

WFCS 2004

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Keynote Automotive Communication

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Communication Requirements for Automotive Systems



Motivation

- Provide a short overview on automotive electronics and system development strategies that are shaping the communication requirements
- Identify side conditions for system and component design specific to the automotive industry that differ significantly from other application fields
- Indicate major challenges on R&D for automotive communication systems



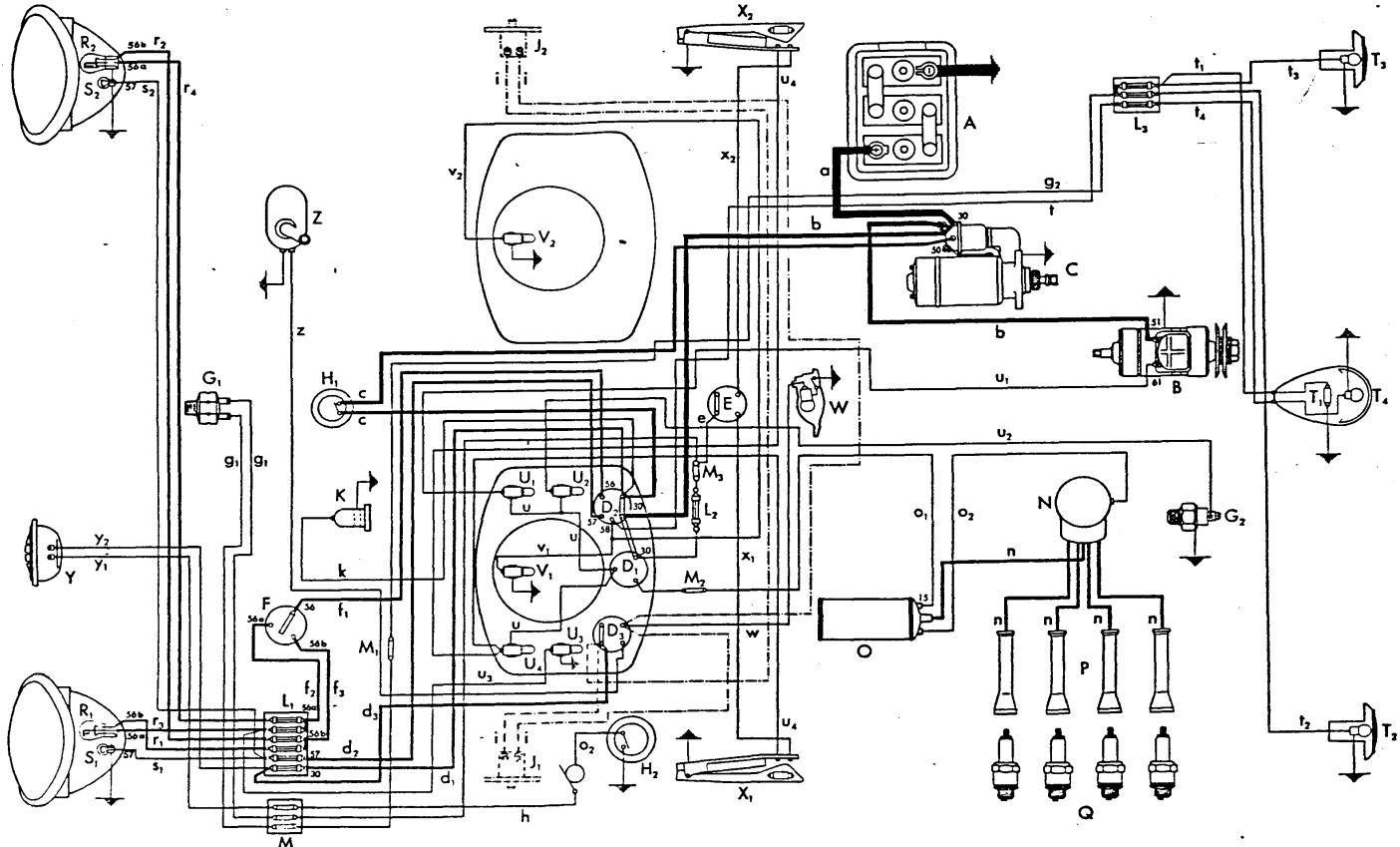
Overview

1. Evolution of automotive electronics
2. Typical automotive systems and market demands shaping them
3. New applications coming up: from global chassis control to DAS
4. Communication system architecture
5. Automotive industry paradigms
6. Standardization efforts and communication protocols roadmap
7. Meeting automotive requirements... - illustrated by LIN v2.0
8. Conclusion



where we are coming from ...

Elektrischer Schaltplan (Volkswagen)



KABELSCHLÜSSEL	
e schwarz-weiß-grün 1,0 mm ²	h braun 0,75 mm ²
f ₁ weiß-schwarz 2,5 mm ²	i grau-grün 0,75 mm ²
f ₂ weiß 2,5 mm ²	k rot 0,5 mm ²
f ₃ gelb 2,5 mm ²	n schwarz 0,85 mm ²
g ₁ schwarz-rot 0,75 mm ²	d ₁ weiß 1,5 mm ²
g ₂ schwarz 0,75 mm ²	d ₂ weiß 1,5 mm ²
r ₁ gelb-schwarz 1,5 mm ²	t grau 1,0 mm ²
r ₂ gelb 1,5 mm ²	t ₁ grau-rot 0,5 mm ²
r ₃ weiß-schwarz 1,5 mm ²	t ₂ grau-schwarz 0,5 mm ²
r ₄ weiß 1,5 mm ²	t ₃ grau 0,5 mm ²
s ₁ grau-schwarz 0,5 mm ²	t ₄ schwarz-rot 0,75 mm ²
s ₂ schwarz 0,75 mm ²	u ₁ blau 0,5 mm ²
u ₂ blau-grün 0,5 mm ²	u ₂ blau-weiß 0,5 mm ²
u ₃ schwarz-grün 1,0 mm ²	u ₃ blau-rot 0,5 mm ²
y ₁ braun 1,0 mm ²	u ₄ schwarz 0,5 mm ²
y ₂ schwarz-gelb 1,0 mm ²	v ₁ schwarz 0,5 mm ²



Automotive electronic systems today

VW Phaeton:

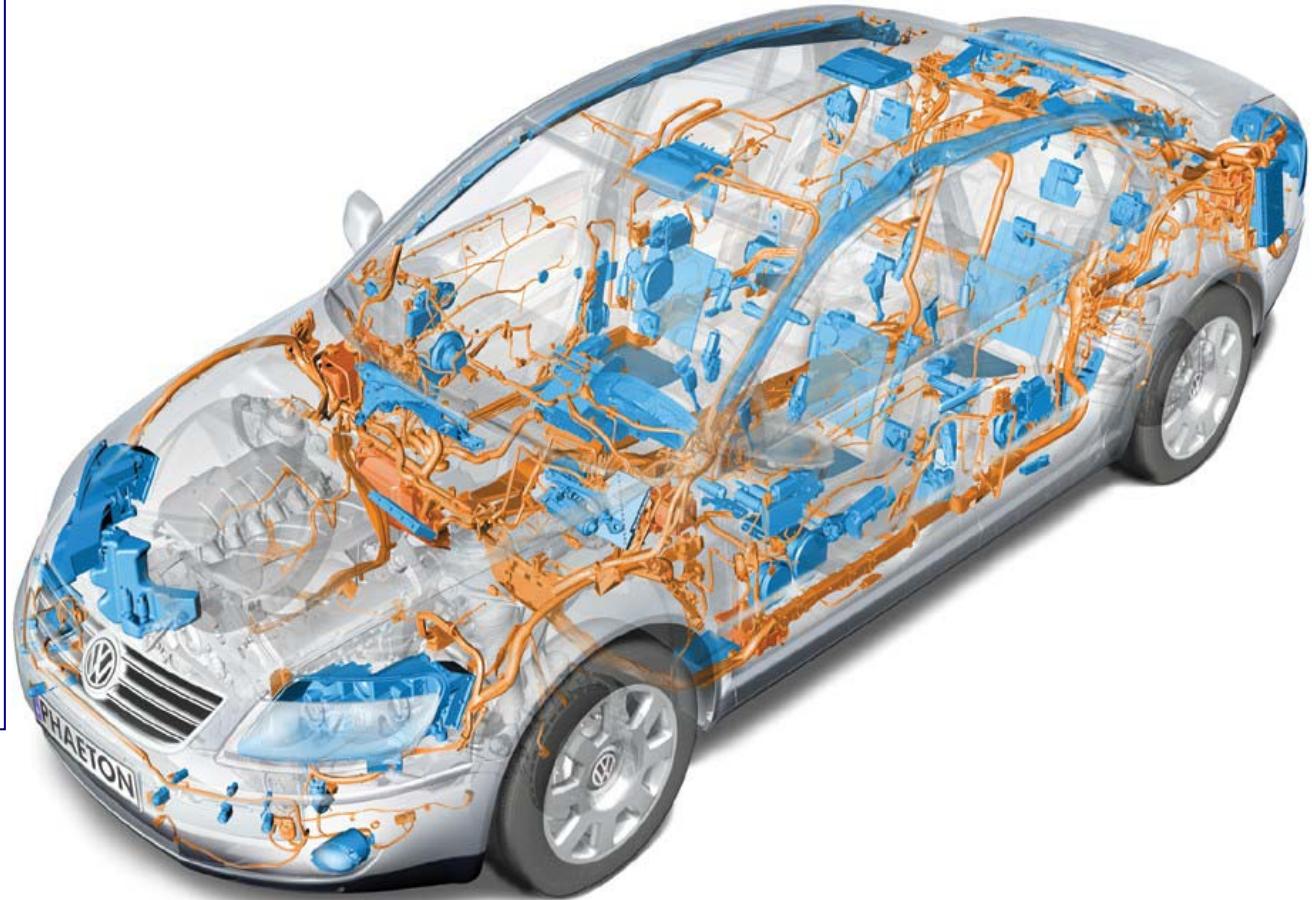
- 11.136 electrical parts in total

communication:

- **61 ECUs** in total
- external diagnosis for 31 ECUs via serial communication
- optical bus for high bandwidth Infotainment-data
- **sub-networks** based on proprietary serial bus
- **35 ECUs** connected by **3 CAN-busses**

sharing

- appr. **2500 signals**
- in **250 CAN messages**

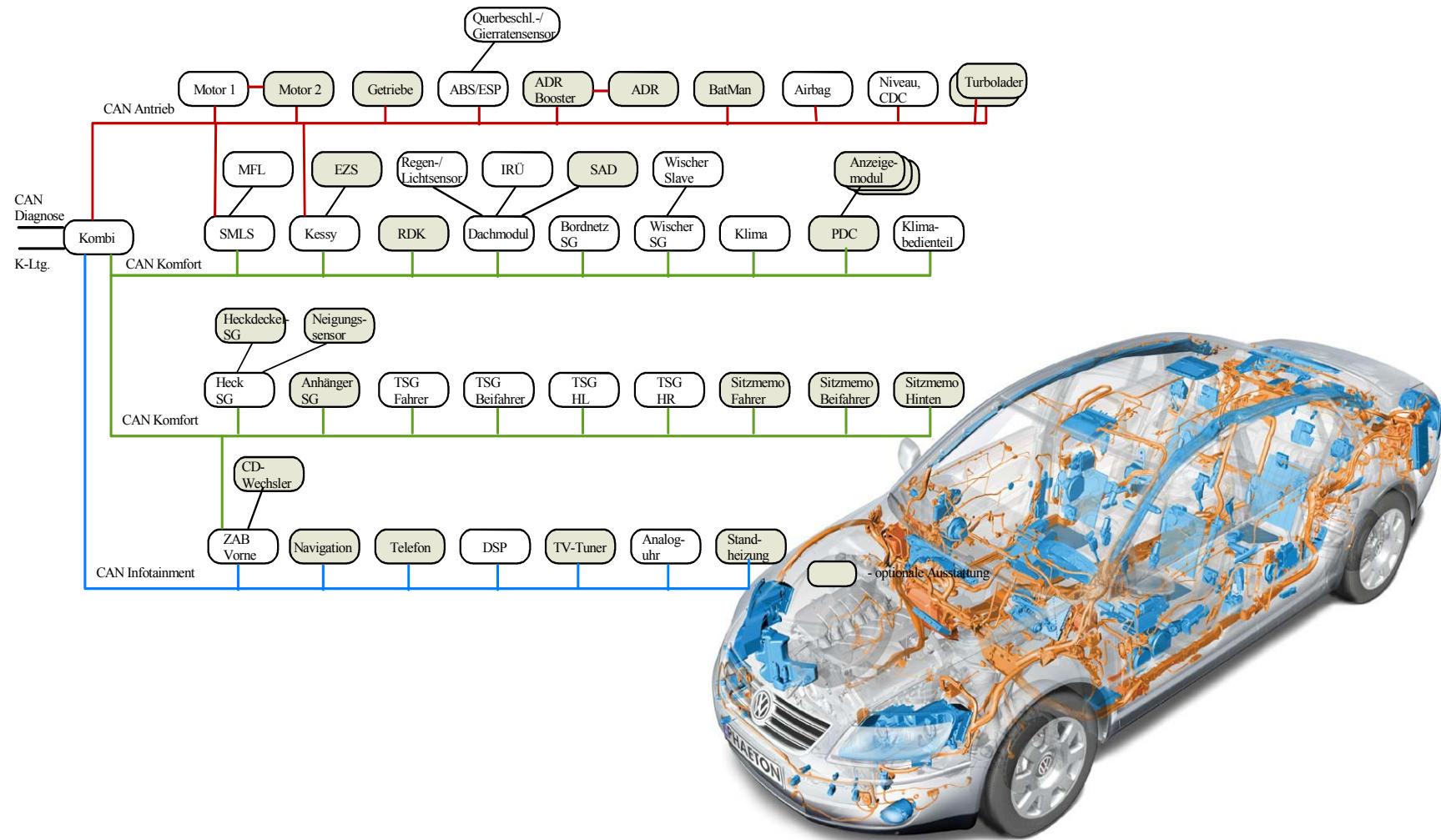


Evolution of automotive electronics

	1960	1970	1980	1990	2000	2010
Drivetrain			<ul style="list-style-type: none"> • Ignition • Fuel Injection • Enginecontrol Otto • Valve control • Diesel pump • Slip control 		<ul style="list-style-type: none"> • FSI • Pumpe-Düse-ECU • 32bit Controller • Hybrid 	<ul style="list-style-type: none"> • electromagn. Valves? • Fuel cell •
Chassis			<ul style="list-style-type: none"> • ABS • ESP • Bremsassistent • controlled Damping 			<ul style="list-style-type: none"> • elektrohydr. Brake • brake-by-wire? • Autom. Cruise Control • ACC Stop+go • Lenkhilfe • Überlagerungslenkung • skyhook-control • Wankausgleich
Safety			<ul style="list-style-type: none"> • Airbag 			<ul style="list-style-type: none"> • 2step Airbags • Pedestrian Protect. • byteflight • precrash
Comfort			<ul style="list-style-type: none"> • Climate control • intervall Wiper 		<ul style="list-style-type: none"> • Keyless Entry • Xenon-lights 	<ul style="list-style-type: none"> • advanced frontlighting • 2Motor-Wiper
Power+Wirung			<ul style="list-style-type: none"> • CAN • 12V 	<ul style="list-style-type: none"> • D2B watercooled Generator • elektron. ZE 	<ul style="list-style-type: none"> • MOST,LIN • Startergenerator • power module 	<ul style="list-style-type: none"> • TTP/Flexray • APU? • 42V?.
Information			<ul style="list-style-type: none"> • Radio • Trip computer 	<ul style="list-style-type: none"> • Sound systems Satellite radio • GSM • GPS Navigation 	<ul style="list-style-type: none"> • TV • DAB • bluetooth • Internet 	<ul style="list-style-type: none"> • Infotainment • UMTS • Veh.-Veh.-Comm.



Automotive communication networks today



Complexity

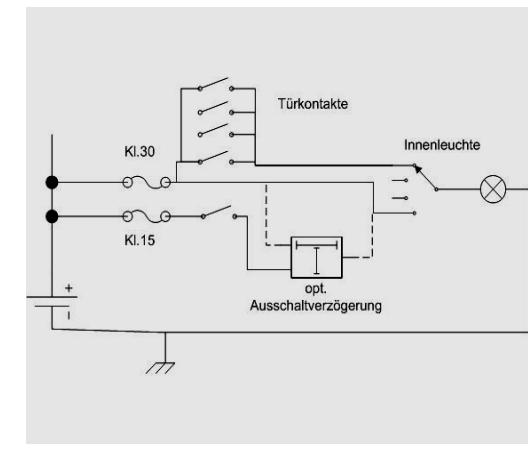
Factors influencing the design complexity of distributed systems

- no. of parts
- no. of nodes/modules
- Interface structure
- communication system
- no. and nature of I/O signals
- internal state: vector size, temporal dependencies...
- tolerance requirements on value and time properties
- functionality (algorithm or logic structure)
- common mode dependencies
-> power management

Example:

Traditional interior light functionality

Interior light controlled by door state and/or passenger switch with an optional light off delay

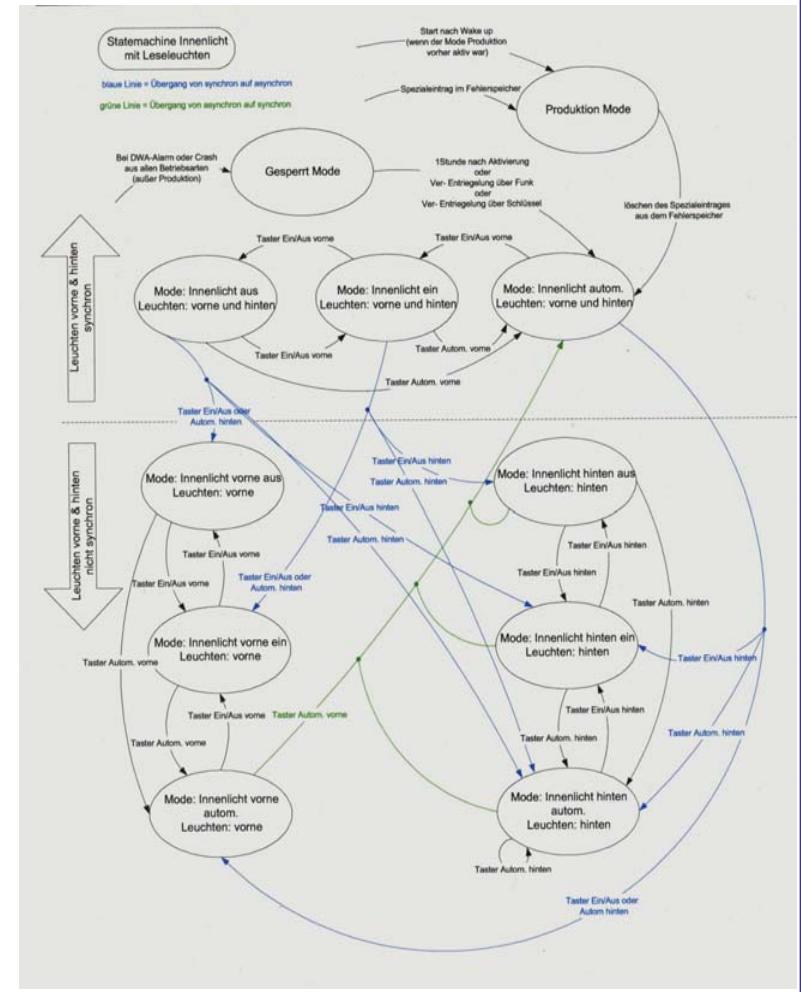
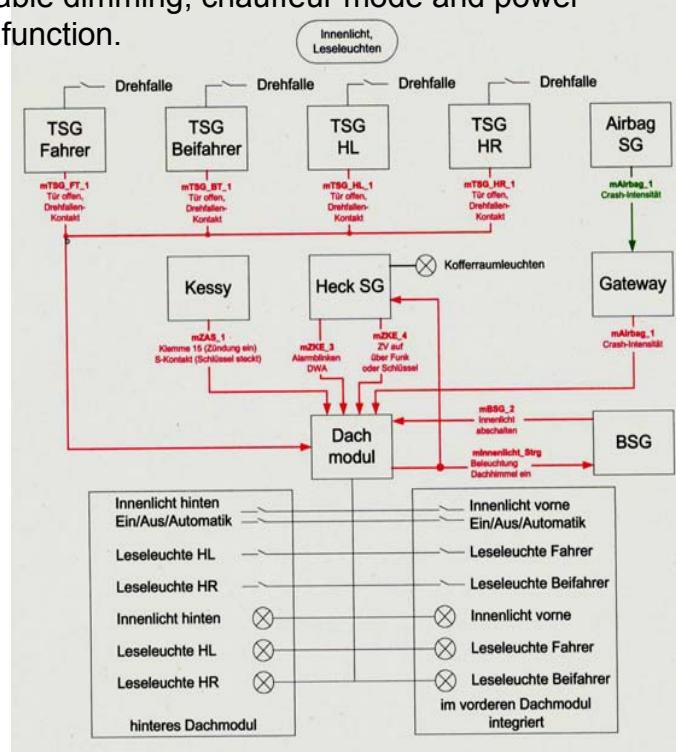


Complexity

Example (cont):

Interior light control in a year 2002 luxury class vehicle

Performance of various interior and exterior light units depending on access mode, key operation, door state, speed; Including variable dimming, chauffeur mode and power management function.



Body electronics example

Climate control components

- ZSB Klimagerät incl Motoren, Sensoren, Vorverkabelung
- Klimasteuergerät mit R/L+V/H-Steuerung
- Luftgütesensor
- IR-Temperatur-Feuchte-Sensor
- Sonnensensor
- Stellmotore Klappen
- Ausblasttemperaturfühler
- Ansaugtemperaturfühler Wasserkasten
- Außentemperaturfühler Stoßfänger
- Innentemperatursensor
- Pumpenventileinheit
- Bedienteil Klimaanlage hinten
- PTC Heizelemente
- PTC Leistungsmodul
- Standheizung, Steuerung
- Standheizung, Fernbedienung
- Zuheizer
- Solardach
- elektrisch beheizte Frontscheibe mit DC-DC-Wandler
- Elektrisch verstellbares Rollo Heckscheibe
- Sitzheizung vorn+hinten
- Scheibenheizung hinten
- Kühlerlüftersteuergerät
- Schalter Ausströmerluftmengenverstellung vorn
- Schalter Ausströmerluftmengenverstellung hinten
- Defrostertaster Seitenscheibe
- elektrisch verstellbare Ausströmer



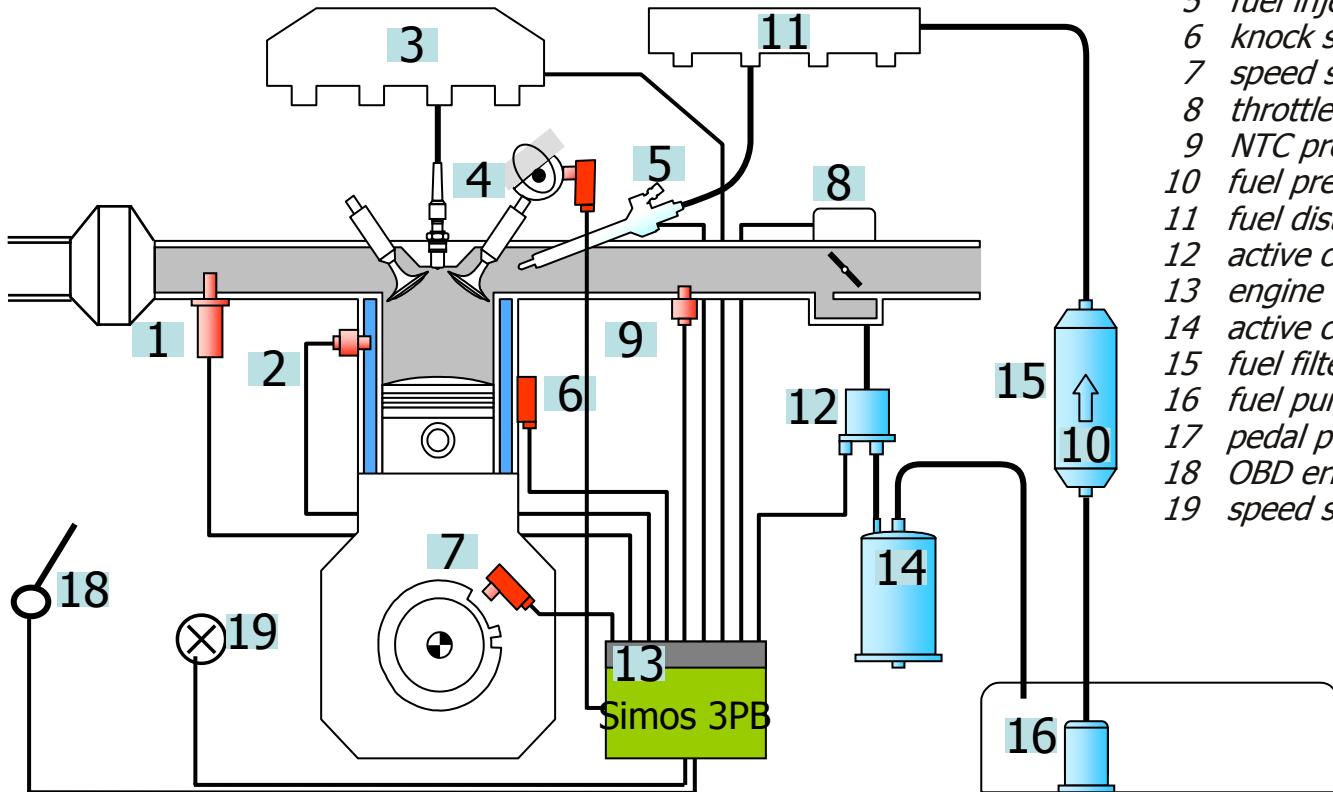
Modern climate control functions:

- up to 4 climate zones
- window defrost (automatic)
- seat climate control (heating, air circulation)
- stand-by heating
- solar driven ventilation



Drive train system example

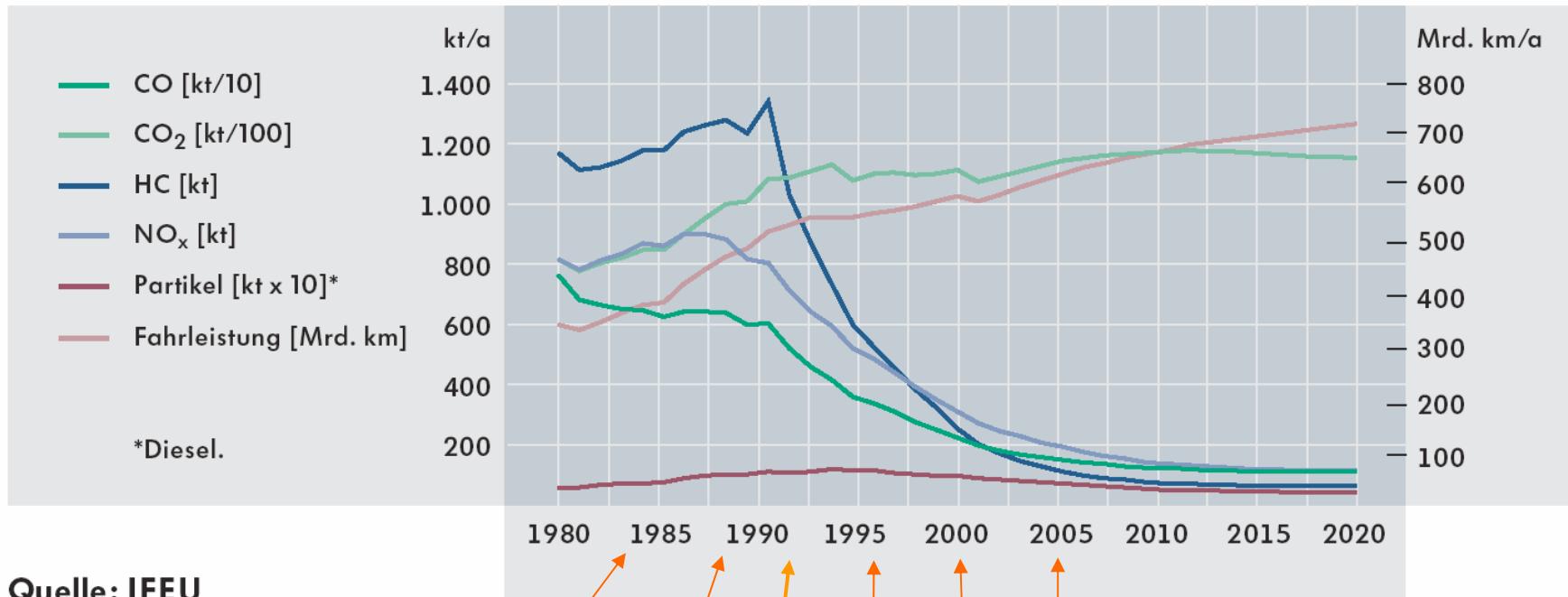
Engine control components



- 1 lambda sensor
- 2 cooling fluid temperature sensor
- 3 ignition coil array
- 4 spark plug
- 5 fuel injection valves
- 6 knock sensor
- 7 speed sensor crankshaft
- 8 throttle control actuator
- 9 NTC pressure sensor
- 10 fuel pressure control
- 11 fuel distribution
- 12 active charcoal filter valve
- 13 engine control ECU
- 14 active charcoal filter unit
- 15 fuel filter
- 16 fuel pump
- 17 pedal position sensor
- 18 OBD error signal
- 19 speed sensor camshaft



Benefits of engine control on emissions



Quelle: IFEU

1984: extension to Diesel engines

1988: particle limits for Diesel vehicles

1992: Euro-1 (>3-way-catalytic converter)

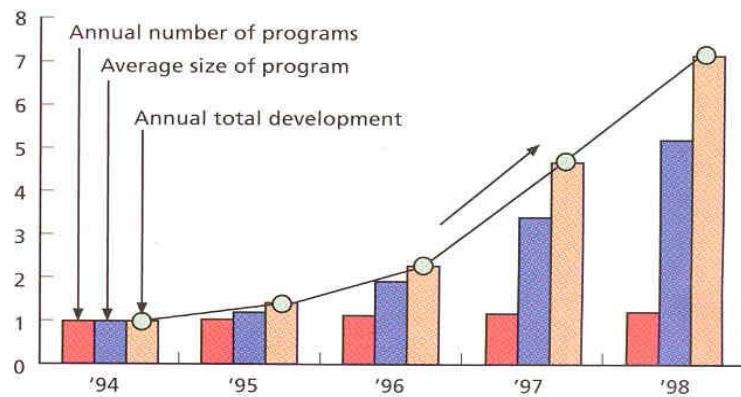
1996: Euro-2

2000: Euro-3

2005: Euro-4

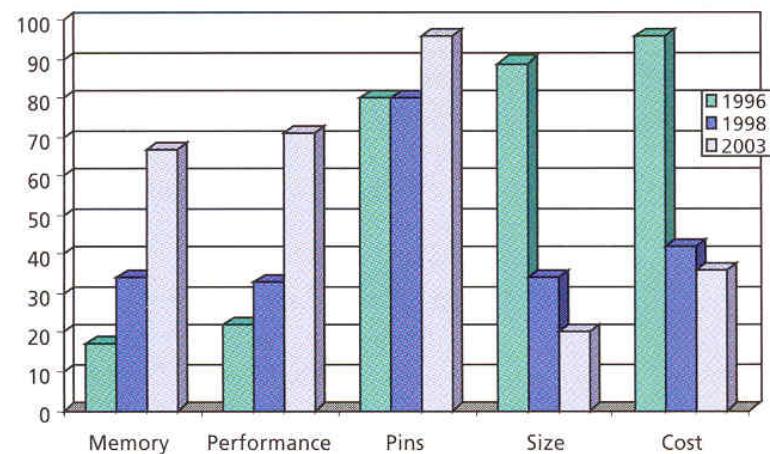


Effects of increasing complexity of mechatronic controls on development resources and component performance

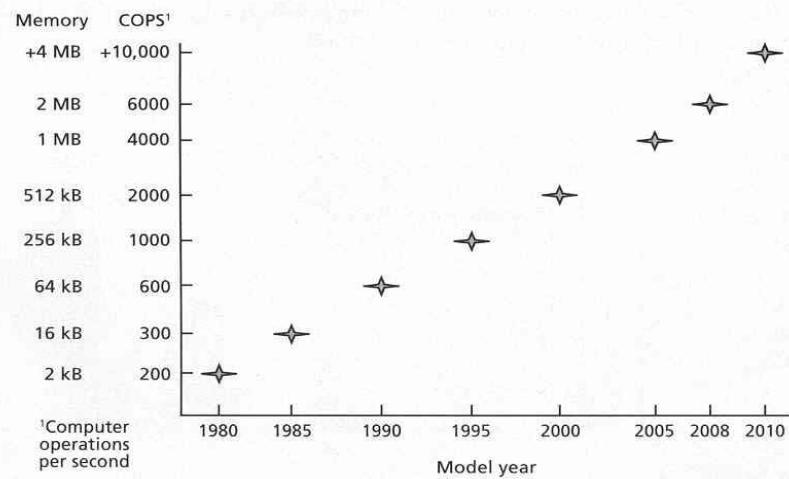


At Toyota, the number of engine-control software programs has not risen, but their size has skyrocketed.

Quelle: Costlow, SAE 2003



The dramatic increases in memory size underscores the growth of software in GM's engine controllers, which, though smaller and less expensive, offer much higher performance.



GM expects memory allotted to powertrain control software to continue its steady growth as faster processors do more tasks with increased precision.



Networking chassis control systems...

EHB (electro hydraulic brake) functions:

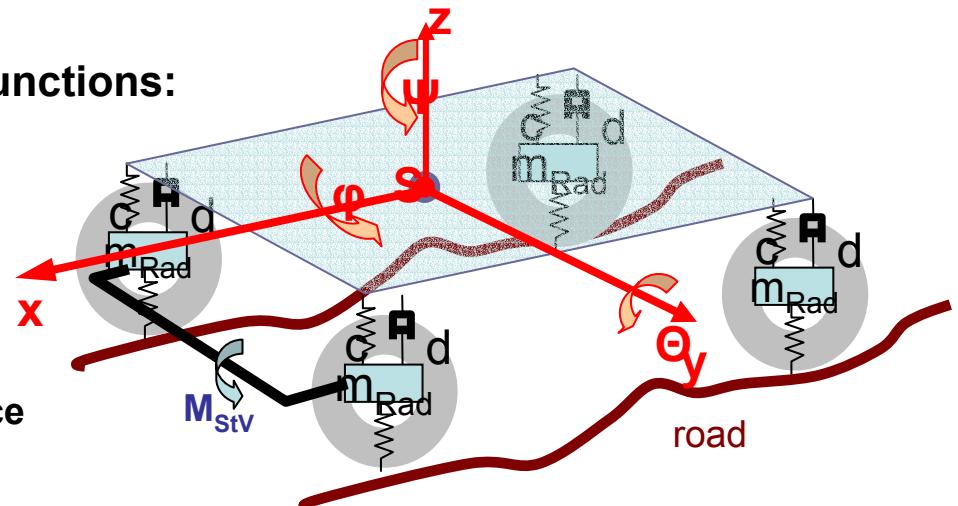
- dynamic full-range brake pressure control
- wheel-specific slip control and brake pressure gradients

CDC (continuous damping control) functions:

- (short-term) wheel load control

Interfacing EHB and CDC enables

- optimization of steering performance
- improved vehicle stability
- decreasing braking distance
- less ESP-control actions lead to improved comfort perception



Networking chassis control systems...

ESP (electronic stability control) functions

- control of longitudinal dynamics
- yaw moment correction by asymmetric braking

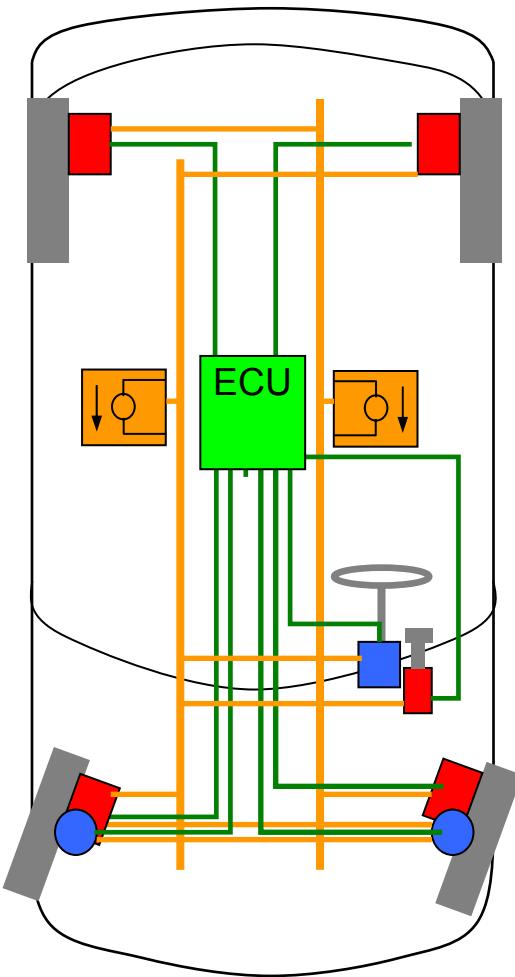
interfacing braking and steering control allows yaw moment correction by active steering action

- improved vehicle stability
- decreasing braking distance
- less ESP-control actions lead to improved comfort perception
- yields further comfort improvement

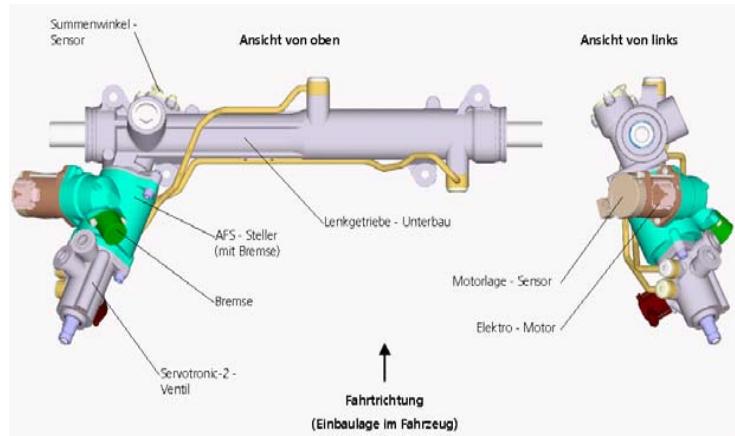
additional interface with vertical dynamics control

- better vehicle stability by controlling wheel forces with damper parameter variation
- rough road detection from vertical dynamics control allows optimized variation of ABS braking function

X-by-wire cars enabling global chassis control



Steer-by-wire



Brake-by-wire

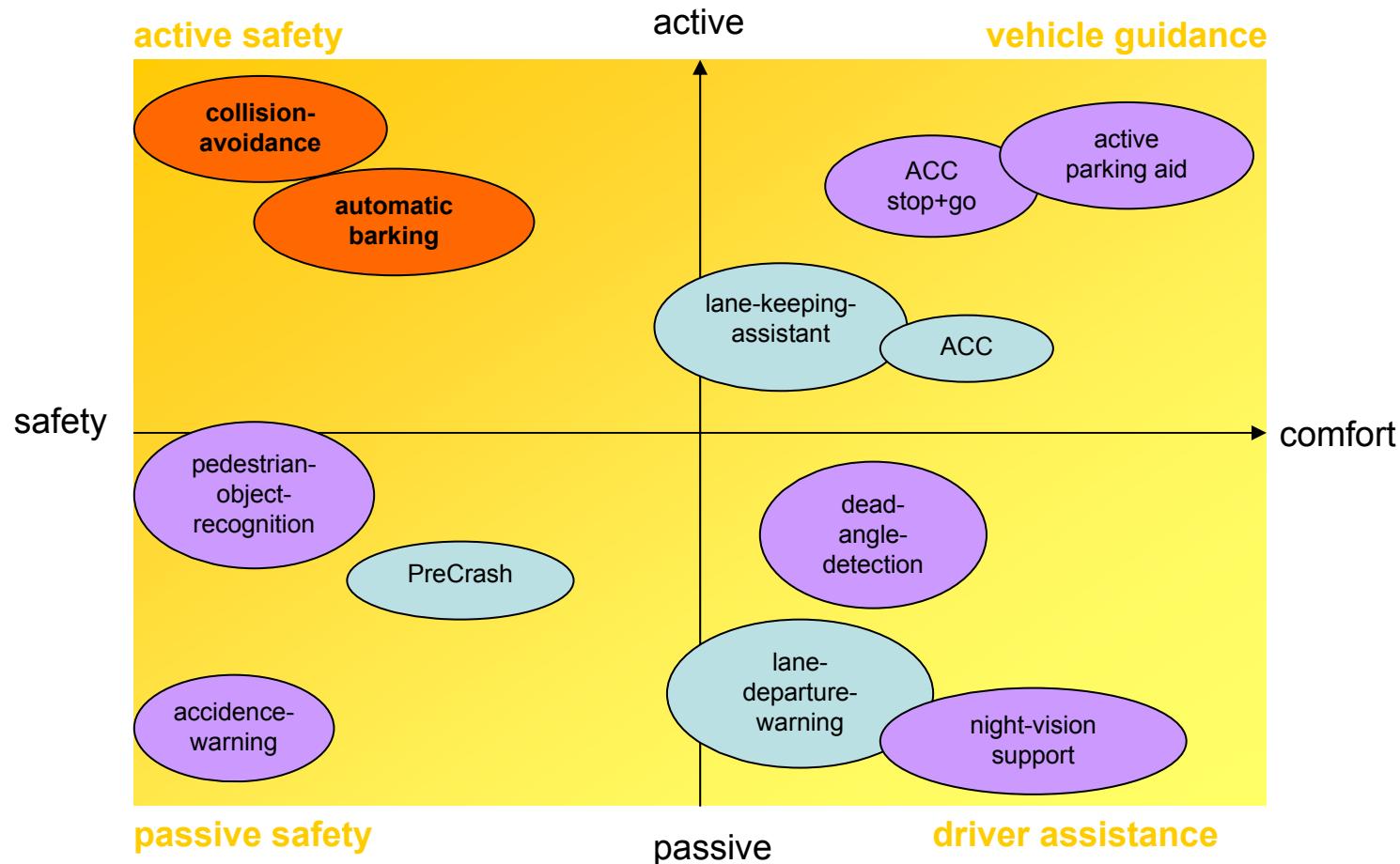
Redundant supply of electric energy

Redundant and deterministic communication system

High dependability control unit



Approaching active safety systems ...

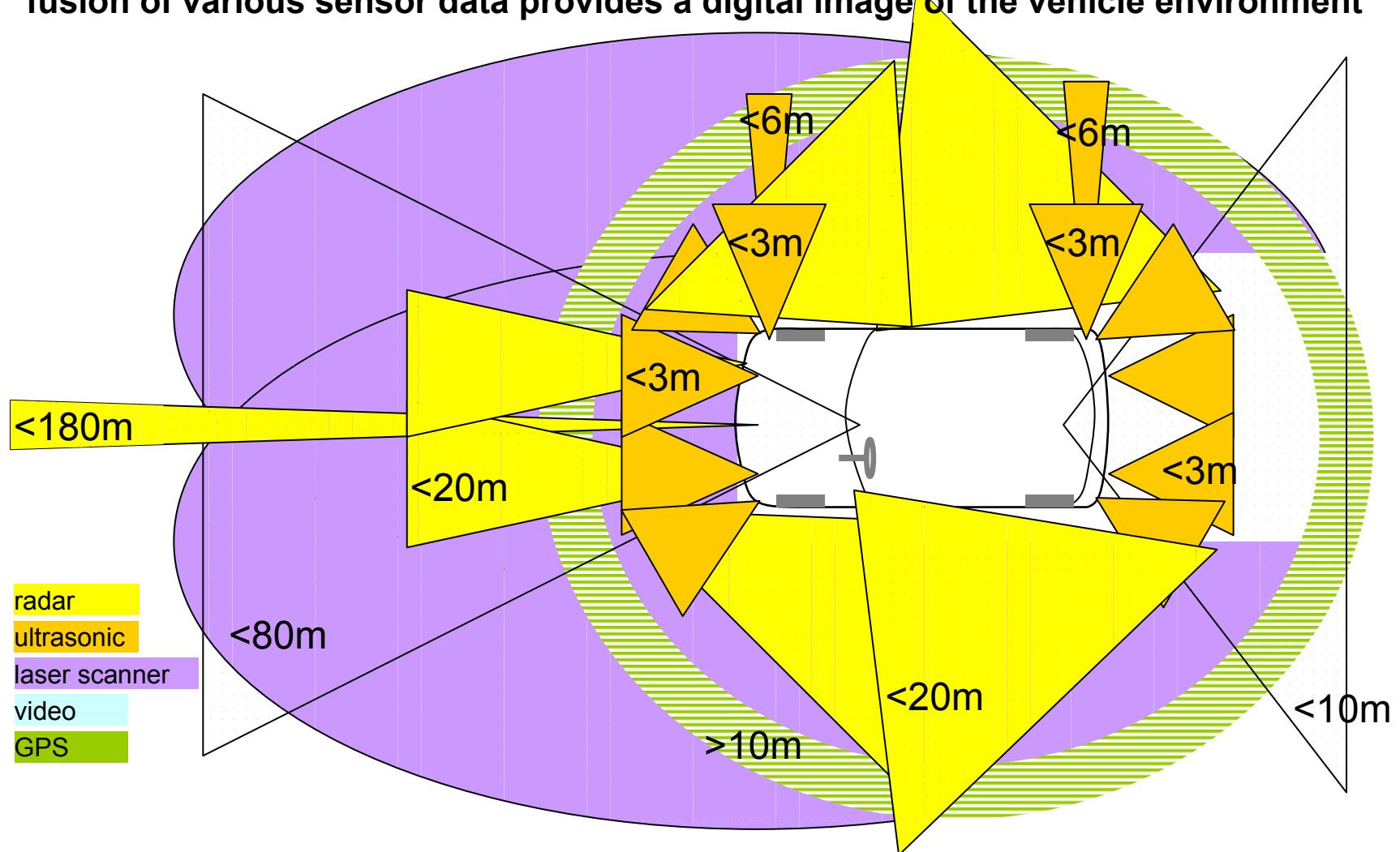


Source: Knoll (2003)

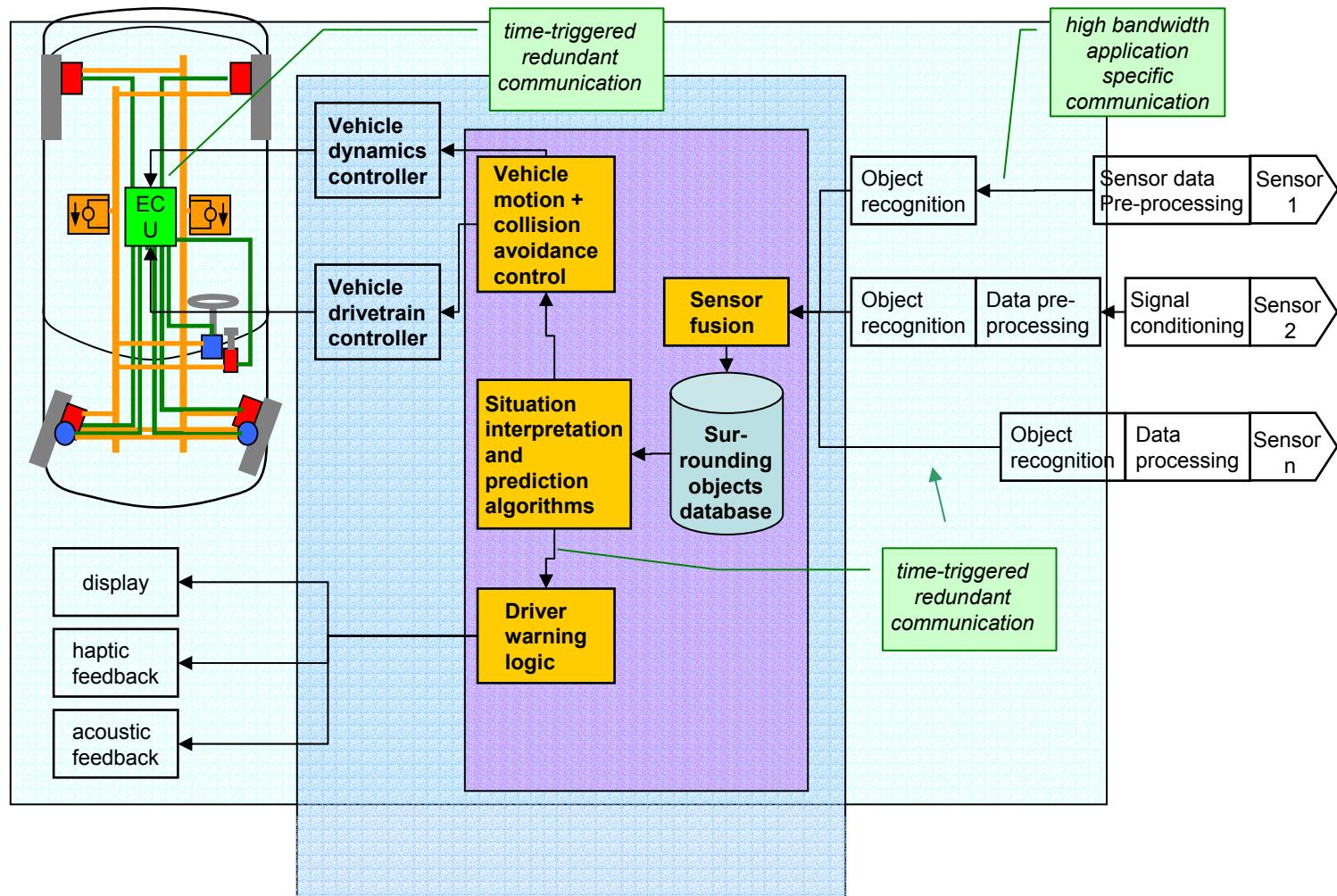


Envisioning the accident avoiding car...

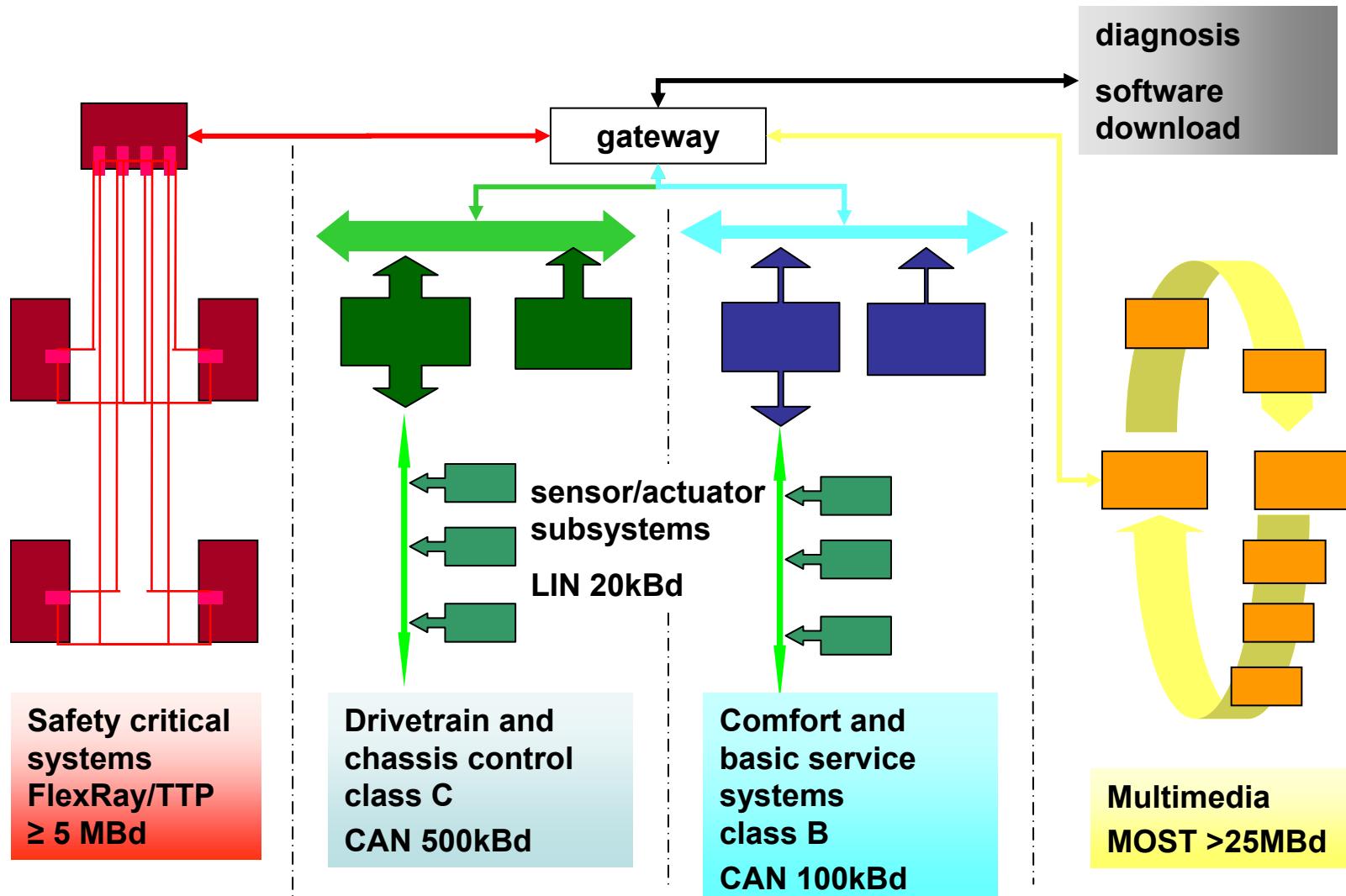
fusion of various sensor data provides a digital image of the vehicle environment



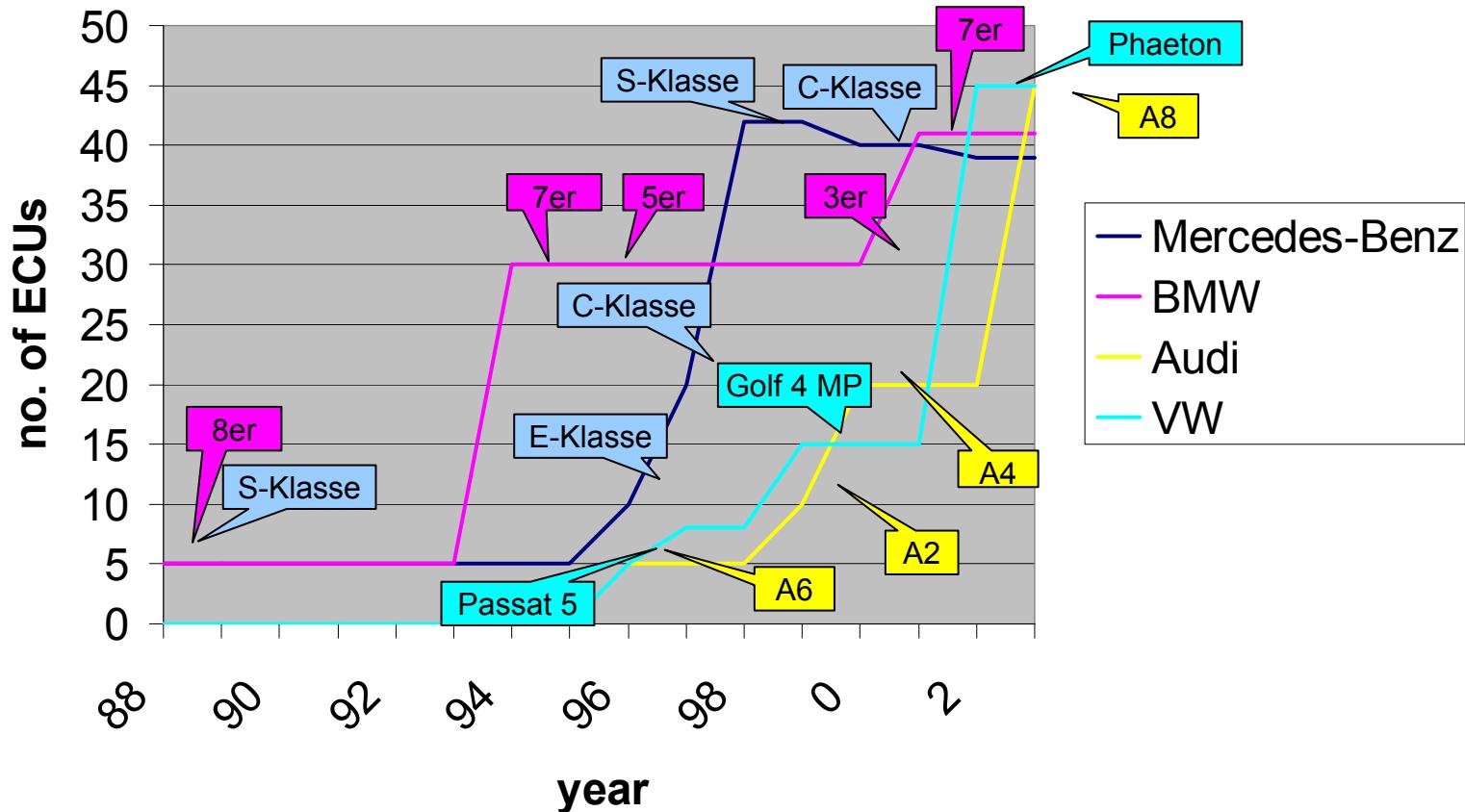
architecture of collision avoidance systems



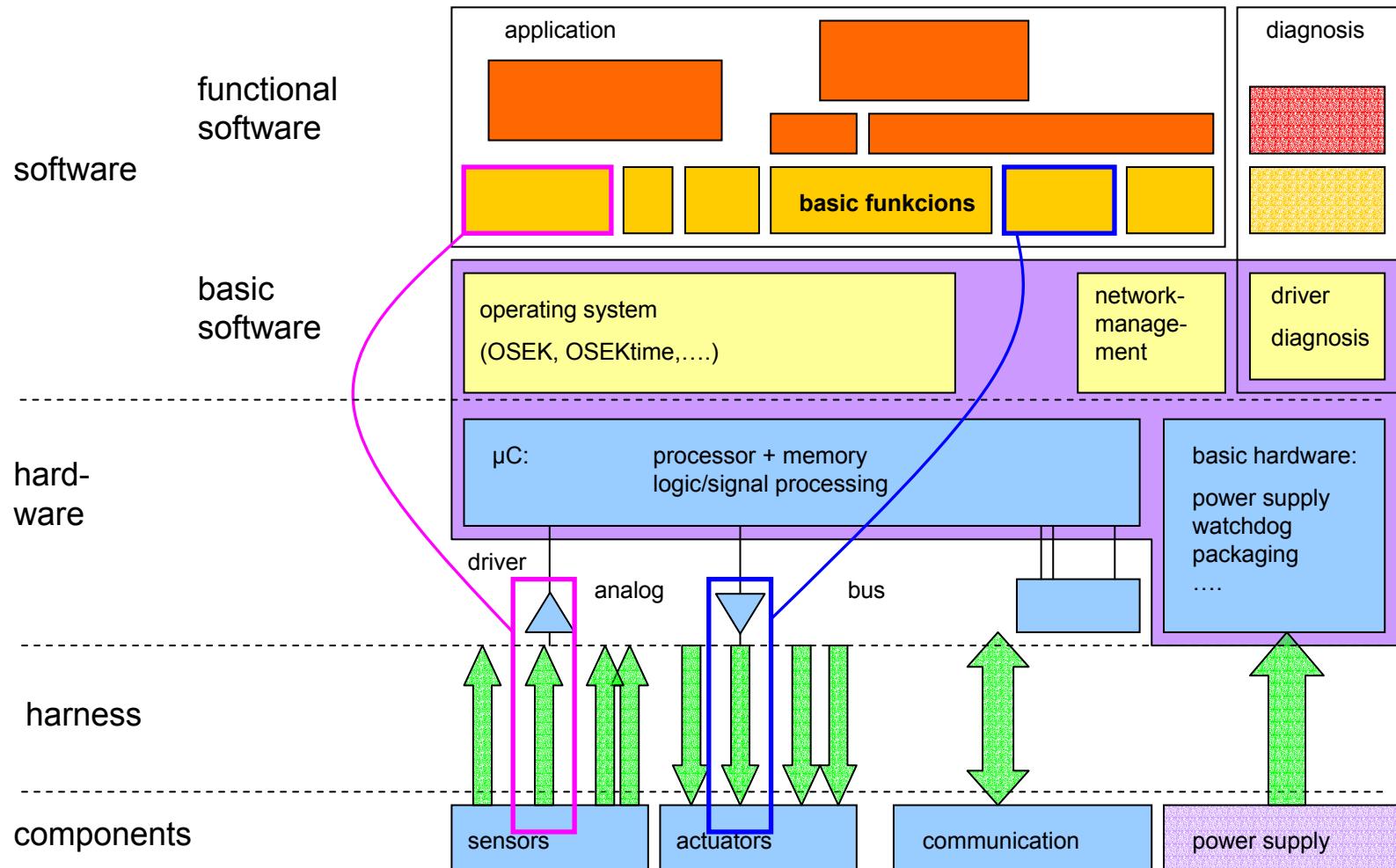
Communication system architecture



Evolution of vehicle networks



ECU and system architecture



Communication system requirements

Comfort and basic service systems	<p>Applications are mostly of state-machine type, event-driven with time intervals from fractions of seconds to several days.</p> <p>Triggers are events, communication is CAN (ET), but usually with periodic transmission (quasi-TT).</p> <p>LIN protocol taking over significant share of communication</p>
challenge:	<p>Complexity of state combinations</p> <p>Testability including temporal and state history dependencies</p> <p>Power management</p>



Communication system requirements

Drive train and chassis control	<p>Applications are mostly real-time controls with event-driven elements.</p> <p>Communication includes state information and analog signals used in process control loops, thus requires repetitive transmission.</p> <p>Particularly in engine control, periods are not always equidistant but correspond to crankshaft revolution.</p> <p>CAN used in almost all cars (even low class), bandwidth is well utilized, propagation to faster network ahead.</p> <p>Propagation to TTA advisable, since many functions are safety-relevant.</p>
challenge:	<p>Bandwidth</p> <p>Fault tolerance, reliability</p> <p>Low cost sensor/actuator integration</p>



Communication system requirements

Multimedia	<p>Simple infotainment systems use existing communication network for control of distributed units, requirements correspond to those of comfort systems (ET bus with quasi-TT transmission -> CAN).</p> <p>Transmission of display information requires sporadic high bandwidth and is fully event-triggered.</p> <p>Transmission of audio and video data streams requires synchronous transmission at very high bandwidth, MOST bus is standard for this application range.</p> <p>No safety applications, data rate more important than reliability considerations.</p>
challenge:	Bandwidth Interfacing popular entertainment equipment wireless



Communication system requirements

Safety critical systems	<p>Safety features dominate these applications, the superiority of a time-triggered architecture is well accepted and basic to all development projects.</p> <p>Even for event driven applications, time-triggered communication is preferred for reliability reasons.</p>
challenge:	<p>Reliability</p> <p>Fault tolerance</p> <p>Testability of vehicle functions (> driver assistance systems)</p>



Paradigms specific to the automotive industry

- **Automotive industry** is primarily **mechanically minded**
- **Electronics** is a „**service**“ domain
- **High volumes**
 - Car platforms up to 1 million units per year
 - Shared parts volume covering several platforms
- **Long product life cycle:**
 - 6...12 years,
 - > 20 years including service
- **Long design phase** compared to electronics industry:
 - ~4 years from concept to production
- **Very high quality standards**
- **Safety requirements** comparable to avionics
 - External access to vehicle communication only via restricted diagnosis port
- **Modular component families** required to meet logistics requirements



Problems and challenges in automotive electronics

- **Little standardization** for automotive electronics and software existing
- **Availability of hardware components**
 - Automotive technology cycles exceeding those for semiconductor industry
 - Redesign with new components requires extensive validation
- **Service personnel** not qualified for electronics or software based systems
- Embedded systems with mostly **hard real-time requirements**
 - Drive train -> order of 100µs
 - Chassis -> order of ms
 - Body -> order of 10..100ms



Characteristics of automotive electronic systems

factors influencing **design cycles of automotive (electronic) systems**:

automobile: increasing more **product variations** within a car family,
manufacturers offering full range of vehicle type spectrum

design cycle **time and resources** decreasing
leading manufacturers competing for
technology leadership and quality

mechatronics: innovative functionality realized through
interaction of formerly autonomous units
resulting in **highly complex distributed system architecture**
only **few strong suppliers** capable of designing
future systems
personnel and financial project **resources** becoming scarce
sourcing decisions dominated by financial factors (**cost**)



System architecture design criteria

different **views** determine the design of a distributed automotive system:

- **layout and packaging** within the vehicle
- electrical (hard-/software) and mechanical/hydraulic/pneumatic **partitioning of system functions**
- **safety concept** (fault tolerance, redundancy decisions, ...)
- **information processing architecture** (TT vs. ET)
- **functional architecture**
(hierarchical functional control with standardized,
vehicle function oriented interfaces → *cartronic* approach)
- communication **network protocol** selection



Characteristics of automotive electronic systems

resulting in a framework for electronics systems design

- creation of **shared parts base** for a product range
- **reuse** of existing components
- **standardization** of software and networking components
- component **life cycle** extending over several car generations
- selection of a range of processor families to guarantee **long term supply**
- vehicle electronics **architecture** must be capable of integrating systems designs from various suppliers and out of multiple component generations – **standardization of functional interfaces**



Standardization

OSEK-VDX

founded 1993/94 with core members:

BMW, Bosch, DC, Opel, PSA, Renault, Siemens, VW

to establish

industry standard for **distributed control** units in vehicles

abstract and **application independent** interfaces

hardware- and **network independent** interfaces

covering

communication: Data exchange within and between control units

network management: Configuration determination and monitoring

operating system: Real time executive for ECU software and basis for the other OSEK/VDX modules

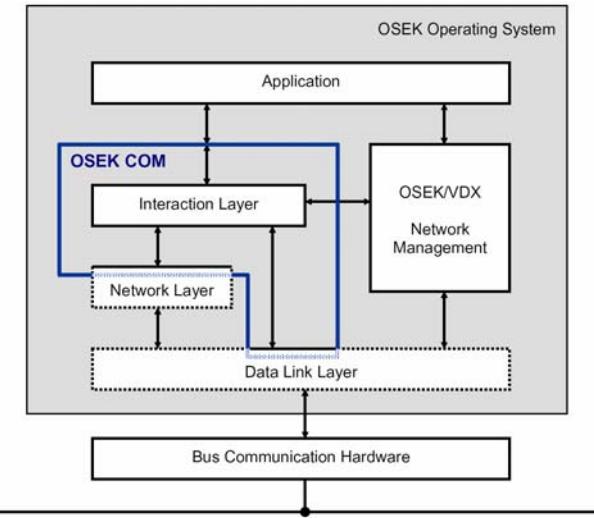


Standardization

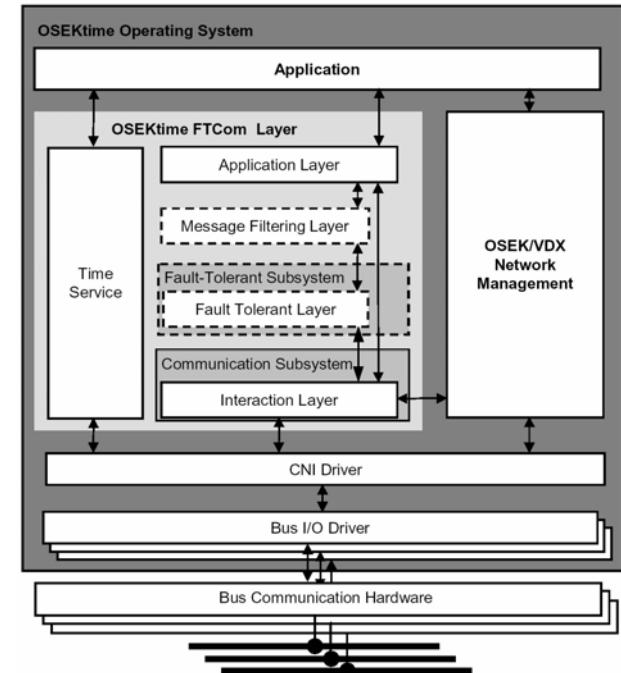
OSEK-VDX

technology:

layer architecture with OSEK-OS



time controlled architecture with OSEKtime-OS and fault tolerant communication



status:

widespread use, especially NM and OSEK-OS

ISO standardization ongoing (ISO 17356)

established **certification process** used by major software and tool vendors

figures from www.osek-vdx.org



Standardization

Automotive Open System Architecture

established 2003 with members:

BMW, Bosch, Continental, DC, Ford, PSA,
SiemensVDO, Toyota, VW ,...

to establish

open standard for automotive E/E architecture

improve reuse

increase efficiency in functional development

featuring

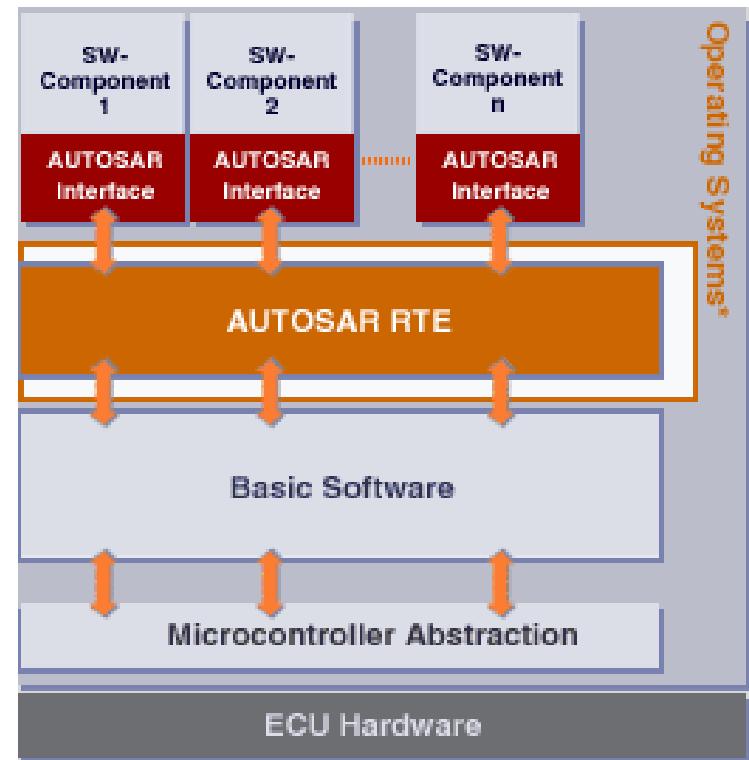
modularity and configurability

standardized interfaces

runtime environment as a **communication center for inter- and intra-electronic ECU information exchange**

target:

end of test and verification phase in 2006



Automotive networks: CAN

features:

- event triggered
- priority driven communication
- multi master
- powerful features implemented in interface and driver hardware
- various fault tolerance mechanisms
- high reliability
- widespread use: millions of interfaces shipped each year
- extensive tool base available



Automotive networks: LIN

**Cost-optimized protocol for connection of sensors and actuators
to ECUs conforming to automotive specifications**



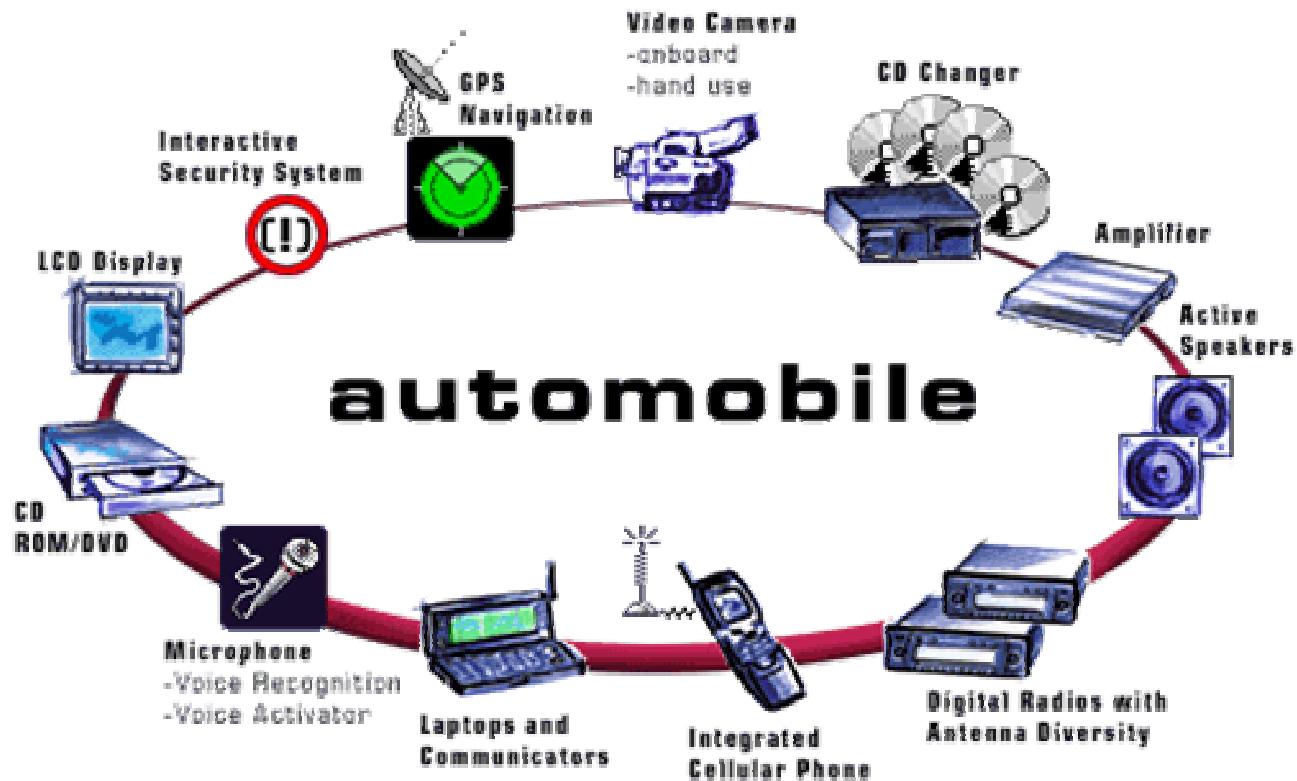
features:

- **single master / multiple-slave:**
- LIN is running on any **UART/SCI**, so can be implemented in software
- Single wire operation on battery voltage
- **data rates up to 20kbit/s.**
- **payload may be 2, 4 oder 8 bytes** per message
- **deterministic** due to time-triggered operation
- **simple time-base for slaves** require no crystal or ceramic oscillatoren
- **fault confinement** and network management must be implemented **in software**



Automotive networks: MOST

target applications are interacting infotainment functions



source: www.mostcooperation.com



Automotive networks: MOST features

- Data Rate 22,5 MBit/s at $f_s = 44,1$ kHz
- Flexible ring-based topology
- Easy to expand
- Up to 64 nodes
- Optimized for optical data transport
 - ➔ EMC
 - ➔ Cost
- Cheap interface
- High data security
- Dynamic addressing
- Basic principle of data transport is synchronous
 - ➔ Real time applications (Audio/Video)
 - ➔ No buffers required (cost)
- Four different transport channels
 - ➔ Control Channel
 - ➔ Synchronous Channel
 - ➔ Asynchronous Channel
 - ➔ Transparent Channel
- Dynamic partitioning of bandwidth
- Embedded Network Management
 - ➔ StartUp/ShutDown
(Stand Alone)
 - ➔ Power management
 - ➔ Fail-Safe
 - ➔ Allocation and Deallocation
 - ➔ Data protection
- Remote Access

source: www.mostcooperation.com



Automotive networks: FlexRay

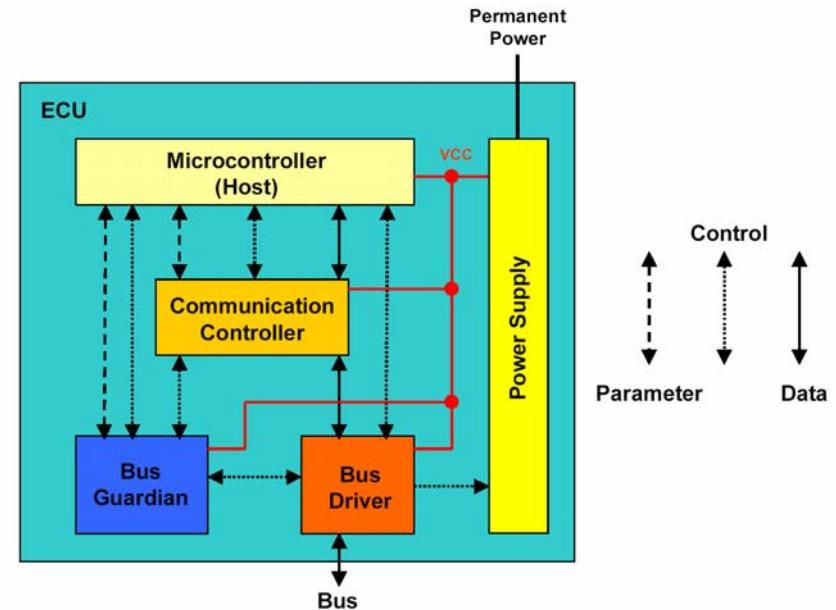
Bus system for future vehicle generations providing high data rates and fault tolerance

featuring

- synchronous and asynchronous communication (variable)
- data rate 5 Mbit/sec net; 10 Mbit/sec total
- deterministic communication with guaranteed latency and jitter
- redundant communication channels
- fault tolerance and time-triggered services implemented in hardware
- fault tolerant synchronized global time base
- independent bus guardians
- arbitration free communication
- optical and electric physical layer
- bus, star and multiple-star topology



source: www.flexray.com

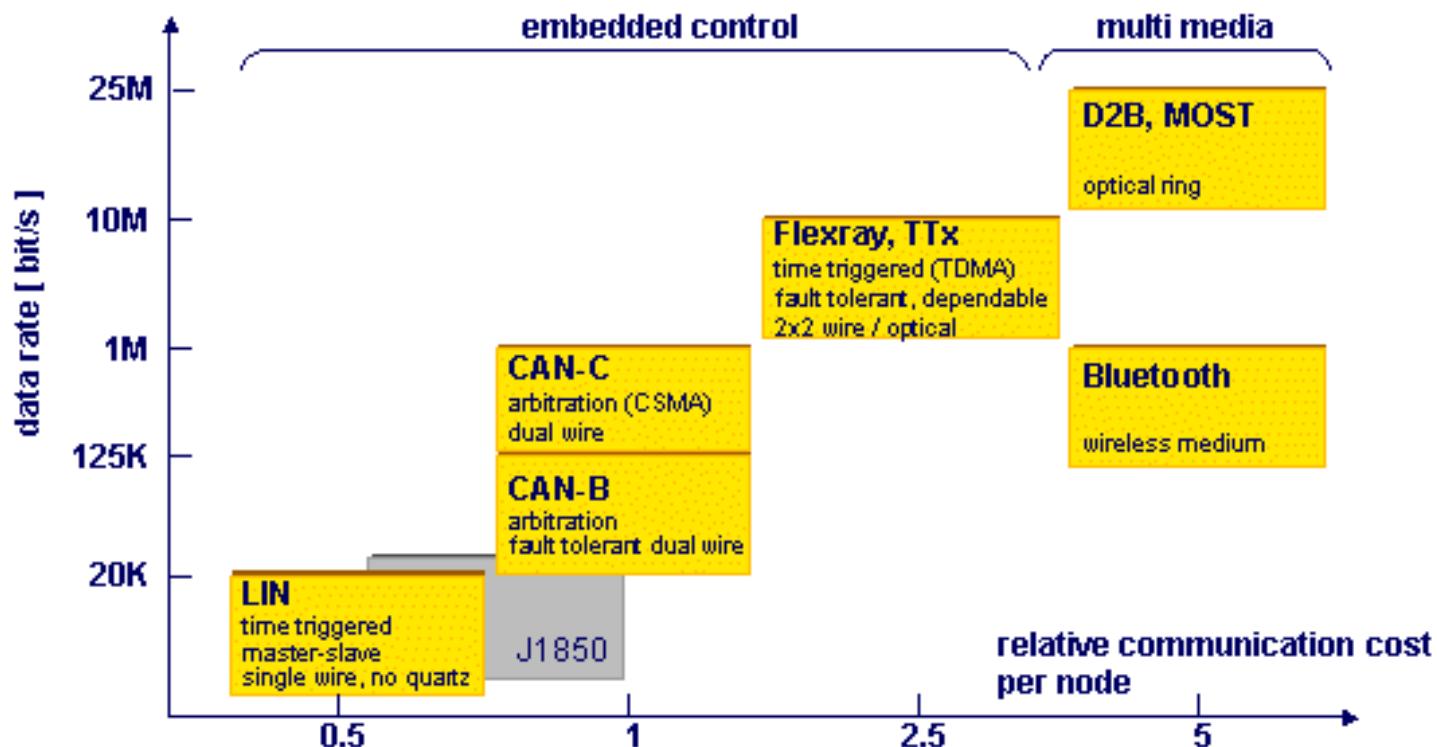


status

presently only FPGA-versions available to consortium members,
ASICs announced for end of 2004



Automotive networks: Roadmap for 200x



source: www.lin-subbus.org



Wireless communication

state of the art:	RDS-TMC via FM radio	- traffic information
	GPS	- navigation
	GSM (UMTS)	- voice communication
	bluetooth	- wireless handset connection
visions:	floating car data	- monitoring traffic conditions
	routing/guidance database update	
	server based route guidance	
	toll collection	
	vehicle-vehicle communication – traffic preview	
	remote diagnosis/telemetry	

> **General problem for telematics: missing business case**
except for commercial vehicle applications



Telematics

Software architecture of MOST-based internet-interface in the Audi-A8 with OSGI compatible services

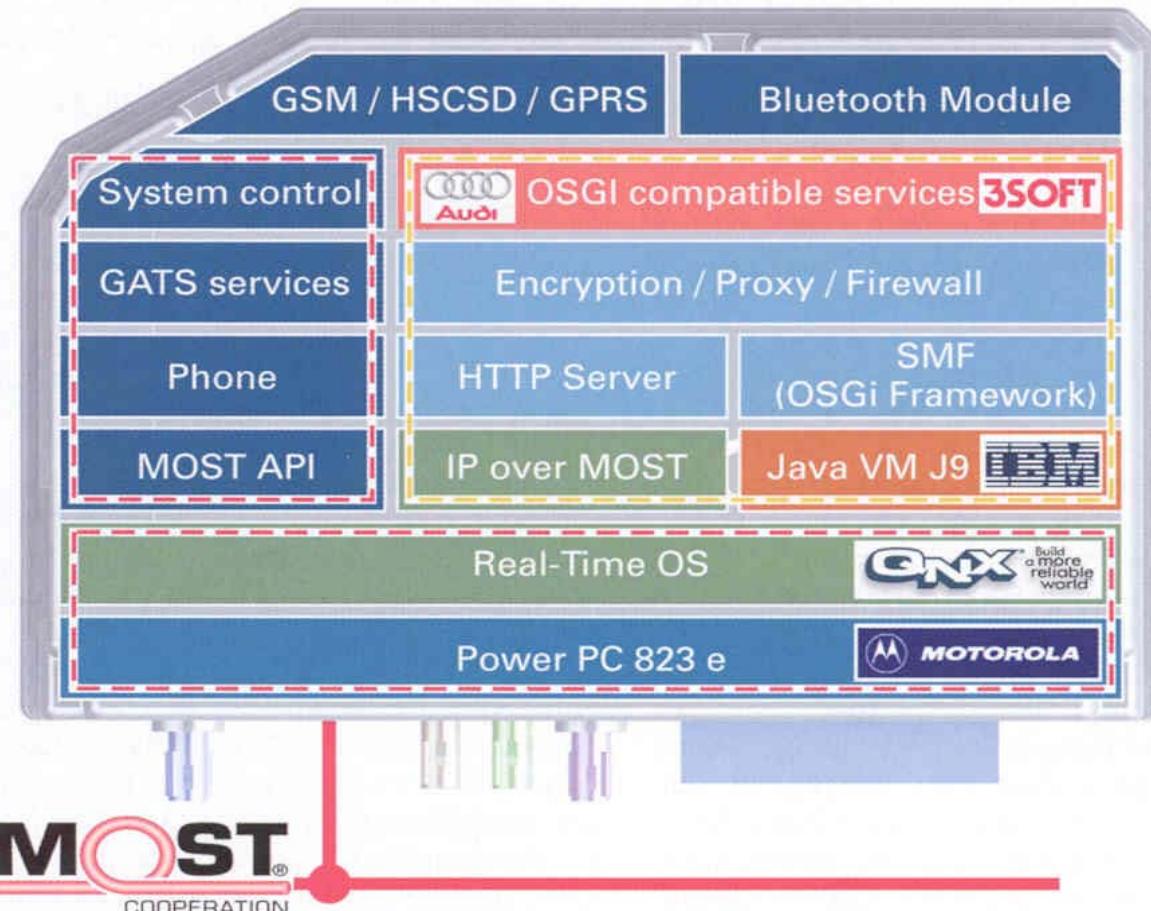


Bild 1: Die Software-Module im Überblick

source: Hudy, Audi/ATZ 2002



Meeting automotive requirements...

LIN protocol and implementation:

- **Low cost implementation**

- Single wire physical layer running on battery voltage
- Almost no hardware overhead, runs on standard SPI

- **Standardized**

- Choice of major European OEMs
- Supported by major automotive µC families

cost reduction
increased reliability

- **V2.0 protocol extension supporting higher layers**

- Slave identification
- Configuration
- LDF (LIN description file) enabling high level tool support

easy and fast
implementation



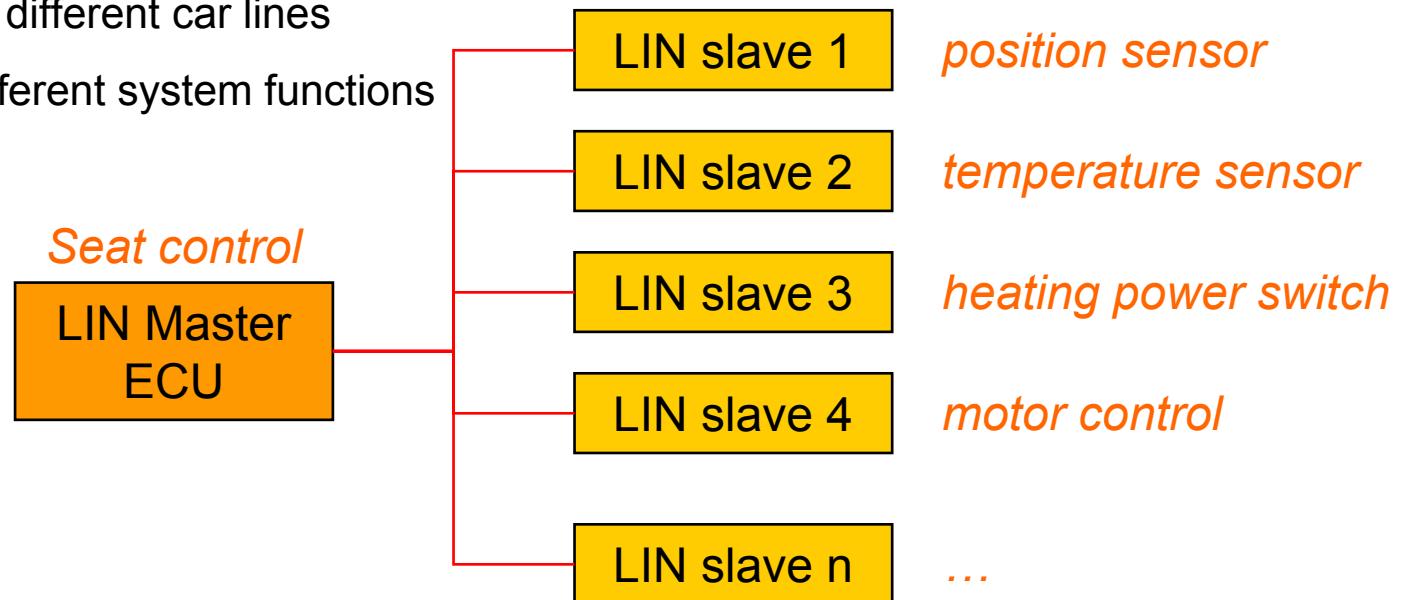
Meeting automotive requirements...

LIN V2 protocol and implementation leading to >plug and play< EE architecture

- system functionality is implemented in master ECU
- >universal< mechatronic devices

sensors and actuators with LIN 2.0 interface allow for

- widespread use
- across different car lines
- and different system functions



Conclusion

Status today

- Standardized protocols
- Accepted and implemented by key market players
- Available for communication classes A, B, C, D

Challenge today is

- Easy, fast and reliable **system integration**
- Supporting **model-based** specification and development

Work required

- Standardization of **OSI levels >2**
Focus will be on tools, network management, fault-tolerant communication, operating systems
- **Long-term stability** of as many system components as possible
is prerequisite for meeting
highest quality/reliability requirements of distributed automotive systems

