All-Weather Capable and ODD Defragmenting Fine Resolution Radar for Automated Driving

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Early Developments of Automotive Radar Systems

Automated Driving on Stress-Test-Parcour in Proving Ground Ehra (1)

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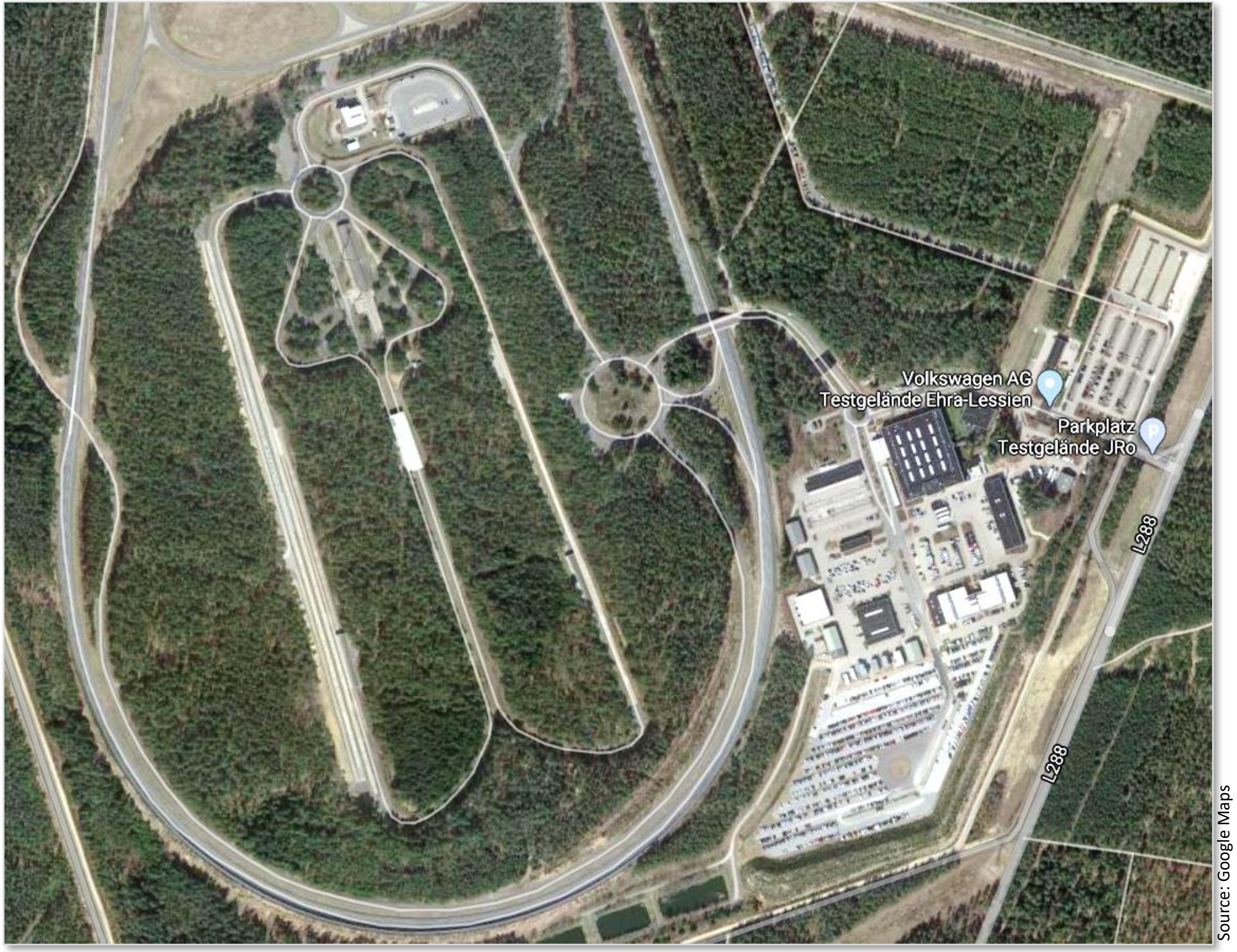
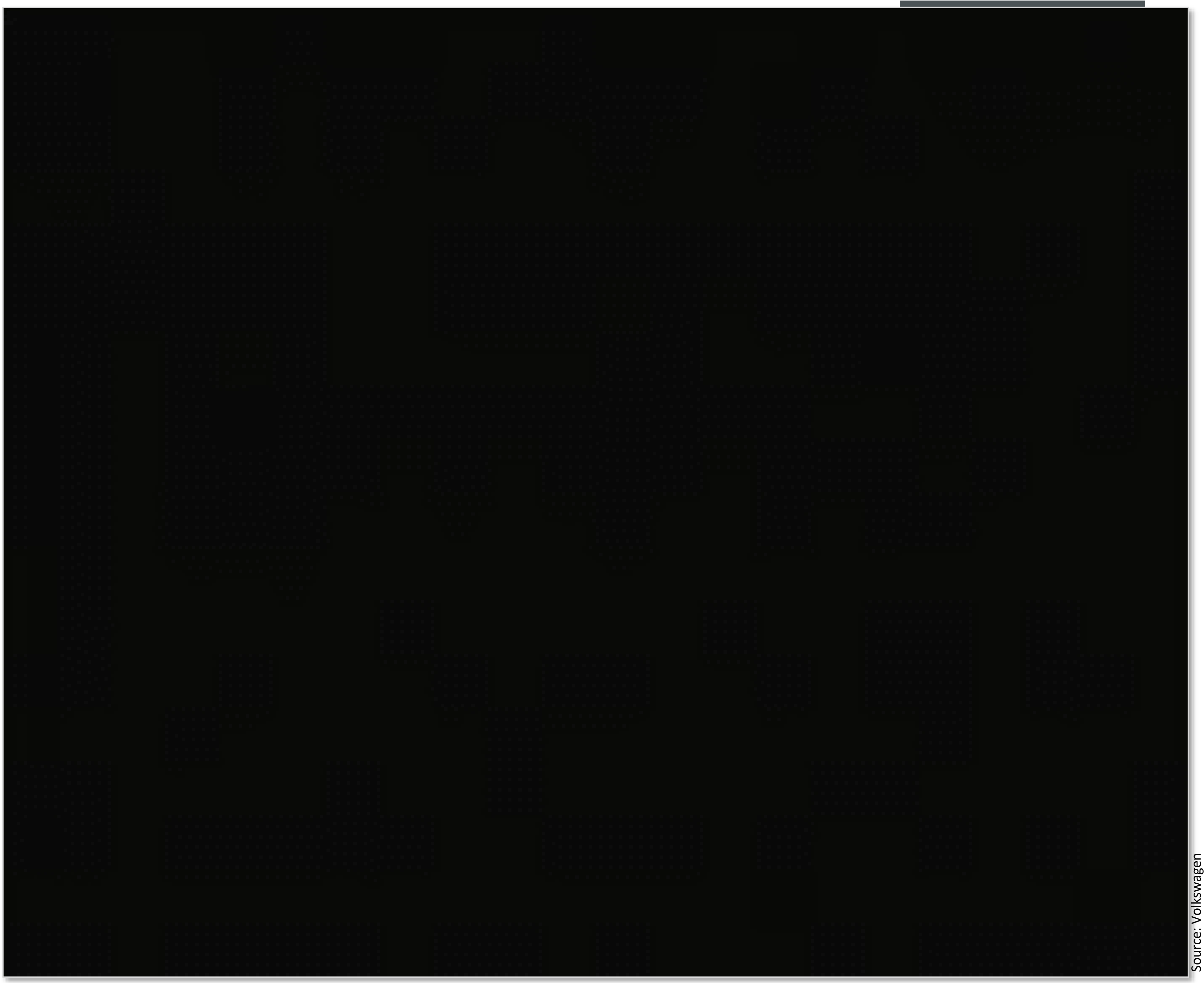
- Volkswagen operates a Proving Ground in Ehra (close to Wolfsburg)
- Prototypical cars are stress-tested in specific parcours consisting of bumpy and curvy road conditions. Mechanical stress applied to prototype is factor 10 higher than under real conditions.
- To reduce test drivers‘ physical load the idea of an automated test was born.



Source: Google Maps

Automated Driving on Stress-Test-Parcour in Proving Ground Ehra (2)

- Exploration project 1998 – 2000 (first project on automated vehicles at Volkswagen)
- Test-driver was replaced by a driving robot
- Localization based on Differential-GPS
- Environmental perception on lidar, camera and radar



Source: Volkswagen

Automated Driving on Stress-Test-Parcour in Proving Ground Ehra (3)

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Challenges:

- Hardware:
  Not existing electronical controllable actuators
  (gas, brake, steering, gearbox)
  made the undertaking challenging

- Perception:
  Signal processing algorithms for cameras and radars
  brought computers to their limits

- Architecture:
  Multi-sensor-system laid foundation
  for modern sensor fusion technology in terms of object fusion strategies

Source: Rhein-Zeitung

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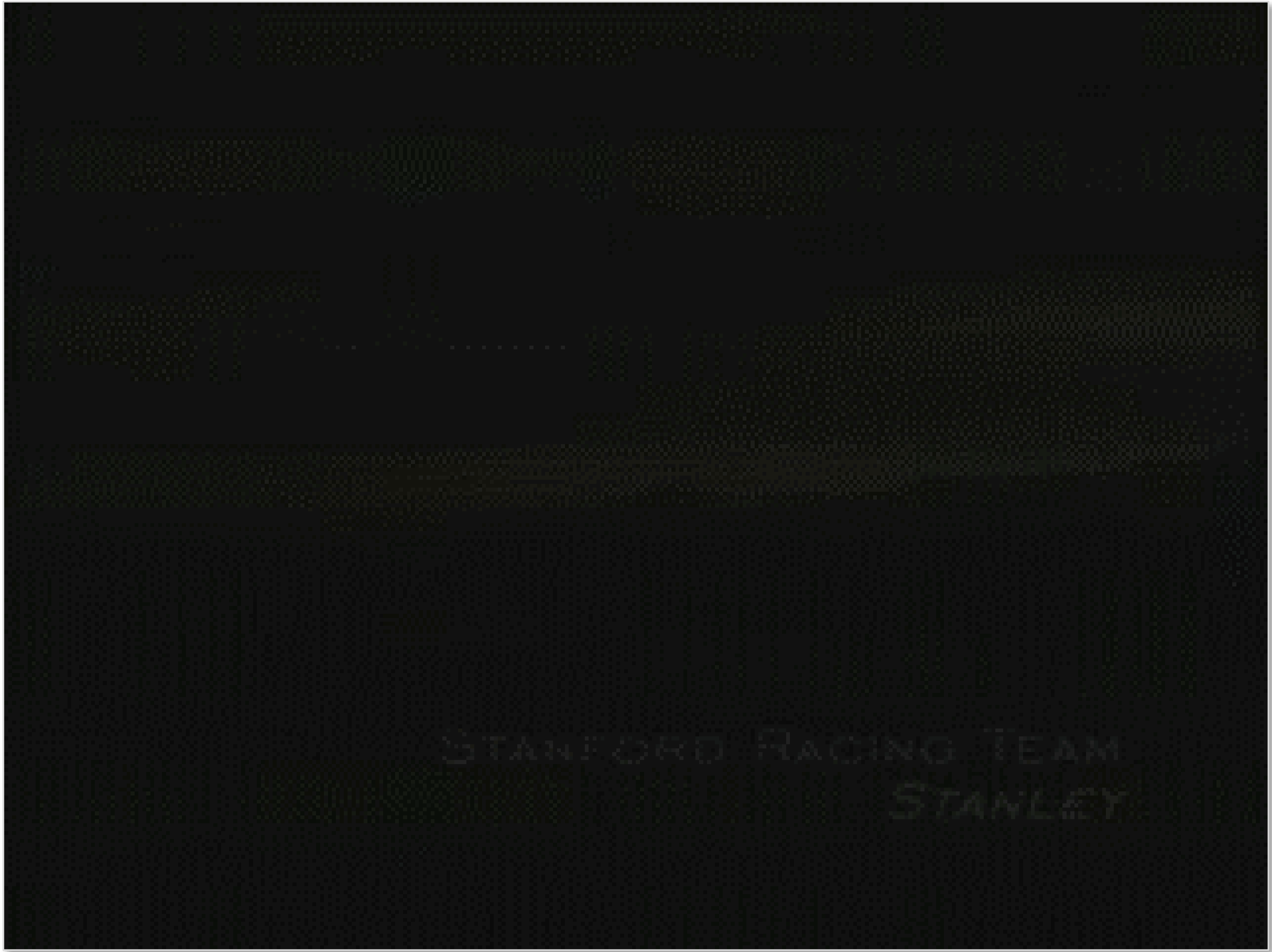
Off-Road Driving during DARPA Grand Challenge, 2005

- Given Challenge:
  - 200 km autonomous race
  - desert environment
  - no map, rough driving corridor info only
- Vehicle:
  Automated Volkswagen Touareg
  equipped with lidar, radar, GPS, camera
- Result:
  Volkswagen won against 200 competing teams



Source: Volkswagen

Automation of Heavy Duty Vehicles in Public Traffic – Traffic Jam Pilot, 2014

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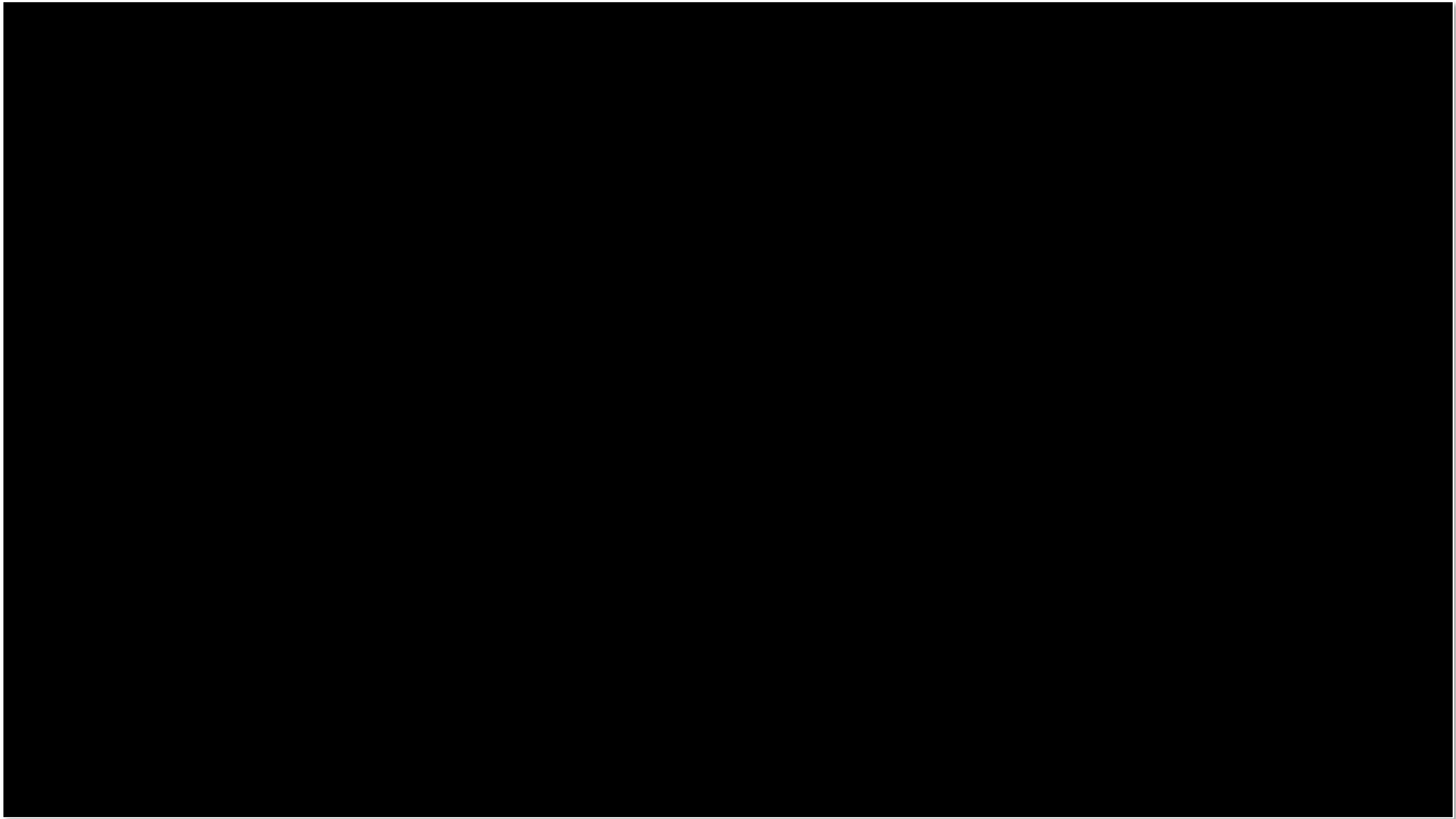
- Automation of a SCANIA truck in traffic jam situations on highways up to speeds of 50 km/h
- Purpose:
  - Reduce workload from truck drivers in traffic jams
  - Prolong legal drive time of a truck per day
- Perception system:
  - 5 radar sensors
  - 10 ultrasonic sensors
  - 1 stereo-camera
  - No digital map
- Actuators:
  - Electronic controlled gas
  - Electronic controlled brake
  - Electronic controlled steering

Source: SCANIA

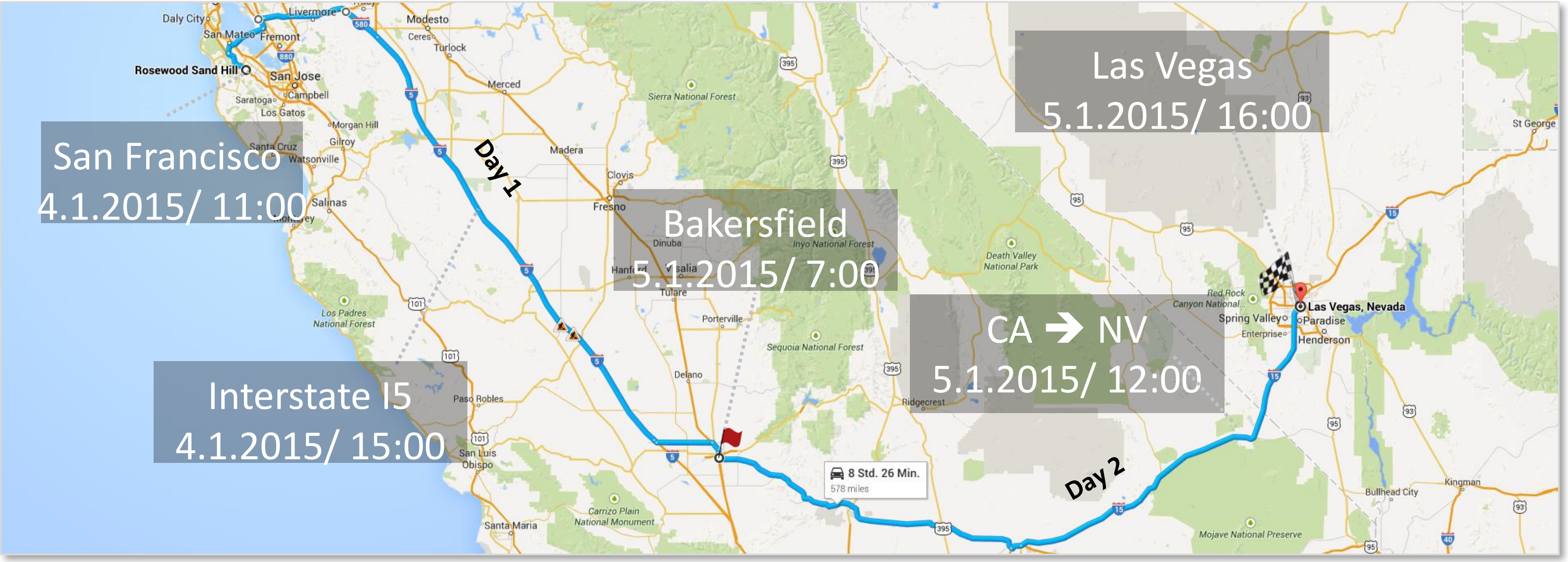
Automation of Heavy Duty Vehicles in Public Traffic – Traffic Jam Pilot, 2014



Source: SCANIA

Autopilot – Automated Driving on Public Highway, 2015

- Demonstration of technology for automated driving under real world conditions, in real traffic
- Route from San Francisco to Las Vegas (~900 km), a 2-day drive
- Journalists seated at driver's seat (accompanied with safety co-driver)



Source: Volkswagen

Automation of Heavy Duty Vehicles in Mining Environment, 2016

- Automation of a SCANIA and MAN trucks in mining environment (off-road)

- Purpose:
  - Reduce workload from truck drivers
  - Operate a mine 24/7

- Perception system:
  - Multiple sensors
  - Occupance grid map
  - Path planner

Source: Volkswagen AG

Example of automized SCANIA Trucks in Rio Tinto Mine/ Australia

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- Automation of tipper in Dampier salt mine in Rio Tinto/ Australia (real customer operation)
- Automated truck follows a salt harvester machine and is being loaded.
  Afterwards the loaded truck drives automatically to an unload station.

Source: SCANIA CV AB

Source: SCANIA CV AB, Rio Tinto

Optimized Vehicle Body for Automation Purposes

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- Former reserved body space for cabin
  is now used to extension of loading volume

- Leads to significant increase in economy and efficiency

Source: SCANIA CV AB

Automated Driving Inner-City 2019, 2021

- Characteristics of inner-city scenarios:
  - Non-structured environment
  - Multiple objects (e. g. Pedestrians, bicyclists)
  - Objects in vicinity to ego vehicle
  - Some traffic participants not sticking to traffic rules (e. g. kindergarten kids, e-scooters)
  - Intersections, traffic lights
  - Curb stones instead of lane markings

- Urban scenario very challenging for perception system

- Automated driving inner-city is king's discipline

Source: Volkswagen AG

Automated Driving Inner-City 2019, 2021

Research Steps in Automotive Radar Technology

- Early research activities in radar technology in 1974 (integrated in VW Golf I) based on RF waveguides, parabola antenna, analogue computing
- Development of a 77 GHz radar by Volkswagen, Rockwell, TU Braunschweig (based on waveguides) in 1995 – 1997
- First series radars introduced in Audi A8 and VW Phaeton around millennium
- Since ~12 years all cars inside Volkswagen Group are equipped with at least 1 front radar


Source: Volkswagen

Source: TU Braunschweig

Source: Volkswagen

Task of the Day

Task of the Day – Defragmentation of the Operational Design Domain (ODD)

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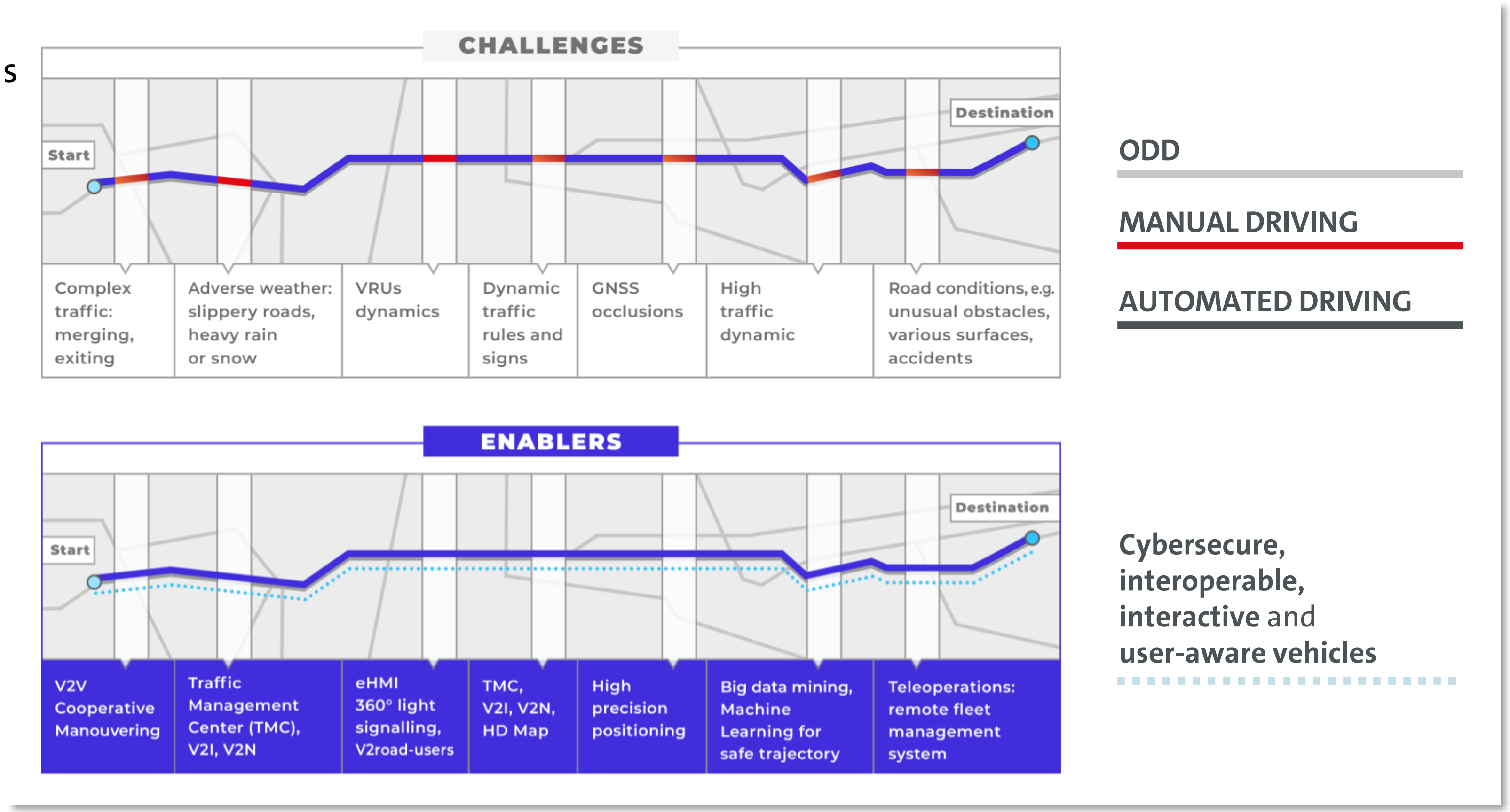
- Decreasing
  ODD (Operational Design Domain) fragmentations
  for L3 - L5

- Strengthen perception system
  by less fragmented sensor sources
  (e. g. radar)

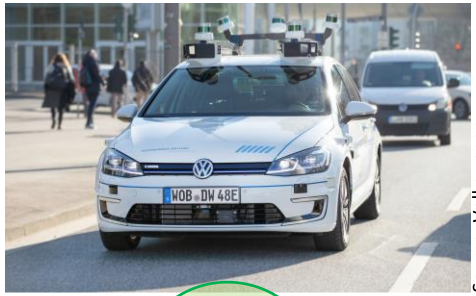
- Possible improvements
  in novel radar technology
  – Angular resolution of 0.1°



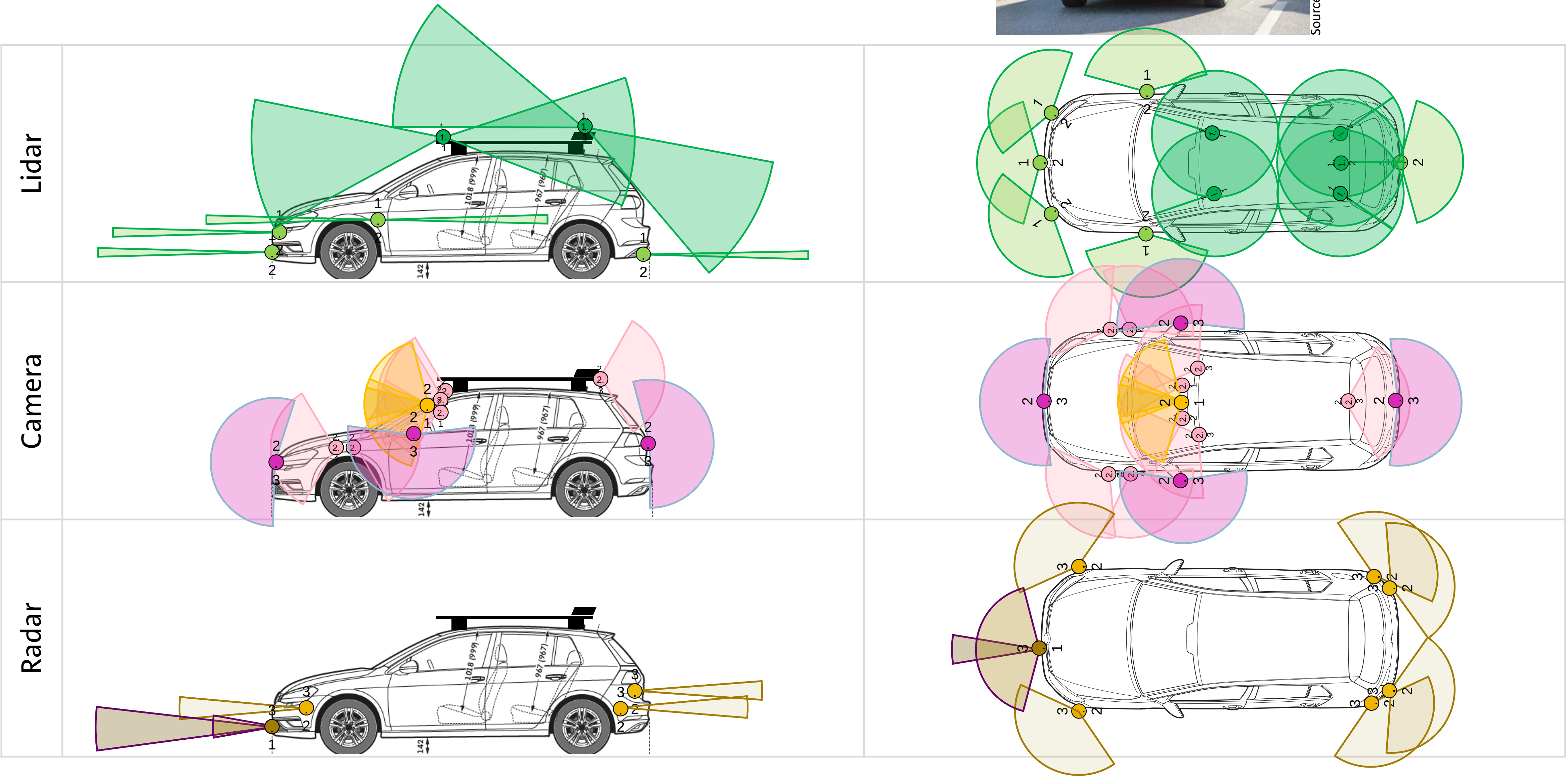
Source: HiDrive

Example of a Perception System for Inner-City Operation

- Environmental recognition in urban scenarios requires all modalities of sensors.



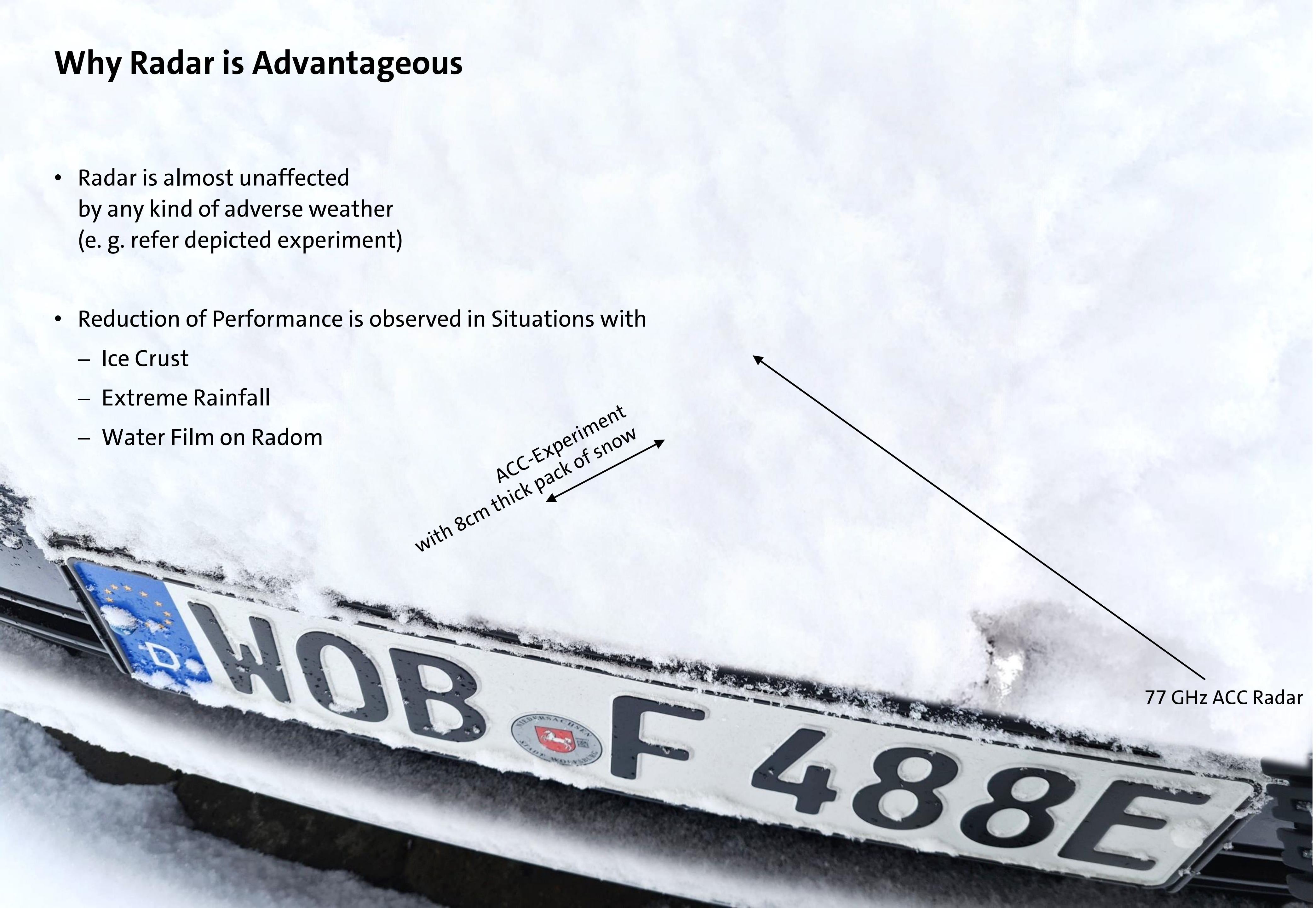
Source: Volkswagen



Why Radar is Advantageous

- Radar is almost unaffected by any kind of adverse weather (e. g. refer depicted experiment)

- Reduction of Performance is observed in Situations with
  - Ice Crust
  - Extreme Rainfall
  - Water Film on Radom



Angular Resolution Matters

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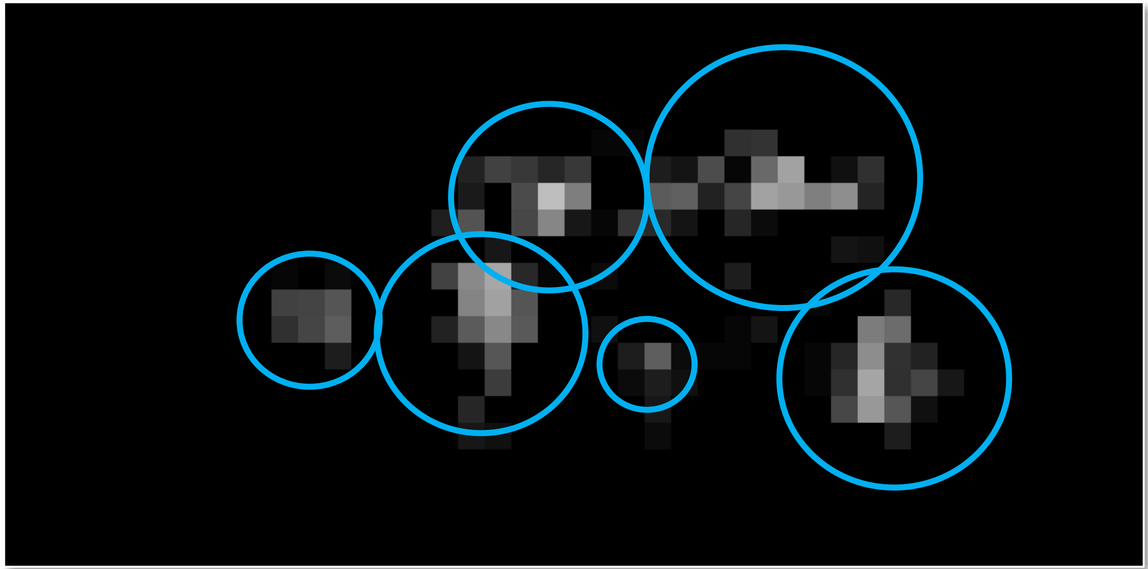
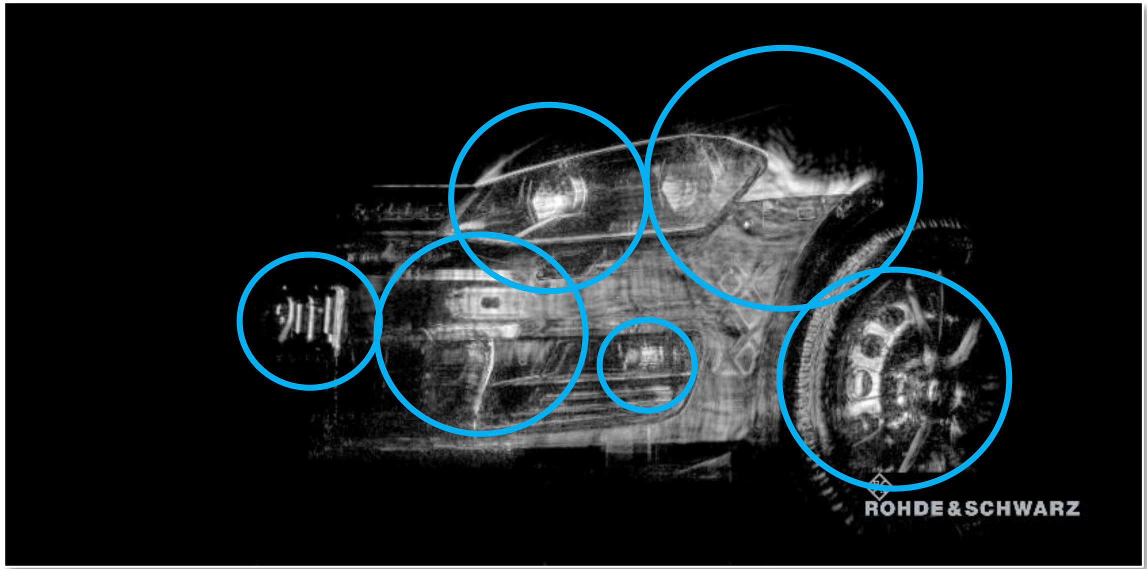


Low Resolution Radar Image (77 GHz)



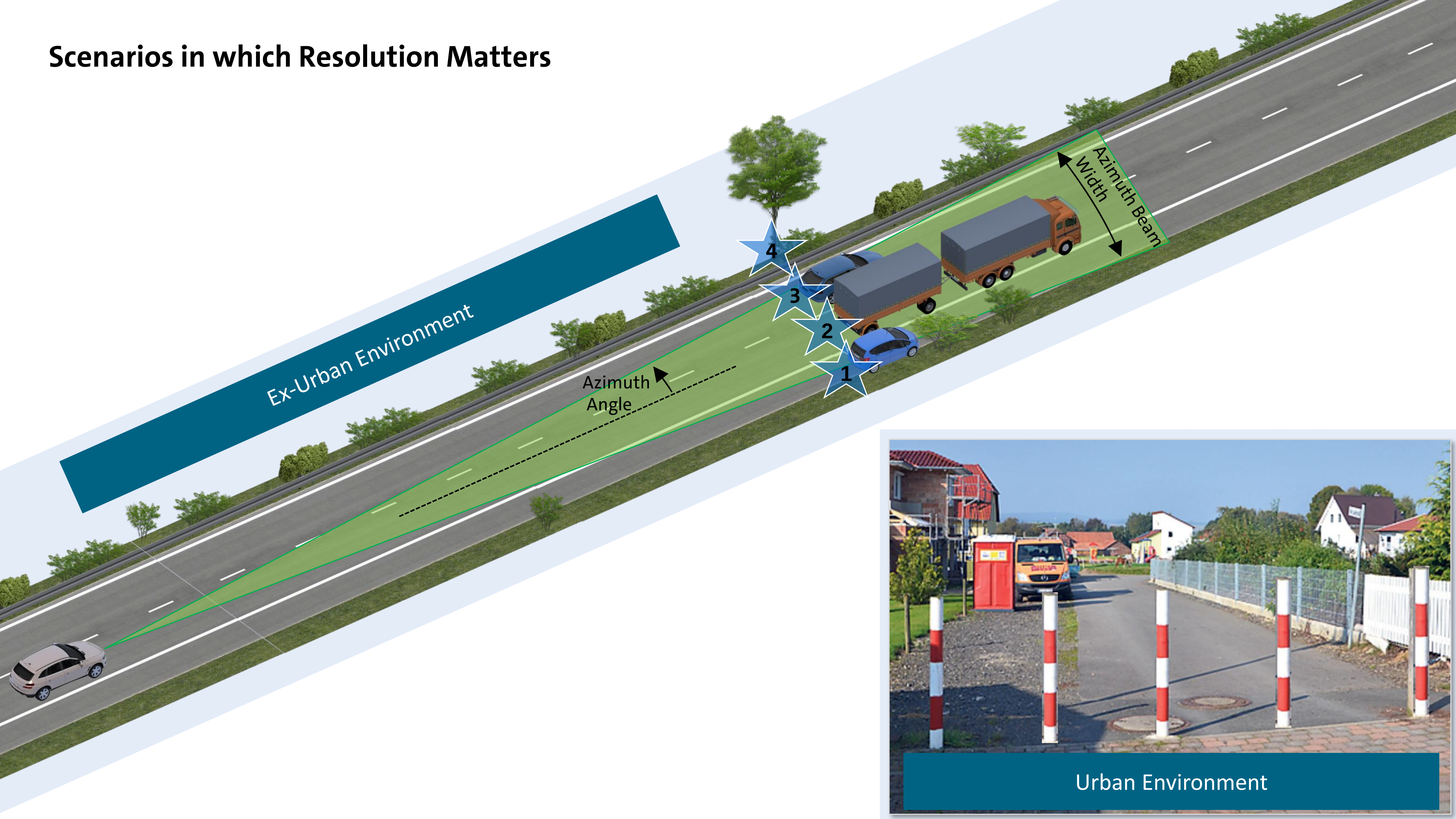
Fine Resolution Radar Image (77 GHz)

Source: Dr. S. Heuel, Rohde & Schwarz

- Fine angular resolution is beneficial for imaging radar of next generation in automated driving functions (L4, L5)

Idea of Distributed Antennas to Enable Automated Driving (Level L4, L5)

Scenarios in which Resolution Matters



Coherent Distributed Radar

- Automated driving requires extremely reliable environmental perception system
- Real angular resolution can be guaranteed by large antenna aperture only (approach follows well-known physical relations)
- Physical relation between angular resolution $\Delta\theta$ and antenna aperture D is given by

$$\Delta\theta = arcsin\left(\underbrace{0.5}_{\substack{\uparrow \\ \text{MIMO}}} \cdot 1.22 \cdot \frac{\lambda}{D}\right)$$

- A large aperture D is required.
  This antenna has to be coherent.
  It might be curved.
  It might be a sparse array.

Coherent Distributed Radar - Concept

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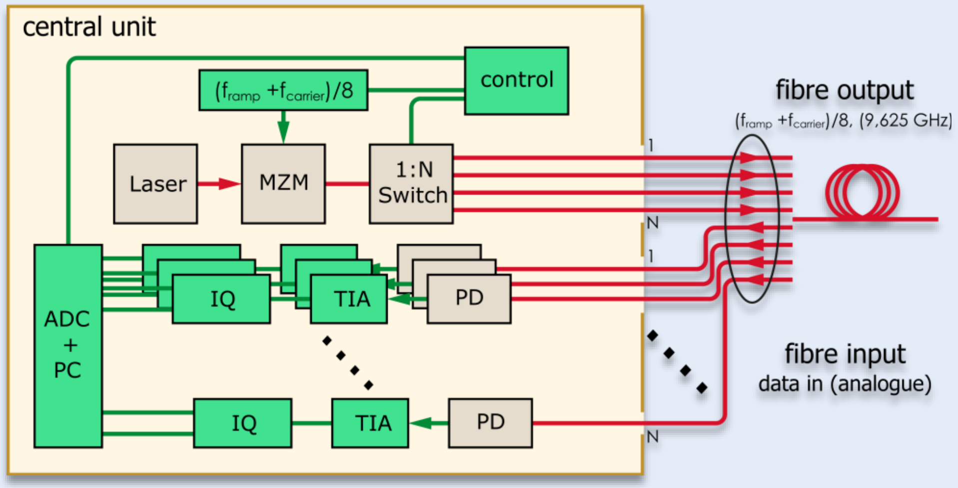
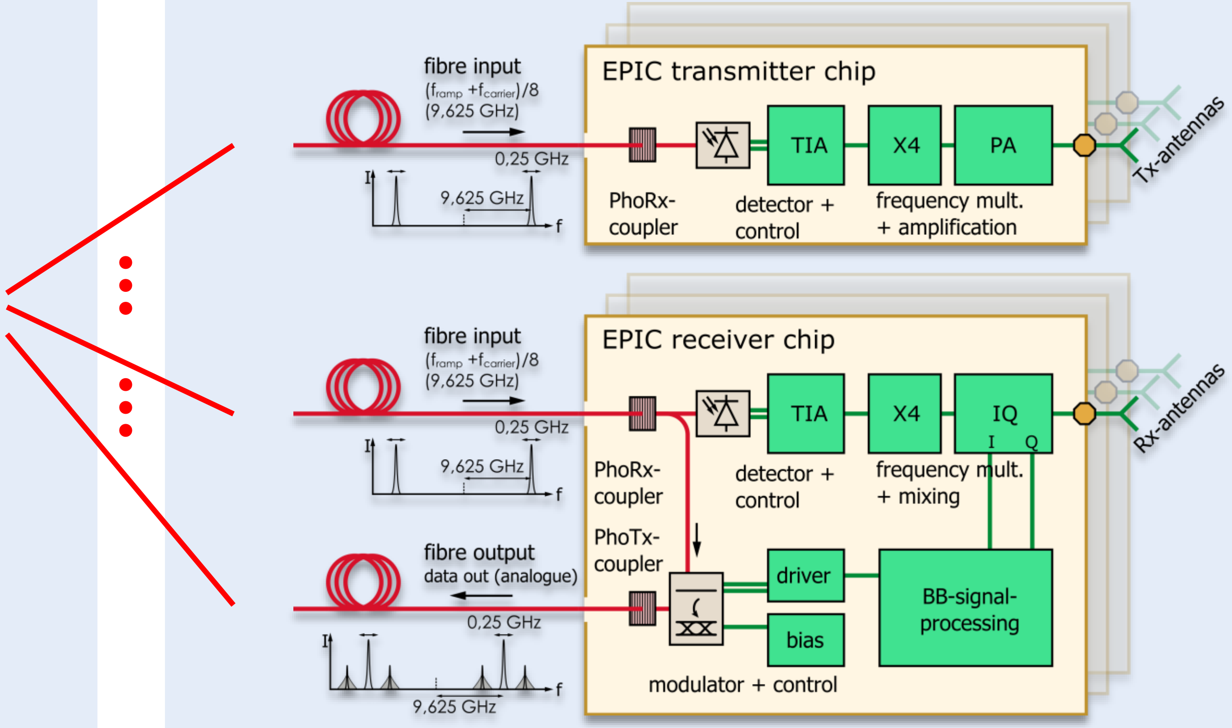
Signal Generation and Processing



- Optical carrier
- Modulation of chirp sequence with 77GHz/8

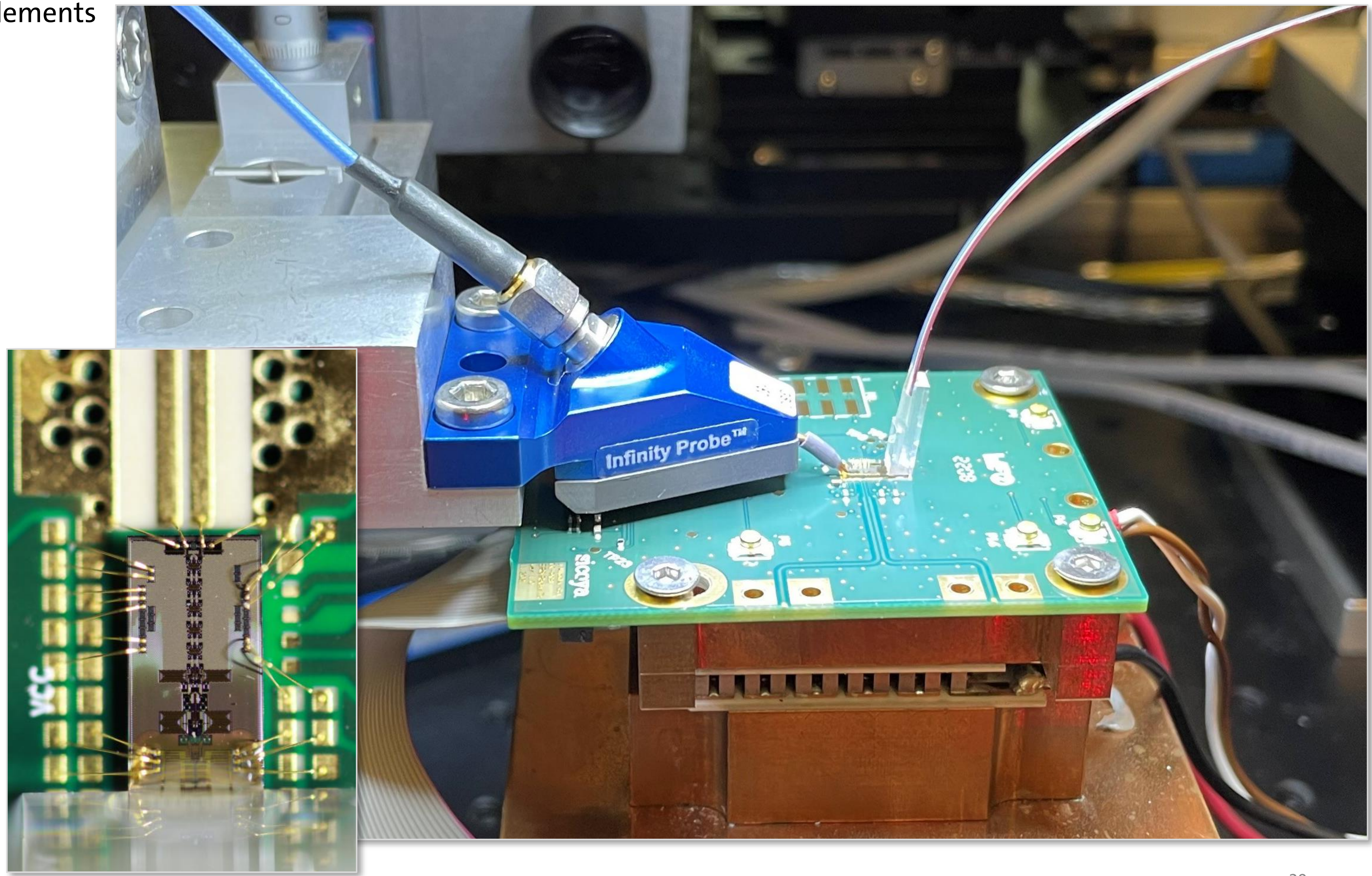
Rx / Tx Antennas



- Frequency octiplation on the chip
- Signal transfer via fiber

Coherent Distributed Radar – Electronic Photonic Integrated Circuits

- Coherency among distributed antenna elements is guaranteed by **optical links**
- Integration of both,
  electronical as well as photonical circuits
  in a combined chip (**EPIC**)
  enables coherent radar systems



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Summary and Outlook

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- Automation of vehicles is a dream since decades.
- Radar sensors play an essential role in the sensor set for an automated vehicle
- Distributed coherent radars have the potential to increase robustness of automated vehicle