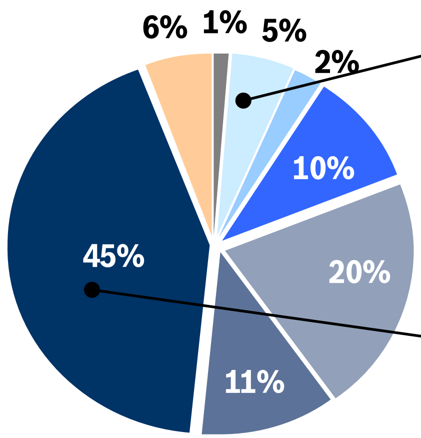
Worldwide Plans for Harmonization of Automotive Radars (Short-Range and Medium-Range) at 77-81 GHz, and Compatibility with Incumbent Users



Automotive Radar Motivation

Scope of Safety Functions – US Accident Data*

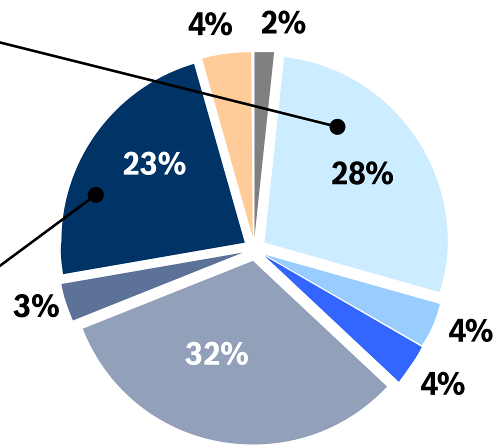
Accidents with Fatalities
n = 38,588



Accidents
Predictive Emergency Braking Systems
could avoid
or mitigate

Accidents
Electronic Stability Control
and
Lane Departure Warning Systems
resp. could avoid
or mitigate

Accidents with Injuries
n = 1,784,588



Collision with …

- **parked vehicle**
- **vehicle moving ahead or waiting**
- **vehicle moving laterally in same direction**
- **oncoming vehicle**
- **vehicle which turns into or crosses a road**
- **pedestrian**
- **fixed object or vehicle leaving carriageway**
- **accident of another kind**
  (unknown, not fixed object, animal …)

*sources:
NHTSA/NCSA 2006

PEBS Functions Examined in Benefit Analysis

common industry view

Predictive Collision Warning PCW

- warning strategy including brake jerk
- driver monitoring to optimize warning strategy
- adapted system reaction for stationary objects

Emergency Braking Assist EBA

- includes PCW
- target braking for optimized brake support to avoid collision

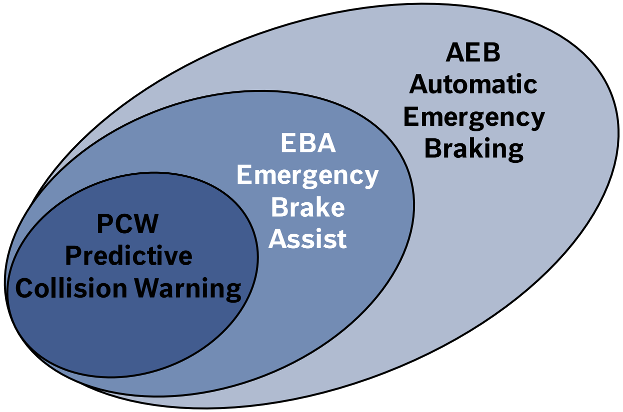
Automatic Emergency Braking AEB

- includes EBA
- automatic partial braking
- automatic full braking when collision unavoidable

NHTSA

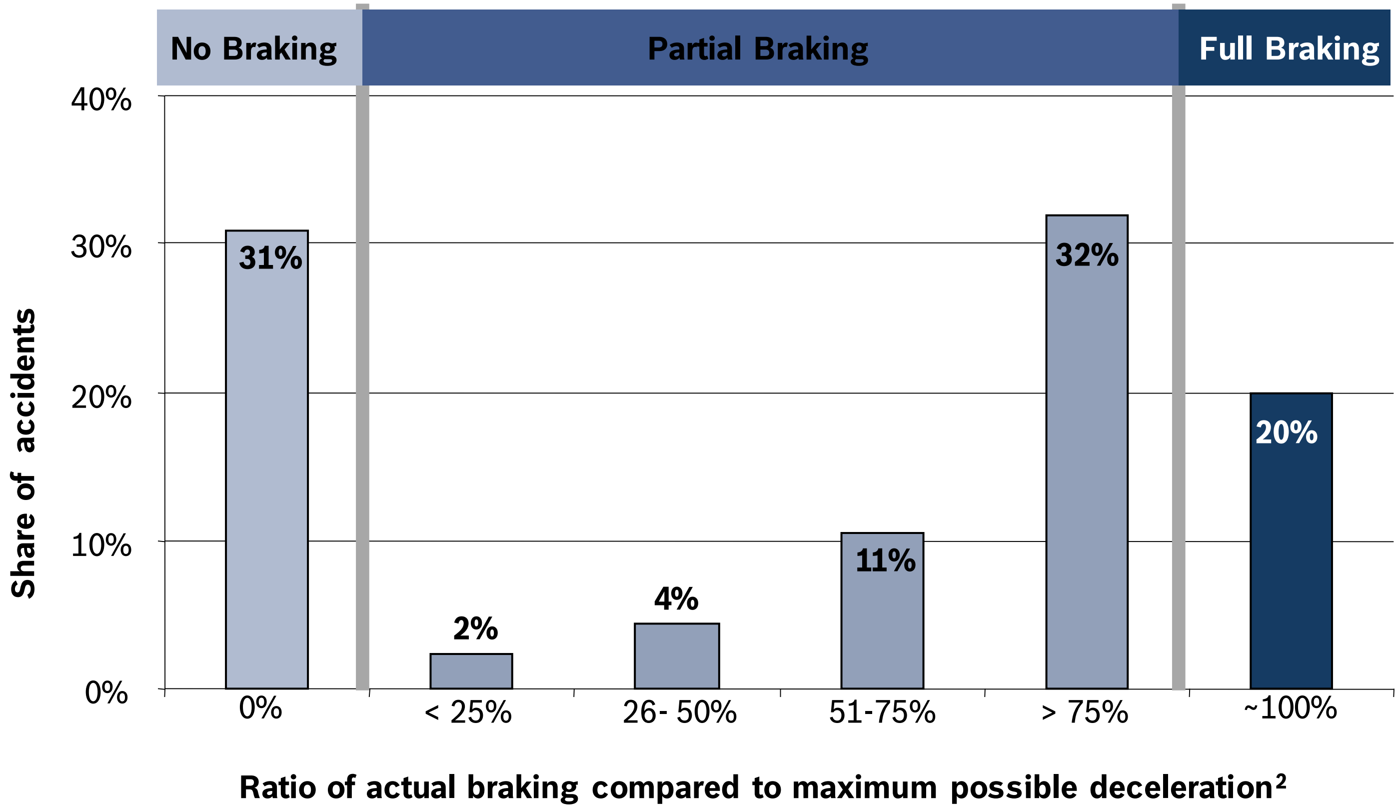
Forward Collision Warning* FCW

- acoustic/optical warning only at fixed point in time
- limited to good weather and to minimum vehicle speed



*Remark: For the following investigation an FCW realization is used that would just fulfill the requirements of the NHTSA FCW Confirmation Test.

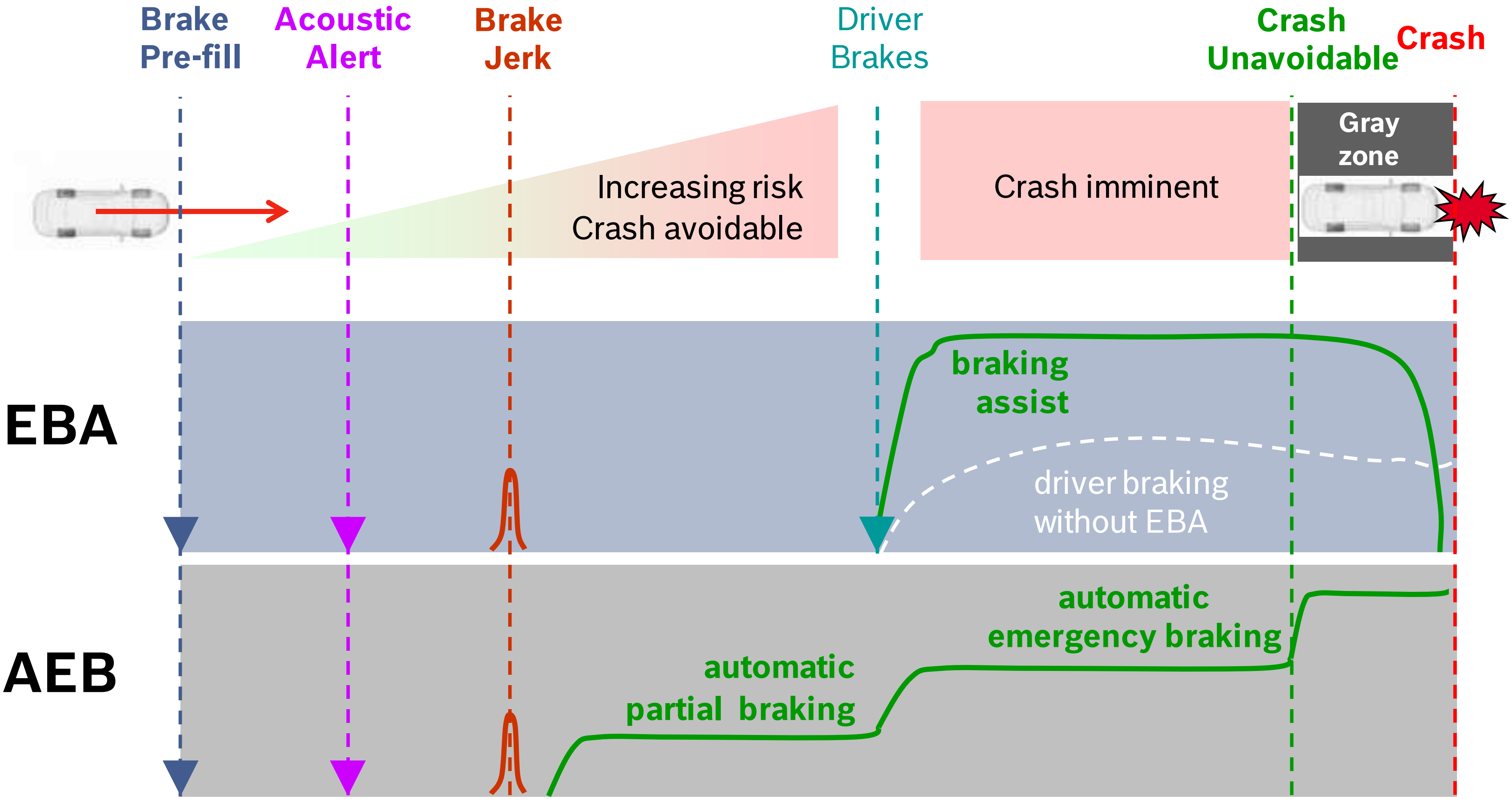
Vehicle Deceleration prior to Rear End Crashes[1]



[1] Evaluation based on 1103 rear end crashes in GIDAS. Source: Bosch Analysis of GIDAS Database (2001-2005)

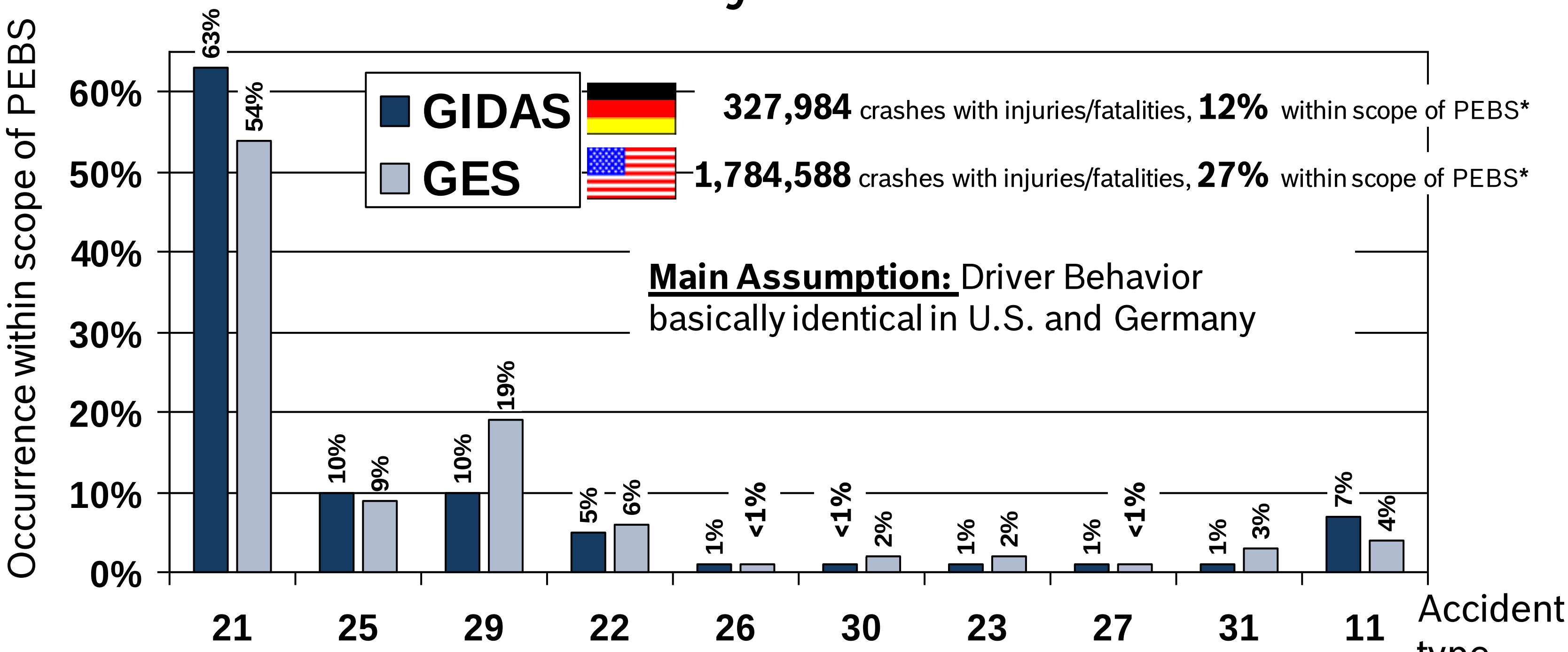
[2] Maximum possible deceleration was determined based on weather and road condition

The PEBS function – A detailed view



Brake jerk was evaluated to be the most effective driver alert

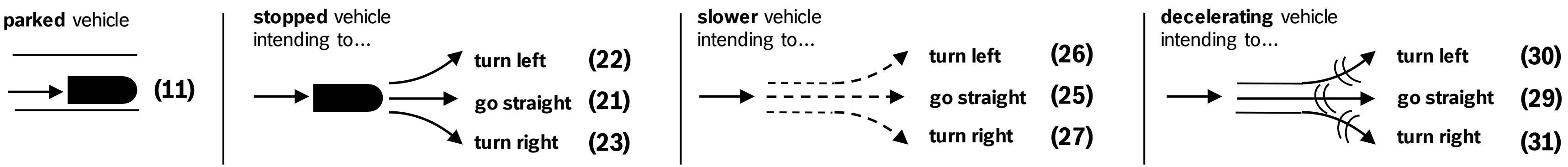
Translation to US Boundary Conditions



GIDAS (German In-Depth Accident Study), http://www.gidas.org/

Collision with ...

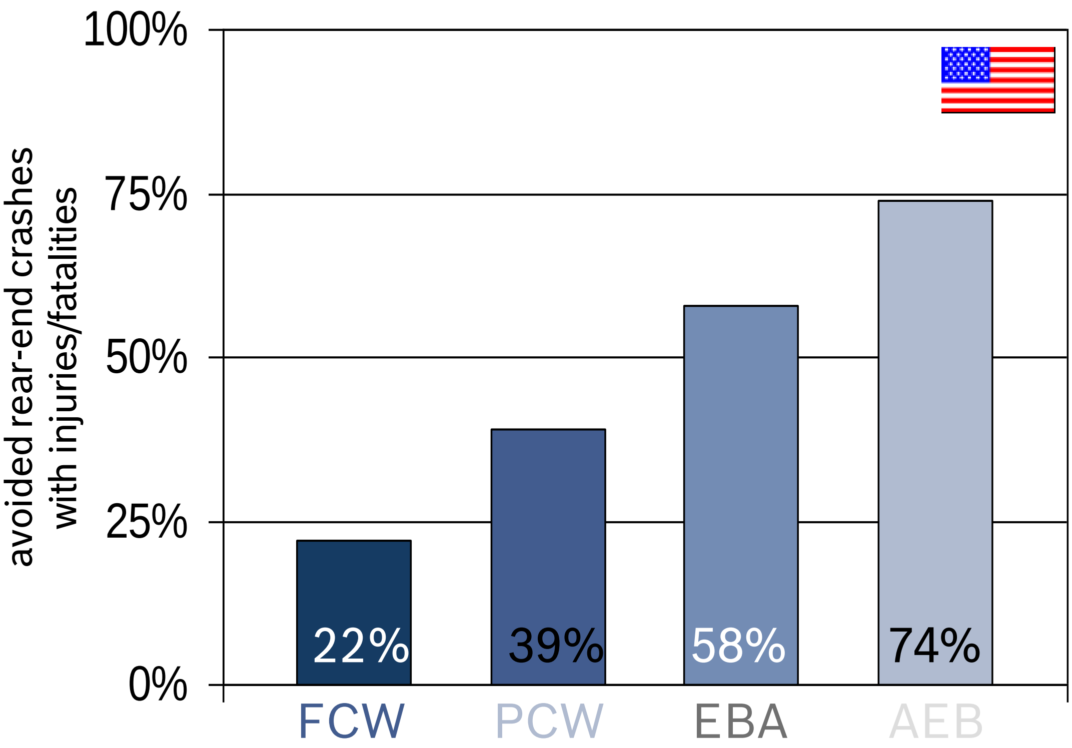
* rear-crash accidents caused by passenger cars only, no trucks



sources: StBA, GIDAS, NHTSA, Year 2006

BOSCH

Fraction of Avoided Rear-End Crashes with Injuries/Fatalities



Source: Bosch Analysis of GIDAS Database (2001-2005), modeled under idealized conditions

* Remark: For this investigation an FCW realization was used that would just fulfill the requirements of the NHTSA FCW Conformance Test.

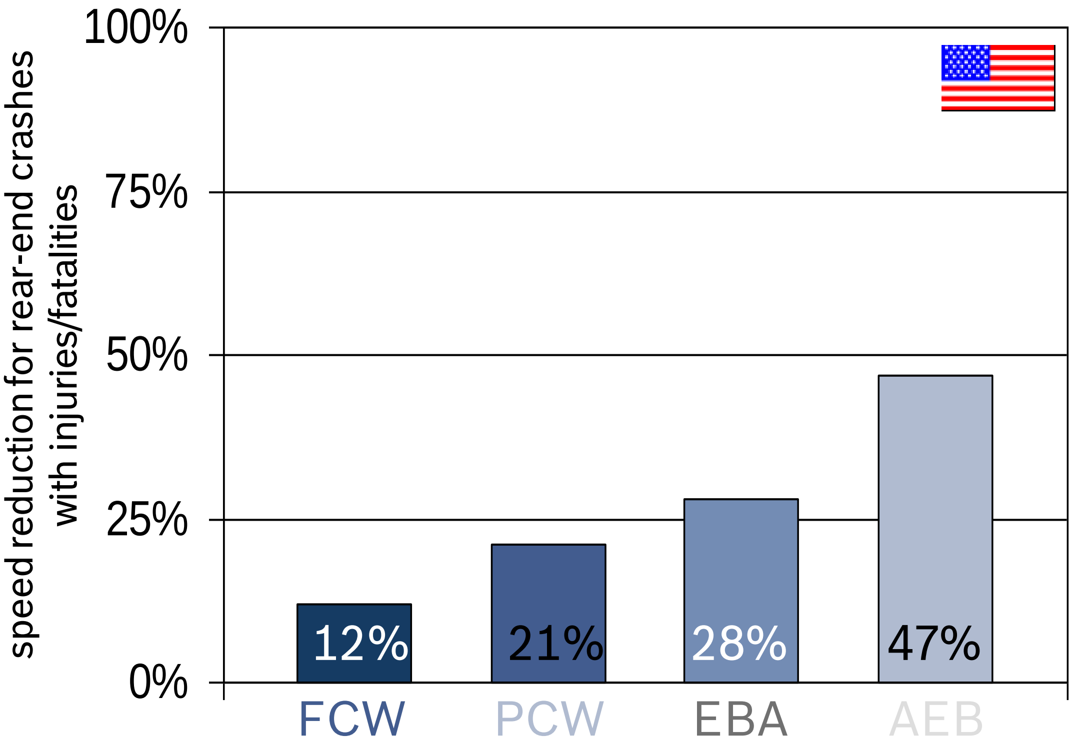
FCW Forward Collision Warning*
- acoustic/optical warning only at fixed point in time
- limited to good weather and to minimum vehicle speed

PCW Predictive Collision Warning
- warning cascade including brake jerk
- driver monitoring to optimize warning strategy

EBA Emergency Braking Assist
- includes PCW
- target braking for optimized brake support to avoid collision

AEB Automatic Emergency Braking
- includes EBA
- automatic partial braking
- automatic full braking when collision unavoidable

Average reduction of collision speed (for unavoided accidents)



Source: Bosch Analysis of GIDAS Database (2001-2005), modeled under idealized conditions

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Status quo;
What regulation already exists?

Current frequency allocation for 24 GHz Narrowband

Japan	Europe	USA	Canada	Mexico	China	Korea	Singa-pore	Russia	Gulf States	Brazil
ARIB STD-T73 1.1版	EN302858	FCC 47 part 15.249	RSS310	Cofetel usually accepts FCC regulations	Technical Specification for Micropower (Short Distance) Radio Equipments, part G	Article 103 (Sensor detecting objects)	IDA TS SRD	SFMC Decision № 07-20-03-001 Annex 7	Specification for Non-Specific Short Range Devices and ancillary equipment	ANATEL resolution No. 506

Pro

- Worldwide frequency allocation

Con

- Only 200 MHz bandwidth ➔ minimum resolution = 1m
- ISM band ➔ no protection from interference from other services

➔ MOSARIM (European funded) project

Current frequency allocation for 24/26 GHz UWB

Japan	Europe	USA	Canada	Mexico	China	Korea	Singa-pore	Russia	Gulf States	Brazil
TELEC－T317（第1.0版）	EN 302 288	FCC 47 part 15.252	RSS220	Cofetel usually accepts FCC regulations			IDA TS UWB	SFMC Decision № 07-20-03-001	Possible in most Gulf states	Anatel usually accepts FCC regulations

Pro

- Large bandwidth (➔ good separation) and only few incumbent frequency users

Con

- **No allocation in Korea and China, sunset date in Europe („2018+4“, new ECC and EC decision April 2011)**
- Low power (-41.3dBm / MHz) ➔ limited range (10-20m)

Current frequency allocation status for 79 GHz UWB

Japan	Europe	USA	Canada	Mexico	China	Korea	Singa-pore	Russia	Gulf States	Brazil
Negotiating with RAS	Allocated EN302264	First contacts and discussions	Negotiating with RAS	Not started	Not started	Not started	IDA TS UWB	In negotiation	Not started	Not started

Pro

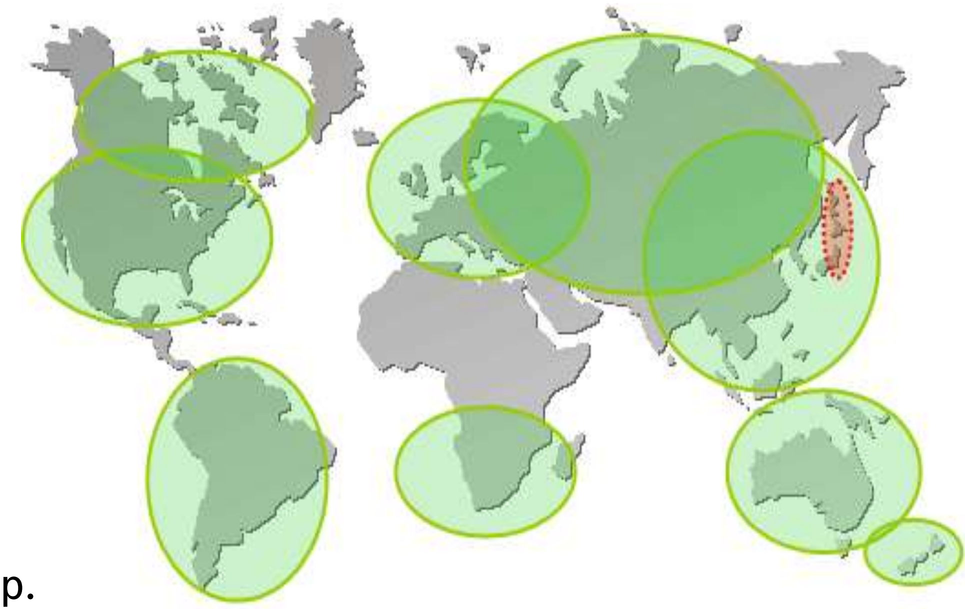
- Large bandwidth (➔ good separation) and marginal incumbent frequency users

Con

- Allocation currently only in Europe, Australia and Singapore
  → new European funded project to clarify all open issues / world wide regulation (CSA 79 GHz)
- 77.5-78.0 GHz is not yet allocated to „radiolocation“ on ITU level
- 77-81 GHz so far „not compatible with RAS “

Worldwide Regulatory Situation - 77 GHz LRR

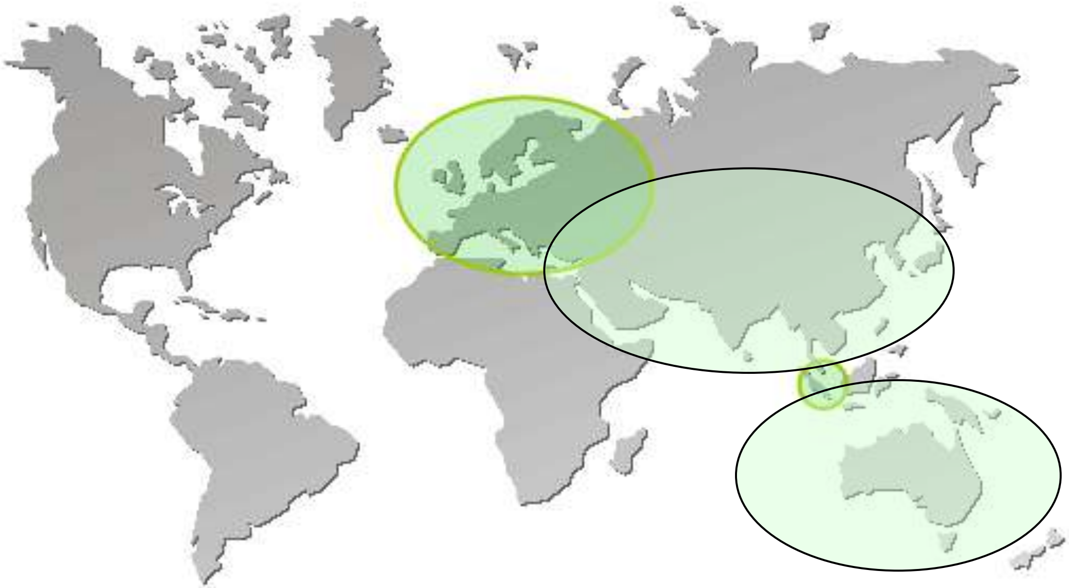
- US: in part 15.253 (reduced EIRP while in standstill with +23.5 dBm)
- EU: European Commission
  Not an ISM band, but available incl. CEPT countries
- Australia: in LIPD Class Licence 2000
- Canada: in RSS 210
- Japan: ARIB STD 48 limited to 500 MHz!!
- Russia: again available after some comp. studies
- Brazil: Recommendation 365
- China: MRE Category G (XIV)



77 GHz "ACC / Long range radar band" from 76 GHz to 77 GHz is nearly worldwide available with a few national restrictions in operational parameters (e.g. bandwidth, output power)

Worldwide Regulatory Situation - 79 GHz UWB

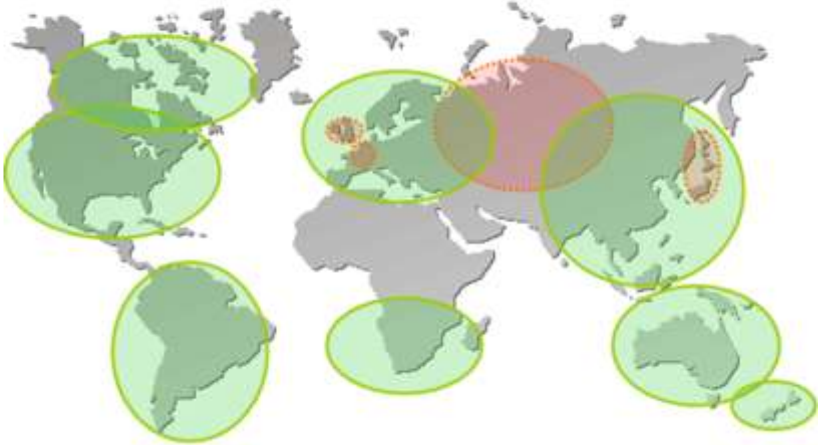
- US: first negotiations started
- EU: allowed since 2004 in decision 2004/545/EC
- Australia: variation to LIPD 2000 in draft version available
- Singapore: allowed since 2007 in IAD TS UWB
- Canada: n.a.
- Japan: HR Radar working group
- Russia: positive study result!
- Brazil: n.a.



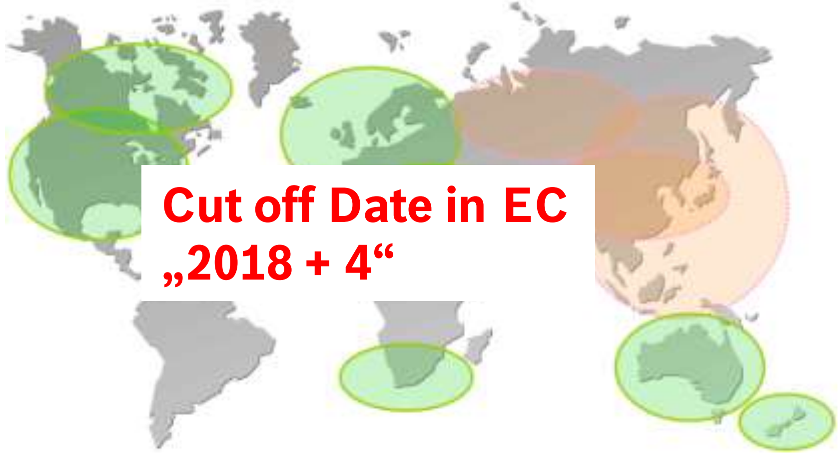
79 GHz "UWB SRR band" from 77 GHz to 81 GHz is actually available in EU countries, Australia, New Zealand and in Singapore. Lobbying work in some important countries started!

Current frequency allocation status - summary

24 GHz NB



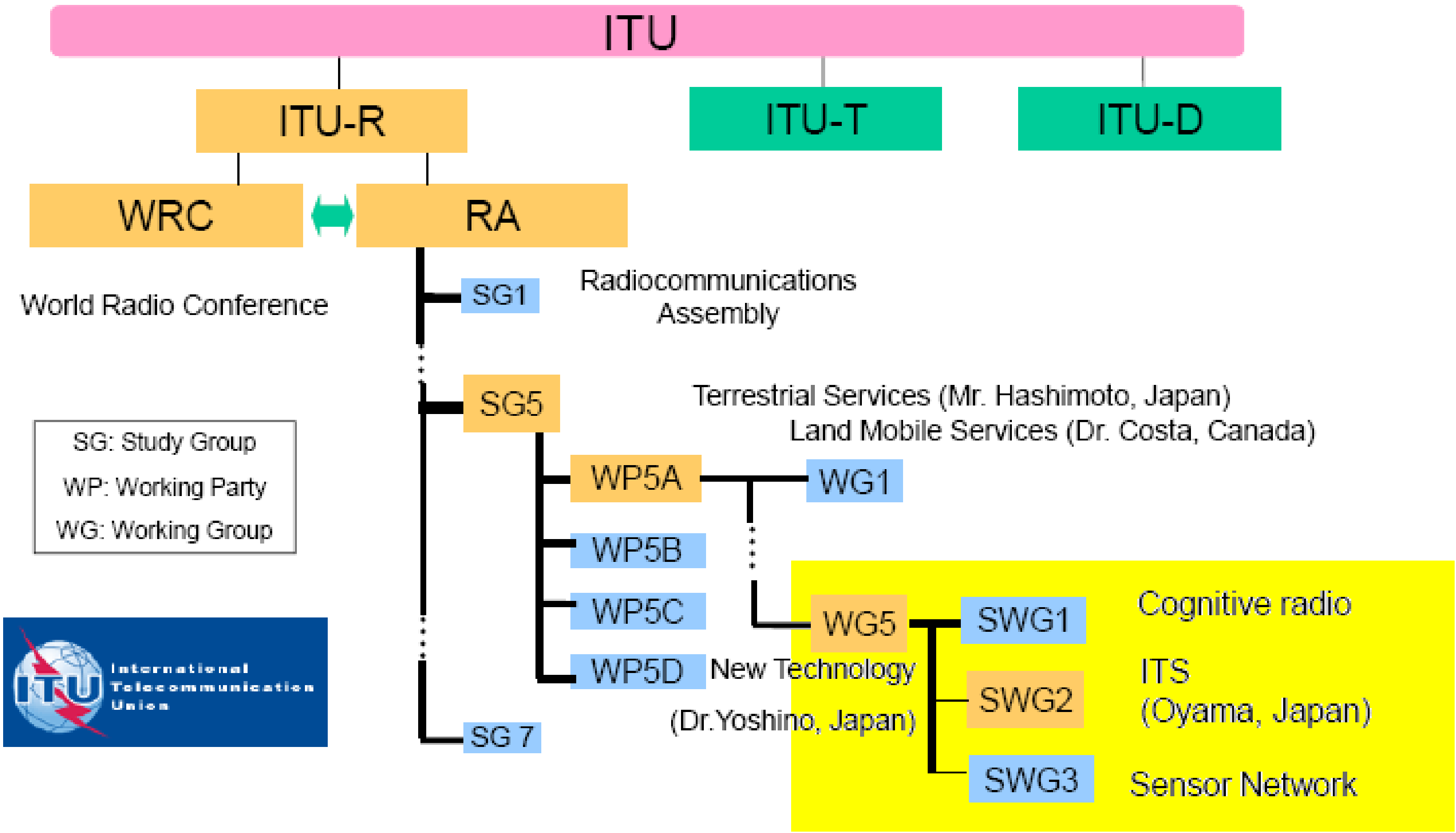
24/26 GHz UWB



77 GHz

79 GHz

ITU-R Organization for ITS – Study period 2008 - 12



ITU-R Organization for ITS – Study period 2008 - 12

ITU-R Recommendation M.1452

Low-power short-range vehicular radar equipment
at 60 & 76 GHz

Revision (Sent to RA)

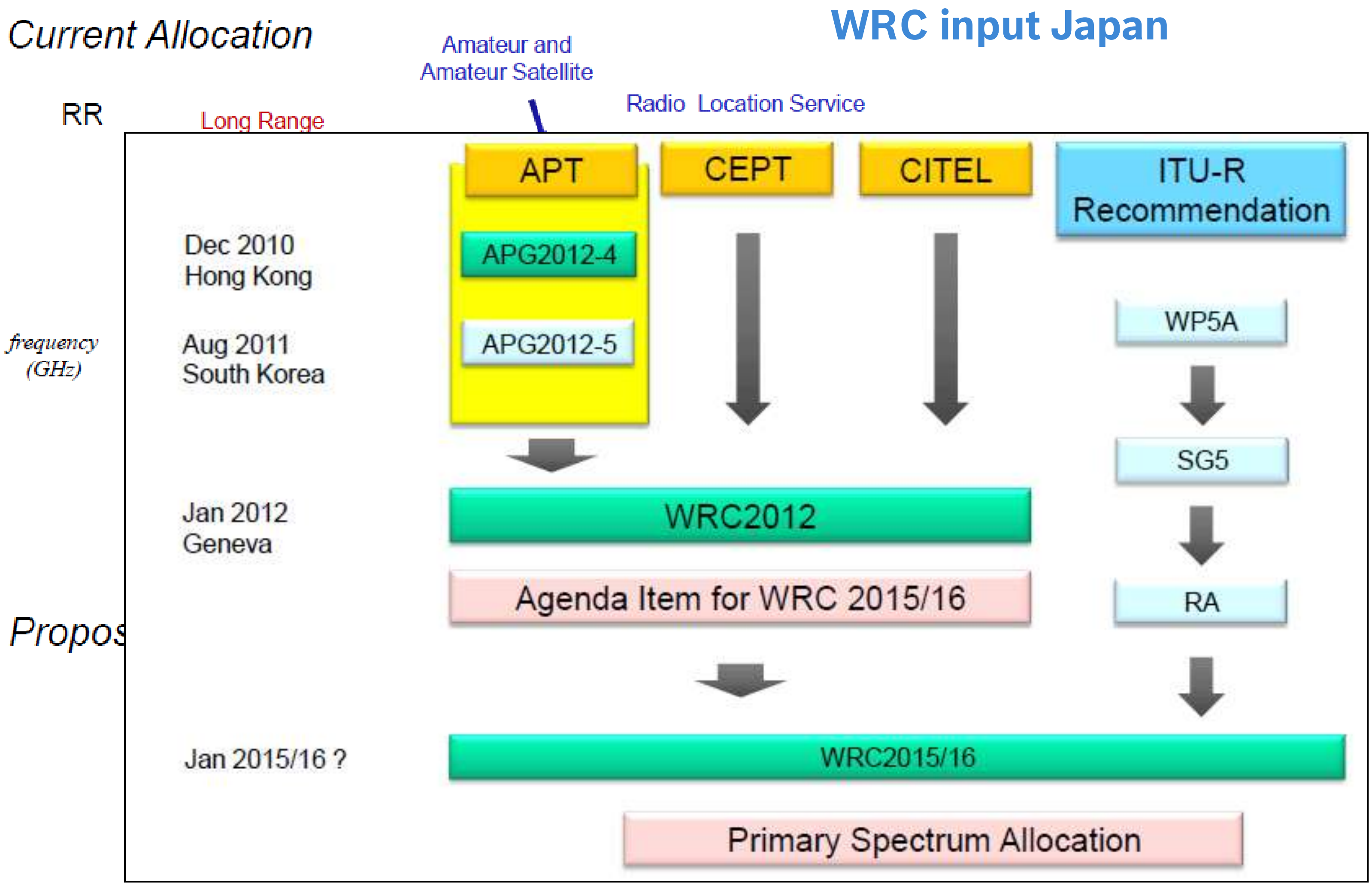
Millimeter Wave Radiocommunication Systems
for ITS Applications

Annex A
Low power
short-range
vehicular radar
equipment
at 60 & 76 GHz

Annex B:
Technical characteristics
of millimeter wave
radiocommunication
systems for
data communications
(vehicle-to-vehicle,
vehicle-to-roadside
infrastructure)

(Annex C):
79GHz Short Range
High Resolution Radar

ITU-R Organization for ITS – Study period 2008 - 12



Technical situation assessment; the key performance indicators

Vehicular radar frequencies – the key performance indicators

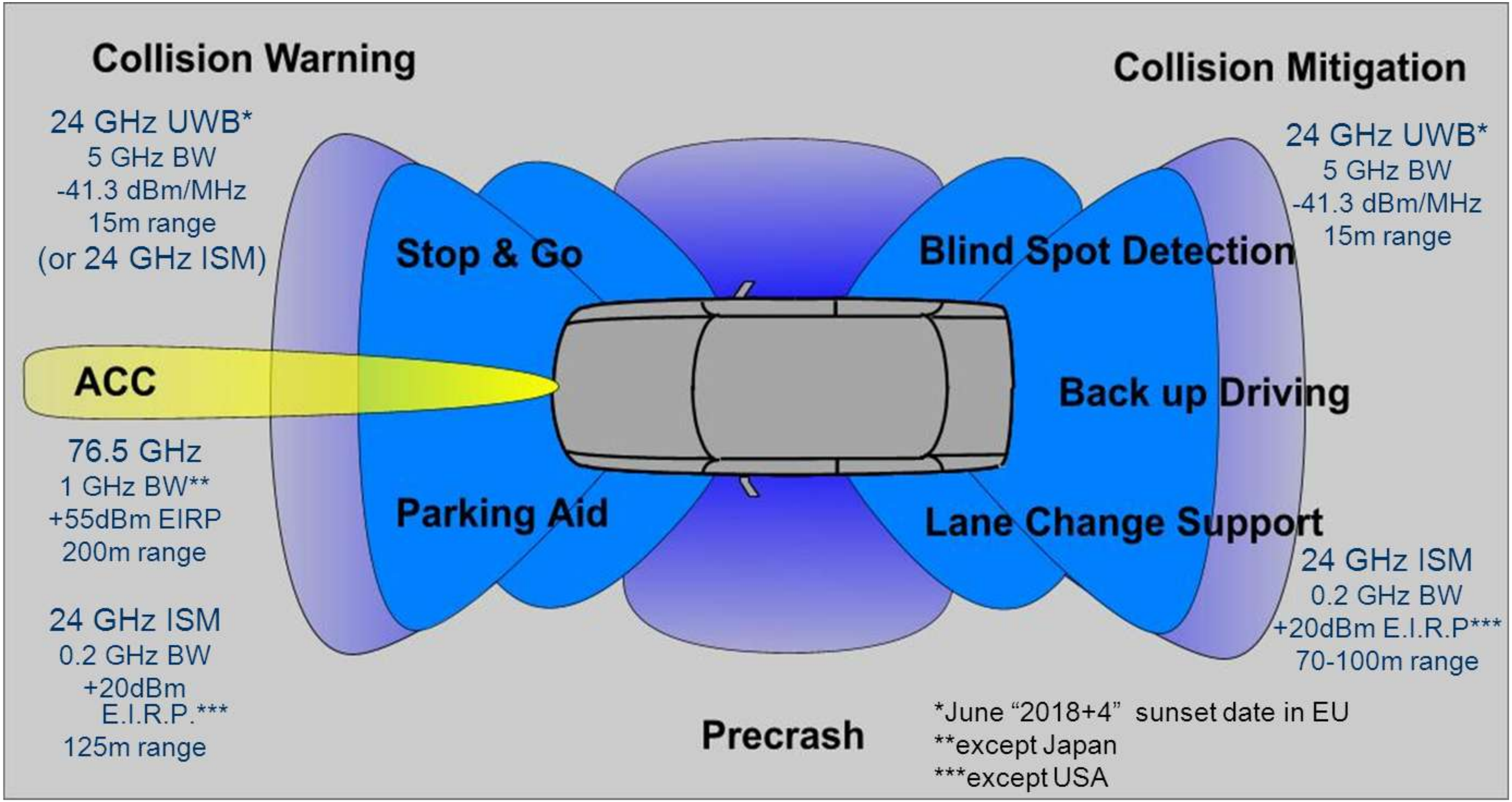
	24GHz NB	24/26 GHz UWB	77GHz ACC band	79GHz band
Available Bandwidth	< 200MHz typ. 100 MHz	5 to 7 GHz typ. 0.5 to 2 GHz	1GHz typ. 200 MHz	4GHz typ. 2 to 3 GHz
target separation capability	150cm	10cm	75 cm	7.5cm
max. power e.i.r.p. in EU/CEPT	20dBm* peak	0dBm/50MHz (peak) -41dBm/MHz (RMS)	55dBm* 50/23.5dBm*	55dBm* -3 (9[1])dBm/MHz (RMS)
S/N ratio gained#	up to 46dB	0dB	≈ 22…42dB[1]	≈ 10…42dB[2]

* measured over the entire bandwidth
\# compared to 24GHz UWB
[1] measured outside the vehicle
[2] depending on applied modulation and noise figure of system

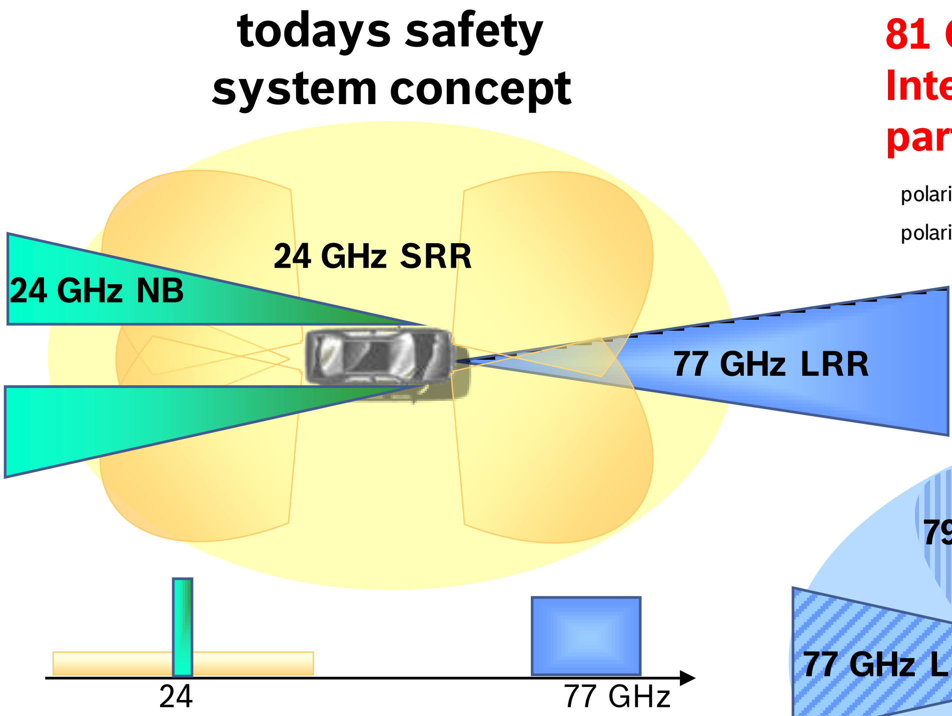
Feasibility overview – what applications are possible?

Applications	24GHz NB	24/26 GHz UWB	77GHz ACC band	79GHz band
ACC	low cost ACC possible	not possible due to range limitation	yes	no, special ACC band available
ACC with Stop & Go	limited due to separation performance	yes	yes	yes
Precrash and Pedestrian protection	no, not enough precision	yes	no, not enough precision and field of view	yes
Blind Spot Monitoring	limited performance, often in combination with LCA	yes	no	yes
Emergency brake	no, not enough precision	yes, in combination with ACC radar	yes, in combination with UWB SRR	yes, in combination with ACC radar
Lane Change Assist	yes	no	yes	yes
Parking aid	not possible due to weak object separation	yes	not appropriate due to high power	yes

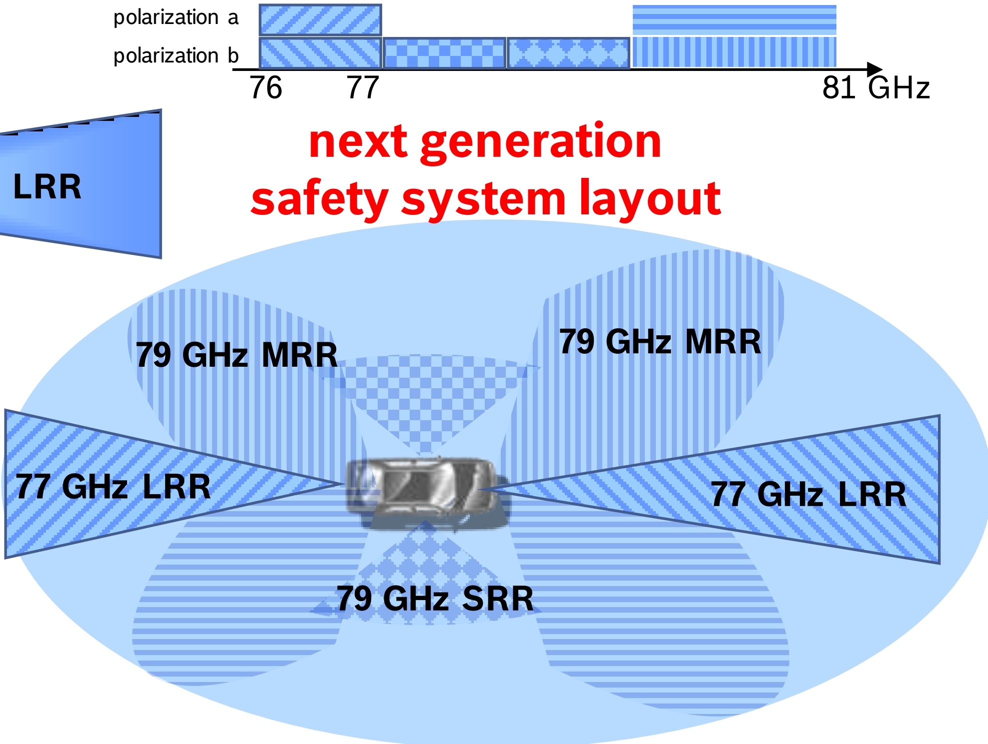
Current frequency usage by applications



Safety concepts evolution by next generation frequency usage



a common radar sensor source from 76 to 81 GHz that covers all applications, Interference free operation (shown partition is only one possible example)



heterogenic approach with different radar systems having different performance, interference risk and application portfolio

The 79 GHz band

PROs & CONs

Mutual interference of Automotive Radars

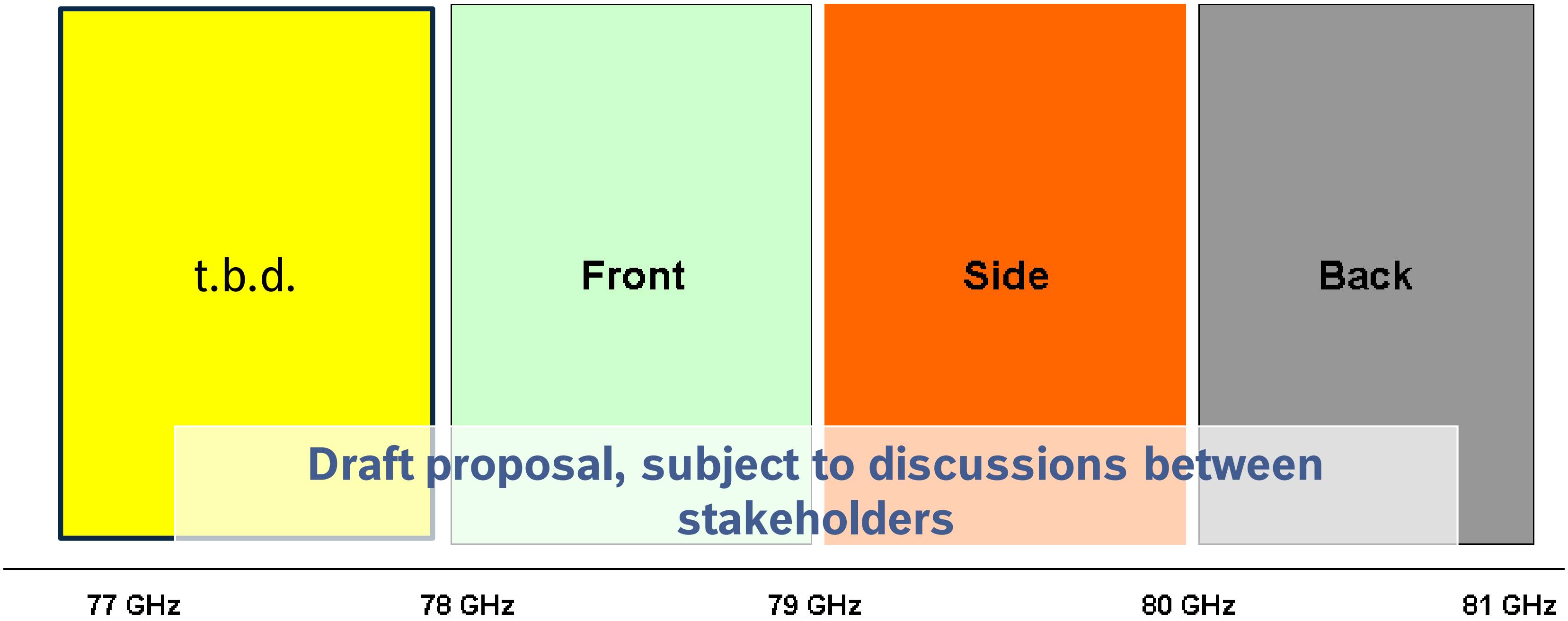
Automotive radar frequency band	bottleneck	consequence
24 GHz narrowband (24.05 to 24.25 GHz)	bandwidth	all radars operate with high power in the same, small frequency range => very high interference risk
26 GHz UWB SRR (24.25 to 29 GHz)	low emission power	very low emission power => low interference risk
77 GHz ACC	high power, no standard	no standard regarding interference mitigation installed or planned
79 GHz SRR	none	De-facto standard possible because no products in the market and interference free design still possible

→ Goal / Topic of the MOSARIM project to clarify this issue

Possible approach: application based band segments

79 GHz band segmentation by application to minimize interference (→ safety applications!)

Proposed polarization for all applications: 45 ° linear



Interference Risks from other services

Automotive radar frequency band	# of other inband users	consequence
24 GHz narrowband (24.05 to 24.25 GHz)	very high	ISM, no control of the band possible, high interference potential, no protection at all
26 GHz UWB SRR (24.25 to 29 GHz)	medium	primary and co-primary services, with very tough interference protection requirements that limit SRR capability
77 GHz ACC	only few	actually very low usage of the band, very high vehicular radar emission power allowed, low interference risk by others
79 GHz SRR	only few	very low interference risk by others due to mainly passive service usage only

→ Goal / Topic of the MOSARIM project to clarify the interference issues

Requirements for Radar Sensors

A) High Range Resolution
- Exact position of two targets
- Differentiation of small targets in front of large targets

B) High Angular Resolution
- Measure target dimension to mitigate accidents
- Characterize lateral targets

C) Wide Detection Range
- Detect potential risk at an early stage

D) Wide Opening Angle
- Simultaneous monitoring of safety relevant targets at the roadside or in intersections

Requirement / Action	Resolution		Field of View			
	Range (high)	Angle (high)	Range (<[illegible]m)	Range (<120m)	Angle (>20°)	Angle (>90°)
Parking in small parking lot	■	■	■			■
Driving through a narrow street	■	■	(■)	■	■	
Breaking in one way street	■			■	■	
Crossing Object moves in own lane	■	■	■			■
Evasion of obstacle in the same lane	■	■	■		■	
Turn off in multi lane crossing	■	■	(■)	■		■
Gateway into invisible junction		■	■			■
Close up to traffic jam	■			■	■	
Braking in front of a crossing pedestrian waiting between two parking vehicles	■	■	■			■
	A	B	C		D	

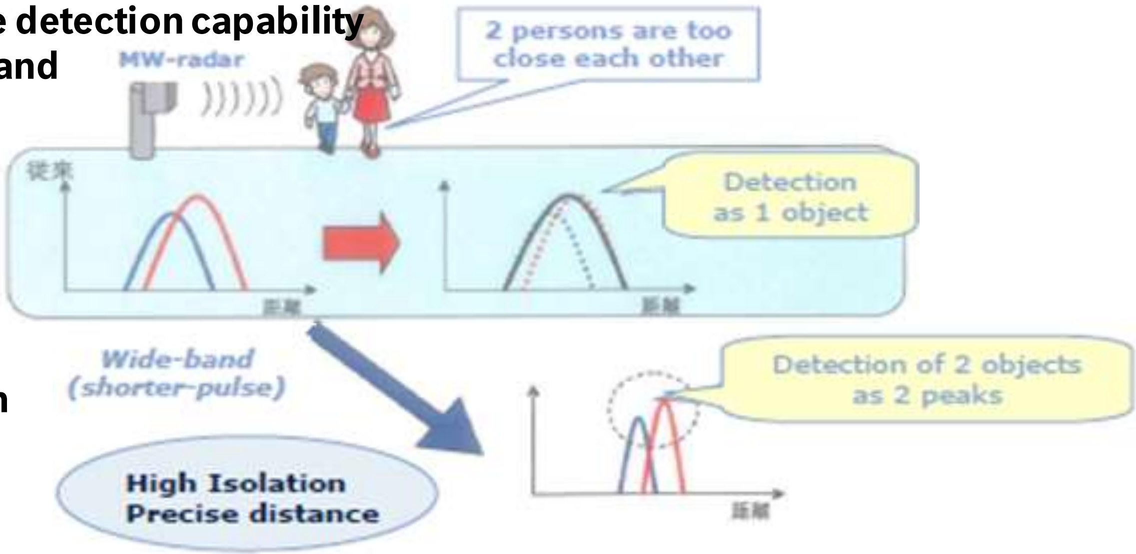
Application specific radar sensor required
- SRR **or** MRR

High-Resolution technology by 7X-Radar system

1) <u>Investigation for new wide-band radar concept</u>
   - Higher Resolution / Isolation capability
   - More precise Distance / Angle detection capability
   - Required frequency range / band

*existing radar systems with 100-200MHz can‘t have such high isolation capability

2) <u>Investigation for new wide-band radar systems</u>
   - Measurement / Characterization of transmission
   - Countermeasures for potential interference



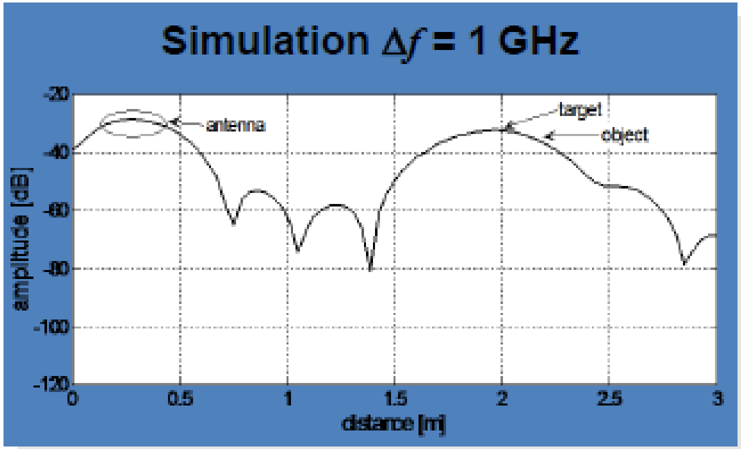
*Interference should be a problem to achieve higher attachment rate

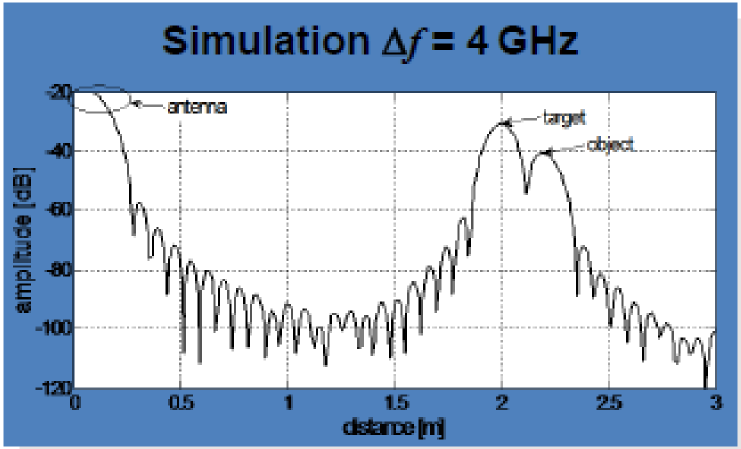
=Goal=
Detect objects with <20cm resolution at x10m
(5x higher resolution)

Motivation for higher frequencies

- small antennas → most suitable for car integration
- high absolute bandwidth available enabling high separation in distance

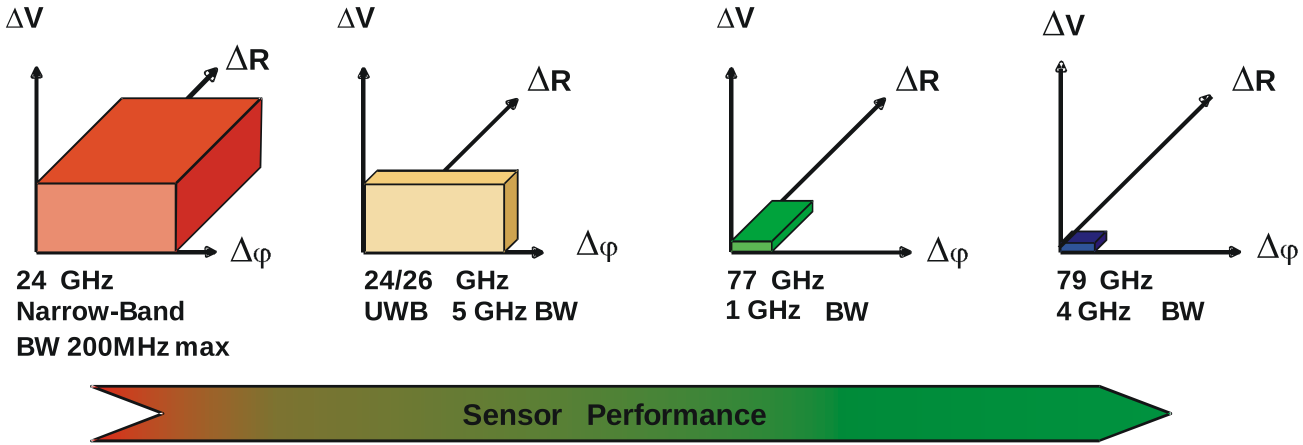
$$\Delta R = \frac{c}{\Delta f}$$





High bandwidth for robust and precise radar measurements

Advantages 76 / 79 GHz Radar Sensors



Legend:

ΔV : Velocity Axis

Δφ : Angle Axis

ΔR : Range Axis

→ Doppler resolution of object distance is RF frequency dependant
Higher RF frequency enables better Doppler resolution

→ For a given aperture, the resolution increases with frequency.
Angular resolution depends on antenna aperture.

The smaller the cubic the better the radar performance

The smaller the cubic, the better is the overall performance
79 GHz outperforms all other frequency operation ranges !!!

Sensor Technology Comparison

Next generation solutions

	SHORT-RANGE RADAR (24 GH2 UWB)	LONG-RANGE RADAR (77 GHz)	LIDAR	ULTRASONIC	VIDEO
RANGE MEASUREMENT <2 m	++	-	0	++	-
RANGE MEASUREMENT 2 to 30 m	++	++	++	-	-
RANGE MEASUREMENT 30 to 100 m	-	++	+	--	-
ANGLE MEASUREMENT <10 DEGREES	+	+	++	-	++
ANGLE MEASUREMENT >30 DEGREES	0	-	++	0	++
ANGULAR RESOLUTION	0	0	++	-	++
DIRECT VELOCITY MEASUREMENT	++	++	--	0	--
OPERATION in RAIN	++	+	-	0	0
OPERATION in FOG or SNOW	++	++	-	+	-
BLOCKAGE (DIRT on SENSOR)	++	++	0	+	--
OPERATION at NIGHT	++	++	++	++	--

++	IDEALLY SUITED
+	GOOD PERFORMANCE
0	POSSIBLE, MODEST PERFORMANCE
-	FEASIBLE, ONLY WITH LARGE EFFORT
--	IMPOSSIBLE

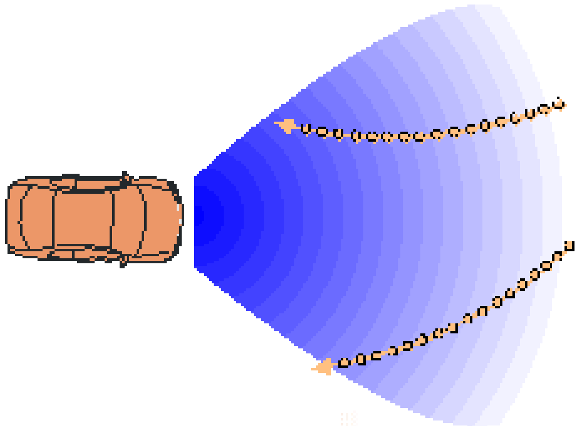
BOSCH

Advantages 76 / 79 GHz Automotive Radar Systems

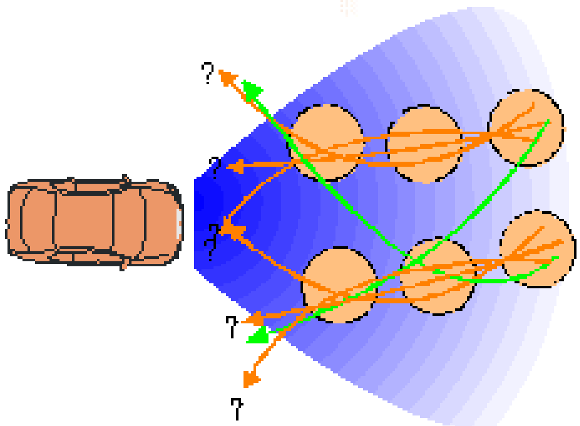
79 GHz is most likely the long-term solution for automotive due to:

- **high range**
- **high spatial resolution**
- **high angular resolution**
- **higher doppler shift**

UWB- Improvements for object tracking



Only a high resolution system is capable of reliable object tracking, i.e. predict the further path of the obstacle. This is essential to forecast a crash.



A low resolution system does not allow a reliable judgement whether an object will crash into the car or not. Predictability even deteriorates with multiple objects in field of view.

Bandwidth and spatial resolution

Situation: „small obstacle in front of a big obstacle“.
A system with low resolution will not see an object in front of a wall

Bandwidth and spatial resolution

Spatial Resolution and the effects on Pre-Crash functions

Close obstacle pass-by

Crash on test objects

Only high resolution radar can distinguish between close obstacle pass-by and collision with low false alarm rate.

Bandwidth and spatial resolution

- High separation is required to analyse the complex car environment and to distinguish between different objects
- Precise object trajectory and location is needed for prediction of further object movement and correct interpretation of the road scenario
- A low resolution will result in unreliable forecasts and false alarms
- Low resolution systems will miss small objects in front of a big one

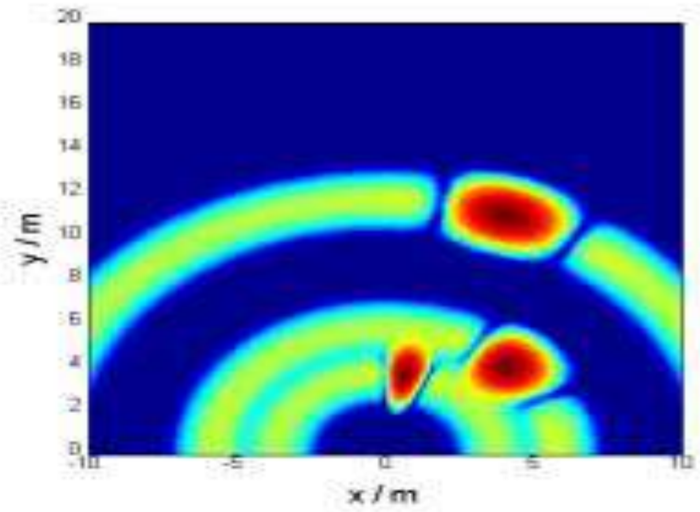
⇨ **High separation is physically linked to high bandwidth**

⇨ **High separation is essential for more sophisticated safety applications**

BOSCH

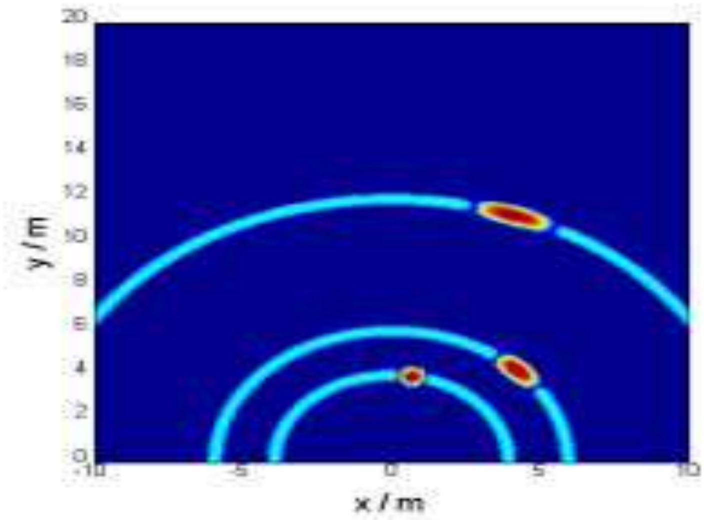
Target separation capability

B = 250 MHz



Typ. Long Range Radar Bandwidth

B = 1250 MHz



Typ. Short Range Radar Bandwidth

Comparison: 77 GHz vs. 24 GHz Mid Range Radar

Size comparison: 77 GHz (BOSCH) vs. 24 GHz (Hella)

77 GHz MRR - 1/3 size of a “typical” 24 GHz sensor at comparable field of view

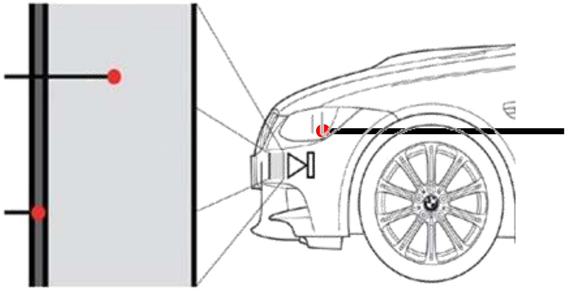
Summary: Advantages of 76 / 79 GHz Radar Sensors

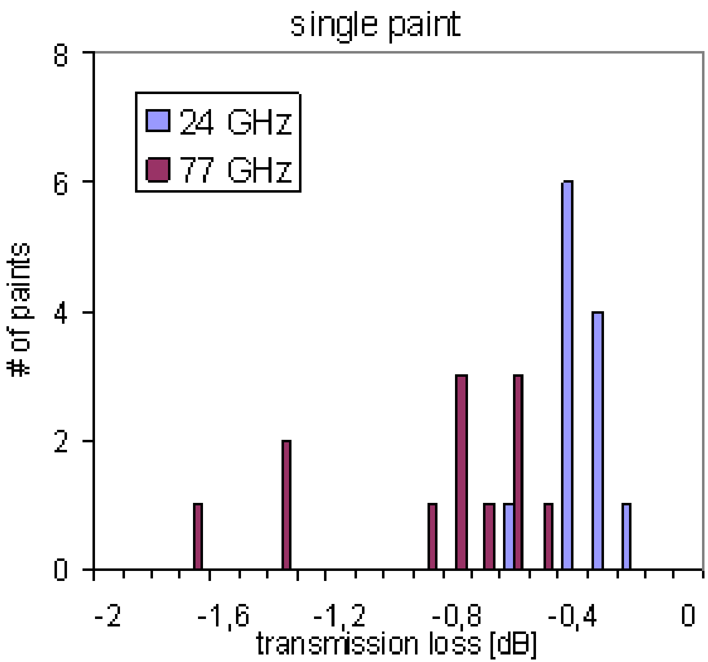
- Factor 5 times better **object separation** by distance compared to 24 GHz narrow band solutions
  - due to higher useable bandwidth of 1000 MHz -4000MHz vs. typical available bandwidth of 200 MHz for 24 GHz ISM sensors
  - Separation capability ~ occupied bandwidth

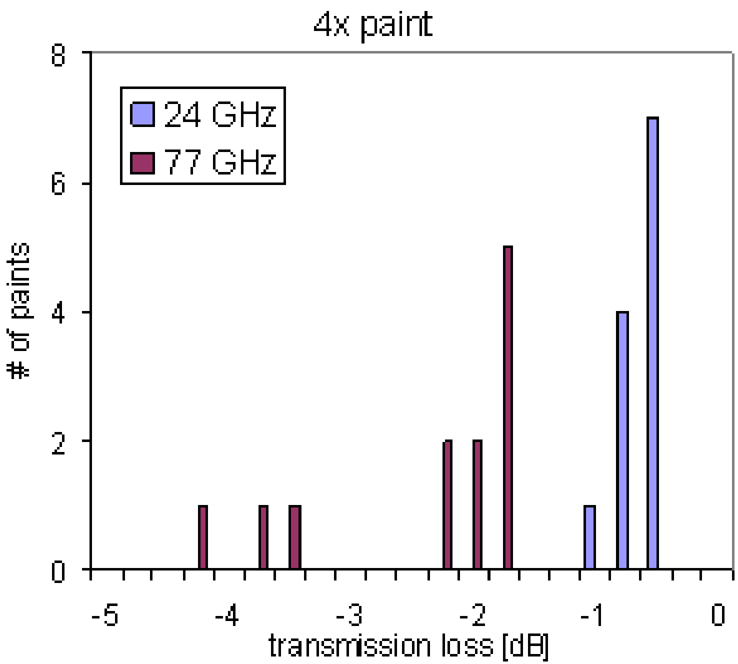
- Factor 3 times **better accuracy in measurement of relative velocity** compared to 24 GHz solutions
  - due to better Doppler resolution at higher carrier frequency ($f_{doppler} \sim f_{carrier}$)

- Factor 1/3 **smaller size of antenna structure** compared to 24GHz for equal field of view (sensor opening angle / detection range)
  - due to direct coupling of wavelength to antenna dimensions!

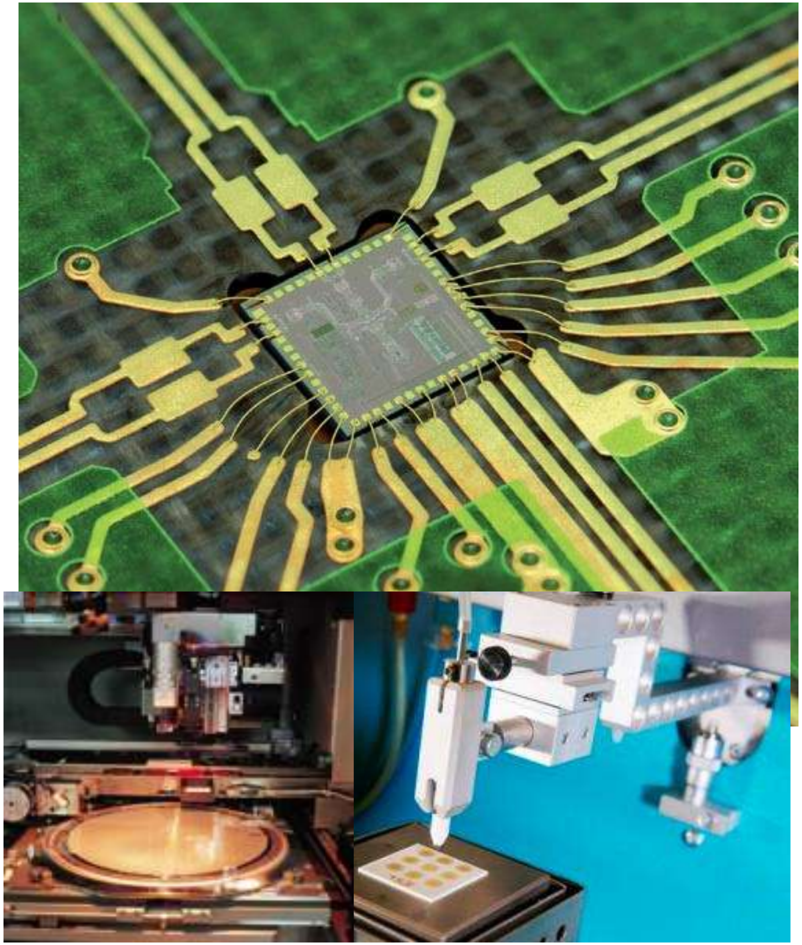
Bumper loss at 79 GHz







Semiconductor technology – are 79 GHz MMICs more expensive?



There are two key cost drivers in the RF front-end:

1) Availability and cost of the MMICs
2) Assembly and manufacturing process

The “scaling” factors:

1) Die size ~ 1/frequency (only 1/3 ofmaterial)
2) GaAs -> SiGe -> RFCMOS roadmap

The economic factors:

1) Worldwide market -> large volume
2) Large volume -> cheaper

Global 79 GHz rulemaking can solve the chicken-egg challenge !

Technical information

3rd Gen. Bosch Long Range Radar Sensor (LRR3)

Performance data (compared to second generation)

- Field of View: **30°** (16°)
- Range: **0.5...250m** (1.5 ...200m)
- Object separation
  - By distance: **<0.75m** (2m)
  - By velocity: **0.6m/s** (1.2 m/s)
  - By angle: **~4°** (none)

74 x 77 x 58 mm
(L x W x H)

Technology:

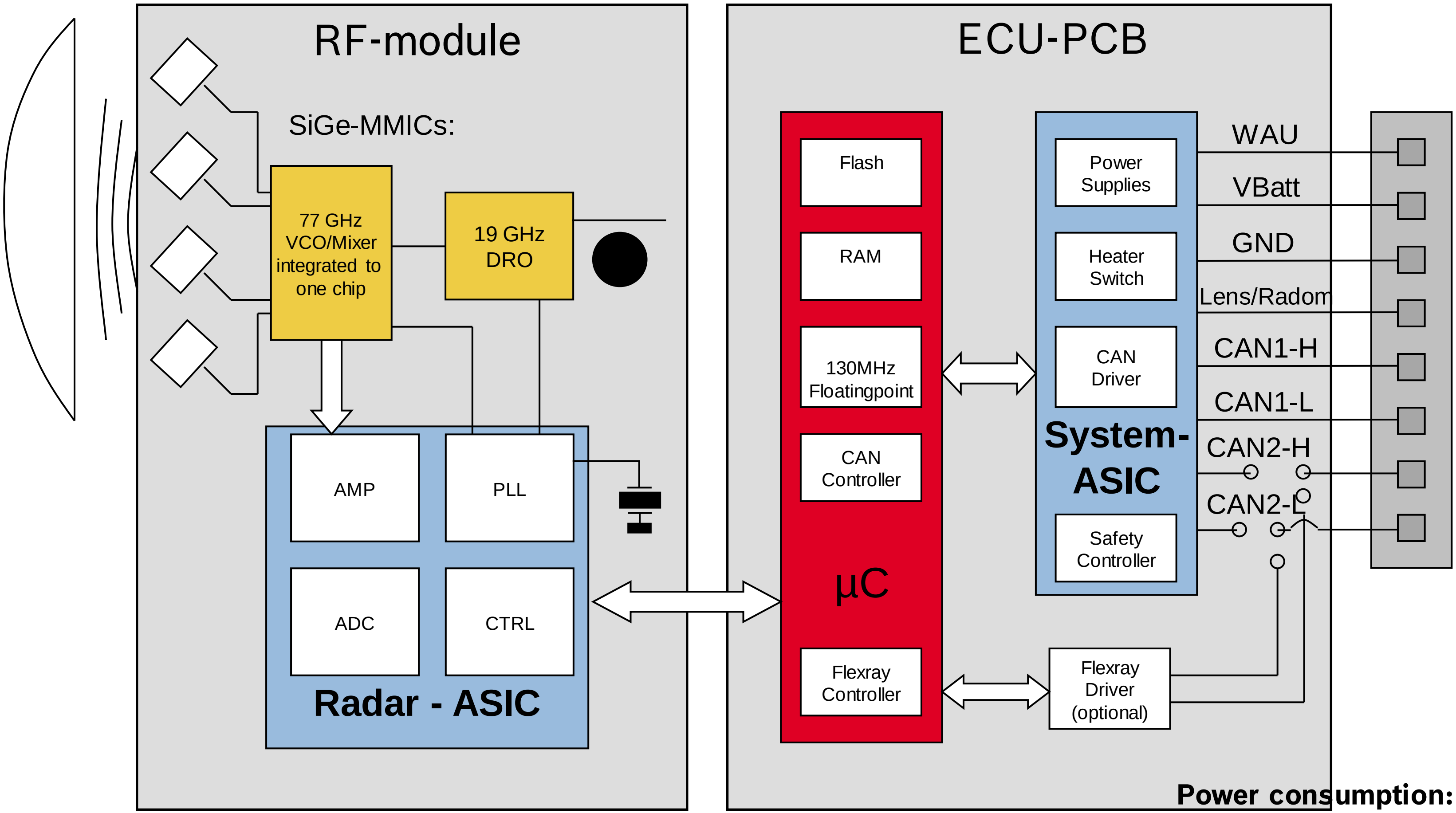
- 76 GHz Silicon Germanium MMIC **(world's first)**
- Flexray communication (optional)
- Package advantages (one of the smallest)
- Lead free technology

Status:

- SOP in 05/2009

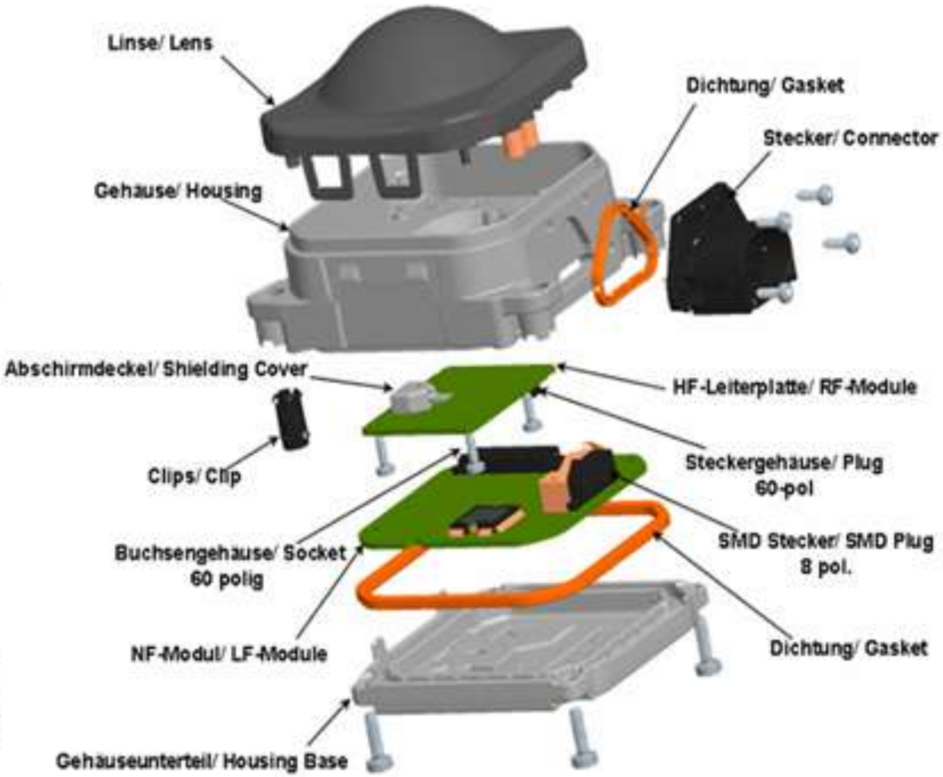
BOSCH

Block – Diagram LRR3

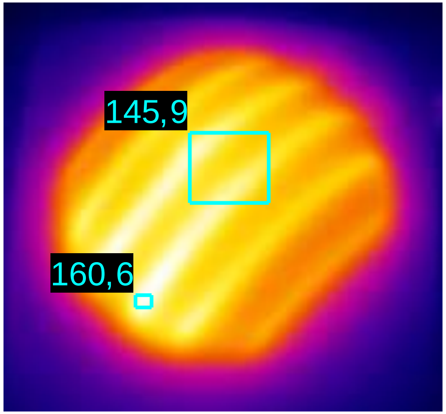


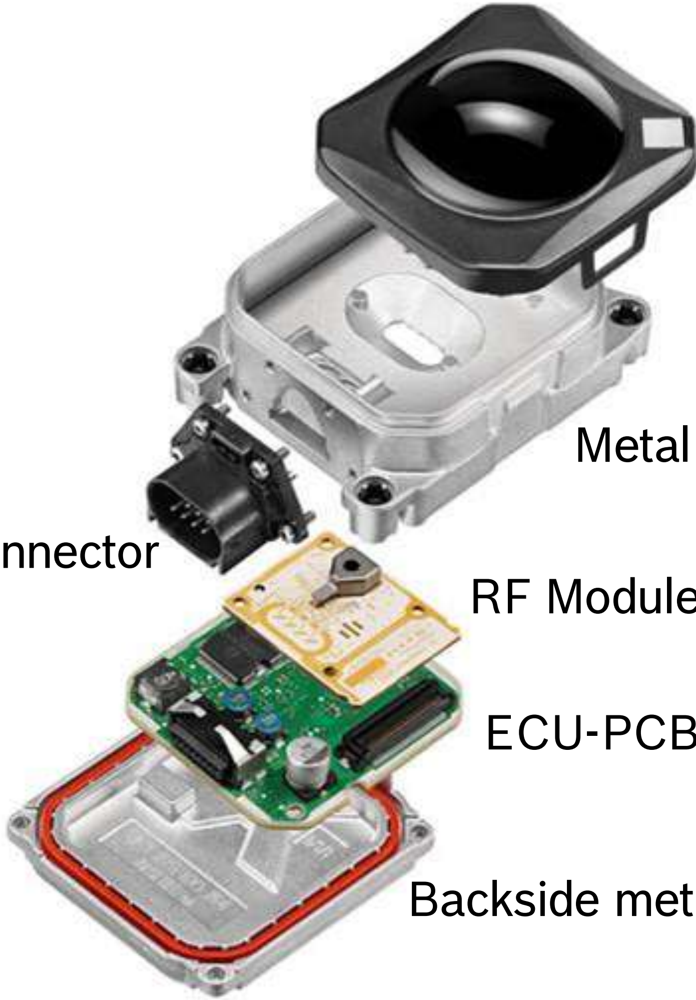
Power consumption: < 4W

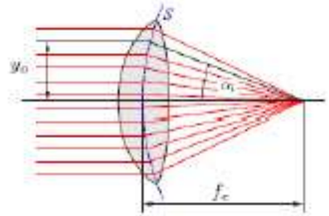
Mechanical Assembly LRR3

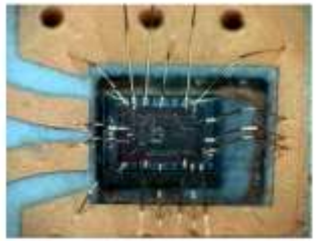


Technical info





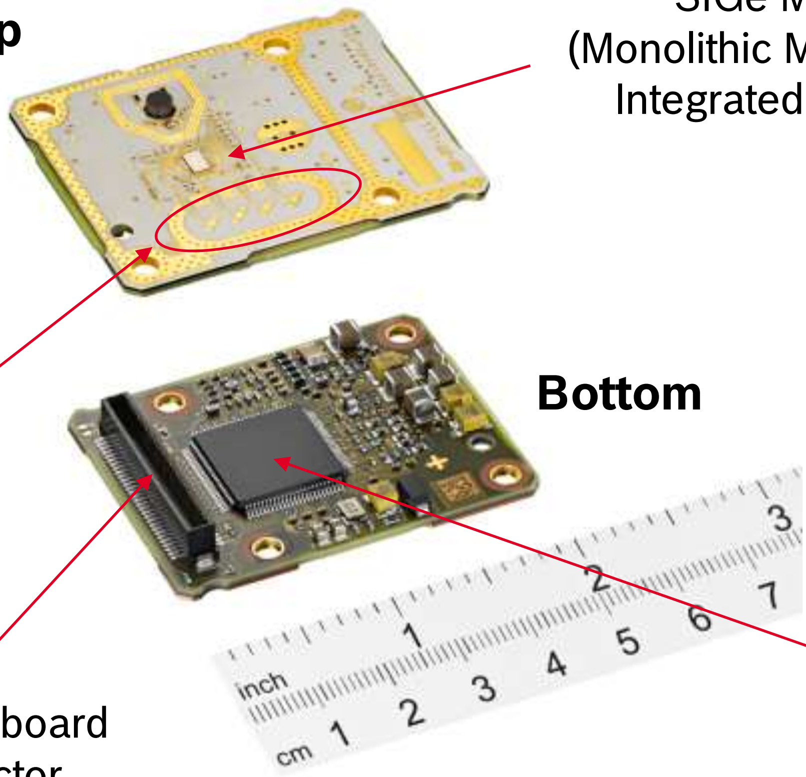


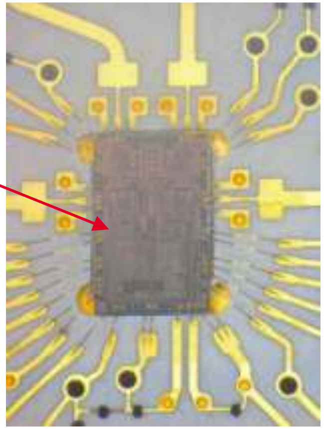


RF-Frontend

Top

SiGe MMIC
(Monolithic Microwave
Integrated Circuit)





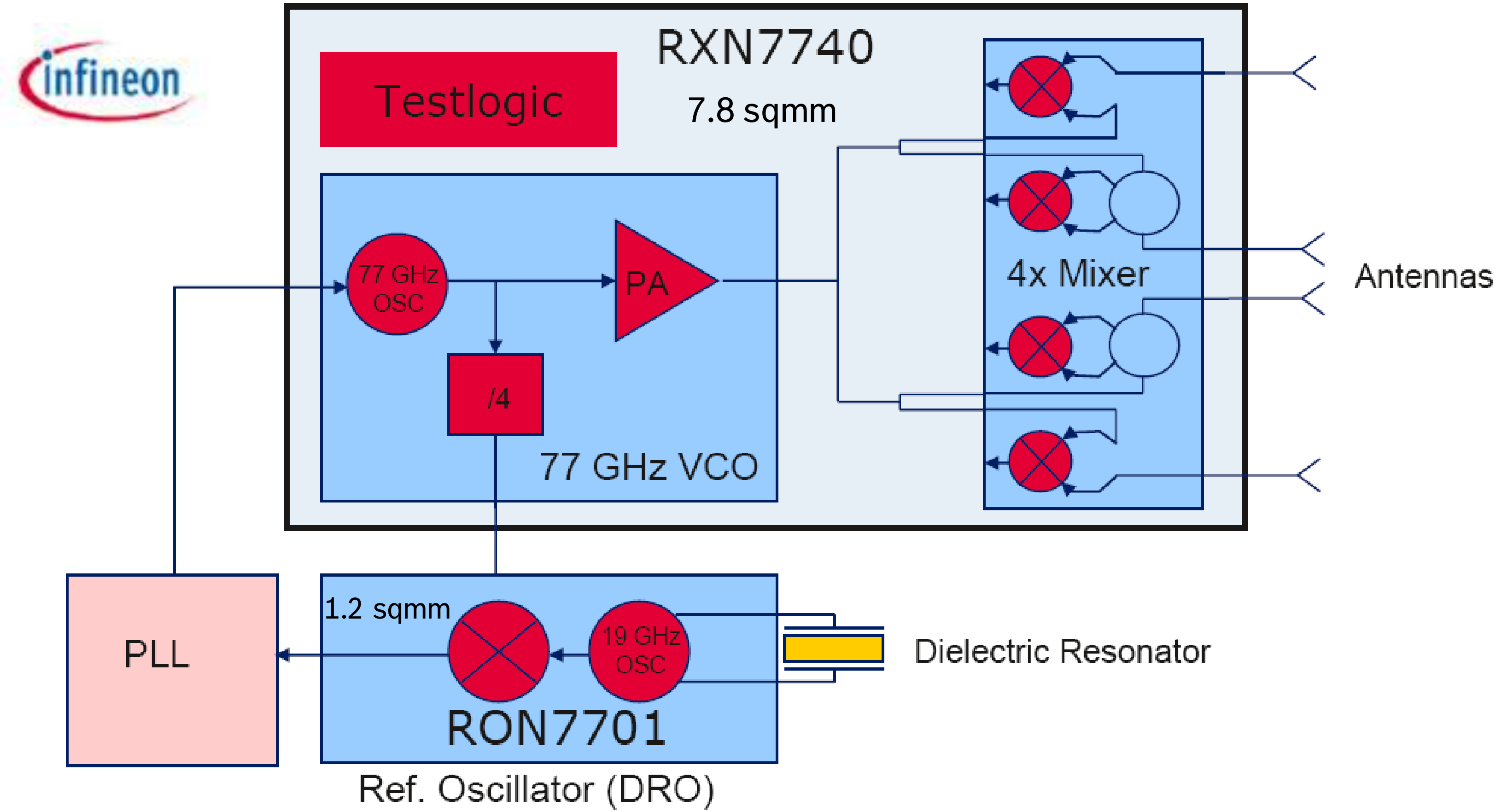
Bottom

4 Patch Antennas

Board to board
connector

Radar-ASIC
CF630

SiGe – technology inside LRR3

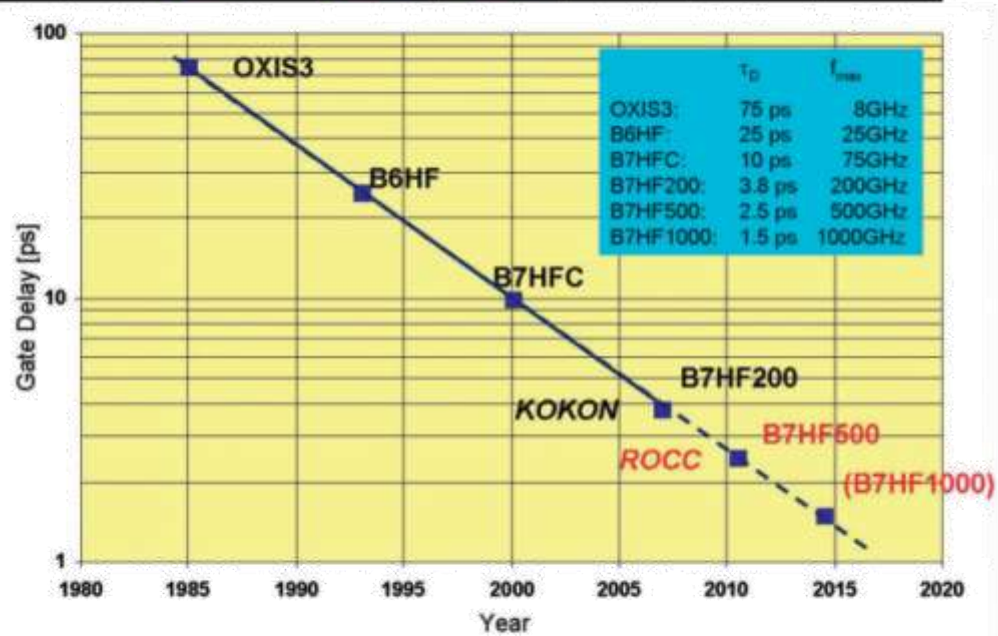


SiGe Technology Roadmap

Generic

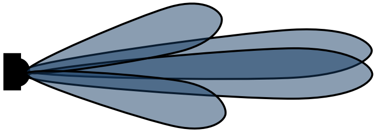
	2007	2008	2009	2010	2011	2012	2013
ITRS (GHz) PeakFmax In production	280	305	330	350	370	390	410
DOTFIVE PeakFmax (GHZ) in R&D		330	400	500			500 in production

Infineon

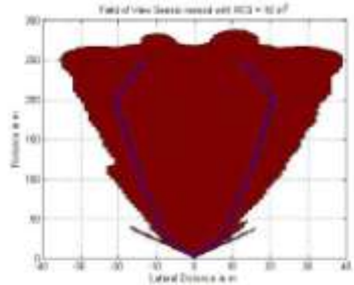


Sensor Platform

LRR3 (standard)

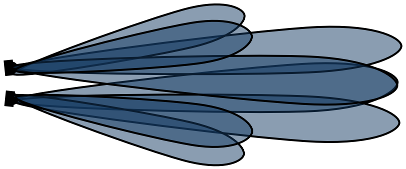


distance 0.5 ... 250 m
FoV 30° @ 30 m

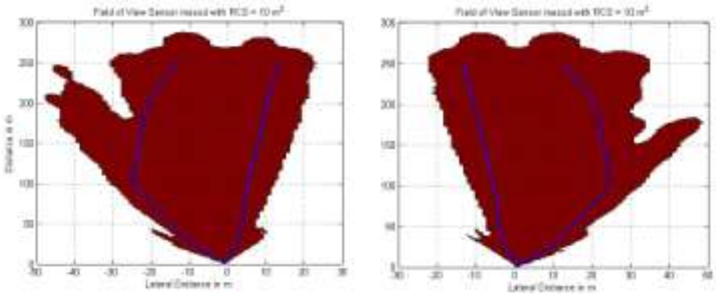


Double-LRR

SiGe MMIC Mixer modification

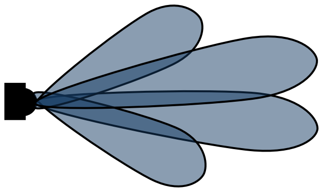


distance 0.5 ... 250 m
FoV 60° @ 30 m

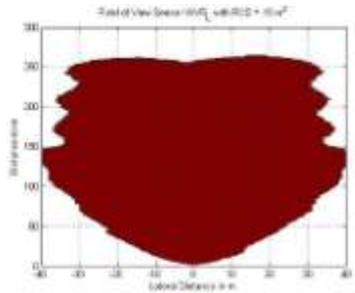


WVR
(Wide View Radar)

Lens modification



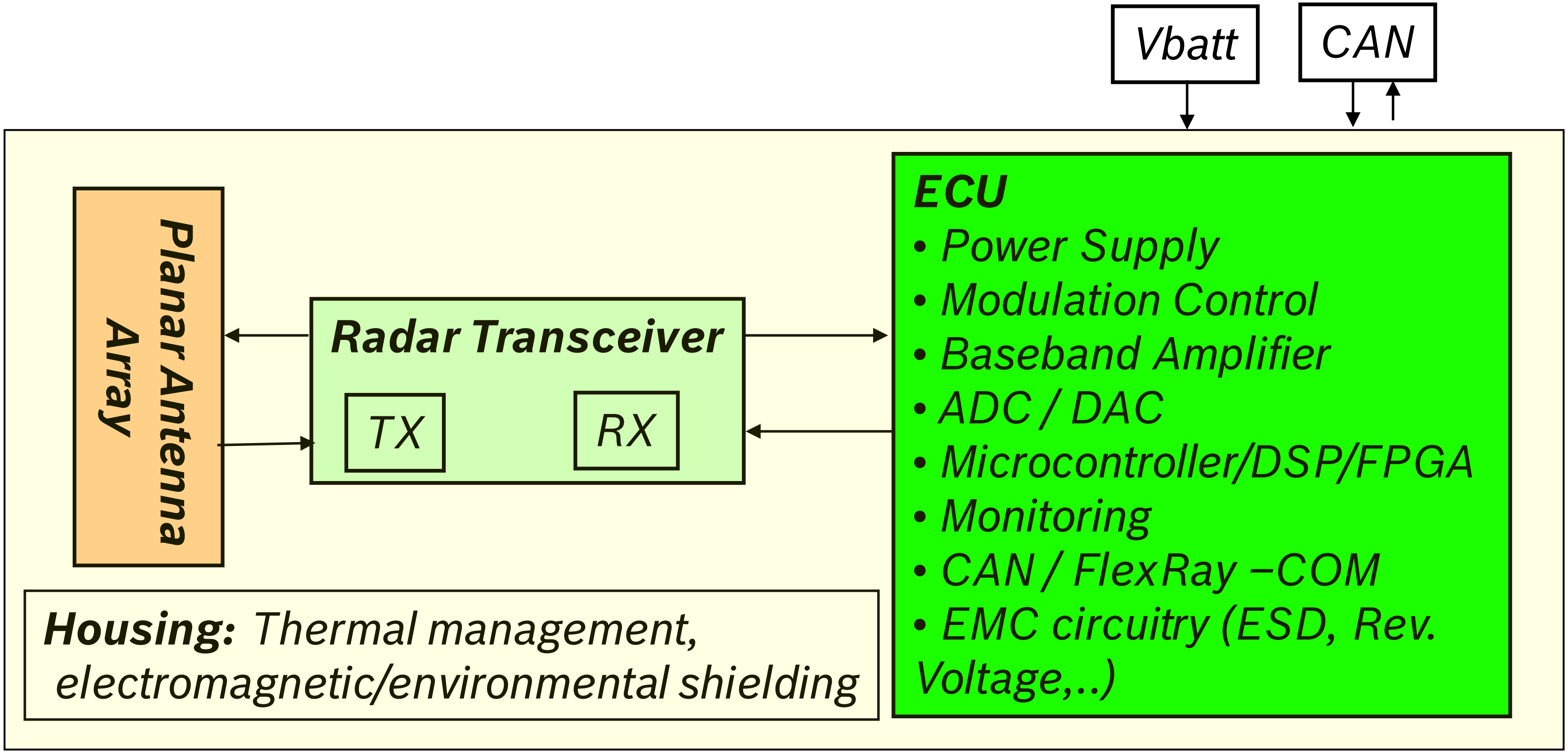
distance 0.5 ... 200 m
FoV 50° @ 30 m



BOSCH

77/79 GHz Mid Range Radar

Top Level Diagram of a Radar Unit:



Mid Range Radar MRR

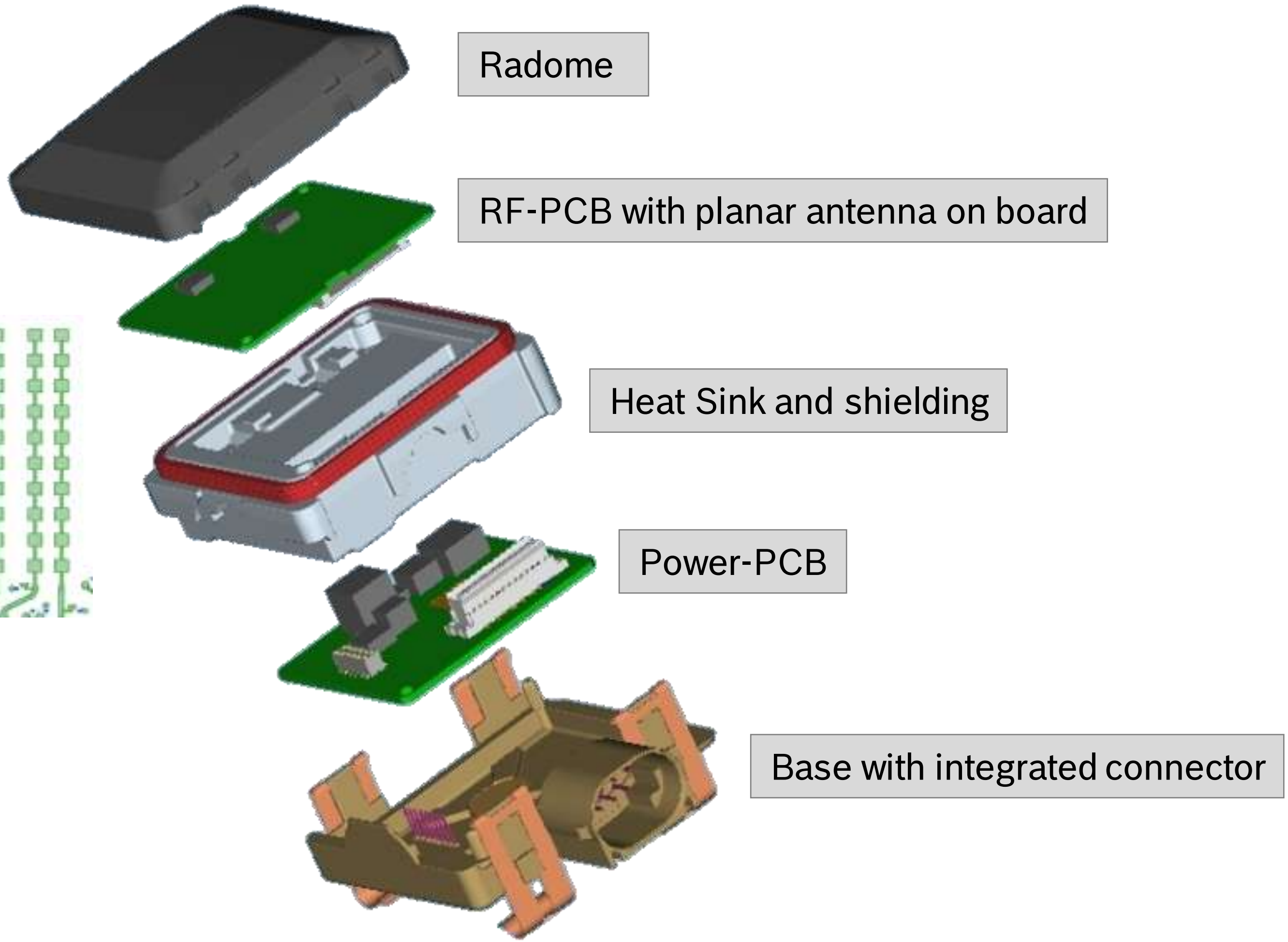
Technical Concept

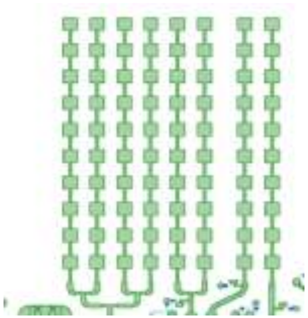
- Based on three generations of well proven automotive radar know-how
- High level of synergy with BOSCH 3rd generation of Long Range Radar
  - same frequency band 76-77GHz, same bandwidth 500MHz
  - FMCW modulation
  - SiGe MMIC technology but: with cost effective packaging
  - re-use of proven LRR3 submodules and ASICs

Dimensions:
Length: 70 mm
Width: 60 mm
Depth: 30 mm

All abbreviations within this presentation used for simplification purpose

Technical info

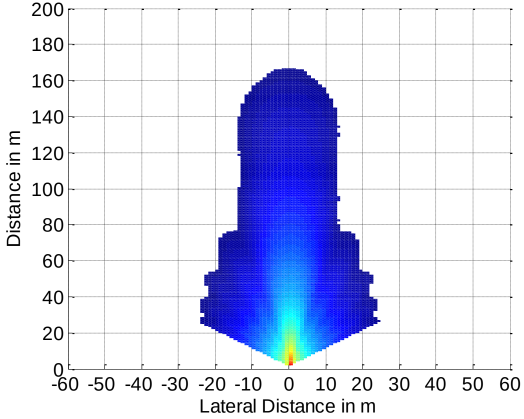




Mid Range Radar – front / rear variants

MRR*front*

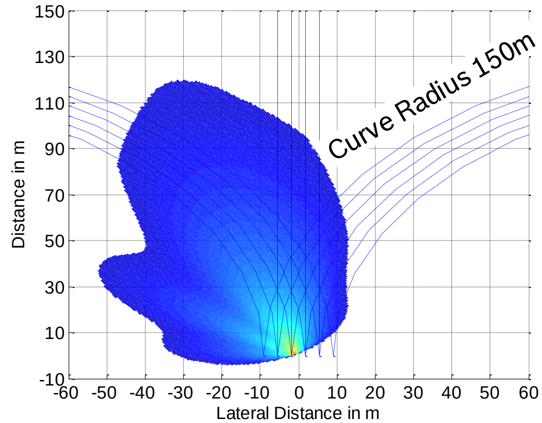
Field of View



Range:
~160m

FOV:
45° (70°)

MRR*rear*



Range:
~120m

FOV: 75°

Situation assessment
Who is doing what?

Activities of Tier 1 suppliers in the different frequency ranges

Competitors	24GHz "narrow band"	24GHz UWB	77GHz ACC band	79GHz SRR band
Autoliv	no	yes	no	no
Continental	yes	yes	yes	yes
Bosch	**no**	**no**	**yes**	**yes**
Valeo(Raytheon)	yes	no	no	no
Delphi	no	yes	yes	no
TRW(Autocruise)	yes	no	yes	yes
Hella (SMS/InnoSent)	yes	no	no	no

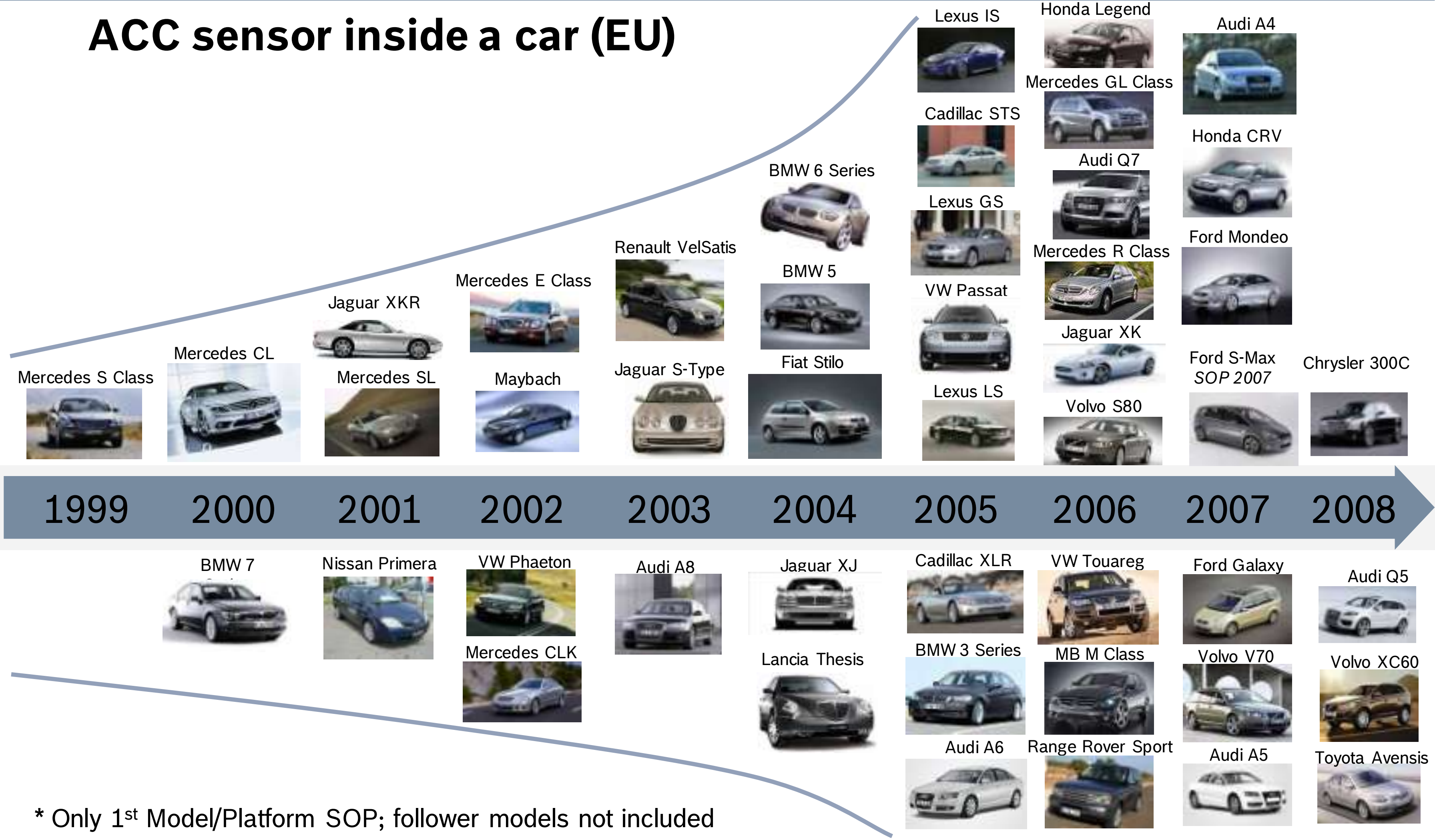
Who is doing what?

Activities of OEMs in the different frequency ranges

Manufacturer	24GHz NB	24GHz UWB	77GHz ACC band	79GHz SRR band
Audi	yes (Q7)	no support	yes	?
BMW	yes (PL6)	yes	yes	support
Daimler	no	yes (S/E class)	yes	support
Fiat	?	?	yes	?
Ford	in favor	Backup in US	yes	?
Honda	?	?	yes	?
Mazda	yes	yes	no	?
Nissan	?	?	yes (also Lidar)	?
Opel/GM		some US support	no (Lidar ?)	?
PSA	yes (ARTIV)	no support	no	support
Renault	in favor	no support	no	support
Toyota	?	?	yes	?
Volvo/Jaguar	yes (LCA)	?	yes	?
VW	in favor	no support	yes	?

Who is doing what?

ACC sensor inside a car (EU)



* Only 1st Model/Platform SOP; follower models not included

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