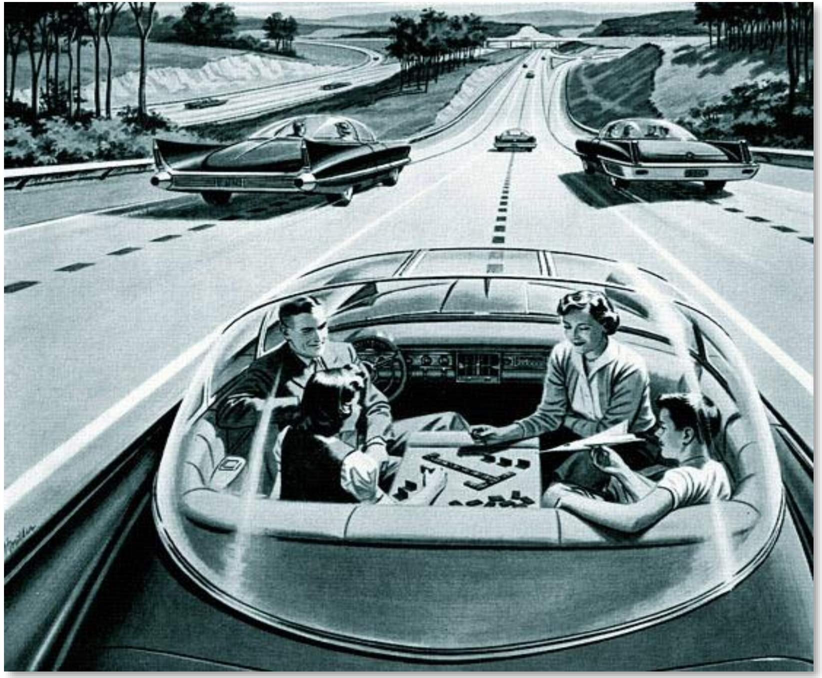
embedded VISION SUMMIT 2018

Understanding Automotive Radar: Present & Future

Arunesh Roy

23 May, 2018

Self Driving Cars
The idea is nothing new…



1956 → **2018**

60+ years and now we are ready…

Agenda

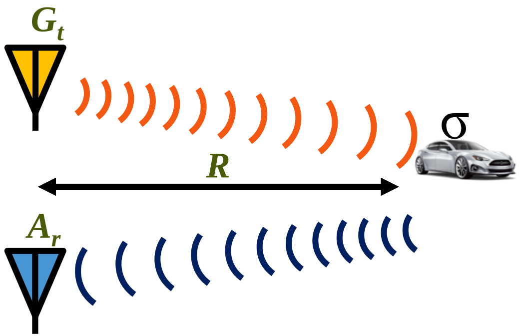
- Automotive radar as it currently exists
  - Radar Basics
  - Relevance to Automobiles
- Future of Automotive Radar
- Radar vs. Vision
  - Roadmap to a safer autonomous vehicle
  - A complement to vision-based sensors
  - Planned sensor architectures for vehicles (L3-L4/5)
- Closing Thoughts

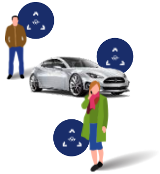
Automotive Radar:
Basics & Relevance to the Autonomous Vehicle

RADAR Basics

RADAR (RAdio Detection And Ranging)

- What is a radar?
  - Transmit a radio signal toward a possible target
  - Some of the radio signal energy that hits the target will return



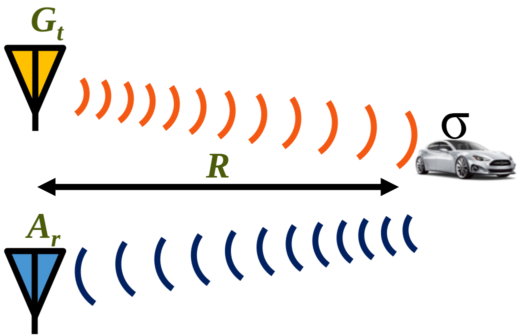


  - Receive the return signal
  - The time delay between the transmitted signal and the received signal gives target range information

RADAR Basics

RADAR (RAdio Detection And Ranging)

- For a target 100 meters away, the time delay is doubled because the signal must travel 100 meters to the target and return 100 meters



  - Target at 100 meters => 666 nanosecond travel time
- The term commonly used is “radio signal” and can take many forms
  - Pulsed
  - Continuous wave

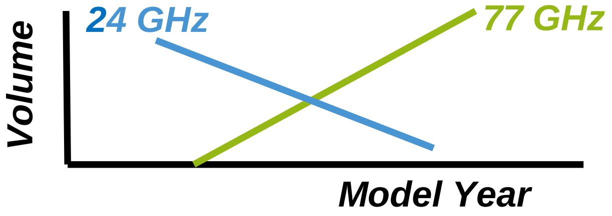
Automotive Radar Technology

Industry standardizations & regulations…

- Measurement Concept – FMCW (Frequency Modulated Continuous Wave)

- Carrier Frequency
  - 24 GHz
  - 77 GHz

TREND

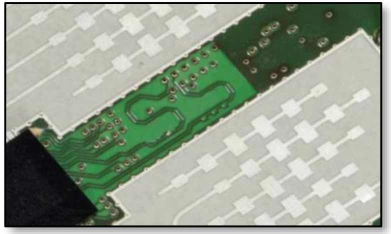


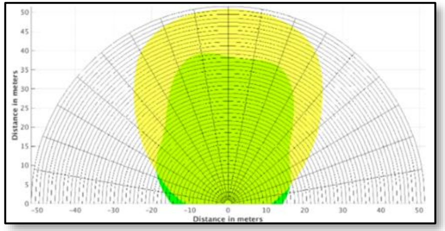
- RF Power
  - Output power limit regulated (ex: 10mW in Japan)
  - Automotive radar range (<60m: SRR, 60-150m MRR, >150m LRR)

Automotive Radar Technology

Industry standardizations & regulations…

- Antennas – Patch antennas on PCB *(printed circuit board)*
  - Patch antennas have enabled more cost-effective solutions
  - Design provides a directional beam with side lobes (not shown below)





- Electronic Components
  - Two IC packages or one IC package for primary functionality
  - Plus support components (power supply, communications, EMC, etc.)
  - System complexity reduction = costs savings (Gen1 ~ $1K, Gen4 ~ <$50)

Automotive Radar Technology Today

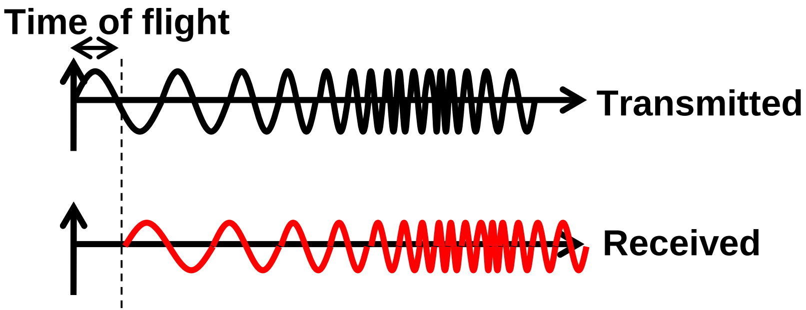
- Automotive Radar Technology today enables:
  - ACC (Autonomous Cruise Control)
    - Long range radar systems (>150m)
    - Calculate 1) distance, 2) relative radial velocity and 3) angle of target
    - More advanced functions tracking of targets
    - Advanced systems today use MIMO for improved angle of target
  - BSD (Blind Spot Detection)
    - Short to mid-range radar systems (40-90m)
    - Identify "targets"
  - Other automotive applications using radar
    - Auto Emergency Braking (AEB)
    - Junction Assist (JA)
    - Cross Traffic Assist (CTA)

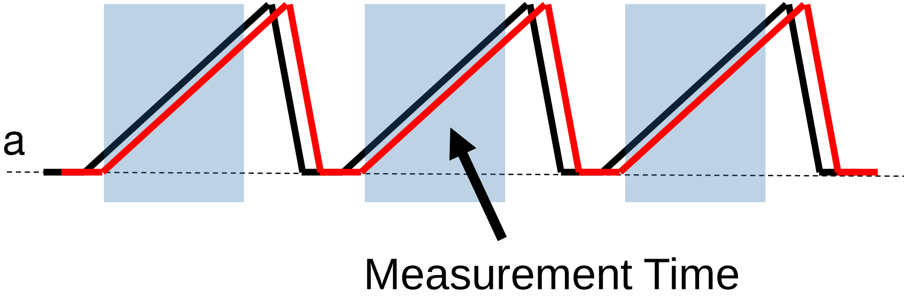
What Can Radar Do for Autonomous Vehicles?

- Radar is an active sensor providing 4-dimensional attributes
  - **Range**
    - Maximum detection range, range resolution
  - **Velocity/Doppler**
    - Maximum detection velocity, velocity resolution
  - **Angular/Azimuth**
    - Angle Resolution
  - **Elevation**
- Single dimension optimizations can lead to trade-offs in others

Range & Doppler Measurements

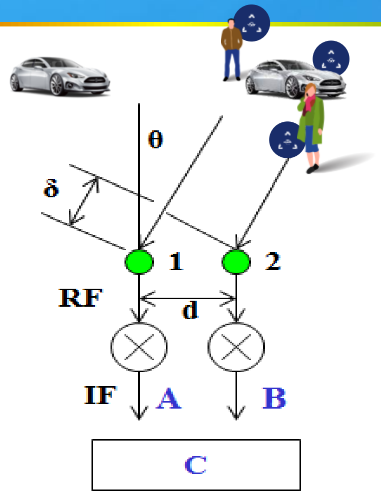
- **Range Measurement**
  - Return signal has the same shape, but is delayed by the round-trip travel time, the “time of flight.”
  - < 4 cm resolution achievable at short range
  - Range >200m (<1m resolution)
- **Doppler Measurement**
  - The typical radar algorithm measures the target radial velocity using multiple chirps.
    - The chirp period is short enough such that the target only moves fractions of a wavelength from chirp to chirp.
    - Example: At ~77 GHz, the wavelength is ~3.9 mm





Azimuth & Elevation Measurements

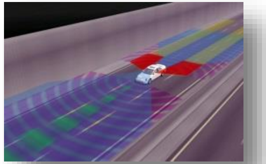
- **Azimuth (Angle)**
  - Multiple Rx channels can be used to improve angular resolution
  - Path length difference leads to phase shift of received signals
  - Measured phase shifts are used to calculate the “angle of arrival” of the received signal
- **Elevation (Angle)**
  - Elevation measurements taken in more advanced schemes
  - Typically the 3rd TX channel is used for elevation scans
  - Direction of arrival is calculated



Today’s Automotive Radar Benefits & Limitations

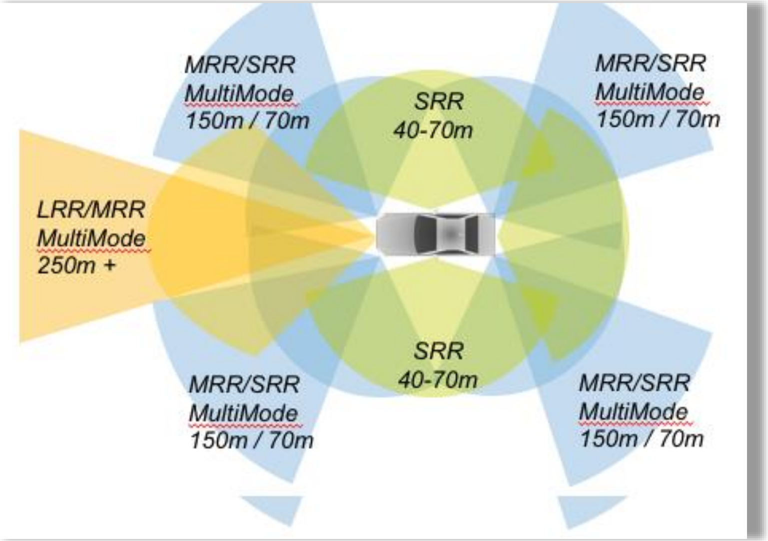
- **Radar in Automotive Benefits**
  - Range & Doppler measurement inherent in technology
  - System costs reducing leading to an increase in the attach rate

- **Today’s Limitations**
  - Resolution in radar (little classification)
  - Module size & location requirements
  - Cost (compared to ultra sonic technologies)
  - System thermal management

	Range	Cost	Module Size
RADAR 	✓	✗	✗
Vision 	✗	✓	✓

Future of Automotive Radar: What’s possible?

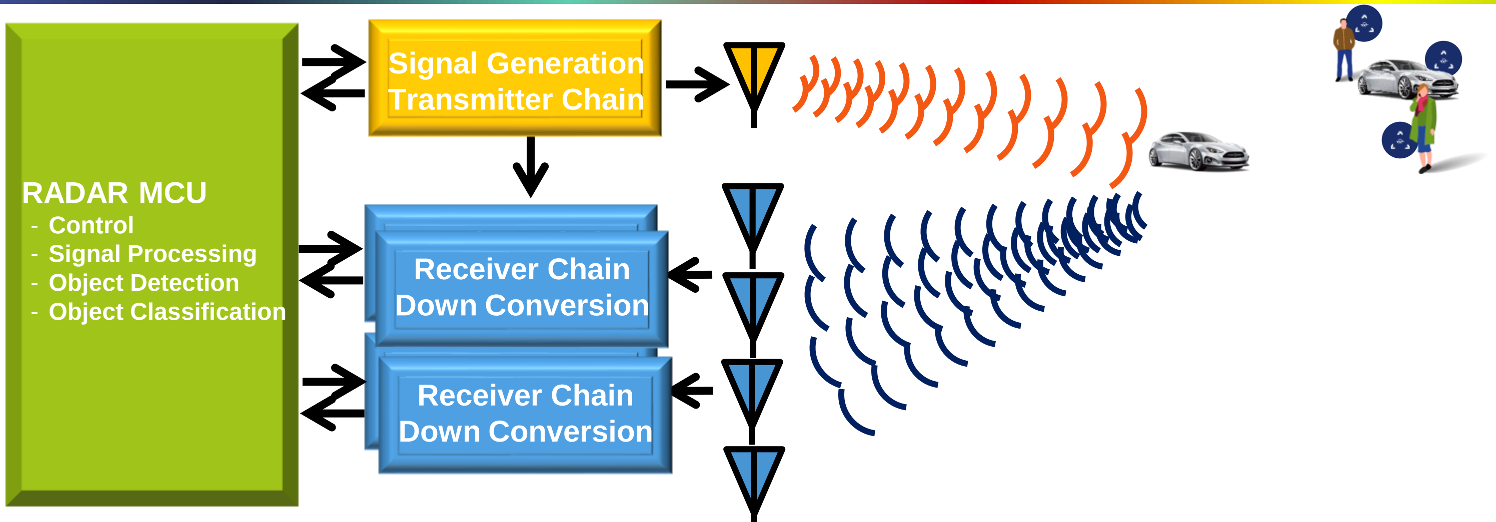
Automotive Radar – Higher Resolution?



- Quest for higher resolution
  - Highway autopilot limitations today
  - Driving higher requirements tomorrow
    - Obstacle detection (>300m)
    - Obstacle size (soda can)
  - Higher requirement for angular resolution
  - Optimizing for maximum detection range & higher range resolution
- System optimizations in one dimension can lead to trade-offs in others.
- Multiple sensor types may be required

Improving Automotive Radar Resolution

Improved angular resolution



- Multiple Rx channels can be used to improve angular resolution:
  - Path length difference leads to phase shift of received signals
  - Measured phase shifts used to calculate the “angle of arrival”
- Comparison to other sensor types (cost competitive with <2º resolution)

Higher Resolution: Automotive RADAR Processing

Higher levels of computation requirements

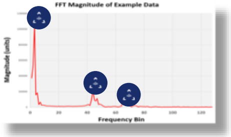
MMIC → | ← High Performance MCU →

Rx → **Signal conditioning** → **Signal analysis** → **Detection** → **Tracking**

- Antenna
- Mixer

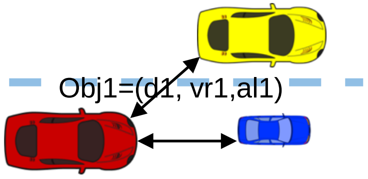
- LNA
- HP/LPF
- AAF
- ADC

Range FFT → **Doppler FFT** → **MIMO & Beamforming** → **Adv Functions Thresholding (ex CFAR), 3D Interpolation** → **DOA Super Resolution (e.g., MUSIC, ESPRIT)** → **Tracking (e.g., Kalman + Munkres)**



Detection

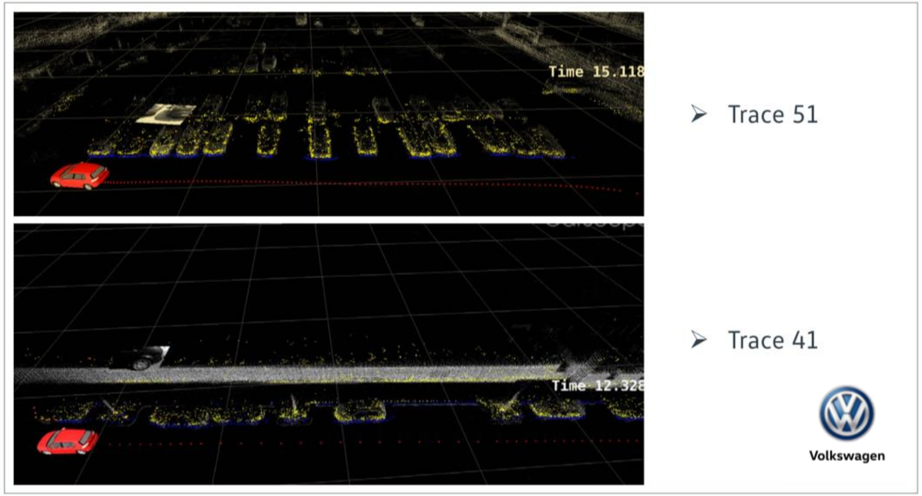
3 Targets
- **~0.5m**
- **~7.0m**
- **~10.5m**

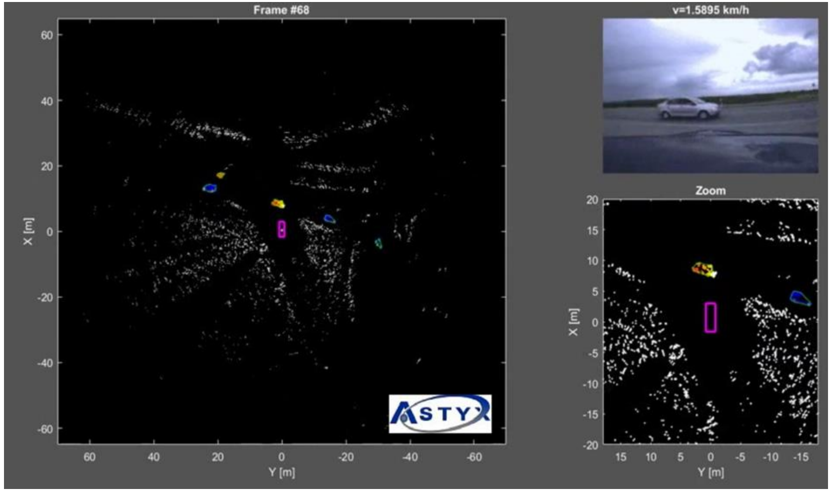


Obj2=(d2, vr2, al2)

- Improving resolution, particularly angular resolution requires higher signal analysis & detection enabling higher levels of classification & detection

Future of Automotive Radar: High Resolution



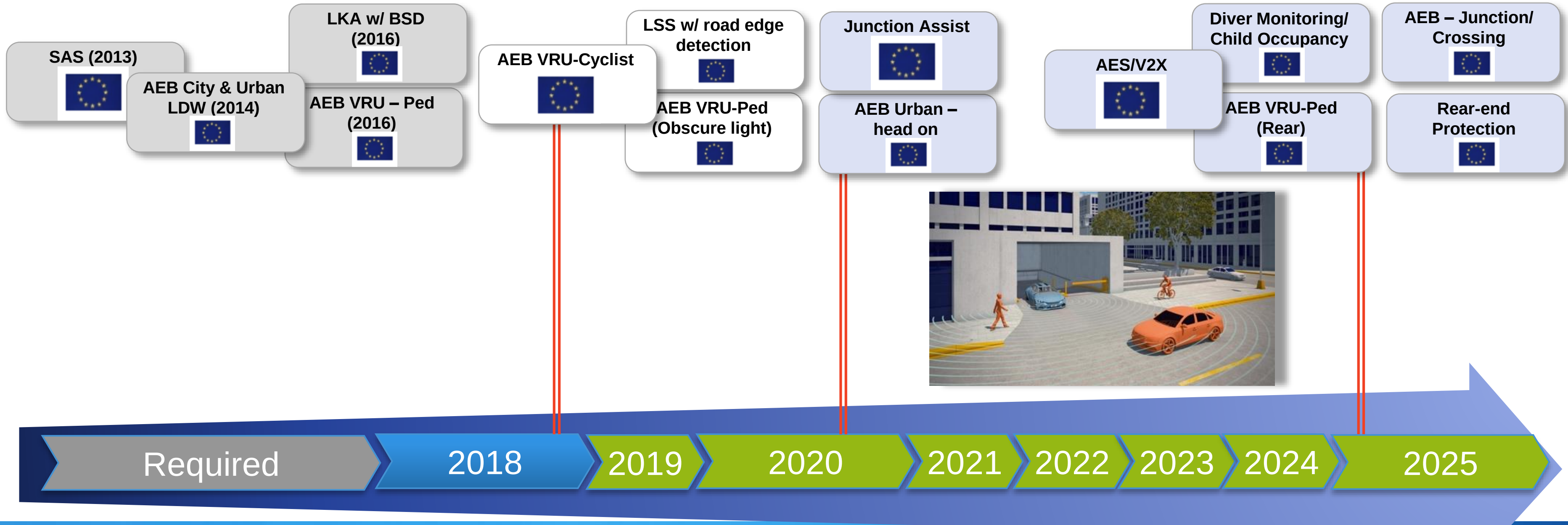


- High resolution radar systems: Enabling localization & mapping for system redundancy

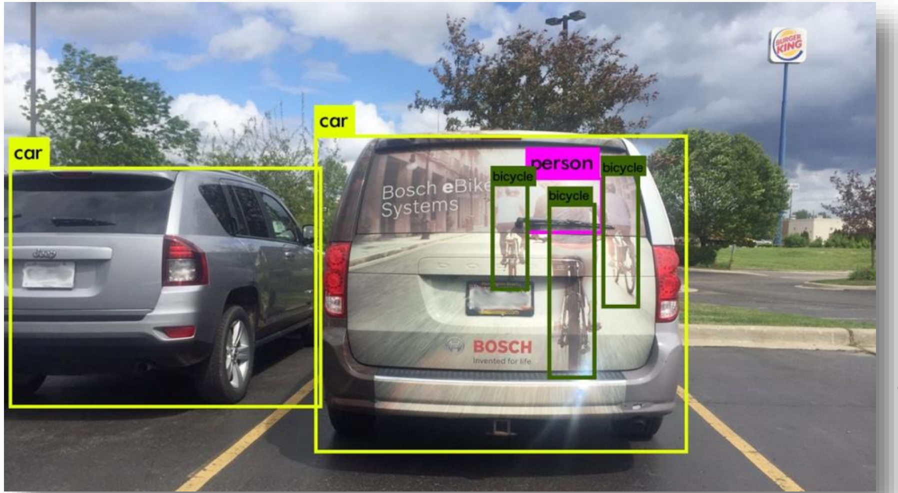
Radar vs. Vision: The road to Autonomy

The eNCAP Roadmap
Building blocks for the Autonomous Vehicle

- Vison & radar sensors are used in all of these functions
  - When should we use radar, vision or both?



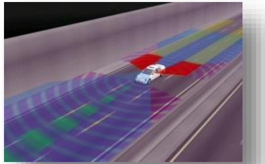
Single-sensor dependence & autonomous vehicle



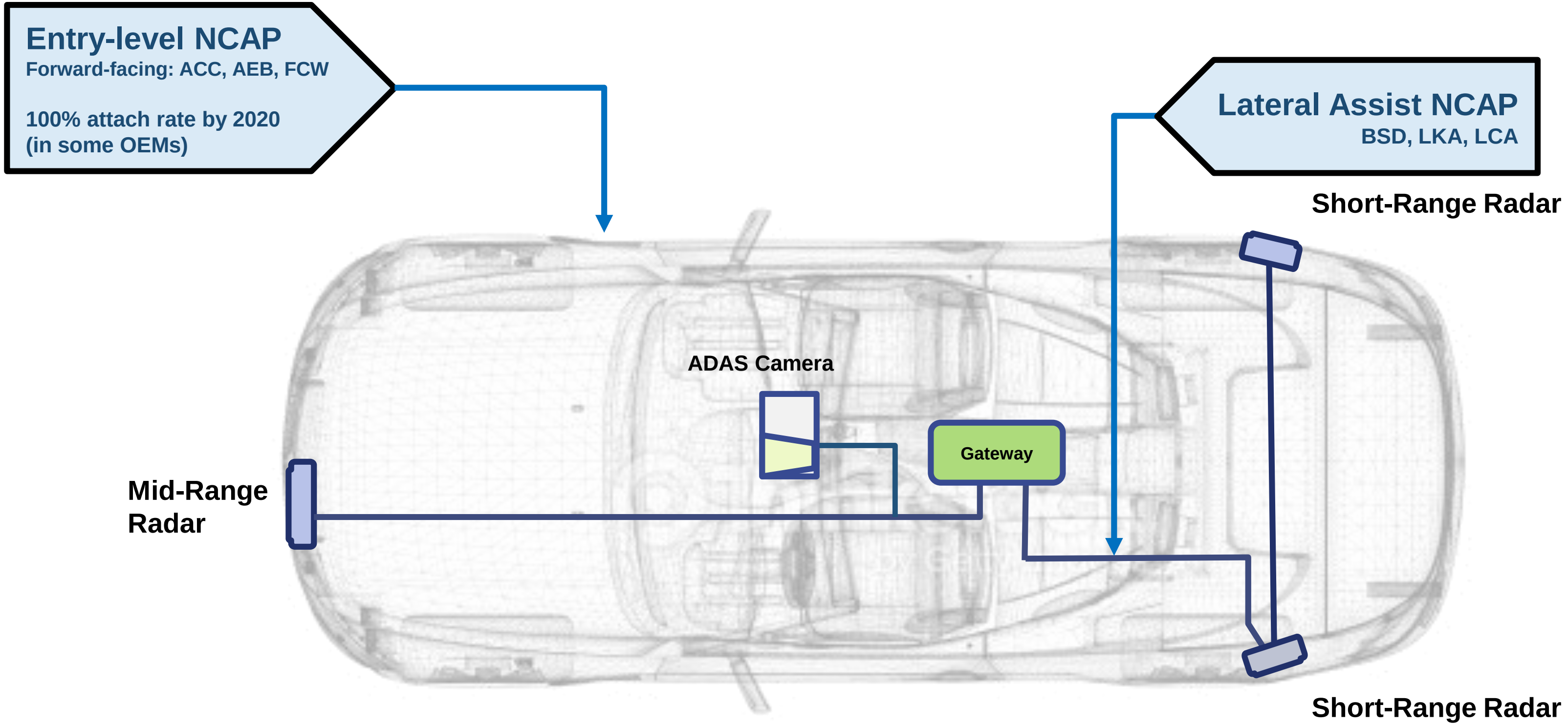
- Single-sensor dependence
  - Dangerous
  - Lack of redundancy
  - Misleading inputs leading to incorrect conclusions
- Exploit positive sensor attributes
  - Complimentary sensor technologies
  - Enable higher performance central processing solving sensor contention

Vision & Radar: Complimentary Sensors

- Vision Attributes (Automotive)
  - High Resolution
  - Color/Optical Recognition
  - Classification
  - Environmental Challenges
  - Social (Driver Monitor)
- Radar Attributes (Automotive)
  - Range & Doppler (Low CPU)
  - All Weather Sensor
  - Detection & Tracking
  - Lack of Resolution

	All Weather	Classify Objects	Resolution	Industry Adoption
Radar 	✓	✓	✗	✓
Vision 	✗	✓	✓	✓

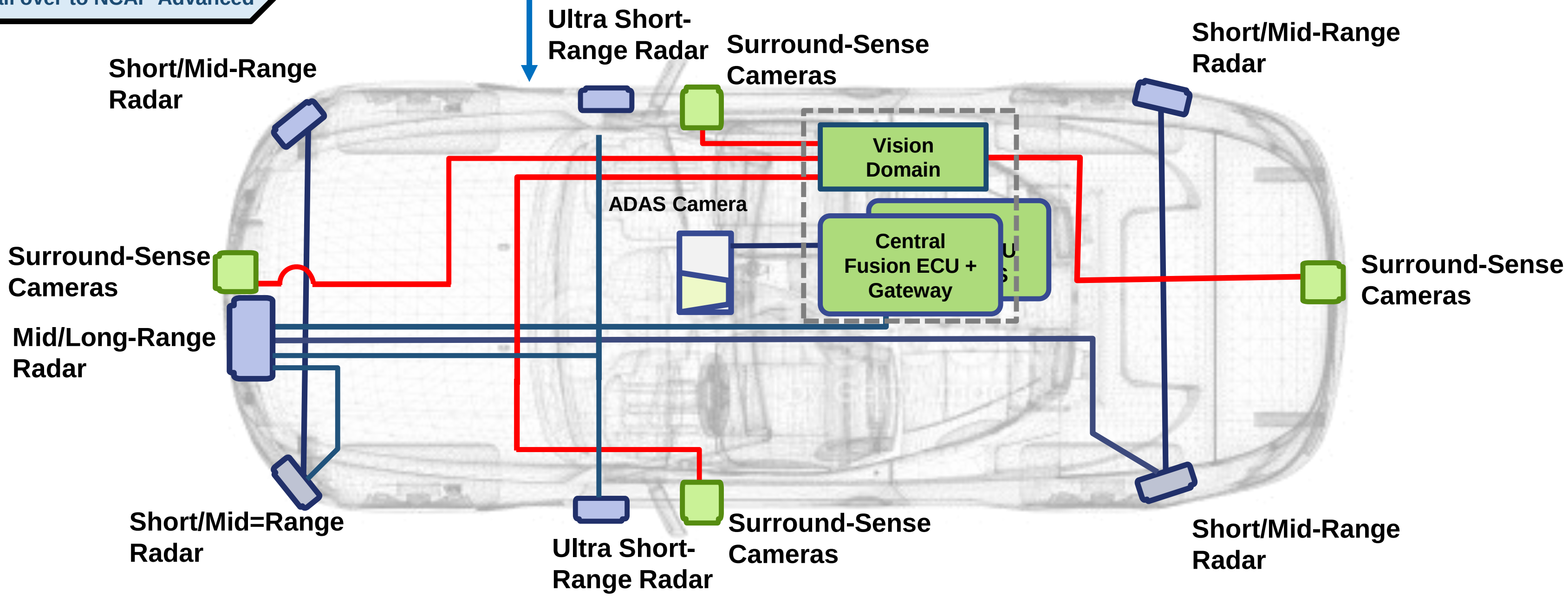
Typical Vehicle Architecture Today (L0/L1)



Planned Vehicle Architecture in 2020 (L3/L4)

L3/L4: w/ fail-over

Highway Pilot, Traffic Jam Pilot, Parking Pilot,
Fail over to NCAP Advanced



Safety in the Autonomous Vehicle

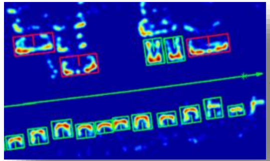
High Resolution Radar & Vision – complimentary sensors

Radar

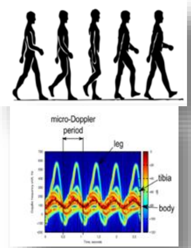
Vision

As resolution with radar improves, we enable a redundant, safer vehicle architecture

Mapping



Classification



High Resolution RADAR **Vision**

Closing Thoughts

- Autonomous vehicle will not have a single sensor type
- Radar provides key attributes to the future of the autonomous vehicle
- Vison & radar are complimentary
- Further industry improvements will enable:
  - Higher performance systems
  - Redundancy leading to safer systems
- High resolution radar & vision sensors will continue to play a vital role