Future sensing for ADAS and HAD automotive systems

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Outline

- Motivation
- Roadmap
- Surround Sensing
- Sensor Types
- Radar Sensors
- Sensor Simulation
- Conclusion

Motivation

Paths to the Car of the Future

costs hybrid electric motor
roaming power electronics
e-bike **electrified** range
driving enjoyment charging infrastructure
market ramp-up battery
e-scooter smart charging plug-in

legislation assistance systems
emergency braking assistant
automated auto pilot
highway pilot sensors
redundancy electric steering
valet parking digital environment

augmented reality electronic horizon
internet of things smartphone integration
connected
vehicle to vehicle cloud
vehicle to infrastructure
services fleet management
entertainment eCall

Vision

https://www.youtube.com/watch?v=FnTKm5XR3M4

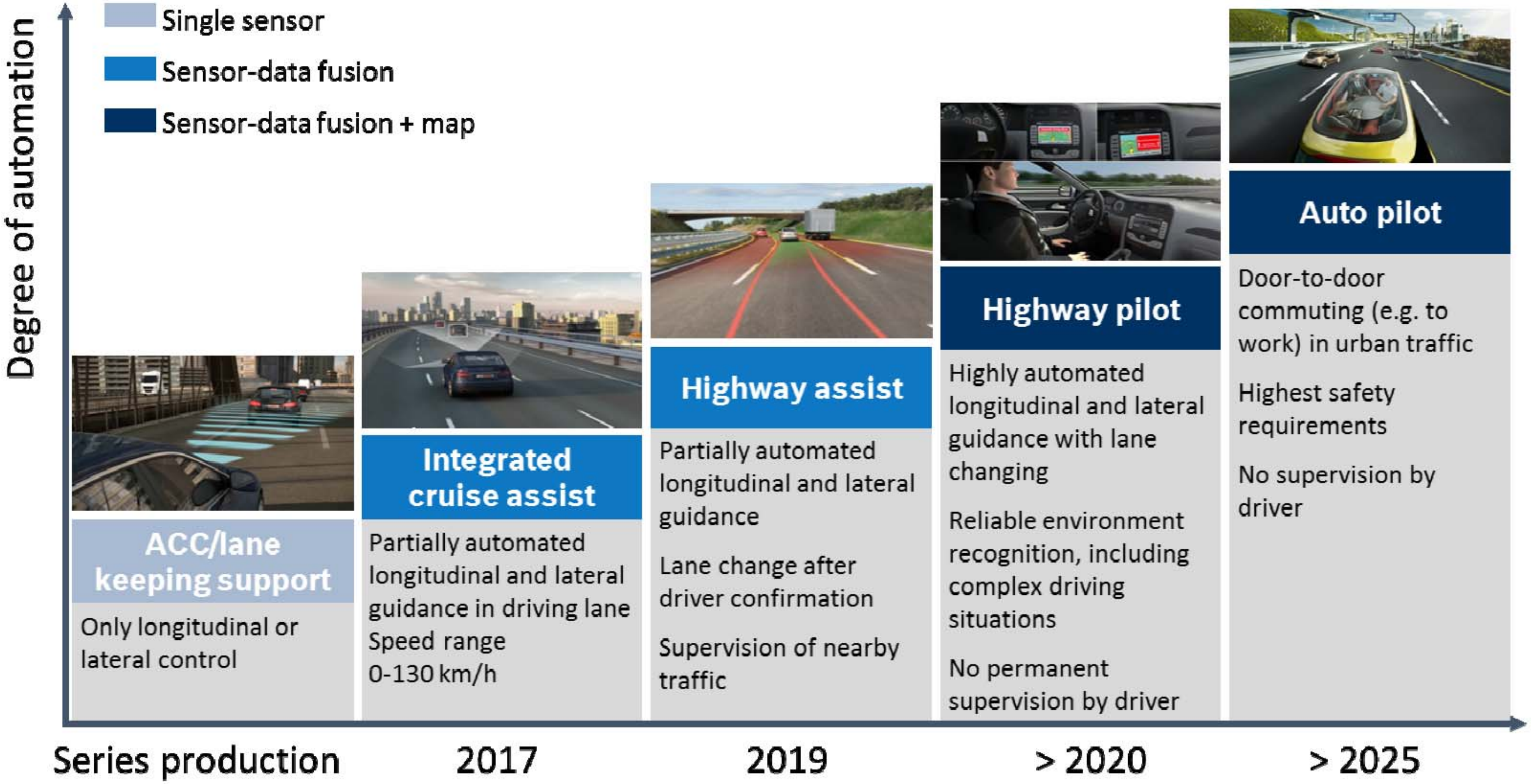
Vision

Automated and Connected – Social Benefits

Safety	Technologies for an intelligent and forward-thinking vehicle → **Injury and accident-free driving**
Traffic Management	Reduced traffic jams and waiting time at intersections and lights → **Relaxed driving even in dense traffic**
Demographics	Reduced driver burden → **Allow a variety of age ranges to be mobile**
Networked Society	Vehicle as part of the driver's connected life → **Time on the road becomes more productive**
Clean Technology	Synchronizes traffic flow → **Improved fuel economy**

Roadmap

Development steps to automated driving



State of the Art: Driver Assistance

Rear Backup Camera
Ultra Sonic Sensors
Park Assist

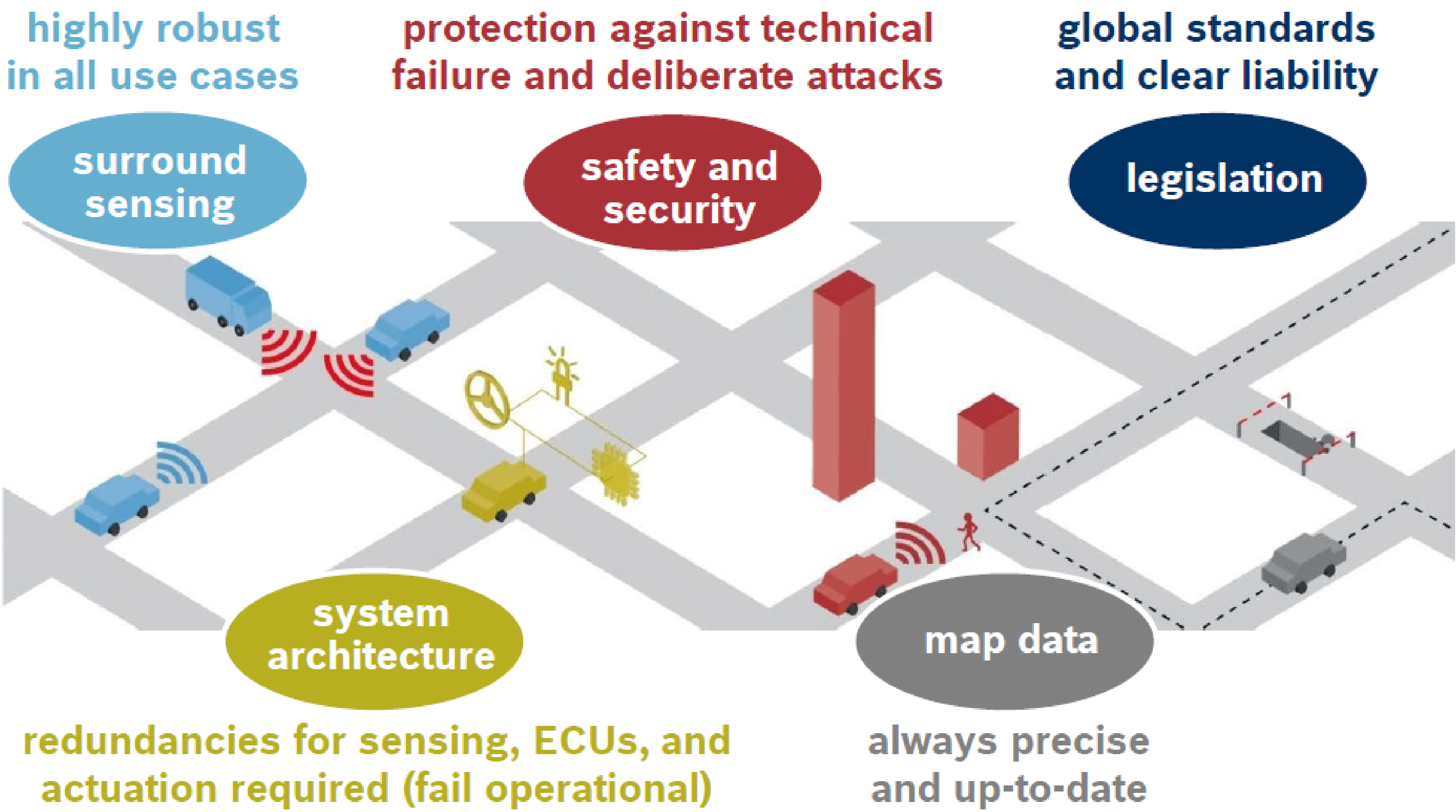
Forward Camera
Automatic High Beam headlights

Radar
Blind Spot Monitoring (BSM)

Antilock Brake System (ABS)
Electronic Stability Control+ (ESC)
Electronic Roll Mitigation+ (ERM)
Brake Assist
All-Speed Traction Control
Trailer Sway Control+ (TSC)

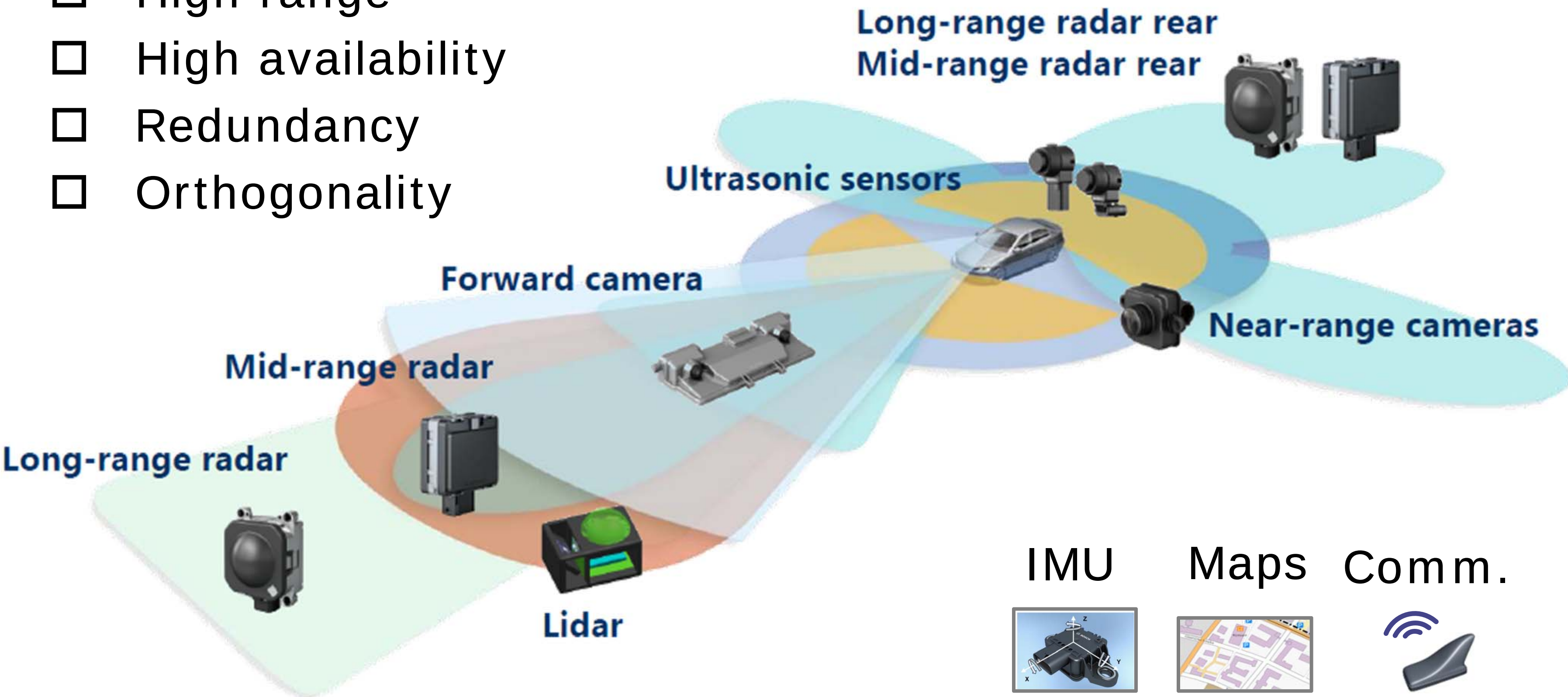
Radar
Adaptive Cruise Control
Advanced Brake Assist
Forward Collision Warning

Prerequisites for Automated Driving

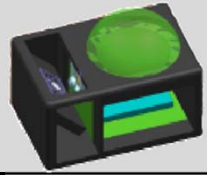


Sensor Set Requirements

- ☐ 360° surround view
- ☐ 3D-information (distance)
- ☐ Robust vs. environmental influences
- ☐ High range
- ☐ High availability
- ☐ Redundancy
- ☐ Orthogonality



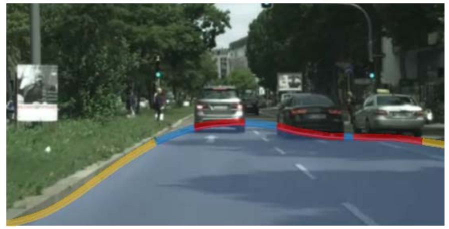
Key Sensors

Video 	**Lidar** 	**Radar** 
Wavelength 400..800 nm	Wavelength 905/1150 nm	Wavelength 3.8 mm
Passive	Active	Active
High angular resolution	High angular resolution	Low angular resolution
Indirect distance and velocity	Direct distance, indirect velocity	Direct distance and velocity
Dependent on lighting conditions	Difficulties in fog and rain	Robust in harsh conditions

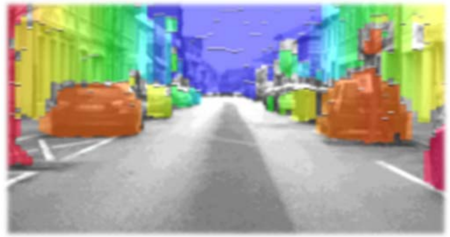
Camera-Based Computer Vision

- Street lane detection
- Traffic light detection, road signs

- Free space estimation



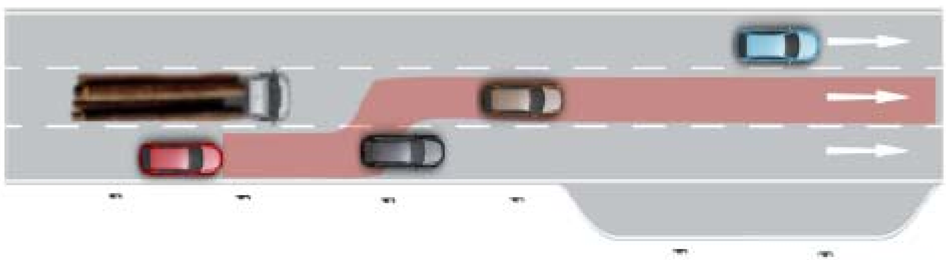
- Reconstruction and Segmentation



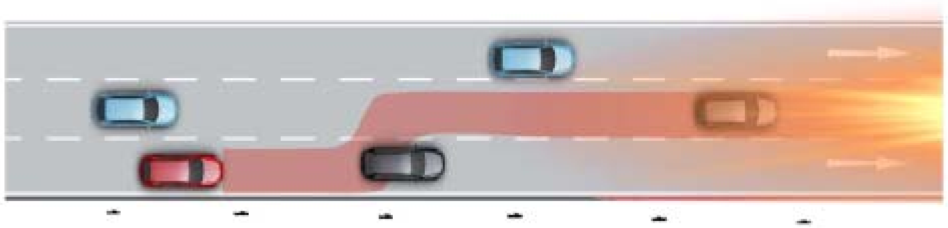
- Object Detection and Classification (e.g. vehicles, persons)

Surround Sensing

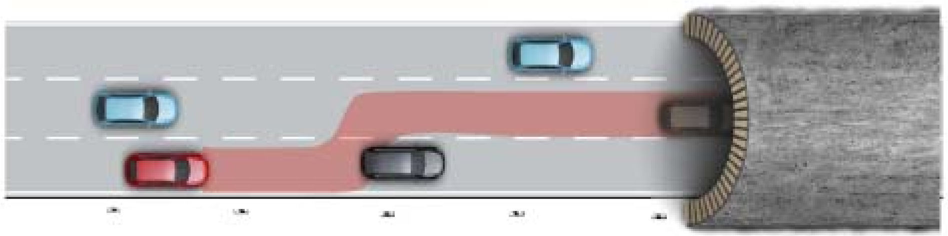
Reliability Requirements



Timber transport may not be detected reliably by radar sensor



Low standing sun can fade the video sensor



Tunnel entrances can affect the radar and video sensors

Radar Sensor Evolution

From simple detection to scene imaging

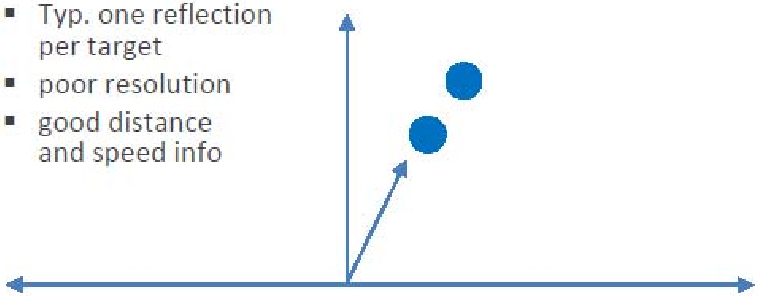
Scenario

Picture source: Bosch

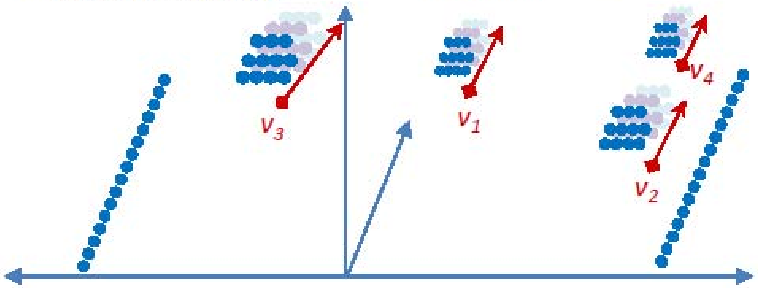
Picture source: Bosch

Radar view

- max. 30 targets
- Typ. one reflection per target
- poor resolution
- good distance and speed info



- typ. > 1000 targets
- high xyz-resolution
- 4D representation incl. instant speed



Radar Sensor Evolution

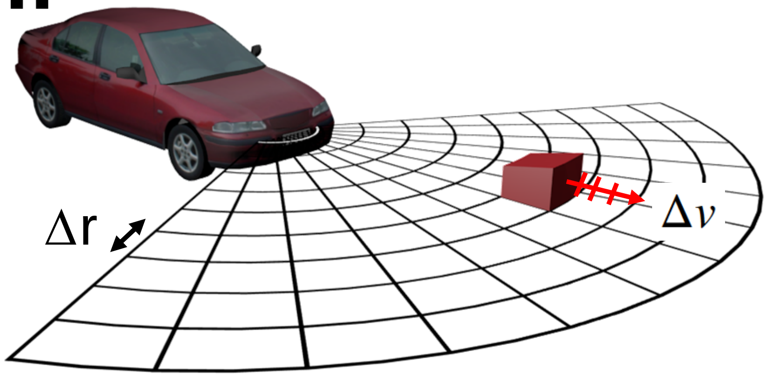
Achieving High Resolution

Distance

- Resolution depends on modulation bandwidth B:

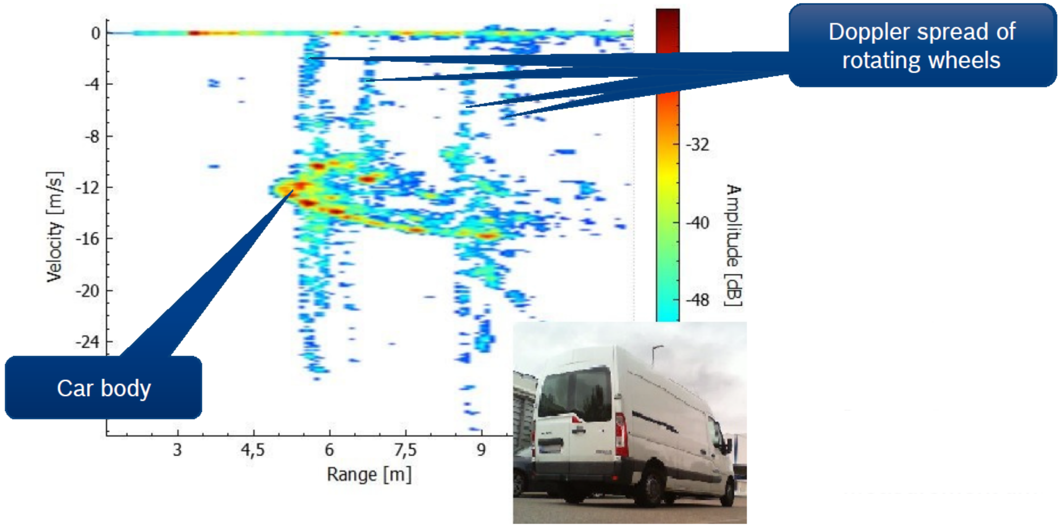
$$\Delta r = \frac{c_0}{2B}$$

- Limit is given by regulation: 4 GHz or 3.75 cm



Velocity

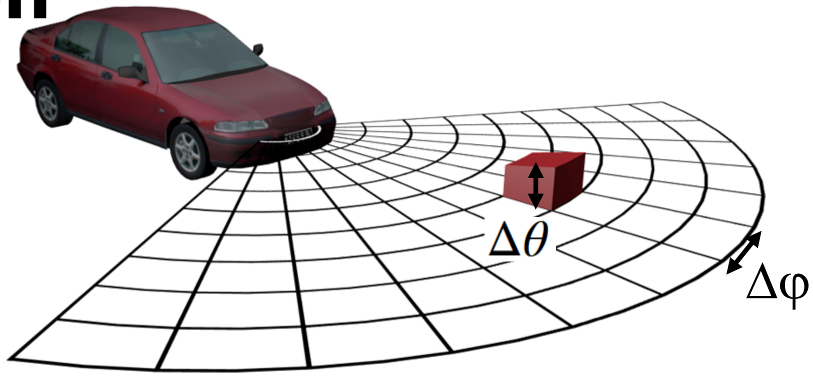
- Fully utilize measuremen time of $\approx 20\,ms$ to get best resolution
- Use of Micro-Doppler for further classification



Radar Sensor Evolution

Achieving High Resolution

Azimuth and Elevation angle resolution

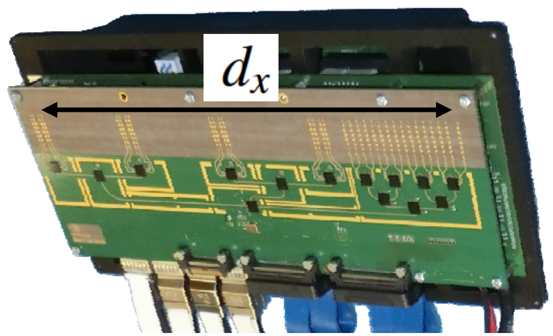


- Depends on antenna aperture size:

$$\Delta\varphi = 1.22\frac{\lambda}{d_x} \quad *$$

$$\Delta\theta = 1.22\frac{\lambda}{d_y}$$

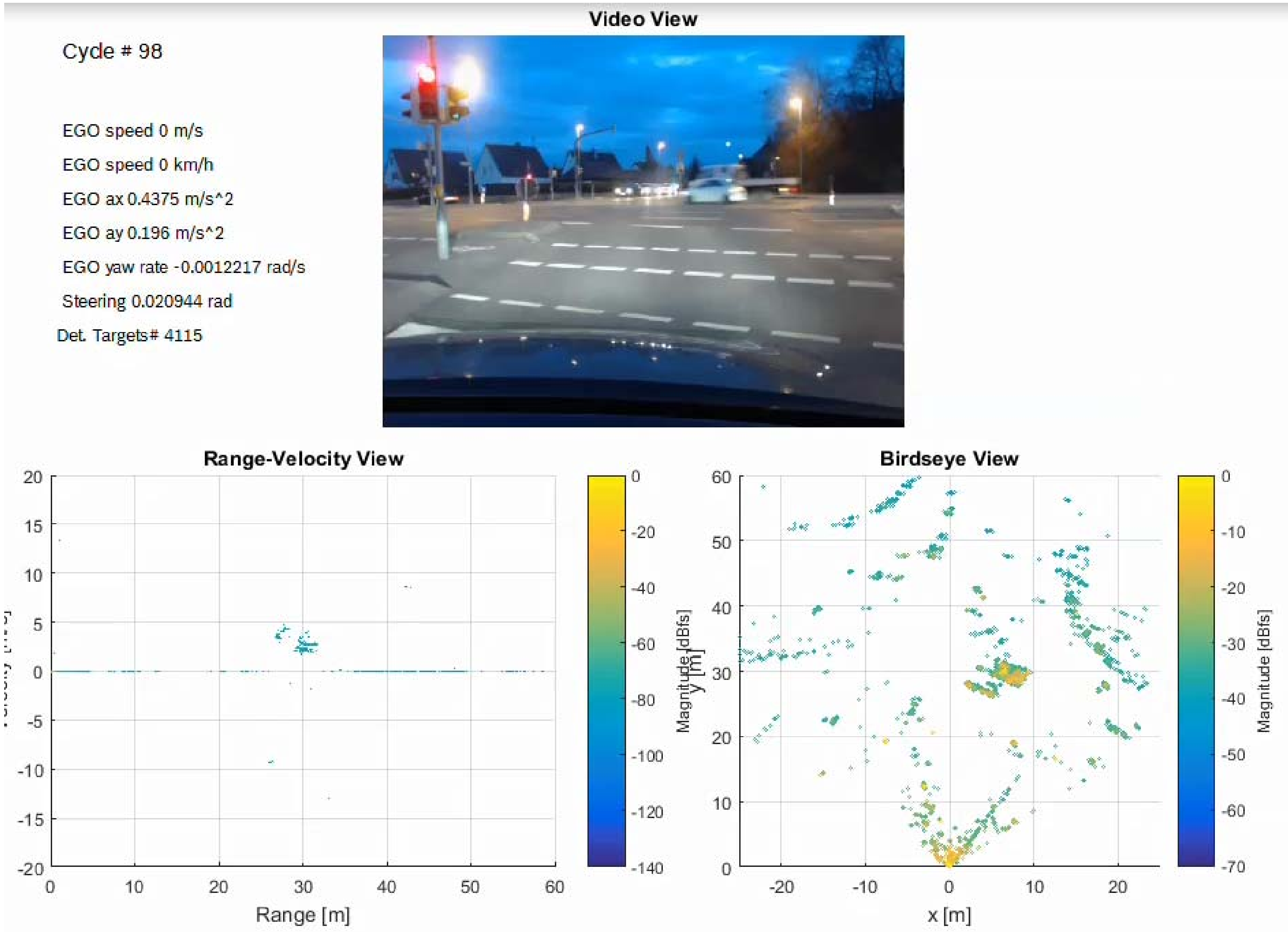
- Aperture area is limited due to sensor size constraints and the need to process a high number of channels



Antenna dimensions

* Rayleigh criterion for angular resolution

Imaging Radar



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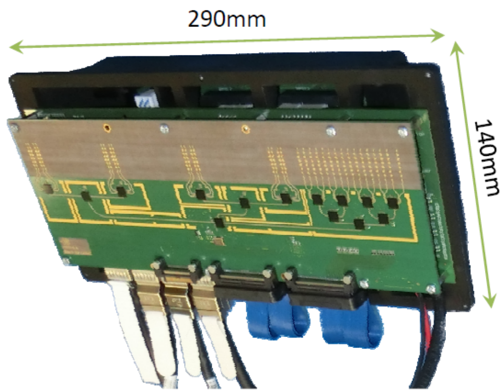
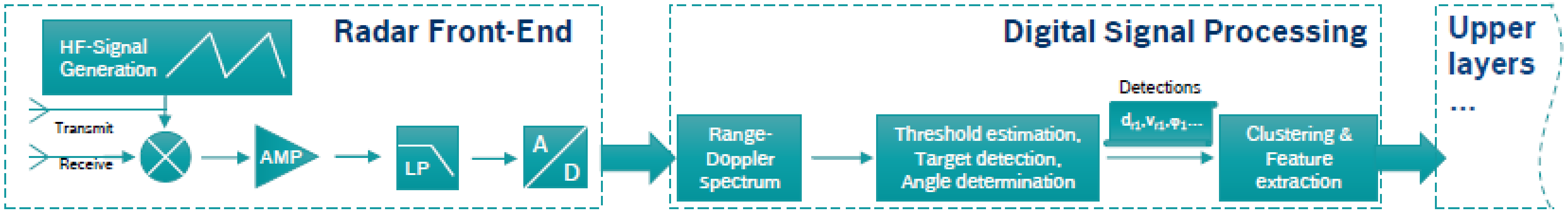
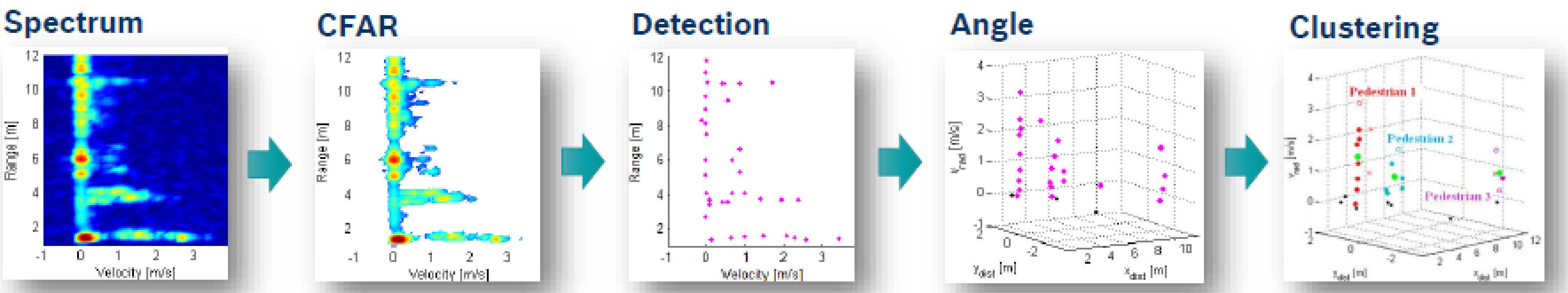
Imaging Radar

- Experimental Radar prototype with 8 transmitters and 16 receivers
- 77 GHz operation
- Realtime signal processing

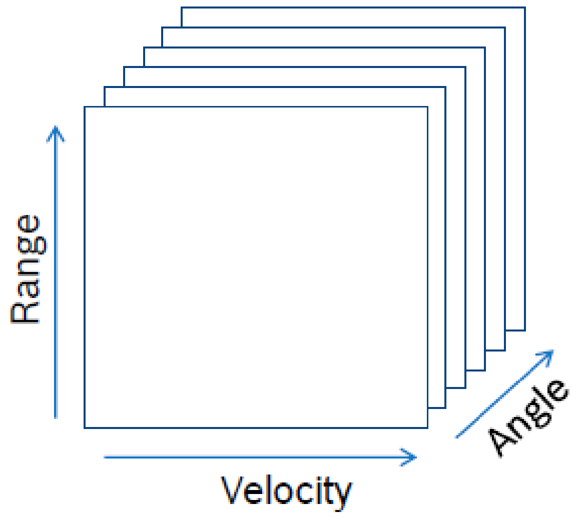






Imaging Radar

MIMO Chirp Sequence
Data Rate Estimation



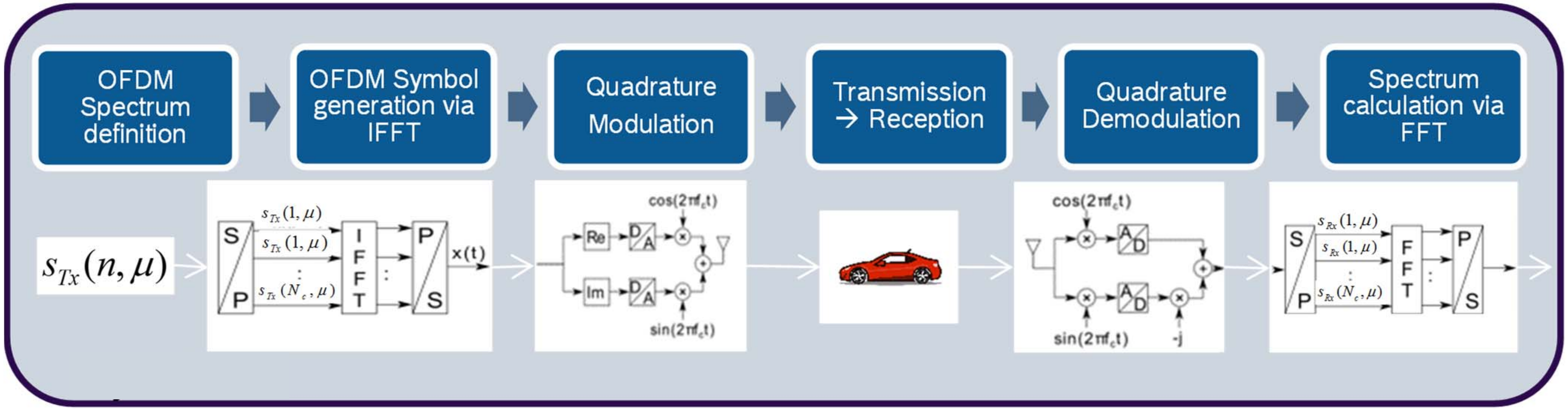
Case study:

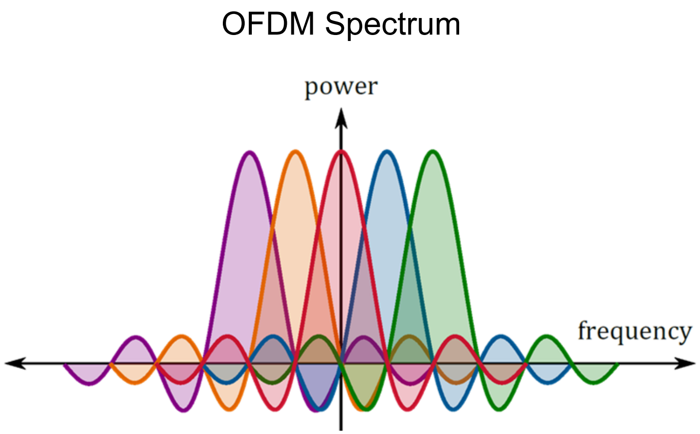
Parameter	Value
Number of transmit channels M	8
Number of receive channels N	8
Number of samples per frequency ramp K	1024
Number of consecutive ramps L	1024
Number of quantization bits Q	14bit
Sampling frequency f_s	250MHz
Resulting data rate R_{MIMO}	28Gbit/s
Resulting data amount per chirp sequence $D_{CS,MIMO}$	117MByte

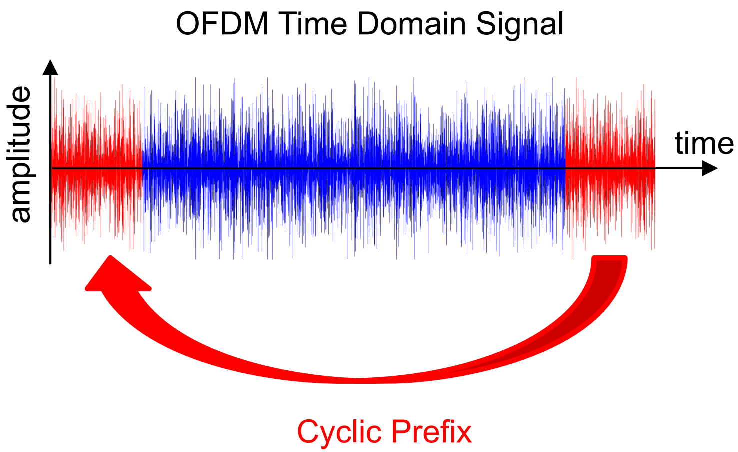
- Huge amount of raw data per cycle (~100 MByte)
- Cycle times of 50 ms (20Hz) required

**Powerful processing unit becomes necessary
Even for prototyping**

OFDM Modulation







OFDM Modulation

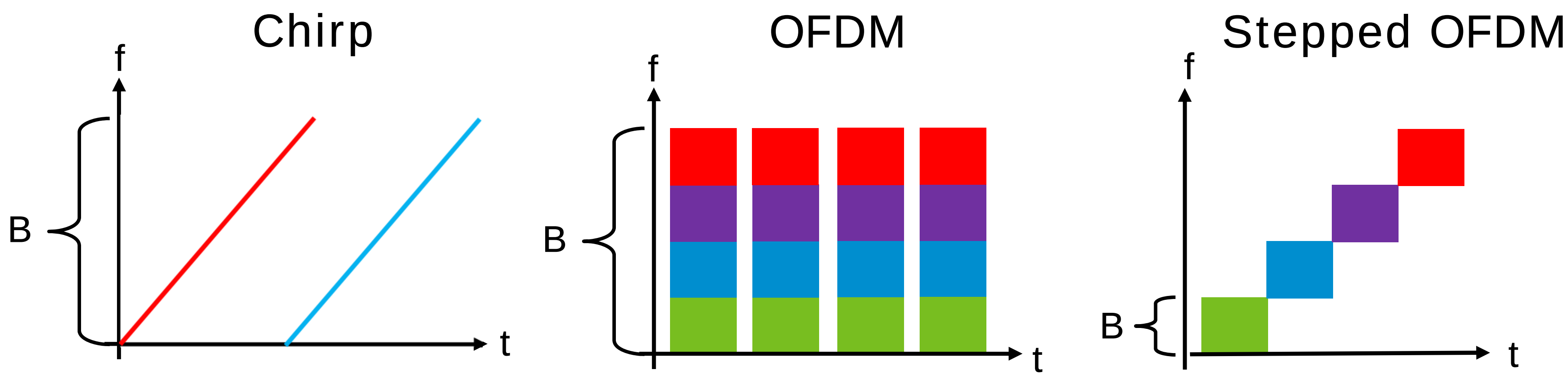
Typical System Design Parameters for OFDM

- High AD/DA converter bandwidth > 2 GHz
- High data rate for signal processing > 50 GBit/s

	@77 GHz	Description
f_c	77 GHz	Carrier
N	4096	Number of subcarriers
Δf	285 kHz	Carrier spacing
T_p	0.66 µs	Cyclic prefix duration
T	3.51 µs	Symbol duration
T_{OFDM}	4.17 µs	OFDM Symbol duration: $T + T_p$
B	1.12 GHz	Bandwidth $B = N \cdot \Delta f$
M	1024	Number of observed consecutive OFDM symbols
T_{obs}	3.6 ms	Observation Time $T_{\mathrm{obs}} = M \cdot T_{\mathrm{OFDM}}$
ΔR	0.13 m	Range resolution
Δv_r	0.45 m/s	Doppler resolution
$R_{\max}$	100 m	Maximum range
$v_{r,\max}$	±55.6 m/s	Maximum Doppler
R_{unamb}	526 m	Maximum unambiguous range
$v_{r,\mathrm{unamb}}$	±233 m/s	Maximum unambiguous Doppler

OFDM Modulation

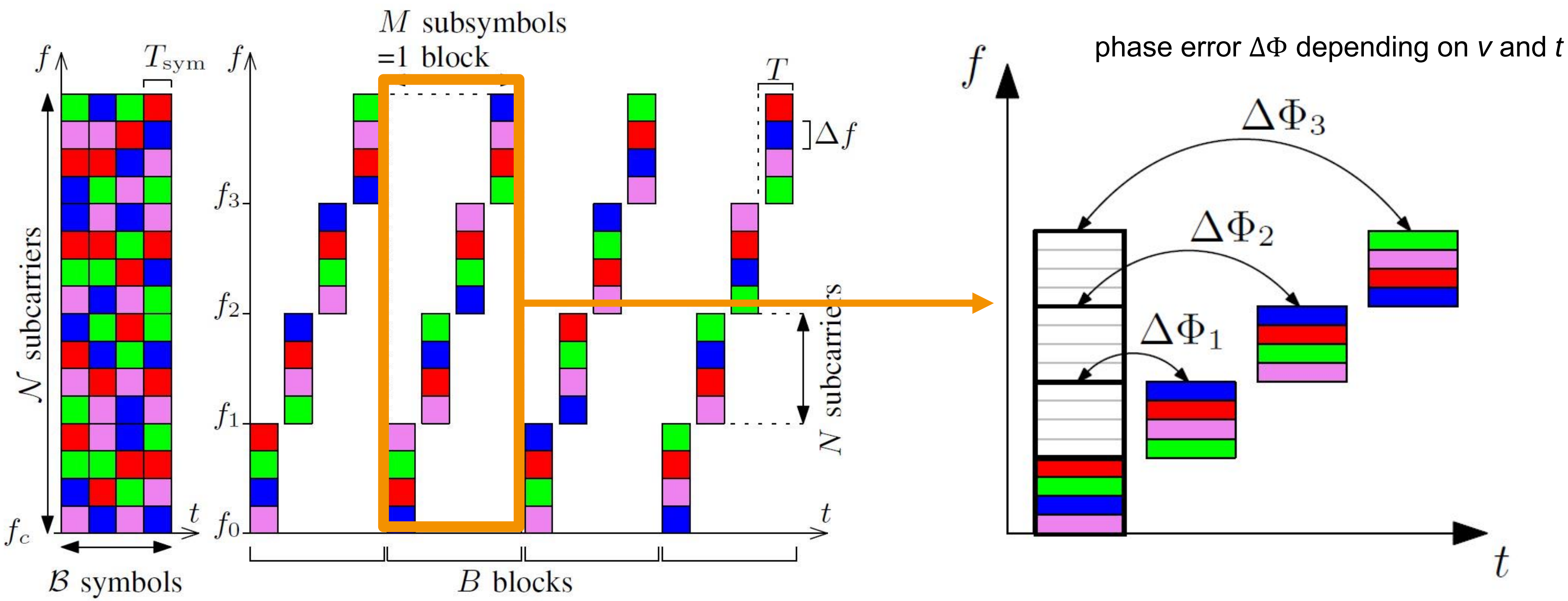
Stepped OFDM Modulation Approach



	Chirp	OFDM	Stepped OFDM
Signal Gen.	+	-	+
AD/DA	+	-	+
Multiplexing	-	+	+
Interference	-	+	+

OFDM Modulation

- Generate smaller-bandwidth subsymbols
- Step through complete bandwidth
- Reassemble stepped subsymbols to full symbols
- Reduced sampling and processing requirements

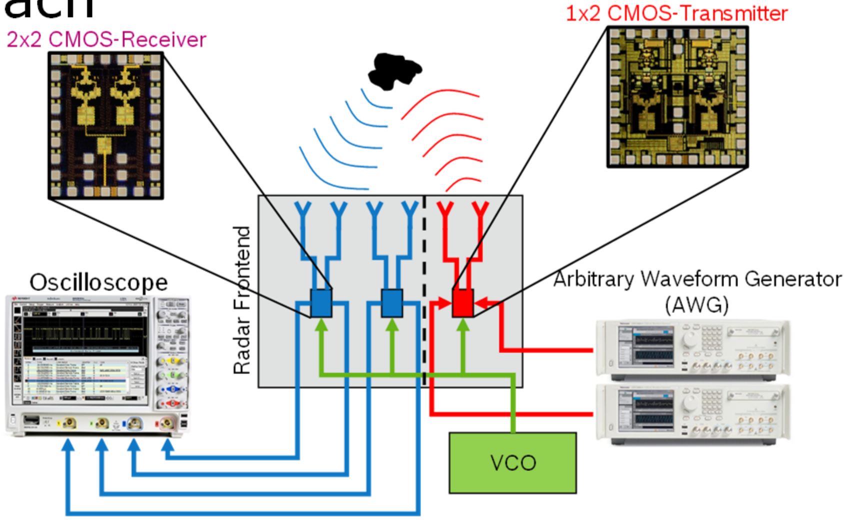


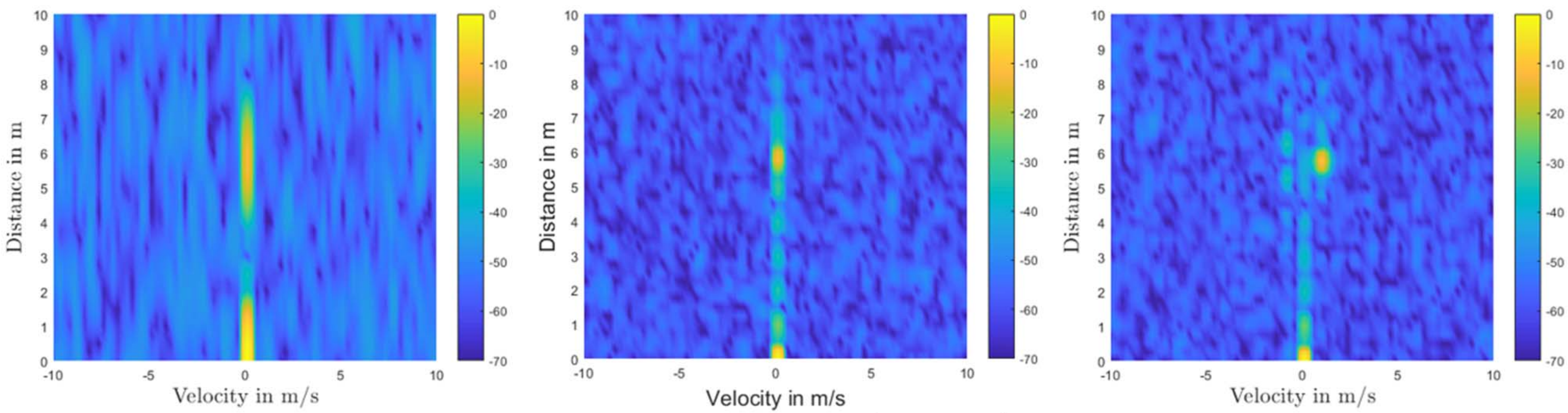
Source: B. Schweizer, C. Knill, D. Schindler and C. Waldschmidt „Stepped-Carrier OFDM-Radar Processing Scheme to Retrieve High-Resolution Range-Velocity Profile at Low Sampling Rate"

OFDM Modulation

Verification of stepped OFDM approach

- 70 GHz CMOS radar frontend using 2 transmitters, 4 receivers
- Test setup using measurement equipment
- Comparison of stepped vs. non-stepped operation:





150 MHz No Steps | 150 MHz x 4 Steps (600MHz) | 150 MHz x 4 Steps Dynamic

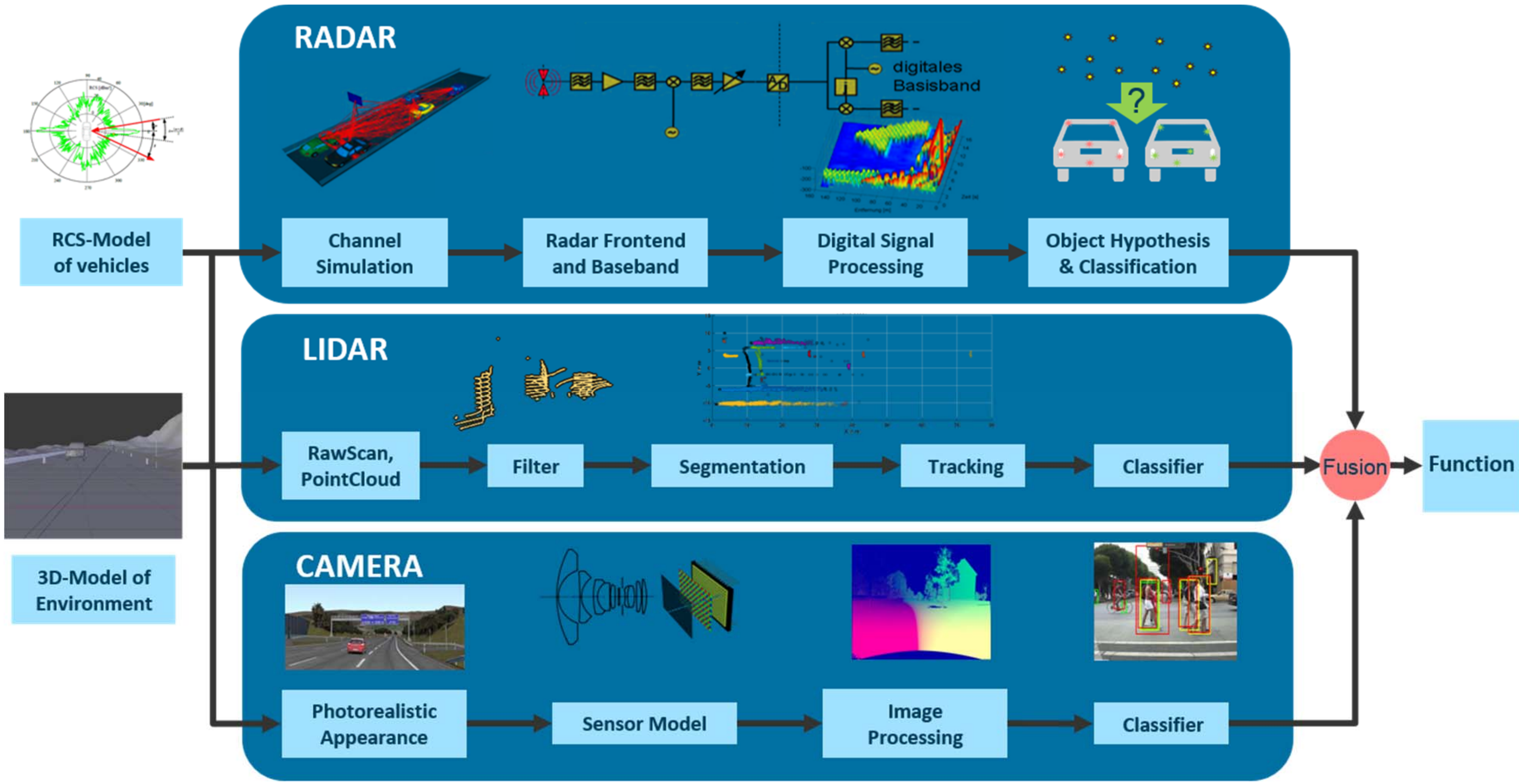
Sensor Simulation

- Sensor models allow virtual test and validation of Automated Driving Functions
- Modelling of virtual driving scenarios, including difficult environmental conditions (nighttime, fog, rain)
- Virtual models for Video, Lidar and Radar sense the environment.
  Key sensor parameters included in model, e.g.
  - Radar: Antenna diagram, path loss, angle/distance/velocity resolution
  - Camera: Weather conditions, time of day (light conditions)
  - Lidar: Number of scan layers, range, noise behavior

Virtual street model

Sensor Simulation

Simulation Framework for Radar, Lidar and Video sensors



Conclusions

- Trends driving the car of the future are:
  - Electrification
  - Automation
  - Connectivity
- Automated Driving requires a Sensor Set that provides accurate and reliable information about the environment
- Radar sensors will be a key sensor for robust environment perception
- Digital modulation schemes for will power the next generation of Radars
- Simulation, using accurate models of the sensor set, is a must for test and validation of autonomous driving functions.

Acknowledgements

- Daniel Schindler
- Martin Kunert
- Thomas Glaser
- Helmut Schön
- Christian Perwass
- Public Funded Project „Pegasus“
- Public Funded Project „Things2Do“