How new Safety Systems and always Connected Vehicles leads to challenges on Antenna Design and Integration in the Automotive Domain

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Our heritage

“Cars are driven by people. The guiding principle behind everything we make at Volvo, therefore, is – and must remain – safety”

Assar Gabrielsson & Gustaf Larson, the founders of Volvo
Safety related functions—buzzwords

- City Safety
- ROPS
- Driver Alert Control
- Lane Departure Warning
- Collision Warning with full Auto brake and Pedestrian Detection
- WHIPS
- Advanced brakes: HBA, OHB, RAB, FBS, PPB
- SIPS
- Que assist
- Pre-prepared restraints
- BLIS
- Alcoguard
- IDIS
- Extended IC
- ACC
- ROPS
- Distance Alert
- DSTC
- Emergency brake lights
- Body Structure & Steel Material
- Pre-prepared restraints
- Active Bi-Xenon
- Lane Departure Warning
- Side airbags
Safety functions realised using radar

- City Safety
  - Que assist
  - Pre-prepared restraints
- Emergency brake lights
- Active Bi-Xenon
- Collision Warning with full Auto brake
  - And Pedestrian Detection
- Lane Departure Warning
- SIPS
- Advanced brakes: HBA, OHB, RAB, FBS, PPB
- Body Structure & Steel Material
- BLIS
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- DSTC
A holistic view of safety

Normal driving:
The driver is well informed and can stay alert.

Conflict:
Technology helps the driver to handle the difficult situation.

Avoidance:
The car acts automatically to avoid a collision if the driver fails to react.

Crash/Damage reduction:
The car’s safety systems help to reduce the crash energy in order to minimize the effect on the occupants.

After collision:
The car automatically calls for assistance and facilitates the rescue work.

Time
Safety technologies

NORMAL DRIVING
- Alcogard
- Driver Alert Control
- Adaptive Cruise Control
- IDIS
- BLIS - Blind Spot Information
- Active Bi-Xenon
- Que assist
- Distance Alert
- Information on traffic flow
- Active information via media system
- Traffic sign information

CONFLICT
- DSTC
- Collision Warning for vehicles and pedestrians
- Emergency Brake Lights
- Lane Departure Warning
- Remote collision warning
- BLIS

AVOIDANCE
- City Safety - low speed autobreake
- Collision Warning with full Autobrake and Pedestrian Detection

DAMAGE REDUCTION
- City Safety
- Collision Warning with full Autobrake and Pedestrian Detection

CRASH
- Patented Front Structure
- PRS
- SIPS
- WHIPS
- ROPS

AFTER COLLISION
- Volvo On Call
Safety technologies using antennas

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AFTER COLLISION
- Volvo On Call
Example of safety function: Pedestrian accidents problem and solution

- Sweden: 16% of traffic fatalities. 11% of seriously injured. Vägverket, 2008 (Swedish Road Authority)

- EU-14: 14% of traffic fatalities (3,500 people) (Safety Net, Traffic Safety Basic Facts 2008)

- USA: 11% of traffic fatalities (4,700 people). 3% of seriously injured. (Traffic Safety Facts 2007, NHTSA, DOT HS 810 994)

- Japan: Pedestrians were 35.2% of traffic fatalities in 2010 (1,714 people) (Japanese Police Agency, 2011-01-27)

- World wide: 41%–75% of traffic fatalities. (2004 World report on road traffic injury prevention, WHO)
Pedestrian accidents, why do they occur?

“**Inattention**, was a contributing factor for **93 percent** of the conflict with lead-vehicle crashes and minor collisions.” *

”**Inattention** to the forward roadway .. may explain why almost half of the drivers (**47 percent**) had no avoidance reaction.” *

**The 100-Car Naturalistic Driving Study**, T. A. Dingus et al, NHTSA, DOT HS 810 593, April 2006. The study involved 100 cars, 241 drivers, and 43 000 hours of data. 85 real collisions were recorded and analysed.
Solution: Pedestrian Detection with full autobrake

Passenger car pedestrian accidents based on real world crash data research and simulations in various accident scenarios.

If this system is applied to all vehicles, the pedestrian fatalities is estimated to be reduced by 24 %

(Source: “Benefit Estimation Model for Pedestrian Auto Brake Functionality” M Lindman et al, ESAR Hannover, September 2010.)
Pedestrian Detection with full autobrake

- A radar and camera scan the area in front of the car
- If the situation becomes critical – audible signal and a red warning flashes on the windscreen
- If you don’t react to that warning, the car activates braking power automatically
- Pedestrian accidents can be avoided for vehicle speeds lower than 35 km/h
- Impact speed can be reduced for vehicle speeds up to 80 km/h
Sensor Properties

<table>
<thead>
<tr>
<th></th>
<th>Vision</th>
<th>LIDAR</th>
<th>RADAR</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Range</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accuracy</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Resolution</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td><strong>Angle</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accuracy</td>
<td>+</td>
<td>-/+</td>
<td>-</td>
</tr>
<tr>
<td>Resolution</td>
<td>+</td>
<td>-/+</td>
<td>--</td>
</tr>
<tr>
<td><strong>Velocity</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accuracy</td>
<td>-</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td><strong>Night capability</strong></td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td><strong>All-weather capability</strong></td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td><strong>Object classification</strong></td>
<td>+</td>
<td>O</td>
<td>-</td>
</tr>
</tbody>
</table>
Radar + Camera fusion

- **Requirements**
  - Need for robust detection
  - Very low number of false positives

- **Solution**
  - Radar provides excellent longitudinal position
  - Camera provides excellent angular position

- Independent tracking for each sensor followed by association allows high level of robustness
Detection scheme
Minimise dependability to increase robustness

- Radar
  - Adaptive Cruise Control
- Association/Fusion
  - Auto Brake
    - Collision Warning
  - Lane Departure Warning
- Camera
Pedestrian protection video
Volvo S60 Sensor Set for Active Safety

- Camera
- Lidar
- Radar
- Accelerometer
- Ultrasonic
- Yaw rate (gyro)
- Camera (radar soon)
- Wheel speed
2014+ vehicles understanding of the environment
9 radars in example

BLUE = RADAR Application
ORANGE = Ultrasonic

Illustration courtesy of Analog Devices
Automotive requirements on radar packaging

- Small size
- Flat
- Location behind plastics
- Location behind metallic (flake) paint
- Location behind curved facia
  - Leading to side lobes
  - Multipath
  - Fading
- Robust to environment

1.8 GHz SAR 8 element antenna
Courtesy of Telia
Radar object detection

Senses: Guardrails, Vehicles, Pedestrians
Radar frequency bands in automotive

- **24 Ghz General**
  - Used in blind spot information and shorter range applications
  - Worldwide band
  - Advantageous cost
  - Lower accuracy on angle (due to size limitation of antenna)
  - UWB will be phased out

- **77 GHz Automotive**
  - Forward looking and side looking radars
  - Almost worldwide band
  - Slightly higher price
  - Good performance up to 150–200 m
  - Reasonable angular accuracy and resolution

- **79 GHz Automotive**
  - Proposed
  - UWB band
## Radar requirements per function

<table>
<thead>
<tr>
<th>Application</th>
<th>Detection Range</th>
<th>Safety Aspect</th>
<th>Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adaptive Cruise Control</td>
<td>200 meters</td>
<td>Normal driving, accident avoidance</td>
<td>• 77 GHz Radar</td>
</tr>
<tr>
<td>Pre-Crash</td>
<td>30 meters</td>
<td>Accident, mitigation of impact</td>
<td>• 77 GHz Radar/24 GHz Radar</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• 76/81 GHz Radar</td>
</tr>
<tr>
<td>Blind Spot Detection</td>
<td>20 meters</td>
<td>Normal driving, accident avoidance</td>
<td>• 77 GHz/24 GHz Radar/Vision sensor</td>
</tr>
<tr>
<td>Lane Departure Warning</td>
<td>60 meters</td>
<td>Normal driving, accident avoidance</td>
<td>• Vision sensor</td>
</tr>
<tr>
<td>Stop and Go</td>
<td>30 meters</td>
<td>Normal driving, accident avoidance</td>
<td>• 77 GHz/24 GHz Radar</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• 76/81 GHz Radar</td>
</tr>
</tbody>
</table>
# Early automotive radars

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Fujitsu Ten</th>
<th>ADC</th>
<th>Delphi</th>
<th>Bosch</th>
<th>Honda elesys</th>
<th>Denso</th>
<th>Hitachi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appearance</td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
<td><img src="image3.png" alt="Image" /></td>
<td><img src="image4.png" alt="Image" /></td>
<td><img src="image5.png" alt="Image" /></td>
<td><img src="image6.png" alt="Image" /></td>
<td><img src="image7.png" alt="Image" /></td>
</tr>
<tr>
<td>External Dimensions (mm)</td>
<td>89×107×86</td>
<td>136×133×68</td>
<td>137×67×100</td>
<td>91×124×79</td>
<td>123×98×79</td>
<td>77×107×53</td>
<td>80×108×64</td>
</tr>
<tr>
<td>Modulation Method</td>
<td>FM-CW</td>
<td>FM Pulse</td>
<td>FM-CW</td>
<td>—</td>
<td>FM-CW</td>
<td>FM-CW</td>
<td>2- frequency CW</td>
</tr>
<tr>
<td>Detection Range</td>
<td>4m to 120m or greater</td>
<td>Approx. 1m to 150m</td>
<td>Approx. 1m to 150m</td>
<td>2m to 120m or greater</td>
<td>4m to 100m or greater</td>
<td>Approx. 2m to 150m</td>
<td>Approx. 1m to 150m</td>
</tr>
<tr>
<td>Horizontal Detection Angle</td>
<td>±8°</td>
<td>Approx. ±5°</td>
<td>Approx. ±5°</td>
<td>±4°</td>
<td>±8°</td>
<td>±10°</td>
<td>±8°</td>
</tr>
<tr>
<td>Angle Detection Method</td>
<td>Mechanical Scan</td>
<td>Beam Conversion</td>
<td>Mechanical Scan</td>
<td>Beam Conversion</td>
<td>Beam Conversion</td>
<td>Phased Array</td>
<td>Monopulse</td>
</tr>
<tr>
<td>EHF Device</td>
<td>MMIC</td>
<td>GUNN</td>
<td>GUNN</td>
<td>GUNN</td>
<td>MMIC</td>
<td>MMIC</td>
<td>MMIC</td>
</tr>
</tbody>
</table>
Modern automotive radar antennas

- The most commonly used antenna is based on microstrip/patch technique
- Low physical volume—essentially flat
- Significant side lobes compared to mechanically scanned antenna
- Requires high level of signal processing

77GHz RFIC with on chip antenna (Felix Gutierrez et.al., Univ. of Texas)
Electronic Scanning Radar (phased array)

Denso
Modern automotive radars

Bosch ACC3

Bosch antenna diagram

Delphi ESR2.5 (SAR)
Special Signal Processing Techniques

- Packaging problem
  - Need for small antenna
  - However small antenna increase the beam width and decrease the angular resolution

- Signal processing solution
  - MUSIC (MUltiple SItual Classification)
  - Allows increased angular resolution

Courtesy of Denso
Rapid radar development within automotive

→ Reduced cost and size reduction are the main drivers

- 2006 Mechanical scanning antenna

- 2009 ESR Electronic Scanning Radar
  - Digital beam forming, SAR
  - GaAs
  - 50% cost reduction

- 2011 ESR2.5
  - SiGe
  - 25% cost reduction

- 2014+ ESRx?
  - BiCMOS? (fmax around 290GHz)
  - 25% cost reduction
# Radar Modulation Techniques

<table>
<thead>
<tr>
<th></th>
<th>Pulse doppler</th>
<th>FMCW</th>
<th>FSK</th>
<th>UWB</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Description</strong></td>
<td>Single carrier frequency is transmitted in a short burst.</td>
<td>Frequency Modulated Continuous Wave. Typically a saw tooth waveform with BW 100–150 MHz</td>
<td>Frequency shift keying with 1 MHz steps. CPI for each frequency is 5ms. Range info is derived from phase diff</td>
<td>Dirac pulse Measure time of flight– auto correlation</td>
</tr>
<tr>
<td><strong>Advantages</strong></td>
<td>Simple algorithm for distance</td>
<td>Good range accuracy</td>
<td>Simple VCO modulation</td>
<td>Simple principle</td>
</tr>
<tr>
<td></td>
<td>- Easy to calculate relative speed and range</td>
<td>- Short measurement cycle</td>
<td>- Can measure at close range due to large BW</td>
<td></td>
</tr>
<tr>
<td><strong>Disadvantages</strong></td>
<td>Difficult to determine range rate</td>
<td>Computation to eliminate ghost targets</td>
<td>Coherent signal required for accuracy</td>
<td>Medium to low range</td>
</tr>
<tr>
<td></td>
<td>Can not transmit and receive simultaneously</td>
<td>Long measurement time for multiple chirps</td>
<td>Poor range direction information</td>
<td>No direct measure of range rate</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sensitive for disturbance</td>
</tr>
</tbody>
</table>
High volume allows increased integration

Typical RADAR System Representation

Transmitter
- Low power consumption
- Extremely low phase noise
- High output power at 3.3V
- Very precise control over frequency (+/-100 ppm)
- No trimming, no adjustments
- Supports RX designs with local oscillator at half of the RF frequency (38.25 GHz)
- Ability to monolithically integrate frequency stabilization (PLL), PA and programmable FMCW modulation
- SPI interface (optional)

Multi-Channel Receiver
- Multiple channels supported
- Local oscillator at 38.25 GHz
- Local oscillator input power level typical ~7 dBm
- Differential IF
- Lowest noise figures
- High IF-to-IF isolation
- Low residual power levels
- Gain/linearity on customer request
- ESD protection (RF and DC)
- SPI (optional)
Automotive radio antennas

In the 80’s the antennas were visible

GSM antenna

FM antenna
## Antennas in a vehicle 2014+

<table>
<thead>
<tr>
<th>Service</th>
<th>Typical Frequency</th>
<th>Tx</th>
<th>Rx</th>
<th>Direction of Radiation</th>
</tr>
</thead>
<tbody>
<tr>
<td>AM Radio</td>
<td>Approximately 1 MHz</td>
<td></td>
<td>Yes</td>
<td>Horizontal</td>
</tr>
<tr>
<td>FM Radio</td>
<td>88 MHz to 108 MHz</td>
<td>Yes</td>
<td></td>
<td>Horizontal</td>
</tr>
<tr>
<td>In-vehicle TV</td>
<td>50 MHz to 400 MHz</td>
<td>Yes</td>
<td></td>
<td>Horizontal</td>
</tr>
<tr>
<td>Digital Audio Broadcasting (DAB)</td>
<td>100 MHz to 400 MHz</td>
<td>Yes</td>
<td></td>
<td>Horizontal</td>
</tr>
<tr>
<td>Remote Keyless Entry (RKE)</td>
<td>315 MHz/413 MHz/434 MHz</td>
<td>Yes</td>
<td></td>
<td>Horizontal</td>
</tr>
<tr>
<td>Tyre Pressure Monitoring System (TPMS)</td>
<td>315 MHz/413 MHz/434 MHz</td>
<td>Yes</td>
<td>Yes</td>
<td>Intra-vehicular</td>
</tr>
<tr>
<td>Cellular Phone (provision of Internet via HSPA)</td>
<td>850 MHz 900 MHz 1800 MHz 1900 MHz 2100 MHz</td>
<td>Yes</td>
<td>Yes</td>
<td>Horizontal</td>
</tr>
<tr>
<td>Satellite Navigation (GPS)</td>
<td>1.575 GHz</td>
<td>Yes</td>
<td></td>
<td>Satellite</td>
</tr>
<tr>
<td>Satellite Digital Audio Radio Service (SDARS)</td>
<td>2.3 GHz</td>
<td>Yes</td>
<td></td>
<td>Satellite</td>
</tr>
<tr>
<td>IEEE 802.11 b/g/n (Wi-Fi)</td>
<td>2.4 GHz</td>
<td>Yes</td>
<td>Yes</td>
<td>Horizontal</td>
</tr>
<tr>
<td>Bluetooth</td>
<td>2.4 GHz</td>
<td>Yes</td>
<td>Yes</td>
<td>Intra-vehicular</td>
</tr>
<tr>
<td>WiMAX</td>
<td>2.3 GHz/2.5 GHz/3.5 GHz</td>
<td>Yes</td>
<td>Yes</td>
<td>Horizontal</td>
</tr>
<tr>
<td>Electronic Toll Collection (ETC)</td>
<td>5.8 GHz (or 900 MHz)</td>
<td>Yes</td>
<td>Yes</td>
<td>Overhead</td>
</tr>
<tr>
<td>V2V+ and VII+</td>
<td>5.9 GHz</td>
<td>Yes</td>
<td>Yes</td>
<td>Horizontal</td>
</tr>
<tr>
<td>Collision Avoidance Radar</td>
<td>24 GHz and 77 GHz</td>
<td>Yes</td>
<td>Yes</td>
<td>Forward</td>
</tr>
</tbody>
</table>

Pell et al., 2011
Increased number of radio functions

could lead to:

→ Need for smarter packaging of antennas
Volvo S60 antennas

GPS  Keyless entry  Radar  Radio for TPMS

GSM  WLAN
Radio AM  Radio FM
Satellite radio  DAB  TV  Radar
Bluetooth
Innovative flat roof antenna on early Volvo XC 90

+ Not visible
+ Vertical polarised signals
- Horizontal polarised signals
- Cost

Low et al., 2006
Highly integrated roof top antennas with integrated front-end

- Antenna and front-end co-located
  + Antenna amplifiers
  - Environmental heat
  + Digital out as option in future
- Integration of multiple antennas
  - Cellular phones (GSM/3G/4G)
  - GPS
  - Satellite radio
- Expansion capability
  - WLAN, Bluetooth™
  - Car-2-Car
  - Remote keyless entry

“Shark fin”

Courtesy of Delphi Fuba
Antenna packaging examples

Dual TV antennas in side windows

Active antennas integrated into plastic trunk lid

Toriyama et al., 1987

Lindenmeier et al., 2006
Antennas for tomorrow?

• Needs for the future
  – Integration of antennas on non flat surfaces
  – Simulation of beam pattern behind curved facia
  – Optimization of micro strips for placement behind curved facia
  – Embedded antennas and electronics in the facia of the vehicle
  – Co-location of antenna and tranceiver
Our vision is to design cars that do not crash.
Highly Automated Vehicles
SARf RoadTRains for the Environment, SARTRE
EU funded collaboration project
Thank you for your attention!