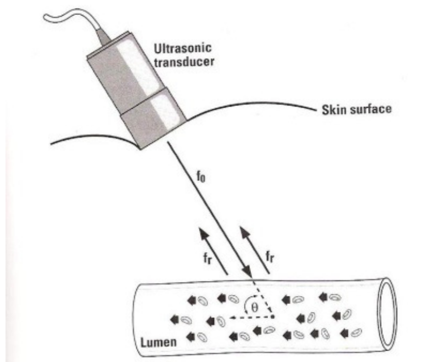
7. Doppler instrumentation

- The Doppler principle
- Different types of Doppler imaging modes
  Image and Estimate Blood flow



-The Doppler effect is used in medical ultrasound to quantify and image blood flow and detect heart motion.

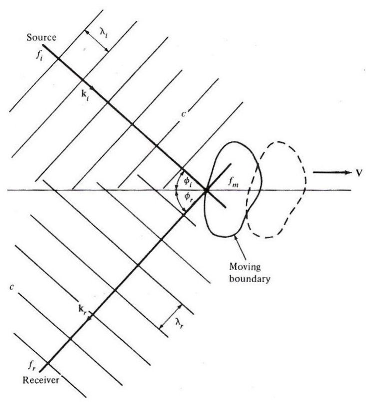
THE DOPPLER PRINCIPLE

Whenever there is a relative motion between an US source and a receiver, the reflected wave scattered from the moving surface is shifted in frequency with respect to the incident wave. This phenomenon is called “Doppler Shift”.

The Doppler effect is actually manifested twice in the production of an echo from a moving reflector:

- First , the reflector is the moving listener: the US waves that the reflector encounters are Doppler shifted
- Then, the reflector is the moving source, sending echoes to the transducer

Doppler Equation



$$f_D = f_r - f_i = -\frac{V}{c}(\cos\phi_i + \cos\phi_r) f_i$$

Observations

-The Doppler shift is proportional to f_i

- $f_D = 0$ when V = 0
- $f_D < 0$ if the reflector is moving away
- $f_D > 0$ if the reflector is moving toward

- In modern instruments, the same transducer is used as a receiver and a transmitter, therefore $\varphi_i = -\varphi_r$ and the equation can be written as

$$f_D = -\frac{2V\cos\varphi}{c} f_i$$

- Note that you can only estimate $V\cos\varphi$, i.e., the component of V along the axis of insonication. To find V, you need an estimate of the angle.

Observations (cont.)

Angles:

φ is the Doppler angle

Note that the transducer beam orientation that produces the best B-mode image results in the least favorable Doppler signal!

There may be uncertainties in the determination of the Doppler angle

Modern scanners allow for angle correction. In the absence of precise angular information, many Doppler scanners are calibrated by assuming φ **= 45˚**

Observations (cont.)

-Spectral Broadening due to

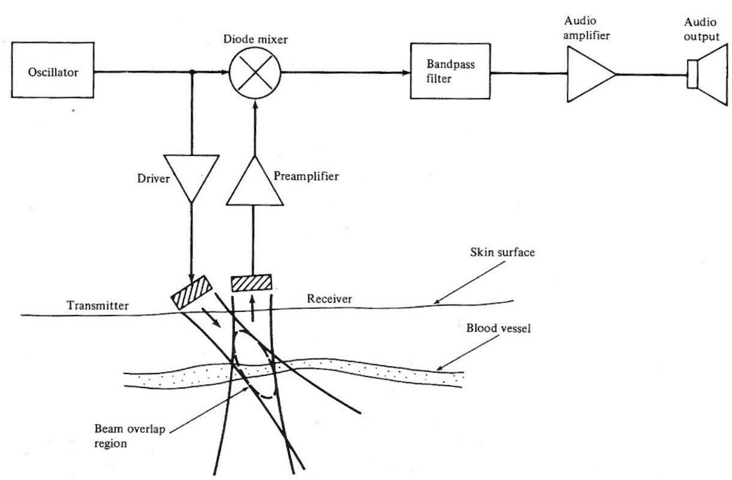
- finite beamwidths of the incident and received beams produce a finite volume of overlap where the scatterers are illuminated rather than a single point
- spatial and temporal variations in blood velocities within the volume
- variations in the incident and received angles across the volume

-Frequency choice is a compromise between:

- good penetration
- maximum scattered power from the collection of red blood cells (recall Rayleigh scattering → f^4)

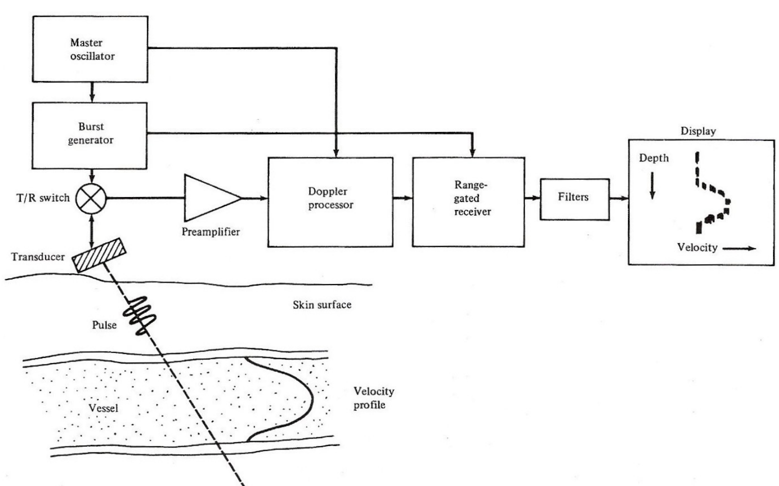
Typical Color Doppler Image

CW Doppler Flowmeter



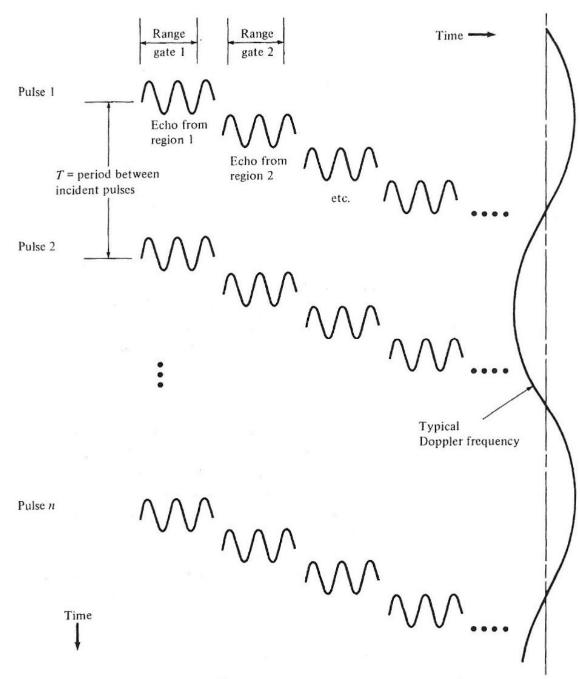
- The transmitter is excited with a continuous sinusoidal voltage
- The signal from the receiver is mixed with a portion of the transmitted signal
- The frequency content of the output can be found using considerations relative to mixing theories
- As a consequence of the mixing operation, the spectrum will be shifted down around the DC
- Any portion of the shifted spectrum, which happens to follow in the negative freq. region is "wrapped around" into the positive freq. side. <u>Therefore, this detection scheme cannot determine the direction of blood flow.</u>
- The desired blood flow spectrum can be isolated passing the signal through a band-pass filter.
- After filtering, other types of processing can be employed

Pulsed Doppler Flowmeter



-The burst generator is driven by the master oscillator and produce few cycles long of incident frequency f_i

- As the transmitted pulse passes through the imaged region, echoes are generated whose frequency is Doppler-shifted proportional to the velocity of the scatterers that are encountered.
- After pre-amplification this Doppler signal is processed.
- The receiver stage is triggered so that it is sensitive to echoes only during a limited time window corresponding to a specified depth (RANGE GATING)
- The magnitude of the Doppler shift is displayed as a velocity value at the appropriate depth position on the screen
- To accurately determine f_D, many pulses at each position of the range gate are required



$$\frac{2l_m}{c} \leq T \leq \frac{1}{2f_{D_{MAX}}}$$

- Since Doppler frequency shifting is equivalent to phase modulation of the scattered signal, the measurement of this shift can be accomplished using a <u>phase detector circuit,</u> which compares the incoming signal with the master oscillator to produce a voltage output that is proportional to the phase angle between the two.

- The output of the phase detector is passed to the range-gated receiver. Here a time-windowed sample of the Doppler signal is taken. Since several samples are needed, a sample-and-hold circuit followed by a filter can be used.

- <u>Spatial resolution of Pulsed Doppler is the same as pulse-echo ultrasound imagers</u>.

-**<u>Pulsed Doppler Controls</u>**:

- Range Gate Position
- Gate or sample volume size
- Pulse duration
- Flow angle cursor (for angle correction)

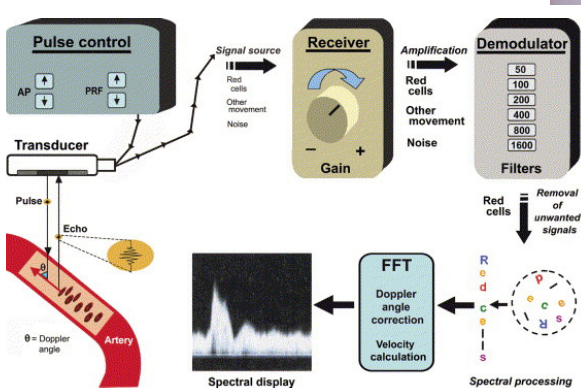
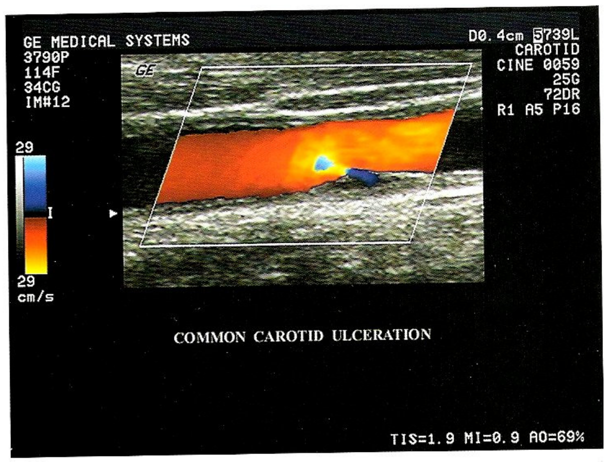


Figure 1. Schematic of the components of a pulse-echo Doppler ultrasound system for production of a spectral display. A sample gate is placed within the walls of the vessel (not shown). Transducer controls for the emitted pulses are acoustic power (AP) and pulse repetition frequency (PRF). Doppler-shift frequencies (signals) are produced by the Doppler effect (see text) of moving red cells and also by extraneous or unwanted movements. The returning Doppler signals are amplified by the receiver. Unwanted signals or Doppler frequencies are filtered by the demodulator. The spectrally processed Doppler signal and Doppler angle are used for computation of blood velocity. The range of Doppler-shift frequencies from the moving red cells are processed and organized (spectral processing).

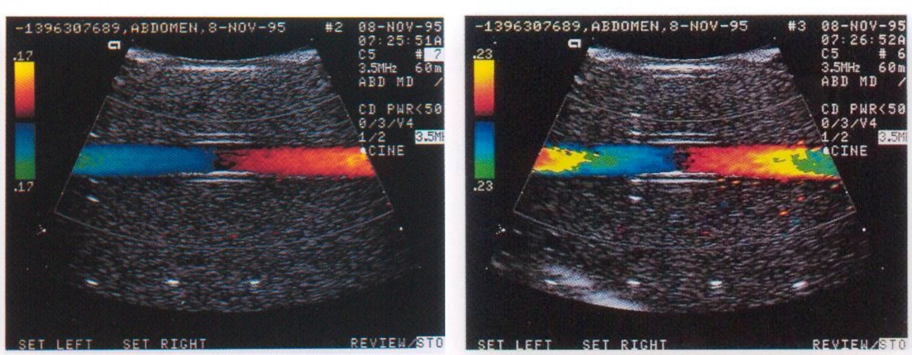
Color Doppler Imaging

Color Flow Imaging provides complete, 2D cross-sectional images depicting velocities of moving reflectors and scatterers.



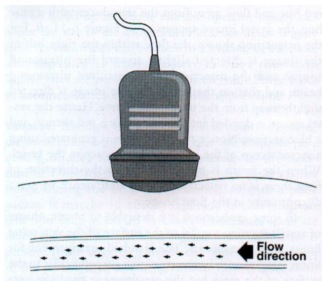
Major disadvantages of CD

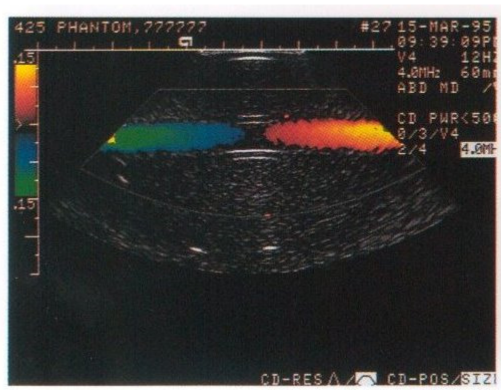
1- Aliasing



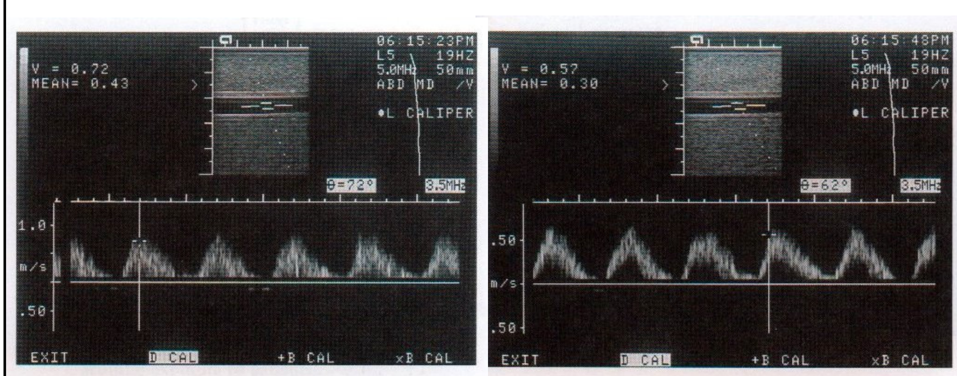
Major disadvantages of CD (cont.)

2- Angle Dependence





Incorrect angle causes Spectral Broadening



Spectral Trace for a vessel with v = 50 cm/s

Major disadvantages of CD (cont.)

3) Difficulty in separating background noise from true flow

4) Very poor sensitivity in slow flow situations

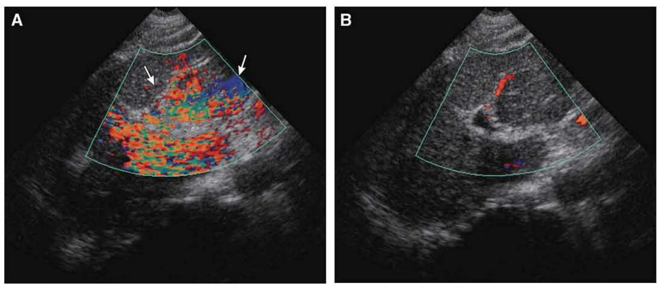


Fig. 20. Flash artifact: patient motion. (*A*) Longitudinal CDUS through the left lobe of liver with flash artifact (*arrows*) produced by respiratory motion. (*B*) Longitudinal CDUS with no motion shows normal vascular flow with no artifact.

Power Doppler

An alternative to CD is a processing method that ignores the reflector velocity but instead estimates the total strength of the Doppler signal within each gated region

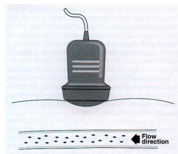
PD displays the total integrated Doppler power in color, which can also be calculated from the autocorrelation of the signal.

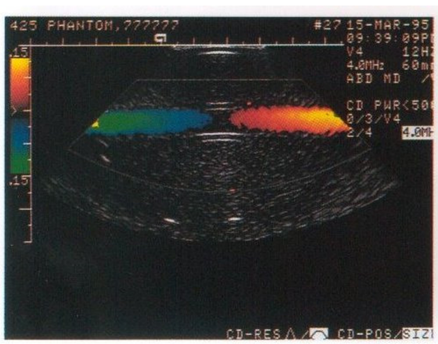
In PD, the information is contained in the amplitude of the reflected signals instead of the frequency shift, and it is integrated to reflect the power of the autocorrelation signal.

Power Doppler

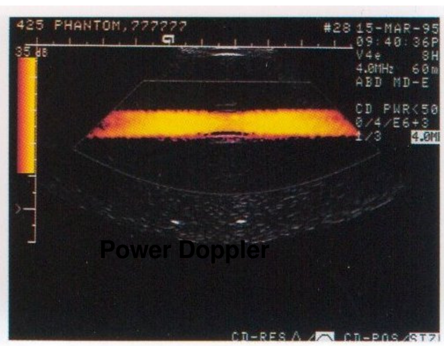
Advantages:

-Representation of random noise in power mode is very different than in a mean frequency mode → Great improvement in flow sensitivity
- NO Aliasing!
-Angle independent





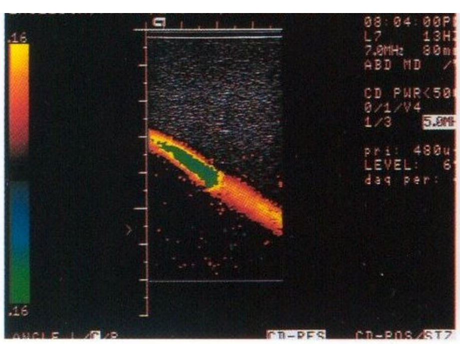
Color Doppler



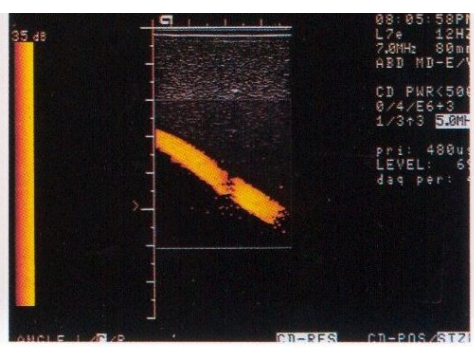
Power Doppler

Power Doppler

Disadvantages:
- no velocity or directional information
- somewhat oversensitive to tissue motion



Color Doppler



Power Doppler

Phantom containing a stenosis.
Higher velocities are seen in the stenosis.