Continuous Wave (CW) Radar

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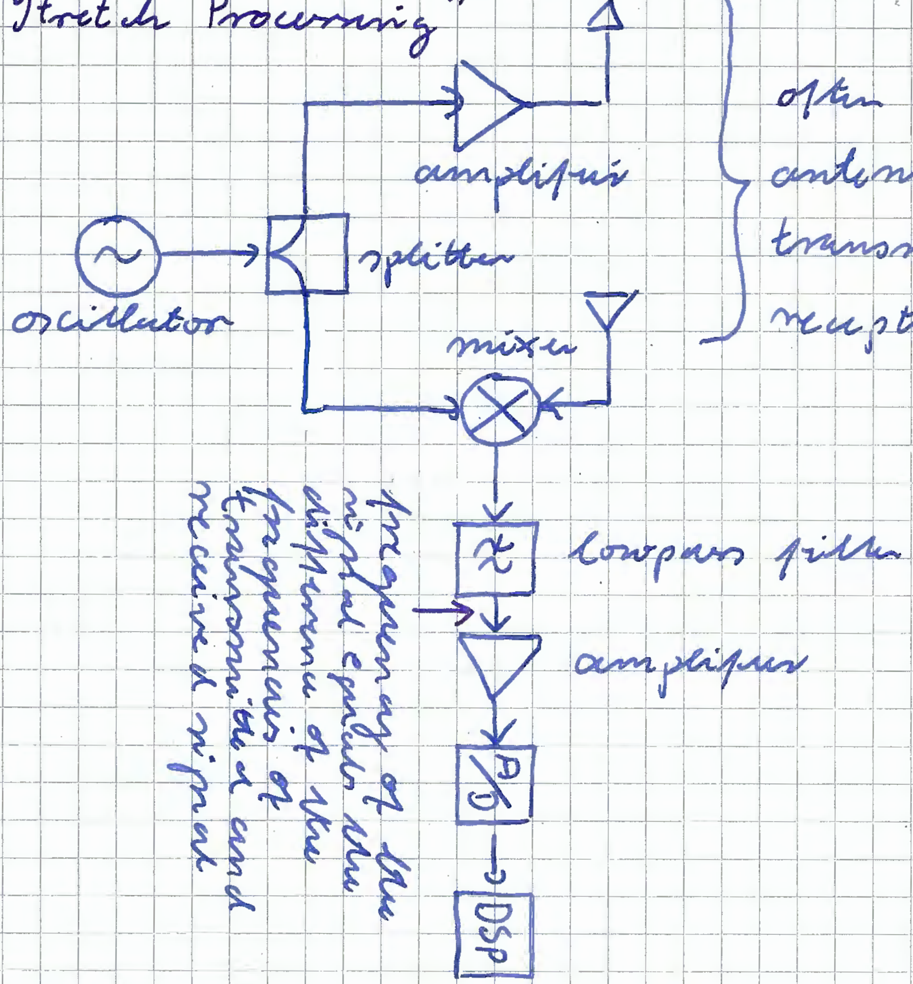
- a signal is transmitted continuously

- typical block diagram → low cost
"Stretch Processing"



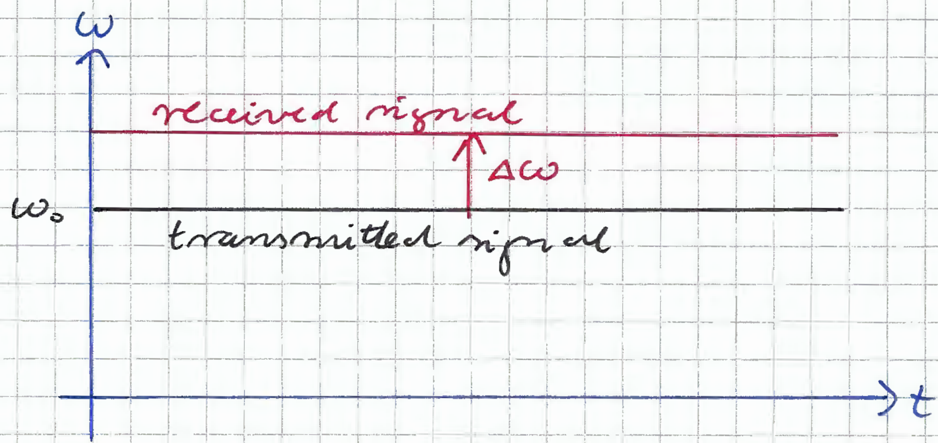
often the same antenna is used for transmission and reception

- due to crosstalk and limited dynamic range
  - only signals with a frequency being different from the instantaneous transmitted frequency can be detected
  - only strong signals from nearby scatterers can be detected

- typical applications
  - industrial level measurement
  - automotive radar

Unmodulated Continuous Wave (CW) Radar

- a sinusoidal signal of constant frequency is transmitted
  $\Rightarrow$ Doppler frequencies of the received signal can be observed
  $\Rightarrow$ moving targets can be detected and their velocities can be measured



attention: the frequency shift $\Delta\omega$ may also be negative!

- velocity

$$v = -\frac{\Delta\omega}{2\beta}$$

- accuracy

$$\text{velocity resolution} \simeq \frac{1}{2\beta}\,\frac{2\pi}{\text{measurement duration}} = \frac{\lambda}{2}\,\frac{1}{\text{measurement duration}}$$

(factor $\frac{1}{2}$ due to two way channel)

$\Rightarrow$ depends on measurement duration and wavelength λ

Frequency Modulated Continuous Wave (FM-CW) Radar

- measuring ranges requires broadband signals
  $\Rightarrow$ frequency modulation
- linear frequency modulation

$$a(t) = \Re\, A \cos\big(\underbrace{\omega_0 t + \tfrac{1}{2} k t^2}_{\varphi(t)}\big)$$

$$\Rightarrow \underline{s}(t) = A\, e^{j \frac{1}{2} k t^2}$$

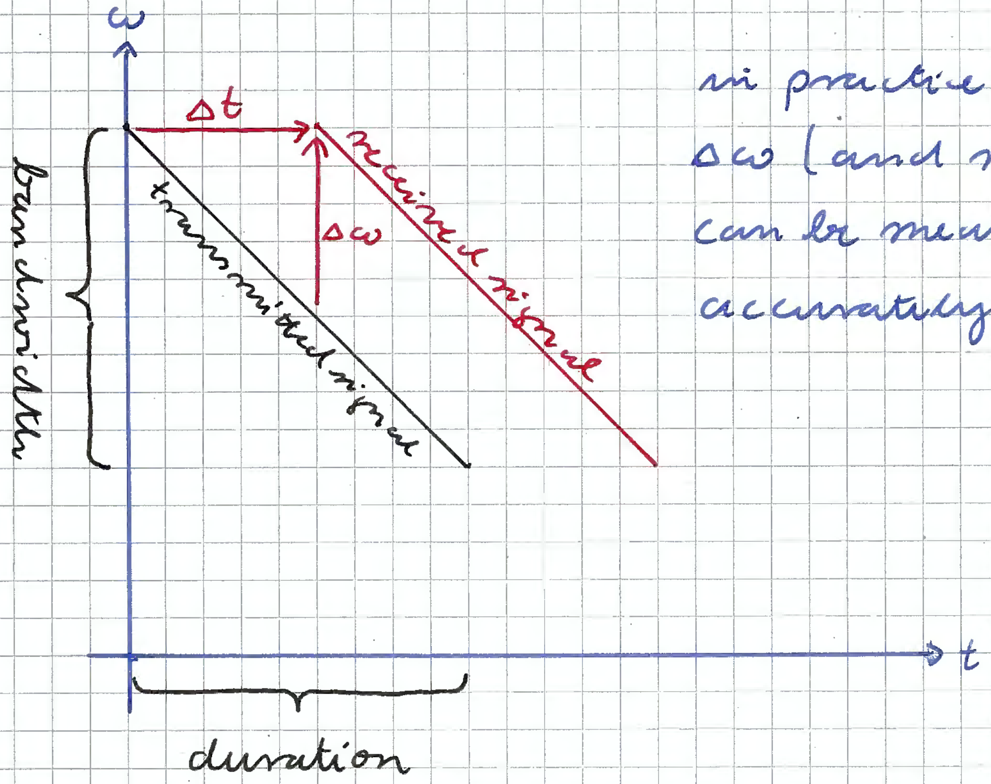
- instantaneous frequency

$$\omega(t) = \frac{\partial \varphi(t)}{\partial t} = \omega_0 + \underbrace{k}_{\text{rate}} t$$

- positive rate $k = |k|$ $\Rightarrow$ up-chirp
  negative rate $k = -|k|$ $\Rightarrow$ down-chirp

Static Scenario

- down-chirp



in practice: only Δω (and not Δt) can be measured accurately

- bandwidth = $|k|$ duration
- frequency shift

$$\Delta\omega = -k \; \Delta t$$

- range

$$r = -\frac{c_0 \, \Delta\omega}{2 \, k}$$

- accuracy

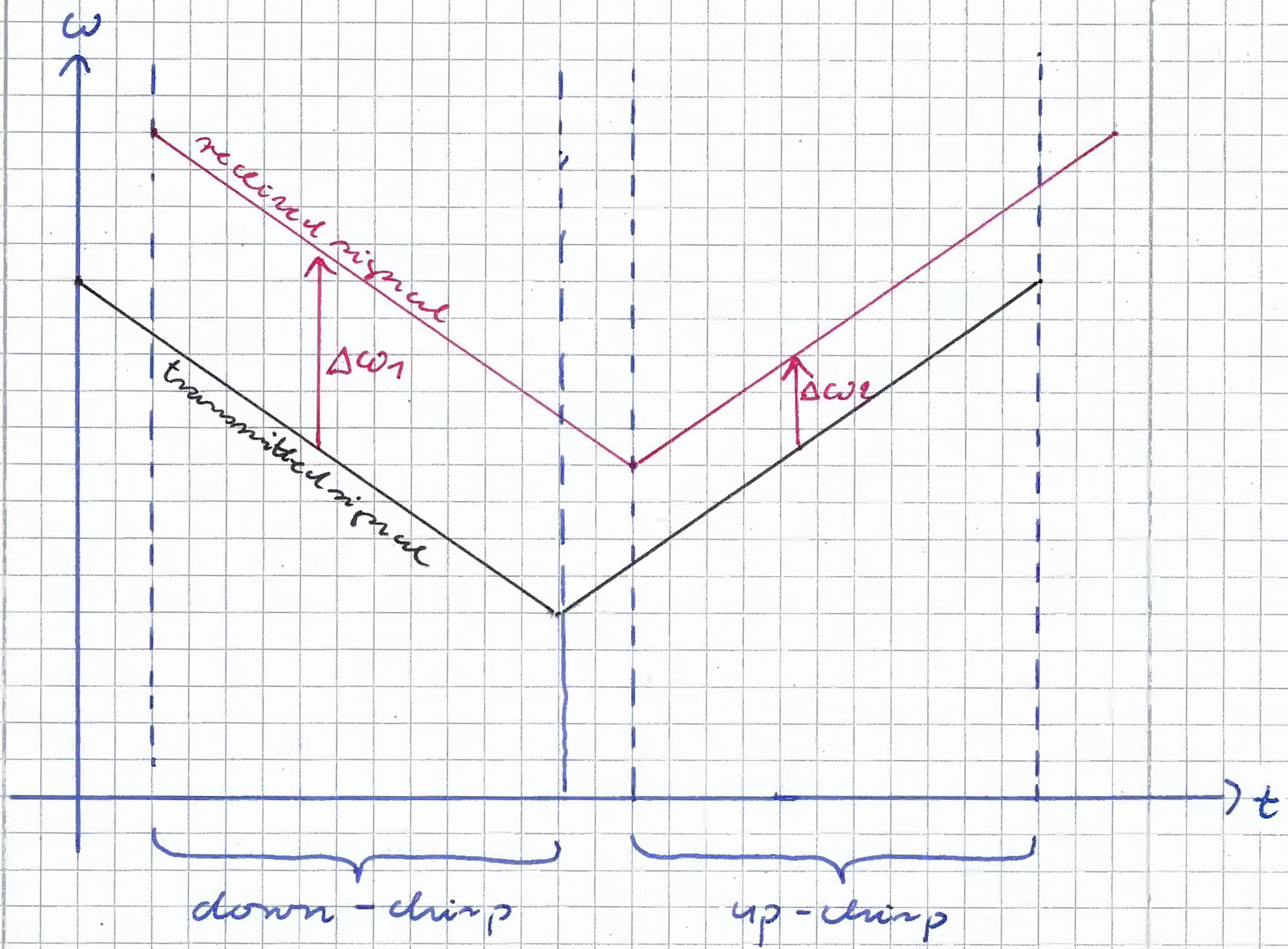
$$\text{frequency resolution} \approx \frac{2\pi}{\text{duration}}$$

$$\text{range resolution} \approx \frac{c_0}{|k|} \; \frac{\pi}{\text{duration}} = \frac{\pi \, c_0}{\text{bandwidth}}$$

(factor $\frac{1}{2}$ due to two way channel)

Measurement of Range and Velocity

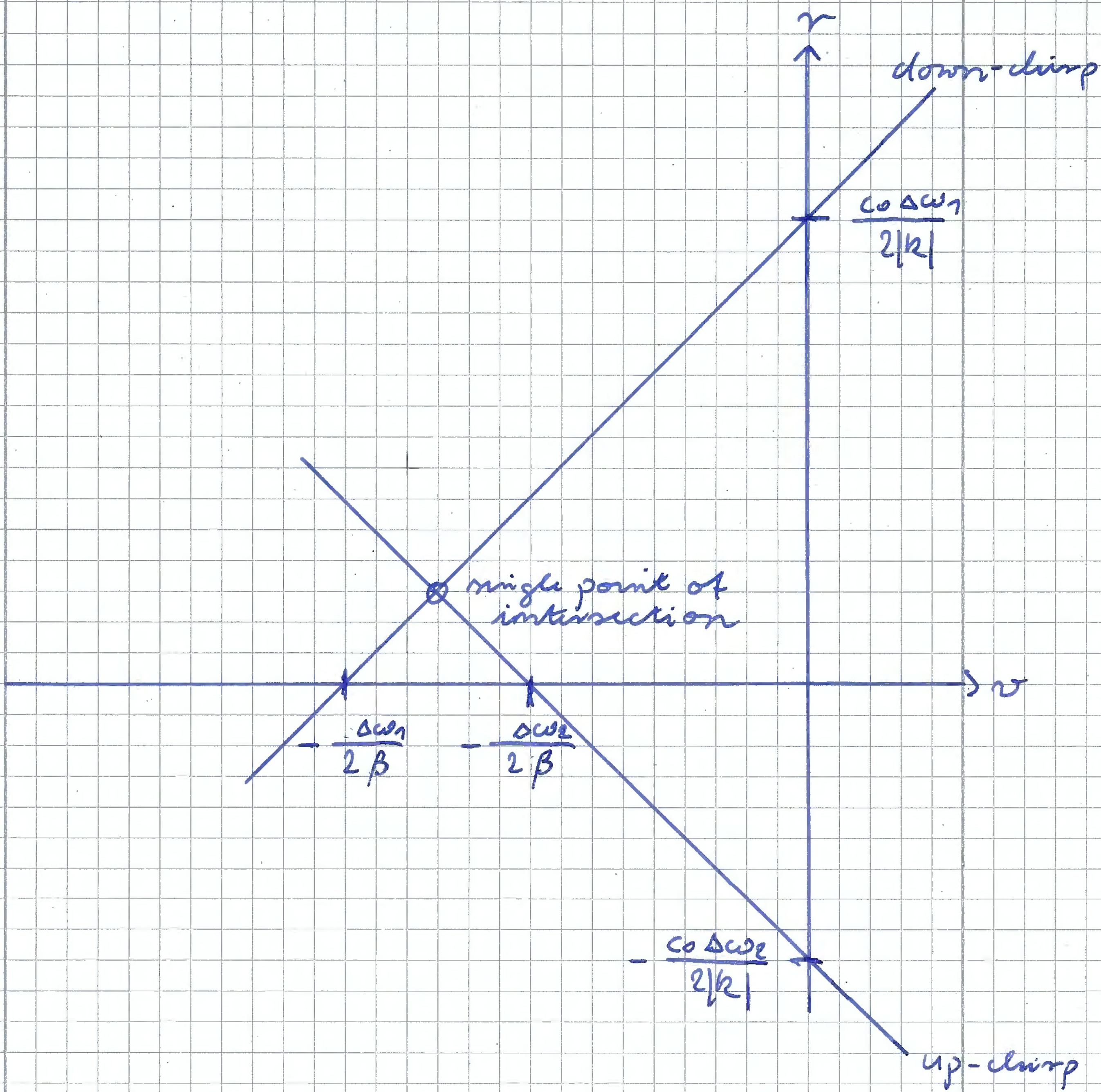
range-velocity ambiguity can be resolved by using a down-chirp and an up-chirp



Linear System of Equations

down-chirp $\Delta\omega_1 = \frac{2|k|}{c_0} r - 2\beta v$

up-chirp $\Delta\omega_2 = -\frac{2|k|}{c_0} r - 2\beta v$



$$\Delta\omega_1 + \Delta\omega_2 = -4\beta v \quad \Rightarrow \quad v = -\frac{1}{4\beta}(\Delta\omega_1 + \Delta\omega_2)$$

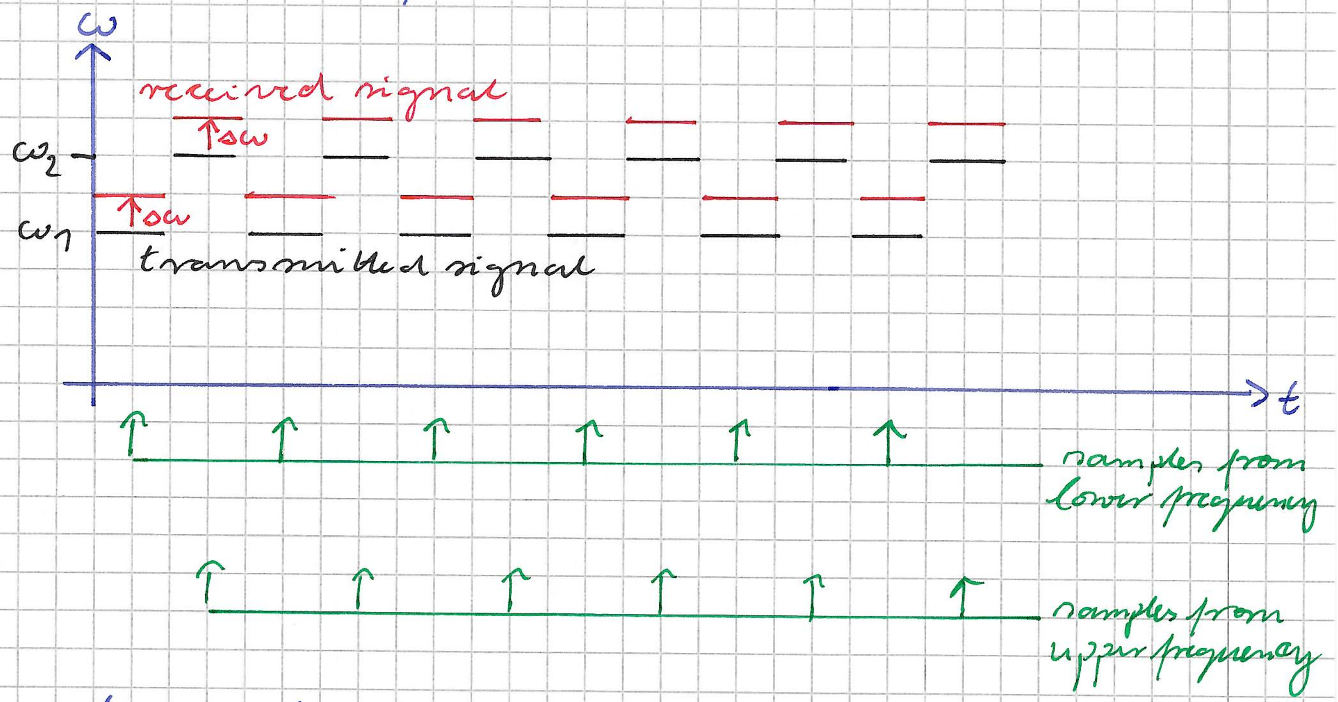
$$\Delta\omega_1 - \Delta\omega_2 = \frac{4|k|}{c_0} r \quad \Rightarrow \quad r = \frac{c_0}{4|k|}(\Delta\omega_1 - \Delta\omega_2)$$

Frequency Shift Keying (FSK) Radar

- similar to continuous wave radar but now two different frequencies ω_1 and ω_2 are used

  $\Rightarrow$ moving targets can be detected and their velocities can be measured

$$v = -\frac{\Delta\omega}{2\beta}$$



- phase shift

$$\varphi_{1,2} = -\omega_{1,2}\,\Delta t = -\omega_{1,2}\frac{2r}{c_0}$$

- phase difference

$$\varphi_1 - \varphi_2 = (\omega_2 - \omega_1)\frac{2r}{c_0}$$

$$\Rightarrow \; r = \frac{c_0(\varphi_1 - \varphi_2)}{2(\omega_2 - \omega_1)}$$ range measurement!

- phase difference can only be measured modulo 2π

  $\Rightarrow$ unambiguous range

$$r < \frac{c_0\,\cancel{2}\pi}{\cancel{2}(\omega_2 - \omega_1)}$$