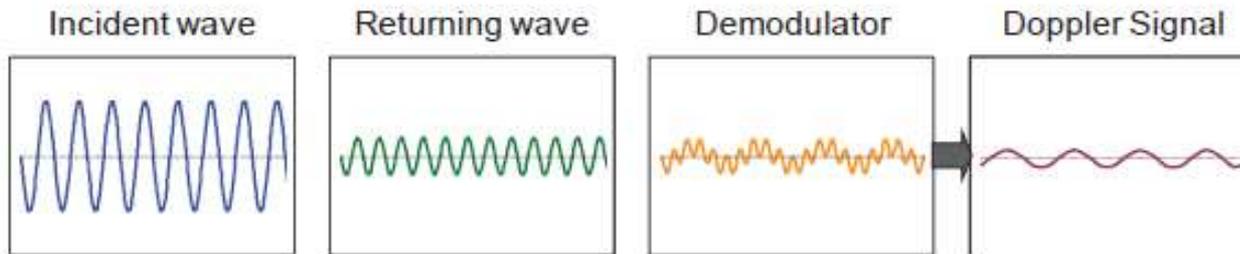
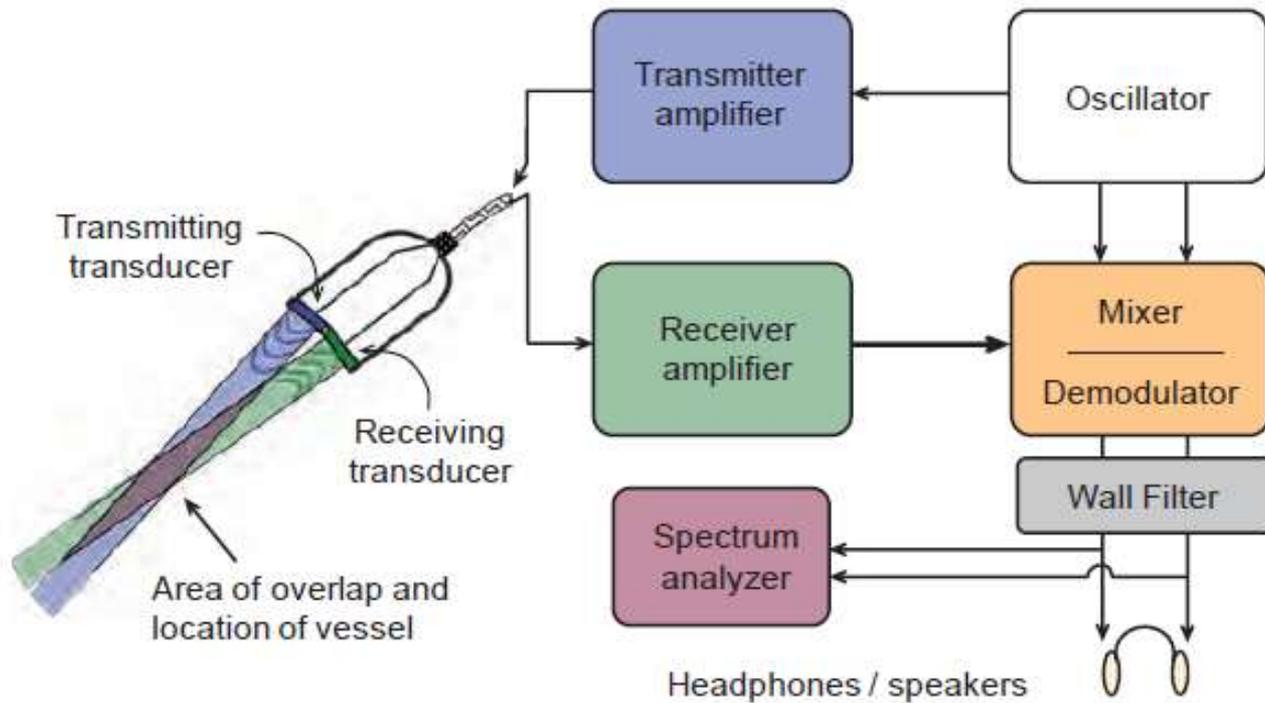


TYPES OF DOPPLER OPERATION

1. Continuous wave doppler
2. Pulsed wave doppler
3. Duplex scanning
4. Color flow doppler imaging
5. Power doppler

1. CONTINUOUS WAVE DOPPLER

- Simplest and least expensive device for measuring blood velocity
- Two transducers required, one transmitting the incident ultrasound and other detecting the resultant continuous echoes.
- Two elements in one transducer at inclination.
- High Q transducer with no backing block
- Suffers from depth selectivity with accuracy affected by object motion within the beam path.
- Multiple overlying vessels will result in superimposition, making it difficult to distinguish a specific Doppler signal.



Advantages:

- Simple, Good quality
- low noise signal,
- No aliasing.

Disadvantages:

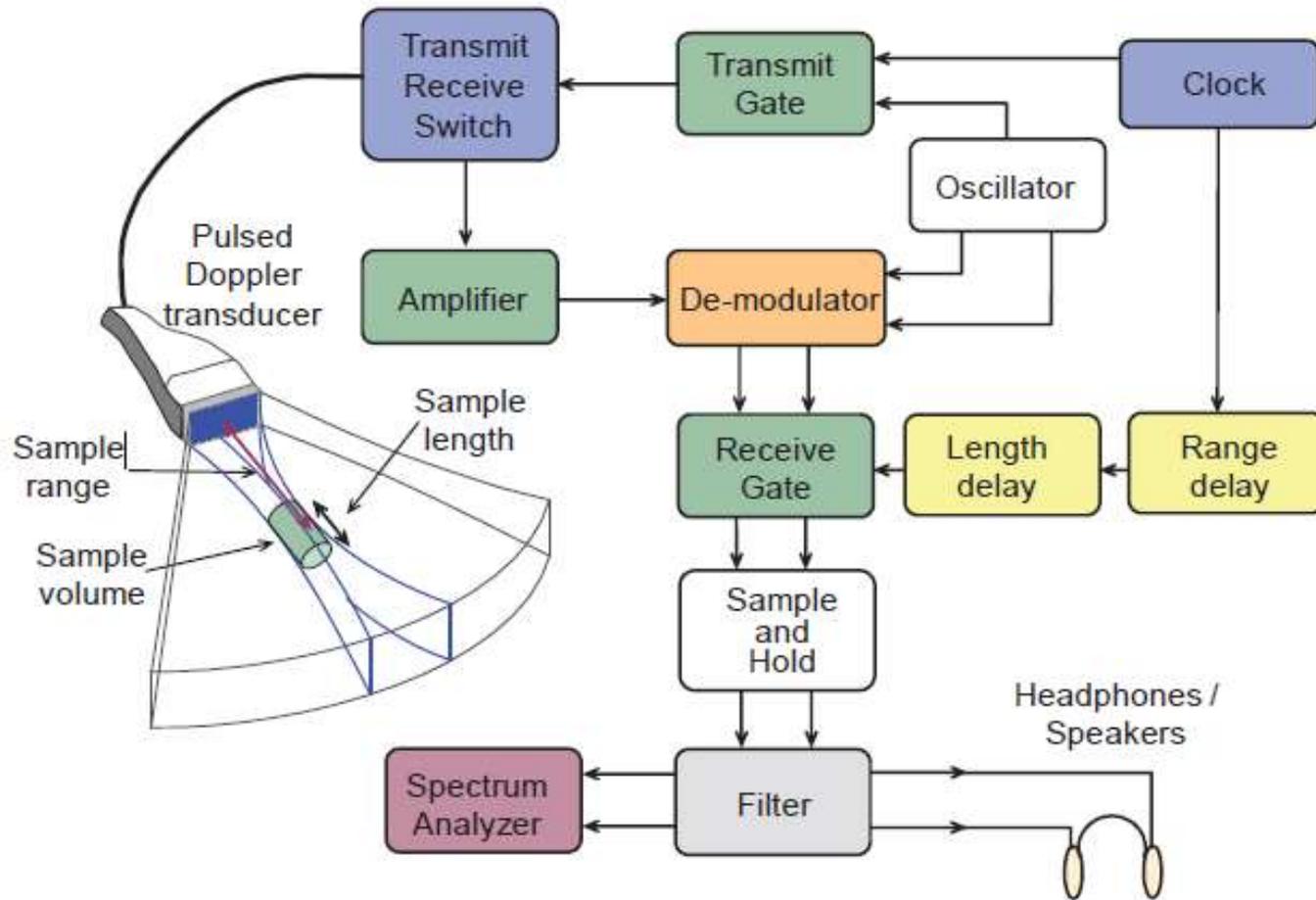
- Lacks depth resolution,
- Confusing superimposition,

Application: Superficial structures, e.g carotid artery, limb arteries.

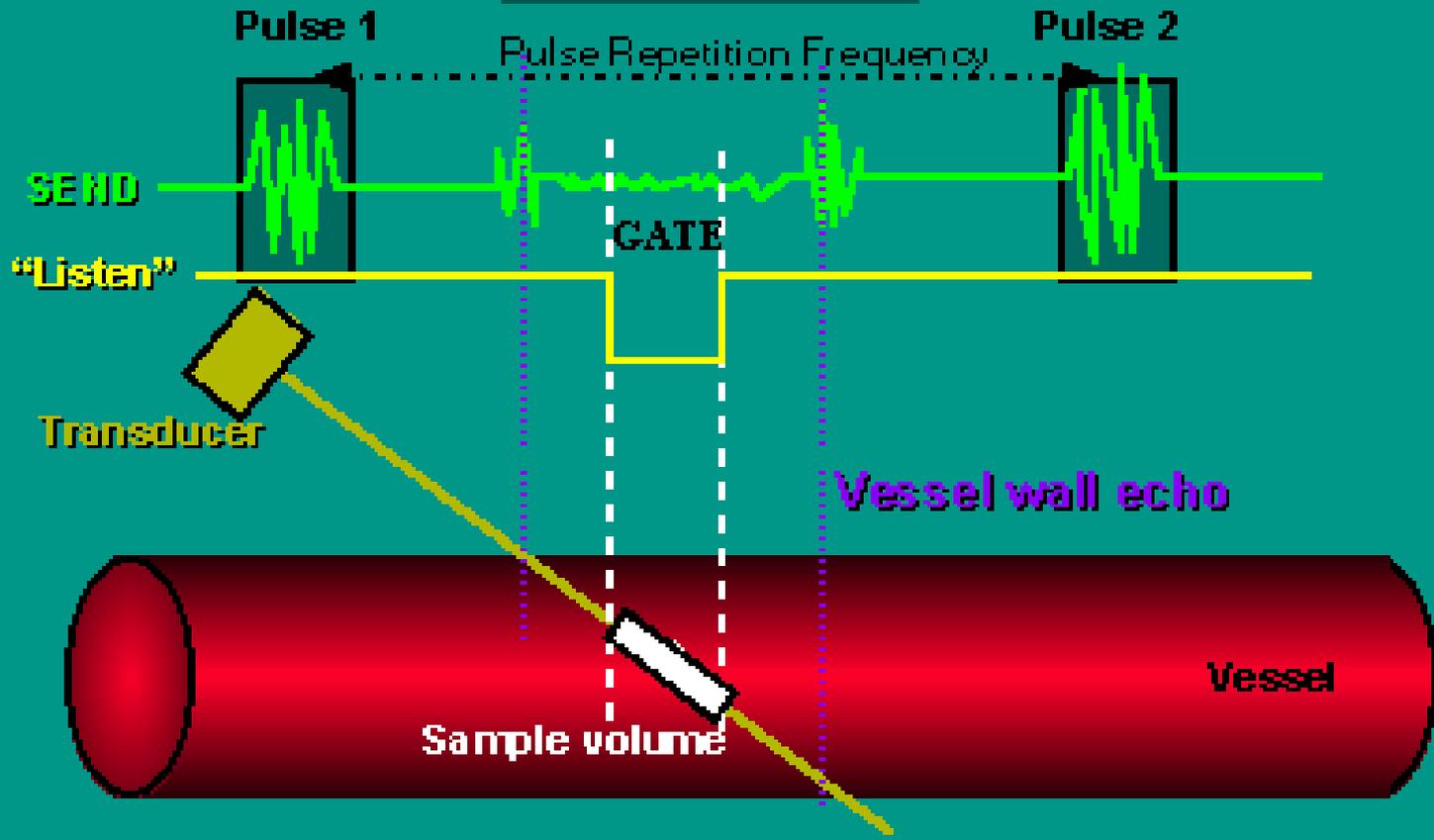
2. PULSED WAVE DOPPLER

- Combines the velocity determination of continuous wave Doppler systems and the range discrimination of pulse-echo imaging.
- Transducer is used in a pulse-echo format, similar to imaging.
- The SPL is longer (a minimum of 5 cycles per pulse up to 25 cycles per pulse) to provide a higher Q factor and improve the measurement accuracy of the frequency shift (although at the expense of axial resolution).
- Depth selection is achieved with an electronic time gate circuit to reject all echo signals except those falling within the gate window, as determined by the operator.

- Each Doppler pulse does not contain enough information to completely determine the Doppler shift, but only a *sample of the shifted frequencies measured as a phase change*.
- Stationary objects within the sample volume do not generate a phase change in the returning echo when compared to the oscillator phase, but a moving object does.
- Repeated echoes from the active gate are analyzed in the sample/hold circuit, and a Doppler signal is gradually built up.

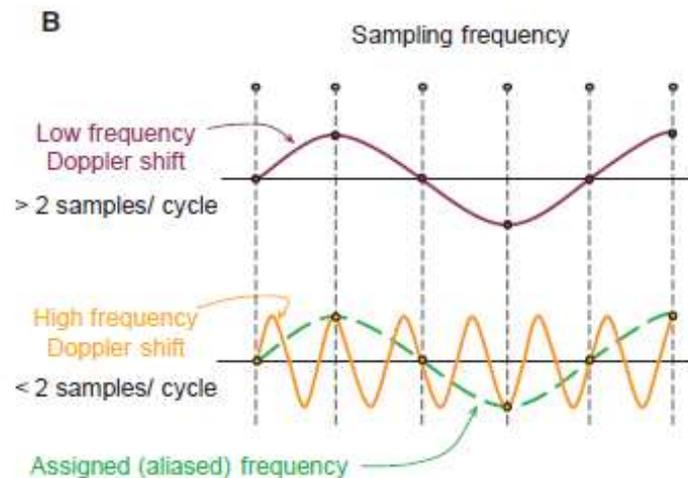
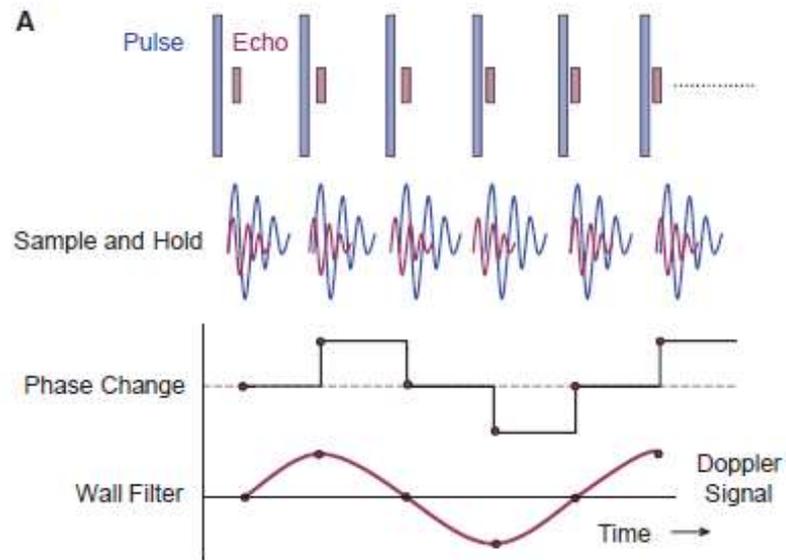


Pulsed Doppler



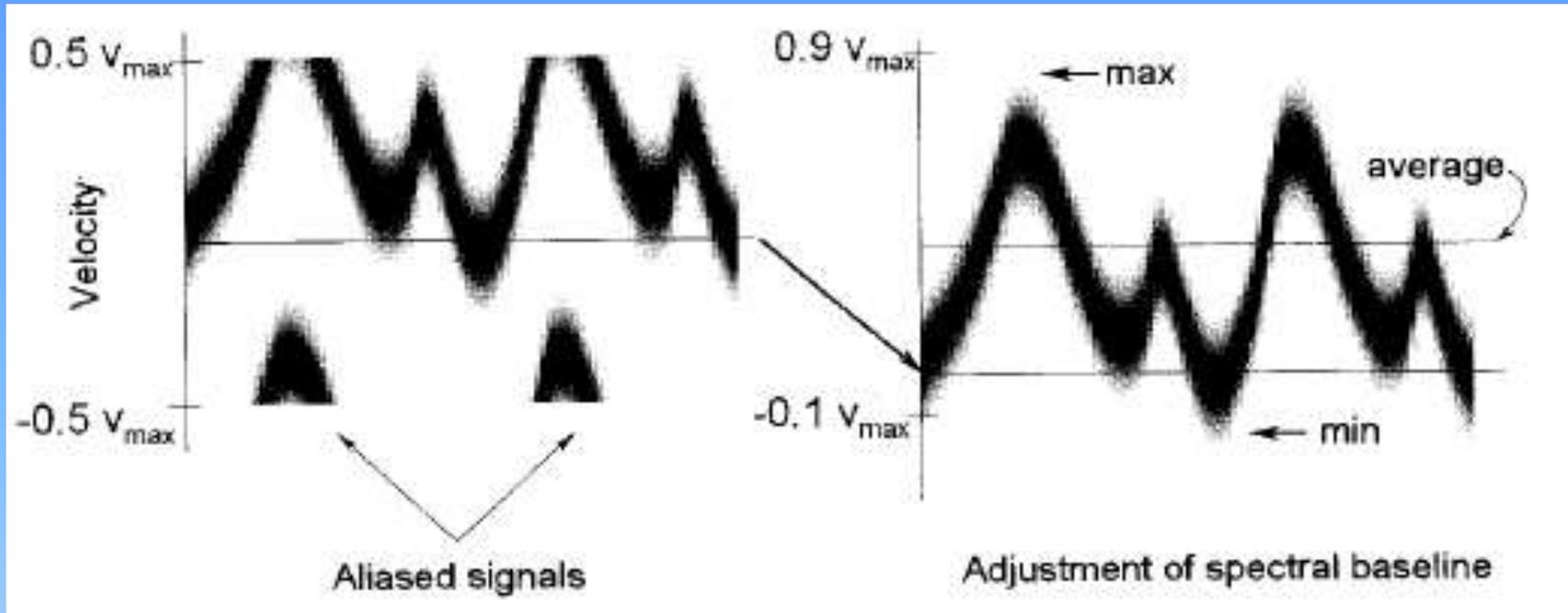
- Depth (range) controlled by time between pulse transmission & gating on. Axial length (thickness) determined by time the gate is open.
- Width of sampling volume (gated Doppler acquisition area) → width of Doppler beam (pear shaped).
- 7 μ s for ultrasound to travel 1 cm (average soft tissue)
- PRF determines the maxm. depth for Doppler shift. So \uparrow PRF → \downarrow depth.
- Doppler shift detection in pulsed Doppler = 1/2 of PRF.
- If Doppler shift frequency > detectable frequency in deep vessels → aliasing (incorrect shift).





■ **FIGURE 14-40 A.** The returning ultrasound pulses from the Doppler gate are sampled over several pulse-echo cycles (in this example, six times), in order to estimate Doppler shifts (if any) caused by moving blood cells. A sample and hold circuit measures a variation of signal with time (note that the echo [purple line] and the pulse [blue line] vary in phase, which are recorded and analyzed by Fourier transform methods to determine the Doppler shift frequencies). The wall filter removes the low-frequency degradations caused by transducer and patient motion. **B.** Aliasing occurs when the frequencies in the sampled signal are greater than $\frac{1}{2}$ the PRF (sampling frequency). In this example, a signal of twice the frequency is analyzed as if it were the lower frequency and thus mimics (aliases) the lower frequency.

- The discrete measurements acquired at the PRF produce the synthesized Doppler signal.
- According to Nyquist sampling theory, a signal can be reconstructed unambiguously as long as the true frequency (e.g., the Doppler shift) is less than half the sampling rate.
- Thus, the PRF must be at least twice the maximal Doppler frequency shift encountered in the measurement.
- For Doppler shift frequencies exceeding one-half the PRF, aliasing will occur, causing a potentially significant error in the velocity estimation of the blood.
- Thus, a 1.6-kHz Doppler shift requires a minimum PRF of $2 * 1.6 \text{ kHz} = 3.2 \text{ kHz}$.
- One cannot simply increase the PRF to arbitrarily high values, because of echo transit time and possible echo ambiguity.



Aliasing of the spectral Doppler display is characterized by "wraparound" of the highest velocities to the opposite direction when the sampling (PRF) is inadequate. **Right:** Without changing the overall velocity range, the spectral baseline is shifted to incorporate higher forward velocity and less reverse velocity to avoid aliasing. The maximum, average, and minimum spectral Doppler display values allow quantitative determination of clinically relevant information such as pulsatility index and resistive index.

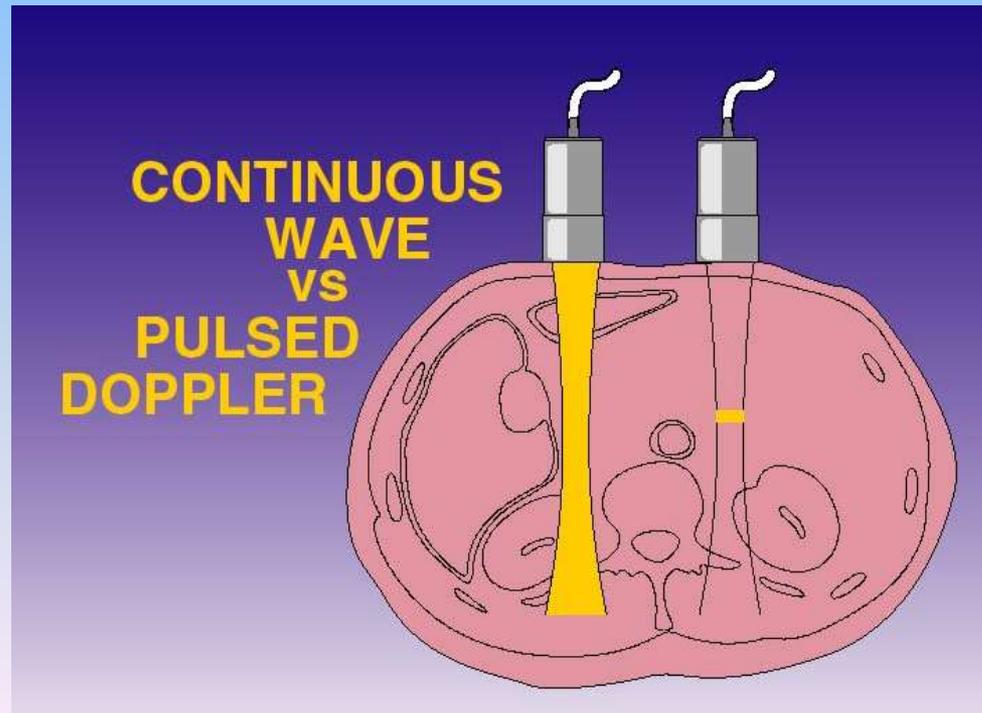


Advantages:

- Identification of source.
- Small signal crystal transducer (cardiology).
- Blood flow signal from ranges gate

Disadvantages:

- Quality may suffer d/t background noise (switching).
- Aliasing.



3. DUPLEX SCANNING

- Combination of 2D B-mode imaging and pulsed Doppler data acquisition.
- Operates in the imaging mode and creates a real-time image.
- The Doppler gate is positioned over the vessel of interest with size (length and width) appropriate for evaluation of blood velocity, and at an orientation (angle with respect to the interrogating US beam) that represents the Doppler angle.
- When switched to Doppler mode, the scanner electronics determines the proper timing to extract data only from within the user-defined gate.

- Most often, electronic array transducers switch between a group of transducers used to create a B-mode image and one or more transducers used for the Doppler information.
- The duplex system allows estimation of the blood velocity directly from the Doppler shift frequency, since the velocity of sound and the transducer frequency are known, while the Doppler angle can be estimated from the B-mode image and input into the scanner computer for calculation.
- Once the velocity is known, flow (in units of cm^3/s) is estimated as the product of the vessel's cross-sectional area (cm^2) times the velocity (cm/s).

- Errors in the flow volume may occur. The vessel axis might not lie totally within the scanned plane, the vessel might be curved, or flow might be altered from the perceived direction.
- The beam-vessel angle (Doppler angle) could be in error, which is much more problematic for very large angles, particularly those greater than 60 degrees
- The Doppler gate (sample area) could be mispositioned or of inappropriate size, such that the velocities are an overestimate (gate area too small) or underestimate (gate area too large) of the average velocity.
- Noncircular cross sections will cause errors in the area estimate, and therefore errors in the flow volume.

○ **Advantages:**

- Selection of site & sample volume for Doppler.
- No overlap of information from other vessels/structures.
- Measurement of vessel angle in 2-3 sec.

○ **Disadvantages:**

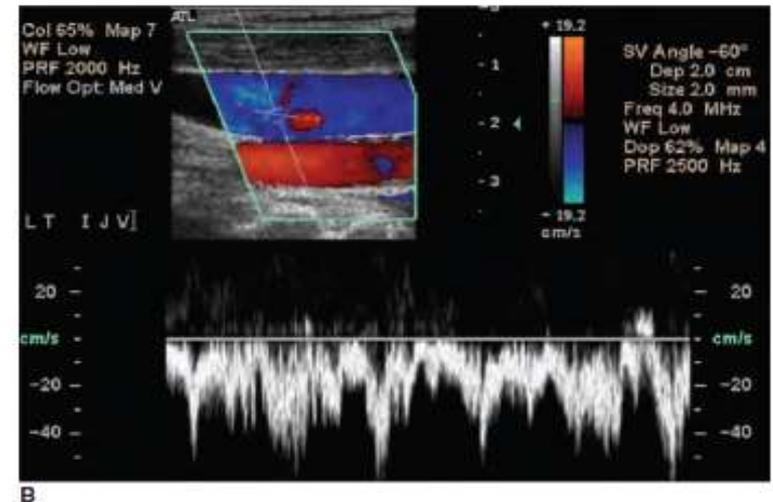
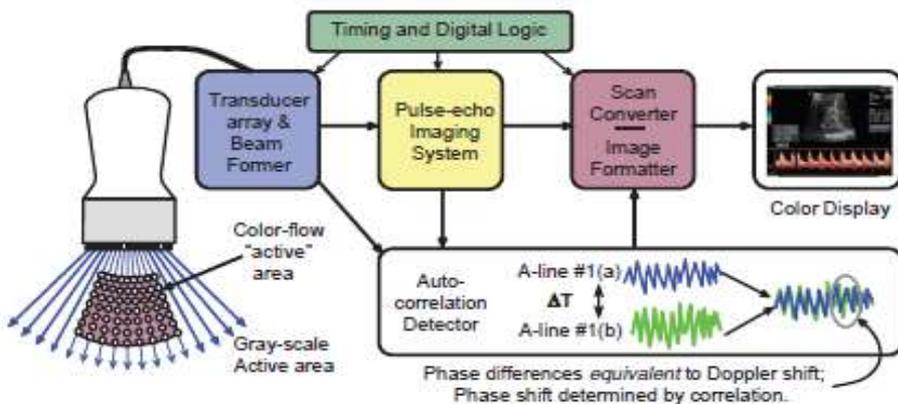
- Angle restriction if same transducer for imaging & Doppler.
- Flow information from one site in image



4. COLOUR DOPPLER FLOW IMAGING.

- Provides a 2D visual display of moving blood in the vasculature which is superimposed on the conventional gray scale image.
- Imaging of flow through entire real-time image.
- Allowing visualization of blood vessels and their flow characteristics + image of tissue surrounding.
- Multiple gate in receiving transducer circuit each gate is controlled by time delay circuit.
- These gate arrange close to each other so they can simultaneously sample Doppler shift information across entire lumen of large vessels.
- Multiple gate+ real time

- Velocities and directions are determined for multiple positions within a subarea of the image, and then color encoded (e.g., shades of red for blood moving toward the transducer, and shades of blue for blood moving away from the transducer).



■ FIGURE 14-41 A. The color flow acquisition produces dynamic gray-scale B-mode images with color-encoded velocity maps in a user-defined "active area" of multiple "gates." Inset. Autocorrelation detection is a technique to rapidly determine phase changes (equivalent to Doppler shift) in areas of motion deduced from two (or more) consecutive A-lines of data along the same direction. B. Patient data showing arterial and venous flow, with color assignments (red towards and blue away from the transducer) depicting the direction of blood flow. Within the image, the Doppler gate and Doppler angle are shown within the blue area, and the bottom graph depicts the Spectral Doppler information extracted from the gate.

Advantages:

- Vessels small on gray scale image can be seen (presence of flow detected with relative ease)
- Differentiation between and other structure simplified.
- Improved definition of lumen.
- Improved measurement of stenosis.

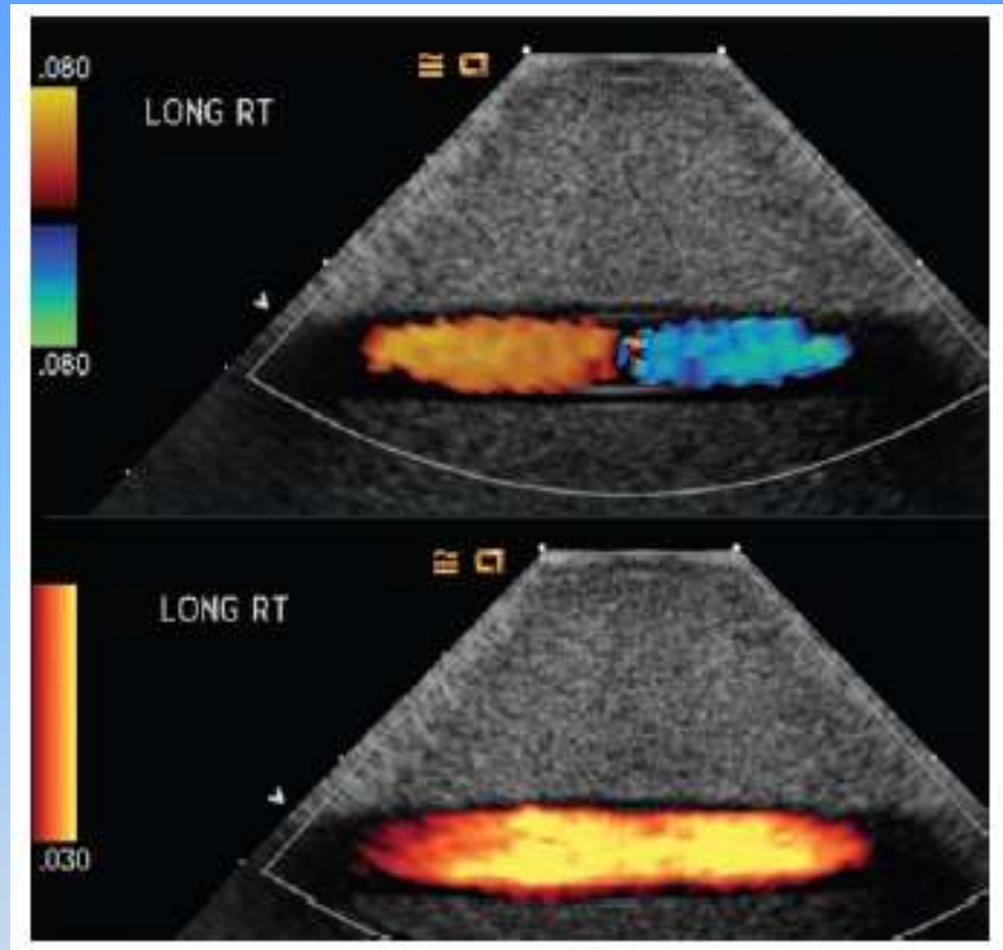
Limitations:

- Compute mean velocity and image not corrected for doppler angle so it is qualitative .
- PRF limited
- Detailed study of vessels not possible.
- May obscure vascular pathology due improper adjustment.
- Other motion like peristalsis, cardiac motion may represented as color which may obscure signal.
- High cost.
- spatial resolution poorer than gray scale image, noise of slowly moving structure can affect the small echoes returning from the moving blood cell.

5. POWER DOPPLER

- A signal processing method that relies on the total strength of the Doppler signal (amplitude) and ignores directional (phase) information.
- The power (also known as energy) mode of signal acquisition is dependent on the amplitude of all Doppler signals, regardless of the frequency shift.
- This dramatically improves the sensitivity to motion (e.g., slow blood flow) at the expense of directional and quantitative flow information.
- Does not give the flow direction or the velocity, but is more sensitive to detecting small amounts of flow, as noise in the image is reduced.
- Aliasing artifacts do not occur in Power Doppler
- 3-dimensional Power Doppler is also possible

- Power Doppler produces images that have more sensitivity to motion and are not affected by the Doppler angle (largely nondirectional),
- Aliasing is not a problem as only the strength of the frequency shifted signals are analyzed (and not the phase).
- Greater sensitivity allows detection and interpretation of very subtle and slow blood flow.
- On the other hand, frame rates tend to be slower for the power Doppler imaging mode, and a significant amount of "flash artifacts" occur, which are related to color signals arising from moving tissues, patient motion, or transducer motion.



Color flow (top) and power Doppler (bottom) images of the same phantom under the same conditions. The directions of flow toward and away from the transducer are seen in the color flow image (top). The power Doppler image (bottom) displays only the intensity of the Doppler shift



Advantages:

- No aliasing
- Angle independent
- Increased sensitivity to detect low- velocity flow
- Useful in imaging tortuous vessels
- Increases accuracy of grading stenosis

Disadvantages:

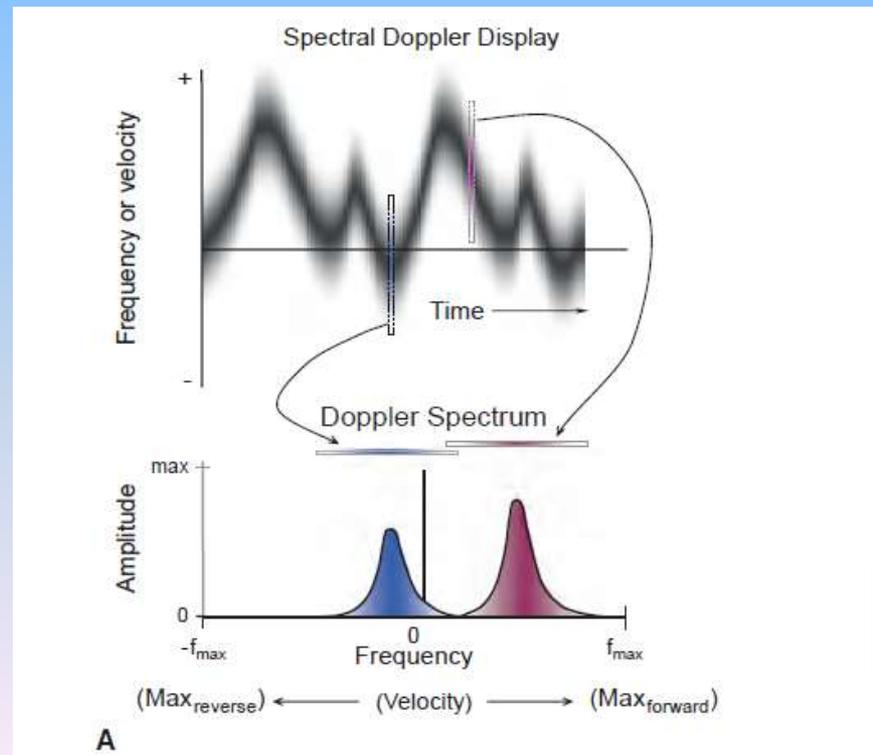
- Do not provide velocity of flow
- Do not provide direction of flow
- Very motion sensitive(poor temporal resolution)

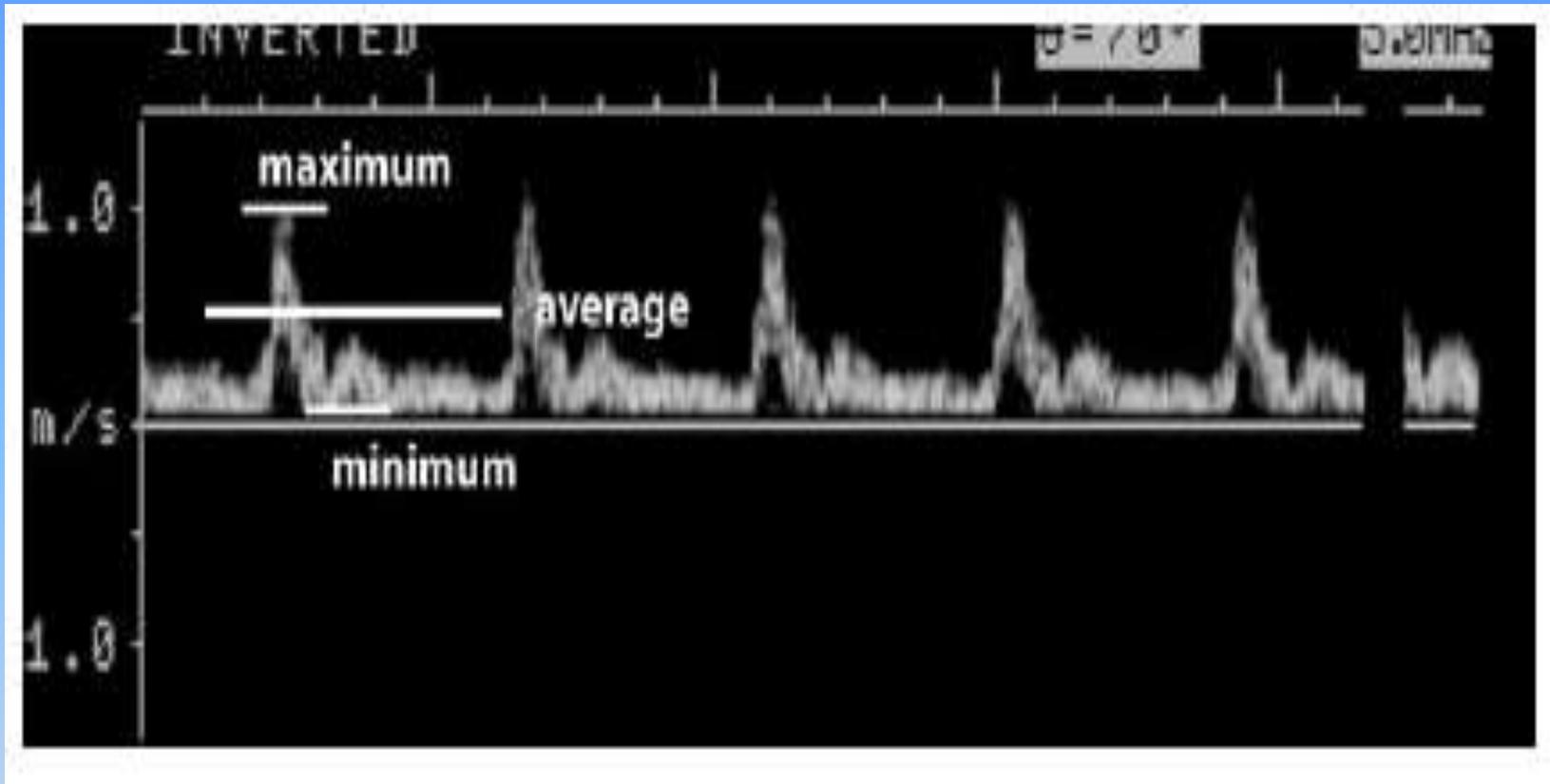
SPECTRAL ANALYSIS

- The Doppler signal is typically represented by a spectrum of frequencies resulting from a range of velocities contained within the sampling gate at a specific point in time.
- With the pulsatile nature of blood flow, the spectral characteristics vary with time.
- Interpretation of the frequency shifts and direction of blood flow is accomplished with the fast Fourier transform, which mathematically analyzes the detected signals and generates amplitude versus frequency distribution profile known as the Doppler spectrum



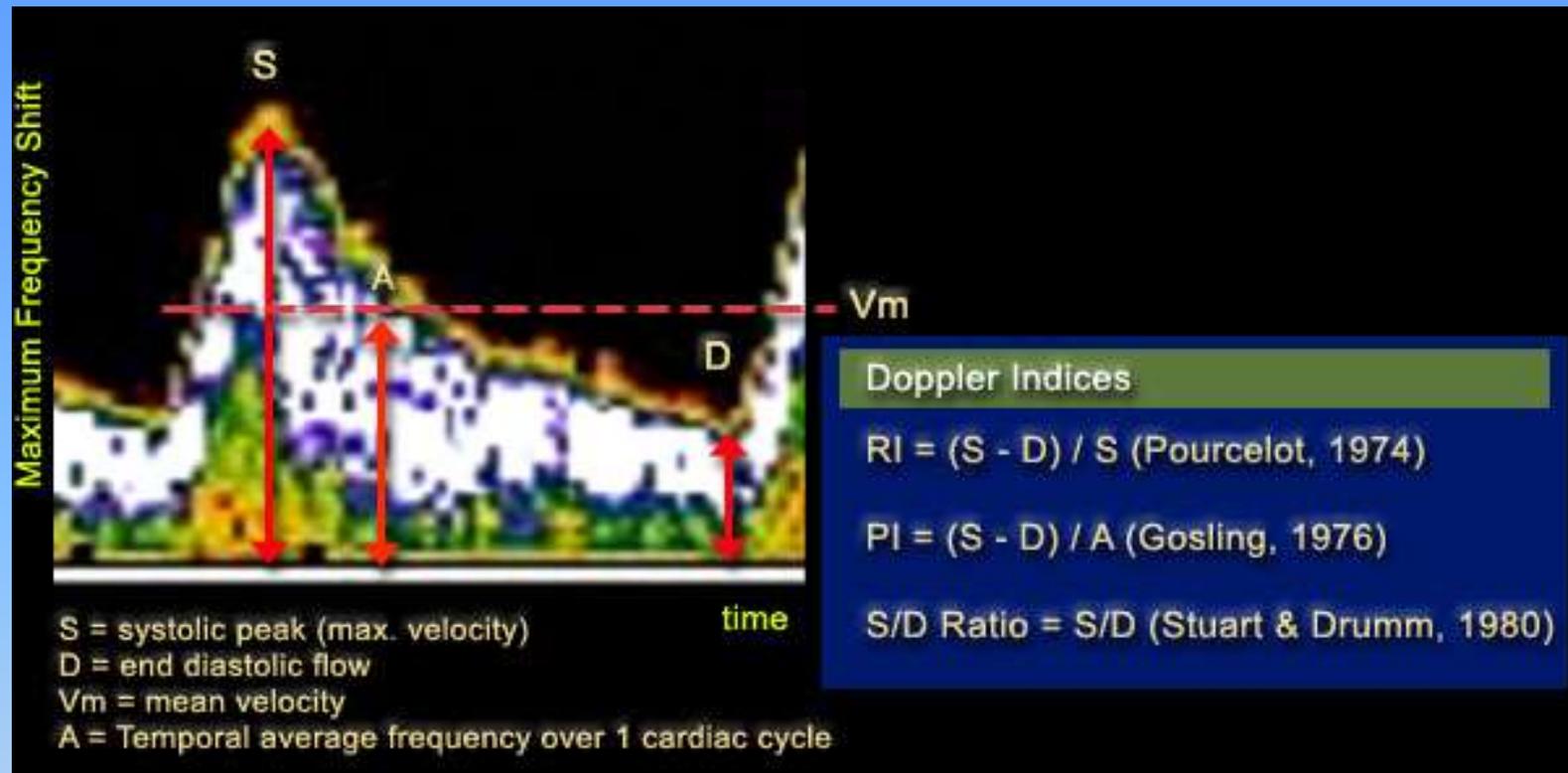
- The intensity of the Doppler signal at a particular frequency and moment in time is displayed as the brightness at that point on the display.
- Velocities in one direction are displayed as positive values along the vertical axis, and velocities in the other direction are displayed as negative values. As new data arrive, the information is updated and scrolled from left to right.





Pulsed-wave US spectrum displays the maximum, minimum, and average calculated blood flow velocities. The pulsatility index, resistivity index, and systolic-to-diastolic ratio are calculated from these values





The PI will increase as flow is impeded by a stenosis. Care must be taken when the PI is used. Proximal and distal stenoses as well as natural flow resistance from the vascular bed may affect PI measurement. The RI is easier to calculate and is used to evaluate a number of physiologic conditions. Both of these indexes are used to assess the resistance to flow in the vascular system

