Hochschule Kempten University of Applied Sciences

Vehicle Technology SS 23
Lecture 5

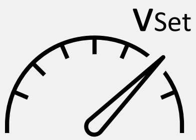
FT30 – Advanced Driver Assistance Systems

ADAS/AD for Longitudinal Guidance

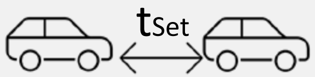
Ludwig Kastner

Short introduction of ACC

Source: Audi AG

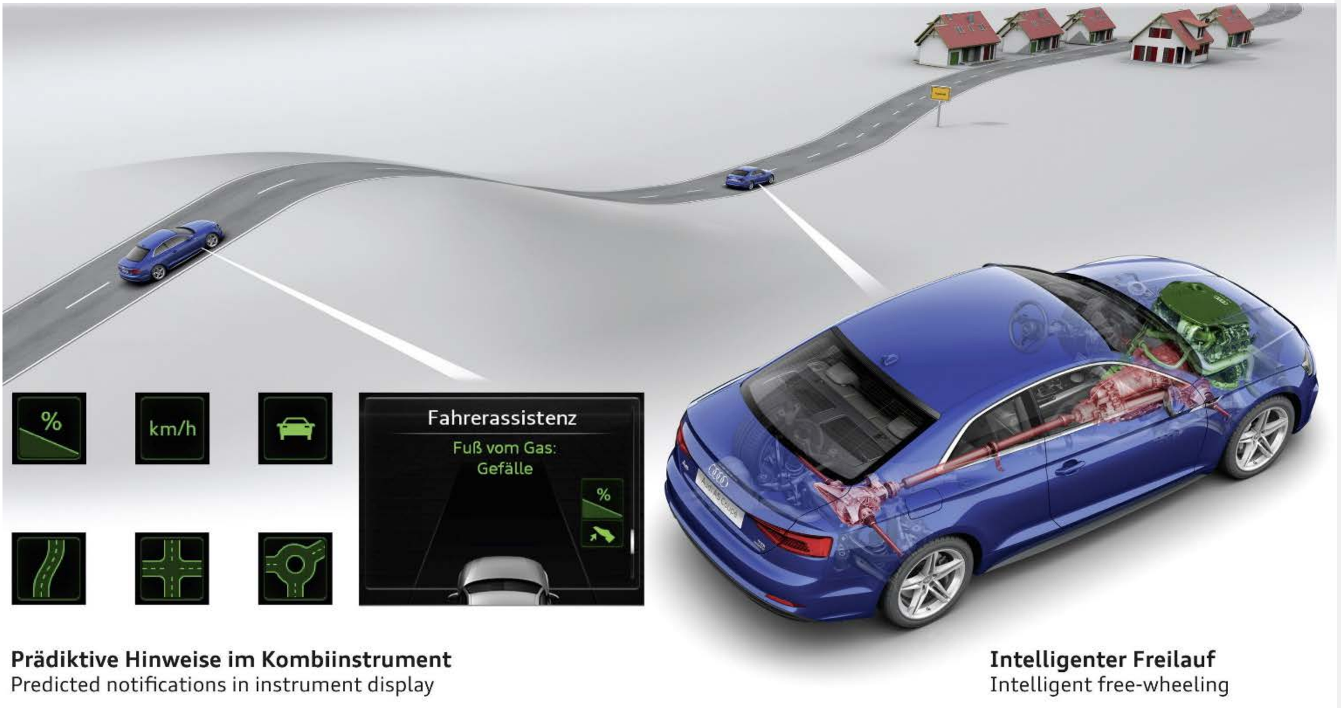


The vehicle adapts its speed to a set value by the driver v_{Set}, usually by controlling the engine torque.

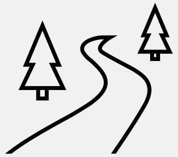


The vehicle can follow a vehicle with a given time gap t_{Set} by controlling the engine torque and the brake.

Short introduction of PCC

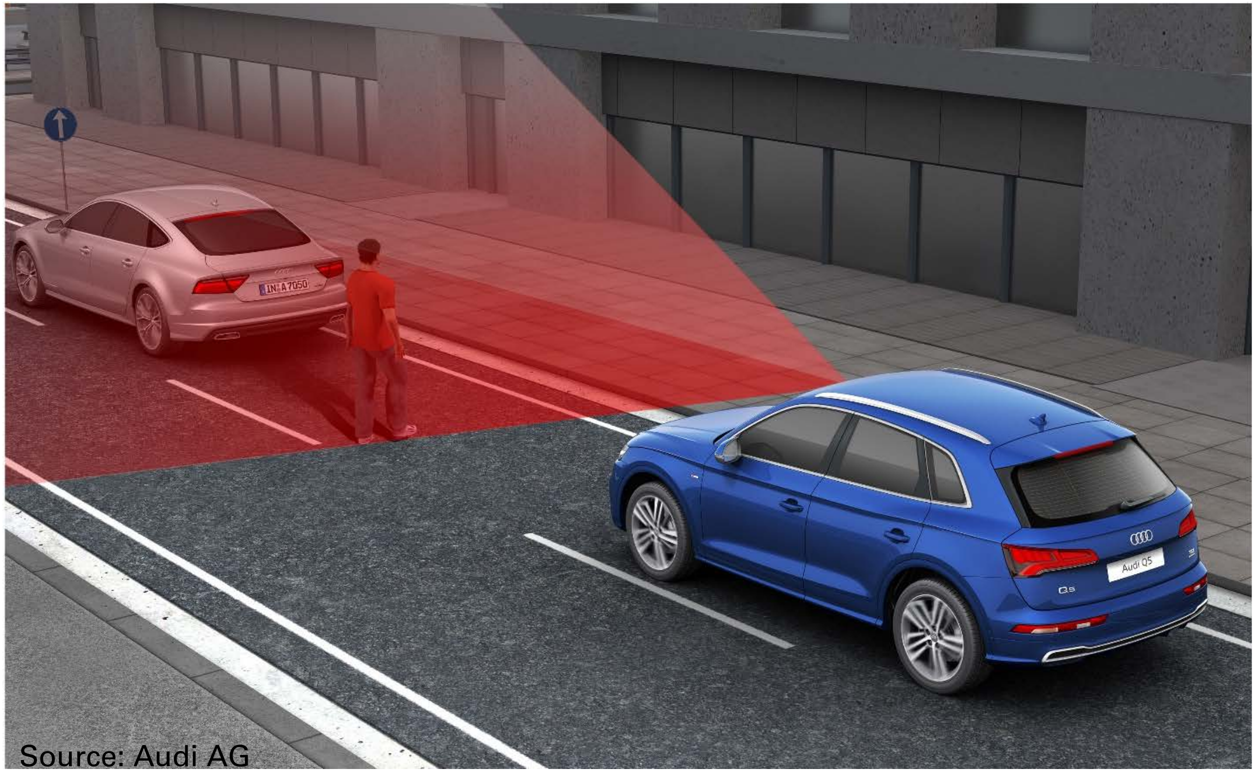


Source: Audi AG



The vehicle adapts its speed to the roadway ahead and increases efficiency and safety. The function takes various characteristics of the roadway ahead into account: Topography, Curviness, Intersections, Roundabouts, Speed Limits.

Short introduction of FVCX


Source: Audi AG

FVCX are systems that take appropriate action to influence an impending or imminent frontal collision. They range from collision condition to full collision avoidance and can perform a wide variety of actions according to their system design.

Important steps since the introduction in 1999

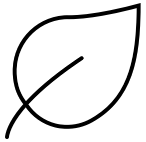
- **1986** – **PROMETHEUS**
  European Research Project
- **1995** – Release of ESC
  Mercedes S-Class C140
- **1999** – **Release of ACC**
  Mercedes S-Class 220
- **2000** – Euro III now mandatory
- **2005** – Usable range start from 0km/h
  Mercedes S-Class 221
- **2012** – Release in the A-Class W176

Motivation

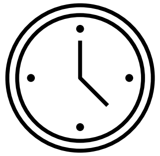
Benefits are mainly inclusion, efficiency, time and safety

Our main motivations for autonomous driving are:

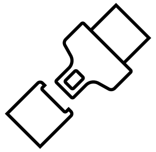
People with disabilities and old people are able to enjoy the benefits of personal mobility



Transport for people and goods can be more efficient and 24h/365 days per year



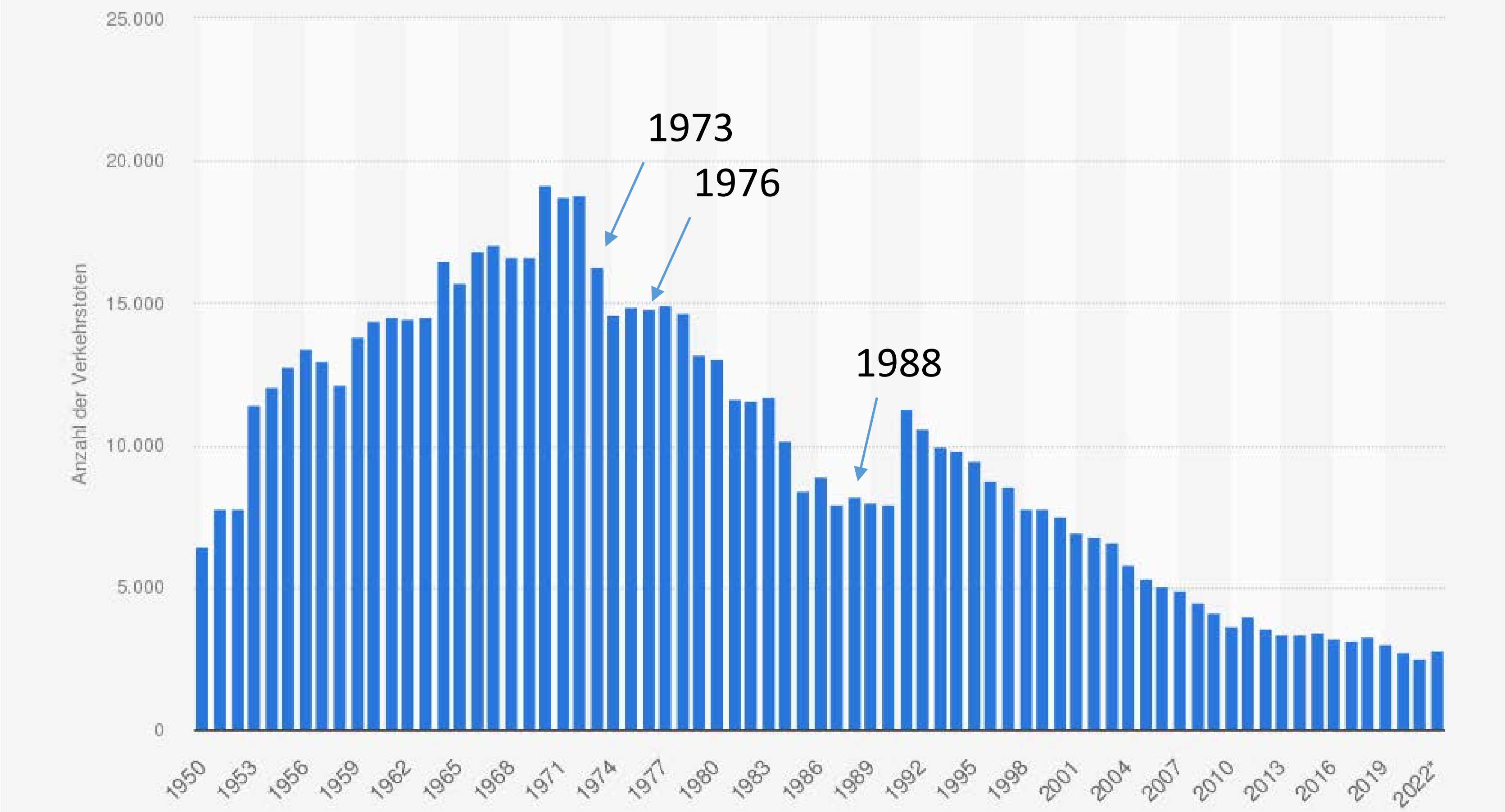
Free time and people can choose to relax, to be productive or to consume books, movies, etc.



Road traffic safety can be increased as human errors are decreased

Source: ADAC

Fatalities in road accidents in Germany are set to be further reduced



LFAS can greatly help with human driving errors

Pkw-Schadenfälle in der UDB [100%]	Anteil in %
(1) Zusammenstoß mit anderem Fahrzeug, das einbiegt oder kreuzt	34,5
(2) Zusammenstoß mit anderem Fahrzeug, das - vorausfährt oder wartet - anfährt, anhält oder im ruhenden Verkehr steht	22,2
(3) Zusammenstoß mit anderem Fahrzeug, das entgegenkommt	15,5
(4) Zusammenstoß zwischen Fahrzeug und Fußgänger	12,1
(5) Zusammenstoß mit anderem Fahrzeug, das seitlich in gleicher Richtung fährt	6,9
(6) Abkommen von der Fahrbahn nach rechts/links	6,3
(7) Aufprall auf ein Hindernis auf der Fahrbahn	0,1

Lkw-Schadenfälle in der UDB [100%]	Anteil in %
(1) Zusammenstoß mit anderem Fahrzeug, das - vorausfährt oder wartet - anfährt, anhält oder im ruhenden Verkehr steht	31,6
(2) Zusammenstoß mit anderem Fahrzeug, das einbiegt oder kreuzt	22,3
(3) Zusammenstoß mit anderem Fahrzeug, das seitlich in gleicher Richtung fährt	18,5
(4) Zusammenstoß mit anderem Fahrzeug, das entgegenkommt	14,3
(5) Abkommen von der Fahrbahn nach rechts/links	5,1
(6) Zusammenstoß zwischen Fahrzeug und Fußgänger	4,4
(7) Aufprall auf ein Hindernis auf der Fahrbahn	0,4

Source: Winner, Kühn, Hannawald

Workshop

Workshop 1: Using the crash report, think of maneuvers for LFAS ADAS/AD!

LFAS can greatly help with human driving errors

Pkw-Schadenfälle in der UDB [100%]		Anteil in %
(1) Zusammenstoß mit anderem Fahrzeug, das einbiegt oder kreuzt		34,5
(2) Zusammenstoß mit anderem Fahrzeug, das – vorausfährt oder wartet – anfährt, anhält oder im ruhenden Verkehr steht		22,2
(3) Zusammenstoß mit anderem Fahrzeug, das entgegenkommt		15,5
(4) Zusammenstoß zwischen Fahrzeug und Fußgänger		12,1
(5) Zusammenstoß mit anderem Fahrzeug, das seitlich in gleicher Richtung fährt		6,9
(6) Abkommen von der Fahrbahn nach rechts/links		6,3
(7) Aufprall auf ein Hindernis auf der Fahrbahn		0,1

Lkw-Schadenfälle in der UDB [100%]		Anteil in %
(1) Zusammenstoß mit anderem Fahrzeug, das – vorausfährt oder wartet – anfährt, anhält oder im ruhenden Verkehr steht		31,6
(2) Zusammenstoß mit anderem Fahrzeug, das einbiegt oder kreuzt		22,3
(3) Zusammenstoß mit anderem Fahrzeug, das seitlich in gleicher Richtung fährt		18,5
(4) Zusammenstoß mit anderem Fahrzeug, das entgegenkommt		14,3
(5) Abkommen von der Fahrbahn nach rechts/links		5,1
(6) Zusammenstoß zwischen Fahrzeug und Fußgänger		4,4
(7) Aufprall auf ein Hindernis auf der Fahrbahn		0,4

Tab. 4.2 Sicherheitspotenzial von FAS für Pkws bezogen auf alle Pkw-Unfälle [8]

Theoretisches Sicherheitspotenzial	FAS
Notbremsassistent (v)	17,8 %
Fahrstreifenverlassenswarner (v)	4,4 %
Totwinkelwarner (v)	1,7 %

v = vermeidbar

Tab. 4.3 Sicherheitspotenzial von FAS für Lkws bezogen auf alle Lkw-Unfälle [8]

Theoretisches Sicherheitspotenzial	FAS
Notbremsassistent (v)	6,1 %
Notbremsassistent (reagiert auf stehende Fahrzeuge) (v)	12,0 %
Abbiegeassistent für Fußgänger (v)	0,9 %
Abbiegeassistent für Radfahrer (v)	3,5 %
Fahrstreifenverlassenswarner (v)	1,8 %
Totwinkelwarner (a)	7,9 %

v = vermeidbar, a = adressierbar

Roughly 41% of accidents with cars and 55% of accidents involving trucks happen in scenarios of ACC and AEB. With AEB, 43,5%* of car crashes and 12% of truck crashes are avoidable.

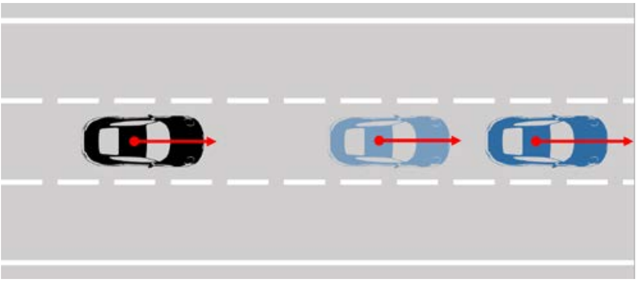
*AEB for cyclists and passengers aswell

Source: Winner, Kühn, Hannawald

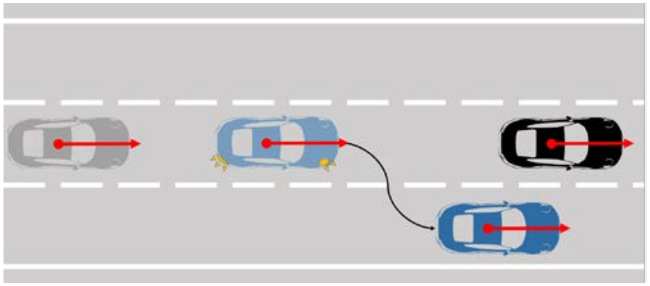
Maneuver catalogue – Create a variety of possible scenarios from the real world

Stationary distance

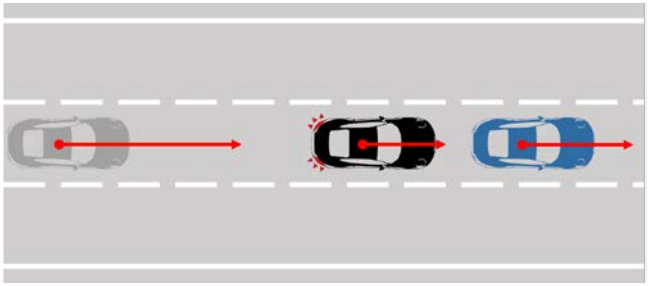
Target is accelerating



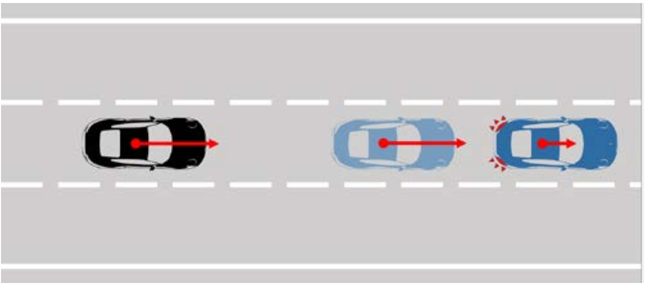
Target changes lanes



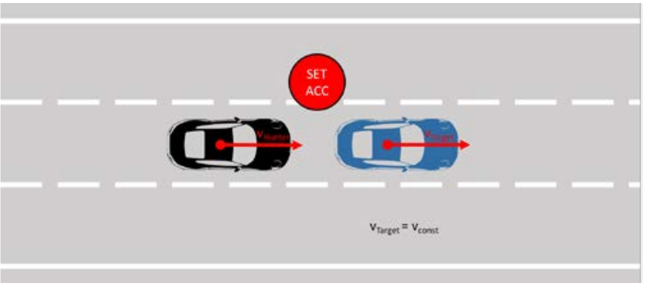
Approaching a slower target

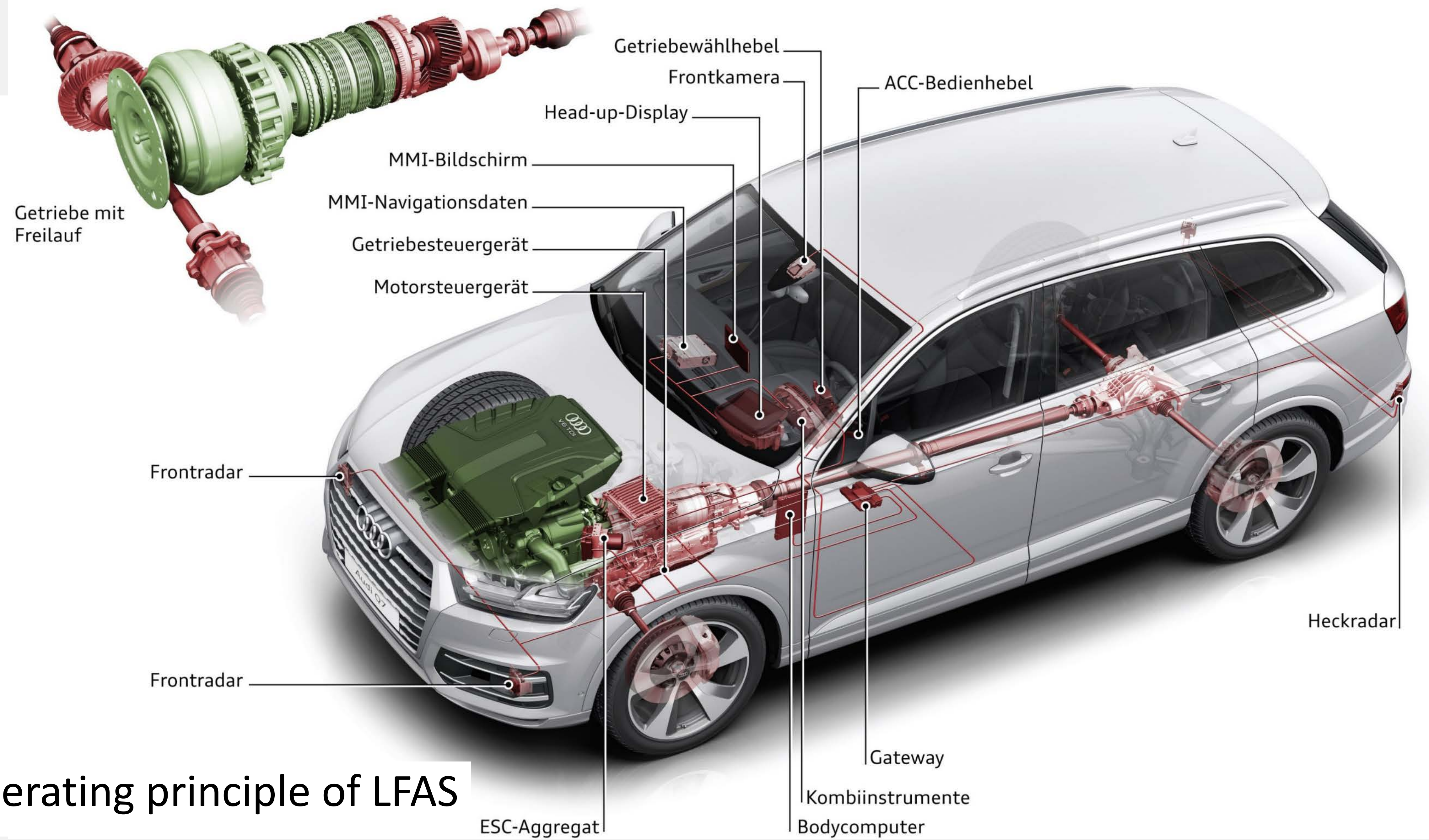


Target is braking



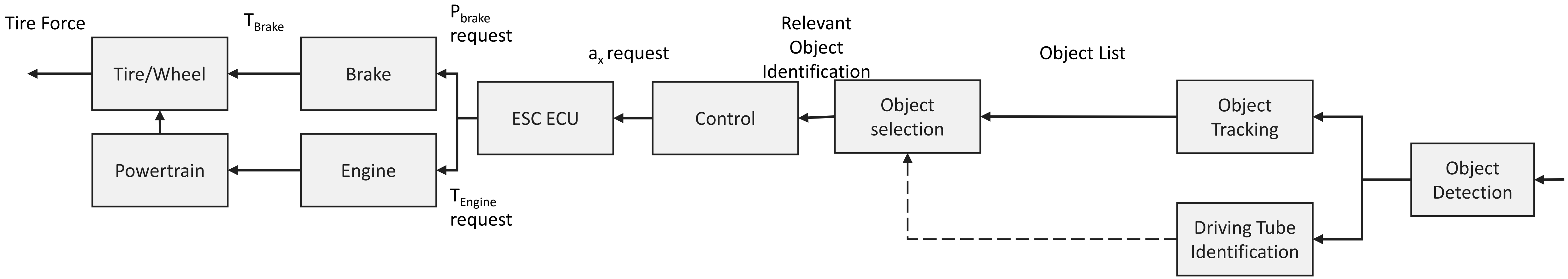
Activating ACC from close range





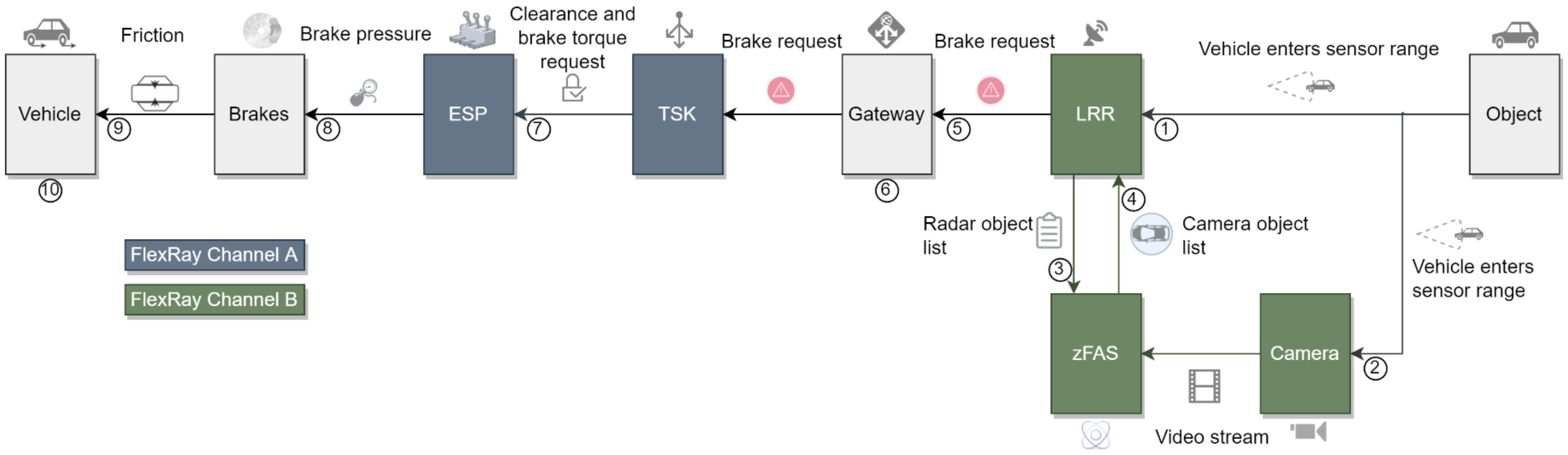
Operating principle of LFAS

Operating principle of ACC

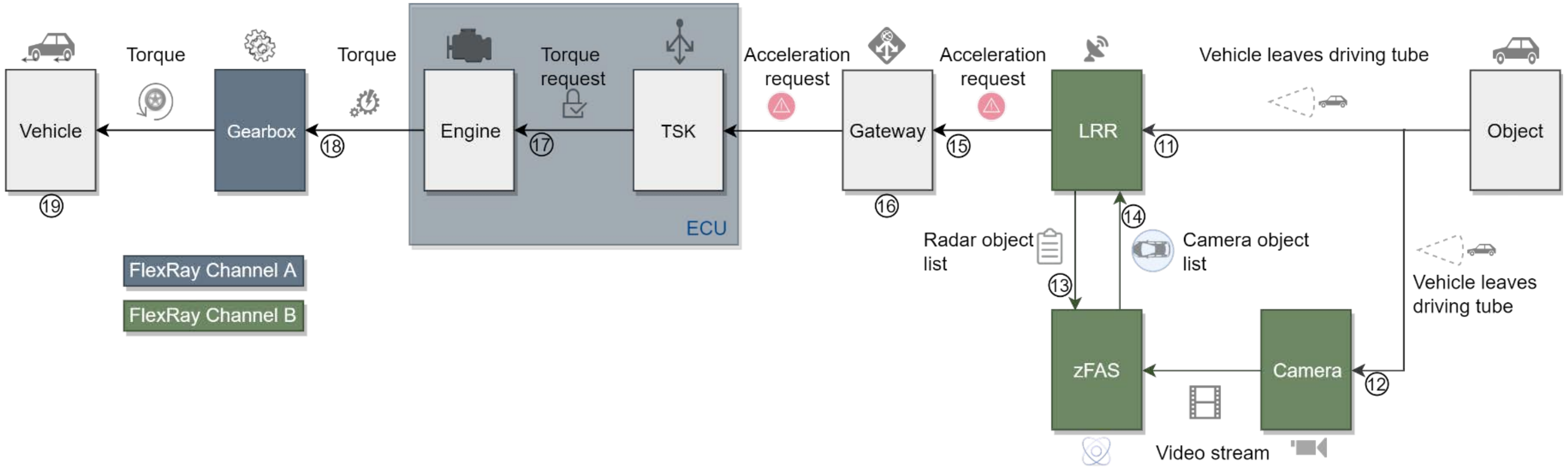


Sense-Plan-Act implementation in the Audi Q7

Brake path



Acceleration path



Solution space for Sense

A few information are critical, a lot are optional: Position, Heading, Speed

- Important: Distance to the object, direction, velocity, probability of existence

Nice to have: Acceleration, classification, identification, length, width, indicator on/off, tail lights on…

Possible sensors for LFAS are: Radar, Camera and LiDAR and Ultrasonic as support in some situations

RADAR – Function principle

Function principle of Radar: Electromagnetic waves are..

1. generated by the Radar transmitter and
2. emitted with an antenna and
3. reflected by the irradiated object and
4. picked up by the Radar reciever and evaluated.

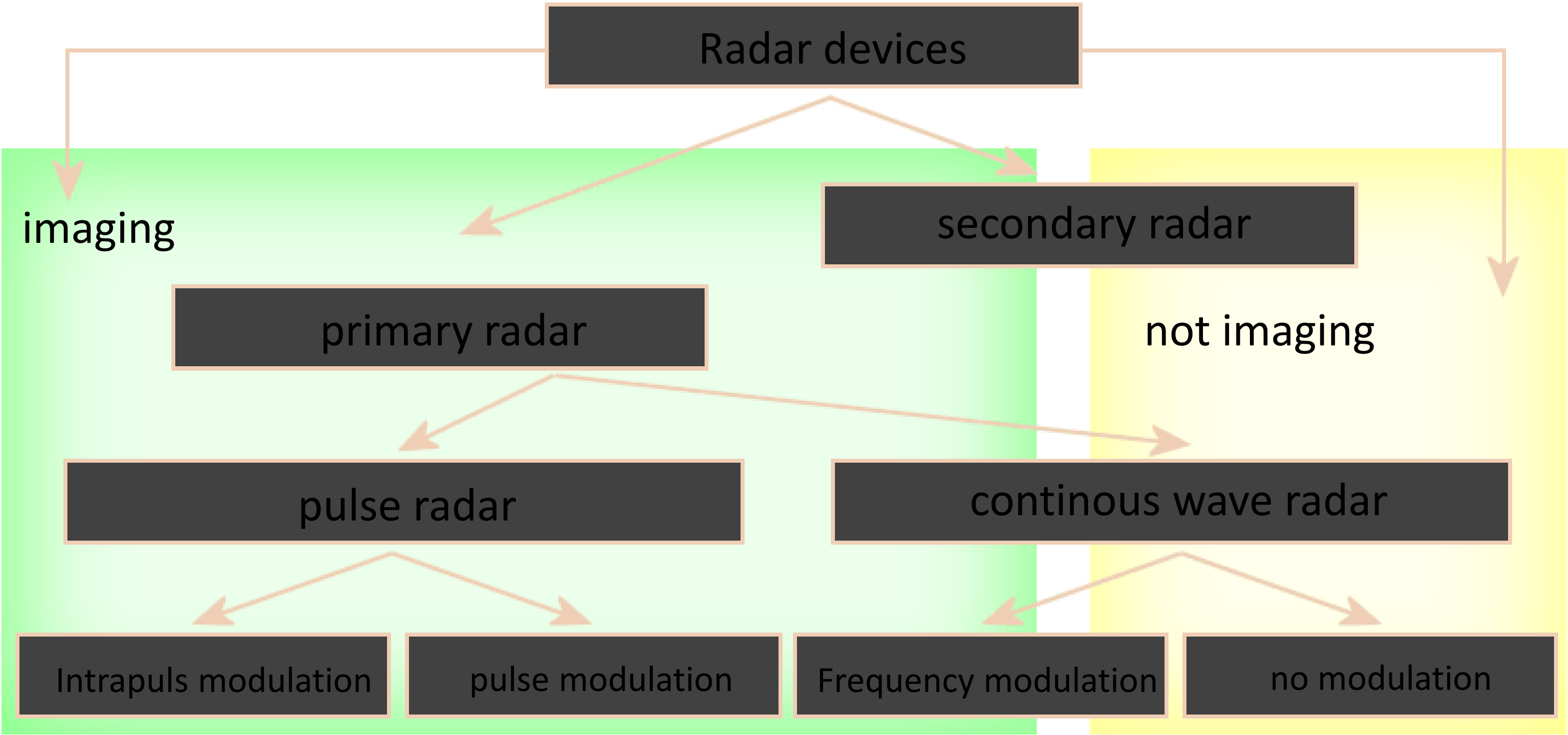
-> Radar is an active sensor!

Source: Bosch

Fundamental principles:

1. Reflection. Prerequisite are electrically conductive targets.
2. Constant wave velocity with $\approx 3 * 10^8 \ \frac{m}{s}$
3. Straight forward electrical wave propagation

RADAR – Lots of possible implementations



Source: Radartutorial.eu

RADAR – Lots of possible implementations

Primary radar vs secondary radar: Primary for non cooperative targets, secondary for e.g. planes that respond with a radar themselves

Modulation is needed to evaluate the distance to the object and to differentiate between multiple objects, otherwise only the objects velocity can be determined.

Puls radar vs: CW-radar:

Pulsradar has a high pulse energy, while CW-radar has a lower, continous energy

Pulsradar can switch between transmission and reception, while CW-radar needs separate antenna

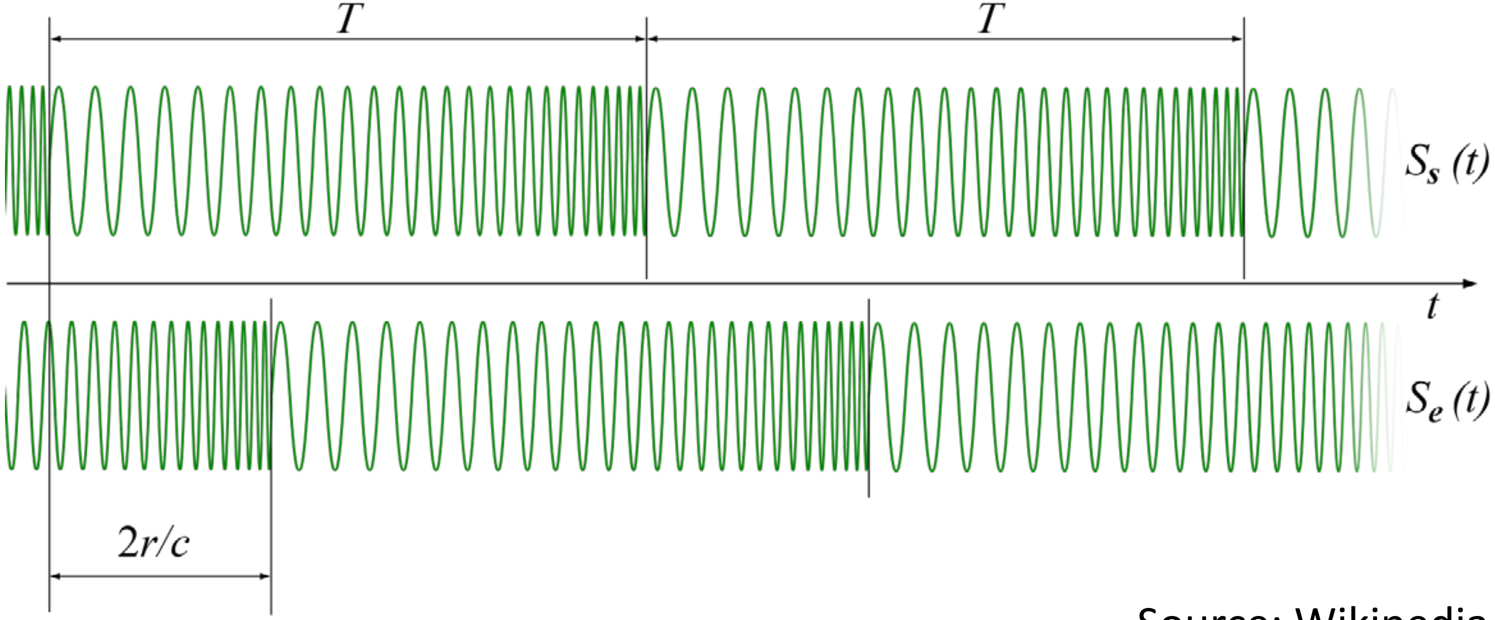
Pulsradar is typically used for high ranges, while CW-radar are typically used more for close ranges

Typical automotive radar:

24/76-77GHz, frequency modulated continous wave (FMCW)

Wave forms can look very different – Example here FMCW

FMCW Radar

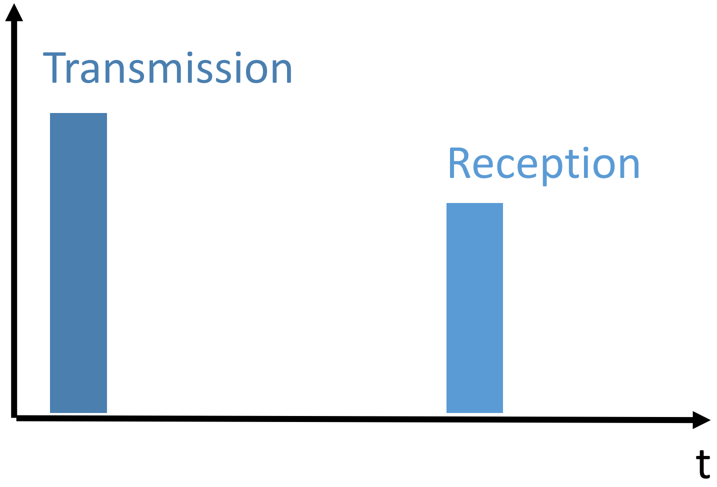


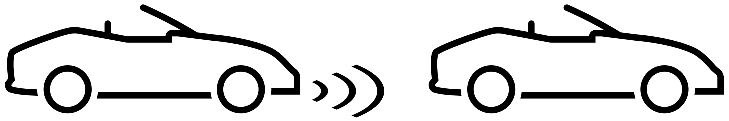
Source: Wikipedia

RADAR – Distance measurement – ToF principle

Time of Flight principle:

Runtime t of a pulse (transmission to reception)





$v = \frac{s}{t}$

Example: t=1µs; R=?

$c_o = \frac{2 * R}{t}$

$R = \frac{c_o * t}{2}$

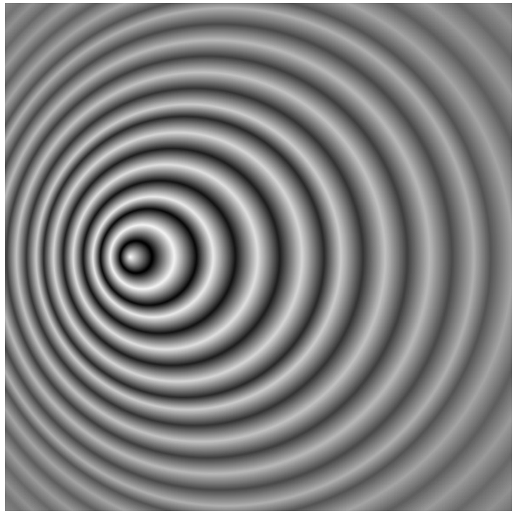
RADAR – Velocity measurement with Doppler effect

The Doppler effect is the compression or stretching of a wave over time due to changes in the distance between the transmitter and receiver.

->Change in waves frequency.

Is the transmitter frequency known, and the receiver frequency evaluated,

the delta velocity can be calculated.

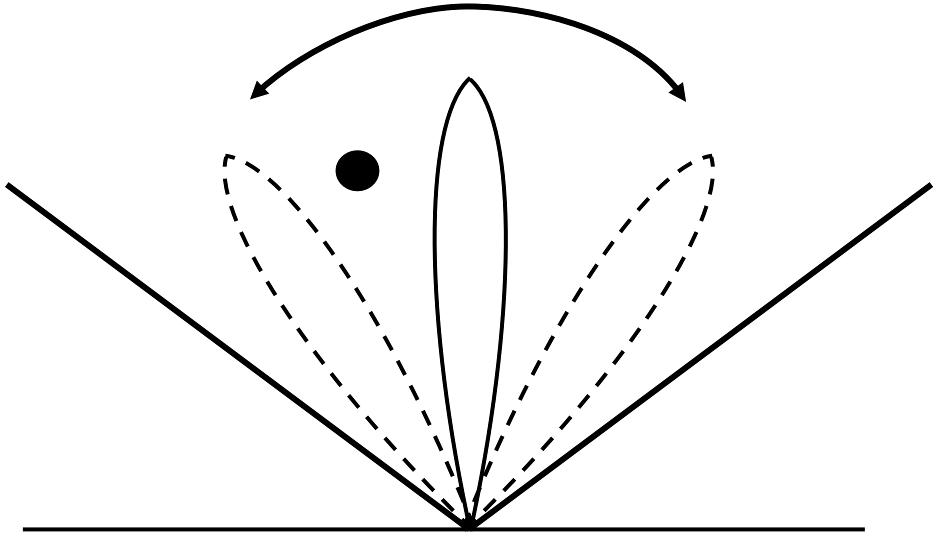


$$v_r = \frac{c_o}{2 * f_S} f_D = \frac{\lambda_S}{2} f_D$$

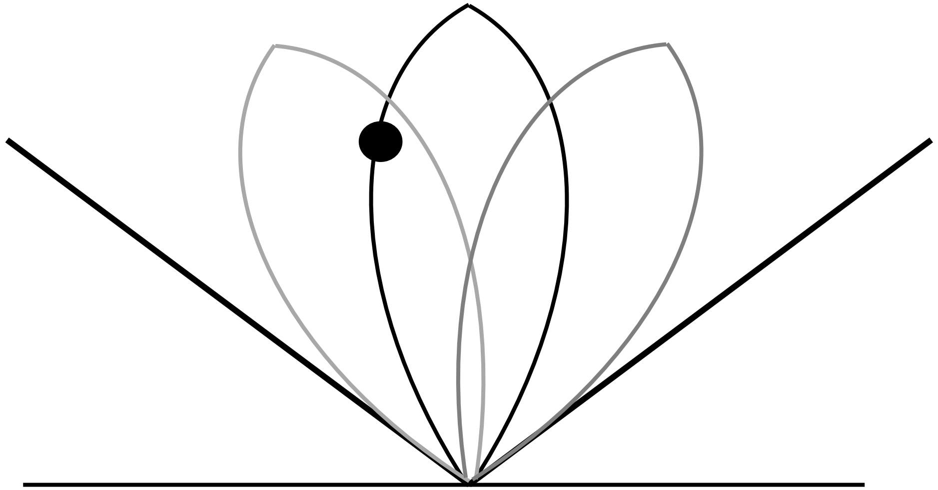
$f_S = transmitter\ frequency,\ f_D = Doppler\ frequency,$
$c_o = propagation\ velocity, v_r = radial\ velocity$

Source: Wikipedia

RADAR – Angle measurement – Scanning or multiple beams



Scanning



Overlapping beams

LiDAR – Function principle is similar to RADAR

Similar to RADAR: Time of flight principle

Wavelength: Ultraviolett / infrared

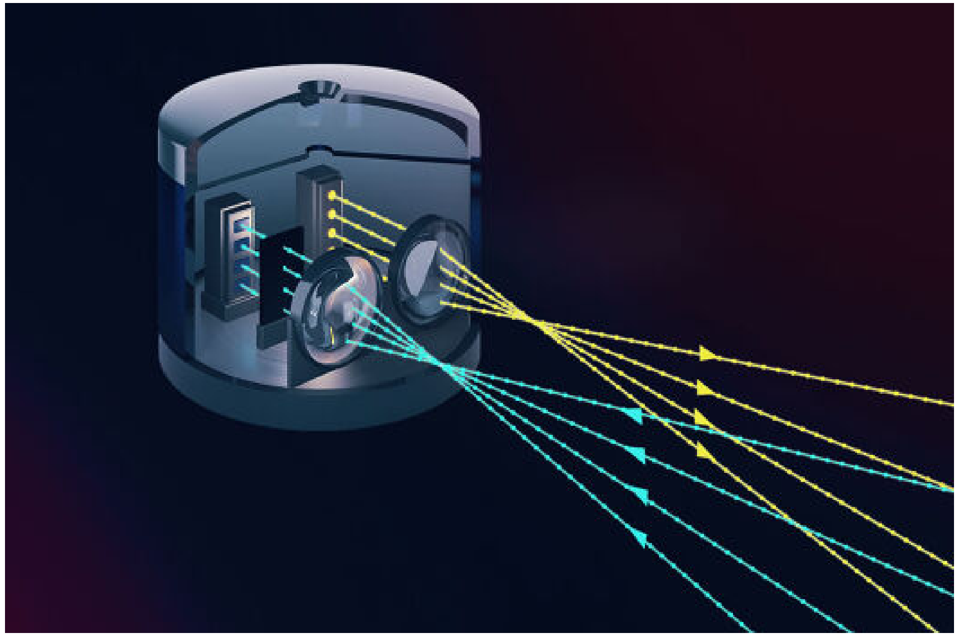
FoV: Previously 360°, now mostly more narrow.

Solid-state (=without moving parts) LiDAR sensors are currently not in mass production for use in the automotive sector.

Absorption, Transmission and Reflection properties of the object are determinant for the reception of emitted light.

Black cars for instance can cause problems for LiDAR sensors, where the reflected energy can be too little to distinguish it from background noise.

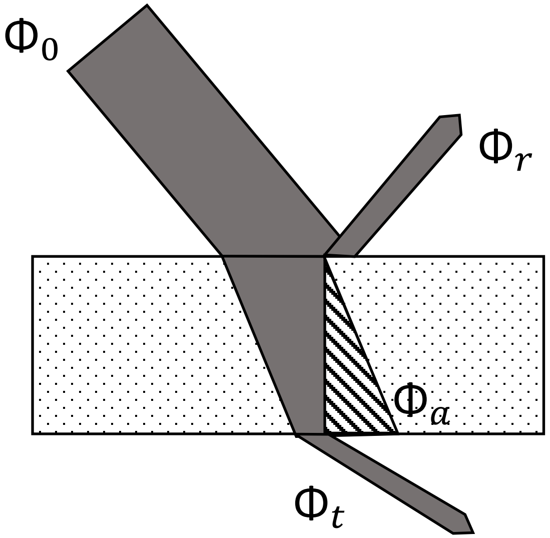
$$R = \frac{c_o * t}{2}$$



Source: Radartutorial.eu

Reflection phenomena

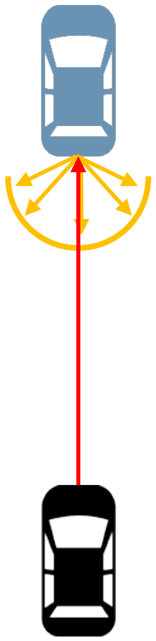
a) Reflection, Absorption and Transmission



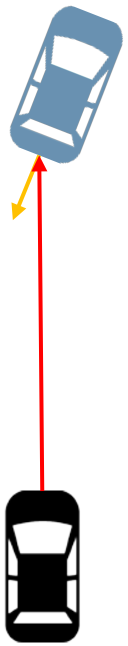
$\Phi_0 = \Phi_r + \Phi_a + \Phi_t$

Φ_0 *Light power from sender*
Φ_r *Reflected light power*
Φ_a *Absorbed light power*
Φ_t *Passed light power*

b) Lambert diffuse reflection



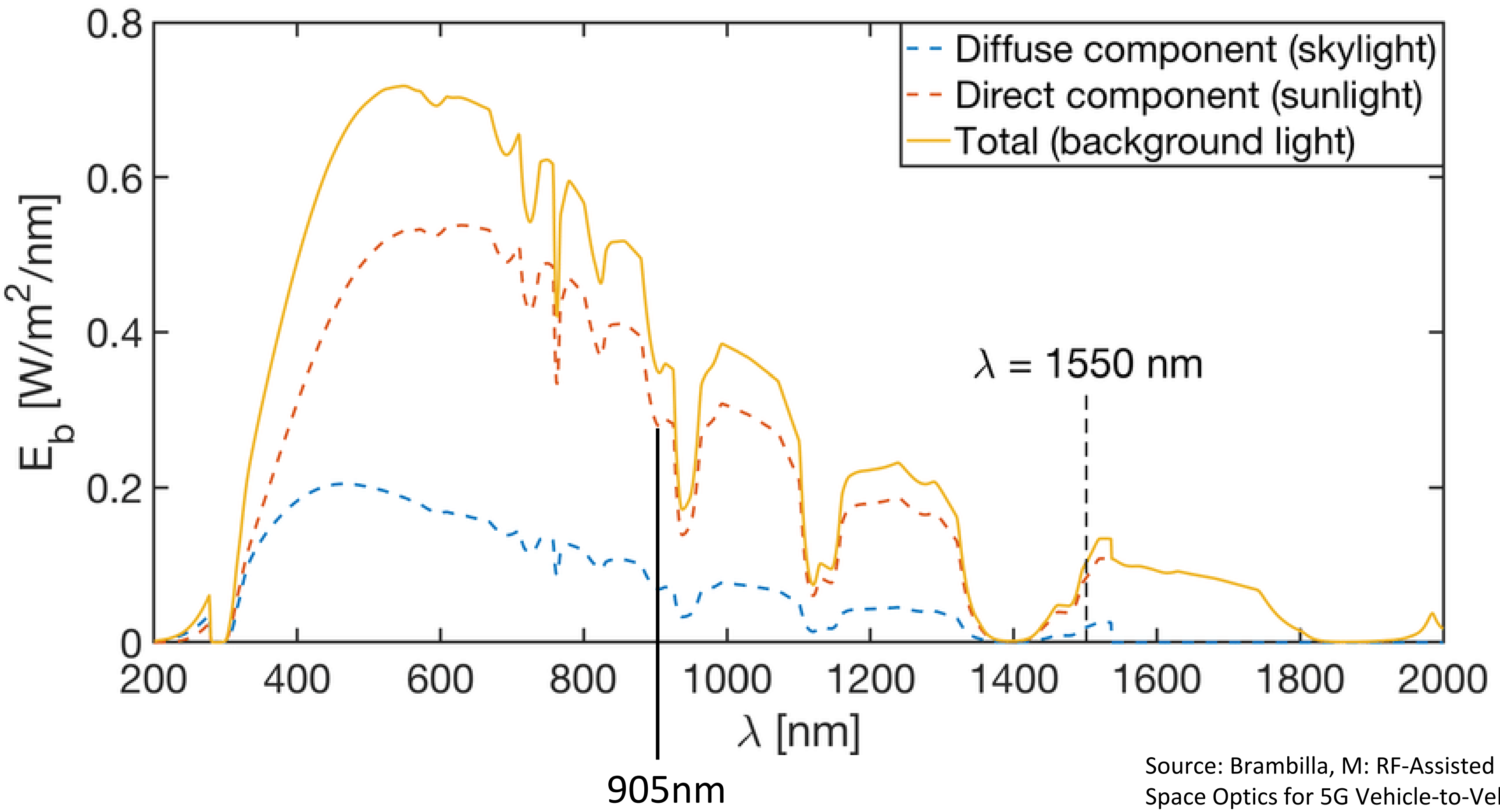
c) Total reflection



Transmit power is limited, so focusing the beam to increase energy density may be necessary. But this increases the chance for total reflections when facing even surfaces in small angles.

LiDAR sensors have to deal with sunlight

LiDARs today operate mostly at either 905nm or 1550nm.



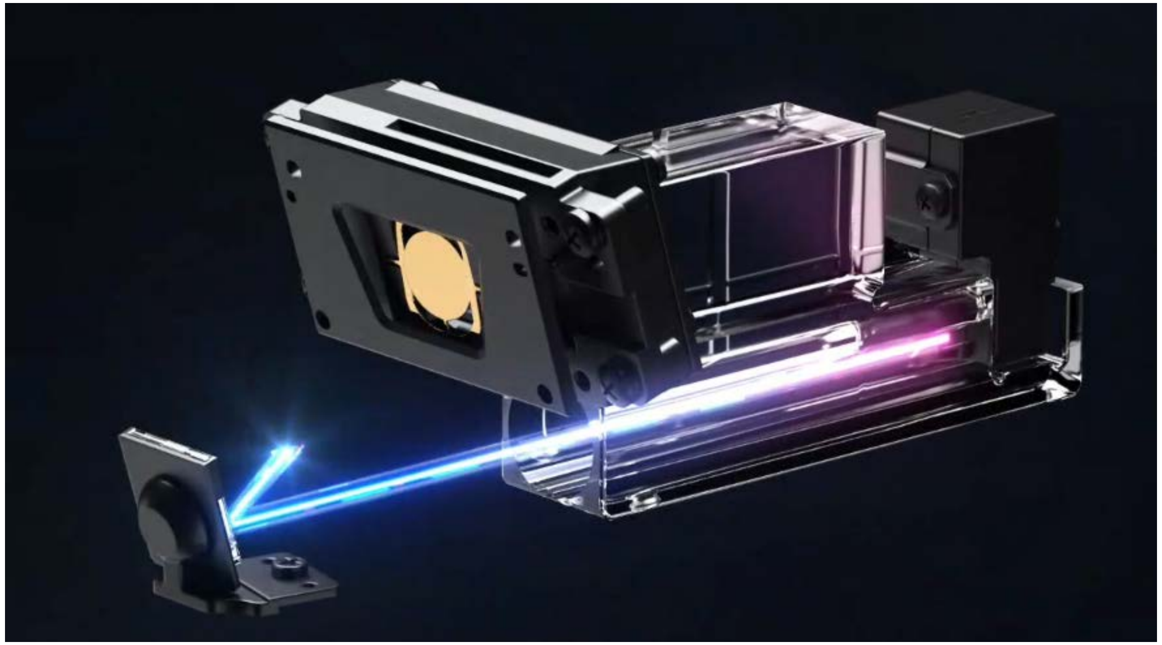
Source: Brambilla, M: RF-Assisted Free-Space Optics for 5G Vehicle-to-Vehicle Communications (2019)

Both wavelengths have advantages and disadvantages

	905nm	1550nm	Meaning
Water	+	−	Water absorbs 1550nm approx. 145x more than 905nm
Rain/fog	+	−	In rain & fog, 1550nm degrades 4-5x worse than 905nm
Snow	+	−	Snow reflects 1550nm approx. 97% worse than 905nm
Power	+	−	Power consumption is 10x more for 1550nm to achieve same performance in wet conditions
Range	−	+	During sunlight, 1550nm has less noise floor
Eye safety	−	+	Eye safety is approx. 40x better for 1550nm due to less noise (air attenuation) and thus less needed power

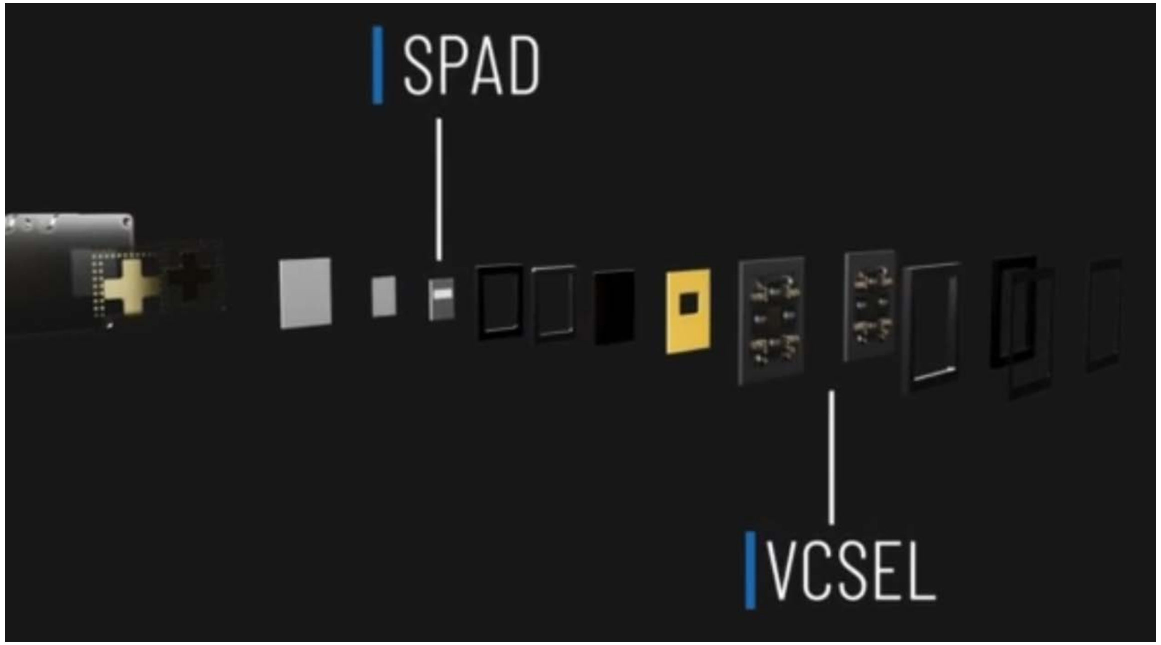
Source: Wojtanowski, J: Comparison of 905 nm and 1550 nm semiconductor laser rangefinders' (2014)

Solid state and true solid state



- MEMS based “solid state” LiDAR

https://www.robosense.ai/en/rslidar/RS-LiDAR-M1

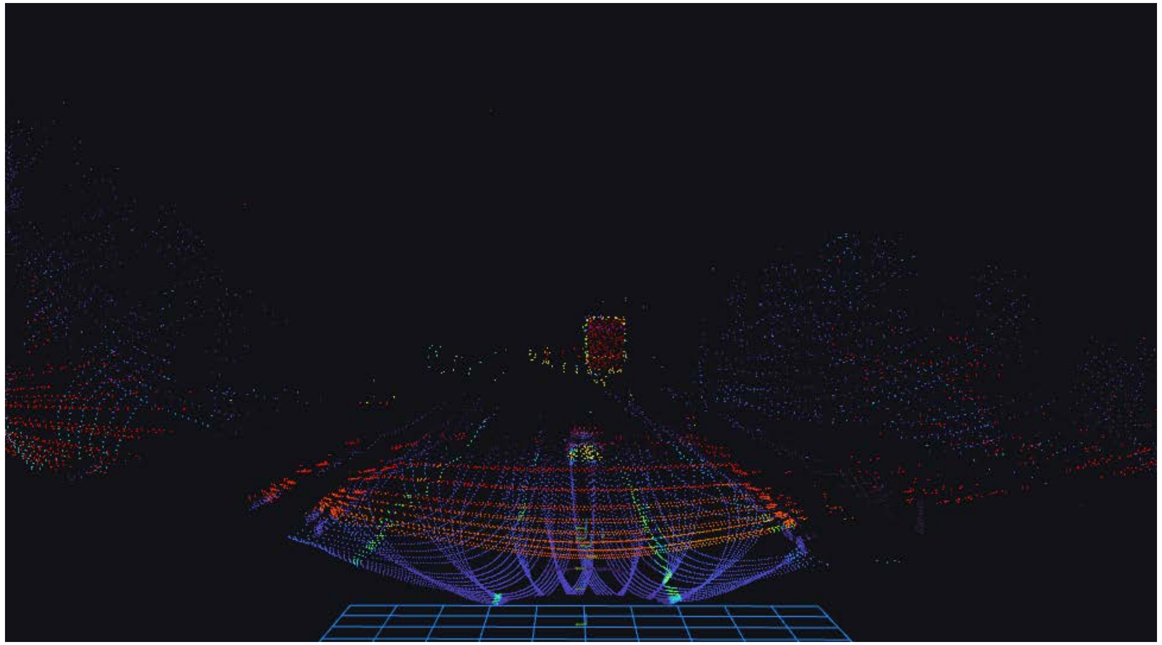


- VCSEL-Laser + SPAD-Chips true solid state LiDAR

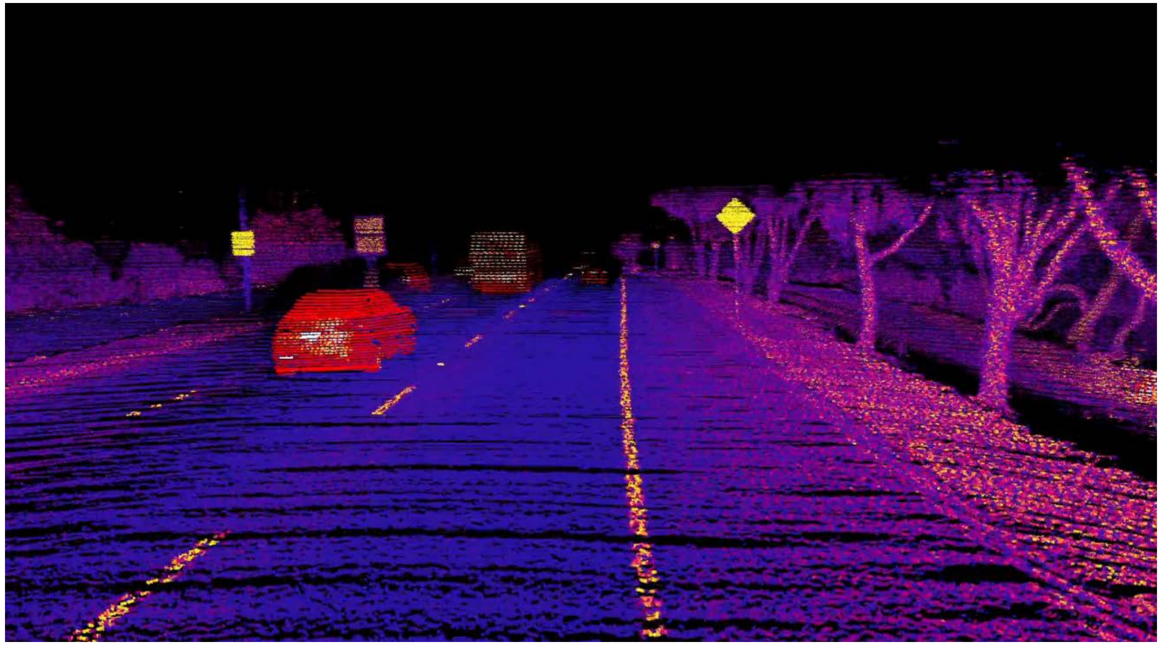
https://www.opsys-tech.com/

Pointcloud example – Opsys Tech SP3C solid state

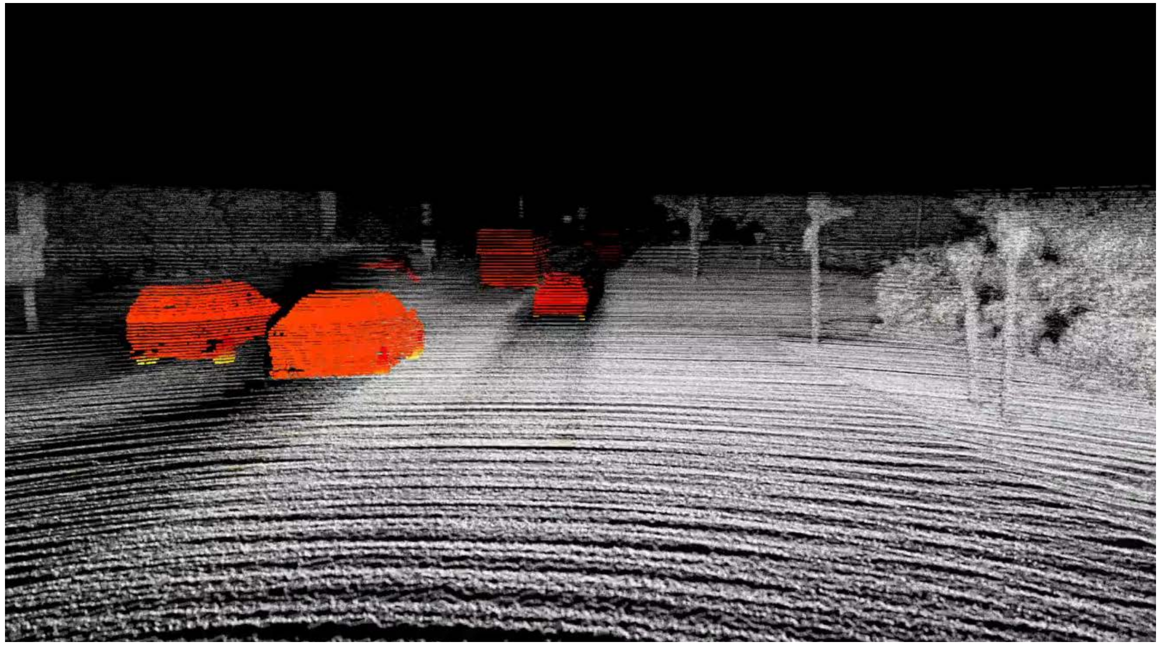
Pointcloud example – Livox Avia (Non-repetitive pattern)



Pointcloud example – Aeva Aeries II (FMCW LiDAR)

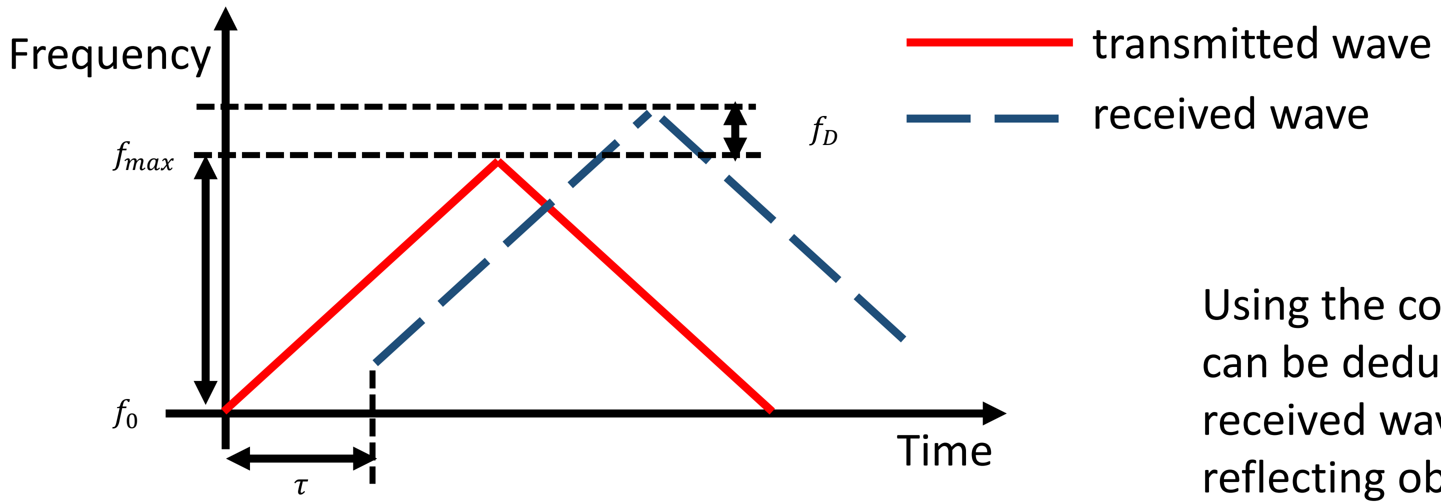


- Reflectivity map



- Velocity map

Velocity measurement with FMCW



Using the continuous wave, the doppler frequency can be deducted from the transmitted and the received wave. This enables the calculation of the reflecting objects velocity for every point in the pointcloud.

$$v_r = \frac{c_o}{2 * f_s} f_D = \frac{\lambda_s}{2} f_D$$

f_S = transmitter frequency, λ_s = transmitter wavelength,
f_D = Doppler frequency,
c_o = propagation velocity, v_r = radial velocity

Key differences between LiDAR and RADAR

Due to the different wavelenghts, Radar is much less susceptible to weather influences (Radar ~1cm-4mm, LiDAR ~1µm)

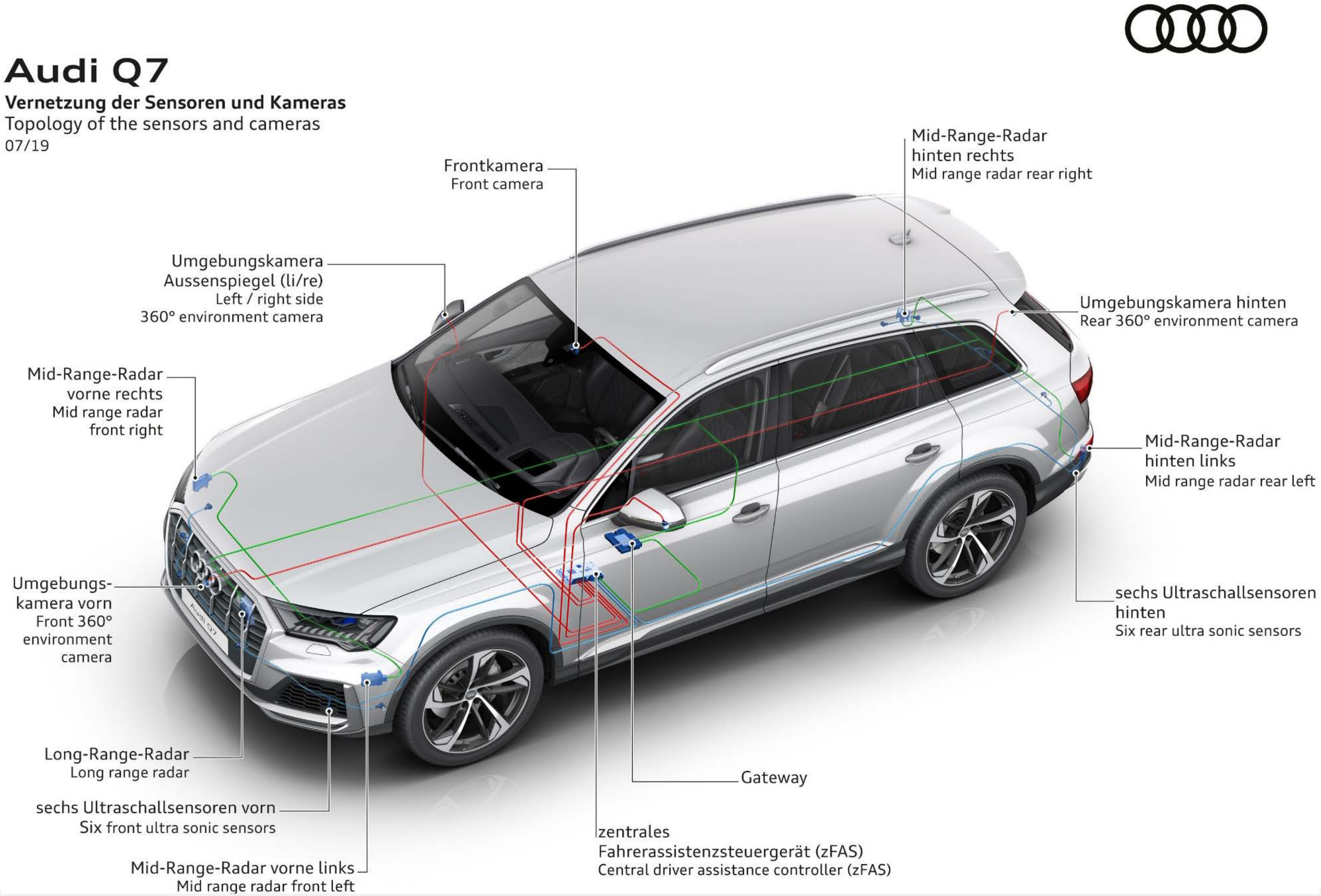
Doppler Effect gives the Radar a clear edge on LiDAR, that usually has to observe the object for at least two points in time. FMCW LiDAR are not yet widely available or used.

LiDAR has a much better angular accuracy considering a small form factor

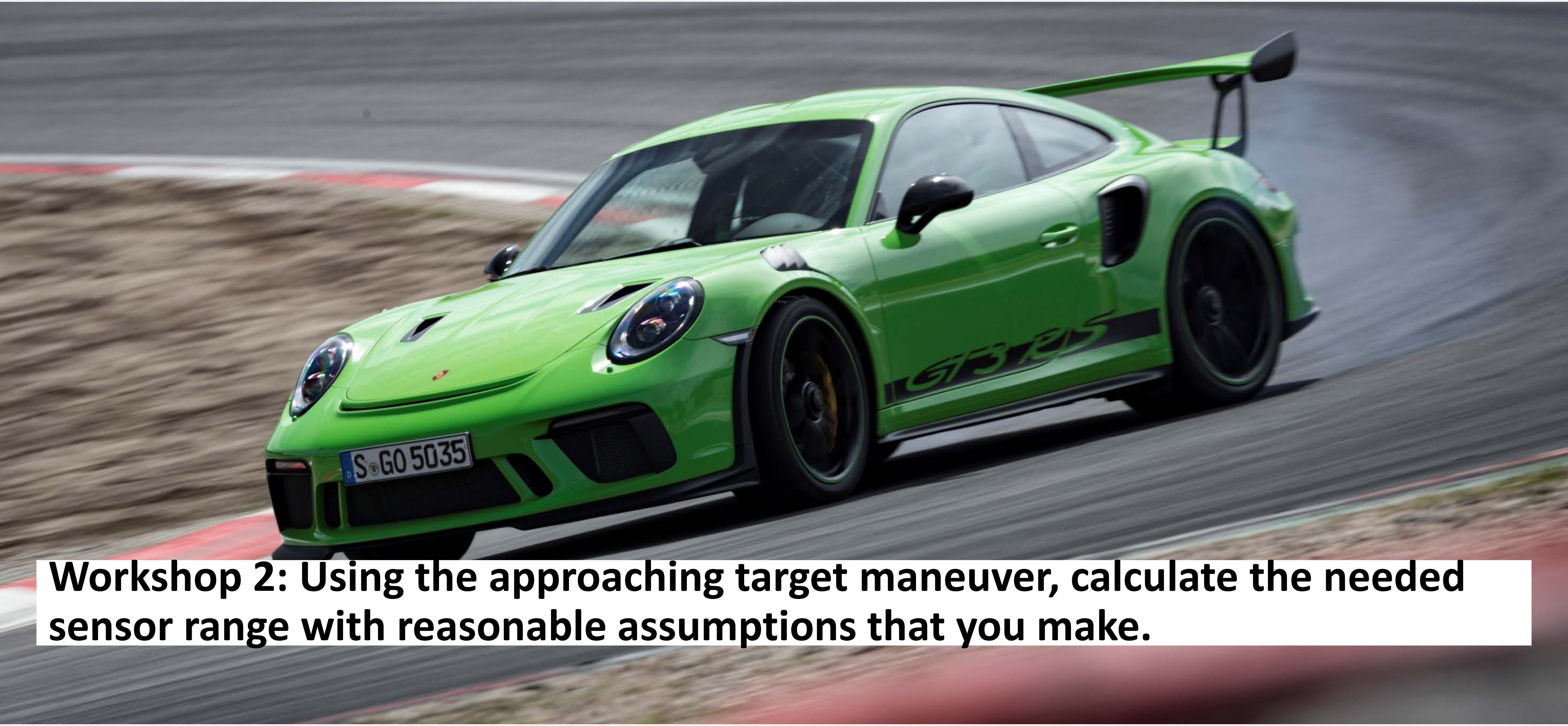
LiDAR transmission power is always limited by human eye safety regulations

NIO ET7

Hands-on Audi Q7



Workshop



Workshop 2: Using the approaching target maneuver, calculate the needed sensor range with reasonable assumptions that you make.

Needed sensor range depends on the chosen velocity

Using basic physics formula, we can calculate the needed sensor range for the approaching target maneuver

Assumptions:

Ego velocity	180 km/h
Target velocity	80 km/h
Minimal safety distance	¼ speedometer velocity
Reaction time	1s
Allowed deceleration	$3.5\,\frac{m}{s^2}$

$$s_{flag} = s_{react} + s_{brake} + s_{safety}$$

$$s_{react} = v_H * t_r$$

$$s_{brake} = \frac{(v_T - v_H)^2}{2 * a_{Mean}}$$

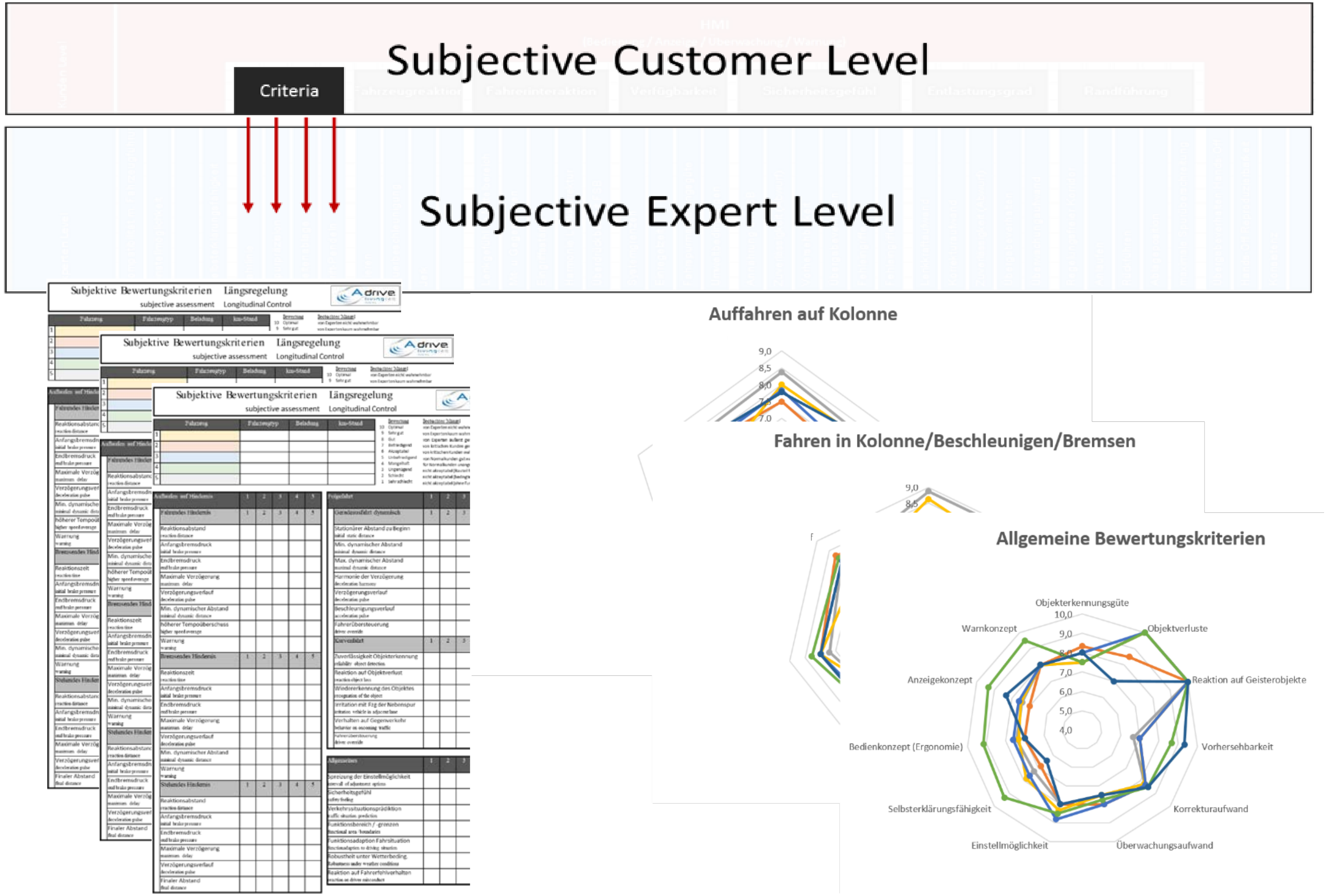
$$s_{safety} = \frac{1}{4} * v_H = \frac{1}{4} * v_T * 3.6$$

See seperate excel worksheet on Moodle!

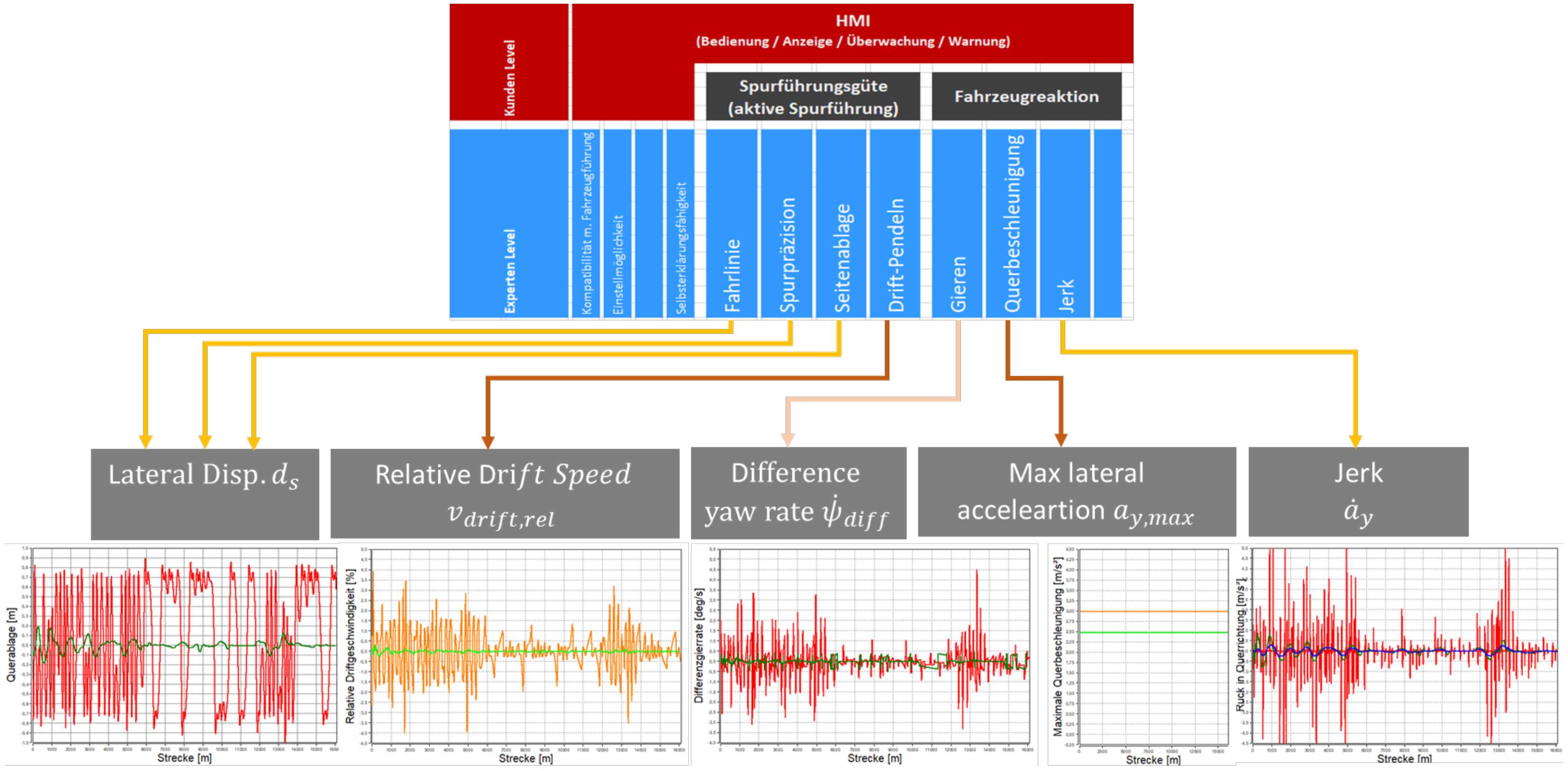
Evaluation of ACC

How can we evaluate degree of fulfilment?

Evaluation of ACC | Subjective Level



Evaluation of ACC | Objective Level

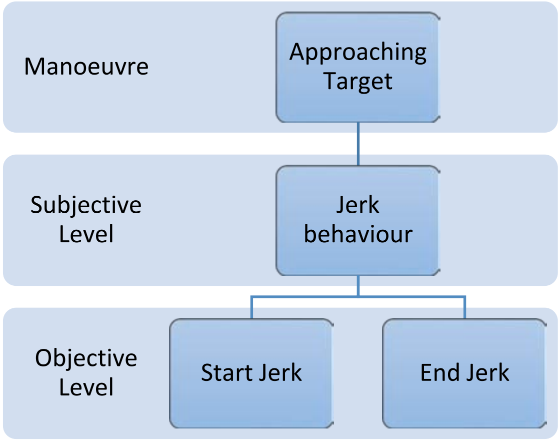


Workshop

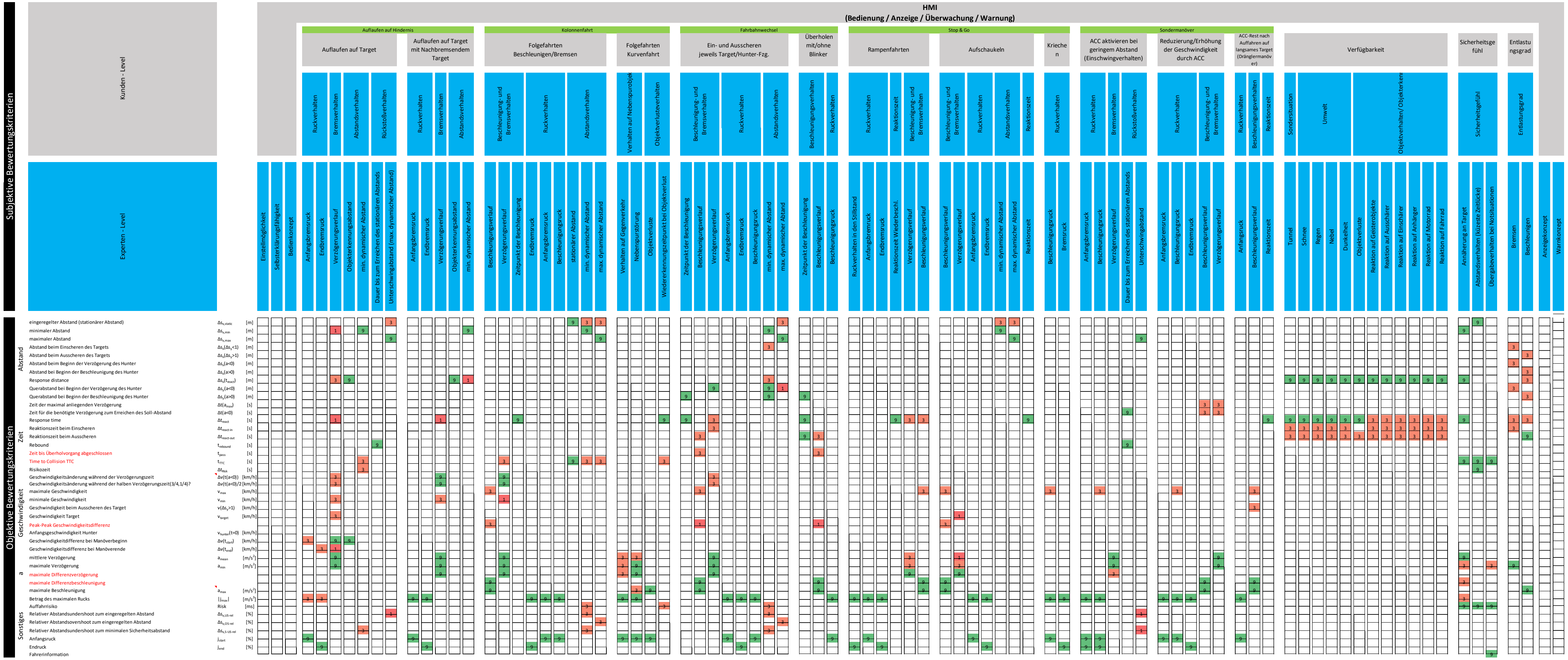
Workshop 3: Using the approaching target maneuver, find appropriate subjective and objective criteria.

GROUP WORK

Find subjective and objective criteria for different manoeuvre:



Linkage Subjective & Objective

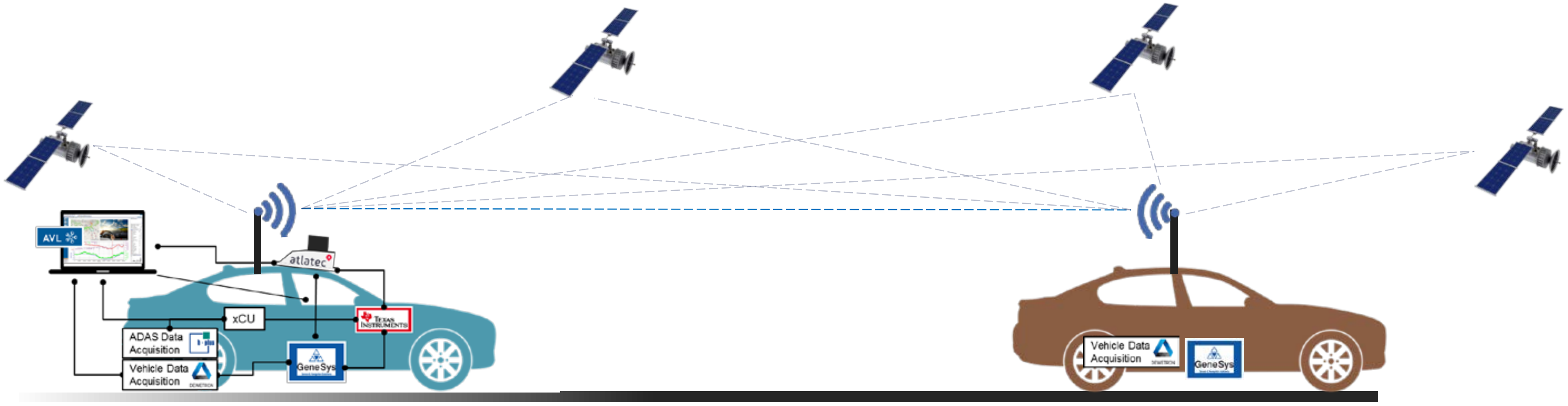


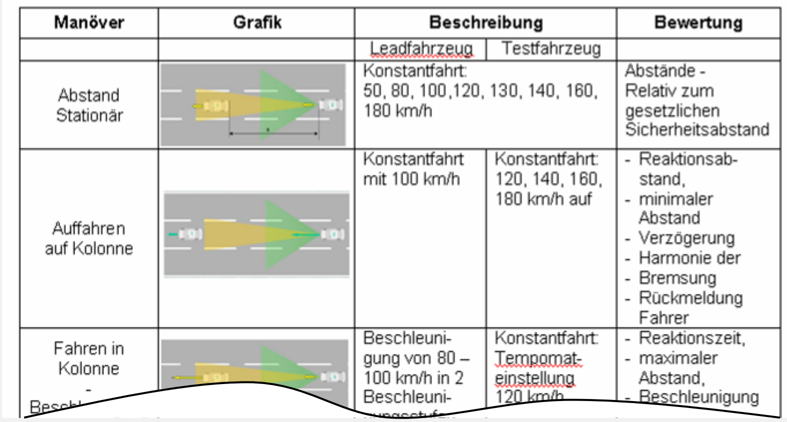
Link Ebenenmodell

MXEval Demo

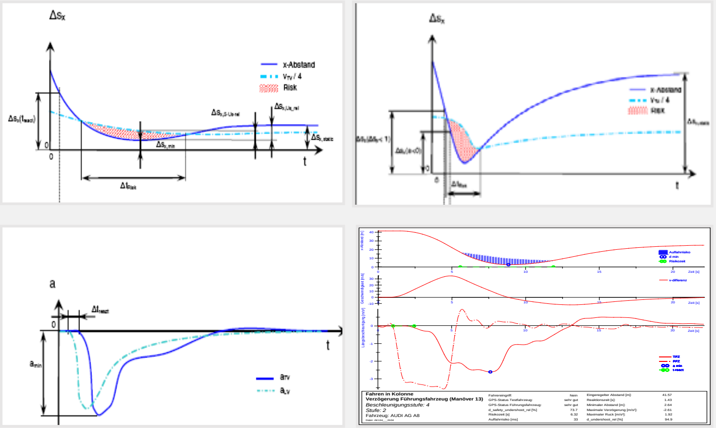
Measurement Methods

Measurement Methods





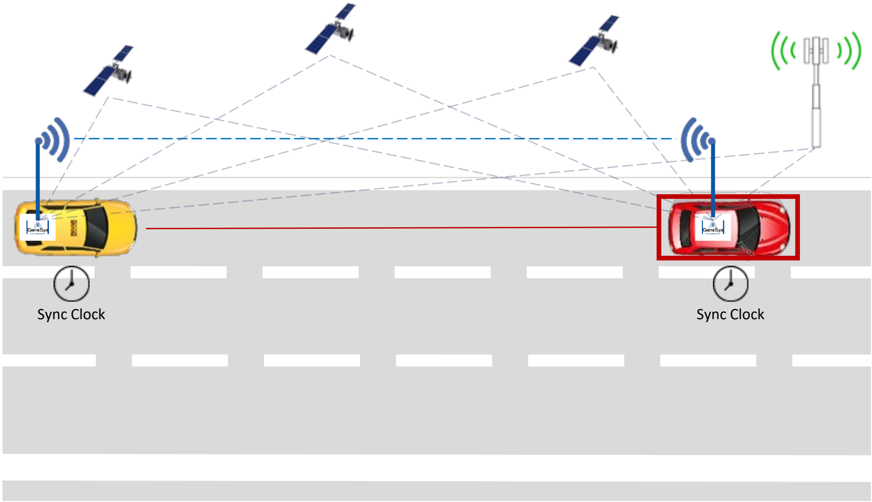
Manöver	Grafik	Beschreibung		Bewertung
		Leadfahrzeug	Testfahrzeug	
Abstand Stationär		Konstantfahrt: 50, 80, 100,120, 130, 140, 160, 180 km/h		Abstände - Relativ zum gesetzlichen Sicherheitsabstand
Auffahren auf Kolonne		Konstantfahrt mit 100 km/h	Konstantfahrt: 120, 140, 160, 180 km/h auf	- Reaktionsabstand, - minimaler Abstand - Verzögerung - Harmonie der Bremsung - Rückmeldung Fahrer
Fahren in Kolonne - Beschl…		Beschleunigung von 80 – 100 km/h in 2 Beschleuni…ungsstufe…	Konstantfahrt: Tempomateinstellung 120 km/h	- Reaktionszeit, - maximaler Abstand, - Beschleunigung



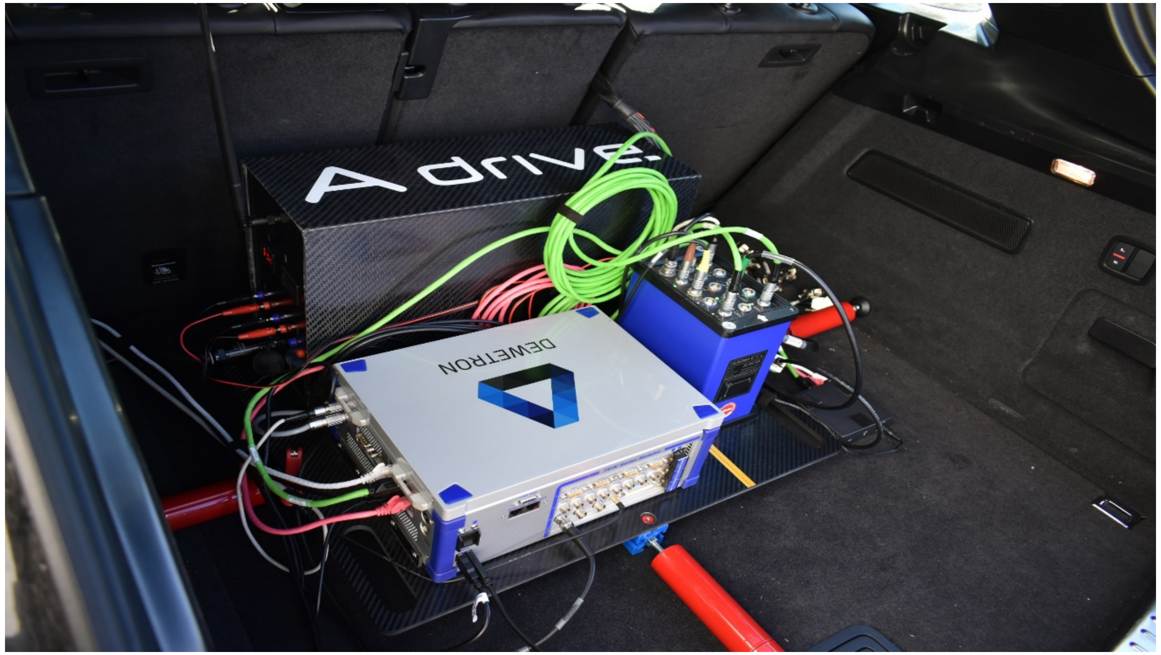
Measurement Methods

Requirements

- position accuracy ± 5 cm
- data exchange between both vehicles for sync. online measuring
- no permanent satellite positioning necessary (IMU in both cars)
- **Objective Benchmarking through external measurement system**
  (no access to internal bus systems needed)

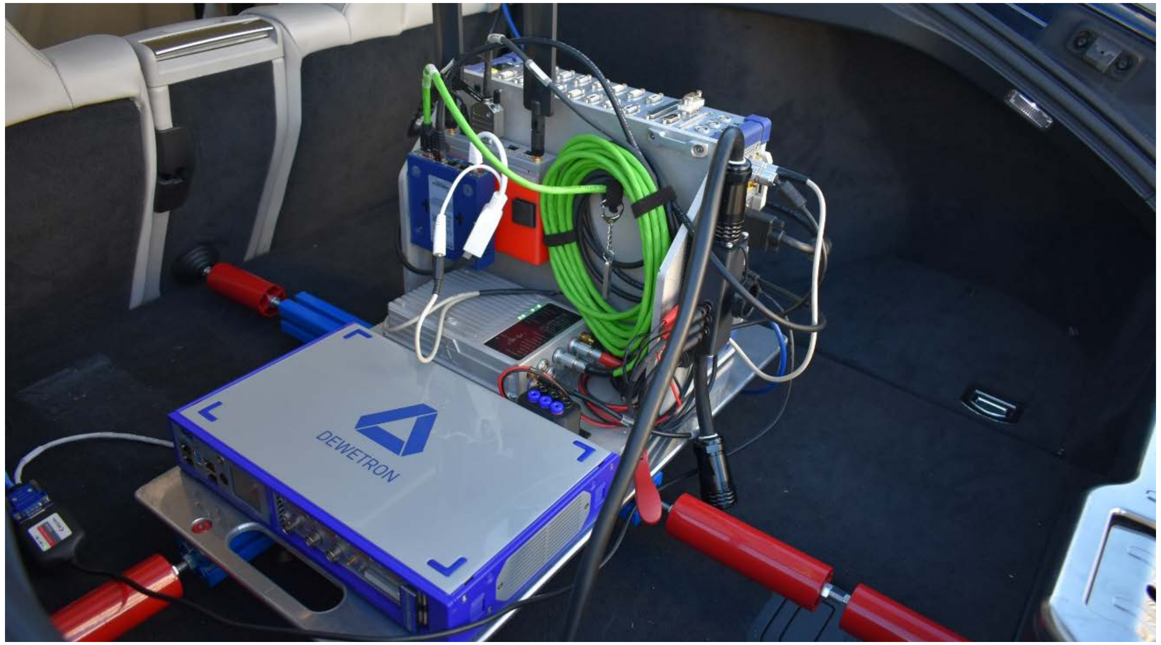


Measurement Setup Hunter



Measurement Setup Target

- C2C - communication



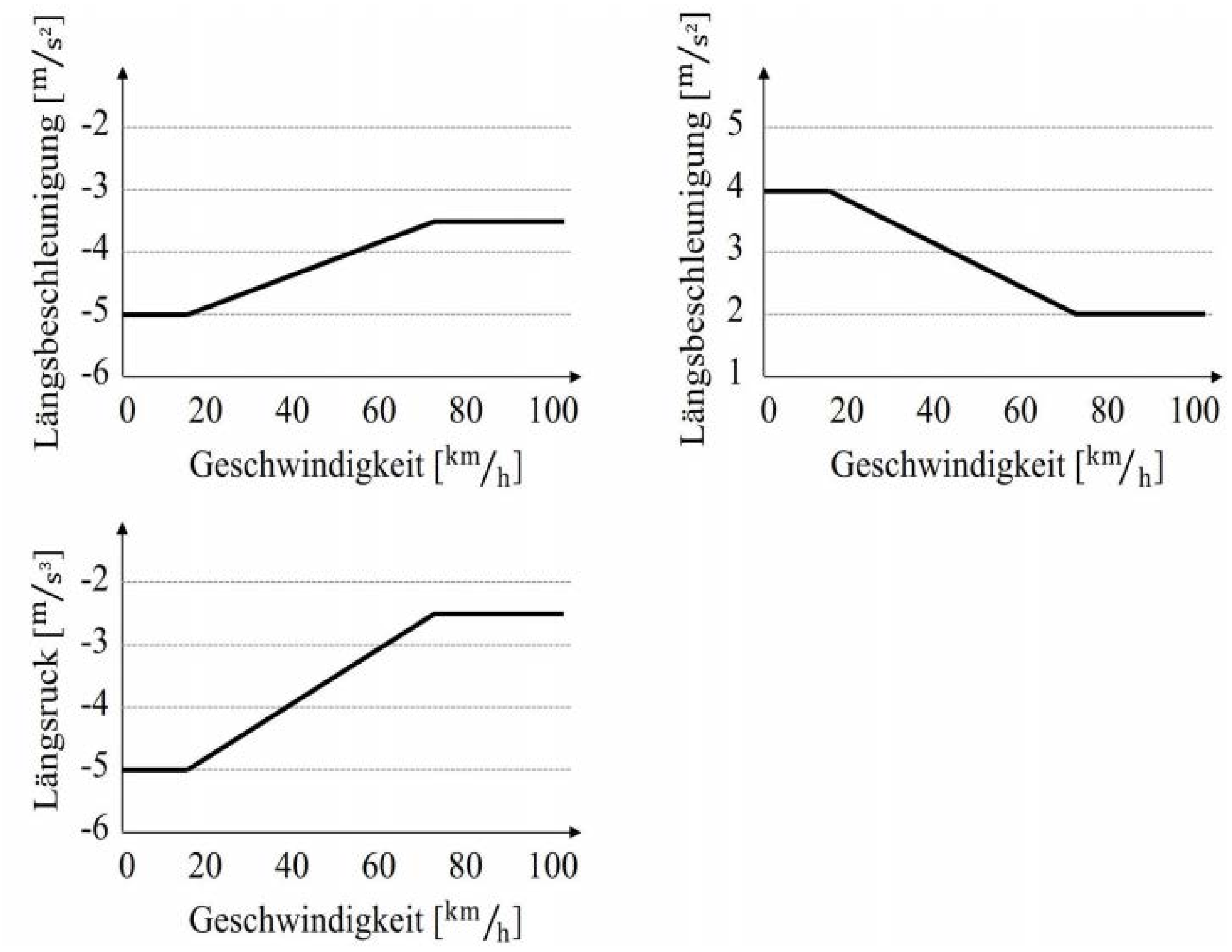
Measurement assembly

Measurement Methods | Checking accuracy

Measurement Methods

Test Methods

ISO15622 for Standard ACC | ISO 22179 for FullSpeed Range ACC

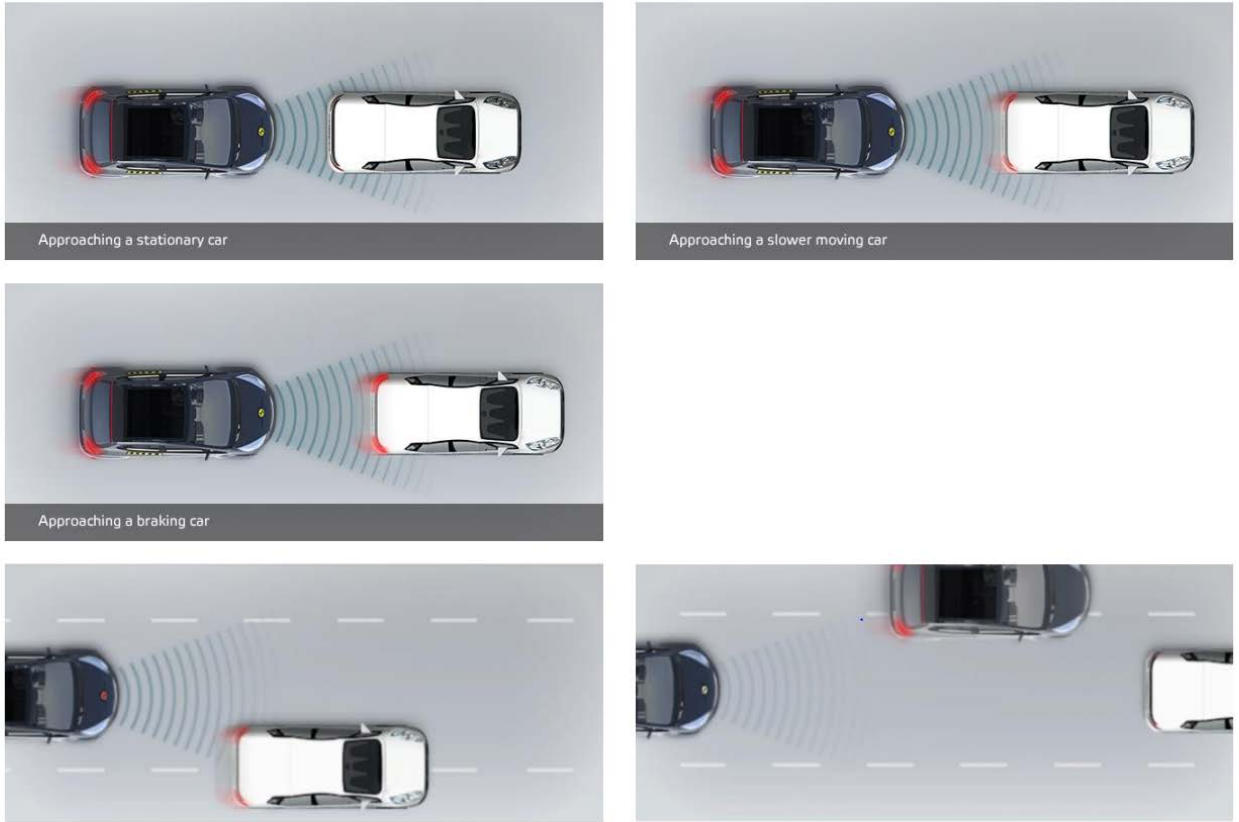


Quelle: ISO15622

- Free Run
- Stationary Drive
- Approaching Target

- The ISO defines functional limits such as maximum acceleration (negative / positive) etc.

ISO15622 for Standard ACC | ISO 22179 for FullSpeed Range ACC



- Left top: Approaching a stationary car
- Right top: Approaching a slower moving car
- Middle left: Approaching a braking car
- Left bottom: Other car cuts-in into your lane
- Right Bottom: Car in front changes lane to avoid a stationary car

Quelle: EuroNCAP

The United Nations have regulations for the approval of vehicles

Addendum 156 – UN Regulation No. 157

Amendment 4

2. Definitions

For the purposes of this Regulation:

2.1. *"Automated Lane Keeping System (ALKS)"* is a system which is activated by the driver and which keeps the vehicle within its lane for travelling speed of 130 km/h or less by controlling the lateral and longitudinal movements of the vehicle for extended periods without the need for further driver input.

4. Test conditions

4.1. The tests shall be performed under starting conditions (e.g. environmental, road geometry) that allow the activation of the ALKS (excluding category "Prevention of activation when the system is outside its ODD" of Table A6/1).

4.2. If applicable to the system's ODD, the composition of the public road test shall allow the verification of the system in free-flow, lightly congested and heavily congested traffic conditions.

4.3. The location and selection of the test routes, time-of-day and environmental conditions shall be determined by the type-approval authority. Such tests shall cover different time-of-day and light intensity. They shall include scenarios in which the ALKS is expected to experience challenging scenarios (e.g. tight curvatures, speed changes caused by variable infrastructural or traffic conditions, merging situations) and to approach the limits of its declared ODD during ALKS operation (changes in visibility or road conditions, planned or sudden end of ODD).

Lane Keeping	Lane keeping on roads with different lane curvature		Mandatory	5.2.1
	Another vehicle driving close beside in the adjacent lane		Recommended	5.2.2
Lane changing performed by the system	The ALKS performing lane change in the adjacent (target) lane with and without surrounding traffic		Mandatory	5.2.6
	Merging at motorway entry		Mandatory	
	Merging at lane end	Free flow and lightly congested traffic conditions	Mandatory	
		Heavily congested traffic conditions (repetition of at least 5 times)	Mandatory	

6. Test duration

6.1. The test, or combination of tests, shall be such that allows recording the ALKS operation including:

(a) at least 5 operating hours in heavily congested traffic conditions; and, if applicable to the system's ODD,

(b) at least 10 operating hours in free-flow traffic conditions.

6.2. Test duration is deemed to be sufficient when all mandatory scenarios have been covered and either:

(a) the durations prescribed above are met; or

(b) testing has continued for at least 16 hours.

6.3. While test scheduling and route planning shall aim to achieve as much system operation time as possible for the public road test, any recommended scenarios that could not be encountered within 16 hours of testing, shall be provided from the manufacturer's internal system validation tests to the satisfaction of the type approval authority.

Measurement Methods

GROUP WORK CarMaker

1. **Step: Create straight road**
2. **Step: Choose DemoCar from examples and add object sensor**
3. **Step: Create a maneuver, with e.g. 150km/h**
4. **Step: Configure the driver so it ignores traffic vehicles and allows 300 km/h**
5. **Step: Add a traffic vehicle to the simulation, with e.g. 80km/h and make sure it‘s out of the object sensors range at the start of the simulation**
6. **Start the simulation and configure the IPGControl module so you can see relevant signals**
7. **Start to play around with parameters, e.g. velocities, sensor range, ACC off/on, time gap, ACC settings**
8. **Add test manager and set different speed, sensor ranges, …**

Solution

1. Create a 5km straight road, insert route at right lane and set speed limit to 999 km/h
2. Choose DemoCar from examples, add object sensor to the front of the vehicle in the middle of the car, insert ACC in the vehicle control module and make sure you enter the object sensors name (usually OB00). S
3. In the IPG driver settings, turn off the consider traffic option so the ACC can take over and the driver does not intervene
4. Create maneuver, set a constant vehicle speed and put in 5th gear, set an end condition of e.g. 50 seconds
5. Step: Add a traffic vehicle to the simulation, choose a model of your taste and set a speed and turn on constant velocity and put in the same end condition as above

Solution – Test manager

Before using the test manager, save your progress and also save the demo car in your project folder

1. Add the car to the test manager and select the file path under configuration
2. Create group „Approaching Target Maneuvers“
3. Add Test run „Approaching Target“ – Select the test run file you created previously
4. Add variation with parameter NVALUE „ve0“
5. In the test run, edit the maneuver settings -> global settings -> velocity -> „$ve0“
6. Save the project and start the test run from the test manager

www.hs-kempten.de/adrive

Sources

ADAC: https://www.adac.de/rund-ums-fahrzeug/ausstattung-technik-zubehoer/autonomes-fahren/technik-vernetzung/aktuelle-technik/

Winner, Donges: Handbuch Fahrerassistenzsysteme 3. Auflage

Winner, Kühn, Hannawald: Handbuch Fahrerassistenzsysteme 3. Auflage, Verkehrssicherheit und Potenziale von Fahrerassistenzsystemen