 3 variables and their relationship to Doppler shift:

- Operating frequency
- Velocity
- Cos**θ**

The other good news is that all 3 of the variables are in the numerator position, so all three variables are **directly related** to Doppler shift.

These relationships will be important when asked about how variables will change in relation to one another.

You will not be given values of variables and asked to complete the calculation.

However you may be asked a question like this:

> *The Doppler shift with a 4 MHz transducer is 3,000 Hz. If the sonographer switches to an 8 MHz transducer, what happens to the Doppler shift?*

You can answer this question knowing that if frequency increases, then Doppler shift increases

A correct answer here would either be doubles, increases by a factor or 2 or 6,000 Hz, depending on the options you're given.

On the next few pages though, I do have some examples of plugging in variable values and seeing what we get, and how the Doppler shift if affected.

See if you can work through what will happen before looking at the math.

19.3.8 Sample Calculations to Show Relationships

1. Calculate the Doppler shift based on this information:

Transducer:	4 MHz
Velocity of Blood	100 cm/s
Doppler Angle	60°

$$2.6\ (kHz) = \frac{2\ \times 4{,}000(kHz)\ \times\ 100\ \left(\frac{cm}{s}\right)\ \times\ 0.5}{154{,}000\left(\frac{cm}{s}\right)}$$

2.6 kHz is the same as 2600 Hz. This is a positive value, so a positive shift. Remember this example, the others will be variants of it.

2. Calculate the Doppler shift based on this information:

Transducer:	8 MHz
Velocity of Blood	100 cm/s
Doppler Angle	60°

Doubled the frequency compared to Example #1…what will happen?

$$5.2\ (kHz) = \frac{2\ \times 8{,}000(kHz)\ \times\ 100\ \left(\frac{cm}{s}\right)\ \times\ 0.5}{154{,}000\left(\frac{cm}{s}\right)}$$

Doppler shift doubled!

3. Calculate the Doppler shift based on this information:

Transducer:	4 MHz
Velocity of Blood	300 cm/s
Doppler Angle	60°

Tripled the velocity compared to Example #1…what will happen?

$$7.8\ (kHz) = \frac{2 \times 4{,}000(kHz) \times 300\ \left(\frac{cm}{s}\right) \times 0.5}{154{,}000\left(\frac{cm}{s}\right)}$$

Doppler shift tripled!

4. Calculate the Doppler shift based on this information:

Transducer:	4 MHz
Velocity of Blood	100 cm/s
Doppler Angle	0°

Changed the angle to 0 degrees….what will happen?

$$5.2\ (kHz) = \frac{2\ \times 4{,}000(kHz)\ \times\ 100\ \left(\frac{cm}{s}\right)\ \times 1}{154{,}000\left(\frac{cm}{s}\right)}$$

Doppler shift doubled! Cosine of 60 degrees is 0.5. Cosine of 0 degree is 1. This change made cosine double, so Doppler shift doubled too.

5. Calculate the Doppler shift based on this information:

Transducer:	4 MHz
Velocity of Blood	100 cm/s
Doppler Angle	180°

Changed the angle to 180 degrees….what will happen?

$$-5.2\ (kHz) = \frac{2\ \times 4{,}000(kHz)\ \times\ 100\ \left(\frac{cm}{s}\right)\ \times -1}{154{,}000\left(\frac{cm}{s}\right)}$$

Doppler shift doubled, but it now negative. This implies that the angle of blood flow has changed so that blood is flowing away from the transducer.

6. Calculate the Doppler shift based on this information:

Transducer:	4 MHz
Velocity of Blood	50 cm/s
Doppler Angle	60°

Changed the velocity to ½ of example #1's….what will happen?

$$1.3\ (kHz) = \frac{2\ \times 4{,}000(kHz)\ \times 50\ \left(\frac{cm}{s}\right)\ \times\ 0.5}{154,000\left(\frac{cm}{s}\right)}$$

Doppler shift halved. They are directly related.

7. Calculate the Doppler shift based on this information:

Transducer:	4 MHz
Velocity of Blood	100 cm/s
Doppler Angle	90°

Changed the angle to 90 degrees….what will happen?

$$0\ (kHz) = \frac{2\ \times 4{,}000(kHz)\ \times\ 100\ \left(\frac{cm}{s}\right)\ \times 0}{154,000\left(\frac{cm}{s}\right)}$$

Doppler shift cannot be detected. Cosine of 90 degrees is 0, making the whole numerator 0.

Section 19.4 Velocity of Blood

Learning the Doppler equation will help us to bridge to calculating the velocity of blood. The machine already knows what the Doppler shift is, so what really needs to be calculated is the velocity.

$$v\left(\frac{cm}{s}\right) = \frac{c\left(\frac{cm}{s}\right) \times f_D(kHz)}{2 \times f_O(kHz) \times cos\theta}$$

By rearranging the Doppler equation, we can now solve for the variable that the machine doesn't know. The values and rules for each variable are the same.

- ➔ **Know the velocity formula (or how to rearrange the Doppler Equation)**

19.4.1 Velocity Relationships

Velocity relationships are a little trickier than the Doppler equation now that everything has been rearranged. We know that the value for "c" in ultrasound won't change.

Looking at the equation we can see that:

- ➔ Doppler Shift and velocity are directly related
- ➔ Operating frequency and velocity are inversely related
- ➔ Cos θ and velocity are inversely related

Your ability to do complex math again will not be tested, but your knowledge of relationship will be.

If the Doppler shift doubles, what happen to velocity? What happens to velocity when the Doppler angle changes from 0 degrees to 60 degrees?

19.4.2 Accurate Velocities

When we learned about the Doppler equation, we talked about the cosine of theta being a modifier on the velocity.

Recall that when the cosine value became less then 1 (or -1) we were only reporting on a fraction of the true velocity.

- ➔ **The most accurate velocity is measured when the sound beam is parallel with the flow.**

Being parallel with the flow is the most accurate way to obtain a true velocity measurement. We are capable of finding windows on the abdomen and heart that allow the transducer to be parallel with the flow.

This is not true for Dopplering of limbs and the neck. It is nearly impossible to be at 0° (or 180°) to the flow.

- ➔ **It is acceptable to be at 60° or less when performing Doppler.**

When a 60° Doppler angle is used to obtain Doppler information, the resulting velocity is actually twice of the true velocity because the cosine of 60° is 0.5. And inversely related to velocity. But, we're still okay with this! Ultrasound values used for diagnosing know there are limitations to equipment.

We will discuss later how the sonographer tells the machine at what angle they are insonating the blood flow. It is through a piece of Doppler instrumentation called **angle correct.**

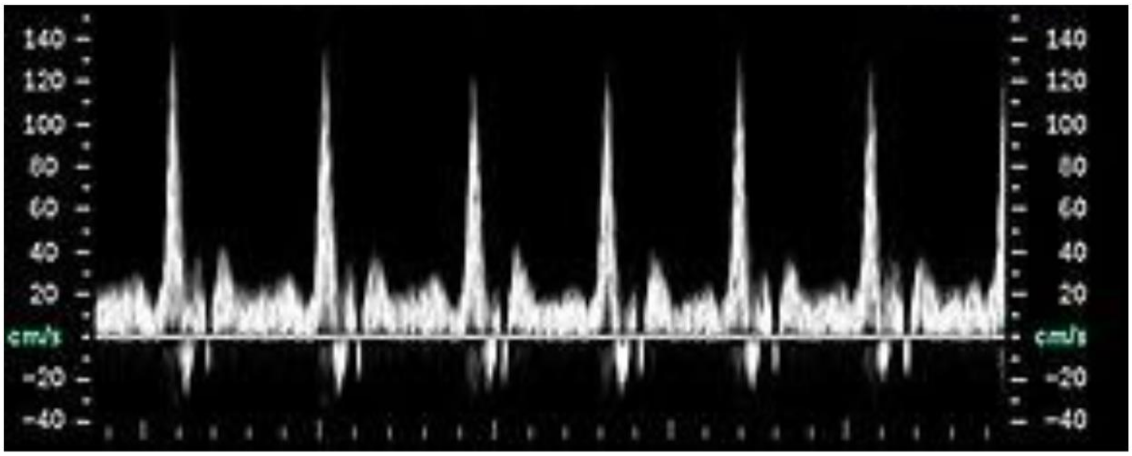
- ➔ **Any angle above 60° (or less than 120°) is too inaccurate for diagnostic ultrasound. 90° is the absolute worse.**

Any velocities measured between 61 degrees and 119 degrees is not diagnostic. Most significantly, a Doppler angle of 90 degrees will cannot calculate a velocity. (can't divide by 0!)

The cosine of theta also determines if the blood is flowing away or towards the transducer. Remember that direction is important to the value of velocity.

When a velocity is reported, it will be displayed as either above or below the baseline.

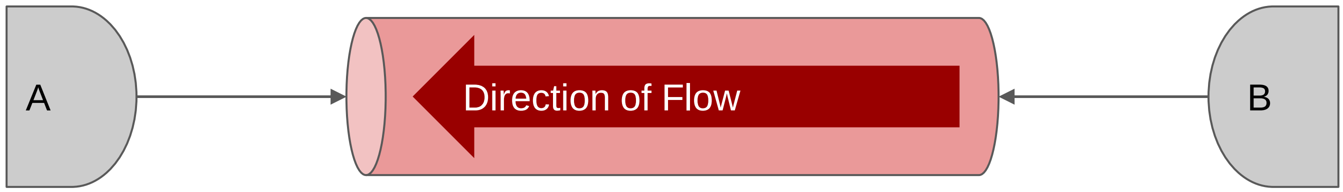
Take a look at this spectral tracing. You can see that these are velocities reported in cm/s and above the baseline are positive, below are negative. Using a measuring tool , the sonographer could measure the velocity recorded at any point along the spectral tracing. It will be accurate (enough) as long as the angle is 60 degrees or less.

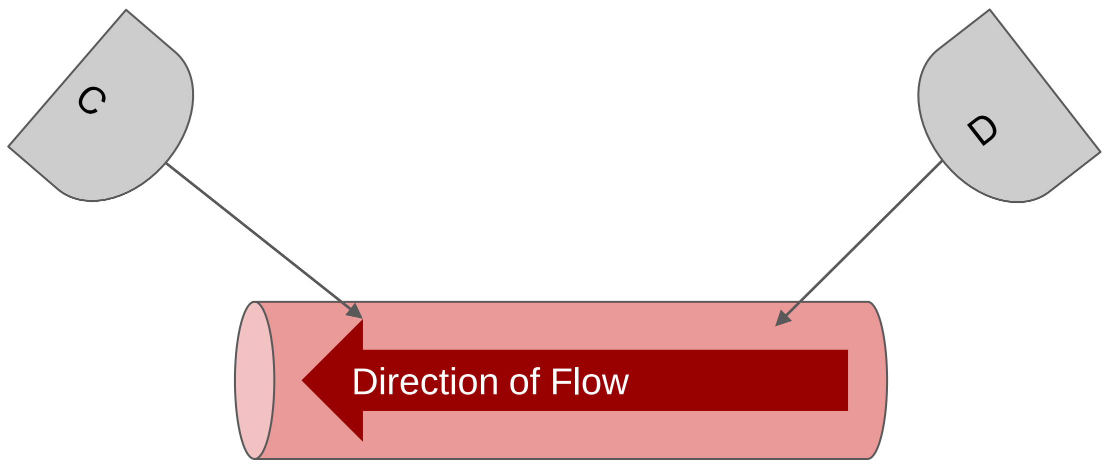


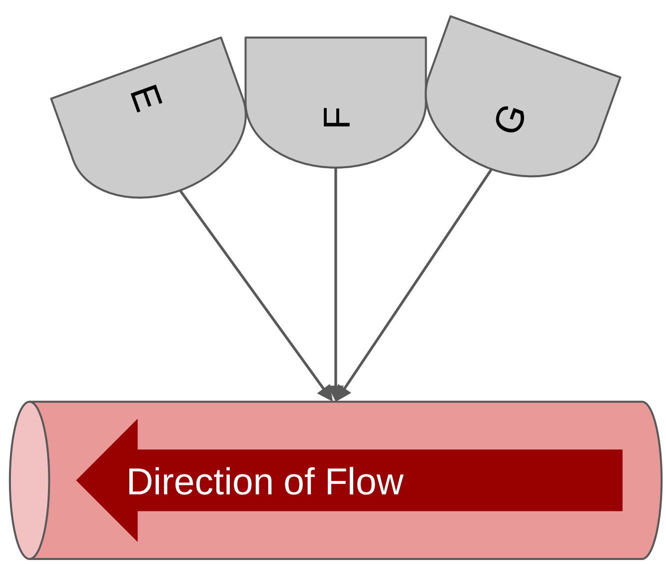
19.4.3 Practice

Take a look at the diagrams on the next page - which transducer(s) will produce:

- Most accurate velocities?
- Acceptably accurate velocities?
- Negative Doppler shifts?
- Positive Doppler shifts?
- No Doppler shift?
- The greatest Doppler shift?
- The smallest Doppler shift?
- The highest velocities?
- The lowest velocities?
- No velocity?


A
Direction of Flow
B


C
D
Direction of Flow


E
F
G
Direction of Flow

Section 19.5 Doppler Instrumentation

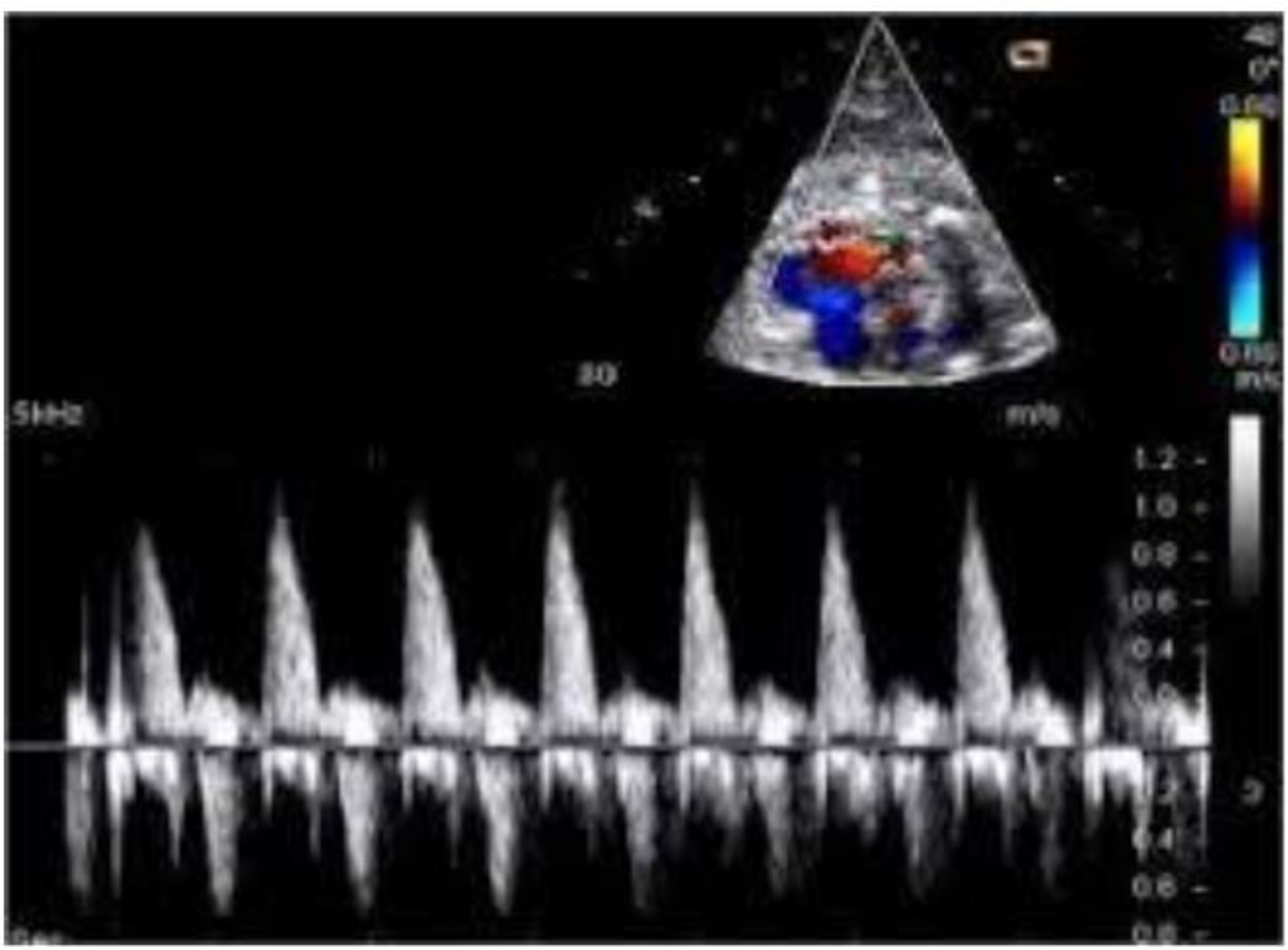
Modern machines allow for bidirectional Doppler detection. This means that they can recognize and display blood flow that is moving towards or away from the transducer.

The reason modern machines can do this is because they can use **phase quadrature.**

- **Phase quadrature or quadrature detection can analyze the Doppler signal to determine the direction flow is in relation to the transducer.**

In ultrasound, spectral Doppler signals can be obtained through **Continuous-wave Doppler and Pulsed- wave Doppler.** These produce a graph showing the velocities of RBCs as they pass through the ultrasound beam.

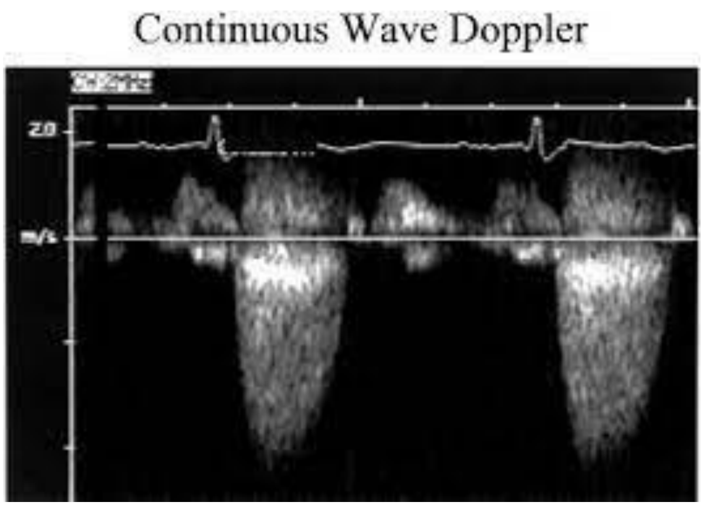
Color flow, is also a type of Doppler that uses pulsed-wave ultrasound. Colors are placed over an image to indicate direction and average velocities.



Section 19.6 Continuous Wave Doppler

Recall that continuous wave ultrasound beams CANNOT produce an anatomical image, but they can produce Doppler shifts, which can be graphed into a spectral waveform.

CW Doppler is most commonly used in cardiac applications and during physiologic vascular testing.

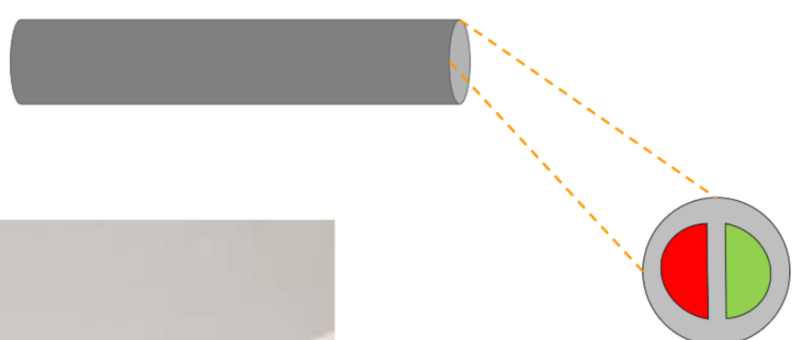


19.6.1 CW Transducers

In the transducer unit, we talked about CW transducers, but to review:

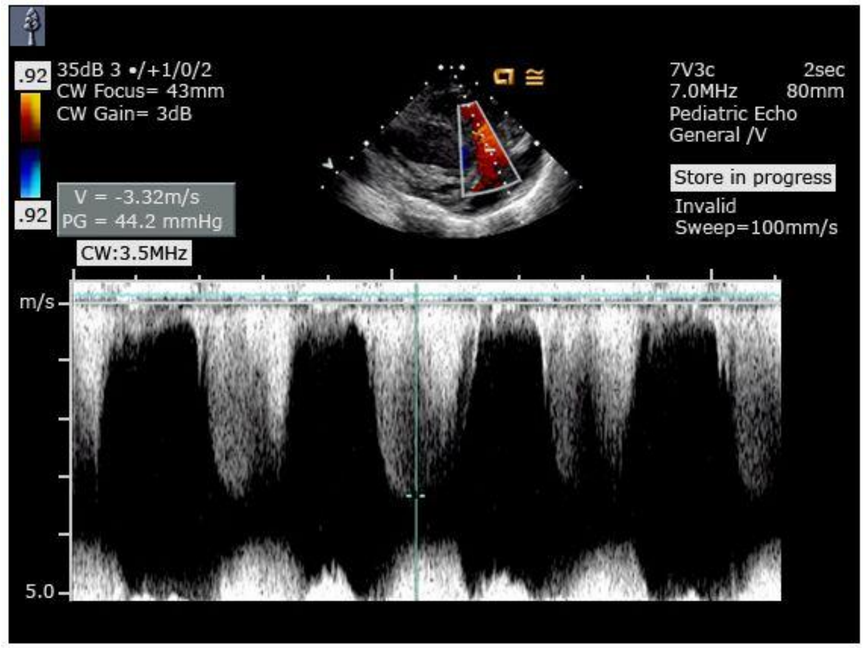
Dedicated continuous wave transducers:

- ➔ Have 2 crystals (one to transmit, one to receive)
- ➔ Are on 100% of the time
- ➔ Are very sensitive
- ➔ Have no backing material
- ➔ Have a High Q Factor
- ➔ Have a narrow bandwidth



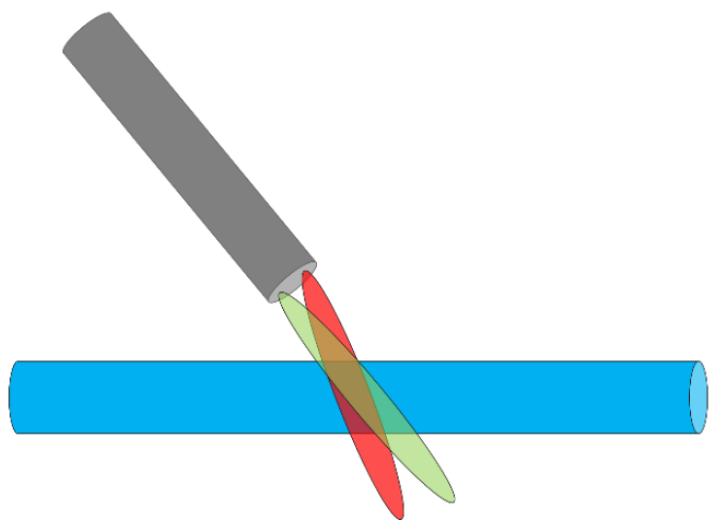
Phased Array transducers are capable of creating images and using 2 crystals to perform CW Doppler tasks. **Continuous wave transducers always need 2 crystals to operate.**

This is an example of an array transducer producing both an image and CW Doppler tracing on the bottom.

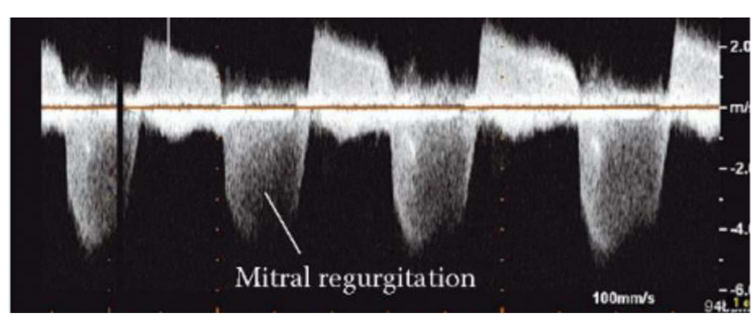


19.6.2 Obtaining CW Doppler

When sound is emitted from one crystal, the other crystal's listening "path" overlaps, creating a large area from which the transducer can receive echoes from. This area is called the **sample volume.** Because there is no imaging to guide the sonographer, they must rely on anatomical knowledge and vascular analysis to interrogate the correct area.



The resulting image is a graph that represents velocities detected from the sample volume. Many sonographers also use speakers to evaluate the flow through the sample volume. *Remember that Doppler shifts are audible!



19.6.3 CW Pros & Cons

There are advantages and disadvantages to using a CW transducer. These however have more clinical implications and will be discussed further in Unit 20.

As a preview though:

Advantages:

- ➔ Ability to detect VERY HIGH velocities
- ➔ No aliasing

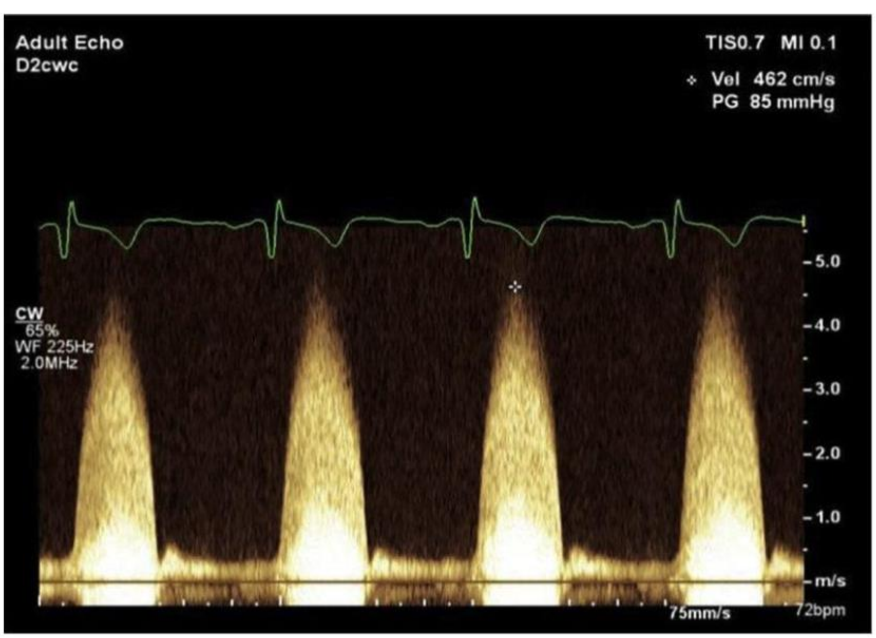
Aliasing is limited by the PRF of the machine. CW has a very high sample rate and is not subject to aliasing

Disadvantages:

- ➔ Range Ambiguity
- ➔ No TGC for display

The CW transducer creates a very large area that the sample can return from. The large area makes it difficult to know exactly where sound is returning from.

It also cannot account for attenuation of the sound beam. This makes it appear that less RBCs are creating signals that are further away.

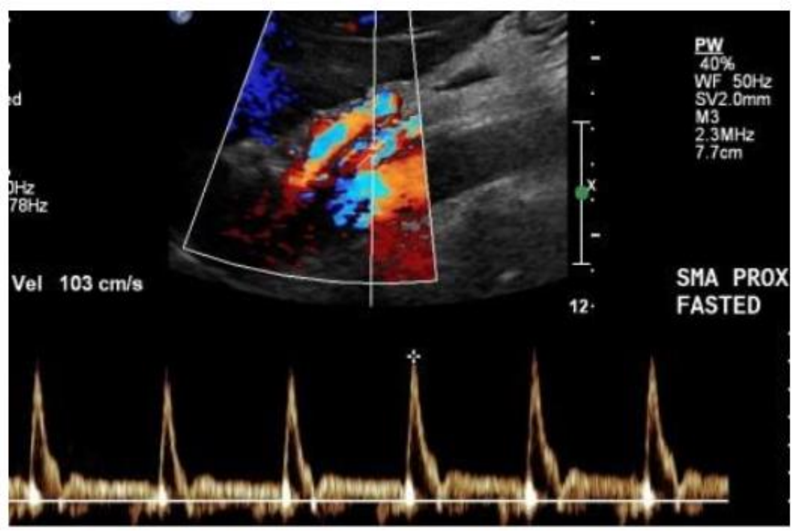


Section 19.7 Pulsed-Wave Doppler

Recall that Pulsed wave ultrasound CAN create an image and only needs one crystal to do so. The same is true for PW Doppler. Only one crystal is needed to create a Doppler spectral tracing. Since all of our modern transducers that can produce images can also produce pulsed- wave Doppler, it is very common that multiple modes are used during an exam.

When the machine is creating an anatomical image and Doppler tracing (or color) it is called **Duplex Imaging.**

When a machine is creating a 2D image, color, and spectral tracing it is called **Triplex Imaging.**



It is very rare for spectral tracings to be obtained without color as well.

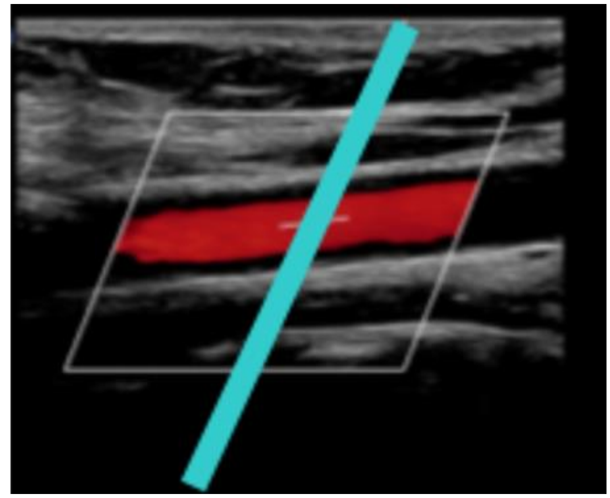
19.7.1 PW Transducers

In the transducer unit, we talked mostly about PW transducers, but to review:

Pulsed wave transducers:

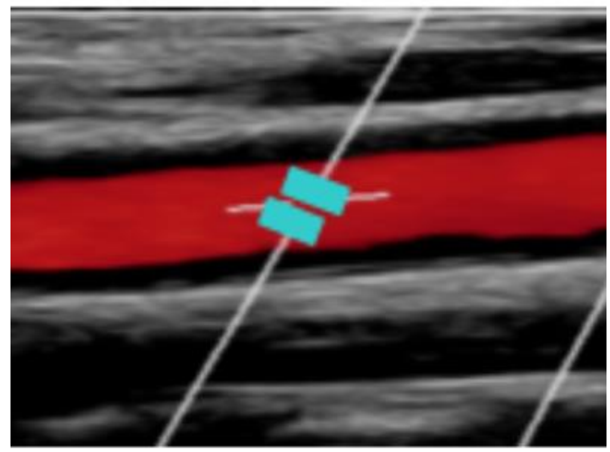
- ➔ Nead at least 1 crystal
- ➔ Are on a small fraction time (mostly listening)
- ➔ Have low sensitivity
- ➔ Have backing material
- ➔ Have a low Q Factor
- ➔ Have a wide bandwidth

19.7.2 Obtaining PW Doppler



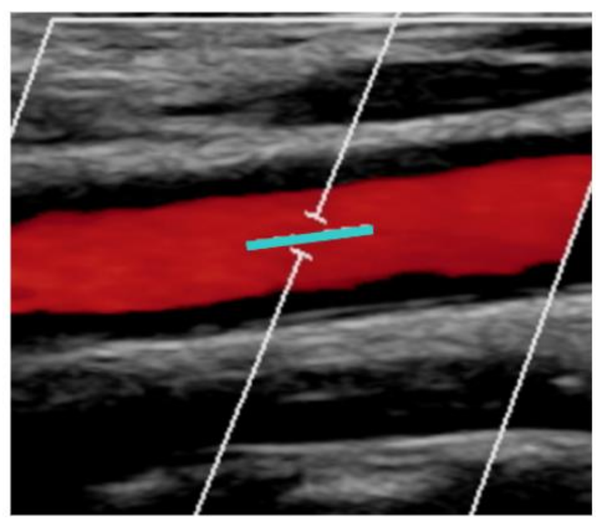
PW Doppler is activated on the console using a knob or button. The machine will display one scanline over a 2D image.

In the scan line are 2 parallel lines. This is called the **sample gate or sample volume.** The size of the gate is adjustable.



The sonographer can place the sample gate where ever they like in the image.

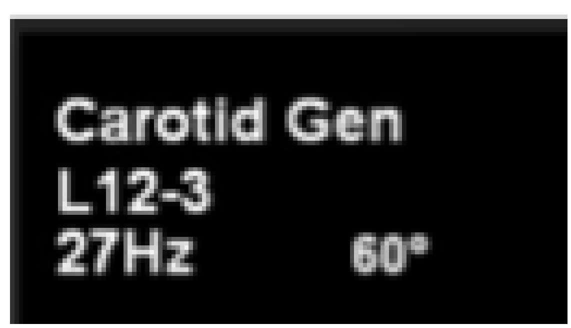
The gate designates where Doppler information will be obtained from.



If there is not a 3rd line at the gate, the machine is assuming a Doppler angle of zero degrees. This is usually the case when Dopplering in veins and in the heart.

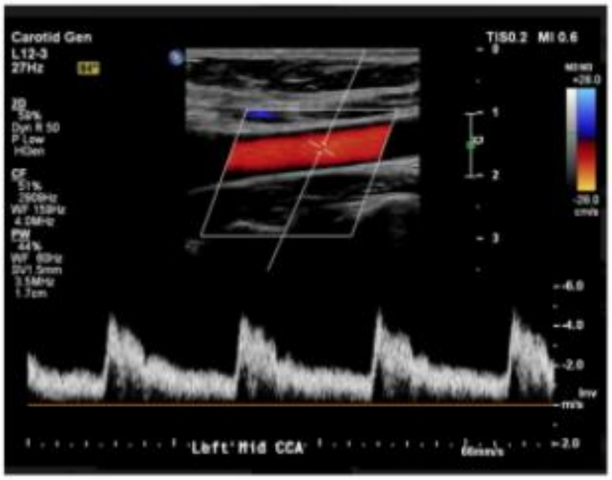
The third line, when present, is called the **Angle Correct.**

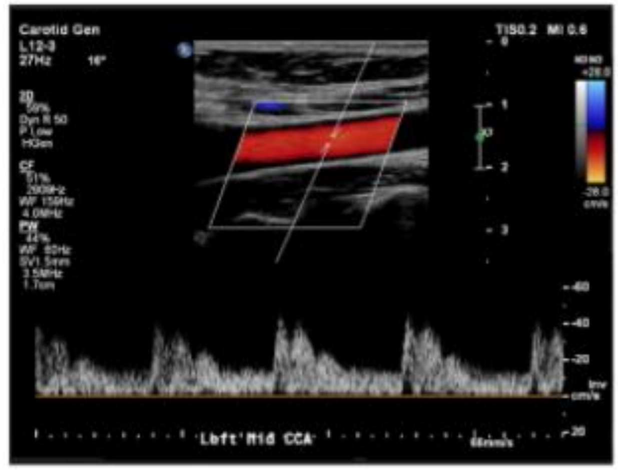
The angle correct allows us to tell the machine what angle to use for cos **θ** when calculating the velocity.

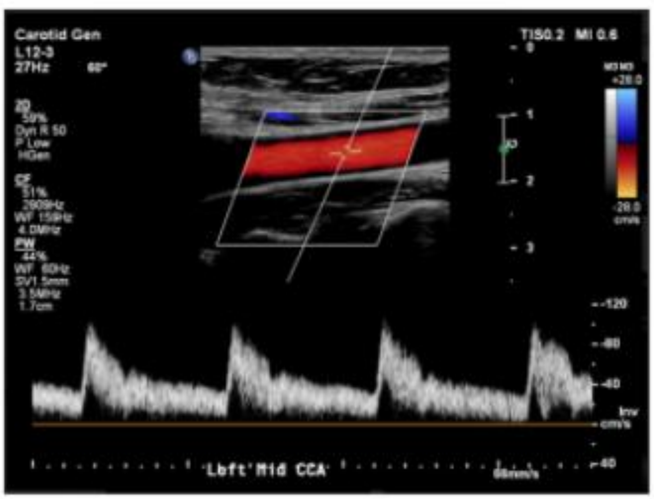


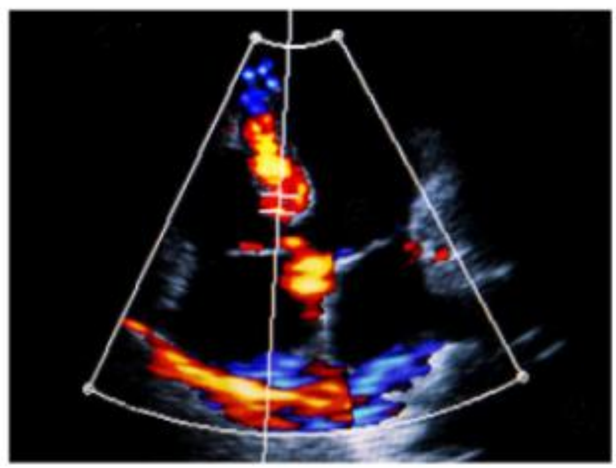
The sample gate allows the sonographer to choose EXACTLY where they want the blood flow information to come from. This is known as range resolution. This is very different from CW Doppler and the greatest advantage of PW Doppler.

The gate and angle correct are the most important features of PW Doppler when trying to obtain accurate velocity measurements.









Best practice is to place the gate within the fastest portion of the blood flow. This is typically in the center of the blood vessel or valve jet.

The angle correct must be set to 60° or less. Typical labs will encourage the use of 60, 45 or 0 degrees as they are the most reproducible. The angle correct is positioned parallel with the blood flow.

Remember that the cosine of the angle will change the accuracy of the true velocity.

19.7.3 PW Pros & Cons

Just like CW, pulsed-wave also has advantages and disadvantages that are more clinical in practice.

Advantages:

- Range Resolution (aka: range specificity)
- Sample Volume

The sonographer can choose where to get Doppler information from.

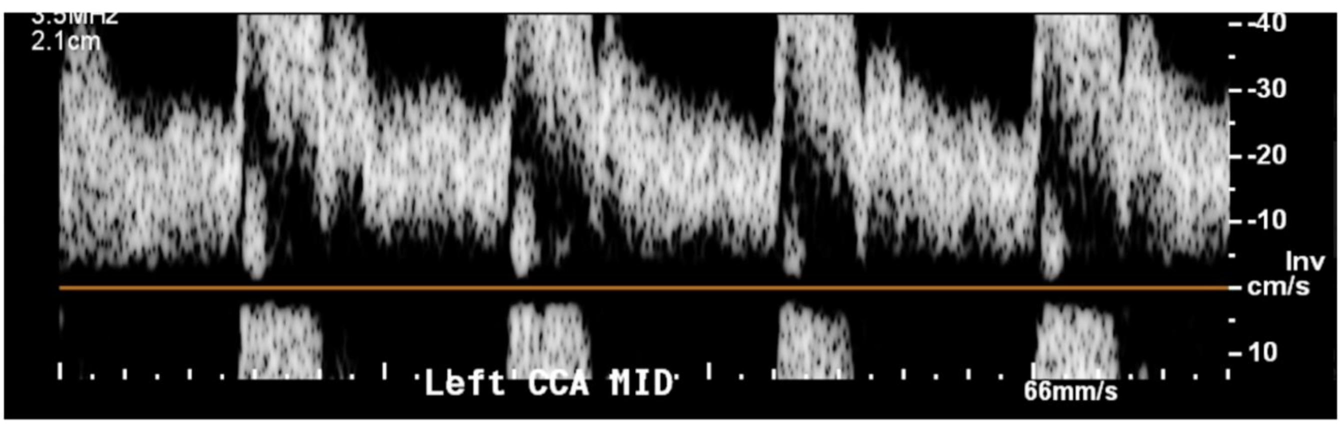
Disadvantages:

- Cannot detect high velocities
- Aliasing

The machine can only send out one pulse and must wait for that information to come back. This is the PRF. Remember that PRF is based on depth. If the Doppler information exceeds the limits of the graph, then aliasing occurs.

There is a limit to what graphs in PW can display, this is called the **Nyquist Limit.** Aliasing is likely to occur when using PW Doppler and high velocities.

An indepth look at aliasing will be in Unit 20, as this is a clinical issue and must be corrected to produce diagnostic images.



19.7.4 Fast Fourier Transform

➔ **Fast Fourier transform is the technique used by modern ultrasound machines to understand the Doppler shift information returning to the machine and create the spectral waveform.**

The resulting waveform can be measured with machine calipers to accurately identify velocities . The FFT analyzes and displays all of the velocities returning, so it can also help to determine laminar vs. turbulent flow.

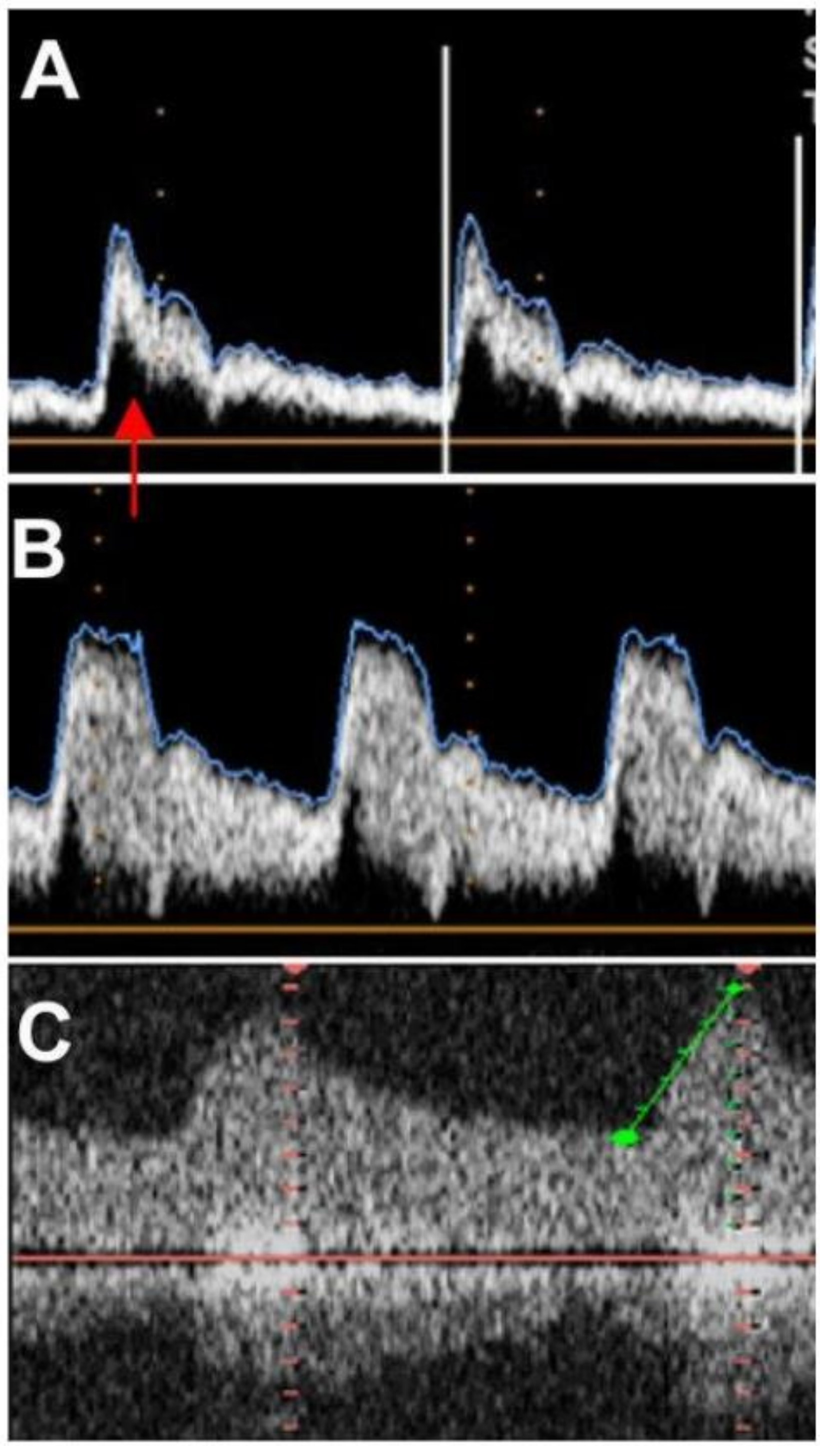
Laminar flow: narrow, well defined, due to all RBCs traveling at similar speeds. The red arrow represents the spectral window.

Turbulent flow: wide range of velocities, filled in spectral window, due to RBCs traveling chaotically, the spectral window is filled in.

More discussion around waveform analysis will be covered in unit 20.

Older methods for spectral analysis included:

- **Zero crossing detectors**
- **Chirp-Z Transform**
- **Interval histograms**



Section 19.8 Color Doppler

Color Doppler is also a pulsed-wave Doppler technique, but instead of giving measurable, accurate velocities,

- ➔ **Color Doppler displays average velocities as a 2D overlay.**
- ➔ **The assigned colors provide information about direction of flow.**

Color Doppler uses pulsed waves, so we can choose where to get Doppler information from, but it is also subject to aliasing.

Since color Doppler does not provide exact velocities, it is considered a semi-quantitative method of velocity measurement.

Just like the other Dopplers, color Doppler performs best at an angle, where 0° is still best and 90°won't be calculated, but because it doesn't provide exact velocities, and exact Doppler angle isn't necessary.

19.8.1 Color Maps

Color maps are the reference tool the machine uses to match velocities to a color.

The map is displayed on the machine as a vertical bar. It is adjustable in that you can change the scale (PRF), which color is assigned towards/away, and the baseline (rarely changed). The maps can come in different hues.

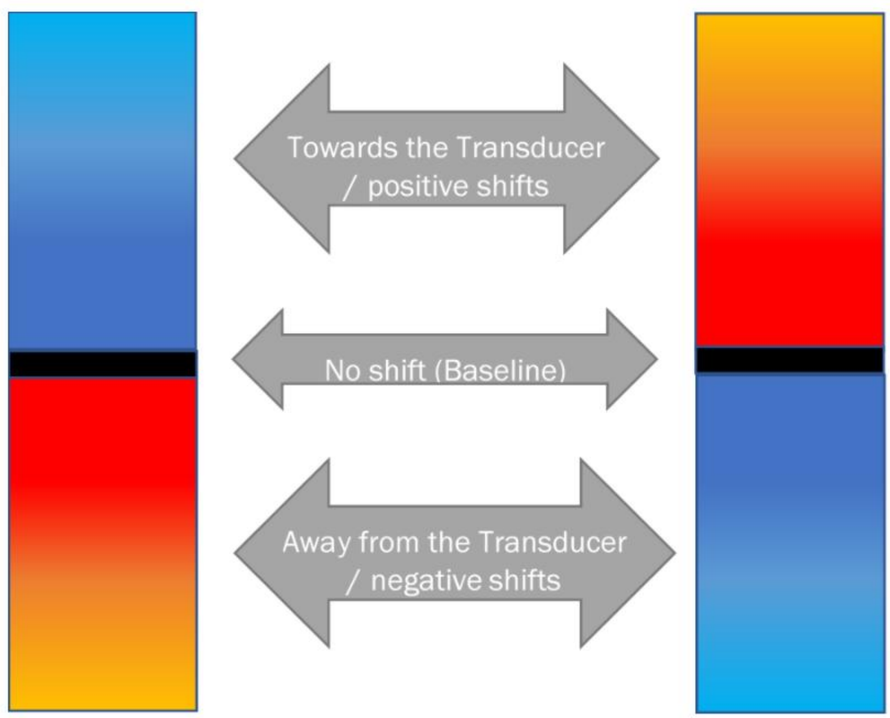
There are two types of color maps commonly used:

- ➔ **Velocity Mode**
- ➔ **Variance Mode**

<u>Velocity Mode</u>

- ➔ **Velocity mode shows direction and velocity.**

- Whichever color is displayed on the top of the bar represents positive Doppler shifts.
- The black bar in the middle represents NO Doppler shift.
- The color displayed on the bottom represents negative Doppler shifts.
- Colors closer to the middle black bar are slower, colors at the edge are faster.



Variance Mode

➔ **Variance mode shows not only speed and direction, but adds in laminar and turbulent flow.**

- The color above the black bar is still towards the transducer and the color below the black bar is away from the transducer.
- The black bar still represents no Doppler shift.
- The color towards the LEFT represents LAMINAR flow (both above and below the baseline and the color towards the RIGHT represents TURBULENT FLOW.

No matter the color map being used:

➔ **Top color represents flow towards the transducer**

➔ **Bottom color represent flow away front the tranduder**

*****It does not have to always be Red toward/ Blue away or vice versa - it is whatever the sonographer sets it as.**

19.8.2 Obtaining Color Doppler

Color Doppler is activated through a knob or button on the machine.

A box appears on the image, usually in the shape of the sector.

The box is adjustable. The sonographer can:

- Move it where they want
- Make it bigger or smaller
- Steer the box (linear sequential transducers only)

The box should be placed where there is some angle to the area of interest. Avoid making the box perpendicular to flow.

Multiple ultrasound pulses are sent from the crystals assigned to creating the color box. Information.

➔ **The multiple pulses that are sent are known as a packet or ensemble.**

A minimum of 3 are needed, but most systems use 10 -20.

There are benefits and drawback to using small or large packets.

More Pulses (Large packets / Long Ensembles)

- **Greater accuracy**
- **Increased Sensitivity to slow flow**
- **Requires more time to get information**
- **Frame Rate and Temporal resolution are reduced.**

The sonographer needs to decide what is more important - frame rate or better color sensitivity. Often we choose to balance between the two.

19.8.3 Autocorrelation

- **Autocorrelation is the computer-based technique that is used to analyze color flow Doppler.**

Autocorrelation is sometimes known as **correlation function.** It is less accurate than FFT, but much faster. The speed is good for the amount of data that is processed for color imaging. If it took longer to process, color Doppler would greatly affect temporal resolution.

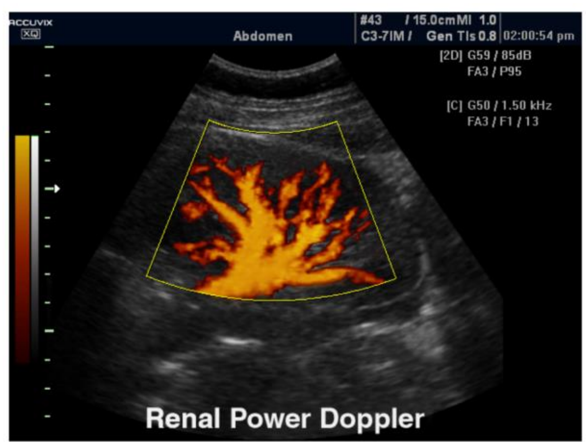
19.8.4 Power Color Doppler

Power Color Doppler is a subset of color Doppler. It is also known as **energy mode or color angio.**

Original power color Doppler removed the directional analysis of the Doppler shifts. It simply colorized ANY motion detected by the machine.

This has some advantages and disadvantages:

- **Very sensitive - could show slow flow, flow in tiny vessels, flow in depe vessels**
  - **But then it would also be more likely to show excessive color with transducer or patient motion**
- **Not angle dependent**
  - **Except for 90 degrees**
- **No Aliasing - just looking for motion**
- **Low Frame Rate**
- **No direction information**
  - **Newer machines have power Doppler with direction, so this is an improvement!**



Section 19.9 Activities ← Link to Answers

You are in your car next to an ambulance. Breaking the law, you stay right next to the ambulance while driving down the road. If the ambulance's siren is putting out a sound at 395 Hz, what is the frequency you can hear?	
The ambulance driver is annoyed that you've been keeping pace with them, so they take off. You are now behind the ambulance as they move away from you. What is the frequency of the sound you are hearing now? **310 Hz** or **395 Hz** or **425 Hz**	
A police officer see you breaking the law and is driving towards you with their siren on (also 395 Hz.) What is the frequency you are hearing as the police car comes to you? **310 Hz** or **395 Hz** or **425 Hz**	

Fill in the chart:

$$Doppler\ Shift\ (Hz) = frequency_R - frequency_T$$

Doppler Shift	Received Frequency	Transmitted Frequency
	5,003,400 Hz	5,000,000 Hz
5,000 Hz		4,000,000 Hz
1,250 Hz	12,001,250 Hz	
	2,980,000 Hz	3,000,000 Hz
-2,300 Hz		2,000,000 Hz
-40 Hz	9,999,960 Hz	

Move the block to make the statements true.

When the RBCs are moving towards the transducer, a shift is created.

POSITIVE

NEGATIVE

When the RBCs are moving away from the transducer, a shift is created.

Define each parameter of the Doppler equation:

$f_D(kHz)$	
2	
$f_O(kHz)$	
$v(cm/s)$	
$\cos\theta$	
$c\ (cm/s)$	

Arrange the pieces to create the Doppler equation solving for the Doppler shift.

$$= \frac{\quad \times \quad \times \quad \times \quad}{\qquad\qquad}$$

$c\ (cm/s)$ $cos\theta$ $f_D(kHz)$

2 $f_O(kHz)$

$v(cm/s)$

Arrange the pieces to create the Doppler equation solving for velocity.

$$= \frac{\times}{\times \quad \times}$$

$f_O (kHz)$

$cos\theta$ $f_D (kHz)$

$c\ (cm/s)$ $v(cm/s)$ 2

Fill In the Chart:

Angle (degrees)	Cosine Value
0°	
30°	
60°	
90°	
120°	
150°	
180°	

Fill in the chart for a 6 MHz transducer and a Doppler shift of 6 kHz:

Angle (degrees)	Velocity
0°	
30°	
60°	
90°	
120°	
150°	
180°	

Fill in the chart for a 10 MHz transducer and a Doppler shift of 6 kHz:

Angle (degrees)	Velocity
0°	
30°	
60°	
90°	
120°	
150°	
180°	

Fill in the chart for a 6 MHz transducer and a Velocity of 200 cm/s

Angle (degrees)	Doppler Shift
0°	
30°	
60°	
90°	
120°	
150°	
180°	

Fill in the chart for a 10 MHz transducer and a Velocity of 200 cm/s

Angle (degrees)	Doppler Shift
0°	
30°	
60°	
90°	
120°	
150°	
180°	

Look back at charts you just filled out.

What happened to velocity when the Transducer frequency <u>increased</u> from 6 MHz to 10 MHz?

What happened to Doppler shift when the Transducer frequency <u>increased</u> from 6 MHz to 10 MHz?

Based on your answers above, how is frequency related to velocity and Doppler Shifts?

What mechanism allows the machine to detect bidirectional Doppler?

What is it called when an anatomical image and a spectral tracing is displayed?

What is it called when an anatomical image, spectral tracing and color is displayed?

List 4 facts about dedicated Continuous Wave (CW) Transducers:

1	
2	
3	
4	

The inability to choose where the Doppler information is returning from and a disadvantage to CW transducers is called:

CW Doppler:

ADVANTAGES

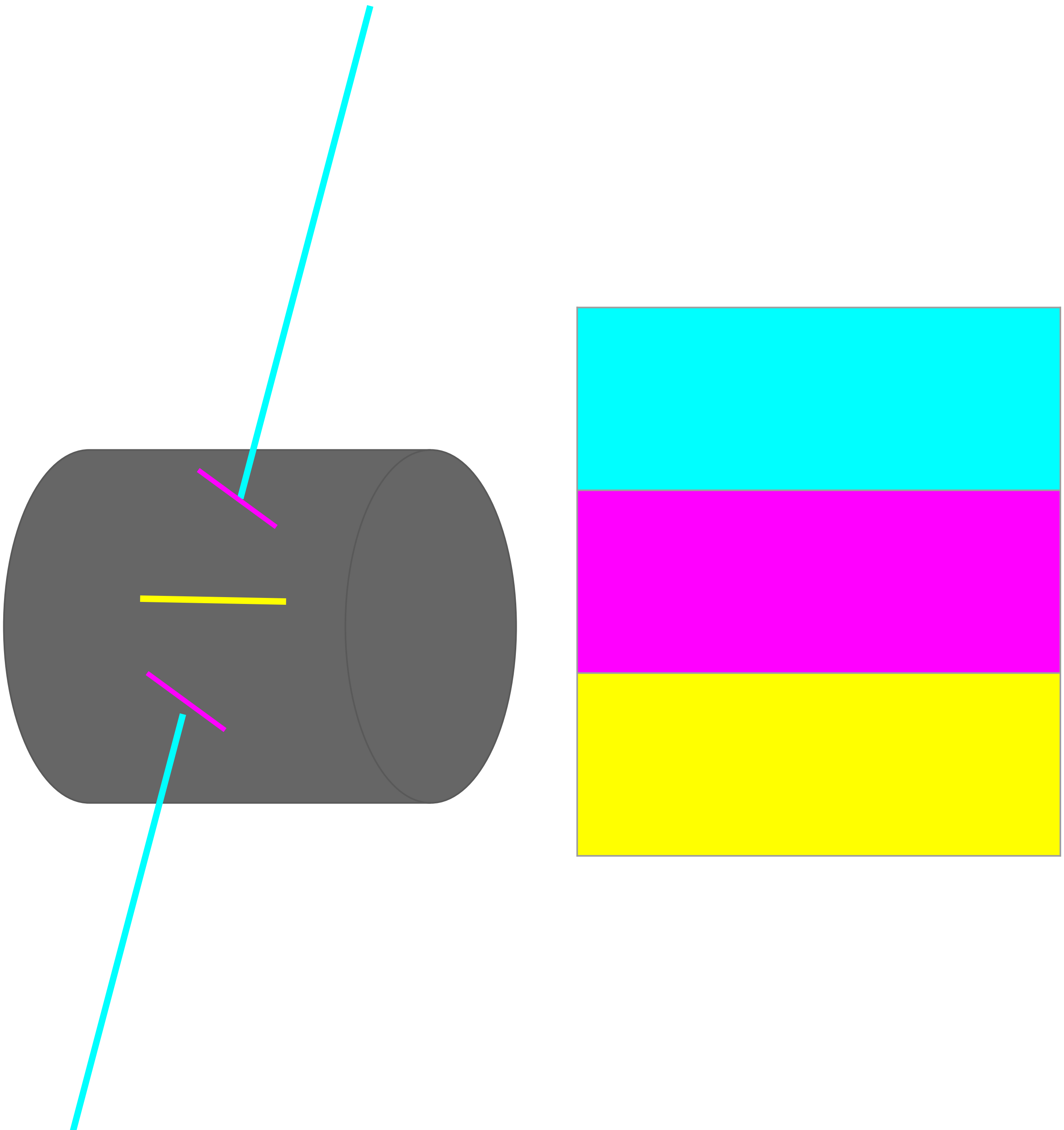
DISADVANTAGES

Ab
VE
vel

Ambiguity

No TGCs

Label the parts of the pulse Doppler display:



Match the statement to the term:

RR-Range Resolution

AC- Angle Correct

SV - Sample Volume

	An advantage to using PW Doppler
	Shows the angle of blood flow to the PW scan line
	Should be set at 60° or less
	If placed too close to the wall or too wide, results in spectral widening
	Not typically used in cardiac applications
	Should be placed in the center of the blood vessel or where blood flow is the fastest
	Should always be used when a velocity is being measured

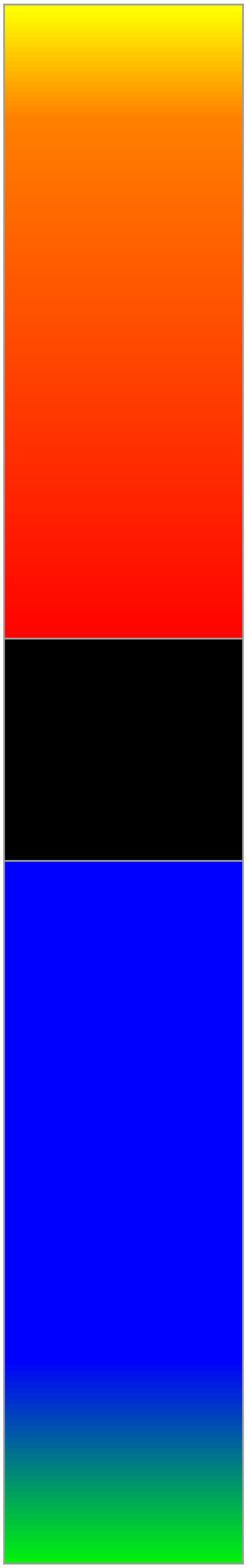
PW Doppler:

ADVANTAGES

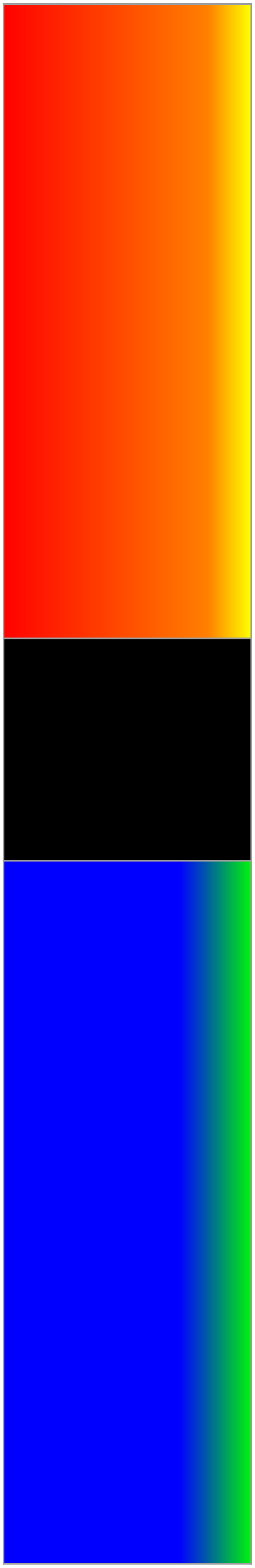
DISADVANTAGES

n

Adjustable
Sample Volume



What color would indicate a small negative Doppler shift?	
What color would indicate a small positive Doppler shift?	
What color would indicate a negative aliased Doppler shift?	
What color would indicate no Doppler shift?	
What color would indicate a large positive Doppler shift?	
What color would indicate a large negative Doppler shift?	
What kind of color map is this?	

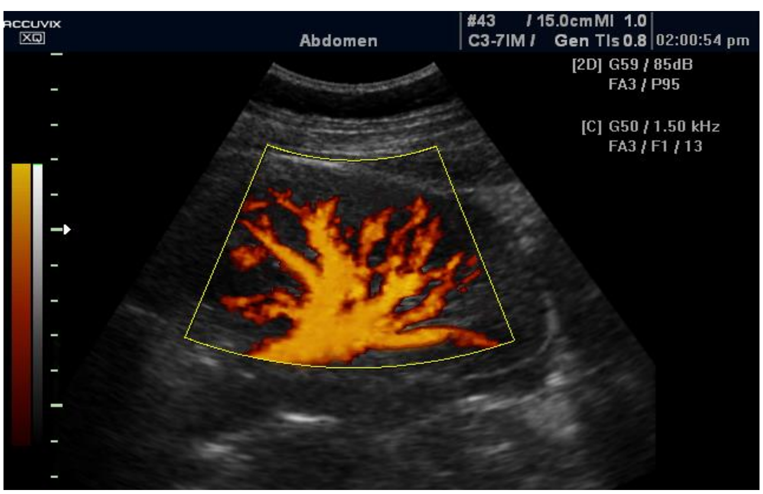


What color would indicate a turbulent negative Doppler shift?	
What color would indicate a laminar positive Doppler shift?	
What color would indicate no Doppler shift?	
What color would indicate a turbulent positive Doppler shift?	
What color would indicate a laminar negative Doppler shift?	
What kind of color map is this?	

What is another name for Doppler packets?

What are the main advantage & disadvantage to Large Doppler packets?

What are the three names of this tool?



What component of a Doppler system allows for all the information of RBCs to be displayed in a spectral tracing?

What are three older types of the spectral analysis methods?

1	
2	
3	

What component of a Doppler system allows for all the color information to be processed?
