Automotive Radar

from comfort to safety and beyond

- the potentials and the obstacles on the road to make it happen

Holger H. Meinel
Automotive Radar Expert
Retired, formerly with Daimler AG, Stuttgart

holger.h.meinel@gmx.de
Introduction
– why me?

1974

That was me - then!
Contents

• Motivation
  - the road traffic death toll

• **History** – the **technical** beginning
  - from “swords to ploughs” to safety

• **Today** - State-of-the Art – the **commercial**
going-on
  - today’ s frequencies – 24 & 77/ 81 GHz
  - paradigm change: from comfort to safety

• **Future** - what’s necessary and available ?
  - technically
  - commercially
  - politically

• Conclusion
Road traffic deaths by WHO region

- Africa: 234,000
- South-East Asia: 285,000
- Western Pacific: 278,000
- European (+ North-West Asia): 118,000
- America: 142,000

Worldwide approximately 1.23 million fatalities per year

Source: Global Status Report on Road Safety, WHO 2009
Weltweite Fahrzeugzulassungen

In diesen Ländern wurden 2012 (Januar bis November) die meisten Pkw neu zugelassen, in Mio.

- **USA**: 13,09
- **BRASILIEN**: 3,29
- **EUROPA**: 11,69
- **RUSSLAND**: 2,68
- **CHINA**: 11,99
- **JAPAN**: 4,29
- **INDIEN**: 2,57

SWP GRAFIK
Quellen: dpa, Weltbank, VDA

*EU 27 ohne Malta, mit Norwegen, Liechtenstein, Schweiz, Island
We are convinced that innovative technologies will make it possible to one day drive a car without any accidents – in all vehicle categories and markets of this world.
But!  
– the turn-around in Europe

Mobile phones and driving...

Drivers who use a mobile phone, whether hand-held or hands-free:

- are much less aware of what’s happening on the road around them
- fail to see road signs
- fail to maintain proper lane position and steady speed
- are more likely to ‘tailgate’ the vehicle in front
- react more slowly, take longer to brake and longer to stop
- are more likely to enter unsafe gaps in traffic
- feel more stressed and frustrated.

They are also **four times** more likely to crash, injuring or killing themselves and other people.

From: Alain Dunoyer, SBD, UK
Early History – ACC in Europe

<table>
<thead>
<tr>
<th>Year</th>
<th>Manufacturer</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1972</td>
<td>RCA</td>
<td>10 GHz FM-CW</td>
</tr>
<tr>
<td>1974</td>
<td>AEG-TFK</td>
<td>35 GHz pulsed</td>
</tr>
<tr>
<td></td>
<td>Lucas Ltd.</td>
<td>32 GHz FM-CW</td>
</tr>
<tr>
<td>1975</td>
<td>SEL</td>
<td>16.5 GHz FM-CW</td>
</tr>
<tr>
<td>1976</td>
<td>AEG-TFK</td>
<td>50 GHz pulsed</td>
</tr>
<tr>
<td>1977</td>
<td>Bendix</td>
<td>36 GHz diplex cw</td>
</tr>
<tr>
<td>1978</td>
<td>SEL</td>
<td>35 GHz FM-CW</td>
</tr>
<tr>
<td>1980</td>
<td>Toyota/Fujitsu</td>
<td>50 GHz FM-CW</td>
</tr>
<tr>
<td>1982</td>
<td>Nissan</td>
<td>24 GHz pulsed/FM</td>
</tr>
<tr>
<td>1984</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1986</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1988</td>
<td>Philips</td>
<td>94 GHz L/c Hybrid</td>
</tr>
</tbody>
</table>
1974 – the first 35 GHz Distance Warning Radar (DWR) from TELEFUNKEN

Technical Data

35 GHz Abstandswarnradar / Collision avoidance radar

Reichweite / Range 130 m

Antennenhalbwellenbreite / Half-wave antenna width

35-GHz-Empfänger/Mischer

horn: Quartz substrate with 15 mixer-inserts for series production
### Table 2 - Status of automotive radar

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Frequency</th>
<th>Type</th>
<th>Range</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toyota Motor Corp.</td>
<td>49.5 GHz</td>
<td>FM-CW</td>
<td>60 m</td>
<td>1974</td>
</tr>
<tr>
<td>Nissan Motor Co.</td>
<td>24 GHz</td>
<td>Pulsed FM-CW</td>
<td>60 m</td>
<td>1978</td>
</tr>
<tr>
<td></td>
<td>60 GHz</td>
<td>Pulsed FM-CW</td>
<td>u.c.</td>
<td>1985</td>
</tr>
<tr>
<td>SEL AG</td>
<td>35 GHz</td>
<td>FM-CW</td>
<td>100 m</td>
<td>1974</td>
</tr>
<tr>
<td>AEG AG</td>
<td>35 GHz</td>
<td>Pulsed FM-CW</td>
<td>100 m</td>
<td>1973</td>
</tr>
<tr>
<td>SMA/FlAIAT</td>
<td>35 GHz</td>
<td>u.e.</td>
<td>1987</td>
<td></td>
</tr>
<tr>
<td>Penn. State Univ.</td>
<td></td>
<td>u.e.</td>
<td>1985</td>
<td></td>
</tr>
</tbody>
</table>

**Early History – ACC worldwide**

DASA – A-Model

C-Model

Fujitsu Sensor

NISSAN

VW-Rockwell

TOYOTA

TRW

IZUZU
History – CWS 20 years ago

1996 – the first 24 GHz Collision Warning System (CWS) from EATON VORAD in series production
**ADAS**
Advanced Driver Assistance Systems

**History – CWS 20 years ago**

**1997**

- more than 4,000 systems installed
- over 900 million km driven (trucks & buses)

**GREYHOUND bus with Oregon license plate pictured in Atlanta, GA**

---

<table>
<thead>
<tr>
<th>Fleet Type</th>
<th>Accidents per Million Kms without CWS</th>
<th>Accidents per Million Kms with CWS</th>
<th>Accident Reduction Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Totals</td>
<td>1.0</td>
<td>0.3</td>
<td>69%</td>
</tr>
<tr>
<td>Beverage Distributor</td>
<td>2.2</td>
<td>0.0</td>
<td>100%</td>
</tr>
<tr>
<td>Leasing Company II</td>
<td>6.32</td>
<td>1.0</td>
<td>100%</td>
</tr>
<tr>
<td>Leasing Company I</td>
<td>0.5</td>
<td>0.3</td>
<td>100%</td>
</tr>
<tr>
<td>Trucking Carrier II</td>
<td>0.8</td>
<td>0.0</td>
<td>100%</td>
</tr>
<tr>
<td>Tractor Tractor I</td>
<td>3.7</td>
<td>0.5</td>
<td>100%</td>
</tr>
<tr>
<td>Total</td>
<td>224.8</td>
<td>0.3</td>
<td>100%</td>
</tr>
</tbody>
</table>

- Provides additional reaction time: 0.5 seconds => 50% accident reduction
  1.0 seconds => 90% accident reduction

The first societal impact - the Greyhound drivers union forced the withdrawal of the system.
History & Background

AUTOMOTIVE RADAR
market introduction strategies

1. increased comfort
   without increasing

2. increased

1999

swords to ploughs ...

the new start

Source: 20th SAMPE Europe, Paris, 13th -15th April 1999
Comparative Test of Advanced Emergency Braking Systems

Products tested: Audi A6, BMW 7-series, Ford Focus, Honda Civic, Lexus GS, Mercedes B, Mercedes C, Opel Insignia, Volvo V40, VW Touareg

Test criteria: Collision alert, adaptive brake assist, fail operation
## ADAS
Advanced Driver Assistance Systems

### Summarized table of results

<table>
<thead>
<tr>
<th>Year</th>
<th>ADAC verdict</th>
<th>Overall rating</th>
<th>Approach on slower vehicle</th>
<th>Approach on steadily decelerating vehicle</th>
<th>Approach on stopping vehicle</th>
<th>Approach on stationary vehicle</th>
<th>Adaptive brake assist</th>
<th>Alert cascade</th>
<th>Upgrade: following distance warning</th>
<th>Downgrade: fall operation</th>
<th>Tier 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>BMW 750i</td>
<td>++ 1.3</td>
<td>1.1</td>
<td>1.0</td>
<td>1.8</td>
<td>1.7</td>
<td>0.6</td>
<td>2.0</td>
<td>-0.1</td>
<td></td>
<td>Conti</td>
</tr>
<tr>
<td></td>
<td>Mercedes C 350 CDI</td>
<td>++ 1.4</td>
<td>1.4</td>
<td>1.6</td>
<td>1.9</td>
<td>1.4</td>
<td>0.6</td>
<td>1.8</td>
<td>-0.1</td>
<td>0.1</td>
<td>Conti</td>
</tr>
<tr>
<td></td>
<td>Volvo V40 T4 Summum</td>
<td>++ 1.5</td>
<td>0.8</td>
<td>2.0</td>
<td>1.9</td>
<td>1.0</td>
<td>0.6</td>
<td>2.0</td>
<td>-0.1</td>
<td>0.2</td>
<td>Delphi</td>
</tr>
<tr>
<td></td>
<td>VW Touareg V8 TDI</td>
<td>+ 1.7</td>
<td>1.5</td>
<td>1.4</td>
<td>2.4</td>
<td>3.3</td>
<td>0.6</td>
<td>1.5</td>
<td></td>
<td></td>
<td>Autocruise</td>
</tr>
<tr>
<td></td>
<td>Audi A6 3.0 TDI quattro</td>
<td>+ 1.8</td>
<td>1.8</td>
<td>1.5</td>
<td>2.7</td>
<td>3.3</td>
<td>0.6</td>
<td>1.3</td>
<td></td>
<td></td>
<td>Bosch</td>
</tr>
<tr>
<td></td>
<td>Lexus GS 250F Sport</td>
<td>+ 2.1</td>
<td>0.8</td>
<td>3.1</td>
<td>1.7</td>
<td>2.8</td>
<td>1.6</td>
<td>2.5</td>
<td></td>
<td></td>
<td>Fujitsu-Ten</td>
</tr>
<tr>
<td></td>
<td>Opel Insignia 2.0 BiTurbo CDTI Sport</td>
<td>O 3.3</td>
<td>2.3</td>
<td>2.4</td>
<td>2.0</td>
<td>3.1</td>
<td>5.5</td>
<td>3.0</td>
<td>0.1</td>
<td></td>
<td>Delphi</td>
</tr>
<tr>
<td></td>
<td>Honda Civic 2.2 i-DTEC Executive</td>
<td>O 3.4</td>
<td>2.8</td>
<td>3.7</td>
<td>2.7</td>
<td>2.6</td>
<td>5.5</td>
<td>2.3</td>
<td>0.1</td>
<td></td>
<td>elesys</td>
</tr>
<tr>
<td></td>
<td>Mercedes B 180 CPA 2.0</td>
<td>O 3.5</td>
<td>3.3</td>
<td>3.3</td>
<td>4.3</td>
<td>4.4</td>
<td>2.2</td>
<td>3.8</td>
<td>-0.1</td>
<td>0.1</td>
<td>Autoliv</td>
</tr>
<tr>
<td></td>
<td>Ford Focus 1.6 i EcoBoost Titanium</td>
<td>O 3.6</td>
<td>2.7</td>
<td>2.7</td>
<td>2.9</td>
<td>4.2</td>
<td>5.5</td>
<td>3.3</td>
<td></td>
<td></td>
<td>Delphi</td>
</tr>
</tbody>
</table>

Source: ADAC Test Zentrum, Landsberg
• ACC in the form of Distronic Plus (at MB) was only the beginning and a prerequisite for further advanced systems, like
• Brake Assist PLUS (BAS)
• PRE-SAFE Brake
and we have
• CPA (today 3.0) – Collision Prevention Assist
• PRE-SAFE Brake

Based on a 77 GHz ACC sensor

Approx. 2.6 s before the accident*
Visual and acoustic collision warning

Approx. 1.6 s before the accident
After the audible warning has been repeated three times:
PRE-SAFE® Brake automatically initiates partial braking if the driver has not responded

Approx. 0.6 s before the accident
If the driver has still failed to respond: autonomous emergency braking with maximum braking performance to reduce impact severity

*Time calculated by the system until the impact where the relative speed remains unchanged
The „all-around collision-free car“ incorporates applications, like:

- **Safety shield**
- Intelligent Brake Assist
- Active stability assist
- RCTA
ADAS could reduce accidents by 80%.

Today roughly one accident per 280,000 miles driven.

2040 only one accident per 1,600,000 miles driven.

Source: KPMG – August 2015
The Electronic Shoulder Check
No-one can see what is going on behind their back. This limitation has always been compensated in vehicles by means of rear-view and exterior mirrors. One area nevertheless remains: the blind spot. Every year, around 9,500 serious road accidents in Germany are caused by motorists, failing to take heed of the traffic behind.

IEEE G-MTT 1971
Wash. DC

IEEE MTT-S 1995
San Francisco

The system is composed of two lane-changing sensors and a back-up sensor. Each sensor is a CW homodyne radar. The antennas for the lane-changing sensors can be mounted adjacent to the automobile tail lights. The antenna patterns intersect adjacent lanes to illuminate the blind areas and to warn of the presence of approaching automobiles with a light or audible signal. The radars are instrumented to ignore roadside objects. The maximum range of these sensors is 50 to 70 feet on cars, with a minimum range response down to the center door post to cover the entire blind zone.
Europe being at the forefront of ADAS and EBS sensor systems
- not only in Europe, but worldwide

- **Hella (NB-sensor)**
  - being employed by Audi, BMW, Mazda, KIA, Peugeot, VW, Volvo …

- **Valeo (NB-sensor)**
  - being employed by GM, Ford, Jaguar, Land Rover, GMC (trucks) …

- **Autoliv (UWB-sensor)**
  - being employed by Mercedes-Benz (MFA & MRA)

Hella as well as Valeo have each sold more than 2 Mio. units p.a. in 2014
Besondere Anforderungen der Automobilindustrie

Automobile sind langlebige Produkte

- Elektronik wird auf 15 Jahre/300.000 km/8000 h ausgelegt

Hohe Anforderungen an Umweltbeständigkeit, abhängig vom Verbaupunt im Fahrzeug

- Temperatur, Feuchte, Vibration, Chemikalien

Hohe Anforderungen an die Zuverlässigkeit der Komponenten

- Ausfallraten im ppm Bereich werden gefordert

Diese Anforderungen bleiben – letztendlich - nachzuweisen!
Applicable for low cost - plastic - packages

- Package temperature: 85°C
- Minimum temperature: -30 °C (due to adhesive materials)
- Channel temperature: 185 °C
- MTBF: 10 years

**ADAS**
Advanced Driver Assistance Systems

**State-of-the-Art**
- component requirements

**Potentials and Obstacles**

---

Fig. 2. Measured speed of CMOS and SiGe transistors

**B. Packaging**

Modern automotive radar sensors like the Bosch MRR [12] are manufactured using surface-mount technology, even for the 77 GHz millimeter-wave parts. This is a key enabler to achieve low-cost and high-volume production.

In addition to the millimeter-wave capable package, the printed circuit board (PCB) is another key element, serving multiple purposes. It is used as antenna substrate, means for RF, DC, power and digital signal distribution, mechanical carrier of electronic components, and for thermal management.

Fig. 3 shows the PCB of the MRR with antenna and frontend integrated circuits on the top side, and baseband with digital electronics on the bottom side.

With increasing performance requirements, fulfilling all these demands gets more difficult and expensive, so new solutions for PCB and package are required. One approach is the introduction of new substrate materials based on liquid-crystal polymer (LCP) or expoy resin, that enable multilayer-structures, and improved manufacturing compared to the current Teflon-based substrates, and are also more cost efficient [13].

Another venue is the separation of the millimeter-wave signals from low-frequency signals to allow new solutions for distributing and radiating the millimeter-wave RF signals. Antenna elements integrated on-chip and in-package have been evaluated for this purpose before, an new approach is the coupling of the RF signal directly from the package using a package to waveguide transition [14].

**C. Antenna Element**

The antenna element has always been a determining factor in radar performance. As the available bandwidth has increased from 1 GHz in the 76-77 GHz band to 4 GHz in the newly available 77-81 GHz band, the antenna element needs to provide this increased bandwidth. In order to simultaneously achieve a good input match, a well defined robust antenna pattern with low sidelobes, without requiring a new complex and costly technology, new antenna concepts are required like [15].

Also, as more information about the environment like road surface or remote object properties are desired, polarization...
**ADAS**

Advanced Driver Assistance Systems

**State-of-the-Art**

- sensor manufacturers in Europe

- **Europe being at the forefront of ADAS and EBS sensor systems**
  - not only in Europe, but worldwide

- **Continental ARS 300/301** (the bench) – **ARS 400**
  - being employed by Cadillac (ATS), Hyundai (Equus), Hongqi (Q3)
  - BMW, MB (MRA), Volvo …

- **Bosch LRR 3 – LRR 4**
  - being employed by Audi, MB (MFA), Lancia, Porsche, VW …

- **Autocruise AC 20 - AC1000**
  - being employed by Citroen, PSA, Renault, VW …

- **Delphi** (research in Wuppertal)
  - being employed by Opel (GM), Ford …

- **Hella**
  - being employed by Audi, BMW, Mazda, KIA, Peugeot, VW, Volvo …

- **Valeo**
  - being employed by GM, Ford, Jaguar, Land Rover, GMC (trucks) …

---

**Infineon announced in July 2015 to have manufactured more than 10 million radar chips for cars**

(Source: Microwave Journal)
Europe being still at the forefront of ADAS and EBS sensor systems

- Continental ARS 300/301 (the bench up to today)
  - being employed by Cadillac (ATS), Hyundai (Equus), Hongqi (Q3)
  - BMW, MB (MRA), Volvo …

- Continental ARS 400
  - to be started by MB (MRA) – E-class: BR213/2016

- Bosch LRR 3 – LRR 4 (Porsche to start with now)
  - being employed by Audi, MB (MFA), Lancia, Porsche, VW …

- Autocruise AC 20 - AC1000
  ZF-TRW AC 1000 Evo (SoP 2017)
  - being employed by Citroen, PSA, Renault, VW, Ford + GM (USA) …

- Delphi - RACam
  - being employed by Opel (GM), Ford, FAW, Yutong …
• It is no longer the question: *radar sensor or not*
• But the sensor performance under *interference* conditions
Visions for Vehicle Motion and Safety

Visions for Vehicle Motion and Safety

Potentials and Obstacles
1949 – Geneva convention
1968 – Vienna convention (article 8 (5))

*Every driver shall at all times be able to control his vehicle or to guide his animals*

2016 – 1st Amsterdam Amendment (since March 23rd)
- systems with influence are allowed
- to be overridden or switched off at all times

2016 – 2nd Amsterdam Amendment (due September)
- detailing BSD, ACC, etc.

From: Francois Guichard, UN Secretary, UNECE
The huge impact on the society AND the automotive industry is barely understood. Consolidation is inevitable as driverless cars will end a century-long status-quo.
Why? - Market Forecast

**ETP vehicle ownership projections**

**Total car stocks by region**

- Other Africa
- South Africa
- Other LA
- Brazil
- Middle East
- India
- Other Asia
- China
- Eastern Europe
- Asian TE
- Russia
- Korea
- Japan
- Australia and NZ
- Other OECD Europe
- UK
- Italy
- Germany
- France
- USA
- Mexico
- Canada

**INTERNATIONAL ENERGY AGENCY**

**AGENCE INTERNATIONALE DE L’ENERGIE**

Potentials and Obstacles
Autonomous Driving at Mercedes
- INTELLIGENT DRIVE

Potentials and Obstacles
State-of-the-Art - sensor technology road map

Potentials and Obstacles

[Yole Développement, Sensor technology roadmap and autonomous functions associated, 2015.]
**ADAS**
Advanced Driver Assistance Systems

**Autonomous Driving at Mercedes**
- INTELLIGENT DRIVE

**Enabler aus technischer Sicht**
- Sensor and ....

**Umgebungserfassung**

**Lokalisierung**

**Planung**

INTELLIGENT DRIVE – Berta Benz Drive 2013
‘Drive Me’
– Volvo Car Group (VCC) Sweden

‘iBUS’
– Yutong Bus Co. Ltd. China

‘European Truck Platooning Challenge’
– creating the next generation of mobility for 2025
- April 2016 Europe
Volvo Car Group (VCC) initiates a world unique pilot project with self-driving cars on public roads
2013-12-02 09:07

‘Drive Me’
– Self-driving cars for sustainable mobility’
is a joint initiative between VCC, the Swedish Transport Administration, the Swedish Transport Agency, Lindholmen Science Park and the City of Gothenburg.

The ‘Drive Me’ project is endorsed by the Swedish Government and based on the SARTRE results. The aim is to pinpoint the societal benefits of autonomous driving and position Sweden and Volvo Cars as leaders in the development of future mobility.

Scope to start with: 70 kph max. – no on-coming traffic – certified roads (maps)

The first autonomous cars (100) are expected to be on the roads in Gothenburg by 2017
**Near Future Trend (2) – sedans**

**A LIMITED SCOPE**

**Functionality:**
- Highly-automated driving on demand
- Certified roads only
- Weather limitations

**Road architecture characterized by:**
- No oncoming traffic or level crossings
- Pedestrian and bicycle traffic not allowed
- No traffic lights
- Max 70 km/h

Source: J. Ekmark; VCC: Automotive Tech.AD 2015
LiDAR sensors, emitting short pulses of laser light, co-operate with cameras to sense nearby objects and allow the automated vehicle to create a real-time, high-definition 3D image of its surroundings. This works extremely well in fine weather. But what happens when the cameras and sensors can't see the road markings because they are buried in snow? Then, the autonomous technology has a real problem.

SNOWY ! STILL A CHANCE FOR DRIVERLESS CARS ?!

Volvo has therefore created a mechanism by which the Drive Me cars will make a decision. “We have designed it so that each car will make an assessment to see if the conditions are ok for self-driving. That assessment will then be sent via a connectivity link to the Volvo cloud. Here, data from all cars will be aggregated and a decision is made if the weather in Gothenburg is appropriate for self-driving or not.”

From the LinkedIn BLOG:
SELF-DRIVING CARS IN WINTER
Feb. 19th 2016
Potentials and Obstacles
Autonomous Driving
- Computer School of Wuhan University

Potentials and Obstacles

Double Antenna GPS
Stereo Camera
Delphi Radar

Source: Ming Li, Wuhan University

2014
NSFC – National Natural Science Foundation of China – founded 1998

2009  First tests – Fiat involved providing the test vehicle

2010  Parking aid/ traffic light tests

2011  Urban tests in inner Mongolia (Hongqi Q3)

2012  12 Univ. involved – incl. NDTU, Shanghai
       (National Defense Technology Univ. – using a
       Hyundai test vehicle)

2013  118 Univ. involved – 18 different test areas and teams

2014  Bridges, U-turns in „clean“ (closed road) and urban environment

2015  iBus – intelligent bus drive on the 29th of August (Yutong);
       3 eyes, i.e. cameras, radar and Lidar
       (26 km, 26 traffic lights, vmax: 68km/h & 2 pass. stops)
FAW - Hongqi HQ3 sedan on the Beijing-Zhuhai-Highway in 2011
built by NDTU: National Defense Technology University in Shanghai

FAW – H7 sedan on the Sichuan International Fair 2015, in October in Chengdu, China with full a-drive features

- The driverless Hongqi HQ3 doesn't use GPS. Rather, it relies solely on its cameras and sensors. Its computer is capable of making driving decisions in 40 milliseconds compared with the 500 milliseconds a human driver takes, and because the HQ3 can respond more quickly to traffic scenarios, it's theoretically safer.

Liane Yvkoff: China hot on Google’s heels, 08/08/2011
**Yutong iBus – the intelligent urban bus**

- being tested on **August 29th, 2015** in an open urban environment
- 4 lidars (forward, 2 x sides, back)
- 1 radar (77 GHz LRR) advanced emergency braking system implemented
- 2 cameras (1x LDW, 1x traffic lights*)
- night vision system
- Sig-Net: actual online traffic data com.
- maintance management system engine, chassis, etc.
- results achieved:
  - **26 km driven autonomously**
  - with 26 traffic lights
  - 2 stops for passengers
  - several passing by sequences
  - **vmax: 68km/h**

*) black & red camera
Near Future Trend – buses

TEB

- transit elevated bus
- shown in Qinghuangdao this week
- up to 300 passengers
- Est. Price per unit: 4 Mio. €

Source: SWP – Ulm, 13.08.2016
Creating the next generation of Mobility for 2025
- organised by Rijkswaterstaat and TNO

Participating:

DAF Trucks (NL)
Daimler Trucks (D)
IVECO (I)
MAN Trucks & Buses (D)
Scania (S)
Volvo Group (S)
Creating the next generation of Mobility for 2025
- organised by Rijkswaterstaat and TNO

**Truck platooning** is innovative and full of promise and potential for the transport sector.
- braking immediately, with zero reaction time, platooning can improve traffic safety.
- platooning is a cost-saver as the trucks drive close together at a constant speed. This means lower fuel consumption and less CO2 emissions.
- platooning efficiently boosts traffic flows. Meanwhile the short distance between vehicles means less space taken up on the road.

![European Truck Platooning Challenge](image)
Creating the next generation of Mobility
- organised by Rijkswaterstaat and TNO
Potentials and Obstacles

CMOS is the next big step:

- Cocoons of radar sensors for 360° surround view
- Driving radar-based safety from premium into volume market
- Making ultra-sonic parking sensors obsolete

Google COCOON radar

Parking, Blind Spot Detection, Cross Traffic Alert, Emergency Braking, …


13. August 2016 48
Near Future Trend – cocoon radar
What is necessary?
- technologically, commercially & politically

- All available sensors are needed (redundancy)
  - radar, lidar, cameras (single, stereo, tri-focal)....
- Worldwide frequency regulations
  - for radar employment
- Pedestrian recognition
  - picture like- and micro-Doppler (wheel, pedestrian) processing
- Security, safety and reliability
  - ASIL definitions beyond ISO 26262
- Artificial intelligence using neural networks to “learn”
  - “powerful supercomputing” *
- Simple verification measurements for all types
  of sensors/ systems - ok – not ok
- HMI standards
- Societal aspects
  - user acceptance and -trust

Car OEMs will need to demonstrate industrial vision and leadership

Potential and Obstacles

D. Shapiro, NVIDIA, USA

* Possible in situ Measurements on Autonomous Radar Sensors
  Sept. 9th, 2015
• 77 – 81 GHz SRR for BSD/ LCA + applications
Countries with approved regulations or regulations under negotiation

Source: 79 GHz
www.79ghz.eu
Why – technology vision!
- bandwidth requirement

The 360° electronic Skin - cocooning - safety shield

From the mechanical crumple zone…

…to the electronic crumple zone

Source: Daimler Research
WARC 2015 – Nov. 17th 2015 - defined:

Automotive radar at 76 to 81 GHz is a “primary service” now
- other possible users have to make sure, that they do not interfere with this primary service (e.g. NavTech)
- They have to protect the functioning as a safety feature for cars

The band is not yet fully established:
- Canada, US and China up to 79 GHz only
- should be open in 2 years ...

Automotive radar at 136 to 141 GHz might be the choice for the future
- However - the packaging problems have to be solved

Thomas Weber: ECO – European Commission Office, Copenhagen


**ADAS**

**Advanced Driver Assistance Systems**

---

### Technology

- **Automotive radar above 100 GHz**
  - **122 GHz** for short range parking aids *
  - **150 GHz** for increased resolution ➔ “picture taking” by radar **

---

* * **LHFT**

Institut für Nachrichtentechnik und Hochfrequenzsysteme

* **BOSCH**

122 GHz sensor realization
Source: DE 102006062725 from Bosch

---

**Current Radar Circuits @ JKU-NTFHS**

- Single-channel and multi-channel
- Frequencies at 24 GHz, 60 GHz, 77 GHz, 94 GHz, 122 GHz, 140 GHz, 160 GHz, and 180 GHz (VCO)
- Homodyne and heterodyne systems
- 1D, 2D, 3D and cooperative measurements
- on-board, on-chip, and in-package antennas

---

* *
Autonomous Driving
- micro Doppler processing

Doppler signature of a walking pedestrian & a vehicle

Wheel recognition

Based on chirp sequence

Potentials and Obstacles

13. August 2016  55
ADAS
Advanced Driver Assistance Systems

Autonomous Driving
- the processing

DEEP LEARNING REVOLUTIONIZES VISION

Source: D. Shapiro, NVIDIA, USA, Automotive Tech.AD 2015, Berlin
Potentials and Obstacles
Measurement technology
- “in situ”?

Possible “in situ” - Measurements on Automotive Radar Sensors
What is necessary? - standardization

A logical HMI standardization is needed * here: BSD

- Initiating the different systems ACC, BSD, LCA, etc.
- Displaying the relevant information timing, deccelleration procedures
- Resulting in the same functions how to display it

*Automotive Tech.AD 2015, Berlin

➢ Otherwise the customer is not able to deal with the systems correctly and safely
Statements like “car drivers are open to automated driving in principle” (Continental 2013: 42) have to be handled with caution:

- It matters who imagines to use the technology where, when, and in what context.
- Merely responding to a technology that makes cars safer, more comfortable and efficient is not enough – specific usage perspectives of autonomous driving should be explored in depth.

Acceptance of autonomous driving is not only a question about whether individuals are ready to use autonomous vehicles but also about the societal implications that come along with the technology – and how they are perceived.

- Individual and societal aspects of acceptance have to be considered.

... remember Greyhound in the 90ies !!!

Slowly Step-by-step instead of an disruptive innovation !?!
Consumer Interest in Autonomous Vehicles (Western Europe)

Compared to other ADAS, consumers express far less interest in autonomous driving.

1/3 not at all interested in autonomous highway driving.

Almost half not at all interested in full autonomous driving.

The word “autonomous” has negative connotations and drives interest down.

Slowly Step-by-step instead of an disruptive innovation!?!
• Pedestrian recognition
  - DBF & switchable modulation waveforms

• All available sensors are needed (redundancy)
  - radar, lidar, cameras (single, stereo, tri-focal)….

• Further enhancement in sensor fusion
  - early or later in processing ? (zFAS vs. distributed processing)

• **Societal aspects**
  - user acceptance and trust has to be built up
    (remember Greyhound 1997)
  - not to forget responsibility!

---

**Car OEMs will need to demonstrate industrial vision and leadership**
RADAR REMAINS THE TECHNOLOGY OF CHOICE FOR DETECTION, TRACKING AND, MORE RECENTLY CLASSIFICATION, OF UNCO-OPERATIVE TARGETS, OVER HUGE VOLUMES OF SPACE AND OVER THE WIDEST POSSIBLE RANGE OF ENVIRONMENTAL AND OPERATIONAL CONDITIONS.

WE HAVE NOT REACHED – OR EVEN APPROACHED – THE LIMITS OF ACHIEVABLE PERFORMANCE.

From:
RADAR 2012
Les Gregory
Director - BAE SYSTEMS
We all knew it, since a long, long time . . .

Radar is it!

Source: Varan Assoc., USA, about 1985