Exercise 9

Ultrasound Signal Processing

TTK 4165 MEDICAL SIGNAL PROCESSING

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Part 1: Theory

Even Florenæs MTEL

a)

Received frequency is the remaining of the transmitted after doppler shift:

$$f_r = f_0 - 2f_0 \frac{v\cos\varphi}{c}$$

$$= \underline{\underline{f_0\left(1 - 2\frac{v\cos\varphi}{c}\right)}}$$

b)

The dopplershift:

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

c)

$f_0 = 2.5\ \mathrm{MHz}$, $c = 1540\ \mathrm{m/s}$, $v = 1\ \mathrm{m/s}$

1) $\varphi = 90°$: $f_r = f_0\left(1 - 2\frac{v\cos 90°}{c}\right)$

$$= f_0 = \underline{\underline{2.5\ \mathrm{MHz}}}$$

$$f_d = f_0 \cdot 2\frac{v\cos 90°}{c} = \underline{\underline{0}}$$

2) $\varphi = 45^\circ$

$$f_r = f_0\left(1 - \frac{2v\cos 45^\circ}{c}\right)$$

$$= f_0\left(1 - \frac{v}{c}\cancel{2}\frac{\sqrt{2}}{\cancel{2}}\right) = f_0\left(1 - \frac{v}{c}\sqrt{2}\right)$$

$$= \underline{\underline{2.4977\ \text{MHz}}}$$

$$f_d = f_0\frac{v}{c}\sqrt{2} = 2295.8\ \text{Hz}$$

$$= \underline{\underline{2.3\ \text{kHz}}}$$

d) $r = 7.7\ \text{cm}$

$\varphi = 45^\circ$

$v_{max} = 1.5\ \text{m/s}$

1) Time per measurement:

$$\Delta t_{min} = \frac{2r}{c} = \underline{10^{-4}\,\text{s}}$$

$$PRF_{max} = \frac{1}{\Delta t_{min}} = 10^4\ \text{Hz} = \underline{\underline{10\ \text{kHz}}}$$

2)

$$PRF_{max} = \frac{4f_0}{c}v_{max}\cos 45^\circ$$

$$f_0 = \frac{c \cdot PRF_{max}}{4v_{max}\cdot\cos 45^\circ} = \underline{\underline{\cancel{147.52\ \text{MHz}}}}$$

$$= \underline{\underline{3.63\ \text{MHz}}}$$

3) $\varphi = 30^\circ$ Even Florenæs MTEL

Need to find phase-shift for this case:

(From Ex. 8):

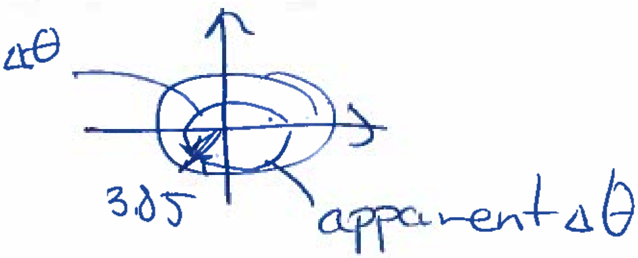
$$\Delta\theta = 4\pi \frac{v}{PRF \cdot \lambda} = 4\pi \frac{v \cdot f_0}{c \cdot PRF}$$

$$= 4\pi \frac{V_{max} \cdot f_0 \cdot \cos(\phi)}{c \cdot PRF}$$

$$= 4\pi \frac{3.63 \cdot 10^6 \frac{1}{s} \cdot 1.5 \frac{m}{s} \cdot \cos(30^\circ)}{1540 \, m/s \cdot 10^4 \, Hz}$$

$$= \underline{3.85 \text{ rad}}$$

$\Delta\theta$ will not be the apparent $\Delta\theta$:



$\Delta\theta_{apparent} \stackrel{?}{=}$ Apparent $\Delta\theta$

$$\Delta\theta_{apparent} = -(2\pi - 3.85) = \underline{-2.43 \text{ rad}}$$

$$\Delta\theta_{apparent} = 4\pi \frac{V_{apparent} \cdot f_0}{c \cdot PRF}$$

$$V_{apparent} = \Delta\theta_{apparent} \frac{c \cdot PRF}{4\pi \cdot f_0} = \underline{\underline{-0.82 \, m/s}}$$

$$V_{apparant} = V_{Max\,apparat} \cdot \cos(30°)$$

$$V_{max\,apparant} = \frac{V_{apparant}}{\cos 30°} = -0.95\ m/s$$

Doppler shift:

$$f_d = f_0 \frac{2 V_{apparant}}{c} = -3865.7\ Hz$$

$$= -3.9\ kHz$$

e)

Even Fløren as I-IT ZL

1) CW Doppler have no depth resolution

True, CW Doppler have continous transmission of waves which will give no resolution along the beam. The results of transmission will all flow along the line-of-sight add together and mix.

2) Maximum velocity with PW (Measurable) is inverseley proportional to the distance.

If this is true: $V_{max} = \frac{k}{r}$ where

k - const. and r - distance to sample volume

Relation between PRF_{max} and V_{max}:

$$PRF_{max} = \frac{4f_0}{c} V_{max} \cos\theta \quad (1)$$

Find PRF_{max}:

$$t_{min} = \frac{2r}{c} \Rightarrow PRF_{max} = \frac{1}{t_{min}} = \frac{c}{2r} \quad (2)$$

(2) → (1):

$$\frac{c}{2r} = \frac{4f_0}{c} V_{max} \cos\theta$$

$$V_{max} = \frac{c^2}{2 \cdot 4 f_0 \cos\theta} \cdot \frac{1}{r} = k \cdot \frac{1}{r}$$

if f_0 = const

$$k = \frac{c^2}{8 f_0 \cos\theta}$$

statement is true

f) Increasing transmit frequency implies a better velocity resolution in PW doppler when the PRF is kept constant.

Velocity (max) in PW Doppler is explained by:

$$V_{max} = \frac{c^2}{8 f_0 \cos\theta} \cdot \frac{1}{r} = \frac{c \cdot PRF_{max}}{4 f_0 \cos\theta}$$

If f_0 is increased (with PRF kept const.) the resolution in velocity will decrease.

Statement is not true (untrue)

g)

In many practices Color flow replaces PW and CW. Color flow can easily be used for measuring size and direction for imaged organs. Timing information is more complicated in 2D-color flow display. For measuring velocity PW and CW would be a better choice. Statement is untrue.

h)

Formula for speed resolution:

$$V = \frac{c \cdot PRF}{f_0 \cdot 4\cos\theta}$$

A shorter pulse will not effect the speed resolution as it will change the spread of frequency (bandwith), but not the PRF or f_0. It will give better lateral resolution.

Statement untrue.