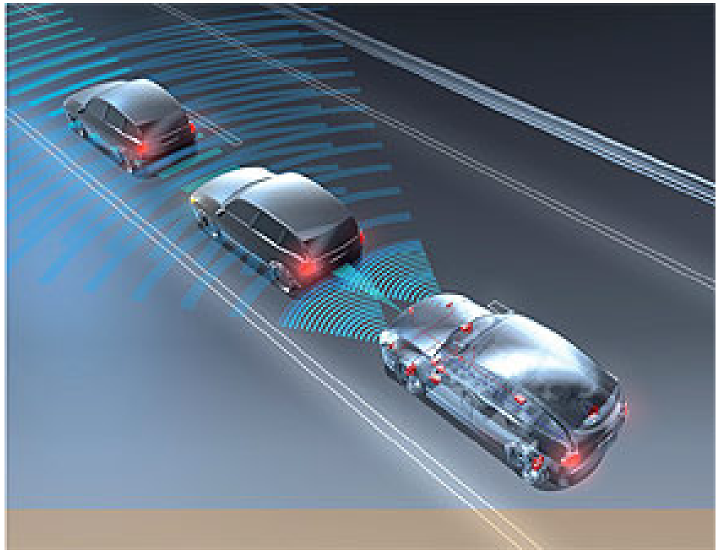
How new Safety Systems and always Connected Vehicles leads to challenges on Antenna Design and Integration in the Automotive Domain



Henrik Lind
Technical Expert Remote Sensing
Volvo Car Corporation

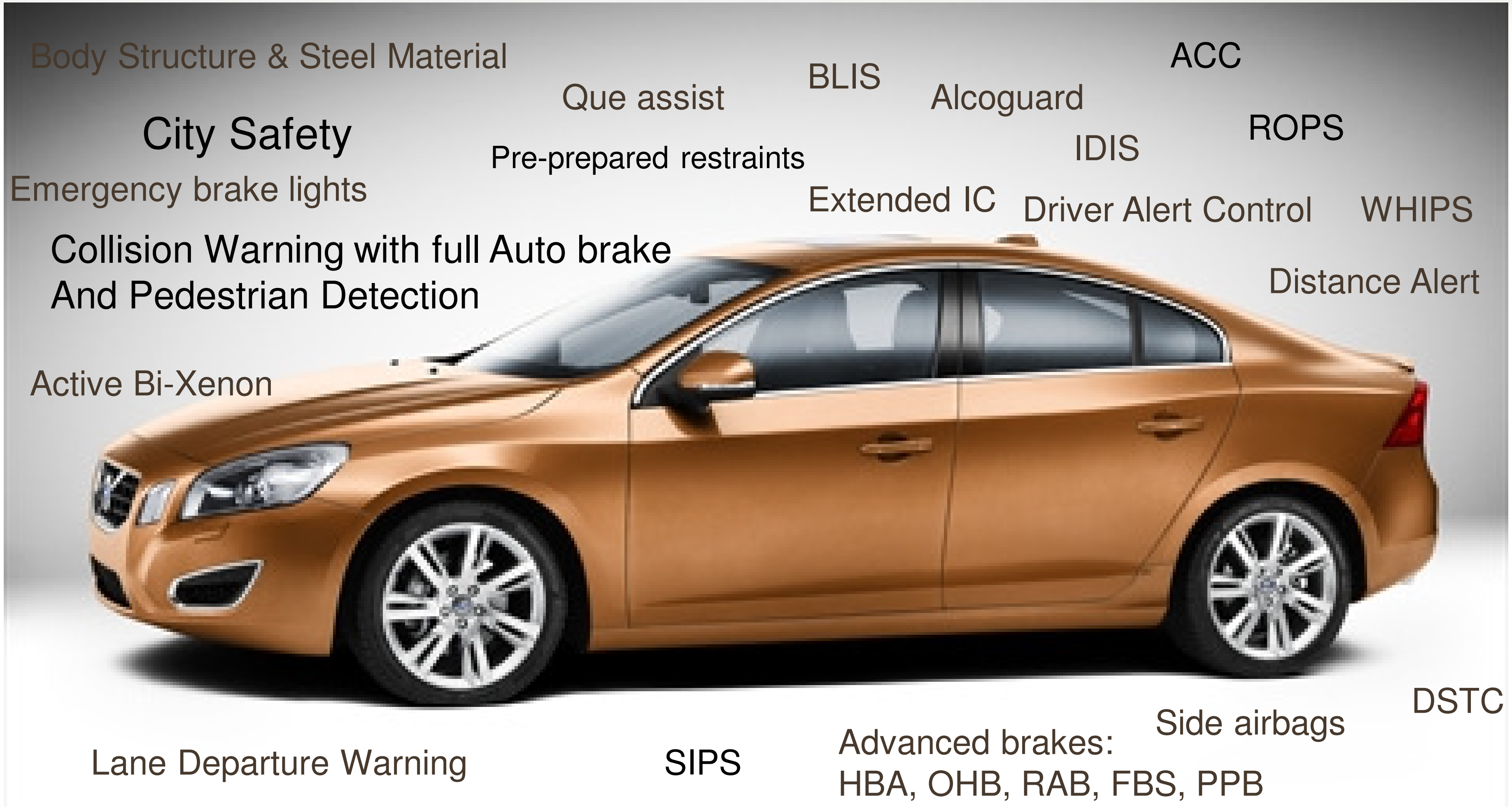
Henrik.Lind@volvocars.com

Our heritage

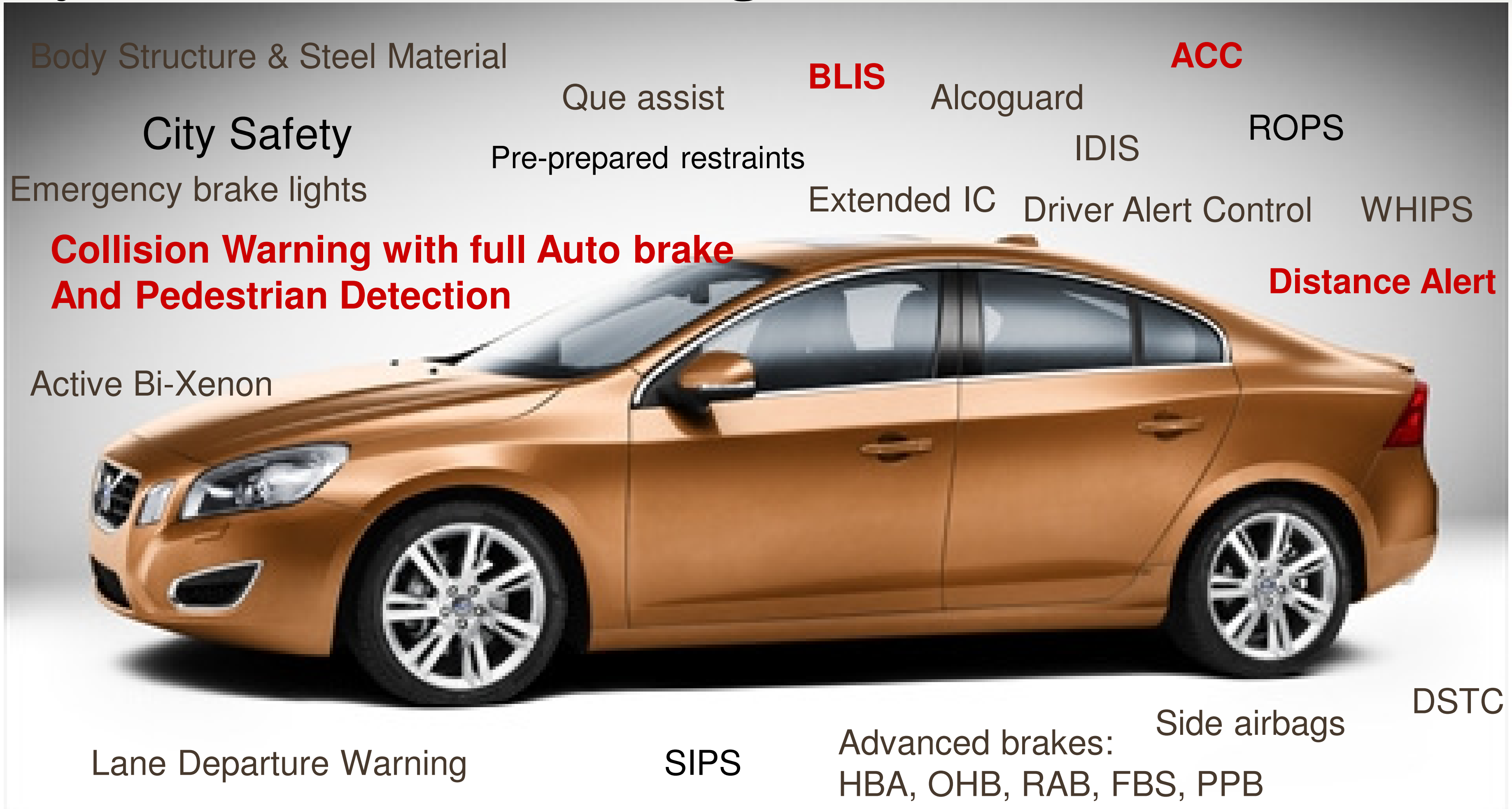
"Cars are driven by people. The guiding principle behind everything we make at Volvo, therefore, is – and must remain – safety"

Assar Gabrielsson & Gustaf Larson,
the founders of Volvo

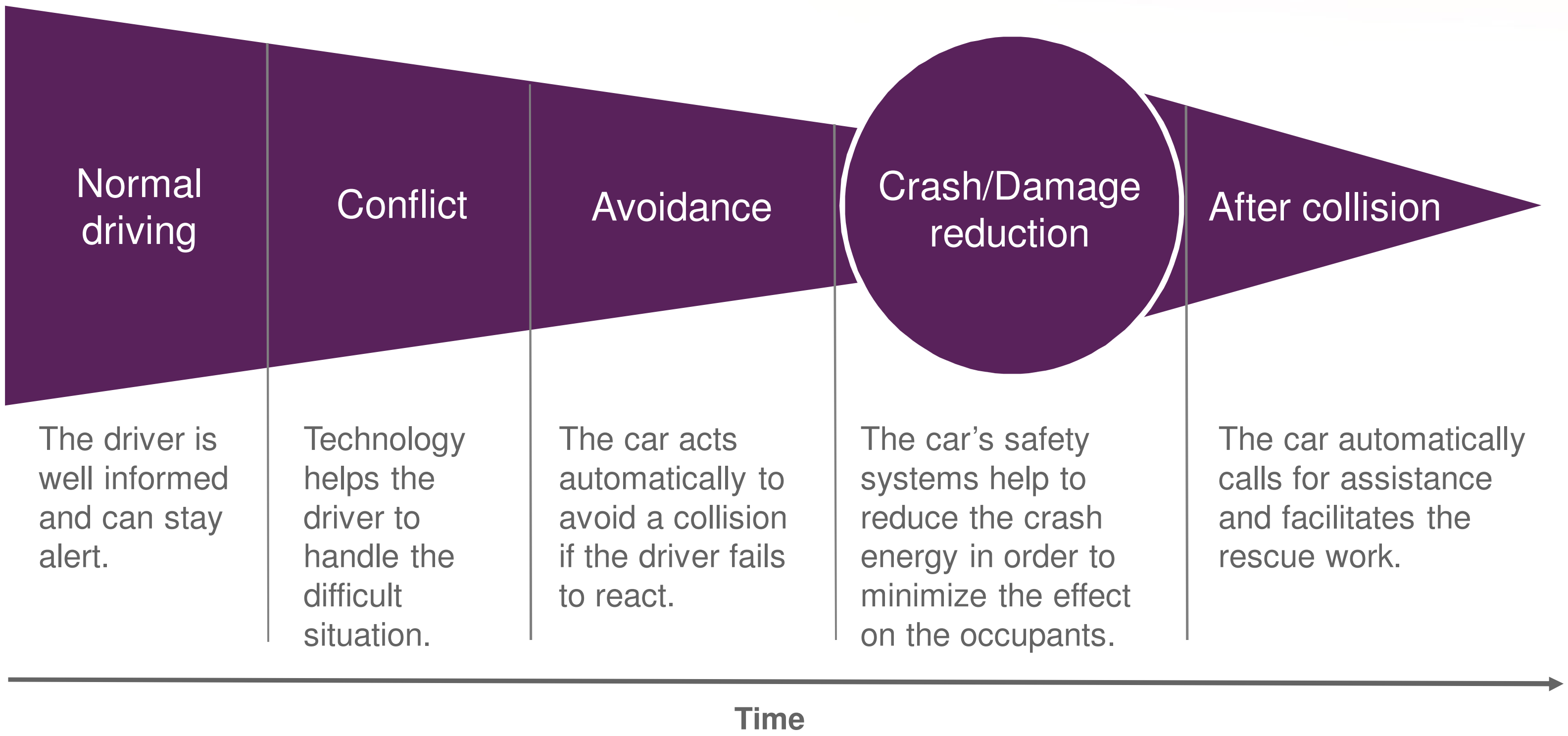
Safety related functions– buzzwords



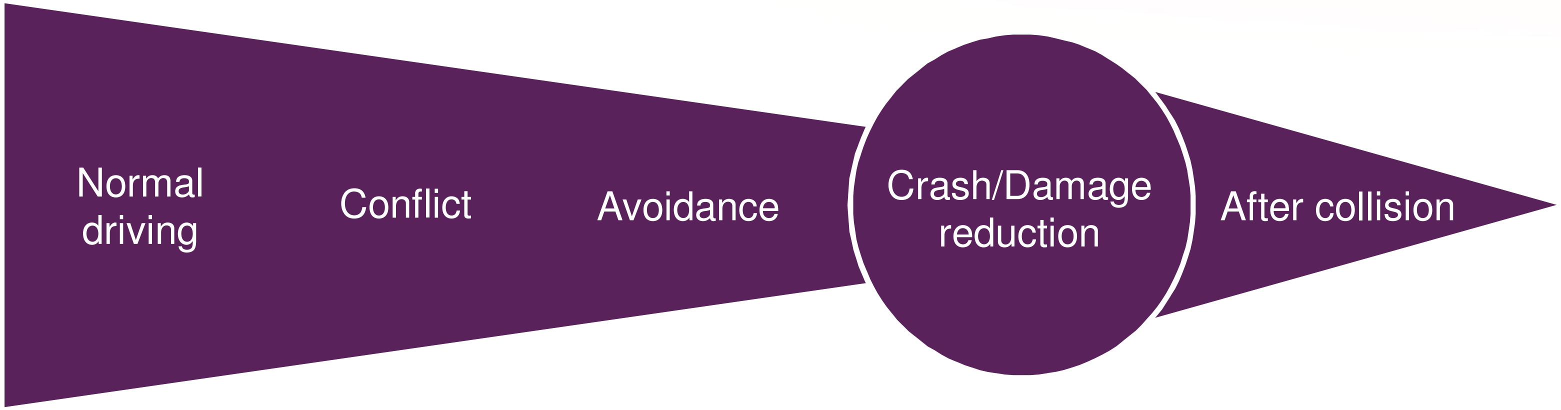
Safety functions realised using radar



A holistic view of safety



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 autobrake
- Collision Warning with full Autobrake and Pedestrian Detection

DAMAGE REDUCTION

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

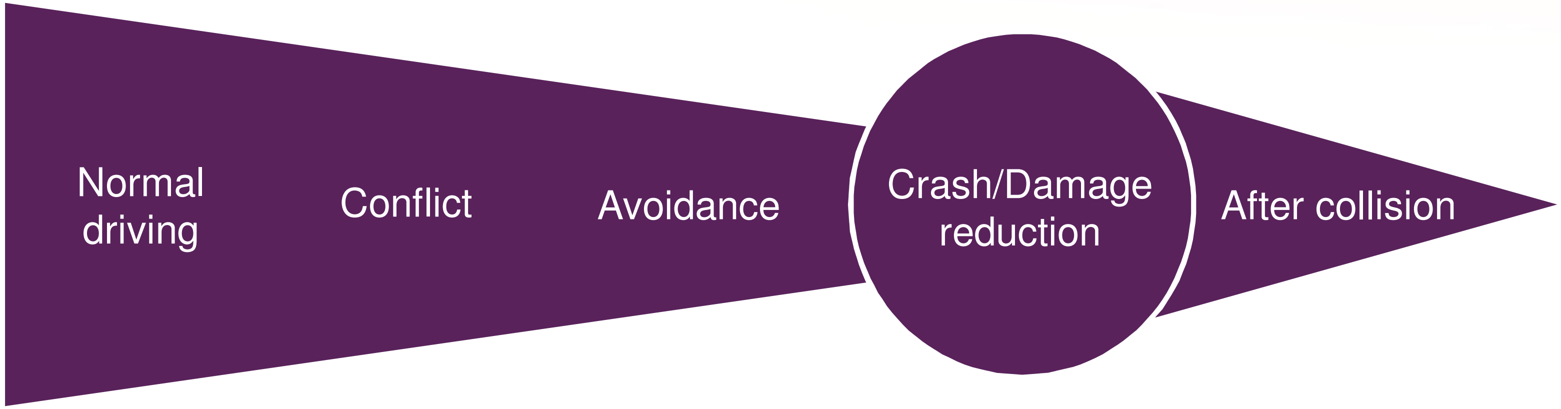
CRASH

- 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 occure?

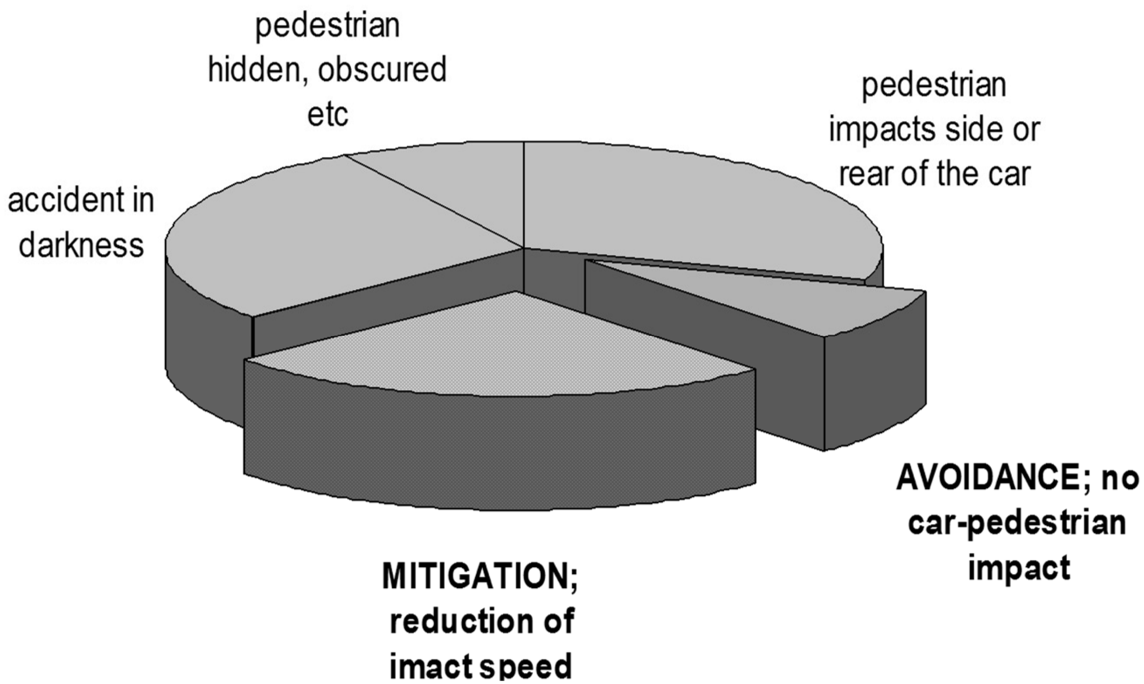
"**Inattention**, was a contributing factor for **93 percent** of the conflict with lead-vehicle crashes and minor collisions." *

"**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 senarios.

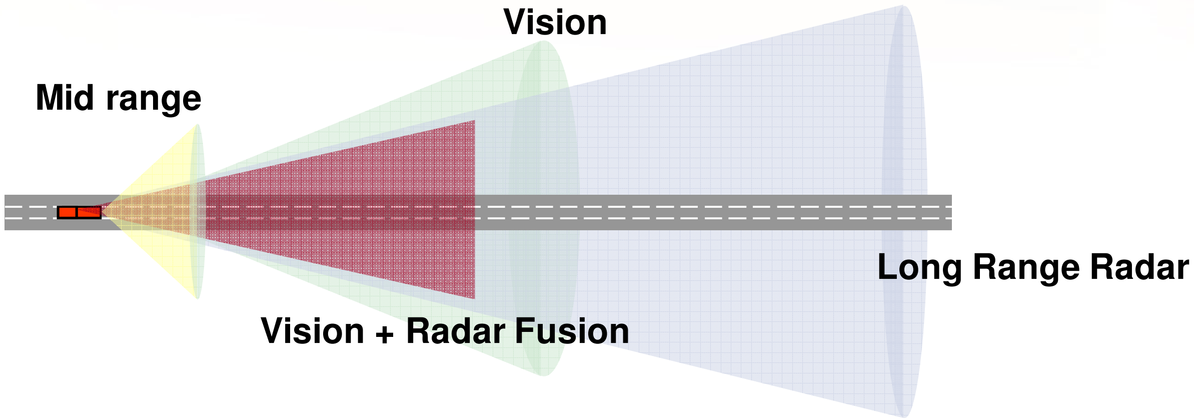


If this system is applied to all vehicles, the pedestrian fatalities is estimated to be reduced by 24 %

(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

		Vision	LIDAR	RADAR
Range	Accuracy	-	+	+
	Resolution	-	-	+
Angle	Accuracy	+	-/+	-
	Resolution	+	-/+	--
Velocity	Accuracy	-	o	+
Night capability		-	+	+
All-weather capability		-	-	+
Object classification		+	o	-

Radar + Camera fusion

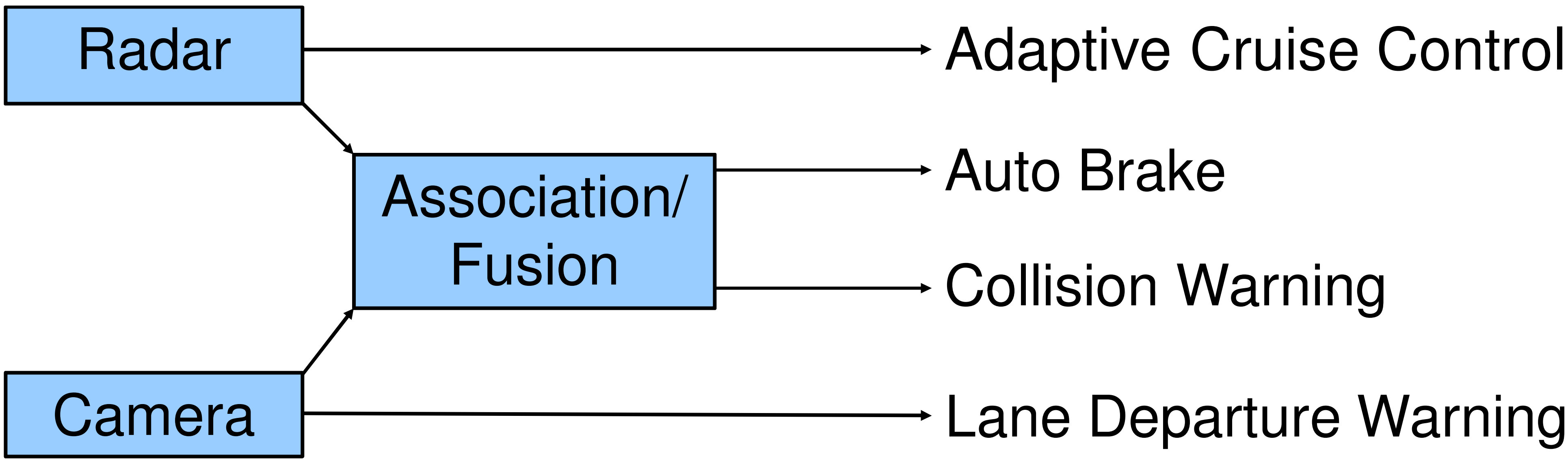
- Requirements
  - Need for robust detection
  - Very low number of false positives

- 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




DPH
Scan:10874
LLane:-0.9m (1)
RLane: 3.4m (0)
Frame No 1163 Idx:43025:Time:3826635:ImgAve:96:Tint:29:Gamma:7:

Pedestrian protection video

Volvo S60 Sensor Set for Active Safety

2014+ vehicles understanding of the environment

9 radars in example

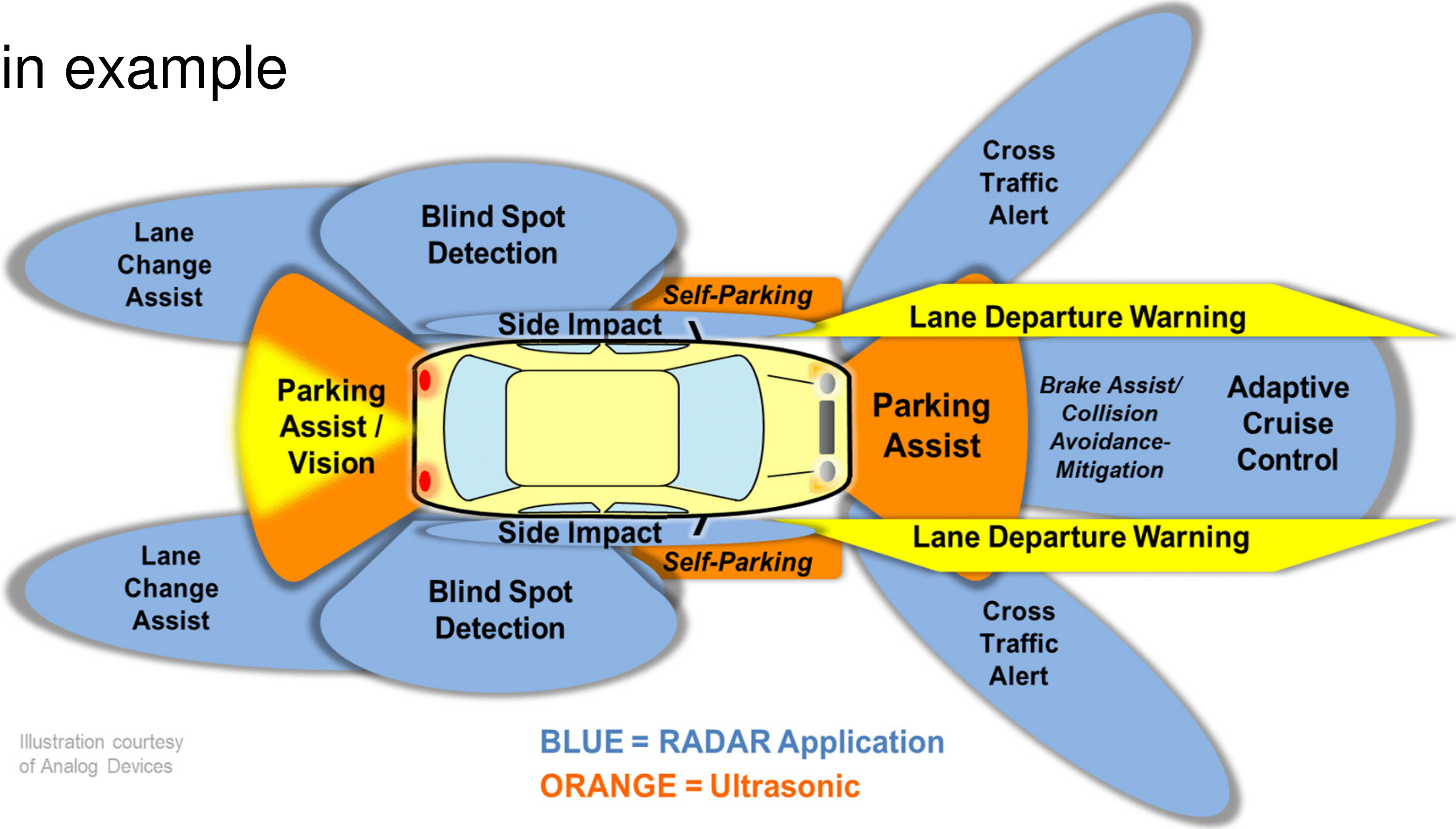


Illustration courtesy
of Analog Devices

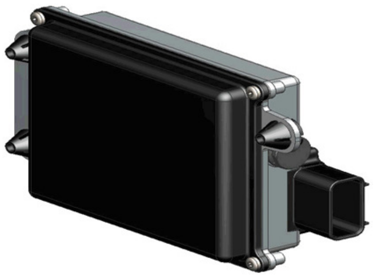
BLUE = RADAR Application
ORANGE = Ultrasonic

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

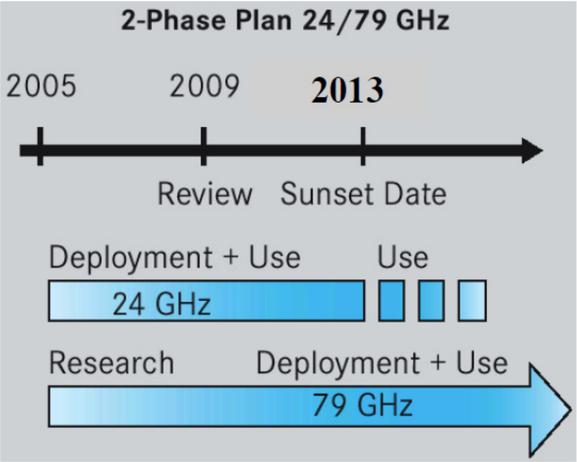


Senses: Guardrails, Vehicles, Pedestrians

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

UWB radar



Radar requirements per function

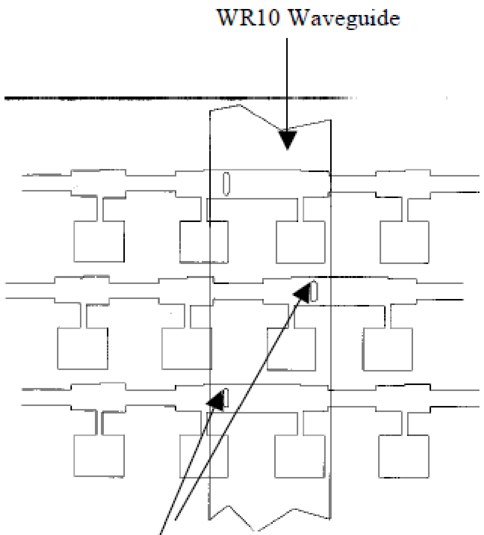
Application	Detection Range	Safety Aspect	Technology
Adaptive Cruise Control	200 meters	Normal driving, accident avoidance	• 77 GHz Radar
Pre-Crash	30 meters	Accident, mitigation of impact	• 77 GHz Radar/24 GHz Radar • 76/81 GHz Radar
Blind Spot Detection	20 meters	Normal driving, accident avoidance	• 77 GHz/24 GHz Radar/ Vision sensor
Lane Departure Warning	60 meters	Normal driving, accident avoidance	• Vision sensor
Stop and Go	30 meters	Normal driving, accident avoidance	• 77 GHz/24 GHz Radar • 76/81 GHz Radar

Early automotive radars

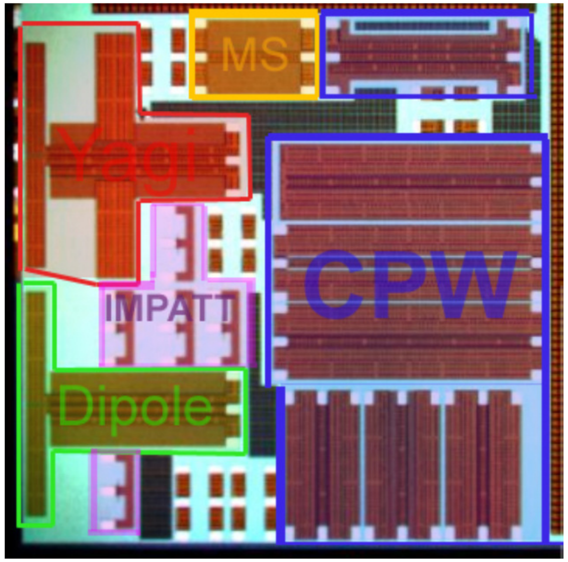
Manufacturer	Fujitsu Ten	ADC	Delphi	Bosch	Honda elesys	Denso	Hitachi
Appearance							
External Dimensions (mm)	89×107×86	136×133×68	137×67×100	91×124×79	123×98×79	77×107×53	80×108×64
Modulation Method	FM-CW	FM Pulse	FM-CW	——	FM-CW	FM-CW	2- frequency CW
Detection Range	4m to 120m or greater	Approx. 1m to 150m	Approx. 1m to 150m	2m to 120m or greater	4m to 100m or greater	Approx. 2m to 150m	Approx. 1m to 150m
Horizontal Detection Angle	±8°	Approx. ±5°	Approx. ±5°	±4°	±8°	±10°	±8°
Angle Detection Method	Mechanical Scan	Beam Conversion	Mechanical Scan	Beam Conversion	Beam Conversion	Phased Array	Monopulse
EHF Device	MMIC	GUNN	GUNN	GUNN	MMIC	MMIC	MMIC

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



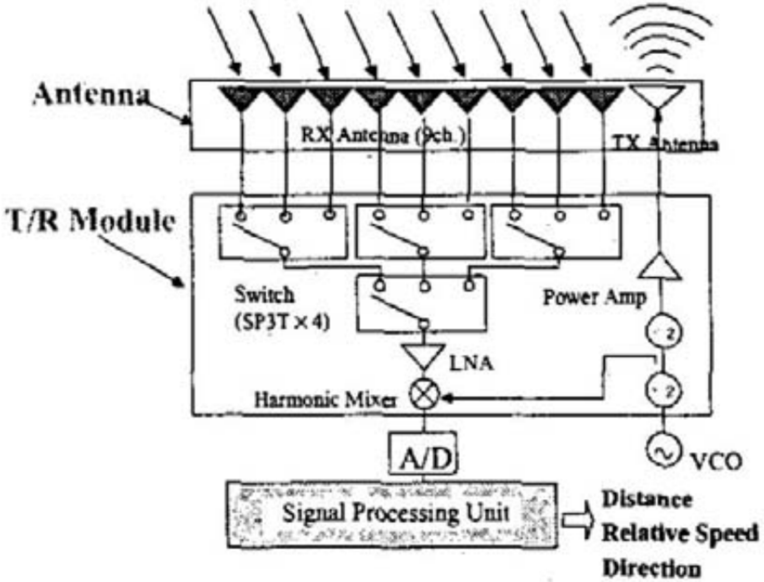
Microstrip antennas

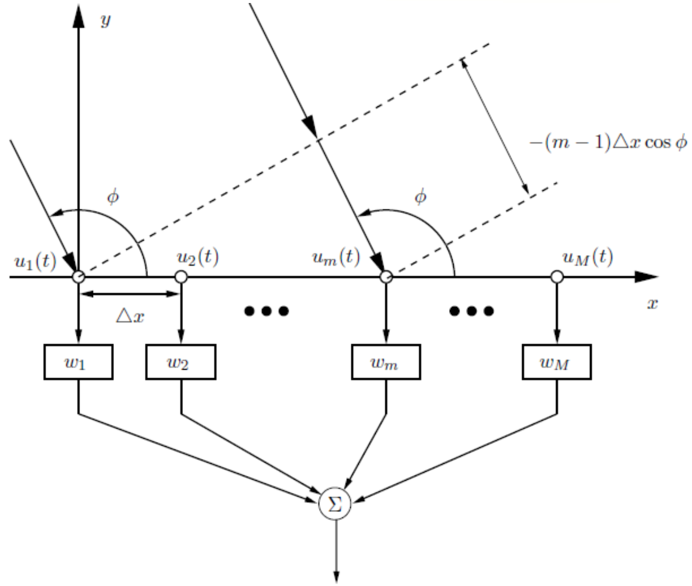


77GHz RFIC with on chip antenna (Felix Gutierrez et.al.,Univ. of Texas)

Electronic Scanning Radar (phased array)

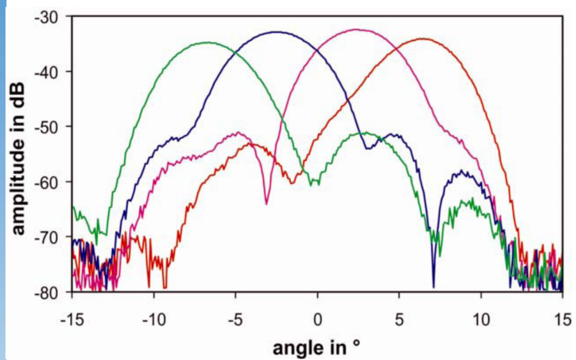
Denso



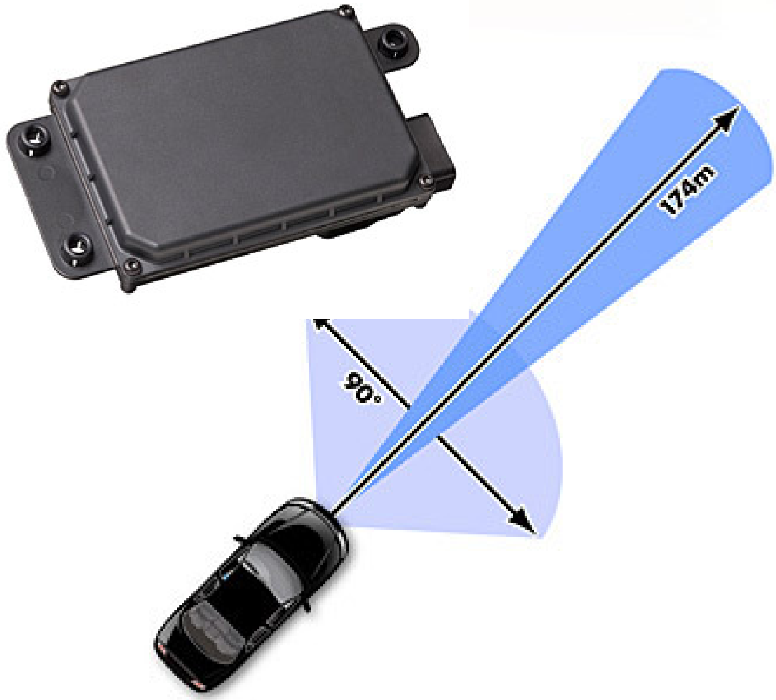


Modern automotive radars

Bosch ACC3



Bosch antenna diagram

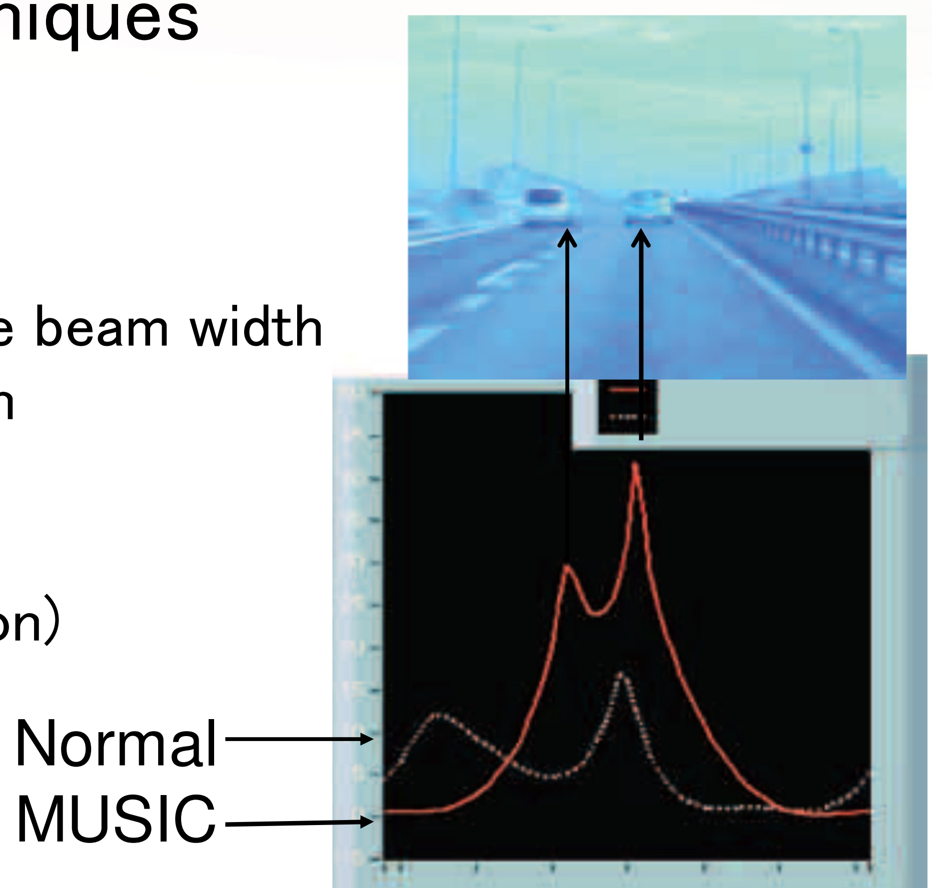


Delphi ESR2.5 (SAR)

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 SIgnal Classification)
  - Allows increased angular resolution

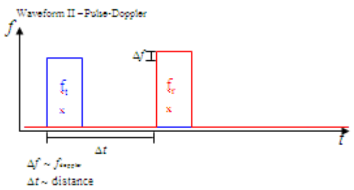
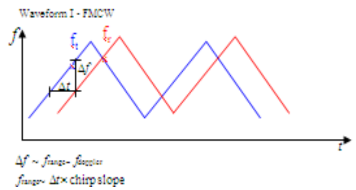
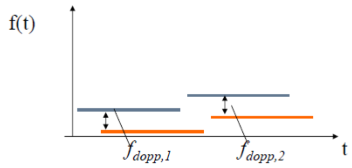
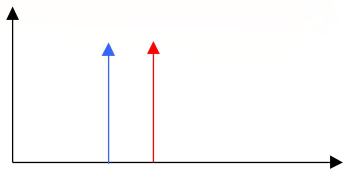


Courtesy of Denso

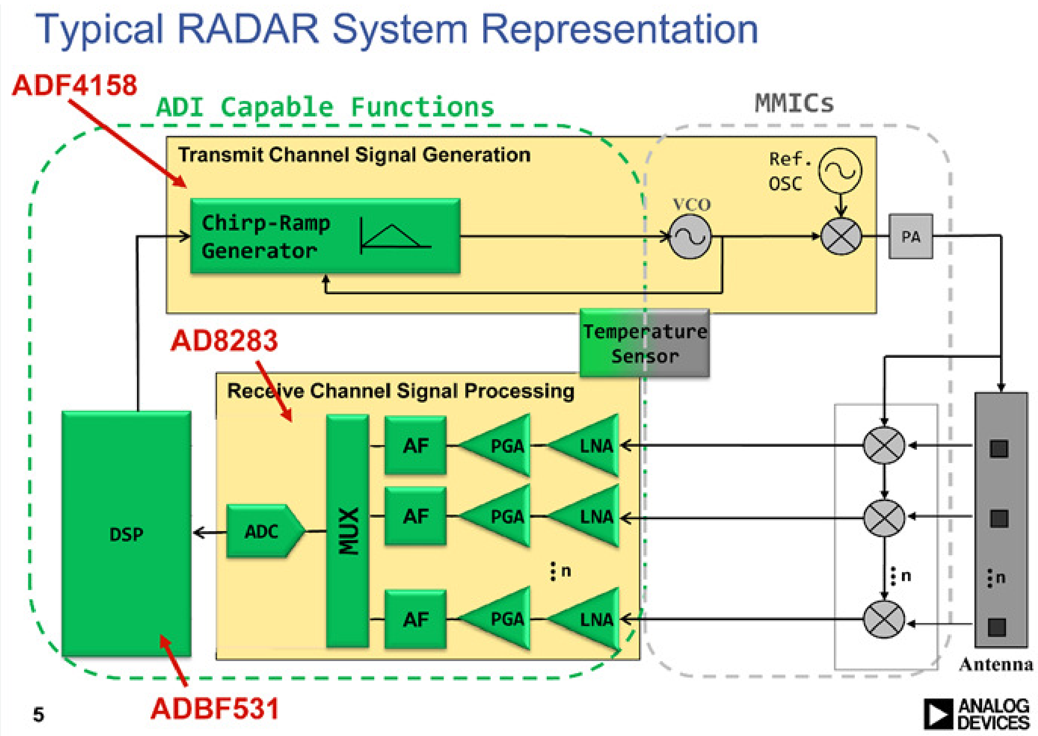
Rapid radar development within automotive
->Reduced cost and size reduction are the main drivers

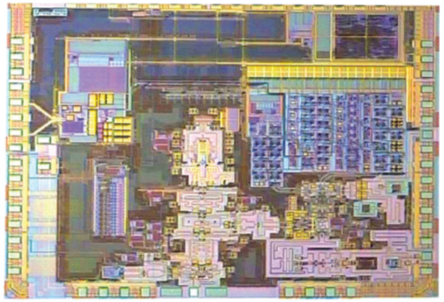
- 2006 Mechanical scanning antenna
- 2009 ESR Electronic Scanning Radar –50% cost reduction
  - Digital beam forming, SAR
  - GaAs
- 2011 ESR2.5 –25% cost reduction
  - SiGe
- 2014+ ESRx? –25%? cost reduction
  - BiCMOS? (fmax around 290GHz)

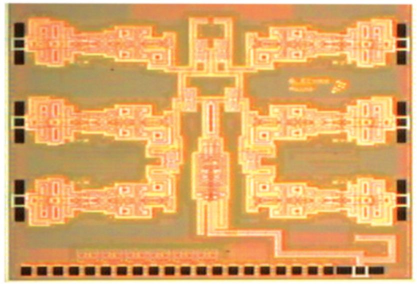
Radar Modulation Techniques

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

High volume allows increased integration







Transmitter

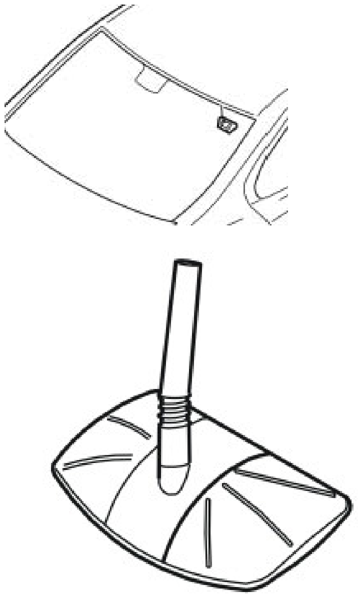
- Low power consumption
- Extremely low phase noise
- High output power at 3.3V
- Very precise control over frequency (+/-100 ppm)
- No trimming, no adjustments
- Supports RX designs with local oscillator at half of the RF frequency (38.25 GHz)
- Ability to monolithically integrate frequency stabilization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

Multi-Channel Receiver

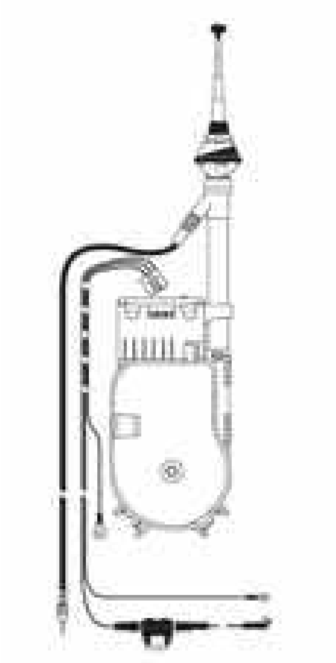
- Multiple channels supported
- Local oscillator at 38.25 GHz
- Local oscillator input power level typical -7 dBm
- Differential IF
- Lowest noise figures
- High IF-to-IF isolation
- Low residual power levels
- Gain/linearity on customer request
- ESD protection (RF and DC)
- SPI (optional)

Automotive radio antennas

In the 80's the antennas were visible



GSM antenna



FM antenna

Antennas in a vehicle 2014+

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

Pell et al.,2011

Increased number of radio functions

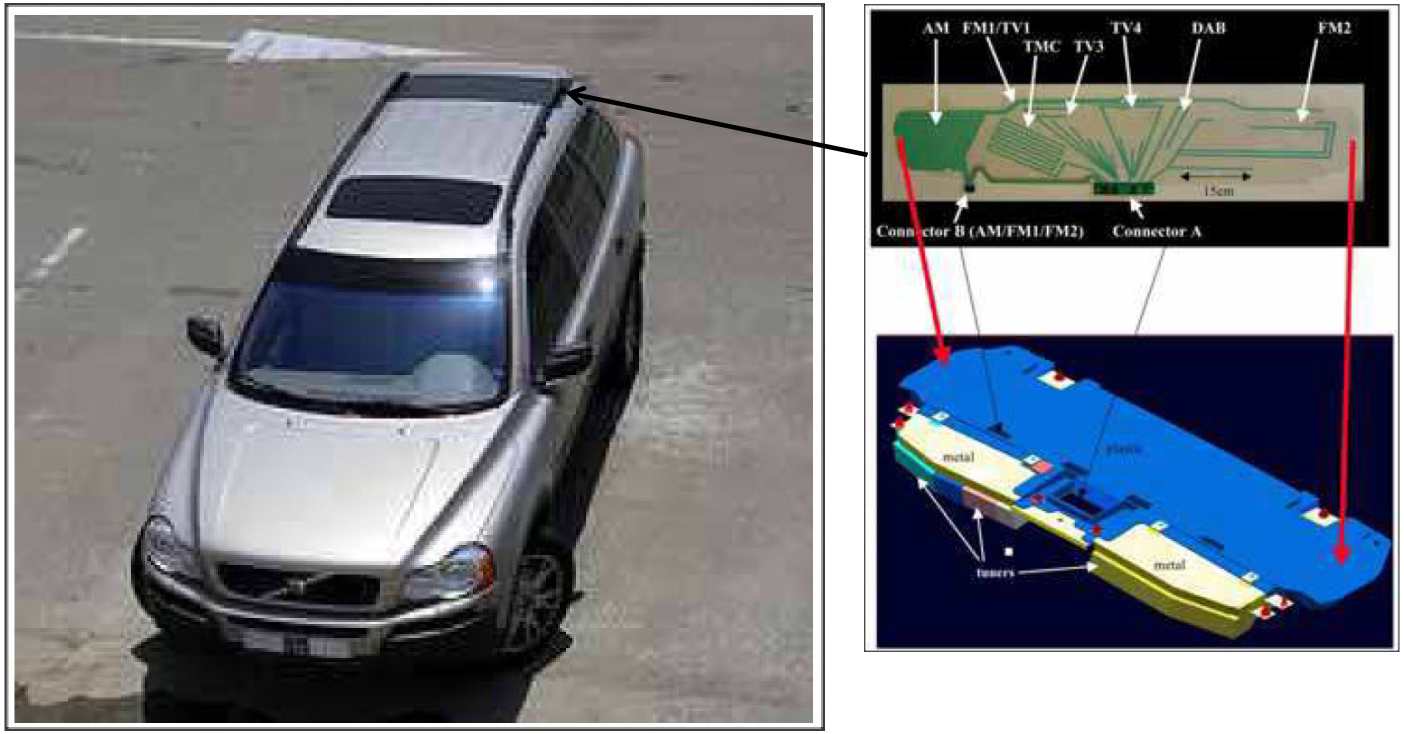
could lead to:

->Need for smarter packaging of antennas

Volvo S60 antennas

Innovative flat roof antenna on early Volvo XC 90

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



Low et al., 2006

Highly integrated roof top antennas with integrated front-end

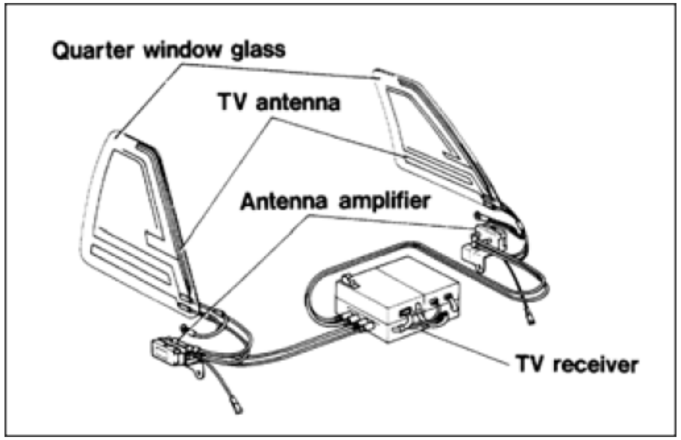
- Antenna and front-end co-located
  + Antenna amplifiers
  – Environmental heat
  + Digital out as option in future
- Integration of multiple antennas
  - Cellular phones (GSM/3G/4G)
  - GPS
  - Satellite radio
- Expansion capability
  - WLAN, Bluetooth™
  - Car-2-Car
  - Remote keyless entry

”Shark fin”

Courtesy of Delphi Fuba

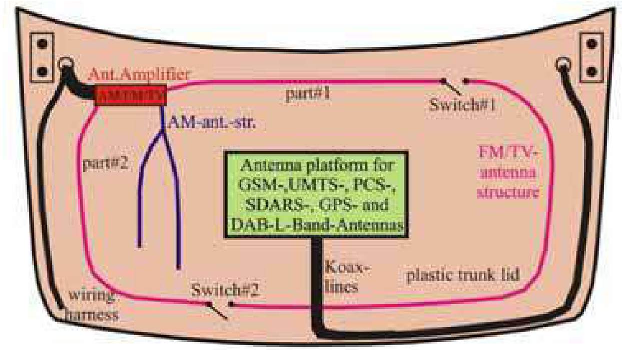
Antenna packaging examples

Dual TV antennas in side windows



Toriyama et al., 1987

Active antennas integrated into plastic trunk lid

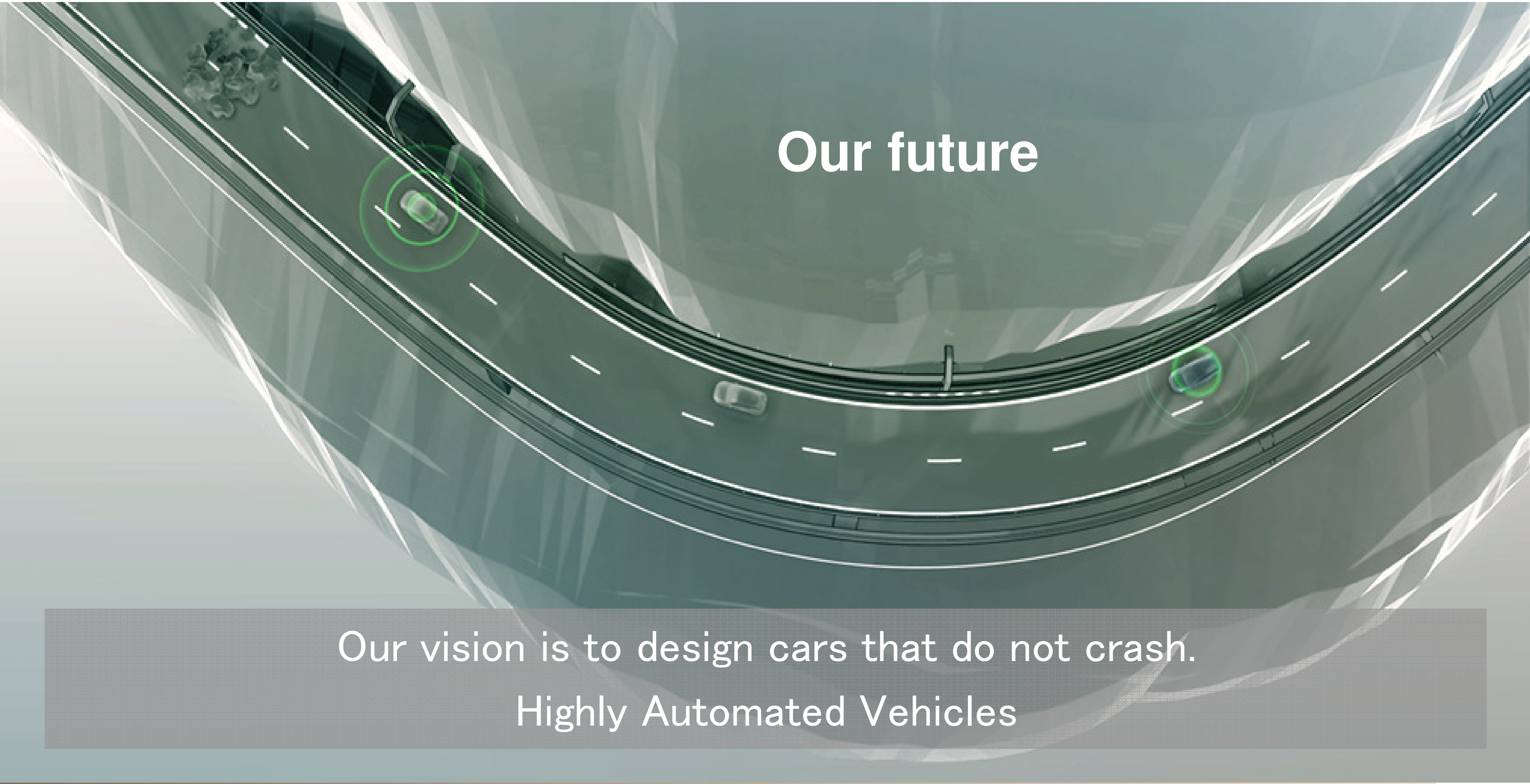


Lindenmeier et al.,2006

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 future


Our vision is to design cars that do not crash.
Highly Automated Vehicles

SAfe RoadTRains for the Environment, SARTRE

EU funded collaboration project

Thank you for your attention!