Tutorial 4: FMCW Radar
Modern Radio Systems Engineering

M.Sc. Akanksha Bhutani
M.Sc. Joerg Eisenbeis

INSTITUTE OF RADIO FREQUENCY ENGINEERING AND ELECTRONICS

Tutorial 4: FMCW radar

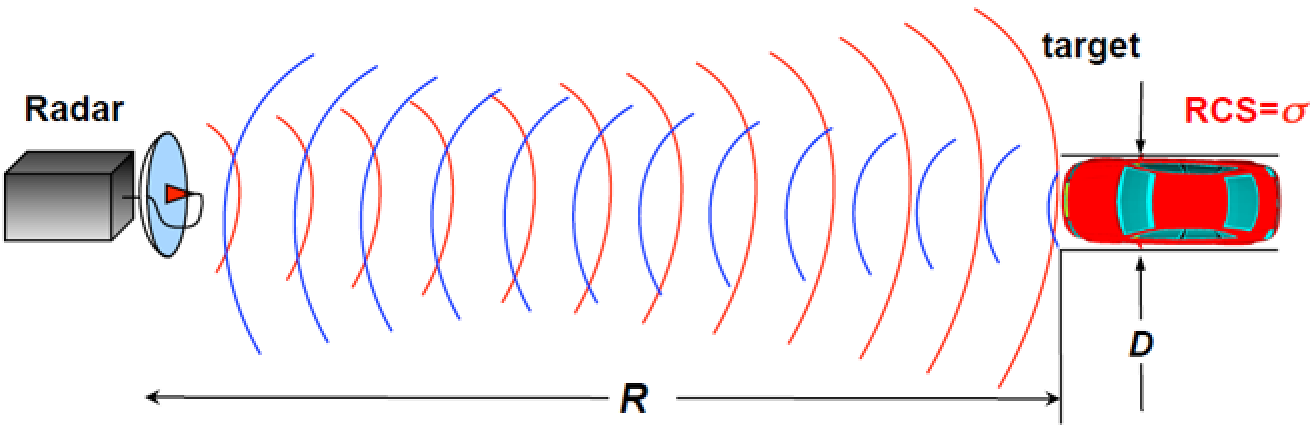
Karlsruhe Institute of Technology

- Basic radar theory and with focus on FMCW radar
- Visualizing chirp signal in frequency and time domain. Changing the chirp direction.
- Estimation of range and velocity in a simulation of an Automotive Cruise Control (ACC) in MATLAB
- Simplified control of velocity in the simulation of an ACC in MATLAB

Basic radar principle

- Range: $R = \frac{1}{2} \cdot T \cdot c_o$
- Radar equation: $P_{Rx} = \frac{P_{Tx} \cdot G_{Tx} \cdot G_{Rx} \cdot \lambda^2 \cdot \sigma}{(4\pi)^3 \cdot R^4}$

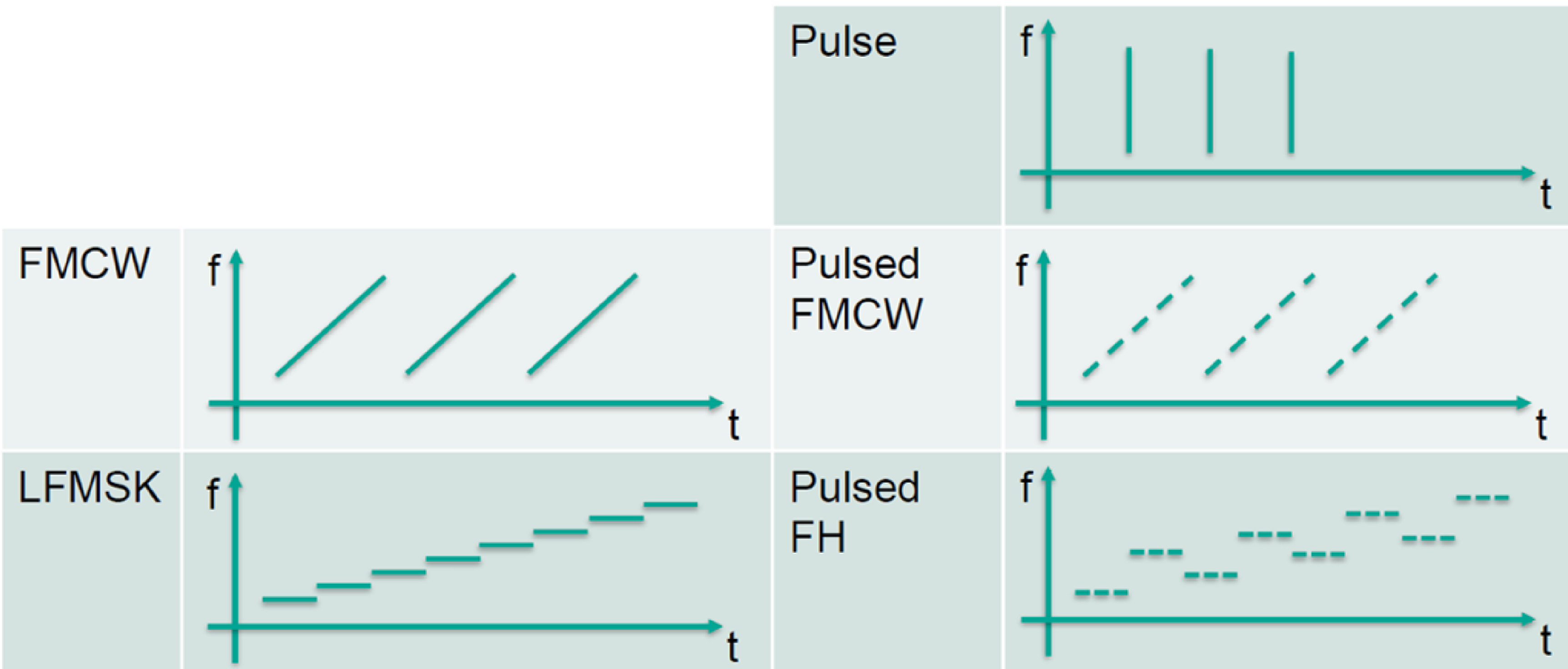
with transmit antenna gain G_{TX}, receive antenna gain G_{RX}, transmit power P_{TX}, receive power P_{RX}, radar cross section σ



For further information see KIT lecture: Radar System Engineering, Prof. Wiesbeck, IHE.

Radar modulation schemes

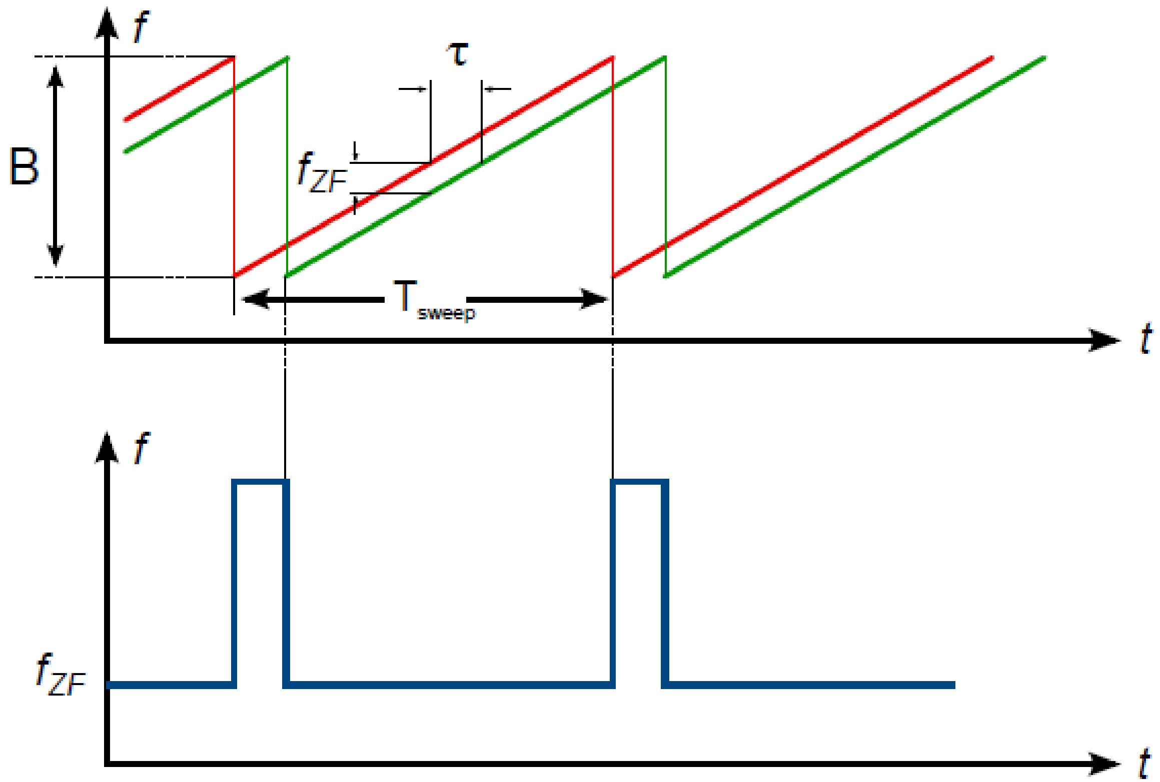
Continuous Signal | **Pulsed Signal**



Institute of Radio Frequency Engineering and Electronics

FMCW Radar

- FMCW radar with saw-tooth modulation



beat frequency:

$$f_R = slope \cdot \tau$$

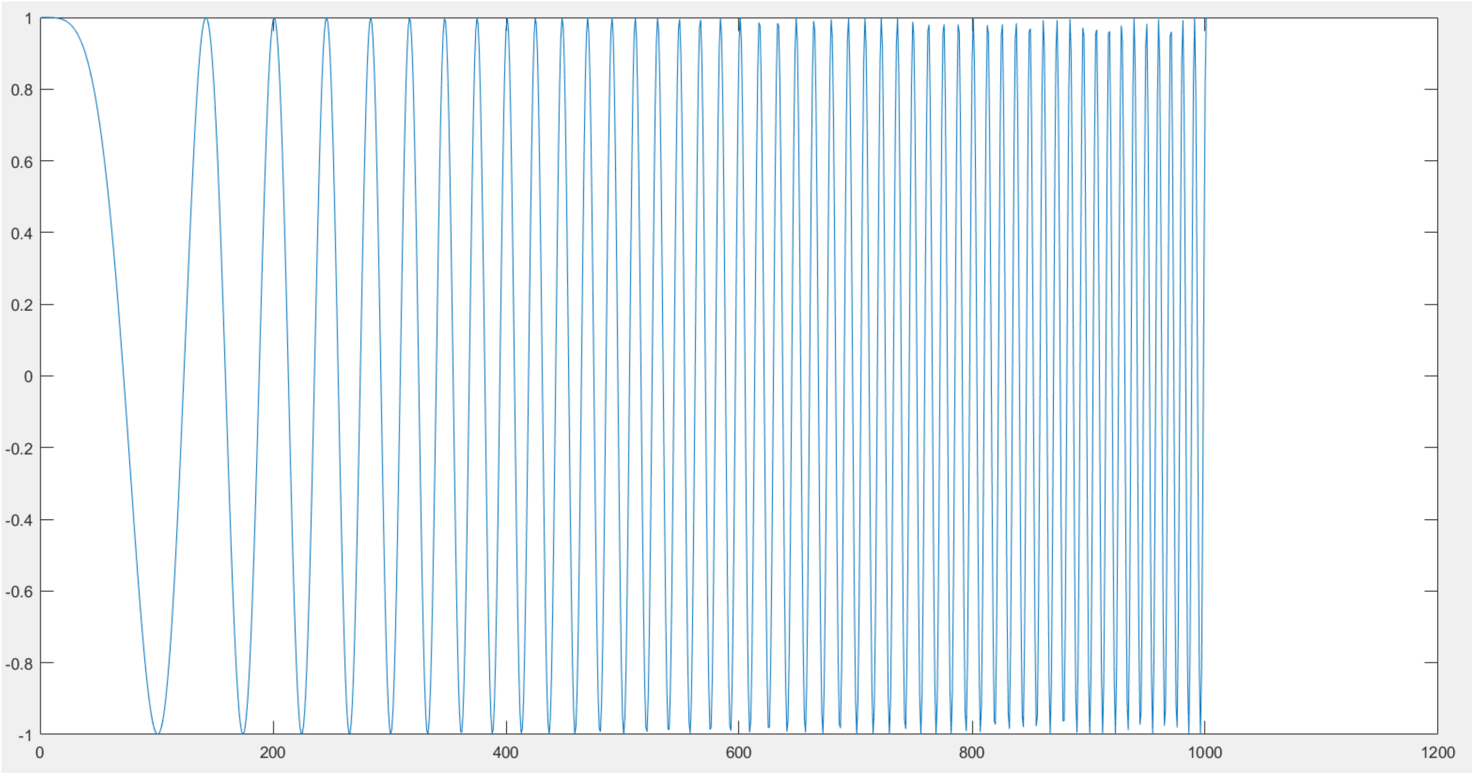
with $\tau = \frac{2R}{c_o}$ and

$$slope = \frac{f_{max} - f_{min}}{T_{sweep}}$$

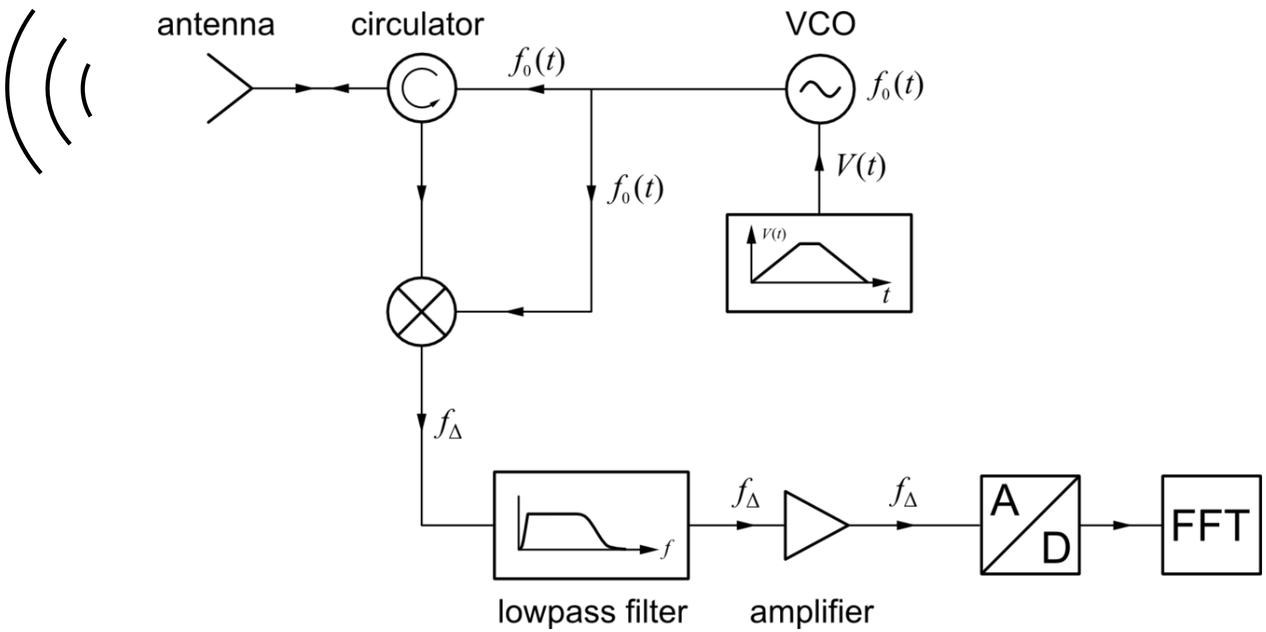
Institute of Radio Frequency Engineering and Electronics

Chirp Signal

- A chirp is a signal in which the frequency increases or decreases with time
- Linear chirp: $f(t) = f_o + nt$



FMCW-Radar



- Advantages compared to pulsed radars
  - Much smaller by size
  - Lower power consumption
  - Lower costs
- Drawback compared to pulsed radars
  - Maximum detectable distance is much smaller

Institute of Radio Frequency Engineering and Electronics

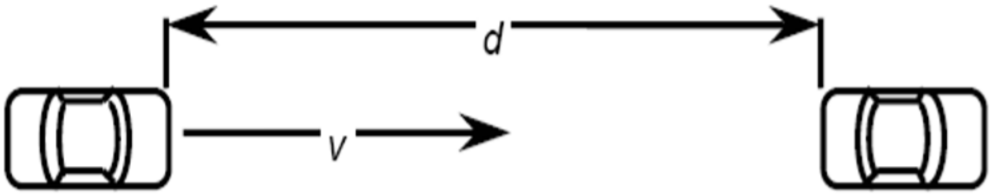
Automotive Cruise Control (ACC)

- Definition:
  - ISO: 15622

  Adaptive Cruise Control is fundamentally intended to provide longitudinal control of equipped vehicles while travelling on highways (roads where non-motorized vehicles and pedestrians are prohibited) under free-flowing traffic conditions. ACC can be augmented with other capabilities, such as forward obstacle warning.

  Time gap τ: The time gap between two cars depends on velocity difference v and distance d.

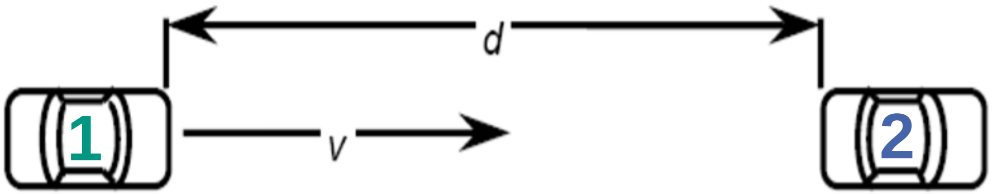
$$\tau = d/v.$$



Simulated Scenario

t = 0:

d = 43 m



v_1 = 100 km/h

v_2 = 96 km/h

- In the following simulation two cars drive behind one another with a certain velocity and a fixed distance at the beginning (t=0). Due to the difference in velocity the distance between the cars will change over the simulation duration. The situation is seen form the view of a radar in car 1 (ego car), the vehicle ahead car 2 represents the radar target.

Goal 1
Understanding ACC System in MATLAB

- *Load the m-File fmcw_example and try to understand the MATLAB code until the part of the simulation in comments.*

Tasks:

- Complete the expressions for sweep time and sweep frequency in Matlab.
- Complete the expression for the maximum possible doppler shift.

Questions:

- What are the main properties of FMCW radar? Why do we use it in connection with ACC?
- What is an advantage/disadvantage of a long sweep time?
- Where can you see the Doppler frequency in the frequency/time diagram for FMCW radar? Make a sketch for a saw-tooth modulated signal.

Goal 2
Visualize the chirp signal for the ACC System in MATLAB

Task:

- Plot the Chirp Signal in time and frequency domain. To get the samples of the chirp signal use the step() function of the Phased Array System Toolbox. For the plots use plot() and spectrogram().
  - Optimize the Spectrogram function with the following parameters (window =32, noverlap = 16, f = 32, fs and ‘yaxis‘).
  - Complete the plots with title, xlabel and ylabel

Institute of Radio Frequency Engineering and Electronics

Goal 3
Estimation of range and velocity

- Comment out the simulation part and try to understand it.

Tasks:

- Make a plot of the buffered dechirped signal xr in frequency domain.
  - *Hint: Use the function fft().*
- Estimate range and velocity out of the speed/range pattern
  - *Hint: The Matlab plot should pop up automatically.*
- Complete the range estimation in the Matlab code.
  - *Hint: For the range estimation use the beat frequency fb_rng and the usual radar equations.*

Questions:

- At which position is the maximum value of the FFT in the buffered dechirped signal?
- What is the estimated value for range and velocity?

Goal 4
Triangular chirp signal

Tasks:

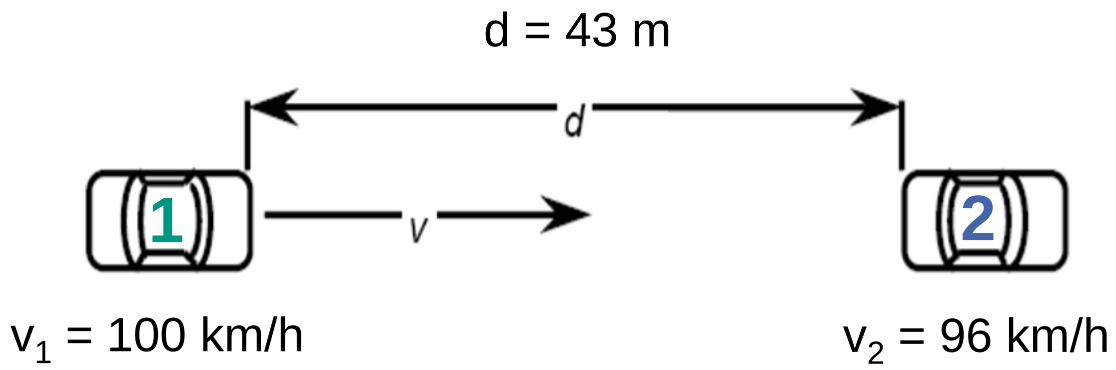
- Change sweep direction to Triangle.
- Run the simulation and read out the value for the Doppler error.
- Change the sweep time at the beginning to t_sweep=2e-3.
- Read out the value for the Doppler error and compare it with the first one.

Questions:

- Why does the Doppler error change?
- Where can you see the Doppler frequency in the frequency/time diagram for triangular modulated FMCW radar? Draw an example.
- What is the advantage of using triangular modulated FMCW?
- What is the formula for calculating the Doppler frequency with triangular modulated FMCW? Shortly explain it.

Simplified control of the velocity

t = 0:



- Until now the simulation determines the distance between the vehicles and the difference in the relative speed. In the next step the velocity of car 1 should be controlled so that the distance between the cars stays constant. That means that the velocity of car 1 should be lowered to the speed of car 2.

Goal 5
Simplified control of the velocity

Tasks:

- Write some Matlab code for a control of the velocity
  - Hint: Use a while loop and the estimated velocity for the control

Questions:

- What is the intention of ACC in relation to the relative velocity
- What features would you add for a full functional ACC?