Ultrasonic Doppler Modes

Piero Tortoli

Outline

- Doppler effect
- CW/PW Doppler systems building-blocks
- Pulsed Wave (PW) mode:

  PRF, sample volume, spectral broadening, mean frequency estimation...

Advanced Doppler systems and methods:

  - Single-gate (TCD, Duplex)
  - Multi-gate
  - Flow-imaging
  - Power, Harmonic & Tissue Doppler imaging

- Doppler artefacts (aliasing, blooming...)

UNIVERSITÀ DEGLI STUDI FIRENZE

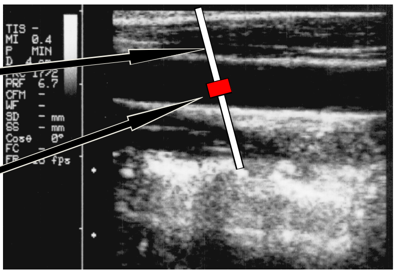
Outline of the 2nd part

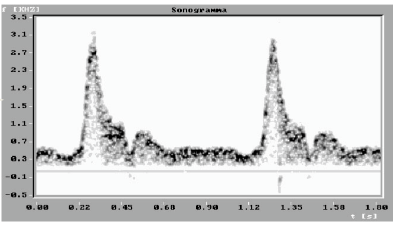
- Pulsed Wave (PW) mode:
  - Duplex (Single-gate)
  - Multi-gate
  - Flow-imaging
  - Power and Harmonic Doppler
  - Tissue Doppler Imaging
- Doppler artefacts (aliasing, angle ambiguity, blooming…)

UNIVERSITÀ DEGLI STUDI FIRENZE

Duplex systems

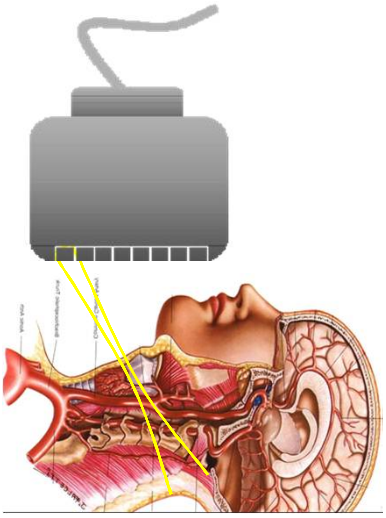
- A (M-mode) scan line can be superimposed to a B-mode image
- Over the scan line, a specific sample volume can be selected
- The Doppler signal produced from the gated sample volume is analysed

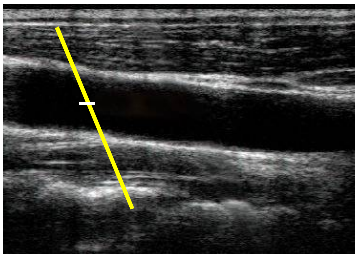




UNIVERSITÀ
DEGLI STUDI
FIRENZE

Duplex systems

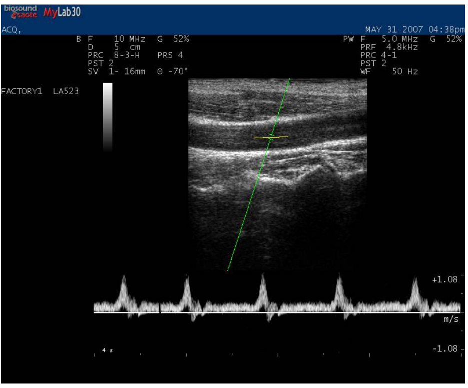




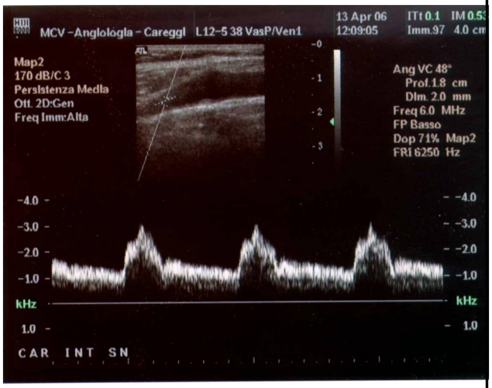
Ideal for stenosis assessment

UNIVERSITÀ
DEGLI STUDI
FIRENZE

Duplex systems application

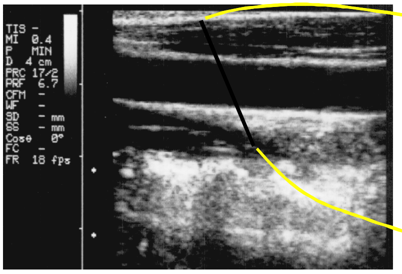


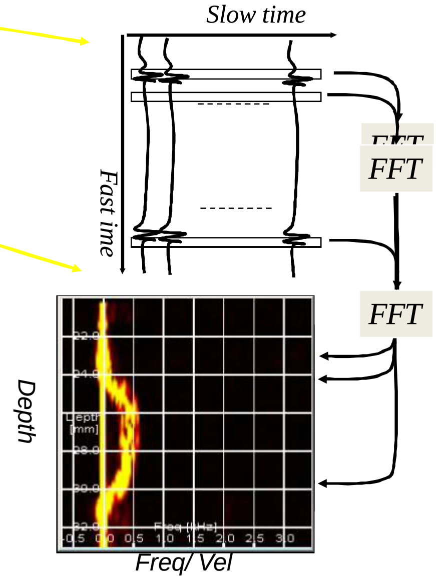
Healthy CCA



Stenotic
Internal CA

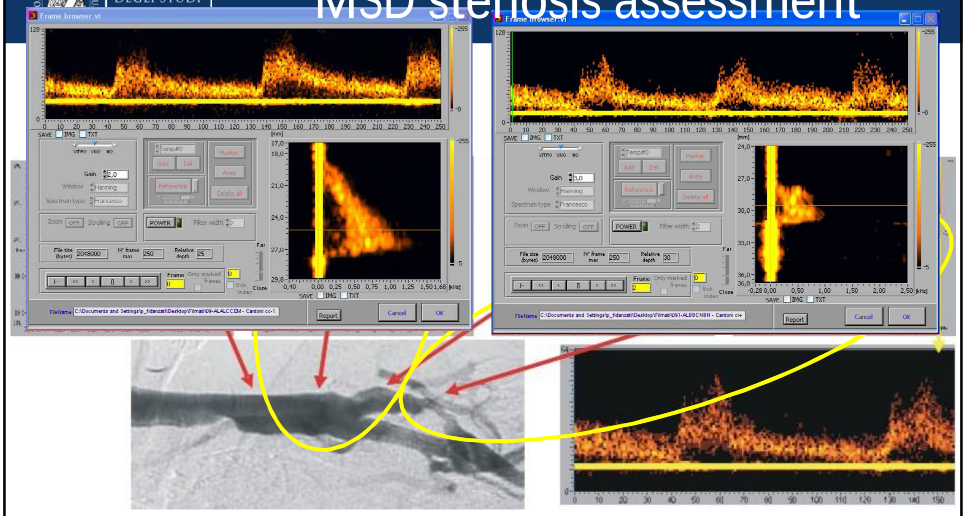
Multigate spectral Doppler



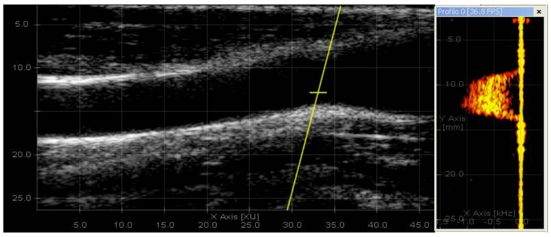


Detection of velocity profiles in arteries and veins

MSD stenosis assessment



Dual (B+MSD) Mode



Flow imaging Mode (Color Doppler)

By firing several pulses for each scan line

By estimating the mean frequency (velocity) detected at each depth

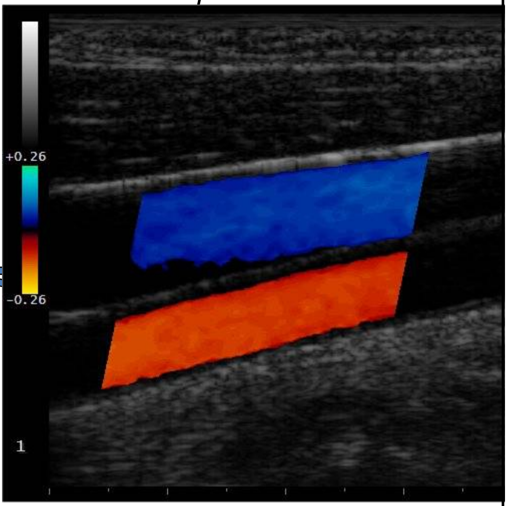
By color-coding consecutive pixels according to the detected mean frequencies

By scanning a 2-D region

Frame rate limitations

Poor sensitivity

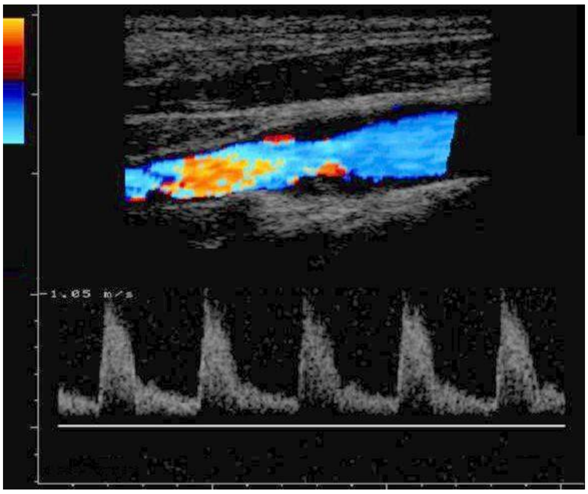
Unsuitable for low velocities



Multigate processing applied to multiple scan lines

UNIVERSITÀ DEGLI STUDI FIRENZE

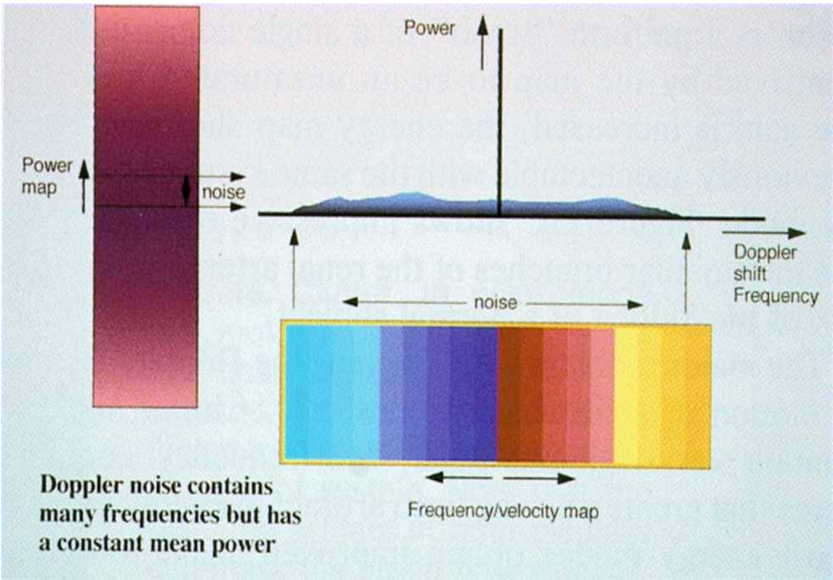
Color Doppler application



non-hemodinamic internal carotid stenosis

UNIVERSITÀ DEGLI STUDI FIRENZE

Power Doppler



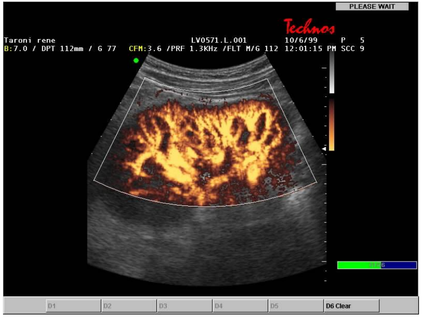
Doppler noise contains many frequencies but has a constant mean power

UNIVERSITÀ DEGLI STUDI FIRENZE

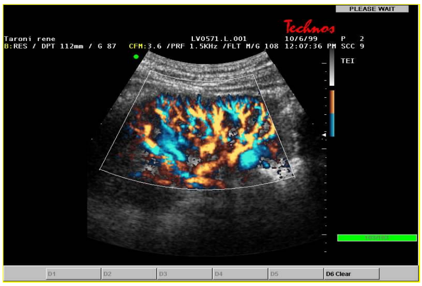
Power Doppler

- For each scan line, the power of Doppler echoes is detected and integrated (persistance)
  - ☺ High S/N
  - ☺ Ideal for small vessels
  - ➢ All movements (including “slow” blood and tissue movements) are detected
  - ➢ Qualitative (velocity magnitude is ignored)

Same hardware as for Doppler imaging: software differences



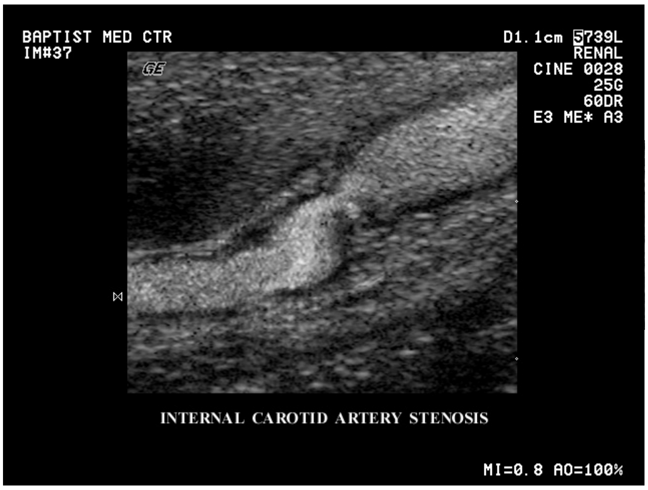
Unidirectional PD



Bidirectional PD

UNIVERSITÀ DEGLI STUDI FIRENZE

B-Flow Mode



High resolution; High blood/tissue ratio

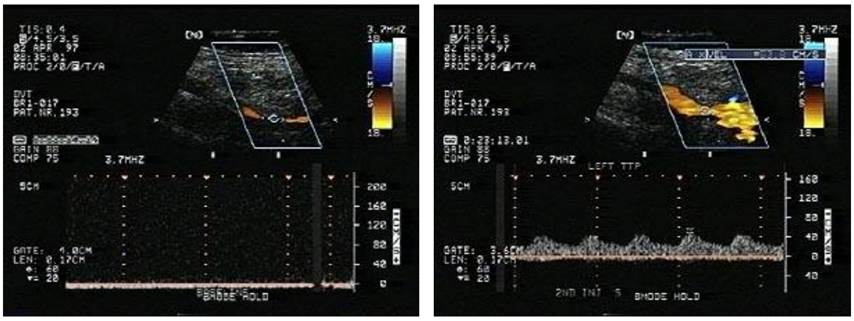
UNIVERSITÀ
DEGLI STUDI
FIRENZE

Doppler modes with Contrast agents

UNIVERSITÀ
DEGLI STUDI
FIRENZE

Echo enhancement

Injection of US contrast agents (microbubbles in a shell) generates strong backscattering (*echo enhancement*)



Useful for small, deep, hardly accessible vessels (eg:TCD analysis)

Harmonic Doppler Mode

- Non-linear behaviour of US contrast agents yields 2nd harmonic ($2\times f_t$) components much stronger than those generated by tissue

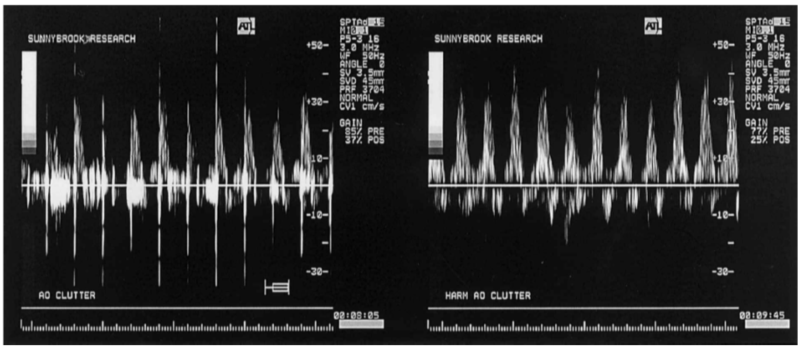
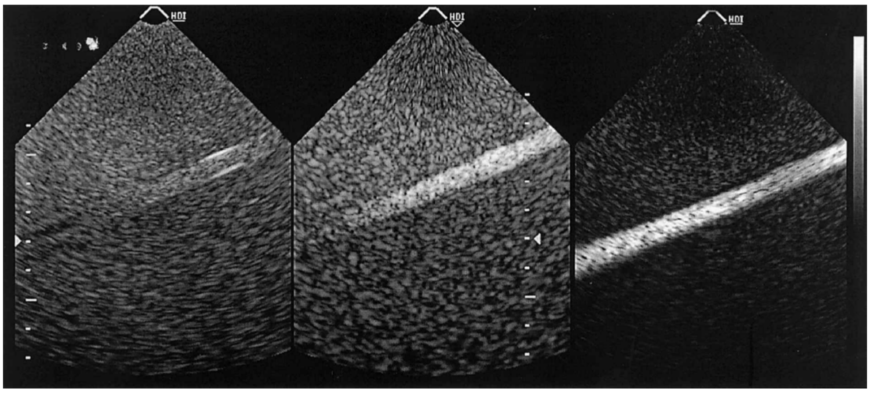


Figure 6. *Clutter rejection with harmonic spectral Doppler.* **A.** *The abdominal aorta of an animal is examined with harmonic spectral Doppler. In conventional mode, clutter from the moving wall causes the familiar artifact, which also obscures diastolic flow.* **B.** *In harmonic mode, the clutter is almost completely suppressed so that flow can be resolved. The*

Need for wideband transducers – Suitable for perfusion assessment

Harmonic Doppler Mode

- Detection of 2nd harmonic echoes allows to reverse the roles of blood & tissue in US images
- More sophisticated TX-RX strategies (eg: *pulse inversion*) allow further increments of blood/tissue ratio to be obtained



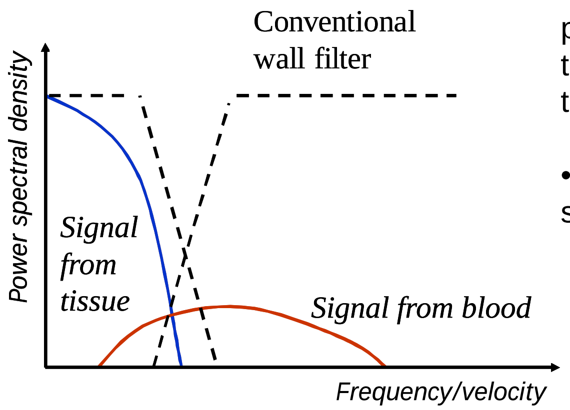
Conventional US imaging

Harmonic Doppler imaging

Pulse inversion Doppler imaging

Tissue Doppler Imaging (TDI)

Tissue Doppler Imaging (TDI)

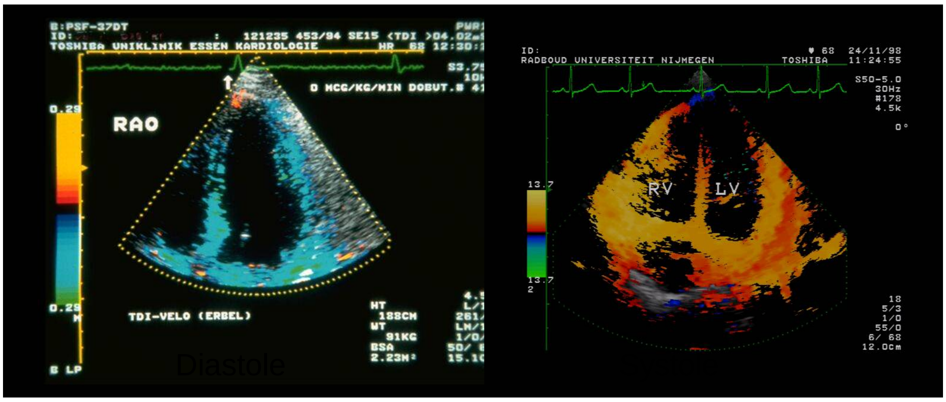


- The wall filter partially suppresses the echo-signal from tissue

- In TDI, the blood signal is suppressed!

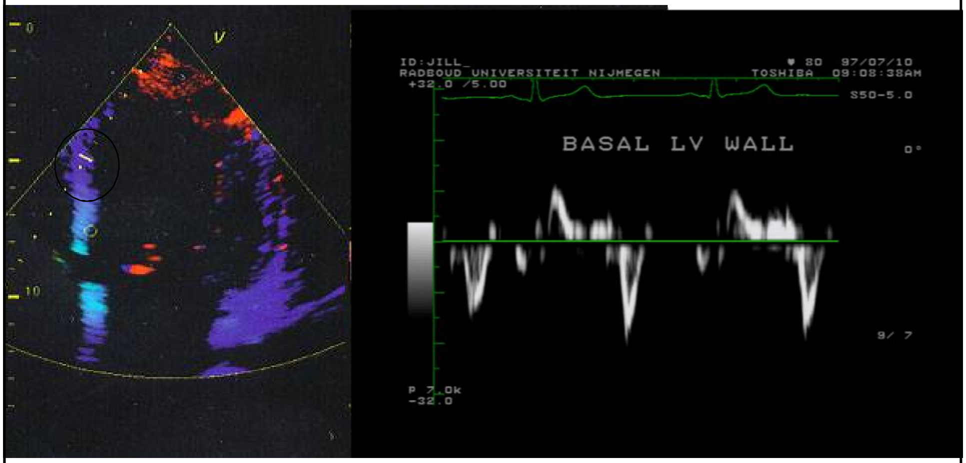
TDI images

Left ventricle

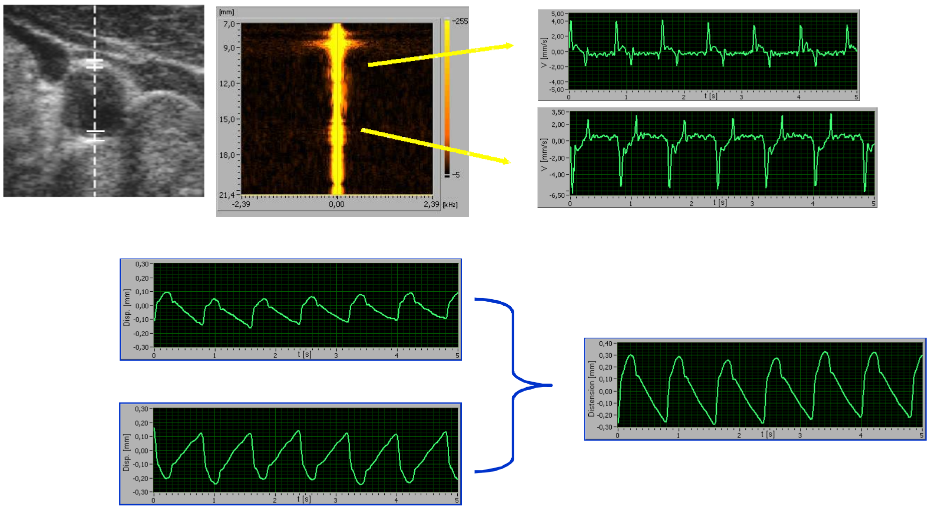


High signal, low velocity image

TDI waveforms

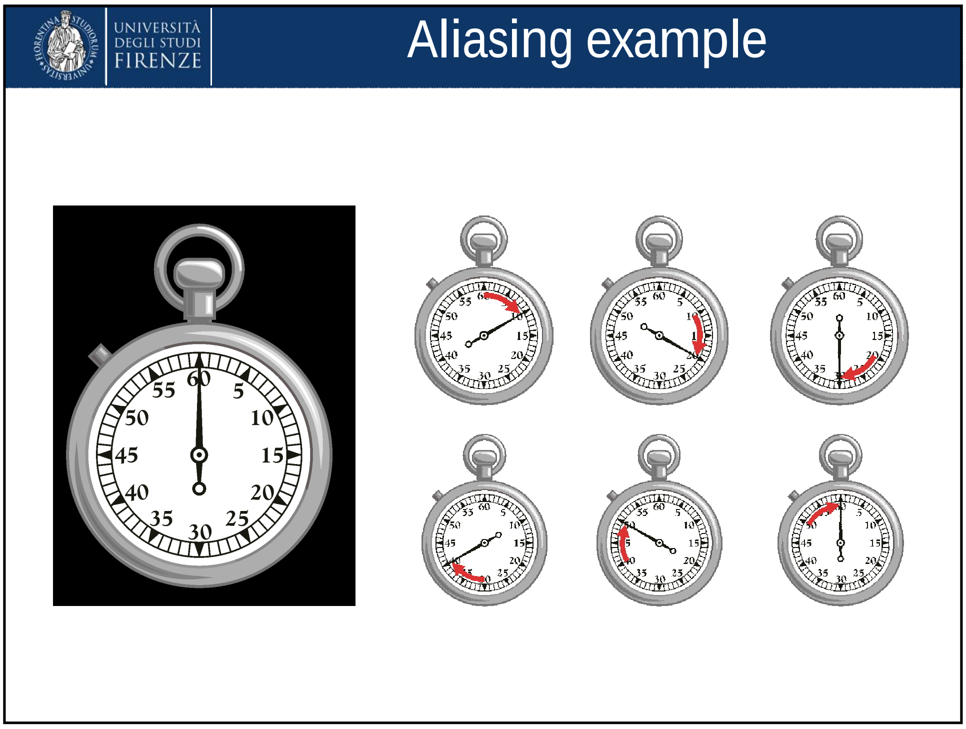


Arterial wall movement detection

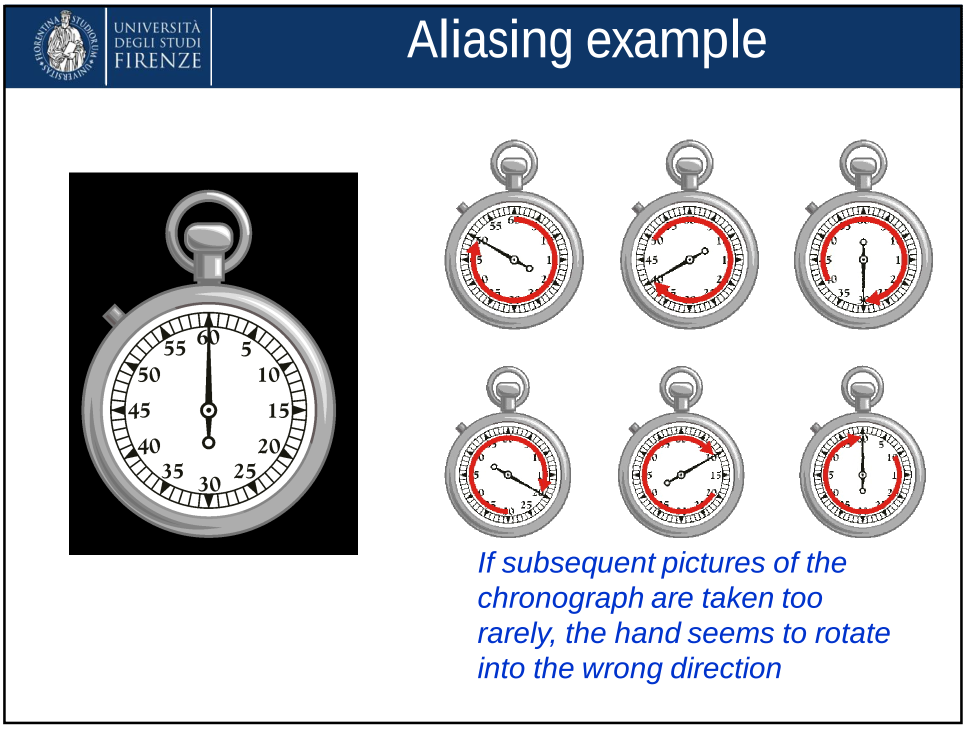


Doppler artefacts: Aliasing

- For each transmitted pulse, <u>one sample of the Doppler signal</u> at a given depth is obtained
- Doppler samples are produced at PRF rate
- If the sampling frequency, PRF, is too low with respect to the Doppler frequency, f_d (i.e. if f_d > PRF/2) →



Aliasing example



Aliasing example

If subsequent pictures of the chronograph are taken too rarely, the hand seems to rotate into the wrong direction

UNIVERSITÀ
DEGLI STUDI
FIRENZE

Aliasing origin

Aliasing occurs for sampling frequency $f_s < 2B$, with B being the signal bandwidth (*Nyquist limit*).

For PW systems:
f_s = PRF
$B = f_{d\max}$ (maximum Doppler frequency)

→ Nyquist limit: $\mathrm{PRF} > 2B = 2 f_{d\,\max} = 4 \frac{v_{\max}}{c} f_0 \cos\vartheta$

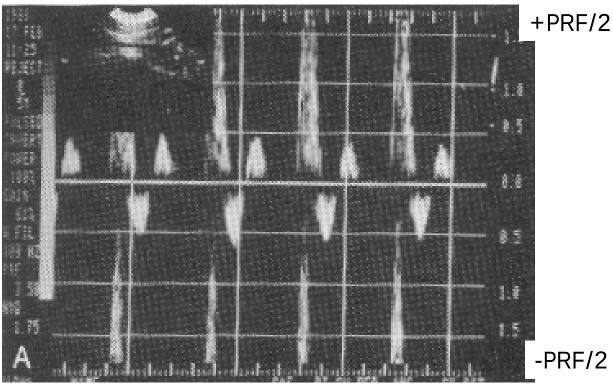
$$\mathrm{PRF}_{\max} = \frac{c}{2d} \longleftarrow$$

$$\boxed{v_{\max} < \mathrm{PRF}_{\max} \frac{c}{4 f_0 \cos\vartheta} = \frac{c^2}{8 f_0 d \cos\vartheta}}$$

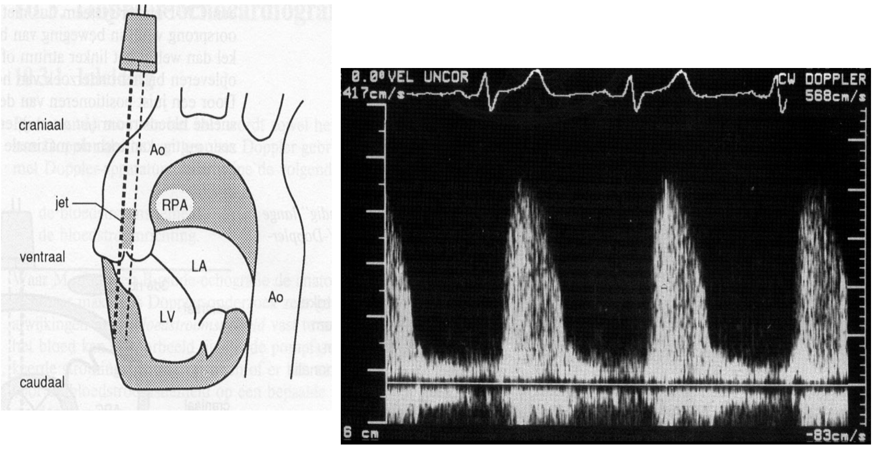
UNIVERSITÀ
DEGLI STUDI
FIRENZE

Aliasing effects

In PW Doppler systems, *aliasing* yields Doppler components in wrong positions, or wrong colors in 2-D flow maps



Methods for aliasing limitation
CW Doppler measurement

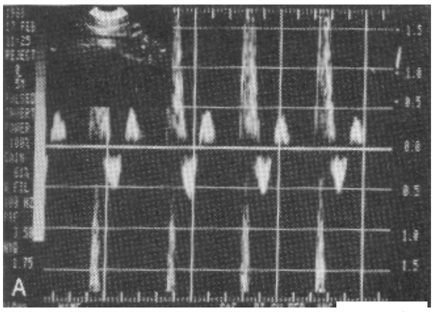


Jet stream through aortic valve stenosis

Aliasing limitation

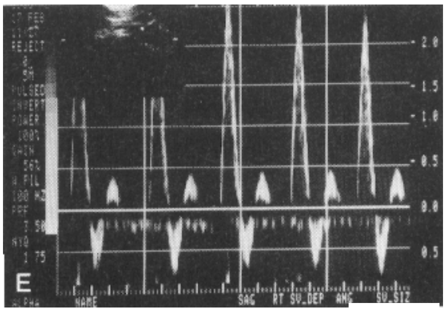
- ✓ Increasing the PRF (D_{max} *decreases*)
- ✓ Increasing the Doppler angle (f_D decreases)
- ✓ Using lower frequency transducers (*worst res*)
- ✓ *Baseline shifting:*

+PRF/2



-PRF/2

+3/4PRF



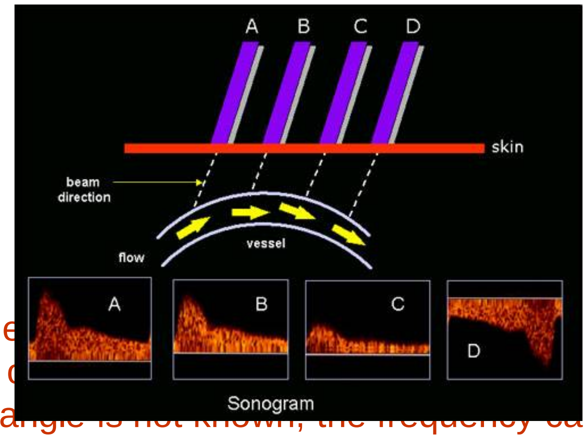
-PRF/4

UNIVERSITÀ DEGLI STUDI FIRENZE

Doppler angle ambiguities

The detected frequency depends on the Doppler angle

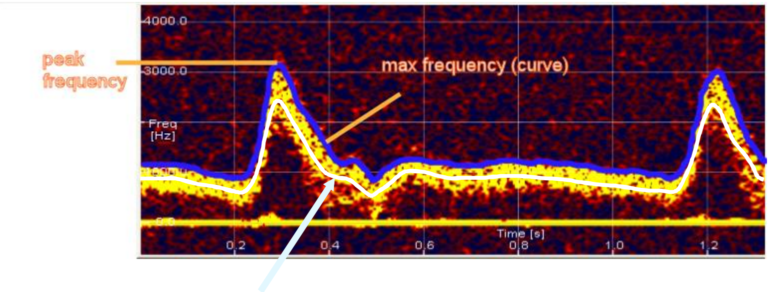
$$f_d = 2\frac{v}{c} f_0 \cos\vartheta$$



- Freque in the angle c
- If the a annot be converted to velocity

UNIVERSITÀ DEGLI STUDI FIRENZE

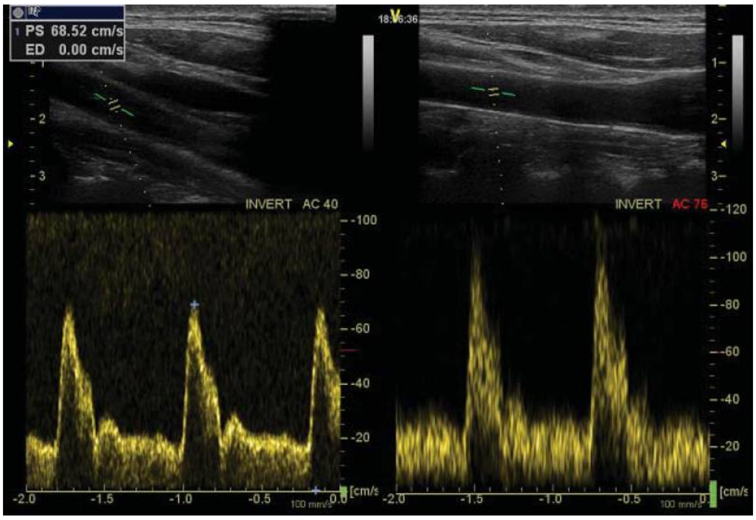
Maximum velocity



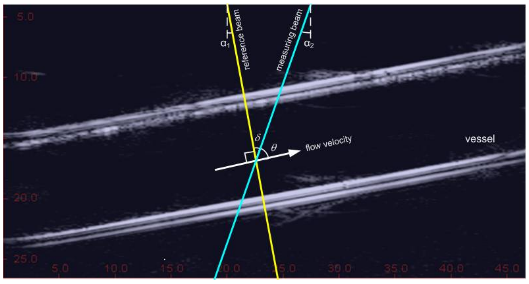
Mean frequency curve

Does max frequency correspond to max velocity?

Angle ambiguity



Vector Doppler

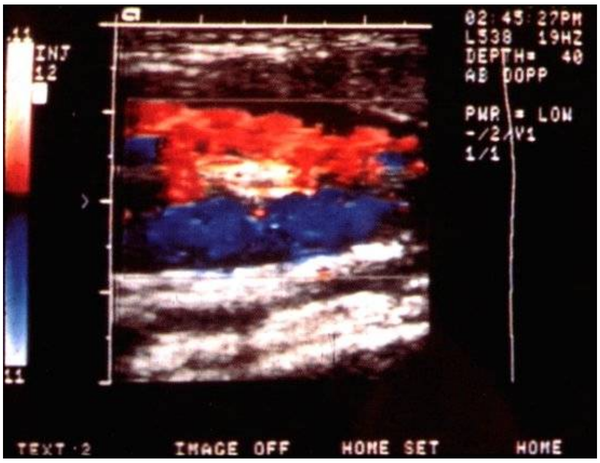


Two beams intercepting the same SV can solve the angle ambiguity

Two equations with two variables (v & θ):

$$f_{d1} = 2\frac{f_0}{c} v \cos\vartheta \qquad f_{d2} = 2\frac{f_0}{c} v \cos(\vartheta + \delta)$$

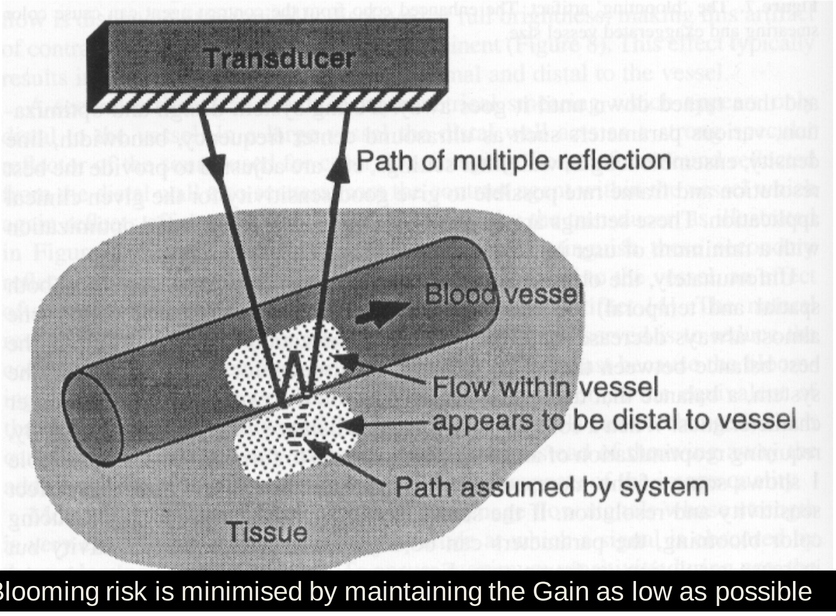
Blooming



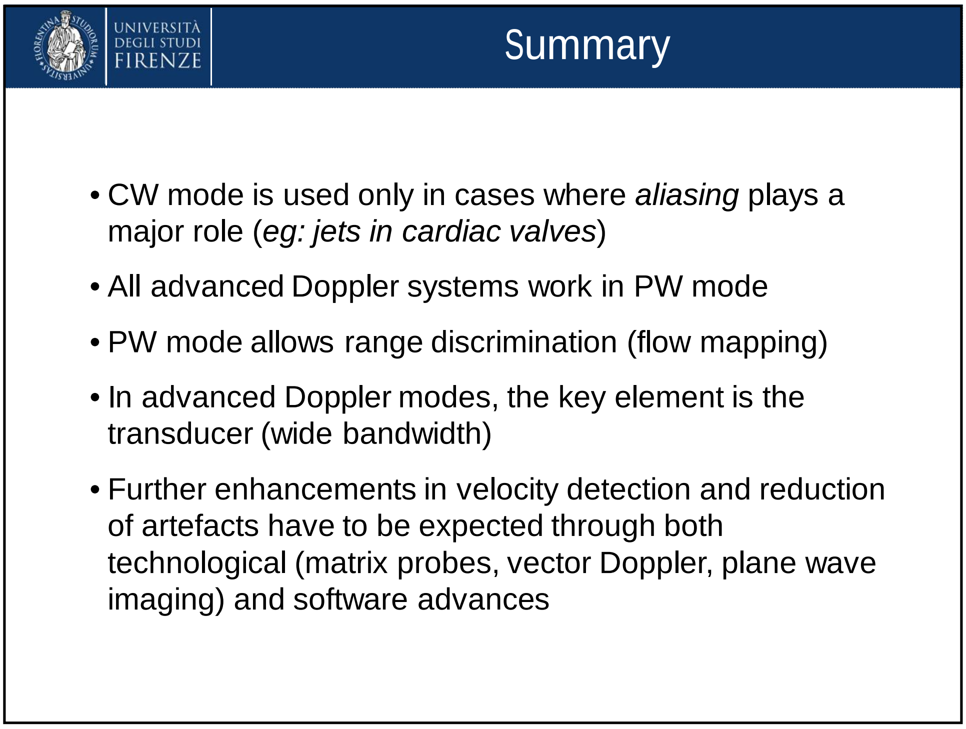
Blooming corresponds to the presence of "color" in regions with no movement. It is due to *eccessive* echogenicity of contrast agents

---

Blooming



Blooming risk is minimised by maintaining the Gain as low as possible



Summary

- CW mode is used only in cases where *aliasing* plays a major role (*eg: jets in cardiac valves*)
- All advanced Doppler systems work in PW mode
- PW mode allows range discrimination (flow mapping)
- In advanced Doppler modes, the key element is the transducer (wide bandwidth)
- Further enhancements in velocity detection and reduction of artefacts have to be expected through both technological (matrix probes, vector Doppler, plane wave imaging) and software advances