CFI simulation in Field II
Color Flow Imaging

- Color encoded image of blood flow
  - Axial mean velocity and direction
- Velocity is found from the mean frequency (shift) estimated in each spatial point
- Several pulses must be emitted for each beam direction, e.g. \( N = 8 - 12 \) \( \rightarrow \) slow time signal

Image borrowed from Lasse's presentation on dynamic imaging
Parameter estimation

- The acquisition leads to a complex (slow time) signal for each spatial position
- Sum from many scatterers - complex Gaussian random process (stationary)
- For such a process, the autocorrelation function is related to the frequency spectrum (power spectral density) through the Wiener-Khinchin theorem

\[
R(m) = \frac{1}{2\pi} \int_{-\pi}^{\pi} G(\omega) e^{i\omega m} d\omega
\]

\[
R(0) = \frac{1}{2\pi} \int_{-\pi}^{\pi} G(\omega) d\omega
\]

\[
R(1) = \frac{1}{2\pi} \int_{-\pi}^{\pi} G(\omega) e^{i\sigma} d\omega = \frac{e^{i\sigma}}{2\pi} \int_{-\pi}^{\pi} G(\omega) e^{i(\omega-\sigma)} d\omega
\]
The estimators

\[ \hat{P} = \hat{R}(0) = \frac{1}{N} \sum_{n=0}^{N-1} z(n)z(n)^* = \frac{1}{N} \sum_{n=0}^{N-1} |z(n)|^2 \]

\[ \hat{f}_d = \frac{\angle \hat{R}(1)}{2\pi} = \frac{1}{2\pi} \angle \left[ \frac{1}{N-1} \sum_{n=0}^{N-1} z(n)^* z(n+1) \right] \quad -0.5 \leq \hat{f}_d \leq 0.5 \]

From the mean frequency, the velocity in each point is found by

\[ v_z = \frac{\hat{f}_d c \ PRF}{2f_0} \]
Scan setup in Field II

- Assignment: CFI simulation of parabolic flow in a blood vessel
- A linear scan was simulated, firing K pulses in each beam direction, with 64 of 192 elements active
- The physical array parameters were similar to the GE 7L probe
- Focus direction with reference point on transducer surface is set by using xdc_center_focus() and xdc_focus
- Hamming apodization was used on tx and rx
2D phantom

- Consists of many point scatterers with equal scattering amplitude.
- Initial positions are randomly distributed in a vessel shaped area, positioned at some angle to the beam direction.
- In each timestep the positions are updated according to a parabolic velocity profile (Poiseuille flow).
- Include enough scatterers to get a gaussian distributed backscattered signal.

\[ v(r) = v_{\text{max}} \left( 1 - \left( \frac{r}{R} \right)^2 \right)^2 \]
CFI setup

- $v_{\text{max}} = 0.5 \text{ m/s}$
- Parabolic velocity profile
- Vessel radius = 7 mm
- PRF = 6000 Hz
- Packetsize = 8
- $dx = 0.5 \text{ mm}$

- Did not include dynamic focusing or dynamic aperture
- Did not include stationary scatterers (clutter)
- Seems to give the right velocity profile
- Can investigate the velocity profile in more detail by using only one image line
Estimator performance

- The performance of the velocity estimator was assessed by repeatedly imaging only the center line.
- The image lines were aligned in depth, and a mean velocity profile calculated.
- The velocity profile was then compared to the equation for Poiseuille flow, which was used to move the scatterers.
Estimator performance

Aliasing effects:
• Is not the problem here, \( v_{nyq} = 0.65 \text{ m/s} \)

Averaging effects:
• Underestimation of high central velocities
  – The sidelobes of the PSF pick up lower velocities from more peripheral sites
• Overestimation of low peripheral velocities
  – The sidelobes of the PSF pick up higher velocities from within the vessel.
Estimator performance

- Problem: The high velocities are also underestimated if the velocity profile is uniform
Estimator properties – questions…

Asymmetric frequency spectrum?

- The autocorrelation estimator is an approximation
- The approximation is poor if the frequency spectrum is asymmetric
- Poor approximation can lead to bias in velocity estimation
Estimator properties – questions...

- Signal not Gaussian enough?