Automotive Radar Technology Trends

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Connecting Minds. Exchanging Ideas.

Outline

- Radar Market
- Roadmap
- State of the Art
- Technology Trends
- Outlook
- Conclusion

Market Drivers

Legislation & Regulation

- EuroNCAP[+] requires pedestrian projection from 2016 on
- NA NCAP[●] & JNCAP[★]: showing clear hints to ADAS[♦], e.g. @ safecar.org
- EU: LDW[Δ] & emergency brake assist mandatory for HDV*

Availability DA Functions

- Low Speed Active Braking and Collision Warning already standard in some cars
- Active Pedestrian protection
- Democratization of DA functions (availability in compact segment)

Consumer

- Consumer surveys indicating willingness to buy
- EuroNCAP[+] advanced and consumer tests (e.g. ADAC[X]) raise end-consumer awareness

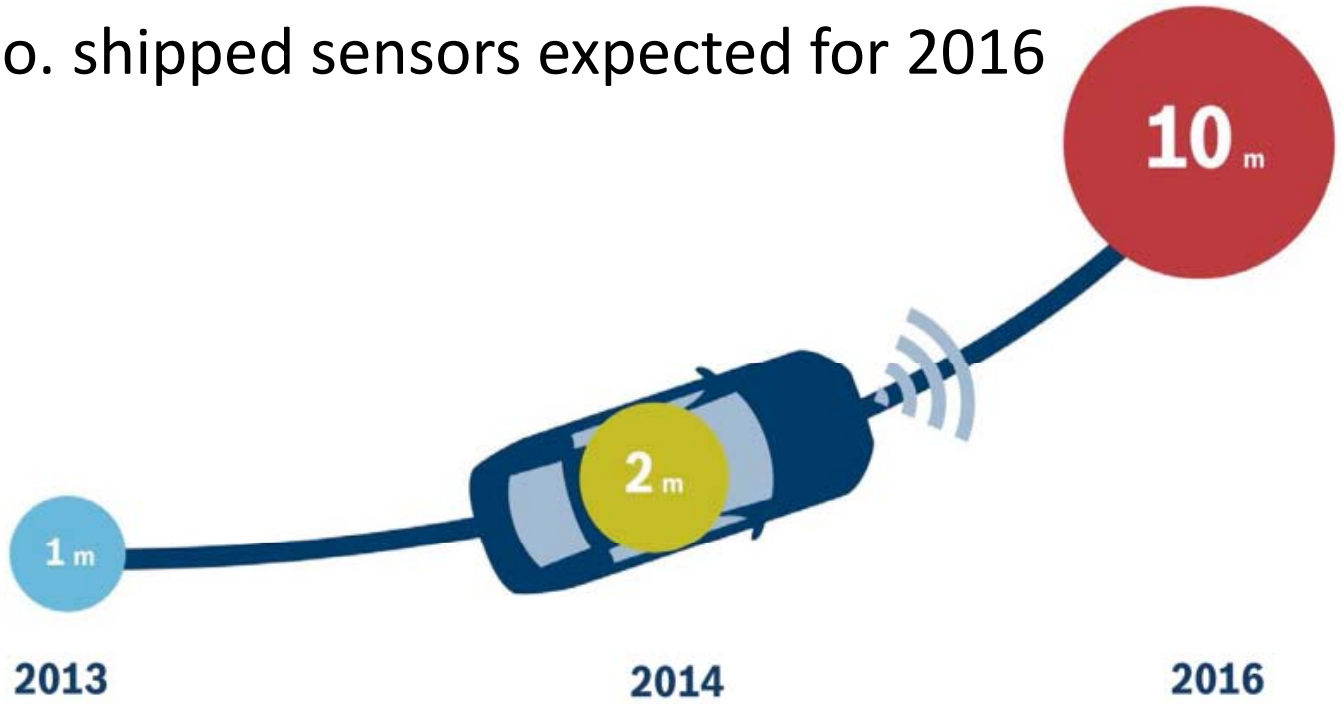
Technology

- Radar and video dominating but no dedicated sensor concept yet as standard settled
- Need for sensor data fusion
- Cost/benefit ratio major focus

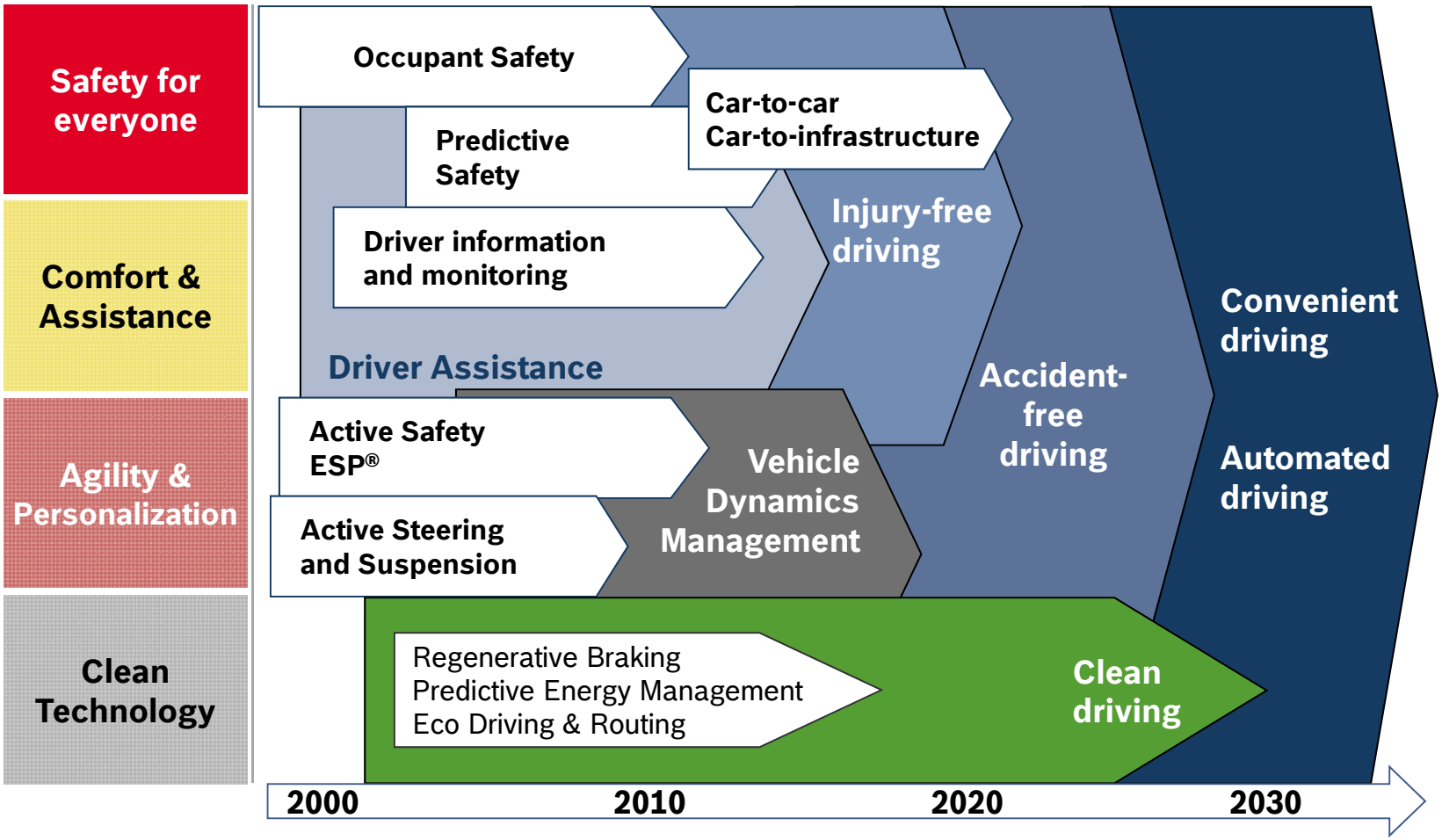
[+] European New Car Assessment Program, *Heavy Duty Vehicle, [Δ] Lane Departure Warning
[x] Active Driver Assistance System, [♦] Allgemeiner Deutsche Automobil-Club
[●] North American New Car Assessment Program , [★]Japan New Car Assessment Program

Market

- 1 Mio. 77 GHz sensors shipped from 2000-2012
- 1 Mio. 77 GHz sensors shipped in 2013
- 10 Mio. shipped sensors expected for 2016



Roadmap


Safety for everyone
Comfort & Assistance
Agility & Personalization
Clean Technology
Occupant Safety
Predictive Safety
Car-to-car
Car-to-infrastructure
Driver information and monitoring
Injury-free driving
Driver Assistance
Active Safety ESP®
Active Steering and Suspension
Vehicle Dynamics Management
Accident-free driving
Convenient driving
Automated driving
Regenerative Braking
Predictive Energy Management
Eco Driving & Routing
Clean driving
2000
2010
2020
2030

State of the Art

LRR3 (2009)

MRR (2013)

MRR rear/corner (2014)

LRR4 (2015)

- **LRR3:** First SiGe chip at 77 GHz
- **MRR:** First 77 GHz sensor realized fully in SMD technology
- **MRR rear/corner:** First 77 GHz sensor for rear/corner operation and covered integration
- **LRR4:** Updated technology for lower cost, additional elevation information

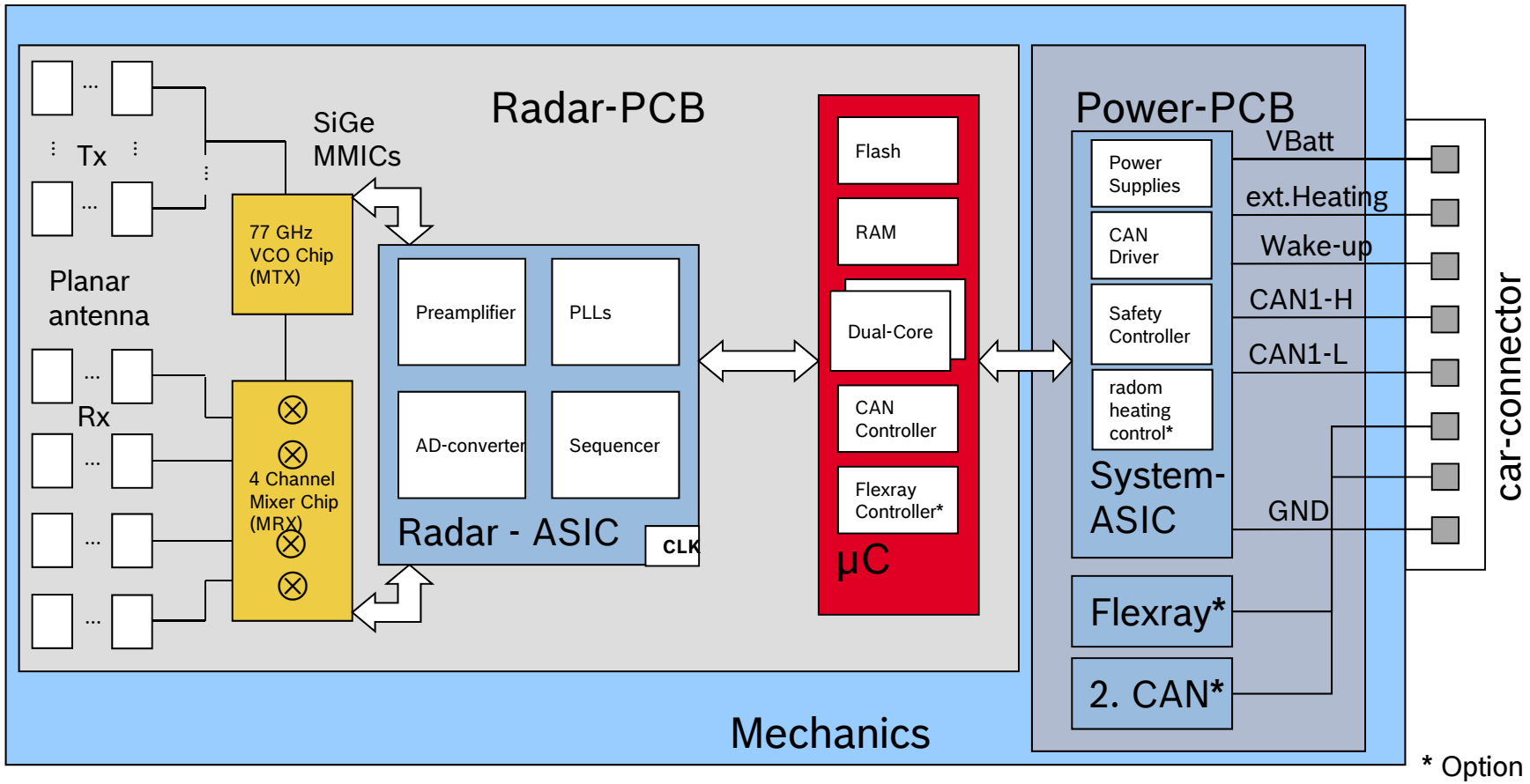
Mid Range Radar (MRR)

Performance Data MRR

FMCW-Mode	Range	Accuracy	Separability
Range (m) (Object Type Vehicle)	(0)1*...160	0.15	1.25
Relative Velocity (m/s)	-80 ... +30	0.09	0.7
Angle (Azimuth)	-22.5 (35°)... +22.5 (35°)	0.5°...1,5°	7.0°
Elevation (3dB)	-4.5°...+4.5°	n.a.	n.a.

* measurement down to 0m possible if relative velocity <-1m/s

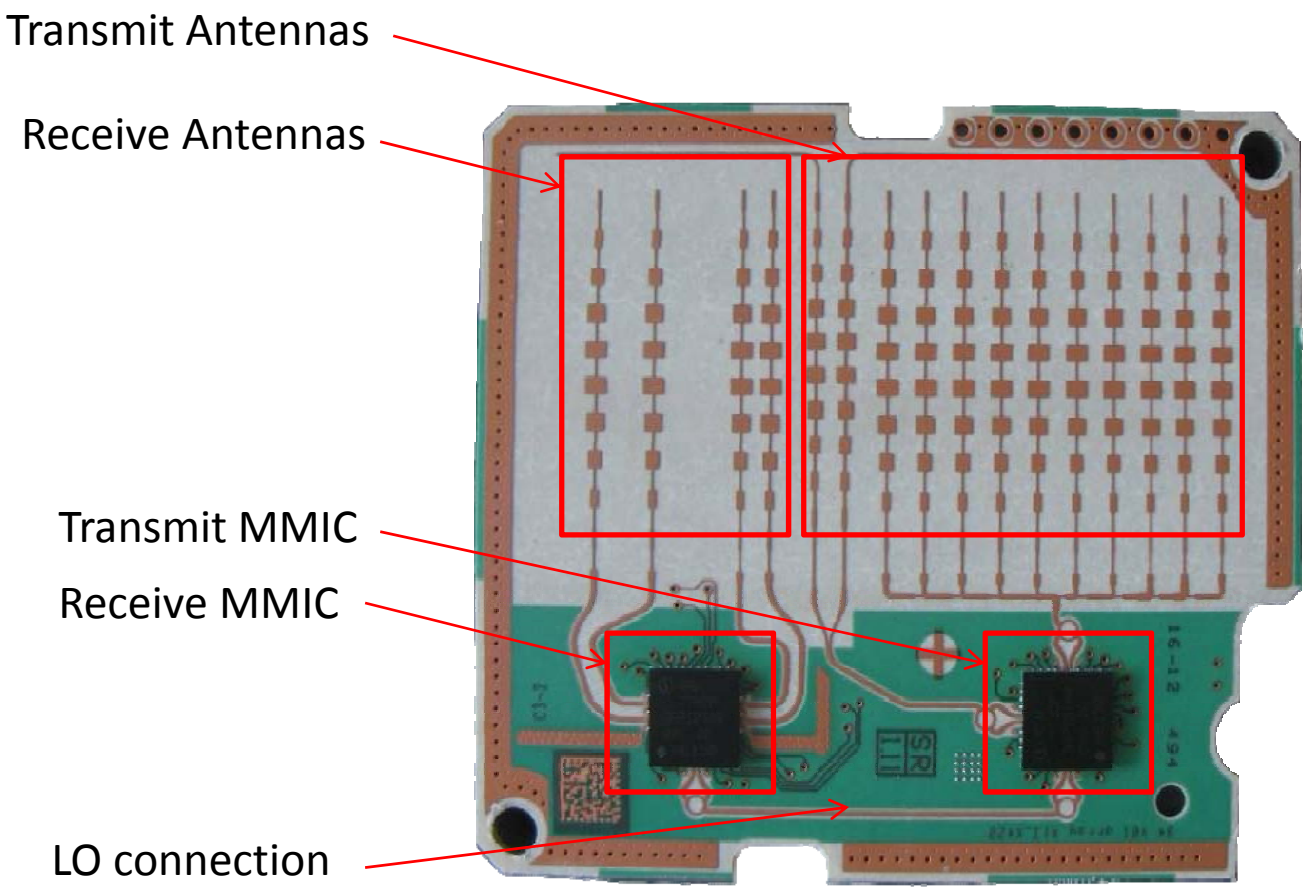
Mid Range Radar



* Option

Block Diagram

Mid Range Radar

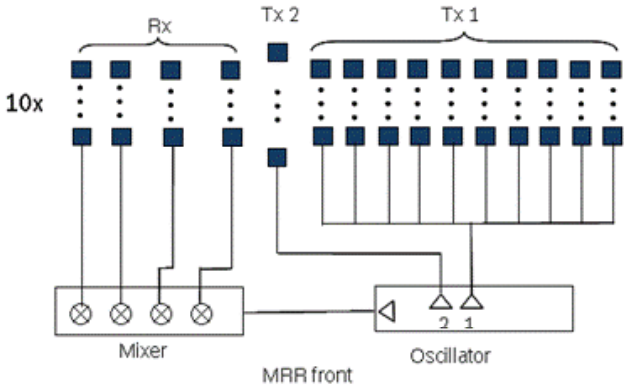


Radar PCB

Mid Range Radar

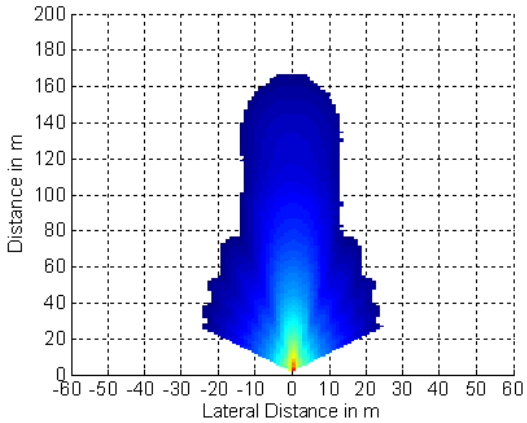
MRR*front*

Antenna



4 × Rx, 10 / 1 × Tx

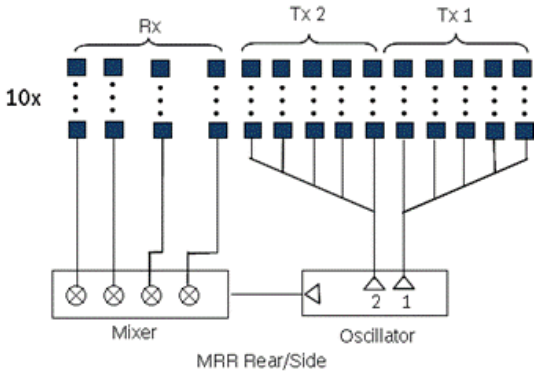
Field of View



Range:
~160m

Opening angle:
45° (70°)

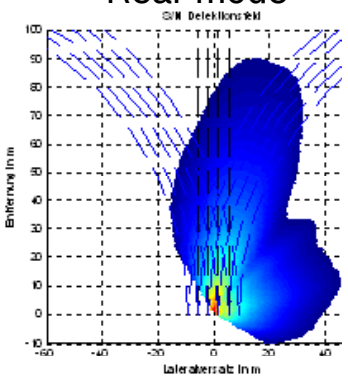
MRR (*rear) dual-mode*



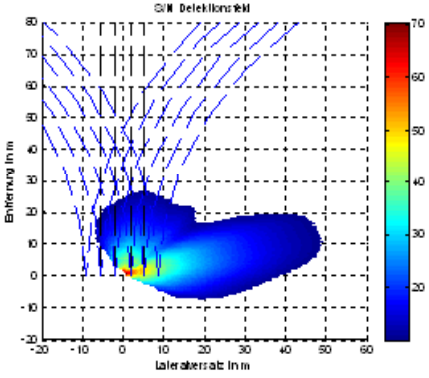
4 × Rx, 5 / 5 × Tx

Range: ~100 m, Opening angle dual mode: >120°

Rear mode



Side mode



IMS
Connecting Minds. Exchanging Ideas.

Technology Trends

- Higher Frequencies
- Field of View
- Angle Information
  - Higher Performance
  - Azimuth and Elevation
- Packaging and Integration
- Covered Integration

Higher Operation Frequency

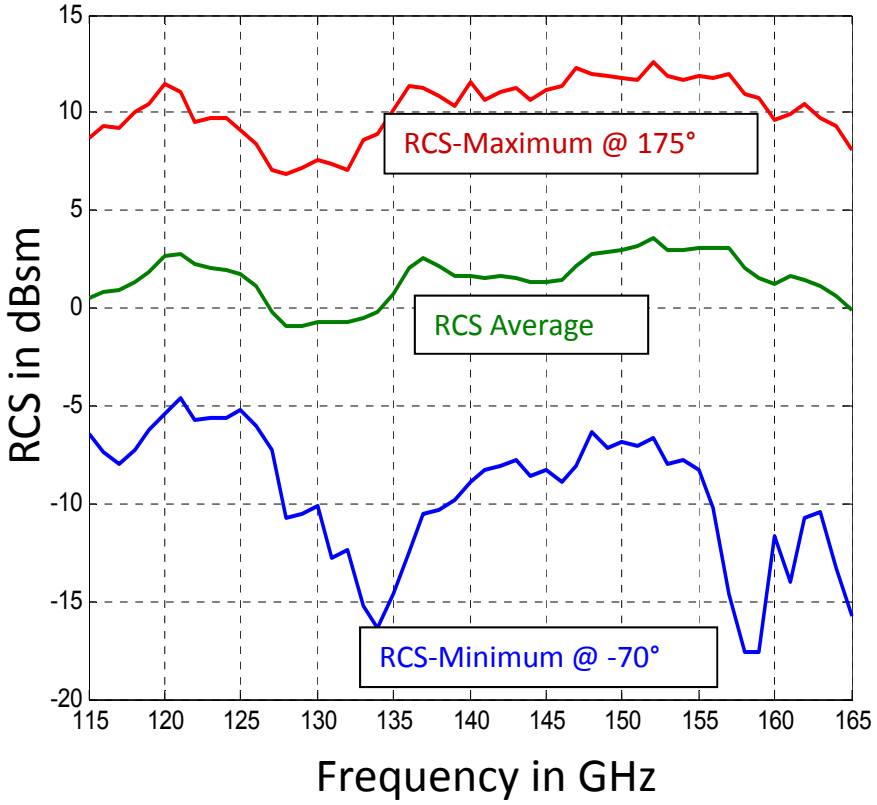
Idea:

- Smaller size
- Higher angular resolution
- Higher velocity resolution

Reality ?

Higher Operation Frequency

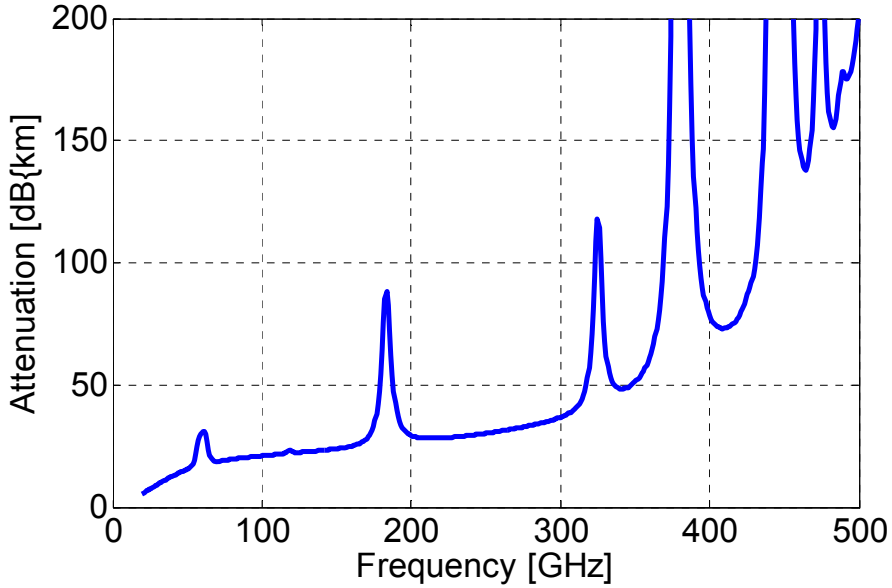
- Motorbike RCS Measurement*



*In cooperation with LHFT Erlangen, Germany

Higher Operation Frequency

- Atmospheric attenuation not an issue up to 200 GHz:



Atmospheric attenuation α(f) according to ITU recommendations ITU-R P.676-7 and ITU-R P.838-3

Parameters:

T=300 K

p=1013 hPa

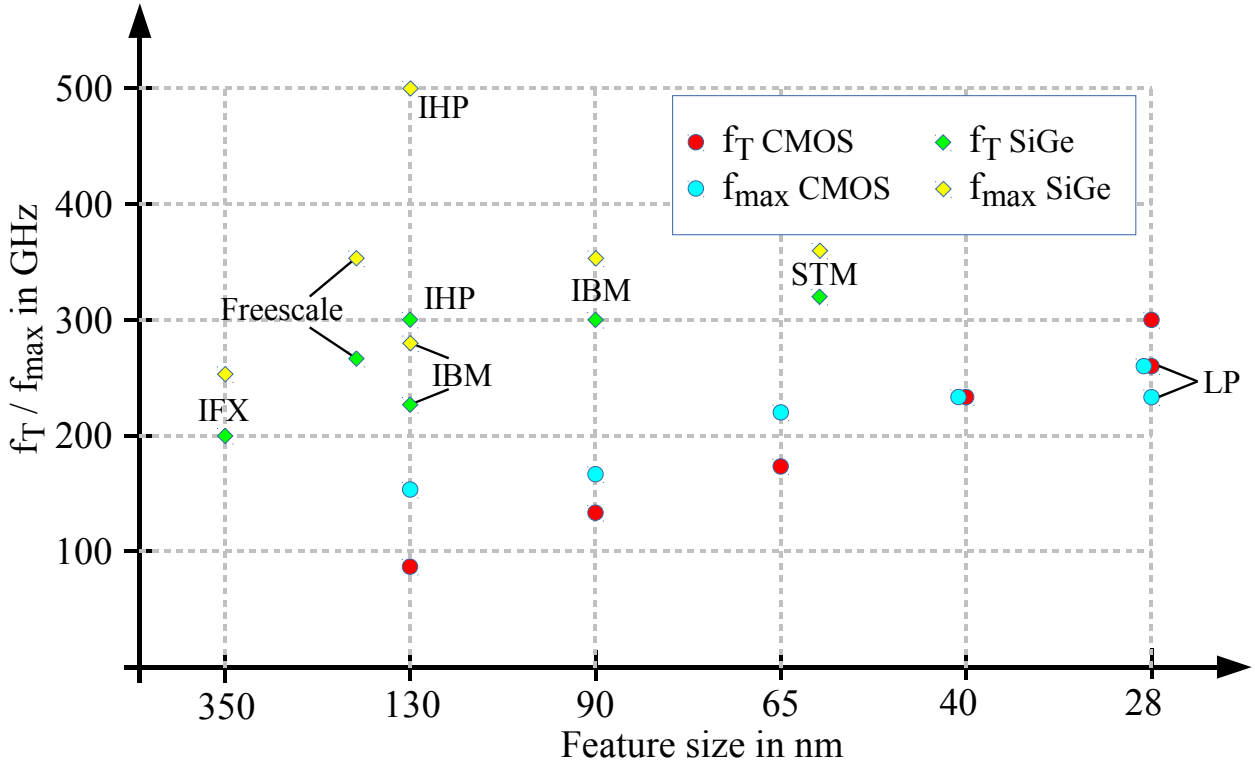
ρ=20 g/m^3 (high water vapour)

r= 50 mm/h (heavy rain)

- Receive power in Radar equation scales with square of wavelength: $P_{RX} \sim \lambda^2$

Transistor Speed

- Lot's of fast Silicon Technologies:



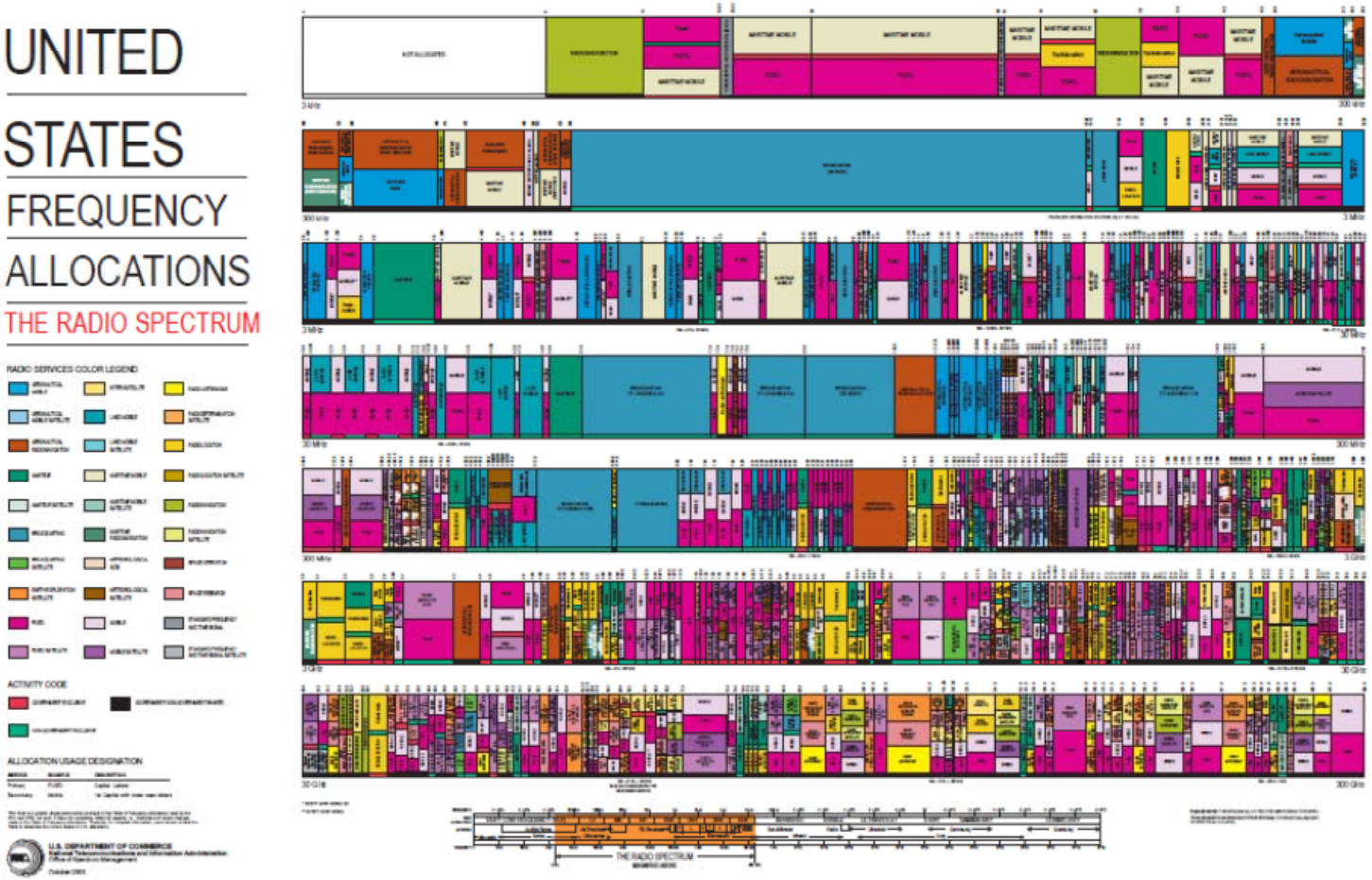
- Go to higher frequency or benefit from lower power / lower noise of faster transistors?

Source: [1]-[8]

Frequency Regulation

	24 GHz ISM	24 GHz UWB	76-77 GHz	79 GHz	122 GHz	< 240 GHz
Europe	EN 302 858 ✓	EN 302 288 ✓	EN 301 091 ✓	EN 302 264 ✓	EN 305 550 ✓	✗
Japan	✓	✓	✓	✓	✓	✗
US	✓	✓	✓	✗	✓	✗
Target separation	~150 cm	~10 cm	~75 cm	~7.5 cm	~30 cm	
Availability	Worldwide (w/o HK)	Industrial countries only	Worldwide (w/o India)	Europe/Japan /Australia/Chile	Not for automotive	no
Comments	Limited resolution	Short range, sunset date in Europe (2018)	Long range band; 500 MHz BW limitation in JP	Marginal incumbent frequency users		

Frequency Regulation



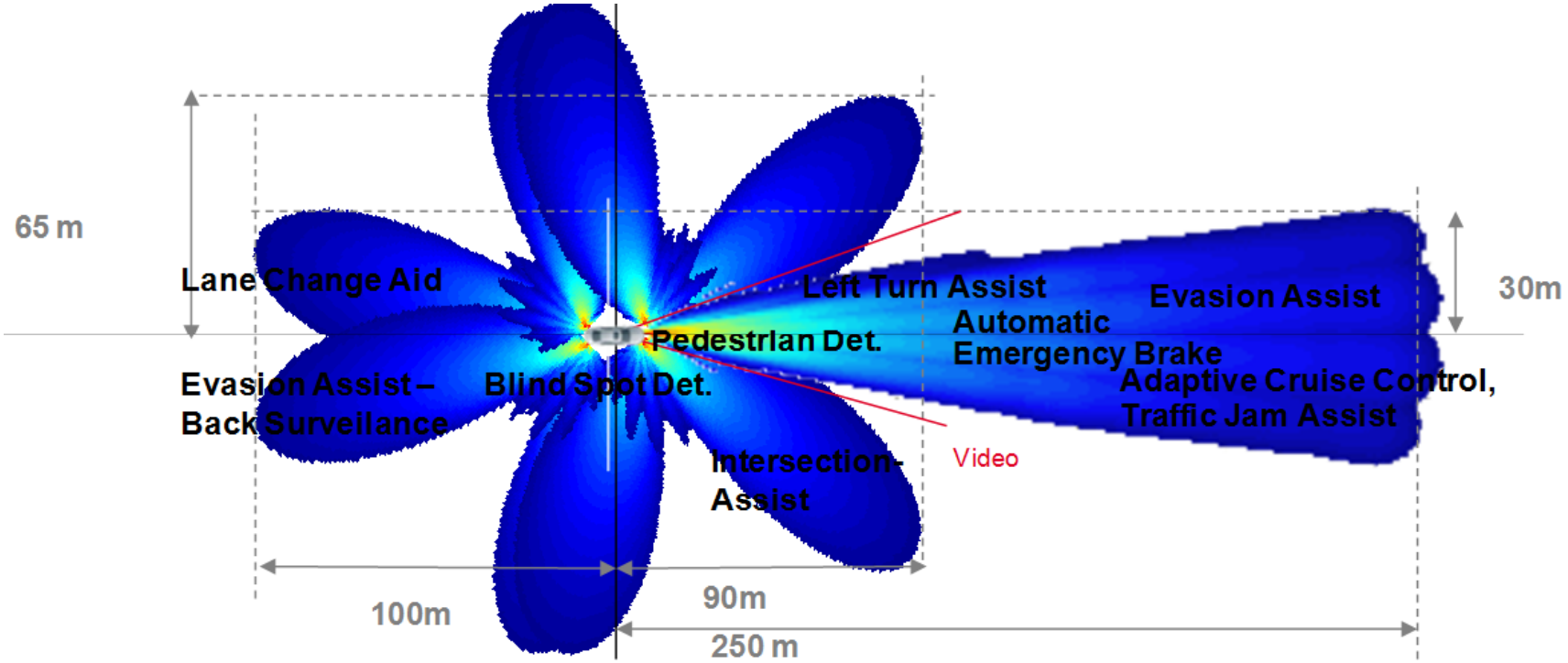
Frequency Regulation

Current Status of Allocations at 79 GHz

Technology Trends

- Higher Frequencies
- **Field of View**
- Angle Information
  - Higher Performance
  - Azimuth and Elevation
- Packaging and Integration
- Covered Integration

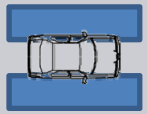
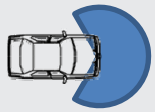
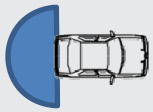
Field of View



Sensors

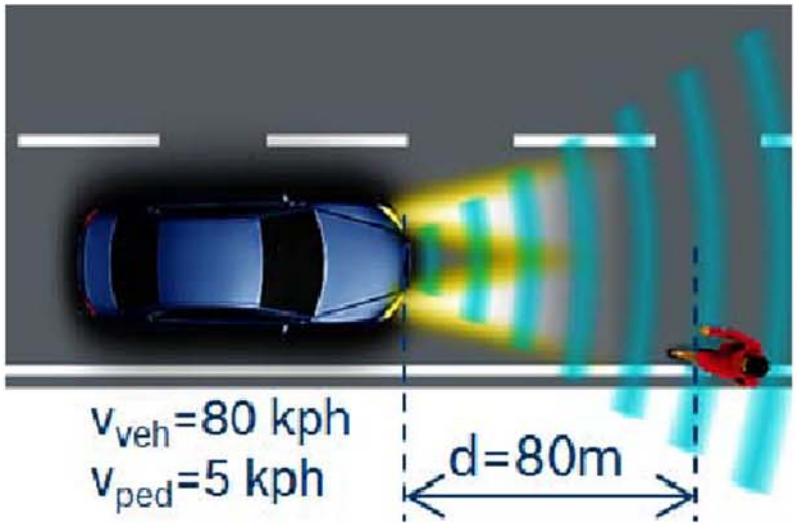
- **Front:** Long Range Radar or Midrange Radar and Mono-Video or Stereo-Video
- **Front/Side:** Two MRR dual mode mounted in corner position 70°,
- **Rear and Rear/Side:** Two MRR dual mode mounted in corner position 45°

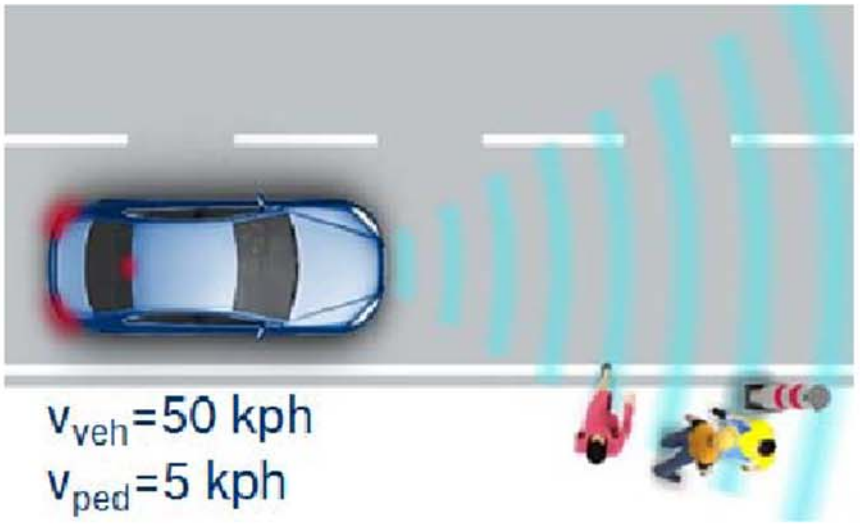
Field of View

Target Motion	Area	Shape FOV	Range	FOV
Longitudinal Far Field	Front		≥ 160 m (≤ 150 kph) ≥ 250 m (high speed)	16°
	Rear		≥ 70 m	16°
Longitudinal near field (cut-in/-out, overtake…)	Blind Spot		Left&right side ≥ 3 m, ≥ 3 m to back	
	Extended Blind Spot		20 m • 20 m total area (5 lanes in total)	360°
Cross traffic	Front/Side		≥ 50 m	up to 240°
	Rear/Side		≥50 m	180°

Pedestrian Detection

- Wide Field of View
- High velocity resolution ≈ 0.1 m/s



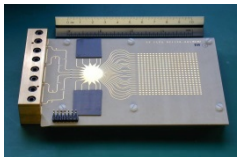


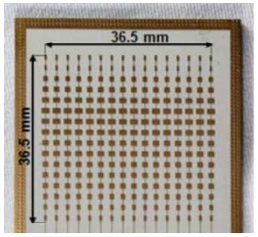
Source: A.Schubert, A Multi-Reflection-Point Target Model for Classification of Pedestrians by Automotive Radar, EuMW 2014

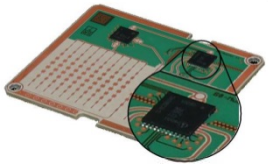
Technology Trends

- Higher Frequencies
- Field of View
- **Angle Information**
  - **Higher Performance**
  - **Azimuth and Elevation**
- Packaging and Integration
- Covered Integration

Antenna System



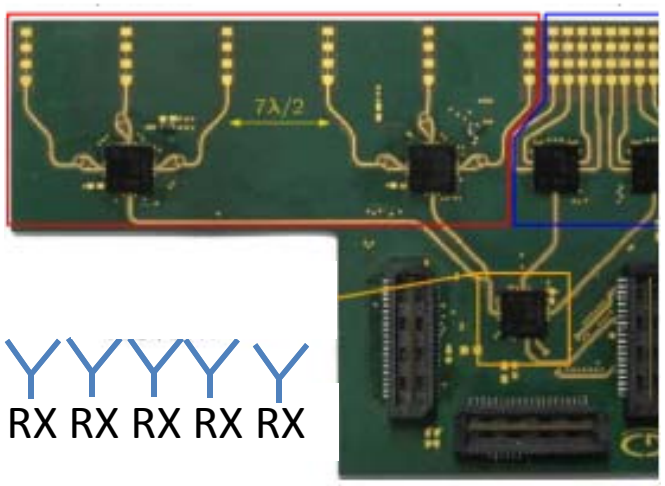




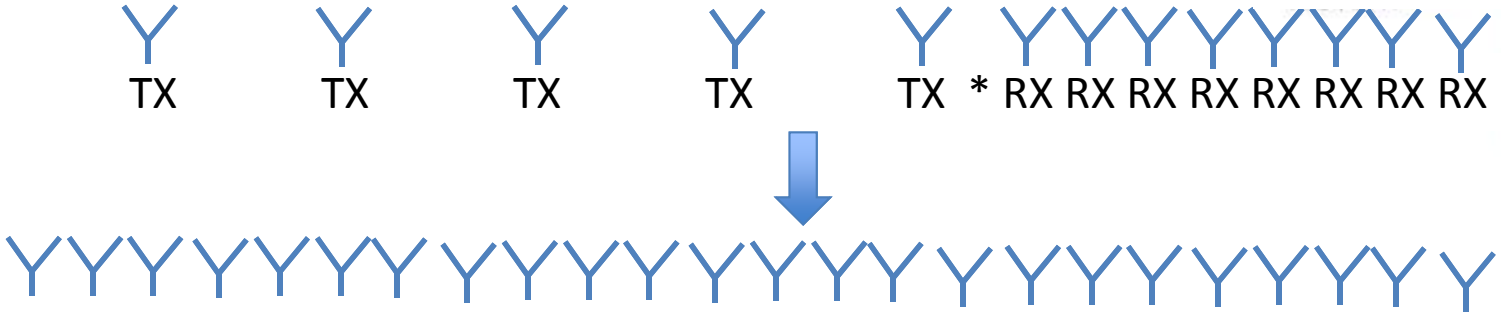
	Dielectric Lens	Rotman Lens	Analog Beamforming	Digital Beamforming	Mechanical Scanner
Multiple beams	yes	yes	no	Yes	no
Beamforming	limited flexibility	limited flexibility	flexible	flexible	fixed
Losses in feed network	low	high	high	low	low
Area requirements	low	high	medium	medium	high
Effort in RF part	low	high	very high	low	medium
Effort in control and signal processing	low	low	high	high	medium

MIMO

- Efficient use of antenna aperture for limited sensor size



Virtual Antenna Array:

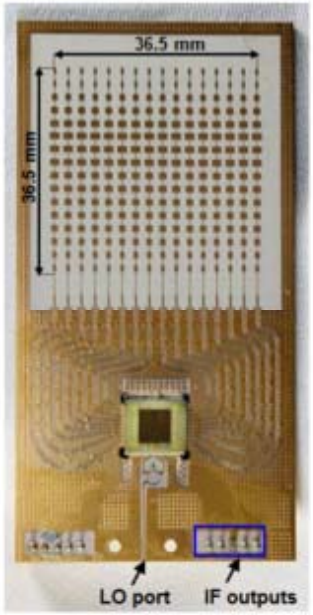


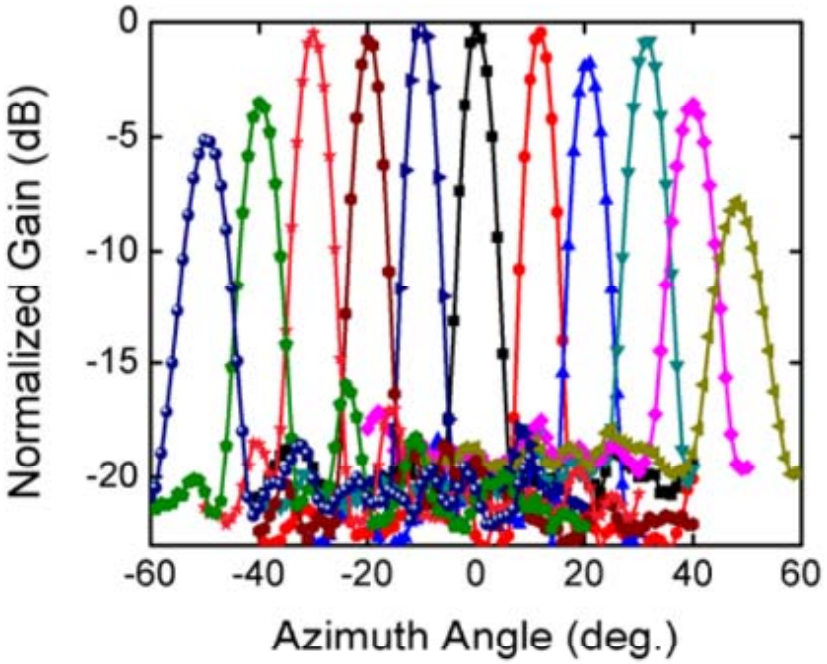
- Flexible trade-off between # of receivers and transmitters
- Does not help in improving range, only angular resolution

Source: R.Feger, WFF, IMS 2014

Phased Array

- The addition of a transmit phased array allows high-gain antenna beams for different directions

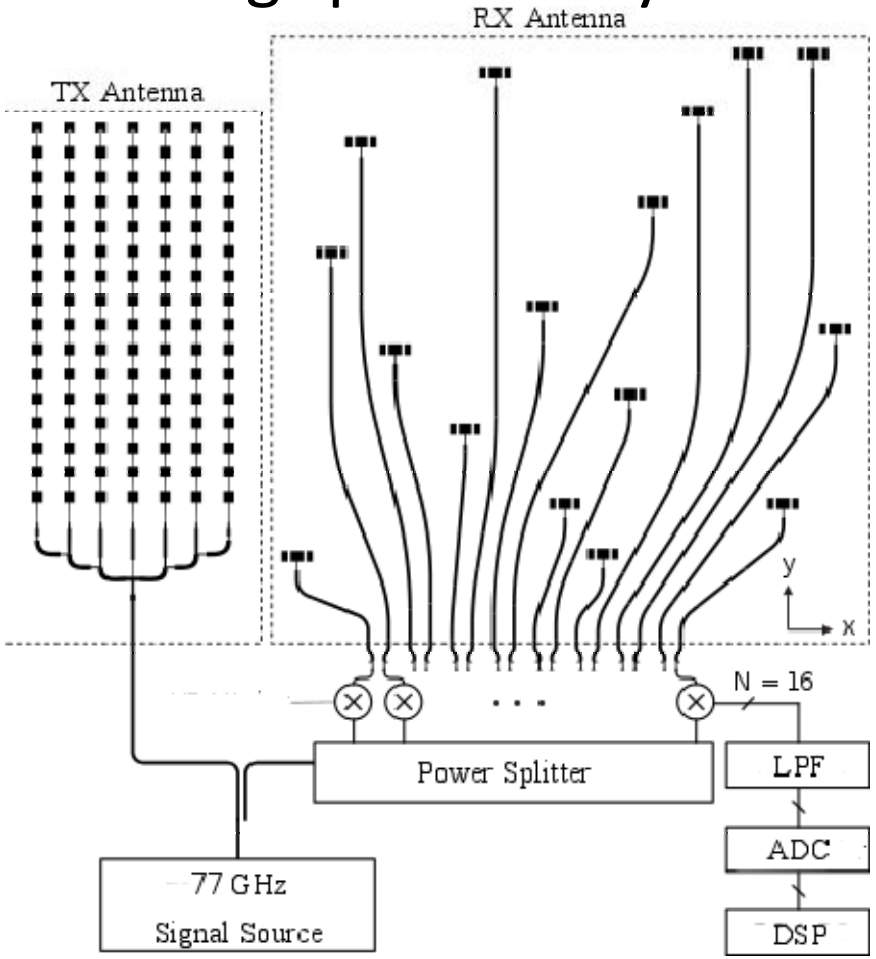


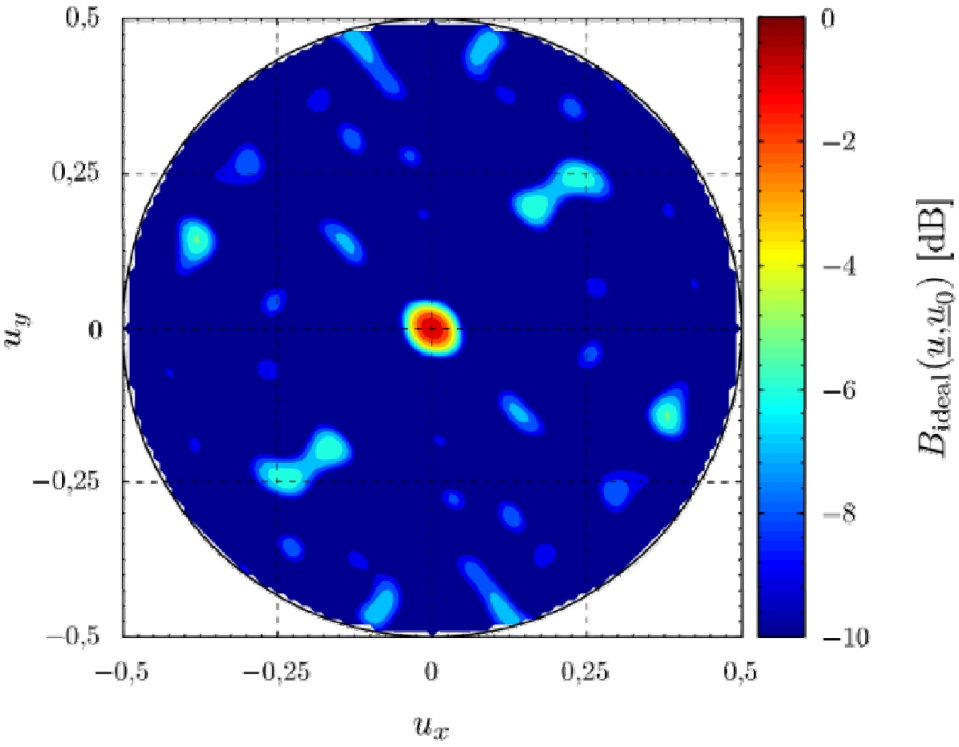


Source: G.Rebeiz

Sparse Arrays

- Angle information with high resolution using sparse arrays





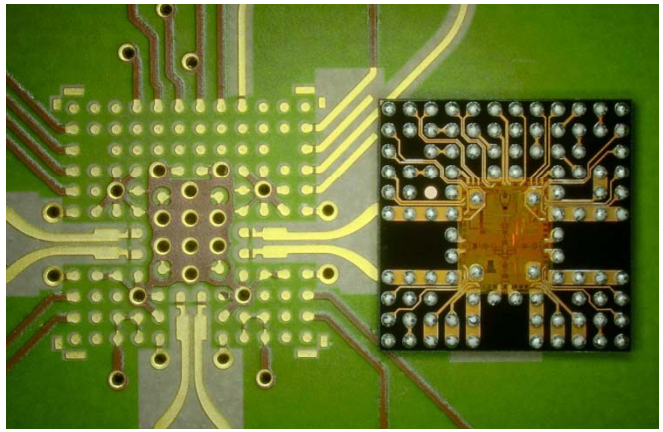
Source: PhD Thesis Oliver Lange, 2012

Technology Trends

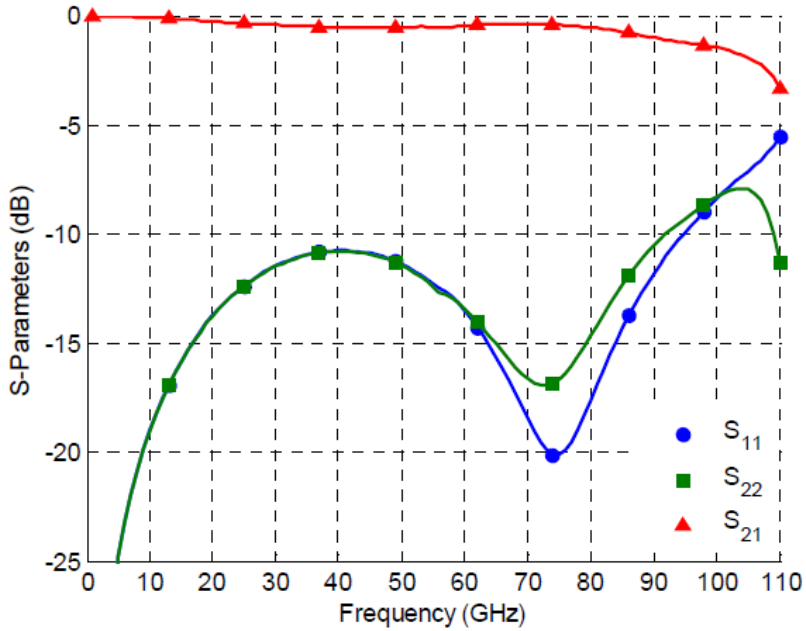
- Higher Frequencies
- Field of View
- Angle Information
  - Higher Performance
  - Azimuth and Elevation
- Modulation schemes
- **Packaging and Integration**
- Covered Integration

Packaging Technology: eWLB

- Standard PCB technology using RF substrate for antenna and millimeter-wave interconnects



eWLB package and PCB footprint

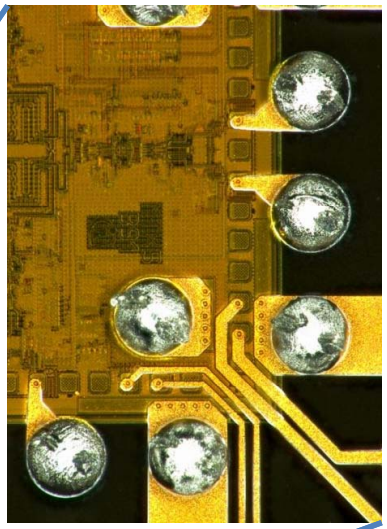


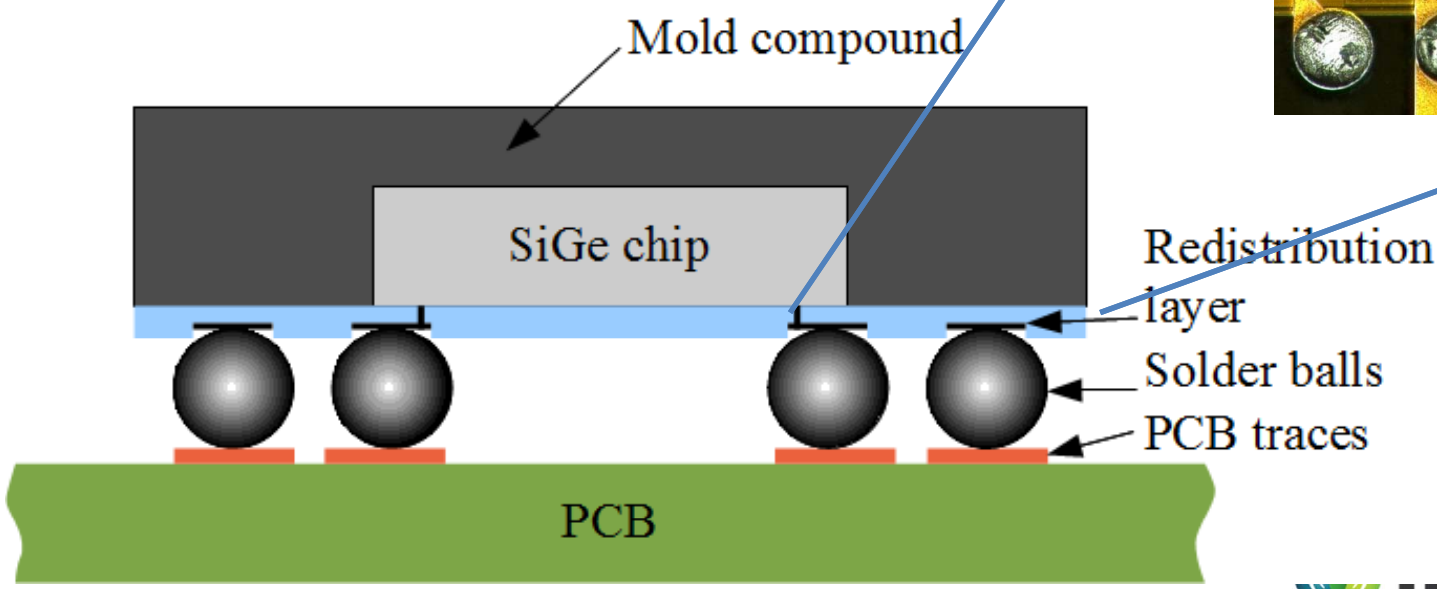
eWLB to PCB interconnect performance

Source: Embedded Wafer Level Ball Grid Array (eWLB) Technology for Millimeter-Wave Applications, 13th Electronics Packaging Technology Conference, 2011

Packaging Technology: eWLB

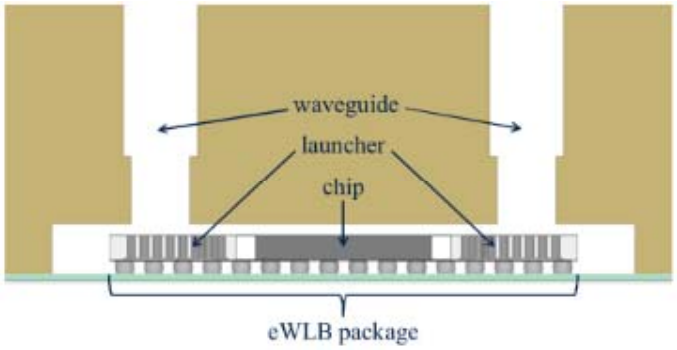
- Standard high-volume SMD package with additional redistribution layer and soldering balls





Packaging Technology

- Separate RF and IF/DC signal components



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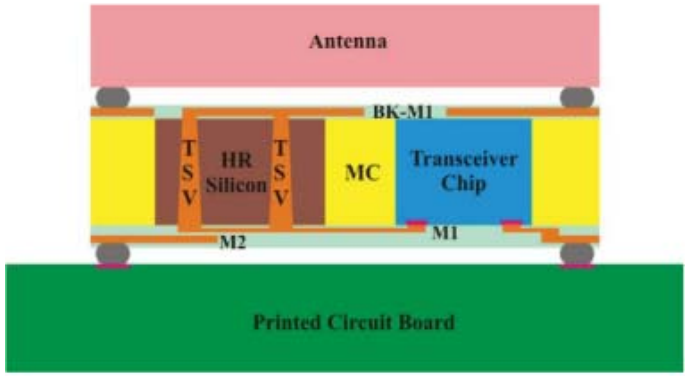
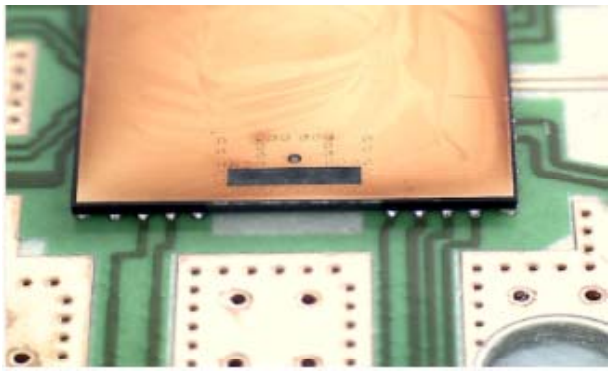
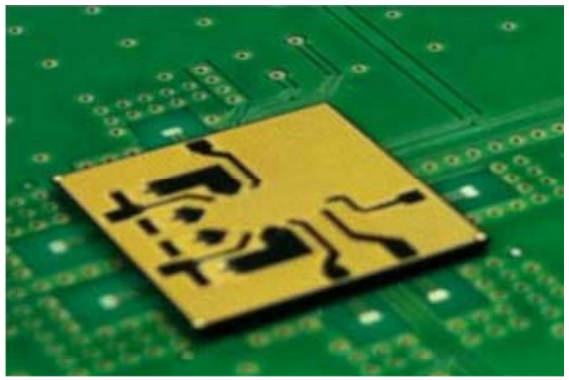




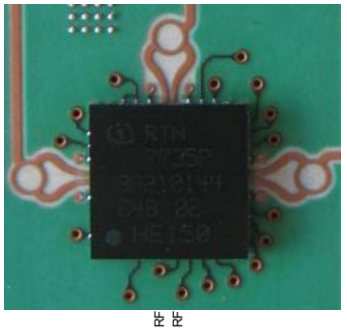


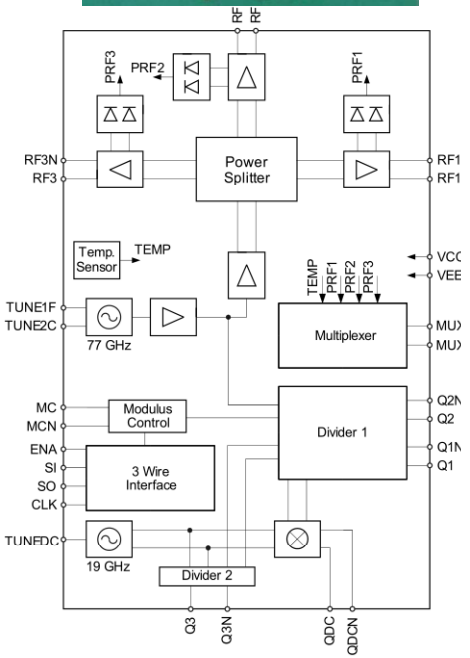
*Source: Riu Li, Embedded Wafer Level Packaging (EMWLP) for 77GHz Automotive Radar Front-End with Through Silicon Via (TSV) and its 3D Integration

Frontend Chips: MRR

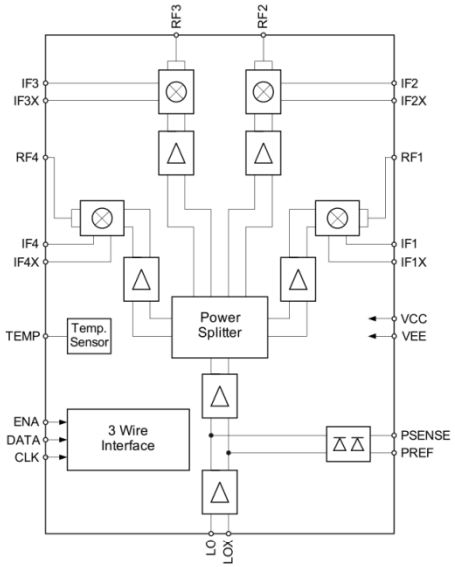
- Second generation of 77 GHz components
- Separate transmitter and receiver
- Single 3.3 V supply, < 2 W DC power
- SMD packaged, 6x6 mm
- Serial control interface
- Used in Bosch MRR

Transmitter





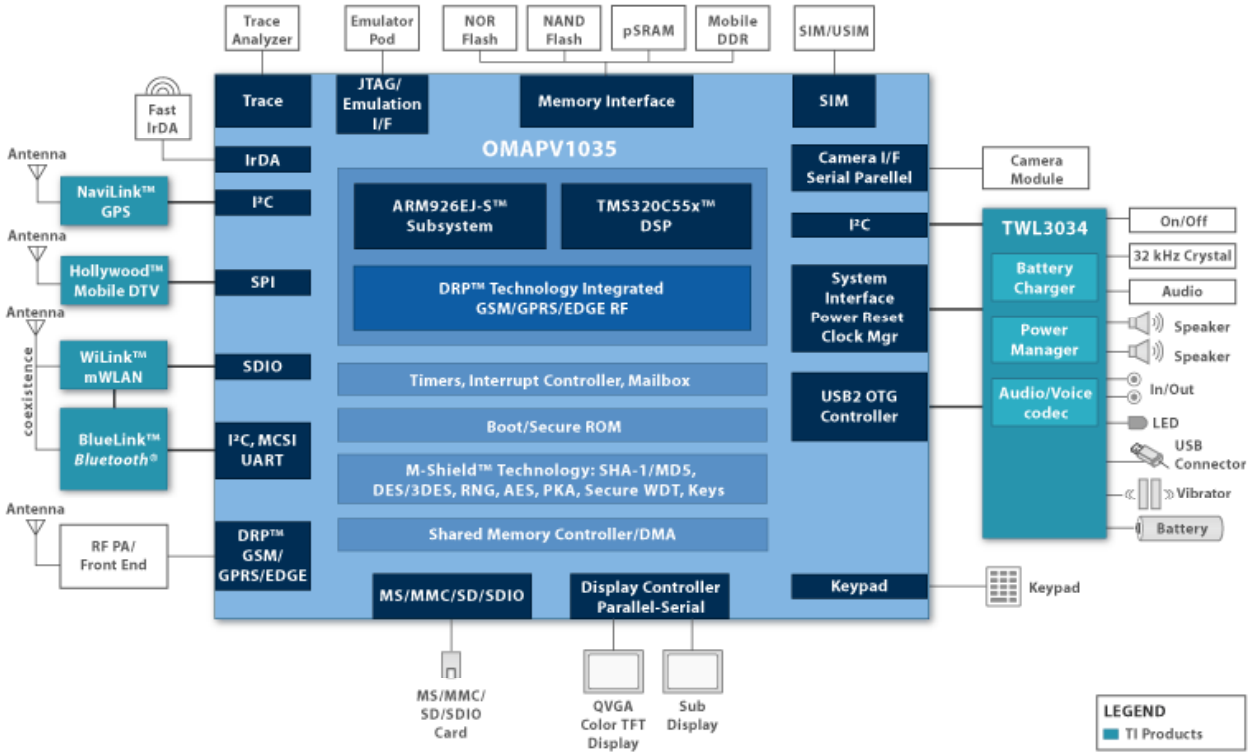
Receiver



Source: Infineon

Radar SoC ?

- Will there be a All-in-one Radar chip like in the smartphone area ?



Source: Texas Instruments

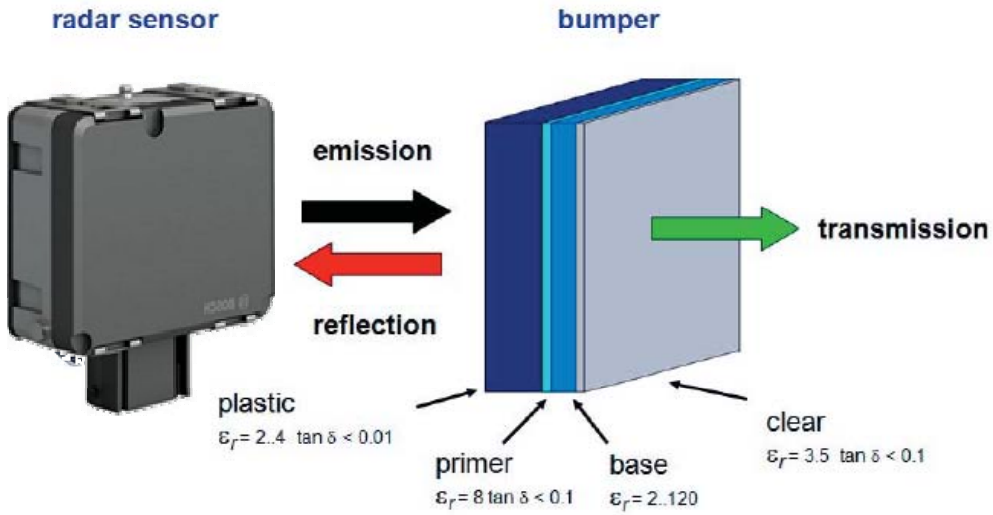
Technology Trends

- Higher Frequencies
- Field of View
- Angle Information
  - Higher Performance
  - Azimuth and Elevation
- Packaging and Integration
- **Covered Integration**

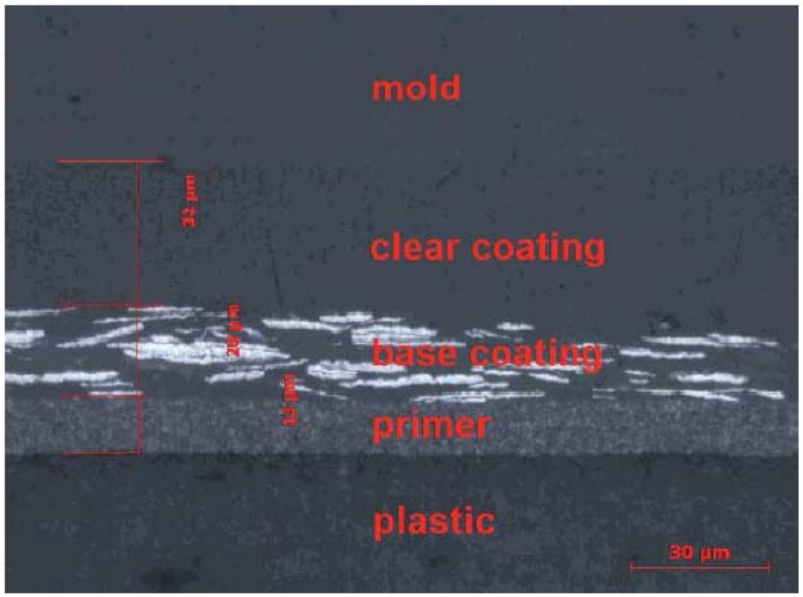
Covered Integration

Source: T.Binzer: Influence of Intra Vehicle Factors on Radar Performance, EuMW 2013

Covered Integration



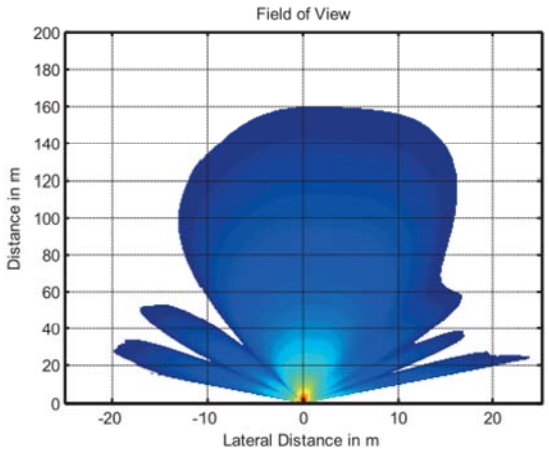
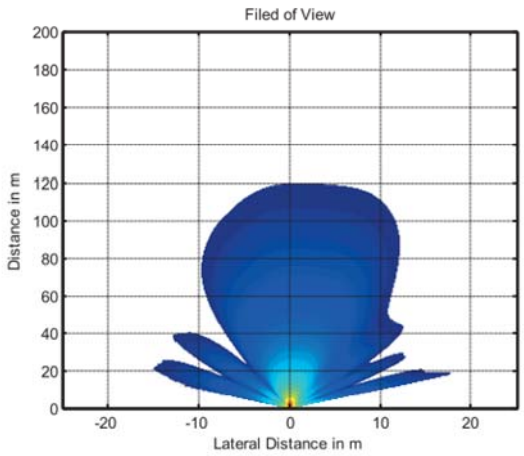
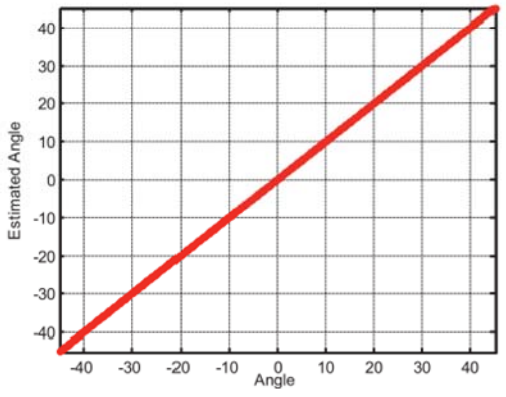
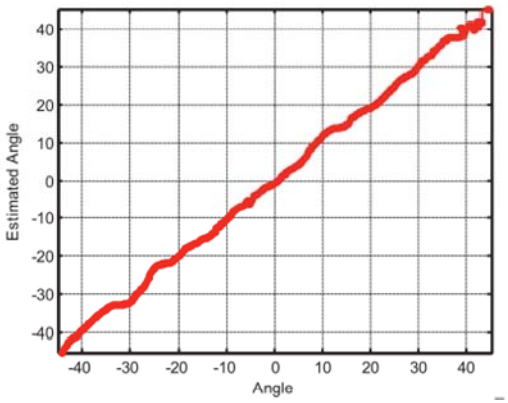
Layer model for a typical coated fascia



Cross-section of a silver-metallic bumper

Source: T.Binzer: Influence of Intra Vehicle Factors on Radar Performance, EuMW 2013

Covered Integration

	Without influence	With influence
Detection Range		
Angular Estimation		

Source: T.Binzer: Influence of Intra Vehicle Factors on Radar Performance, EuMW 2013

Outlook

- Operating frequencies > 100 GHz are not foreseen in the near future
- Radar see will see improvements in
  - Flexible field of view
  - Angle measurement in azimuth and elevation
  - Higher angular resolution
- Lower power and higher integration density using modern semiconductor technologies
  (is “Radar on a Chip” really becoming true ?)
- Covered integration is a key feature for car manufactures

Conclusion

- Strong increase in driver assistance functions based on radar sensors.
- There is still a lot of potential in radar sensing technology.
- Key is implementing new functionality at low cost.

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