Market and Technology Study
Automotive Power Electronics 2015

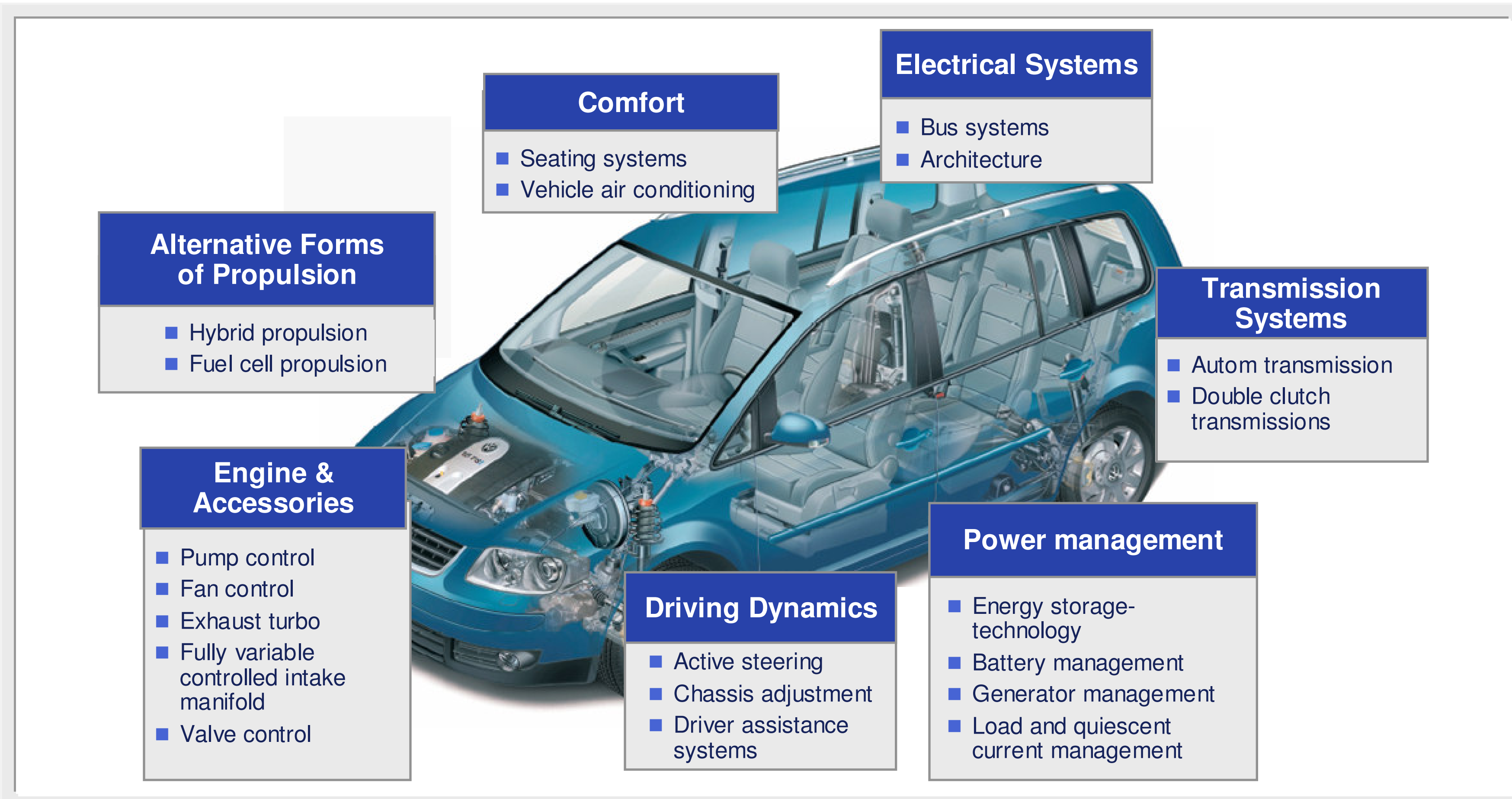
Results

2006

Arthur D Little

Agenda

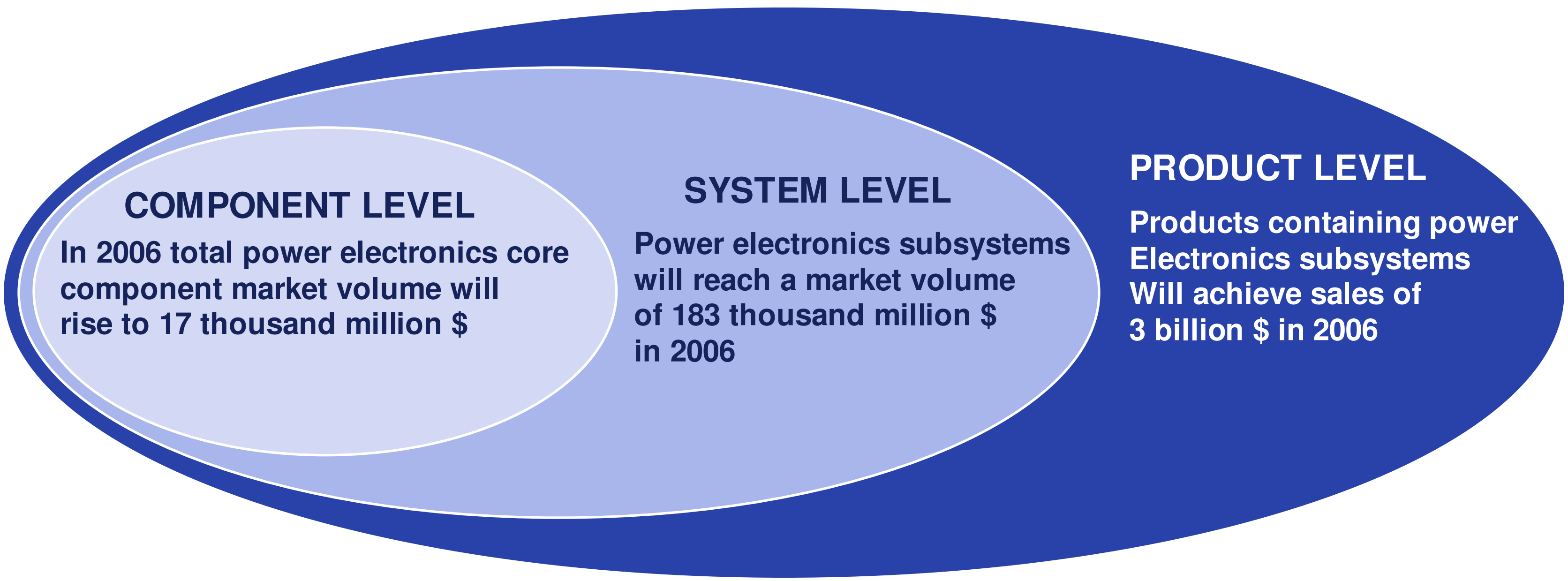
The Study deals with future use of power electronics in automotive technology



Agenda

By 2015 power electronics will play a significant role in all sectors of industry

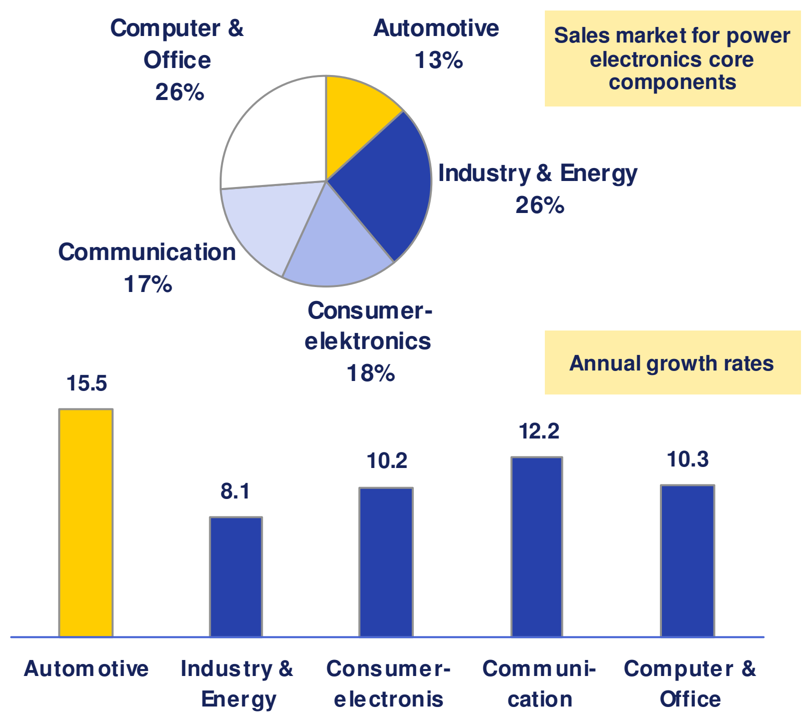
Power Electronics Sales Market Trend



Source: tms Institute for Technology & Market Strategies

With an annual growth rate of 15.5 % the automotive sector is the strongest growth market

Automotive Sector Power Electronics Growth Rate



Notes

- At 13 % total market share of power electronics is if anything still slight, but with a 15.5% growth rate the automotive sector is one of the most promising future markets.
- The market is not driven by the increase in vehicles produced but by the fact that more and more mechanical systems are being replaced by mechatronics systems or existing systems are being so expanded.
- For that reason the value percentage of electronic systems per vehicle of 25% today (2,700 $) will grow to 35% (4,300 $) by 2010.

Source: tms Institute for Technology & Market Strategies

Complex automobile industry requirements influence further development of power electronics systems

The function of power electronics in the automobile

Conversion and control of electrical power
for a multiplicity of automobile applications

Demands on a future system turn out to be an interface overlap of areas of electronics/software/mechanics/heat technology

- low costs
- high level of system reliability
- operation under extreme environmental conditions (temperature, humidity, vibration, EMC)
- greater systems power density
- increasing miniaturisation
- integration of additional functions
- Intelligent coolant and heat dissipation designs
- packaging problems
- use of innovative production technologies
- use of new materials (carbon nanotubes, SICs)

A main reason for the increased appearance of power electronics is the growing number of consumer applications in the vehicle

Growing number of consumer applications in the vehicle

Door modules
Airconditioning
Engine management
Infotainment
Lighting
Combined control systems

Transmissions
ABS/ESP
Shock absorption systems
Sensor technology
Airbag
Door Modules

Notes

- Present-day world market volume of some 2.65 thousand million $ for electronics components will rise to auf 3.83 thousan million $ by 2010
- A significant reason for the rapid rise is the increase of consumer applications in the vehicle providing comfort, safety and communications
- An additional importand growth segment
- Is represented by the market for alternative propulsion technologies
- Market drivers here are primarily statutory regulations aimed at reduction of CO_2 emission levels

Source: tms Institute for Technology & Market Strategies

Agenda

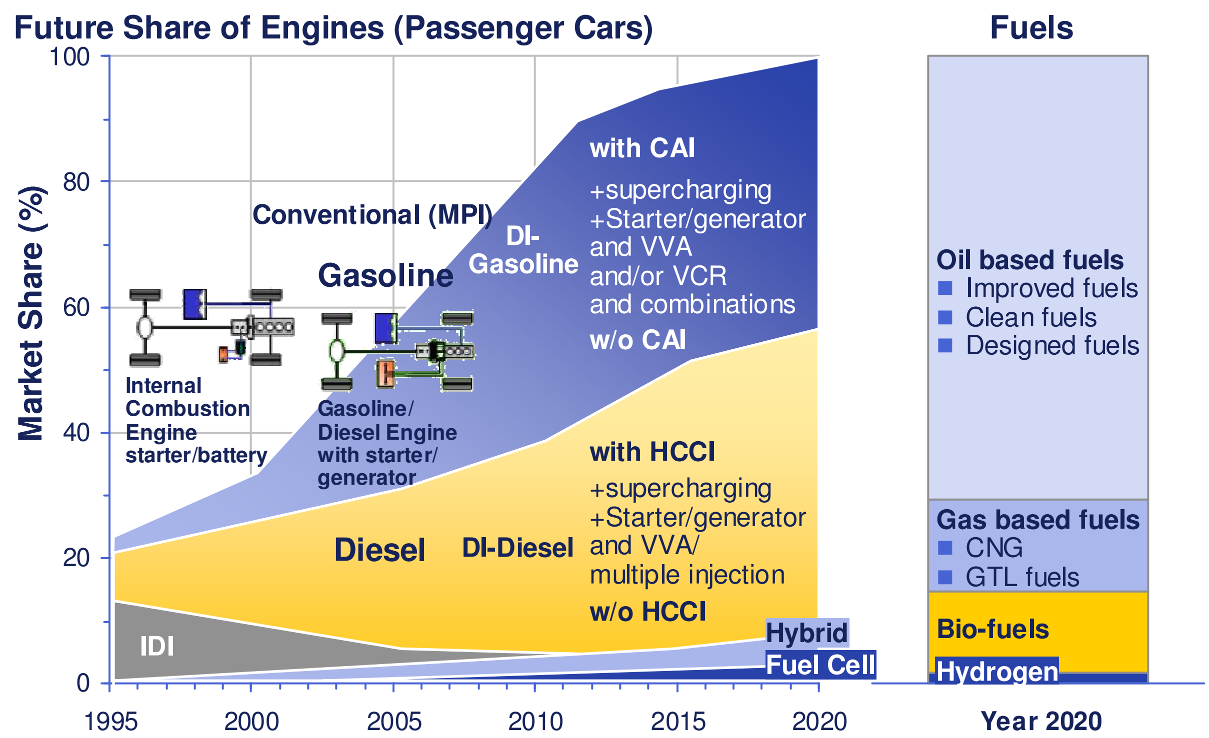
Five Mega-Trends in the automobile electronics will drastically influence the motor industry

1 Development of new vehicle concepts with a regional focus	■ Future vehicle concepts will increasingly be developed to meet regional market trends and customer requirements (localisation concepts) ■ Optional extra models will become standard models and lead to a reduction of the current multiplicity of model variants ■ Hybrid concepts accelerate the increase in power electronics quota in the vehicle drive chain
2 Mechatronisation of vehicle components	■ Use of innovative technologies and production processes (hybrid technology) including increasing use of software-based functions will lead increasingly to mechatronisation of system components ■ Adjusting automotive sector product life-cycles to the electronics industry cycle presents a challenge over the next 5 years
3 Electrification of belt-driven accessories	■ Replacement of belt-driven accessories (pumps, fans etc.) by EC motor-based components for fuel-saving potential ■ Increasing proportion of power electronics components through complete electrification of the drive chain
4 Future innovative vehicle electrical system architectures and intelligent power management concepts	■ Complex dual-circuit networks will be controlled in future via intelligent software-based power management. ■ Future use of approximately 5-7 central Body Control Units will lead to a reduction in the number of control devices despite a further increase in the number of functions ■ Increasing decentralisation of intelligence: use of intelligent sensors and intelligent actuators including local signal preprocessing
5 Increasing proliferation of temporary network organisations in the course of product development	■ Development and control of temporary added value networks ■ Additional key competences on Tier 1 emanating from the areas of mechatronics, software, systems integration, partner-management & logistics necessary

Agenda

Conventional means of propulsion will play a clearly dominant role in future power train designs until 2030

Development of means of propulsion



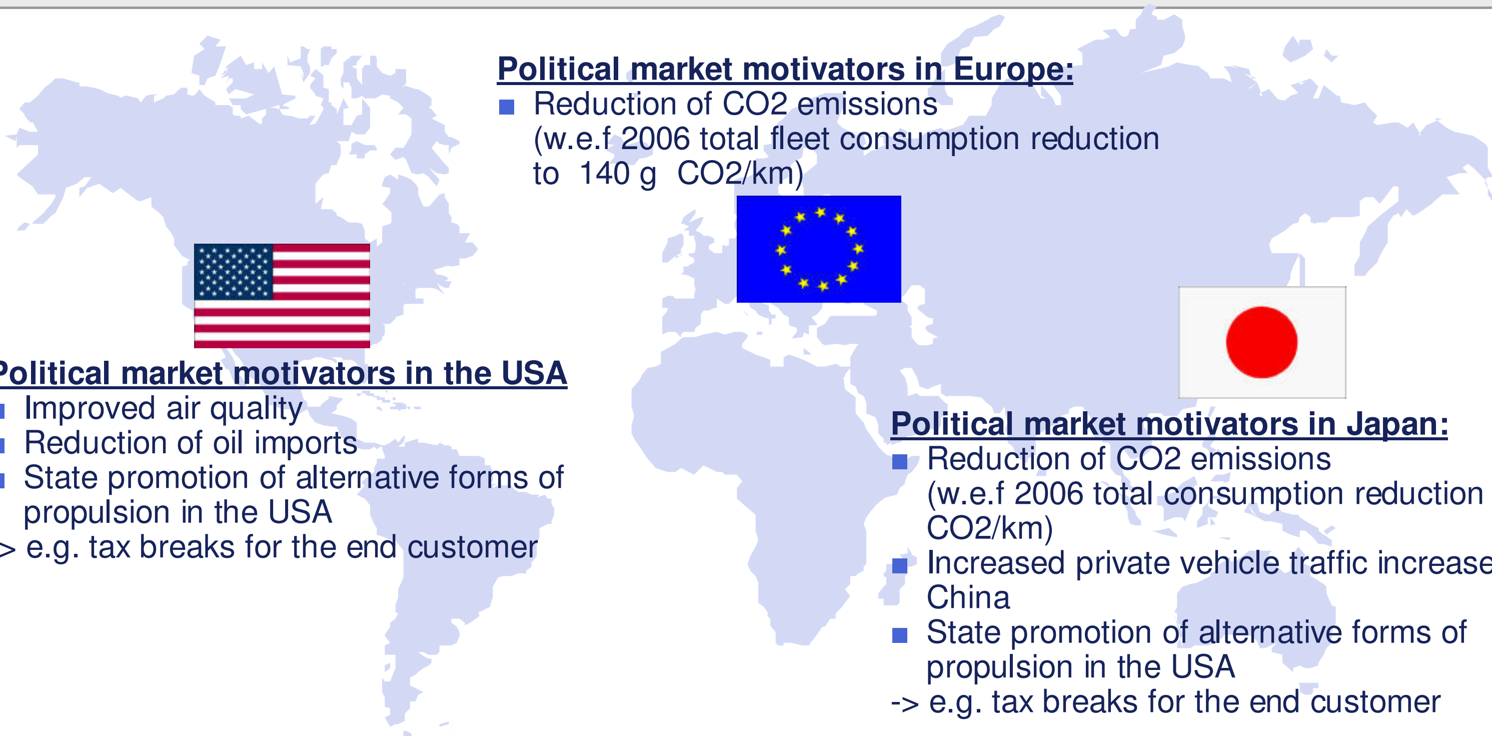
Source: Siemens VDO

Notes

- In the view of European manufacturers up to 2030 the car market will be characterised by 83% domination of conventional gasoline and diesel propulsion technology The remaining 17% market segment will be divided between alternative forms of propulsion.
- The hybrid drive will take over market leadership with 15%. The residual 2% will be covered by vehicles using fuel cell technology.

Primarily environmental considerations are currently driving forward development of alternative means of propulsion in Europa, the USA and Japan voran

Political Parameters



Political market motivators in Europe:
- Reduction of CO_2 emissions (w.e.f 2006 total fleet consumption reduction to 140 g CO_2/km)

Political market motivators in the USA
- Improved air quality
- Reduction of oil imports
- State promotion of alternative forms of propulsion in the USA

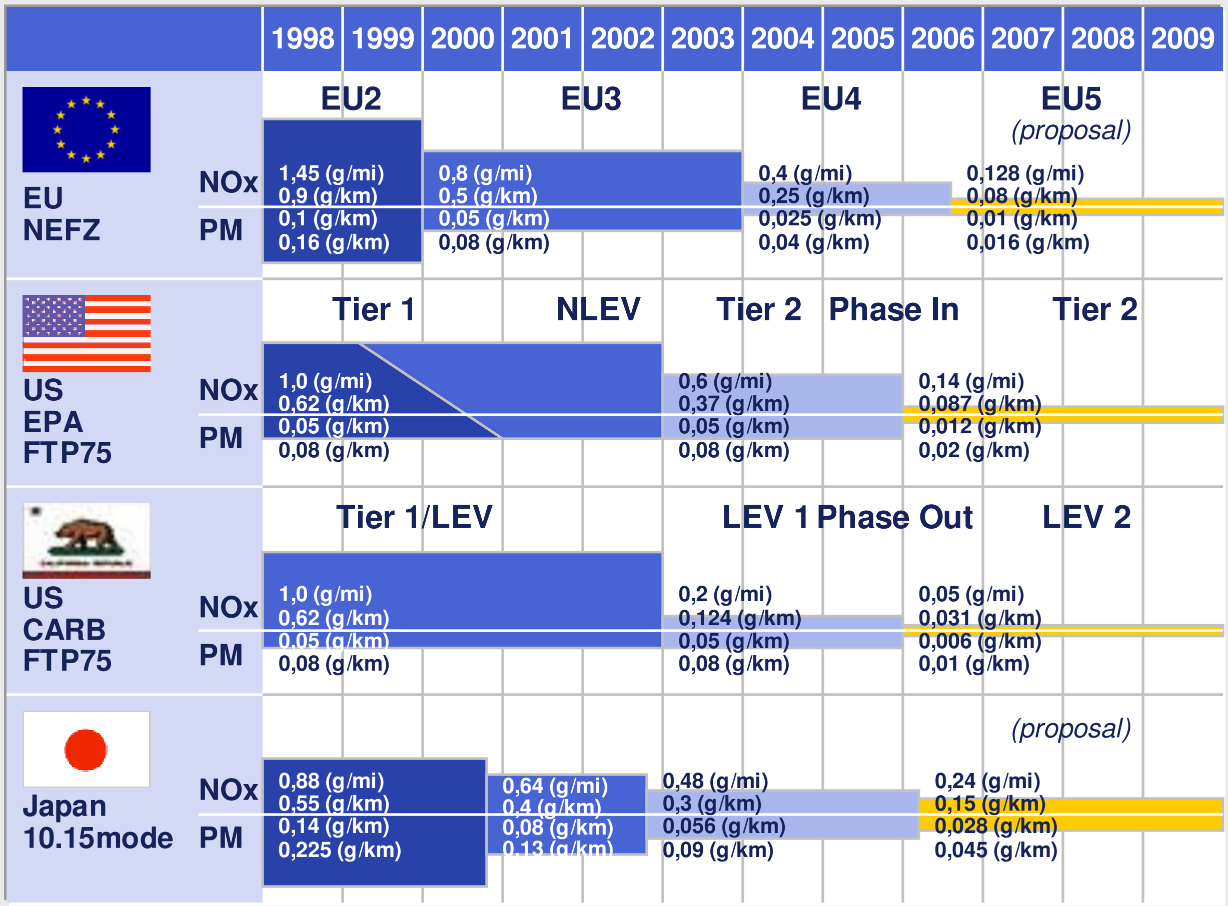
-> e.g. tax breaks for the end customer

Political market motivators in Japan:
- Reduction of CO_2 emissions (w.e.f 2006 total consumption reduction to 140g CO_2/km)
- Increased private vehicle traffic increase in China
- State promotion of alternative forms of propulsion in the USA

-> e.g. tax breaks for the end customer

*Source: Dietrich Naunin Hybrid, Battery and Fuel Cell Electric vehicles

Statutory regulations worldwide will lead to a drastic reduction in emission levels



Erläuterungen

- Stricter statutory regulations worldwide will lead to adaptation of OEMs power-train portfolios of
- California (USA) continues to be the front runner in exhaust emission legislation
- Hybrid vehicle concepts are developing currently at a fixed rate in OEM's propulsion concepts

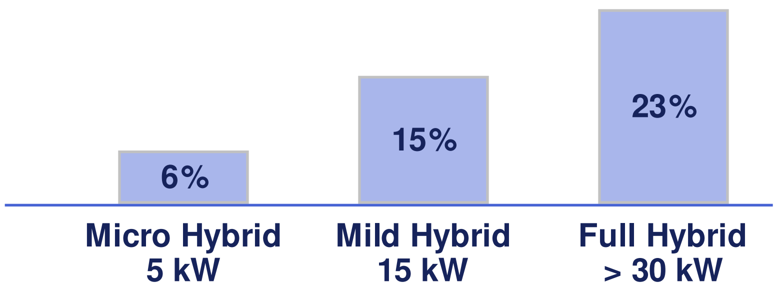
Hybrid concepts show potential with regard to emission levels and fuel consumption and will establish themselves in future alongside conventional means of propulsion in OEMs' propulsion portfolios

Emission level and fuel economy reduction potential

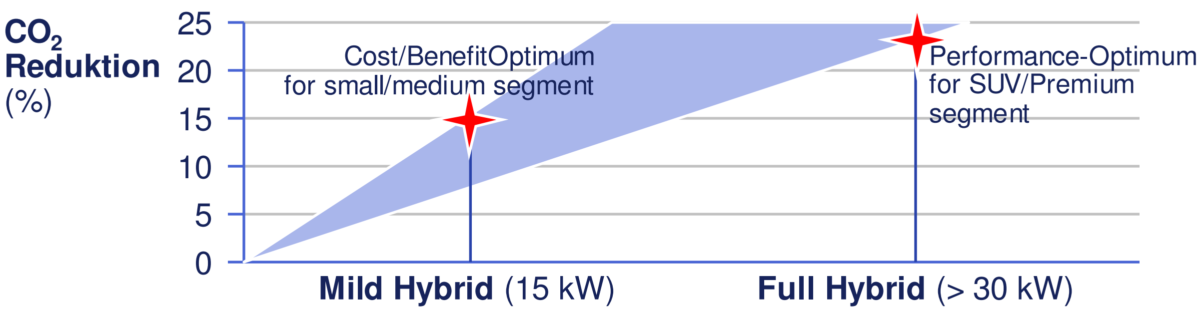
Reduction potential

- Electric driving
- Downsizing of the combustion engine
- Regenerative Braking
- Stop-start function

(Based on NEDC)



Hybrid systems optimum operating aspects



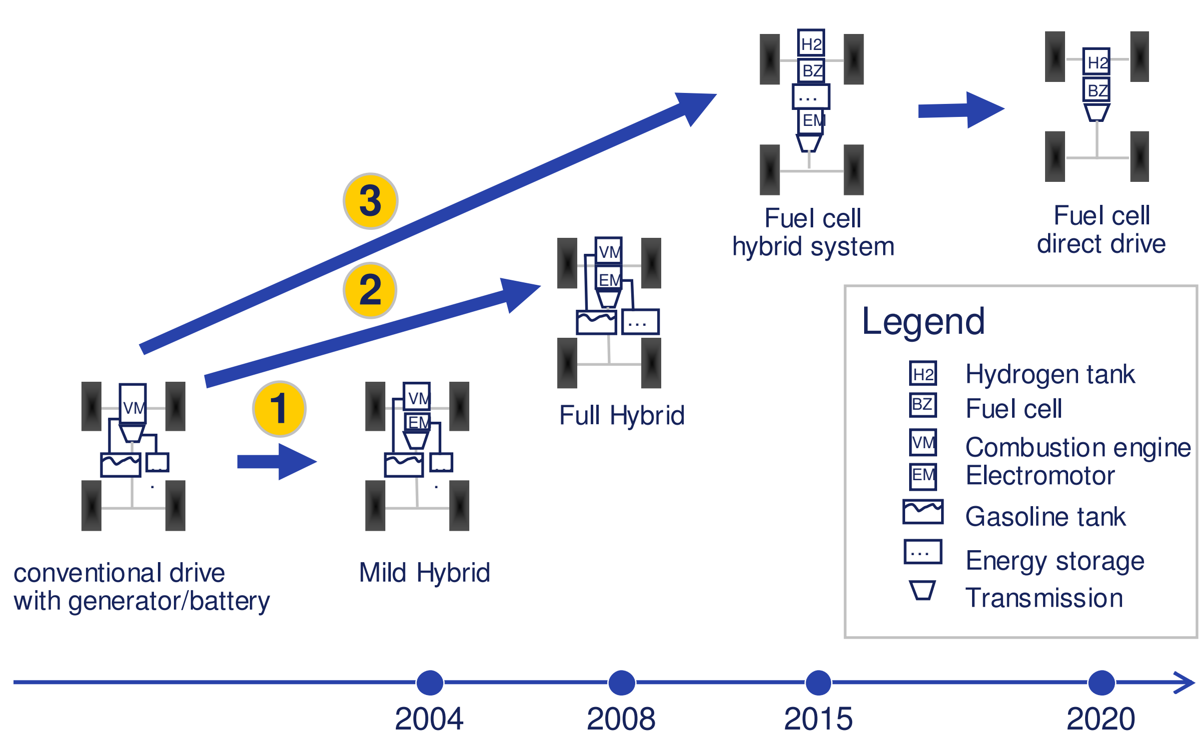
Quelle: Continental, ADL Research

Notes

- Depending on hybrid concept used there is a different CO_2 volume reduction potential
- Full hybrid systems will come onto the market primarily in the SUV segment
- Mild hybrid systems will be used in the small to medium range car segment

Hybrid propulsion is not a transitional technology to fuel cell propulsion; at OEMs worldwide parallel development paths are being followed with differing emphases

Parallel development paths – alternative propulsion concepts



Notes

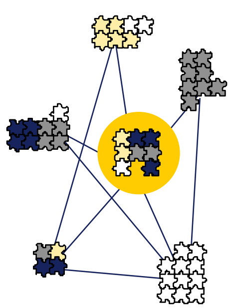
- The Mild Hybrid is characterised by an additional small electromotor
- The Full Hybrid Concept also has complex energy storage capacity in addition to a powerful electromotor
- Fuel Cell/Hybrid System: Released electrical energy is stored via battery systems and drawn on by the electromotor as required
- In Fuel Cell Direct Propulsion hydrogen and oxygen react electrochemically – energy is thereby released and operates the transmission directly

Agenda

The Automotive Industry continues to undergo a massive process of change

	OEMs	OEM Suppliers	Suppliers
80er	■ Broad similarity of business models ■ Vertical Integration ■ Diversification of product segments ■ Globalisation	■ Confrontation ■ Clearly defined boundaries between OEM and Supplier ■ Traditional division of labour	■ Existence of similar business models ■ Purchasing volume = Power ■ Clear restriction of options
90er	■ Vertical Disintegration ■ Outsourcing of Non-Core-Areas ■ Business consolidation / OEM merger activity	■ From confrontation to cooperation ■ Focus of relationship: Efficiency ■ Start of a new definition of Value Chains	■ Increasede Engineering competences ■ from parts/component manufacturers to module und systems providers ■ Increased IT capabilities andquality aspects required

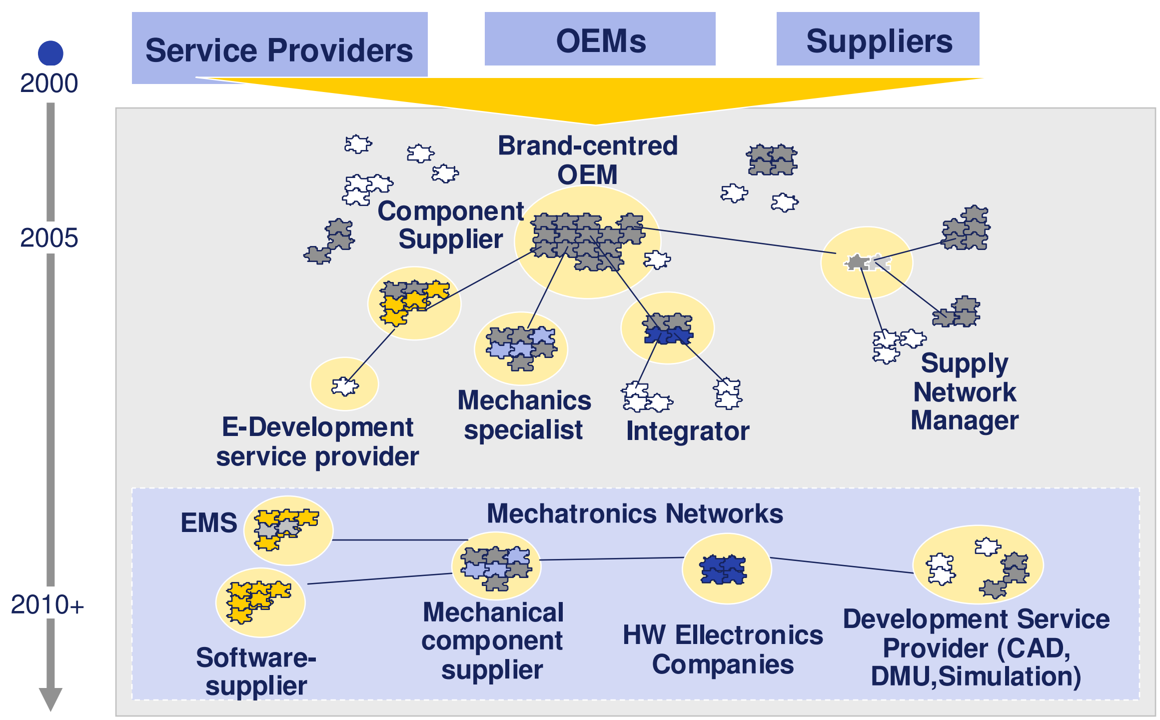
2005+



- Creation of new, even temporary added value networks
- Increased concentration of suppliers, increasing differentiation of business partners
- New entrants from other industries (IT: Architectures & Software)
- Redefinition of the role of project participants
- Verticale and horizontal network structures
- New driving forces

In the development of innovative mechatronic components network structures will be even more strongly to the fore than previously

Increasing trend towards formation of development networks in the field of mechatronics



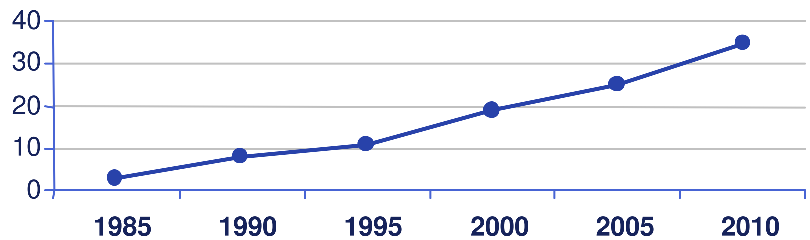
Notes

- With introduction of mechatronic components in the vehicle novel demands are placed by OEMs on supplier companies
- The mechatronics trend forces companies to package complementary competences (software/electronics/mechanics/ heat transfer/hydraulics).
- Company boundaries for manufacture of innovative mechatronics products are redefined
- Future mechatronics networks use a multiplicity of companies each with specialist know-how
- Development networks are not permanent relational intermeshing networks, but are established on a temporary basis for specific development projects

The majority of mechanically based functions will in the medium term be replaced by software-based mechatronic functions in mechatronic products

E-costs/overall production costs

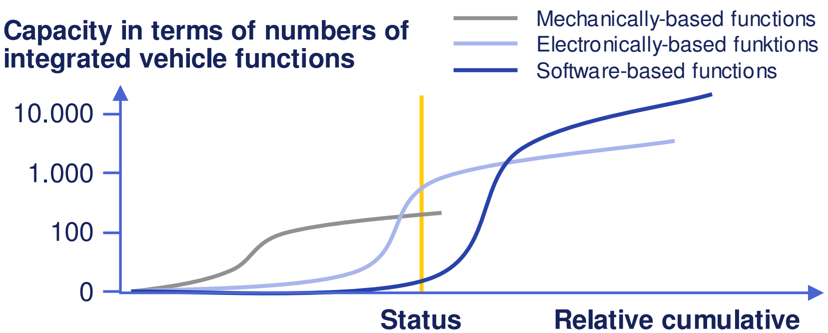
Proportion of electronics to the overall production costs (%)



Source: Central Association for Electrotechnology and industry Innovations Report 11/2004

Number of integrated vehicle functions

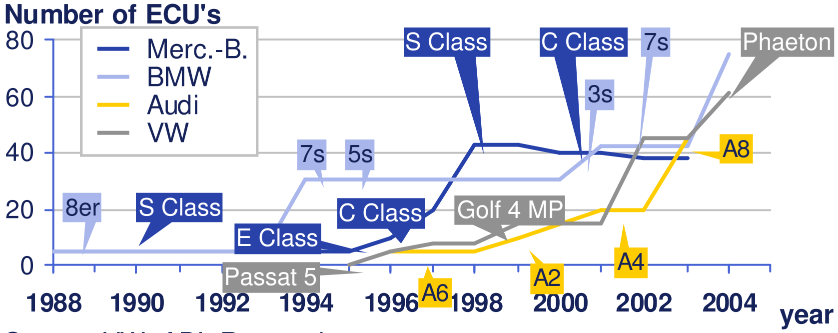
Capacity in terms of numbers of integrated vehicle functions



Source: BMW

Trend in number of control units

Number of ECU's



Source: VW; ADL Research

Notes

- The proportion of electronics to overall production costs will be 35% in 2010
- Development points of emphasis in coming years are:
  - Use of module-based software platforms
  - Consolidation of the number of control units despite same or slightly increasing number of functions

Arthur D Little

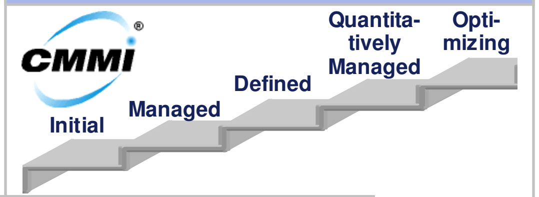
Agenda

3	**Trends in automobile electronics**
3.1	Trends in Propulsion Technology
3.2	Added Value Structures
3.3	**Mechatronics development structures**
3.4	Power electronics innovation roadmap

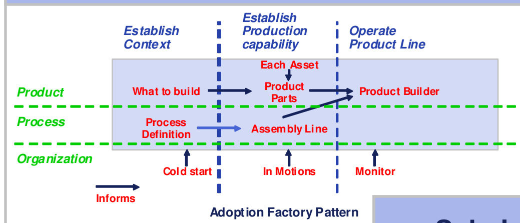
The definition of standards for software development projects and hardware engineering are presently in the course of implementation or are already established

Challenge: Standardisation of a mechatronic development process

CMMI – Area of application: Process Engineering



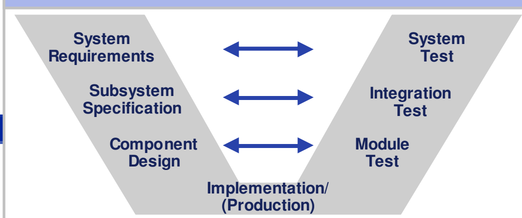
Product line approach – Application area: Software Development



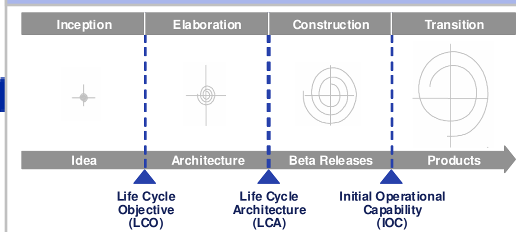
SPICE/ISO15504 & Automotive SPICE – Application area: Process-based Supplier Assessment

Software Process Improvement and Capability Determination

V Model – Application area: Systems Development



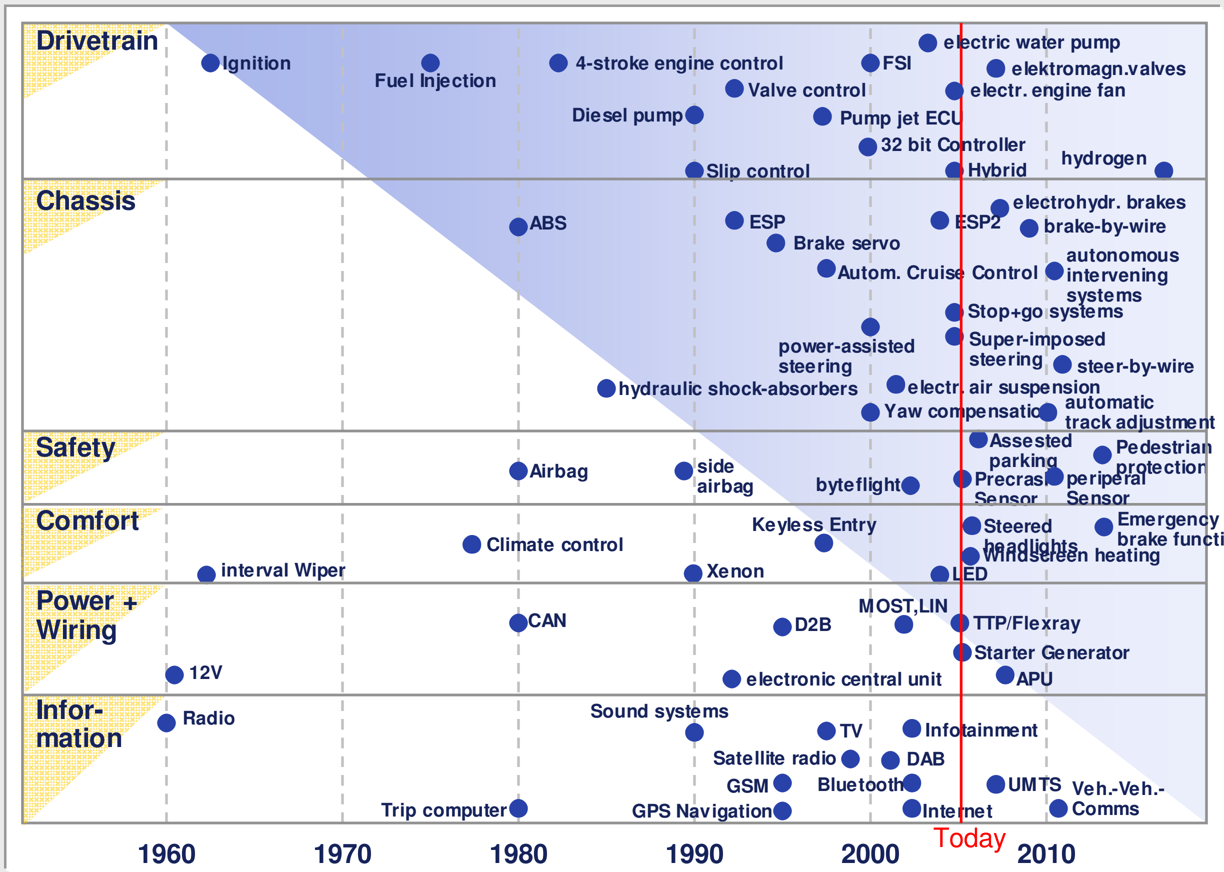
Spiral model – Application area: Software Development



A methodology or standardisation of the developmental process for mechatronics products with defined Q-Gates is presently still in its infancy

Agenda

Primarily competition and costs pressure forces the automobile industry to continually come up with technological innovations



Quelle: ADL Research

Erläuterungen

- Innovations are in the main realised by the increased use of electronics in what were previously mechanical systems
- Examples of electrically driven engine ancillaries are:
  - Electrical water pump
  - Electrical engine cooling
- Steering system examples:
  - Steering angle assistance
  - Active steering

Agenda

Agenda

The need for high temperature electronics, primarily high temperature circuit boards stable above 140 °C, will grow strongly in the next 5 years through use of new manufacturing prcesses and corresponding materials

Engine Compartment Temperatures

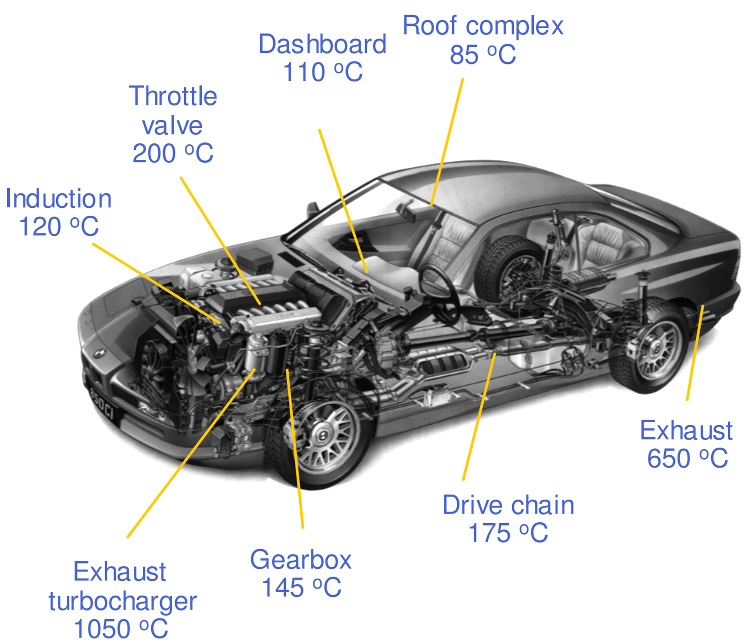


Illustration: BMW AG

High Temperature Electronics Requirement

Annual high-temperature electronics requirement spread relative to differing temperature ranges

Jahr	1998	2003	2008
Temperature range	Requirement spread		
T<200°C	97%	91%	88%
200°C<T<300°C	2%	7%	9%
T>300°C	1%	2%	3%

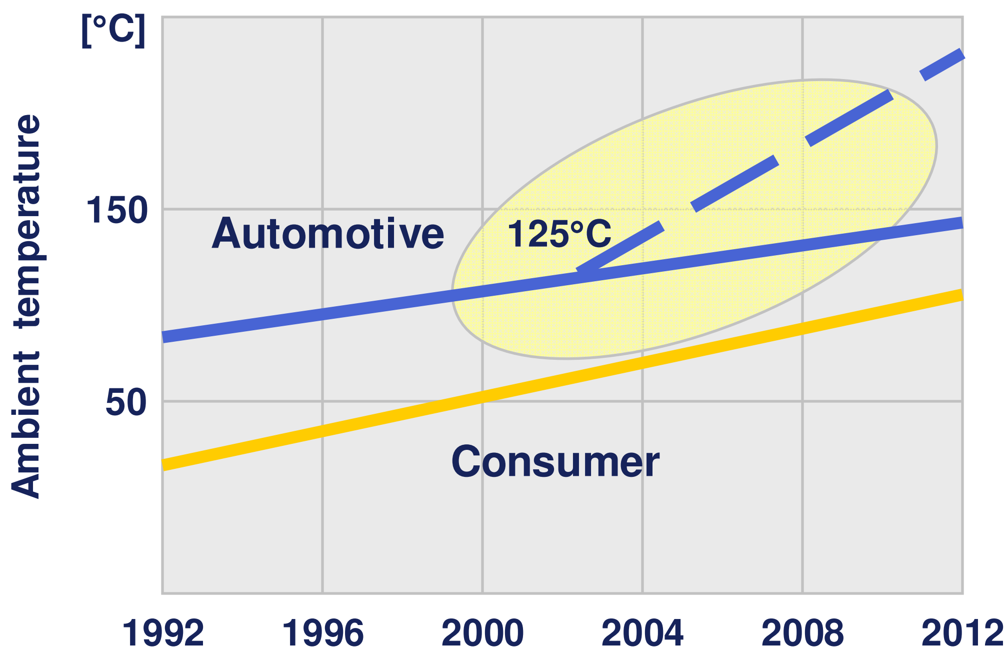
Source: ZVEI

Notes

- Engine management and ABS/ESP system, including driving dynamics bonded systems constitute the most complex electronic application in the vehicle
- Build site of control electronics is increasingly in the directly immediate vicinity of the engine (systems integration)

Future developments in power electronics will be marked by increasing demands in respect of temperature

Increased temperature demands on car power electronics



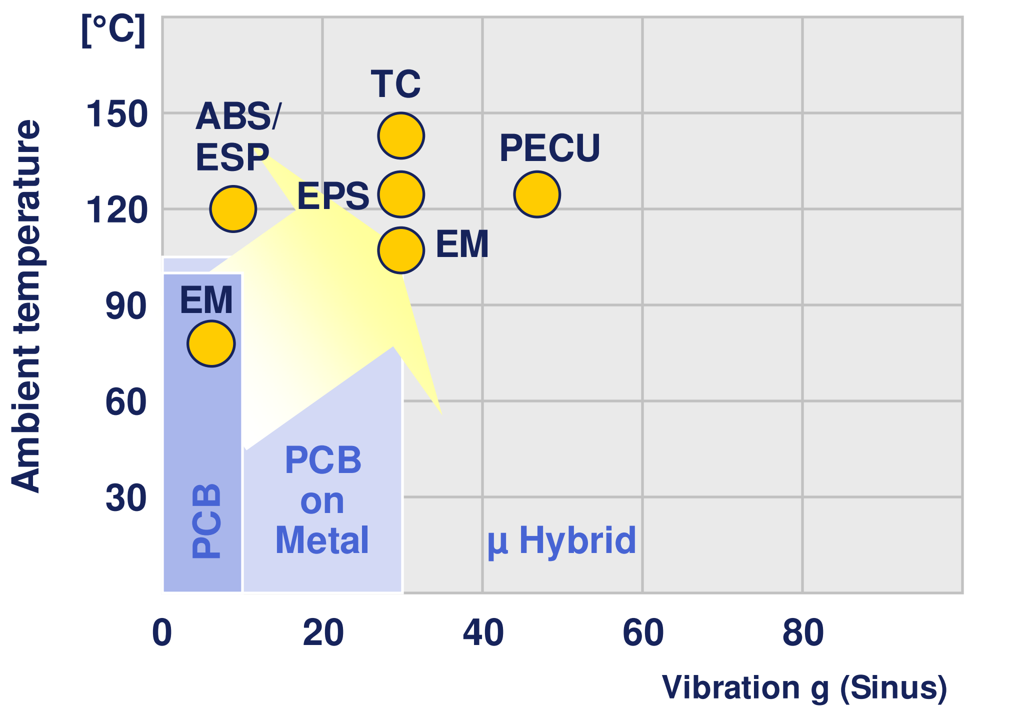
Notes

- **Entwicklungsschwerpunkte der Industrie für die kommenden Jahre**:
  - Integrated circuit packaging in the > 200°C range
  - High-temperature power electronics (Si or SiC)
  - High-temperature control electronics (µController, sensors)
  - High-temperature condensers (Polymer)
  - Innovative heat dissipation concepts
  - Systems integration

Source: Bosch, Siemens VDO

Depending on usage location and operating conditions in addition to new materials special PCB placement technologies are also needed

Increasing systems integration results in increasng temperature demands on power electronics components



Source: Bosch

Notes

- Power electronics systems are being increasingly integrated directly into the main system. This results in increasingly greater demands in terms of temperature, vibration and EM compatibility
- EM = Engine Management
- TC = Transmission Control
- EPS = Electrical Power Steering
- PECU = Pump Electronic Control Unit

Agenda

Belt-driven control of accessories will be replaced by electromechanical drives by 2010

Vehicle module control options

Electrically controlled coolant pump

Fan

E-Booster

EC-Motor

Long life cycle, low noise level and small dimensions make it possible for the EC motor to displace the belt drive

Source: Pierburg, ebm Papst

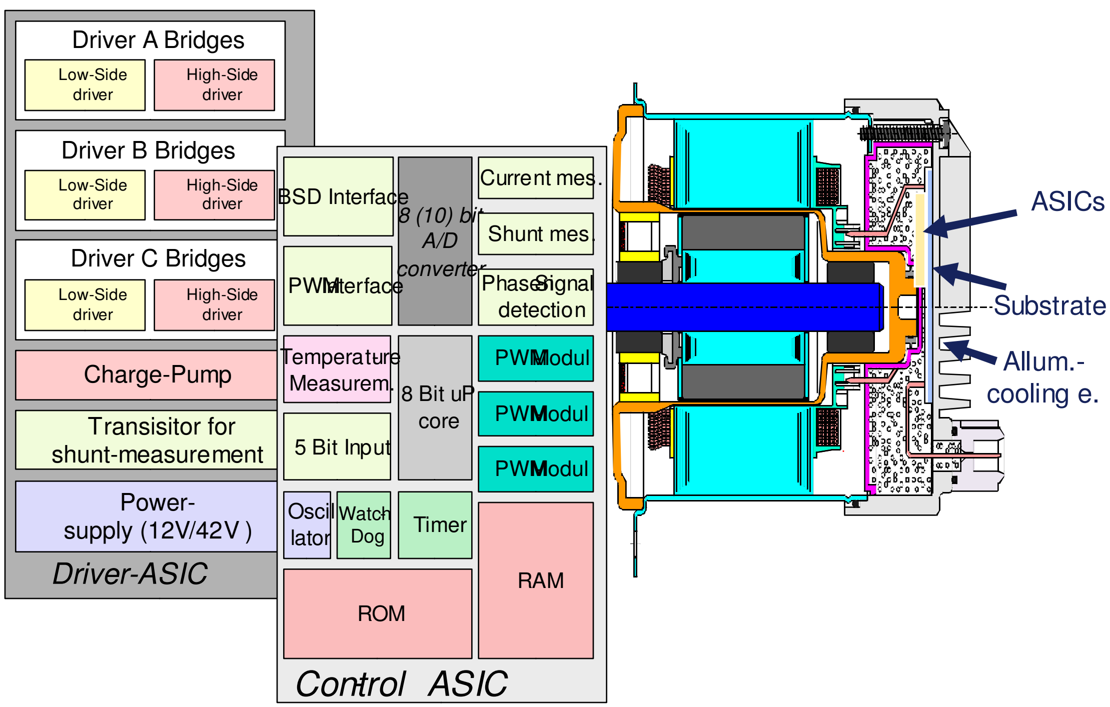
EC-driven water pumps will soon become the accepted norm in all vehicle classes

EC-drive water pump	Notes
 	■ Already in use in the BMW 5-Series ■ Currently a complete spectrum of different engine power class water pumps is being built up ■ In the medium term (2008 – 2010) water EC motor controled water pumps are under consideration for the BMW 3 and 7 Series ■ In the longer term (from 2010) all vehicle classes will be fitted with them

Source: Pierburg, BMW

Use of semiconductors has increased rapidly in recent years primarily in the area of pump control

Water Pump Control with EC Drive



Source: Elmos

Notes

- Centrifugal pump with three-phase brushless DC motor drive
- No rotor positioning sensor, no external shunt resistances
- Communication via BSD-BUS or PWM-control
- Internal chip oscillator with synchronisation capability to BSD master protocols
- PWM control of three external NMOS half-bridges
- Comparators for comparison of coil voltages with mean potential
- 6 Bit DAC for input of overcurrent switch-off threshold
- 8 Bit A/D transformer with multiplexer
- 8 Bit µP with hardware division unit
- Designed as hybrid

With the infinitely variable oil pump introduced by Pierburg in 2004 oil change intervals have been able to be extended

Variable Oil Pump	Notes

Variable Oil Pump

Pierburg variable vane pumps

Notes

- Lubrication need is increasing greatly in new classes of vehicle. Optimum supply can be achieved using an infinitely variable pump.
- Supply volume can be flexibly matched ot lubricant requirement angepasst.
- In the higher revolutions range the pumps are characterised by lower power loss.
- Loading and ageing of the oil is therefore reduced.

➔ Oil change intervals are extended

➔ Cost savings for the end user

Source: Pierburg

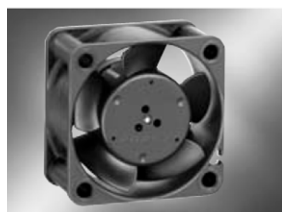
Agenda

EC motors have proven advantageous for fan control and will continue to penetrate the market

Cooling fan + EC motor + control electronics

Booster fan cor cooling and heating the forward area of the vehicle

Radial fan for colling the electronics



Ventilation systems for installation in seats and seat backrests

Notes

- Increasing number of electronic devices in a confined design space requires a good ventilation system.
- Application areas range for example from electronics cooling and seat climate control to cooling of fascia infotainment equipment.
- In the vehicle special variants of fan are used which meet the main requirements of longevity, low noise level and powerful output.
- EC motors with associated control electronics ensure precise control of revolutions and torque.
- With temperatures up to 175°Cplus vibration high demands are placed on the EC motor control unit.
- Control electronics are fitted directly to the motors -> optimum usage of space
- High efficiency level, long service life (up to 25000 operating hours) and extended temperature range make the EC motor the optimum fan drive unit

Source: ebm papst

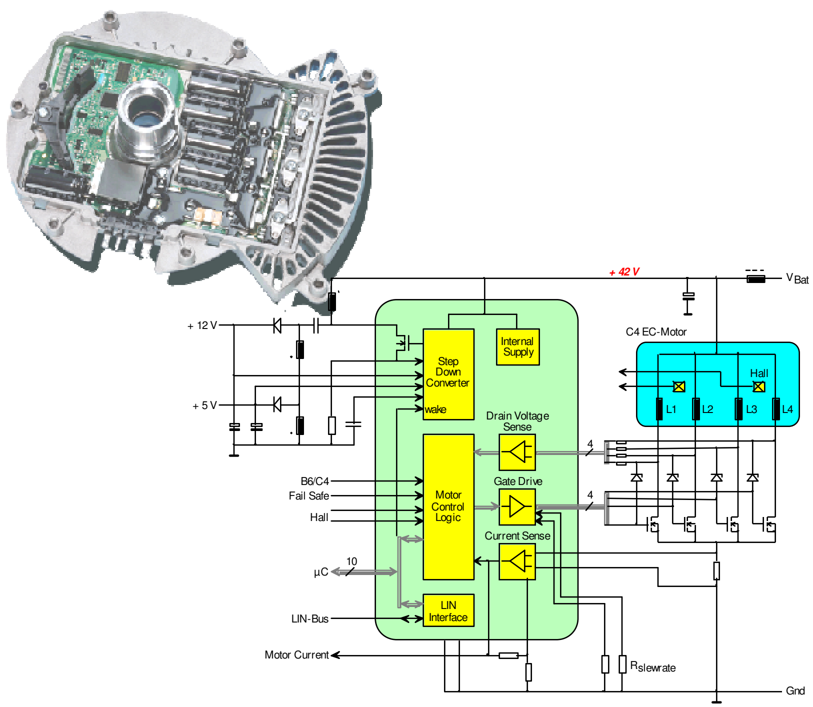
The new generation of internal rotor EC motors opens up new integration options for car manufacturers in the vehicle front end

Internal rotor EC motor	Notes
	■ Brushless ventilation motors operate on the internal rotor principle ■ This provides advantages in terms of performance, longevity and noise volume ■ Micro-electronics used minimise energy consumption ■ Design shape and size result in new possibilities in the integration into the vehicle front end, for example for combustion engine cooling

Source: Siemens VDO

Blower van control also ensures connection to the bus system

Blower Fan Control



Source:Elmos

Notes

- EC motor controller,
- Logic for variable transition control,
- PWM,
- Power driver control,
- Reverberation sensor evaluation,
- Current monitoring,
- Dry running function,
- LIN-Bus,
- DC-DC converter

In line with downsizing tendencies turbochargers with twin-stage charging (R2S) and turbochargers with variable geometry turbines are increasingly discussed

VTG Exhaust turbocharger design

Notes

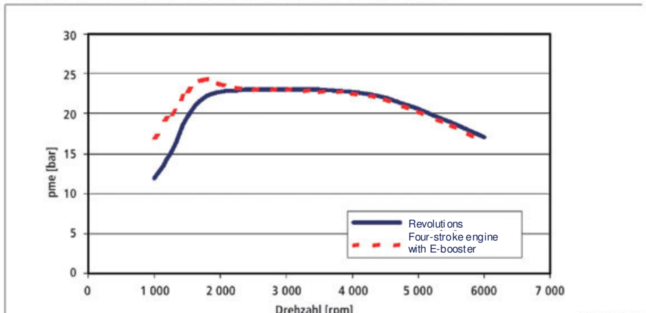
- Exhaust turbochargers with variable turbine geometry (VTG) facilitates effective operation even in the part-load range
- In VTG turbochargers geometry is varied by deflecting the turbine guide vanes
- The advantage here is that the full mass flow is directed over the turbine and is used for output adjustment
- Special thermal requirements result during four-stroke charging in the turbine (1050°C)
- VTG deflection mechanism control is via power electronics components

Source: BorgWarner / KKK

Utilisation of electronics and electrics brings advantages in charging four-stroke engines

E-Booster Exhaust Turbocharger Design

Mean pressure progression for four-stroke engine with and without booster



Source: BorgWarner

The electrical charger makes the engine respond better. This gives the driver the impression of a larger engine

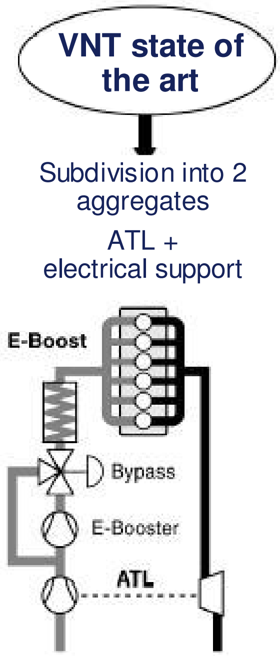
Notes

- Electrical charging design involves additionally fitting an electromotor to the turbo driveshaft
- The E-Booster is connected either upstream or downstrem of the actual exhaust turbocharger
- It draws a maximum power of some 2.4 kW, which the present-day 14V vehicle electrical system cannot yet providet
- From 2008 the system goes into series production
- The E-Booster is driven by a power electronics controlled electromotor
- BorgWarner have developed the charger in collaboration with EBM Pabst (engine) and Fujikura (electrical system)

Source: BorgWarner / KKK

Electrical support (E-booster) exhaust turbochargers enter series production from 2008

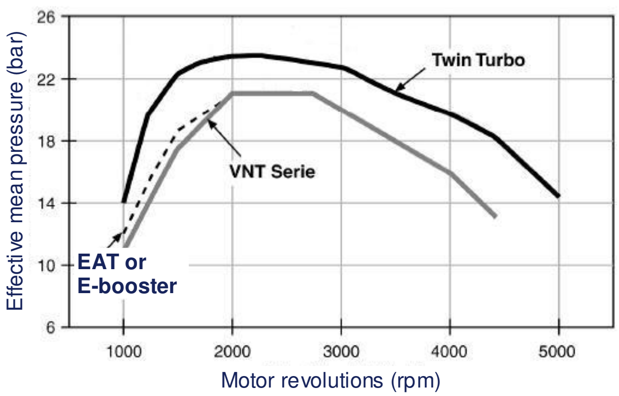
ATL Principle with electrical support



- Due to the complexity and high electrical system loading series production use of the E-Booster/ATL combination has not yet occurred

Notes

- Electrically supported exhaust turbochargers may due to the principles involved improve only a narrow spectrum of the overall engine characteristic map.
- Primarily the engine characteristic is improved in the start-up response spectrum



Source: BMW

Stage charging enables the turbocharger to develop sufficient pressure even at low engine revolutions

Exhaust turbocharger design - stage charging

Source: BMW / Opel

Notes

- Stage charging, which according to BMW is only known of on high performance marine engines should not only increase performance but also reduce turbo lag
- Two turbochargers can be either connected in series or be circumvented by valve-controlled bypasses
- The BMW 535d is the first V6 series production car with stage charging and achieves a 25% performance increase
- The valves are pneumatically activated and electrically controlled
- The power electronics regulate the interaction of both turbochargers

The fully variable intake manifold enables engine management system to fully synchronise intake manifold length with actual engine speed and is already in series production on the BMW (5 and 7 Series)

Fully variable intake manifold

Notes

- An electromotor positions the rotor rings in less than a second to the requisite intake manifold length
- The result and advantage over other engines are optimum performance and torque values for the same fuel consumption
- The system is in the interim used by BMW on the 5 and 7 Series

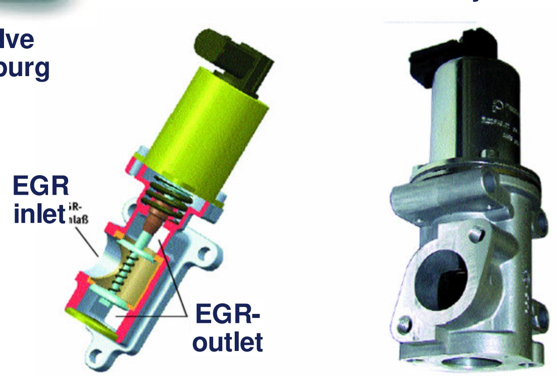
Source: Pierburg, BMW

With electronically regulated exhaust gas recirculation increasingly tight future emission threshold regulations can be complied with in modern car engine

Electronically regulated exhaust gas recirculation

EGR valve by Pierburg

EGR-Ventil by Siemens VDO



elektronic Diesel EGR with positioning sensor

Notes

- Electronically regulated exhaust gas recirculation contributes crucially to a reduction of air pollutant emissions
- The electronically regulated exhaust gas recirculation valve works independently of negative pressure
- This results in both increased reduction in nitrogen oxide emission and a minimisation of fuel consumption

Source: Pierburg, SiemensVDO

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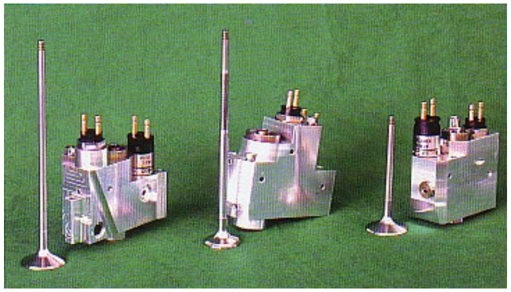
Electrohydraulic valve control optimises fuel consumption, torque curve and pollutant emission

Electrohydraulic valve control



Electrically controlled actuators

Notes

- Electrohydraulic valve control makes possible free controllability of individual engine valves
- The camshaft is replaced by an electronically controllable actuator system
- This makes possible total control of induction and exhaust of combustion gases
- This optimises fuel economy, torque curve and pollutant emission. As against camshaft- driven systems savings of up to 10% can be achieved.

Source: MTZ, DaimlerChrysler AG

Electromagnetic valve timing replaces the camshaft and results in a 15% saving in fuel plus increased torque

Valve timing actuator unit

Source: E-MOTION

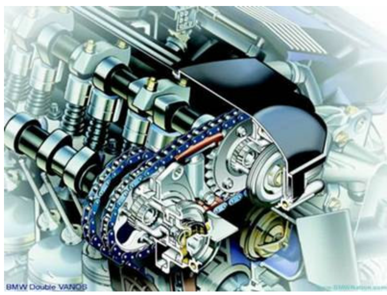
Erläuterungen

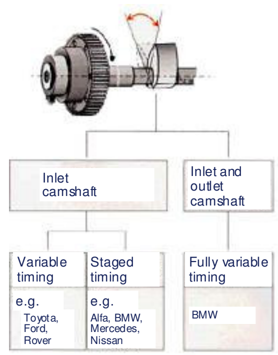
- With the classic camshaft valve timing settings are set in concrete
- Electronically controlled valve timing makes any desired valve actuation parameter possible
- On cost grounds however it is questionable whether electronically controlled valve timing will prevail
- Control of electromagnets and movement parameter is assumed by power electronics
- An actuator virtually replaces camshaft operation

Source: Automobil-Produktion

Variable valve timing and operation make possible increased performance with lower fuel consumption in the partial-load operational range by varying open and close times

Variable Valve Timing

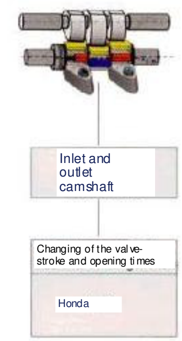




- Inlet and outlet times can be varied
- The BMW VANOS system is operated by an electronic control unit
- The Toyota VVT-i control unit controls camshaft regulator valves electronically on the basis of sensor data processing

Source: BMW

Variable Valve Actuation

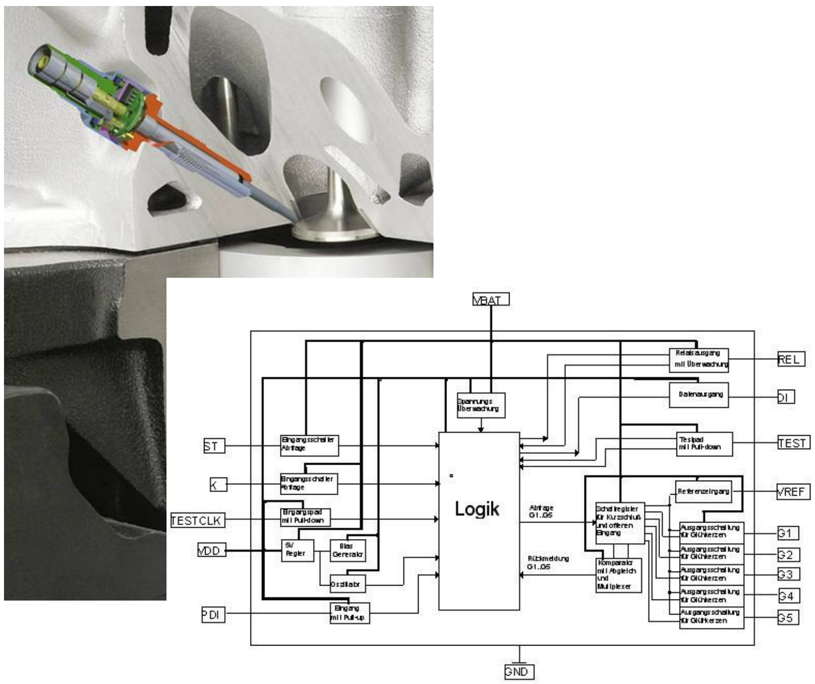


- BMW's Valvetronic gives a 10% reduction in fuel consumption
- The totally mechatronic system was first introduced in 2001by BMW in the BMW 316 ti compact
- The Honda VTEC System varies valve lift by hydraulic control

Source: BMW

Intelligent glow plugs controlled by power electronics can simultaneously reduce fuel consumption and No_x emissions

Pressure Sensor Glowplugs (PSG)



Glow Plug Control

Notes

- The electronically controlled glow system (ISS) is used by all German car manufacturers
- This diesel quick-start system enables low temperature low emission starting bei niedriger Temperatur ermöglicht
- Beru AG plans PSG series production für 2006
- A piezo sensor is integral to the glow plug so that the control unit receives feedback for optimum glow plug control
- The entire power electronics are integrated into the upper section of the glow plug

Source: Beru AG, ELMOS

Agenda

Agenda

Hybrid vehicles permit more economical use of the car without having to forgo the driving comfort of conventional forms of propulsion

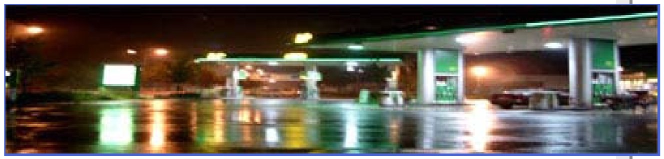
Why hybrid cars?

Fun to drive ....

- Extra torque at low revs – comparable to state of the a diesel technology

Fuel Economy ...

- Regenerative braking
- Start/Stop funktion
- Optimisation of operating strategies



CO2 emission reduction ....

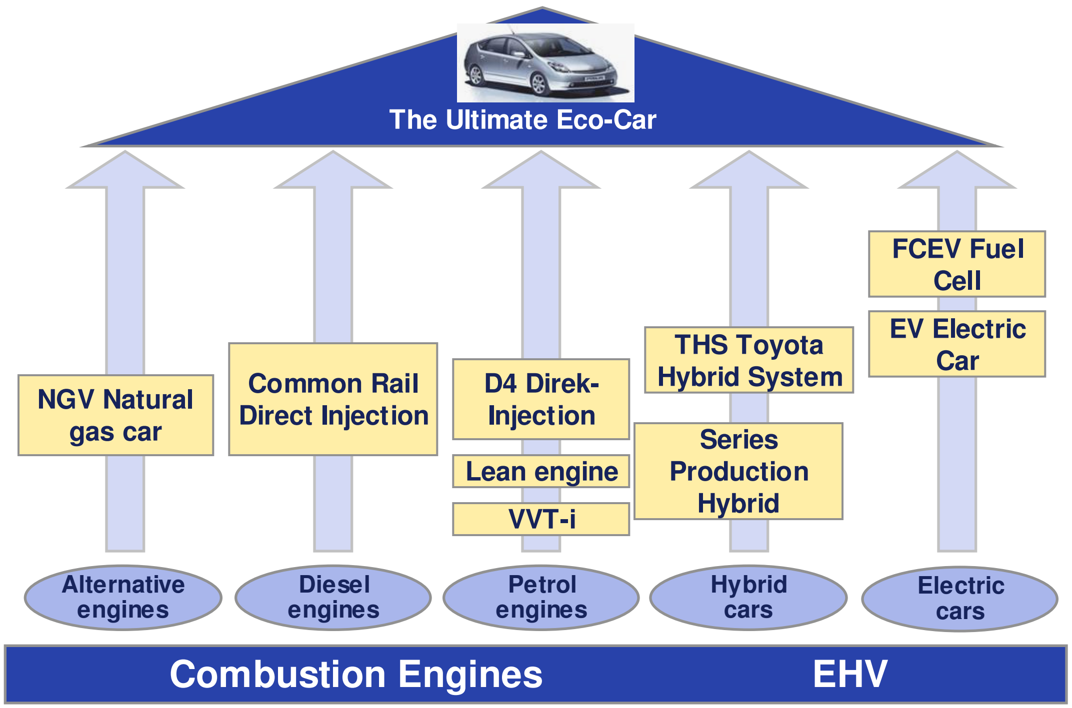
- Driving with electromotor
- Optimisation of operating strategies

Image ....

- Use of a "cleaner" technology
- Innovation

Market leader Toyota see the hybrid car as the best route to the ecologically optimally configured car

Toyota's Vision of the Ecological Car of the Future



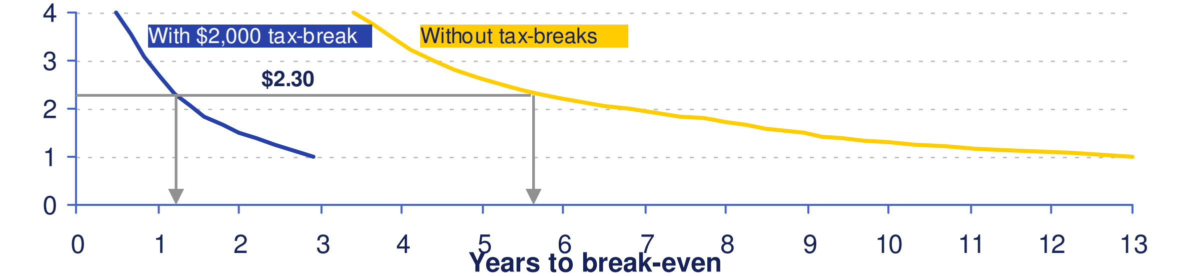
Source: Toyota

Notes

- Differing vehicle concepts lead in parallel to a car with a strongly ecological orientation
- Toyota's Hybrid Strategy aims at a wide market penetration in the USA
- A Toyota production bottleneck at present is battery system suppliers
- For future hybrid technology development potential the USA is the key market
- The SUV market is currently addressed by Toyota with the Lexus RX 400h

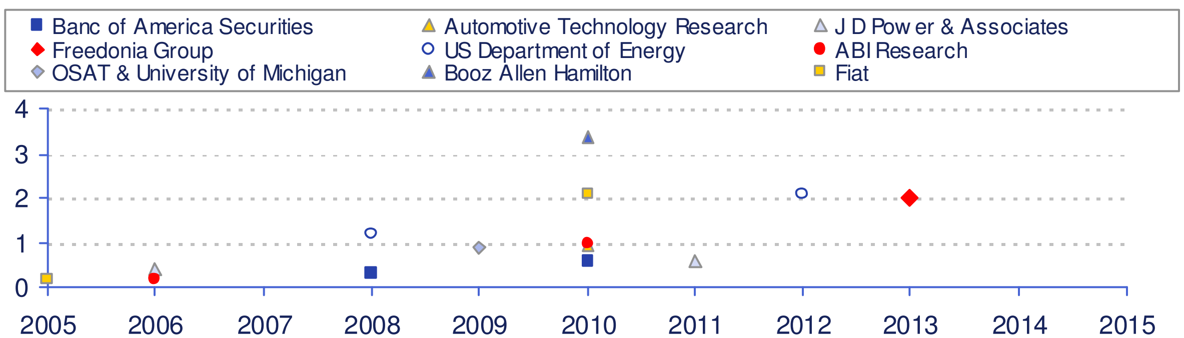
Optimistic forecasts assume that the number of hybrid cars sold in the USA will rise to 3.5 million in 2010

US Gasoline Prices & Hybrid Vehicle Premium: Ford Escape Hybrid (2005)



Note: Annual fuel cost is based on 15,000 miles of travel each year (55% urban, 45% highway), US Department of Energy
Quelle: Ford, MSNBC.com, US Department of Energy, 2005

Various US Hybrid Market Forecasts



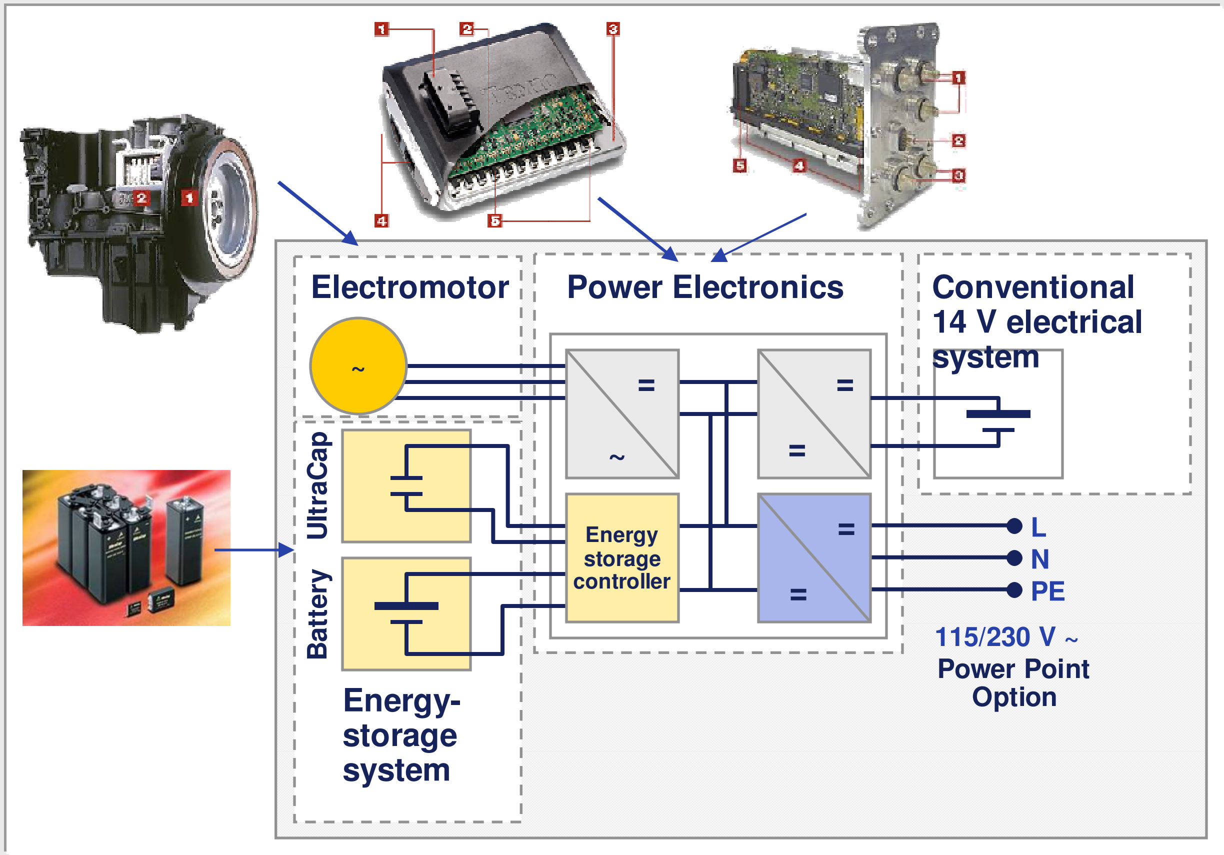
Source: Minor Metals

Notes

- Driven not least by current energy market trends a steady increase in sales figures will take place in the USA in coming years
- A prime mover for this market trend is amongst others the tax break for private individuals
- Purchase of a Ford Escape Hybrid would pay for itself in just over one year due to various tax break incentives

We expect 2.8 million hybrid car sales worldwide in 2011 and 6 million in 2015

First Tier companies are presently positioning themselves as suppliers of modular systems components based on a building block system



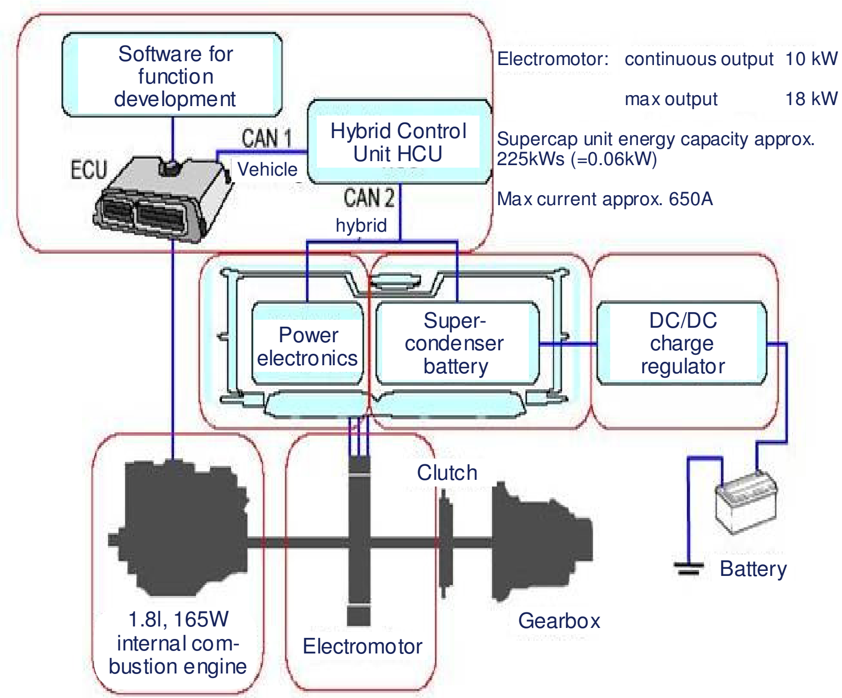
Source: Continental; Epcos

Notes

- First-Tier Companies are presently expanding their hybrid component product portfolio (e.g - ZF-Conti-Partnership)
- Second generation hybrid components are currently in the preliminary development phase
- Possible strategy optionsn:
  - a) Alliances:
    Power electronics providers place themselves as collaboration partners of 1st Tier companies
  - b) In-house competence development:
    Companies (example: gearbox manufacturers) develop in-house competence in hybrid drive systems

The main function of hybrid control is coordination of combustion engine and electromotor plus control of power electronics

Hybrid Control Principle



Source: FEV Motorentechnik

Notes

- Hybrid control has the function of providing an optimum form of propulsion in all driving situations
- This is achieved by intelligent implementation of the driver's momentary wishes to a torque demand on both internal combustion engine and electromotor

Appropriate interplay of propulsion units in a hybrid vehicle facilitates ecologically and economically meaningful use of the car

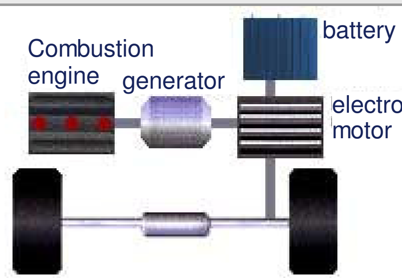
Interplay of propulsion systems - Hybrid propulsion

Normal drive	Full acceleration	Deceleration	Stop and Go
Powered by electromotor and combustion engine in the respective optimum consumption combination	Drive power supplemented by engine and electromotor	Electricity generated and contributes to battery charging	Combustion engine automatically switches off and the car is powered by electromotor

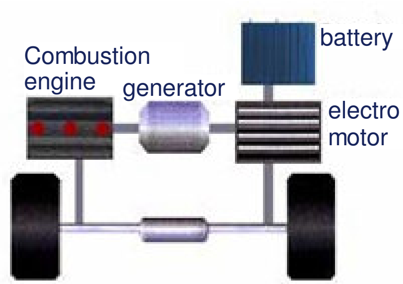
Source:Toyota

Parallel propulsion makes possible optimum exploitation of the respective advantages of electromotor and combustion engine

Main Structures



Series Hybrid



Parallel-Hybrid

Notes

- **Series Hybrid**
  - Combustion engine coupled with a generator
  - ➔ Generated electrical energy is passed to the electric drive
- **Parallel Drive**
  - Here the combustion engine and electromotor are configured separately from one another,
  - ➔ The electromotor is used here mainly for moving off or in town and the combustion engine for road journeys
- Supplemental to serial/parallel drive is a combined structure in which the drive from electromotor and combustion engine are input equally

Source: Dietrich Naunin Hybrid-, Batterie- und Brennstoffzellen-Elektrofahrzeuge

Hybrid designs are classified in 3 categories; differing drive functions are supported in the respective category

Hybrid System Families Overview

	Mini-/Micro-Hybrid	Mild-Hybrid	Full-/Power-Hybrid
Functions:			
■ Start/Stop Funktion	✓	✓	✓
■ Regenerative Braking		✓	✓
■ Torque enhancement		✓	✓
■ E-Drive			✓
Power Supply		< 60 V	100 V – 450 V
Power Output E-Motor	5 – 10 kW	15 – 30 kW	> 30 kW – 75 kW
Current Concept Incentives	■ Fuel economy ■ Emission reduction	■ Fuel economy ■ Emission reduction	■ Fun2Drive ■ Fuel economy

The ISAD System (Integrierter Starter Alternator Damper) replaces alternator and starter in one aggregate electrical unit and at the same time makes possible regeneration of braking energy

ISAD REDBOX	Notes

Source: Continental

Notes

- Start-stop-operation can save up to 15% of fel consumption
- A further 11-14% can be saved through regeneration of braking energy
- Use of ISAD is enhanced by virtually noiseless starting and reduced pollutant emission
- The ISAD System control unit (REDBOX) has powerful electronic components which generate the required operating voltage for the electromotor

The Citroën C3 and C2 (Mild Hybrid) uses a belt-driven starter-alternator

Citroën C3 Start-Stop Function

- The C3 combines two advanced technologies: Sensodrive automated manual transmissionand a reversionary alternator with electronic control

Source: ADL Research, Citroen, Valeo

Notes

- In addition to the Citroen C3 the "C" model also offers start-stop technology
- The system has two main advantages:
  - Reversionary belt-driven alternator with an output of 2 kW which takes over the function of both starter and alternator (storage of electrical energy within the vehicle electrical system),)
  - Power electronics controlling the alternator and establishing the connection to the vehicle computer and the intelligent control unit.
- On braking the engine cuts out shortly before the car comes to a standstill (at speeds under 6 km/h)
- With the start-stop function fuel savings of up to 5% can be achieved and up to 11% with regenerative braking

The Honda Civic IMA (Integrated Motor Assist) combines an electromotor with a petrol engine forming a "Mild Hybrid engine"

Honda Civic IMA

Source: Honda

Notes

- Fuel consumption: 4.9 litres/100 km, so up to 30% less than the Honda Civic 1.4S, comparable in terms of power performance
- The Civic IMA uses a 144V battery as drive unit
- The 1.3l four-stroke engine combined with a 9HP electromotor gives a total power rating of 95HP
- At steady speeds the conventional drive is used; during acceleration and driving away the electromotor is used.
- The IMA system serves as a starter-generator on engine shut-down
- A power electronics control unit automatically regulates electromotor switching in and out

In 1997 the Toyota Prius (Full Hybrid) became the first worldwide series production car with hybrid propulsion

Toyota Prius
Hybrid Synergy Drive Technology

Source:Toyota

Notes

- Toyota's Prius was chosen as European "2005 Car of the Year"
- A 1.5l four-stroke engine in combination with an electromotor gives a total power rating of 82 kW
- The Toyota Prius uses a 201.6V NiMH Battery
- With an acceleration of 0-100 kph in 11.9 secs the Prius is almost 2 seconds quicker than the Civic
- 4.3 litres per 100 km means a reduction of up to 40% as against a petrol engine
- 89% less smog-forming emission than conventional drive cars
- The electromotor provides front-wheel drive and when required by the control unit the petrol engine drives the rear wheels

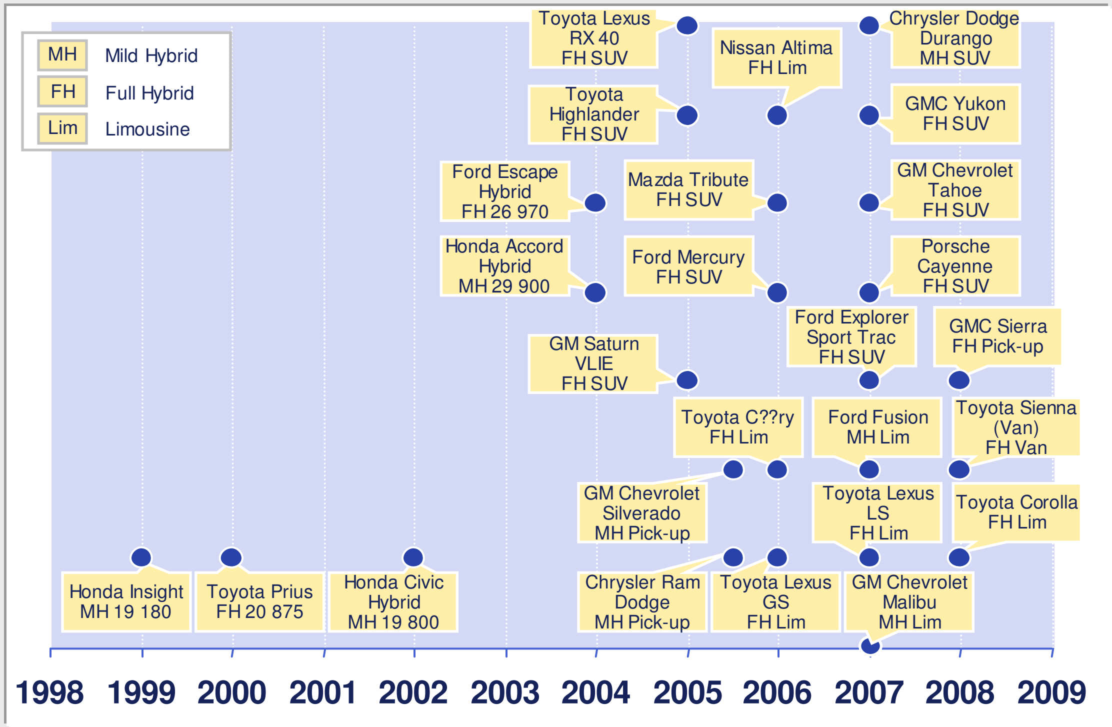
In June 2005 Toyota's Lexus RX400h was the first Hybrid-SUV on the car market

Lexus RX400h	Erläuterungen
  	■ Propulsion unit is a V6 petrol engine and two electromotors – one of which drives the rear wheels when required – and the 3.3-litre petrol engine as main power source ■ This provides an output of 200 kW (270HP) and acceleration of 0-100 kph in 7.6 secs ■ Fuel consumption of 8.1 litres per 100 km does not exceed the average for a medium class vehicle

Source: Toyota, ADL Research

The US market will experience a considerable expansion of the model range in the next 3 years – 21 new hybrid cars will come onto the market

Hybrid Vehicle Roadmap (US market)



Source: B&D-Forecast; ATZ 2005; ADL Recherche

Notes

- In the USA the current range of hybrids is still in its infancy with 4 models
- Market leader Toyota plans to market at least one hybrid version of every future series production model
- Currently Toyota intends to place ten parallel hybrid models in the market in coming years
- Toyota plans for a production facility in the US are under way and will probably be realised in 2007/2007

BMW is also committed to hybrid propulsion and is involved in a hybrid alliance of DaimlerChrysler und GM – the first marketable BMW models will come onto the market in 5-7 years

European OEM Market Hybrid Model Launch Roadmap

DaimlerChrysler and GM off-road model

DaimlerChrysler M Class

Porsche Cayenne

Audi Q7

VW Touran

BMW X5

2006 — 2007 — 2008 — 2009 — 2010

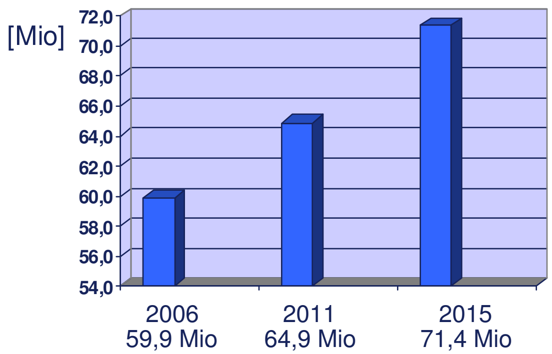
Source: ADL Research

Notes

- BMW has entered into a DaimlerChrysler and GM development alliance
- BMW is operating on the assumption that in 5 years every car manufacturer will have a hybrid vehicle in its car range. At BMW itself the hybrid concept is still in the preliminary development phase
- Only in 5-8 years time will BMW market its own hybrid car
- DaimlerChrysler and GM will market a joint-design off-road vehicle as early as 2007
- Porsche will offer customers a hybrid version of theCayenne
- Audi will market the SUV Q7 in the US in hybrid form from 2007

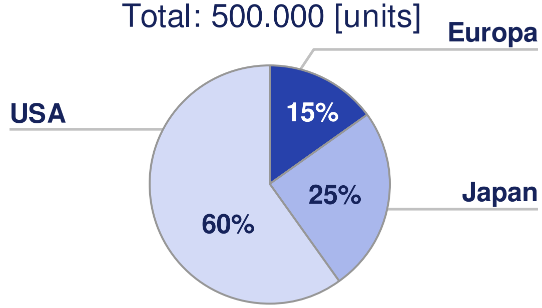
Full hybrid vehicles will in future occupy the major market share of hybrids

Vehicle Production (World)



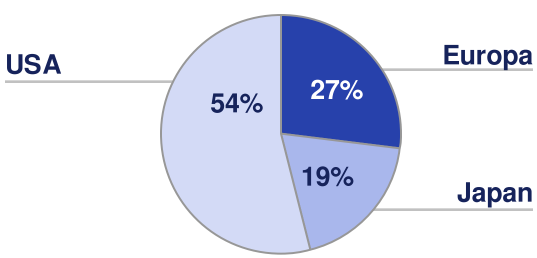
2006 – Hybrid Electric Vehicles

Total: 500.000 [units]



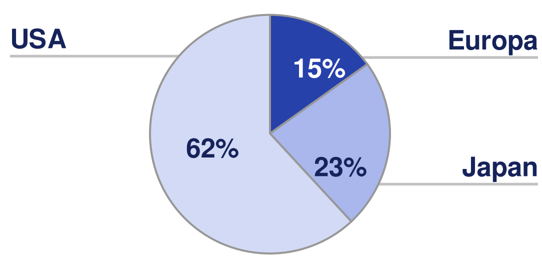
2011 – Hybrid Electric Vehicles

Total: 2,8 Mio [units]



2015 – Hybrid Electric Vehicles

Total: 6 Mio [units]



Notes

- The hybrid share of the car market will rise even further in the USA, since this is seen by OEMs as the key market both now and in the future
- The hybrid share of the car market will rise to 2.8 million in 2011 and increase to 6 million by 2015
- Following a hype phase in Europe in the years from 2006-2001 customer demand will then noticably cool off

Source: ADL Research

Agenda

The second strategy followed worldwide in the field of alternative forms of propulsion is fuel cell technology

Use of Fuel Cell Technology

MAN fuel cell bus undergoing trials at Munich Airport,

Modified B Class, with which a doubling of range can be achieved

Notes

- In the early 90s the Polymer Electrolyte Membrane (PEM) fuel cell was developed and tested
- DaimlerChrysler was a forerunner in fuel cell technology and its NECAR 1 was also the first prototype fuel cell technology vehicle on the market. In the interim this has been superseded and the NECAR 5 is already in existence
- DaimlerChrysler has announced that it will go into series production with fuel cell technology in 2012
- By 2015 intends to achieve sales of some 100,000 zero pollution vehicles. Soon a new series, the B Class will use this form of propulsion

➔ Doubling of the range to 400 kms

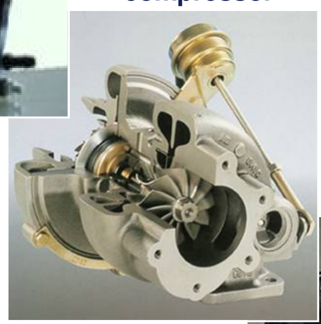
Source: ADL Research MAN, DaimlerChrysler

The fuel cell system is the core element for production of a water vapour and air mixture

Fuel Cell System Design

Fuel Cell Stack

Rotary screw compressor



Drive motor

Notes

- **Fuel Cell Stack**
  - Constructed from 200 individual fuel cells (PEMs) collected electrically in series
  - ➔ Delivers a continuous output at 80°C of up to 94 kW
- **Oxygen supply**
  - The required air is compressed by a compressor
  - ➔ relative humidity is increased
  - ➔ External humidifier unit is unnecessary
- **Hydrogen supply**
  - Feeds hydrogen from tank to fuel cell
- **Power electronics**
  - Transforms fuel cell stack voltage to values of between 250V and 380V.

Source: ADL Research

As with other forms of propulsion the significance of power electronics is increasing rapidly

Power Electronics in the Fuel Cell Vehicle

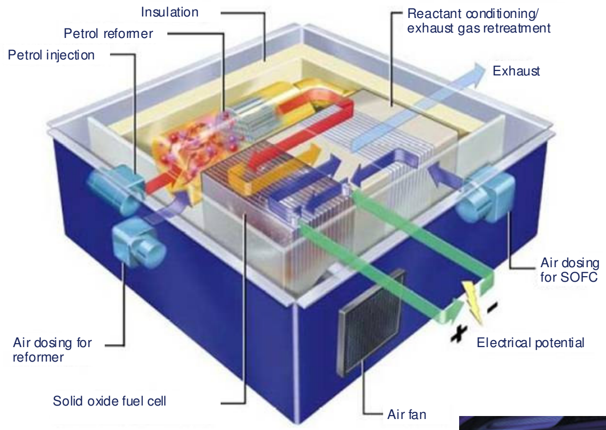
Quelle: Pierburg

Notes

- Similar to hybrid propulsion and conventional drive the number of power electronics circuits is also strongly on the increase in fuel cell propulsion:
  - Valves (for air and hydrogen)
  - Blowers (hydrogen recirculation blower)
  - Sensors (hydrogen sensors)
  - Compressors
  - Pumps (waterpumps)

BMW is replacing the conventional battery with an Auxiliary Power Unit (APU) in which power supply to the vehicle electrical system is provided independently of the engine

APU (Auxiliary Power Unit)



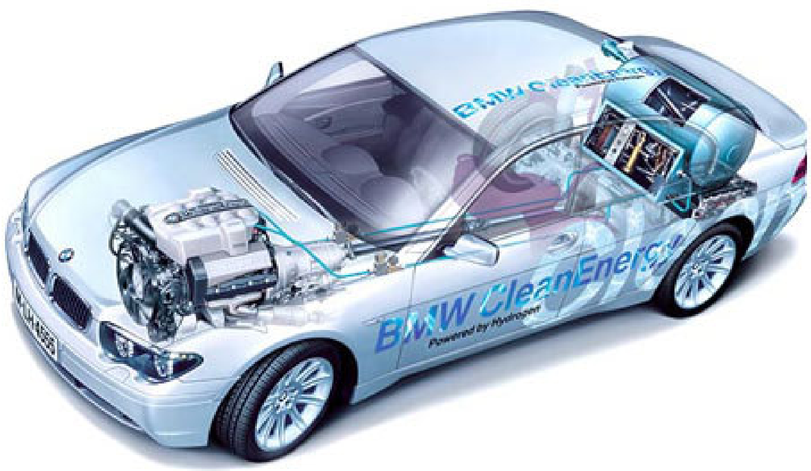
Source: BMW, Webasto

Notes

- Asearly as 2001 BMW presented an APU for power supply to auxiliary functions such as telematics, in-car entertainment and x-by-wire in the BMW 7 Series
- According to information supplied by manufacturers use of APUs can reduce fuel consumption by up to 1litre per100 kms
- Series production of APUs has not so far been announced by any car manufacturer due to deficiencies in terms of service life and reliability
- Power electronics control switching in and out of the APU and auxiliary switching in of the generator for brake energy regeneration
- Primary area of application are inter alia idling mode for onboard power supply in commercial vehicles or leisure applications

By 2020 intends to convert most of its vehicle range to hydrogen drive

Clean Energy WorldTour



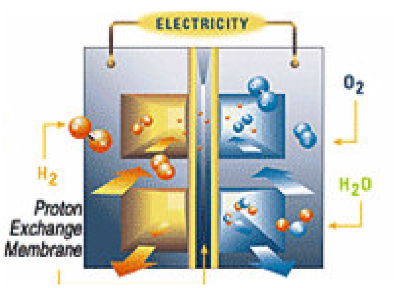
Notes

- With its **Clean Energy Project** BMW is lobbying for acceptance at political and customer level
- This campaigns for acceptance at the leveo of politics and the customer.
- Strategic target venues such as Brussels, Milan, Tokyo and Los Angeles were visited
- BMW itself has set a target to establish a pan-European network of hydrogen filling stations by 2010.
- By 2020 BMW will convert most of its vehicle range to environmentally sound hydrogen drive

Source: BMW, ADL Research

CaFCP, a worldwide collaboration project between car manufacturers, fuel suppliers, fuel cell manufacturers and US Government agencies has set a target to make fuel cell drive the propulsion technology of the 21st century

Califonia Fuel Cell Partnership (CaFCP)



Notes

- CaFCP consists of well-known company names from the car and crude oil sectors: DaimlerChrysler, Ford, Exxon Mobil BP, Toyota; supplemented by US Government agencies
- Its aim is to make fuel cell technology the propulsion technology of the 21st century. To this end the following measures are being implemented:
  - Testing and further development of fuel cell technology by in real condition simulation tests
  - Planning of an infrastructure for hydrogen recovery and distribution
  - Technological appraisal and preparation of a roadmap to bring fuel cell technology to series production level
  - Marketing and Promotion Tours in order to gain acceptance by future customers

Source: ADL Research

With the Ford Focus FCV fuel cells have already been extensively tested in the USA

Ford Focus FCV	Notes
	■ In collaboration with Ballard Power Systems Canada Ford has developed the Focus FCV (Full Cell Vehicle) ■ Fuelling is with hydrogen compressed to 250, giving the car a range of 160 kms ■ Despite its high 1727 kg weight the FOCUS FCV can reach a speed of 130 km/h

Source: Ford, ADL Research

As early as 1994 Mercedes presented the fuel-cell-driven and emission-free NECAR 1

NECAR	Erläuterungen
	■ In 2010 according to Ballard the fuel cell should be ready to go into series production use ■ By 2007 A-Class fuel cells will be undegoing trials in Asia, North America and Europe ■ Fuel cells function at temparatures of approximately 80°C. To reach these temperatures the cell must be heated on motor starting and subsequently cooled during operation ■ The fuel cell's high degree of efficiency can also be used to heat the vehicle interior ■ The asynchronous motor with integral power electronics for the NECAR 5 is lighter and more cost-effective that the module in its NECAR 3 technological predecessor

Source: DaimlerChrysler

At the German-American Global Alternative Propulsion Center development work by Opel and General Motors in the field of fuel cells has been forging ahead

Opel HydroGen Series

Notes

- A total of 250 employees have been pressing ahead with development work in the field fo fuel cell technology
- In the shape of the HydroGen1 in 2000 the first demonstable results were presented to the public at the Geneva International Motor Show
- After conversion of direct current to alternating voltage the voltage is fed to a three-phase electromotor which then drives the car with 55 kW.Nach dem Umrichten von Gleichspannung auf
- The fuel cell itself has an output of 80 kW
- In the Opel HydroGen3 some component savings were achieved, for example the battery was dispensed with, thus achieving a considerable weight reduction

Source: Opel, ADL Research

A major challenge crucial to the success of this form of propulsion is the development of an economically cost-effective infrastructure for the production of hydrogen

Hydrogen Filling Stations

Notes

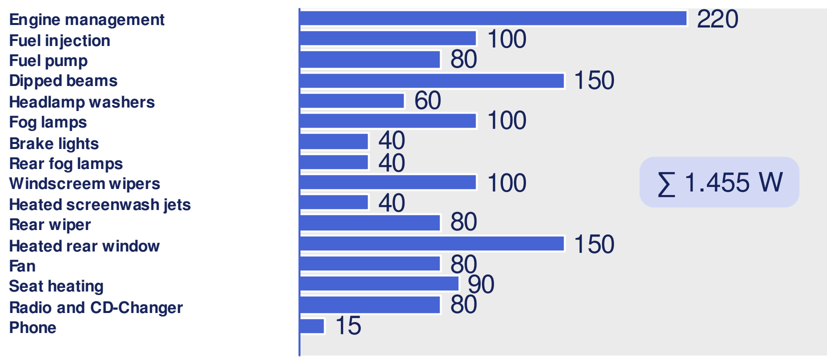
- A consortium of State and Industry has made possible the construction of the world's first hydrogen filling station
- Using a filling robot fully automatic refuelling of vehicles with hydrogen is achieved
- Gaseous hydrogen is produced directly on site using an electrolyser.
- After the gasous hydrogen has been cleansed and dried it can be fed to the metallic hydride storage reservoir
- During refuelling the temperature of the hydrogen discharged is always maintained at a low level (approx.5°C)
- Independently of further development of propulsion this infrastructure system must also be extended and epanded to give area coverage
- Only then will it be possible to use fuel cell technology in series production vehicles

Source: ADL Research

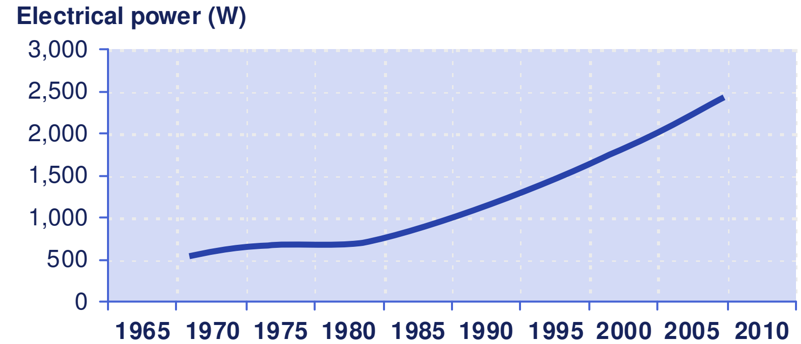
Agenda

Further increase in the energy requirements of vehicles is limited by existing power management concepts

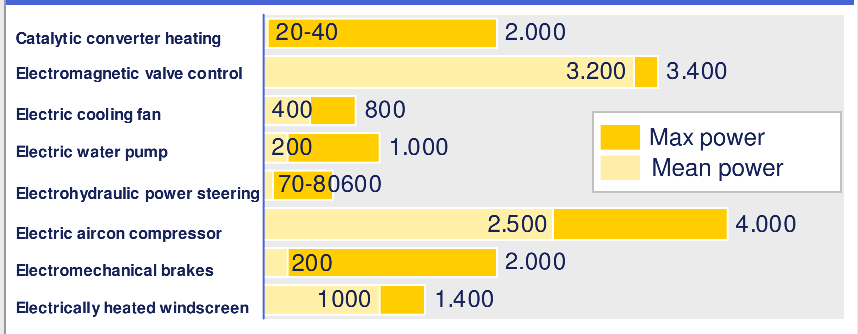
Power supply (W): What services are needed?



Increase in average electrical power supply in the vehicle



New Consumer Power Requirements (W)



Source: ADL Research

Current Energy Management Situation

- Average power requirement today is approx. 2,5 kW; it has trebled since 1985
- In luxury class models during start phase the power requirements are already up to 8 kW
- Customer requirements in the areas of safety, increased comfort and easier handling are still intensifying this trend
- New concepts in relation to intelligent energy management must therefore be urgently developed
- The "power supply of tomorrow" will also be determined by the form of vehicle propulsion

Currently several solution initiatives are employed including in combination with new vehicle models

Compensatory measures in relation to increasing power requirements

- Use of dual-battery-systems (starter battery/electrical system battery): One battery (in the engine compartment) is responsible solely for engine starting, whilst the second battery in the boot/trunk provides electrical power to electrical/electronic consumer systems
- *Example*: Phaeton, Mercedes SL

- Use of dual-circuit systems via DC/DC converter (with 14V and xV power supply)
- *Example*: Electric front screen heating (Audi A8) powered on a 42 V basis (power consumption 1000 W; max loading 1400 W); heating elemet being a thin metal foil sandwiched between inner and outer glass

- Use of software-based "Intelligent Power Management Systems' for continuous assessment, prioritisation and where necessary switching off consumer appliances
- *Example*: Bosch power management system control unit
  The control unit is responsible for regulation of the entire vehicle electrical system; responsible *inter alia* for anticipatory battery diagnosis and consumer device power coordination

Source: DaimlerChrysler, Bosch, ADL Research

Increasingly complex interplay of vehicle consumer devices requires an overall Electronic Power Management system (EEM)

Electronic Power Management System

EEM

Vehicle Operating State

Coordination Strategy

Power Coordinator

Battery management

Load/ No-load current management

Generator management

Interface to other systems

Generator

- Aircon control unit
- Engine electronics
- Gateway
- Relays
- DC/DC-converter

Notes

- In order to supply the increasing number of consumer devices in the vehicle in a technically and economically logical manner a structural architecture power management system is used
- The makes it possible to coordinate battery, consumer device and generator management on the basis of an operational state analysis

Source: Bosch

Li-Ion-Batteries and Ultracaps are currently the power storage media with the greatest development potential

Overview of current vehicle power storage media

	NiMH	NaNiCl	Li-Ion	Ultracaps
Main features	■ High performance ■ High cycle resistance ■ Low internal impedance ■ High raw material costs ■ High self-discharge level	■ High energy density ■ average cycle resistance ■ Low internal impedance ■ High-temperature battery	■ High energy density ■ High performance ■ Very low internal impedance ■ High cell voltage ■ Average to high cycle resistance ■ High cell monitoring drain	■ Extremely high performancet ■ Extremely high cycle resistance ■ Very low internal impedance ■ Practically maintenance-free ■ Low energy density
Development potential	average	average	high	high
Availability	yes	yes	prototypes	prototypes

Notes

- To accelerate development of NiMH batteries Toyota has entered into a strategic alliance with Matsushita.
- This resulted in a Joint Venture in1996 under the name Panasonic EV Energy (EVE) which provided a production line as early as 1997 with a capacity of 300,000 cells per month and secured sales rights stretching to 2014.

Source: ADL Research

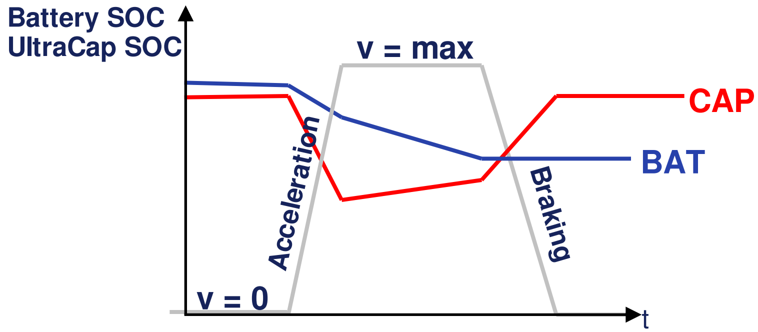
A combination of supercaps and battery represents the way to optimum use of vehicle power resources

Supercaps + Battery	Notes
 	■ A significant starting point for conserving the battery system resources is the use of supercaps ■ All peak loadings are covered by supercaps and low average loadings are powered from the battery ■ Use of supercaps brings improved road performance: – Range is increased by more than 20% – Acceleration is improved by up to 15 %

Source: Siemens VDO, Dietrich Naunin; Hybrid-, Batterie- und Brennstoffzellen-Elektrofahrzeuge

Supercaps store energy released on braking

VW Bora HY Power	Notes



Battery + Supercap operation energy flows

- The supercap used in the VW-Bora HY-Power fuel cell car increases engine performance briefly from 30 to 75 kW
- Charging and discharge efficiency of supercaps used is clearly in excess of 90%
- Siemens VDO anticipates series production introduction of supercap technology from 2010
- Regulation of power flows between supercaps and adjacent components requires current regulation at differing levels

Source: PSI

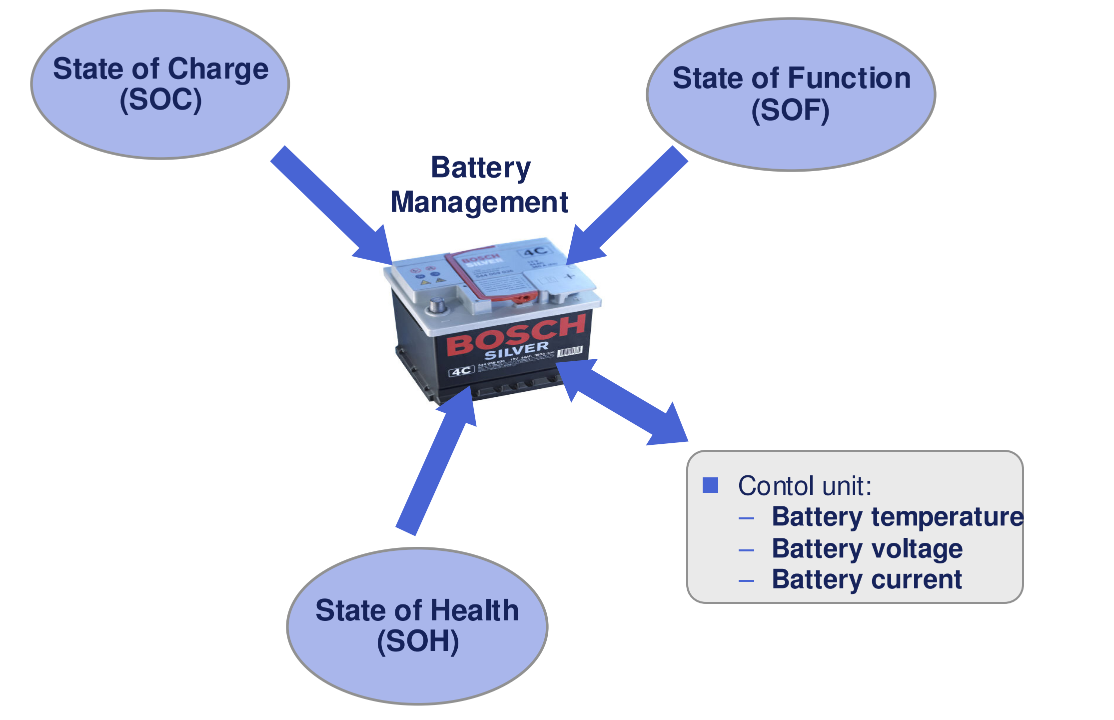
Li-Ion batteries will increasingly gain in significance in future – the battery will develop into a complete system comprising power source and diagnostic electronics

Outlook

- **Nickel metal hydride (in the short term) and li-Ion-batteries (in the long term)** will paly a crucial role in future
- From 2008 the first **li-Ion batteries will go into series production.** Current manufacturing costs have held back their use as a mass application but by effects of scale this will be compensated from 2008/2009 on
- **Ni-Cd batteries** on the other hand will be forced off the marketdue to mounting environmental charges
- The **likelihood of supercaps** becomiong sole power buffer are limited and for that reason the future power storage concept remains a combination of battery and supercaps
- No **ultimate series production power storage design** is currently discernible on the market

Battery management is gaining enormous significance in the power management system

Battery Management

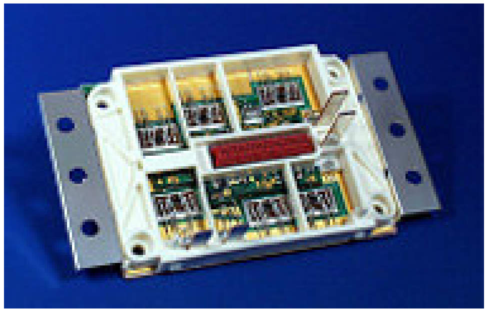


Notes

- Supreme goal of the battery management system is to guarantee an ecomomically logical distribution of available power
- This is the case when even the weakest module displays satisfactory operation
- From this operational state corresponding improvements can be derived for the overall system:
  - Increased working life
  - Increased reliability
  - Increased economy

Source: Bosch, Siemens VDO

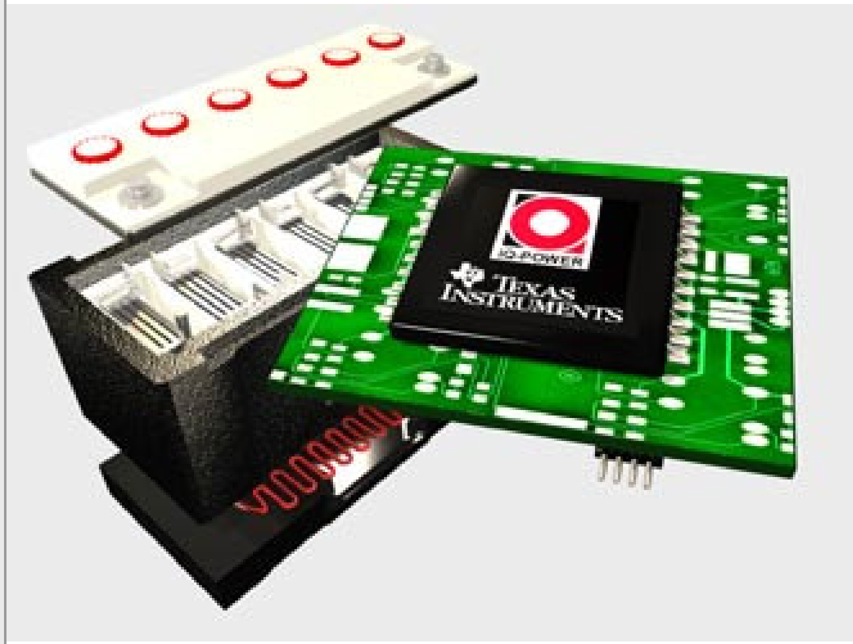
The intelligent battery sensor is the basis for ascertaining battery state

Intelligent Battery Sensor + Power Module	Notes
 Intelligent Battery Sensor  Power Module	■ The sensor concept works independently of electronics fit and vehicle battery ■ Precise determination of current, voltage and temperature of the battery is possible ■ Thus available capacity can be ascertained ■ The reliability of the vehicle electrical system and safety can therefore be increased ■ The power module helps to optimise energy housekeeping and battery charge state

Source: Hella

Because of the constantly increasing power requirements in the vehicle the need for electronically controlled electrical system management increases accordingly

Battery including Microelectronics Unit



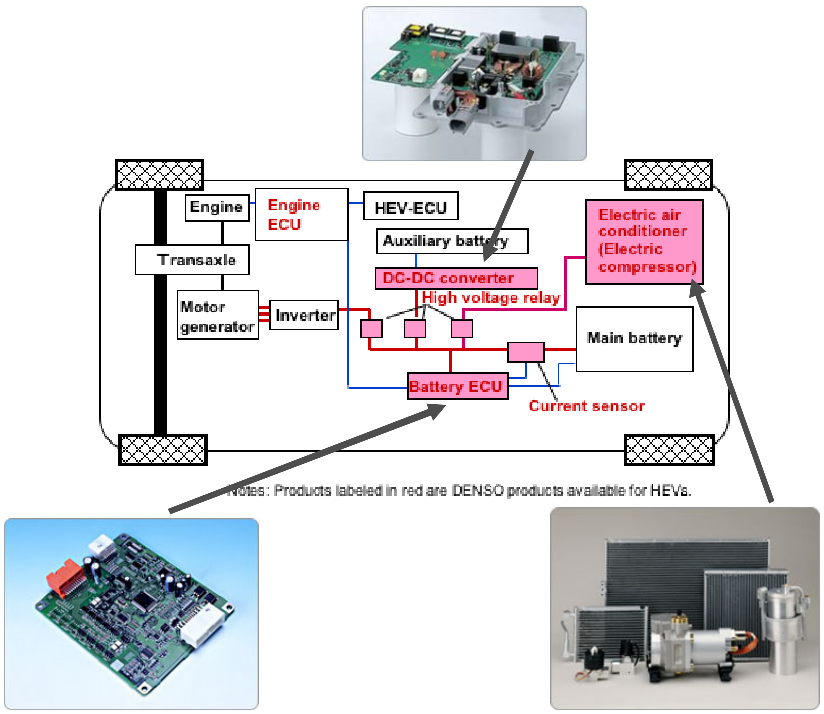
Source: IQ-Power

Notes

- Demands on the vehicle electrical power system increase with use of new mechatronics systems
- The battery – formerly a low-priced commodity with conventional energy storage technology is developing here into an intelligent overall system
- Improvement of overall performance by eleiminating negative influences (acid striation, temperature)
- The acid striation problem is solved by flow channel in the battery cells
- A small microelectronics unit is coupled directly to the battery

Delphi is one company offering a total system for hybrid vehicles

Hybrid Vehicle Battery Management



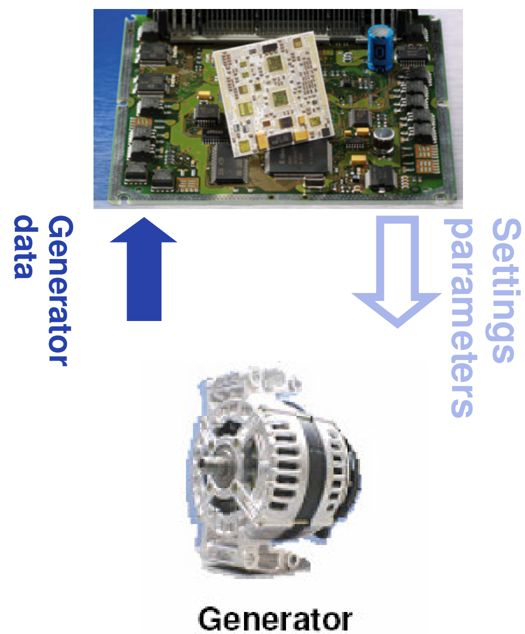
Notes

- **Battery ECU**
  – Holds battery set values
- **DC-DC Connector**
  – Serves primarily as a voltage transformer (200 V -> 12 V)
- **CO_2 Air Conditioning System**

Source: DENSO

Agenda

Efficient engine management is based on a level of generator management which coordinates interaction between combustion engine and generator

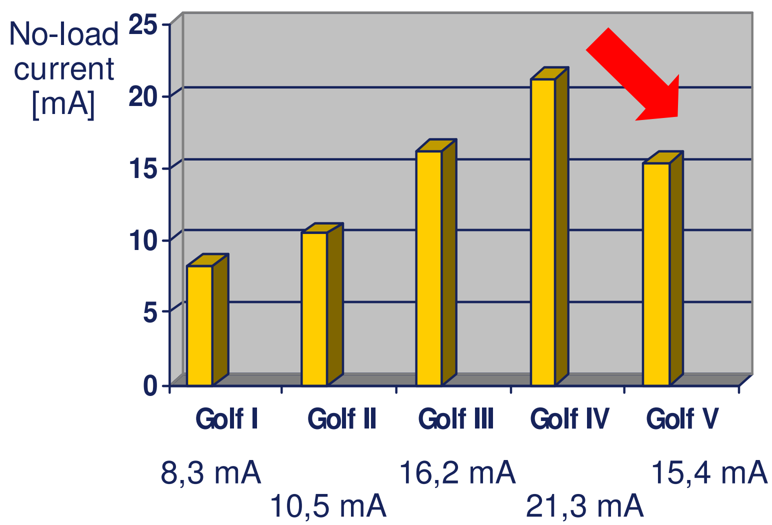
Generator Management	Notes
	■ Power electronics circuitry holds essential data control data (torque, output, reserve) ■ This generates generator regulator settings parameters (generator voltage set value *inter alia*) ■ The enables optimum motor management and more efficient battery re-charging

Source: Bosch

Agenda

The Bosch Load and No-Load Current Management System guarantees power supply when the vehicle is at a standstill including starting after lengthy unenergised periods

Load and No-Load Current Management



Despite increasing vehicle electronics architecture complexity there are initial indications of an imminent trend reversal in no-load current management

Notes

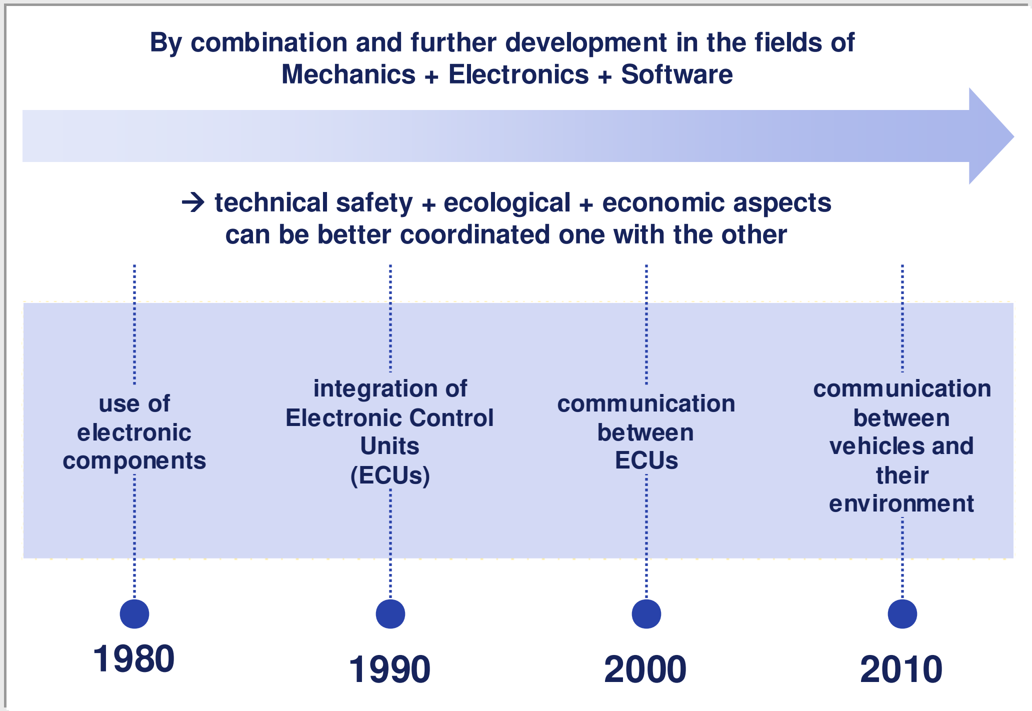
- In most control units installed efficient load and no-load current management is essential
- **Electrical power requirements when the vehicle is at a standstill** to be covered are :
  - Fan
  - Infotainment/telematics
  - Seat heating
  - Vehicle unlocking
- Load current management fulfils the following tasks
  - Coordination of **consumer system switch-in and switch out**
  - Consumer system **prioritisation**

Source: VW, ADL Recherche

Agenda

From 2010 bus systems will enable vehicles not only to communicate with one another but also to exchange information with their surrounding environment

Automotive Networking Trends up to 2010



Notes

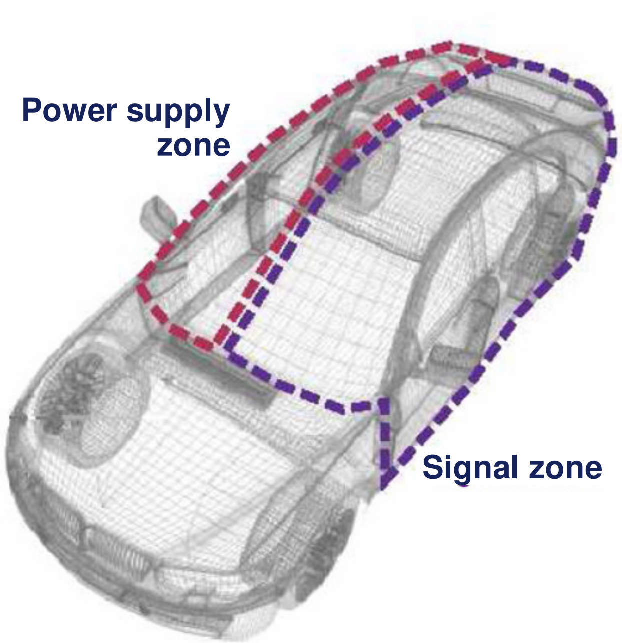
- Hierarchical bus communications will be expanded even further in future
- Several **communication levels** will therefore be enabled:
  - ➔within and between vehicles of **one manufacturer**
  - ➔between vehicles of **different manufacturers**
  - ➔With the remaining **environment**
- To establish the necessary standards for these development the **car2car consortium** has been created

Source: Bosch, FHT Esslingen

Agenda

Systematic separation of power supply and signal source zone avoids signal interference

Electrical System Partitioning

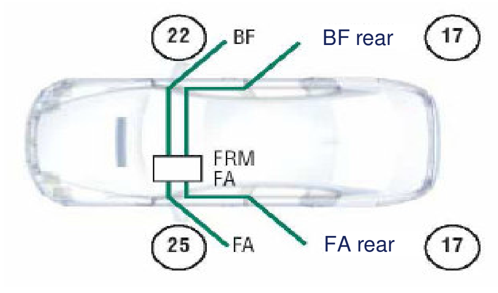


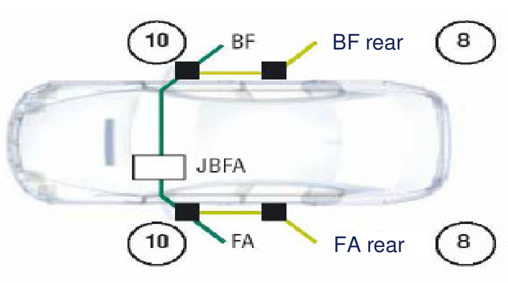
Source: Kromberg & Schubert GmbH & Co. KG

Notes

- To avoid signal interference caused by electromagnetic interaction power supply and signal source zones are spatially separated one from the other:
  - ➔RH installation area: **Power supply**
  - ➔LH installation area: **Signal source zone**
- This subdivision has a corresponding effect on control unit siting.
- Two approaches are followed:
  - ➔**central siting**
  - ➔**decentral siting**

Decentralised control unit configuration supports partioning the vehicle into separate modules…

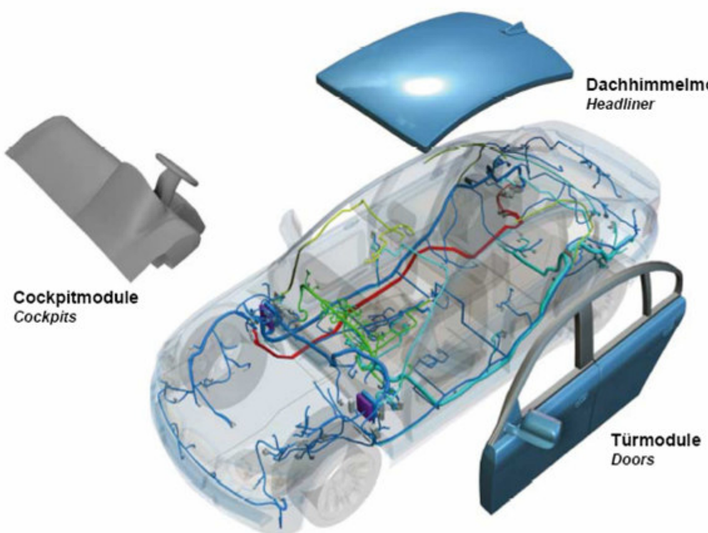
Centralised Siting	Notes
	■ With a central control unit sited in the foot well up to 25 leads including bus lines are ducted via the door spaces ■ All functions run by interplay with the central control unit

Decentralised Siting	Notes
	■ With decentral siting one control unit per function block is sited at the relevant location ■ With door structure this means that a central control unit is situated in each door

Source: Kromberg & Schubert GmbH & Co. KG

… and therefore helps to slim down manufacturing processes

Vehicle Modularisation



Notes

- In this way the vehicle can be subdivided into different modules:
  - door module
  - roof module
  - driver's compartment module
- This provides advantages for the individual modules:
  - slimmer door pillars
  - minimum volume
  - weight reduction
  - simplified assembly
- Therefore completely autonomously function modules can be supplied to the OEM for final assembly, thus enormously simplifying the process of manufacture

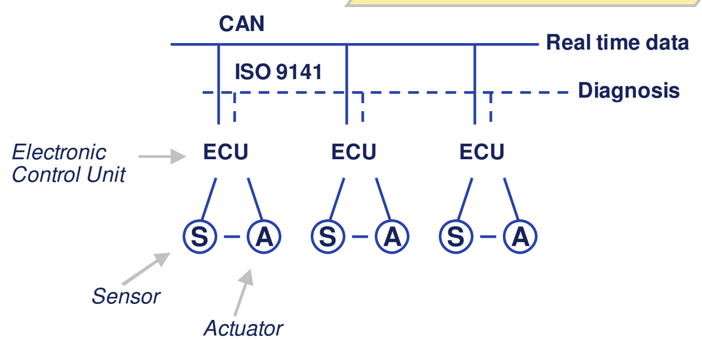
Source: Kromberg & Schubert GmbH & Co. KG

Agenda

The number of control units has increased disproportionaltely in recent years

First Car Data Networks (1991)

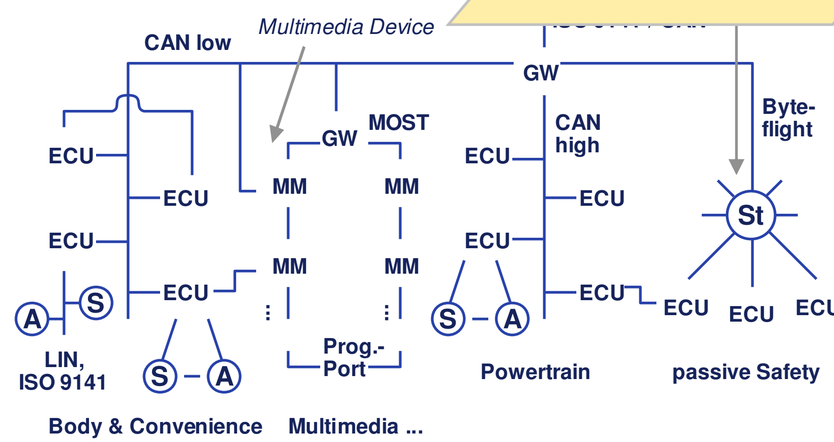
1991:
Numbering 3



In 1991 Mercedes had three control units in the S Class (W140) – for engine, transmission and control panel – linearly and homogenously connected to the CAN

Car Data Networks Today

2005:
Numbering 70

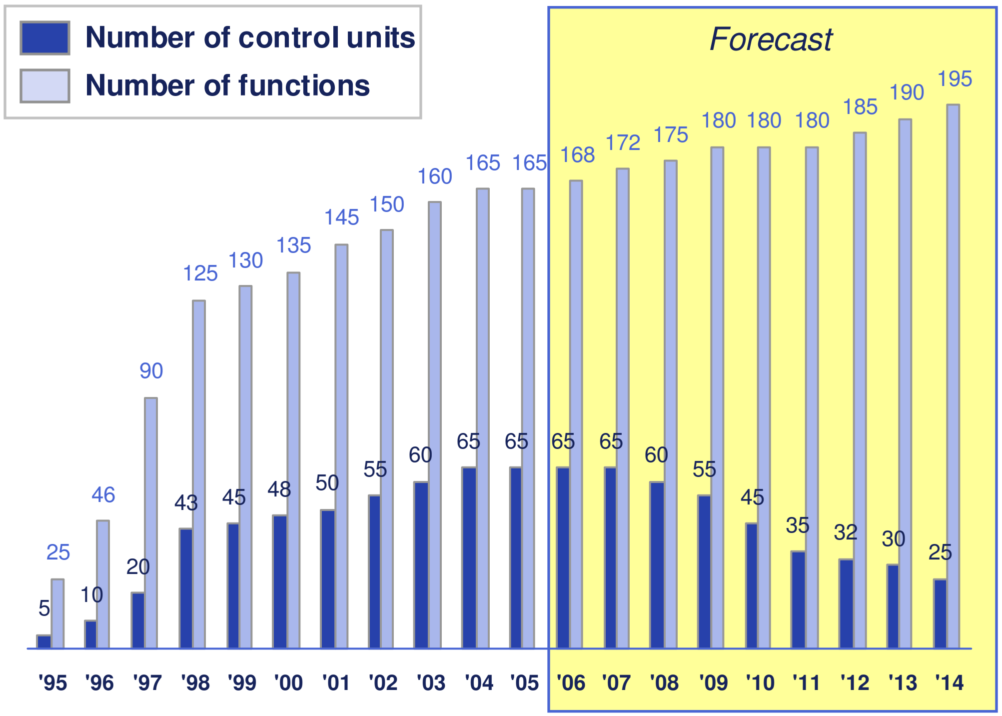


By the present day the number of control units in the car has risen to 70.

Source: ADL Research

For numbers of control units in the car a reduction is indicated; existing and any new future functions must be distributed over fewer control units

Trend regarding numbers of control units including functions



Notes

- After a brief stagnation the number of control units in the vehicle will decline in the next 3-5 years
- Target architecture for 2015 will consist of approximately 20 control units with some 5-7 central control units
- Total number of implemented functions per vehicle will rise only slowly in the next 3-5 years
- Current multiplicity of functions without any obvious customer benefit (e.g. Individually adjustable footwell illumination per passenger) is undergoing a reduction
- Any increase in additional functions will result in association with implementation of new future power management concepts

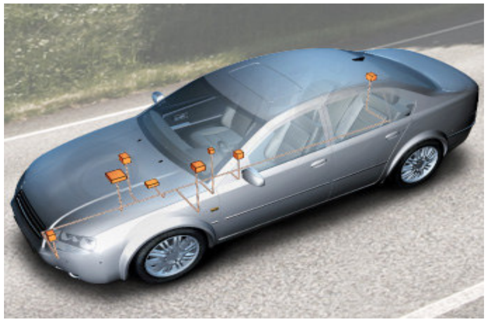
Source: ADL Research

An important aim for reducing costs and complexity is reduction of control units which accompanies an increase in software performance

Trend: Containment of complexity through a reduction in the number of control units

TODAY:
High level of complexity due to multiplicity of ECUs and various bus systems

TOMORROW:
Network of 20 control units with 5-7 maincomputers



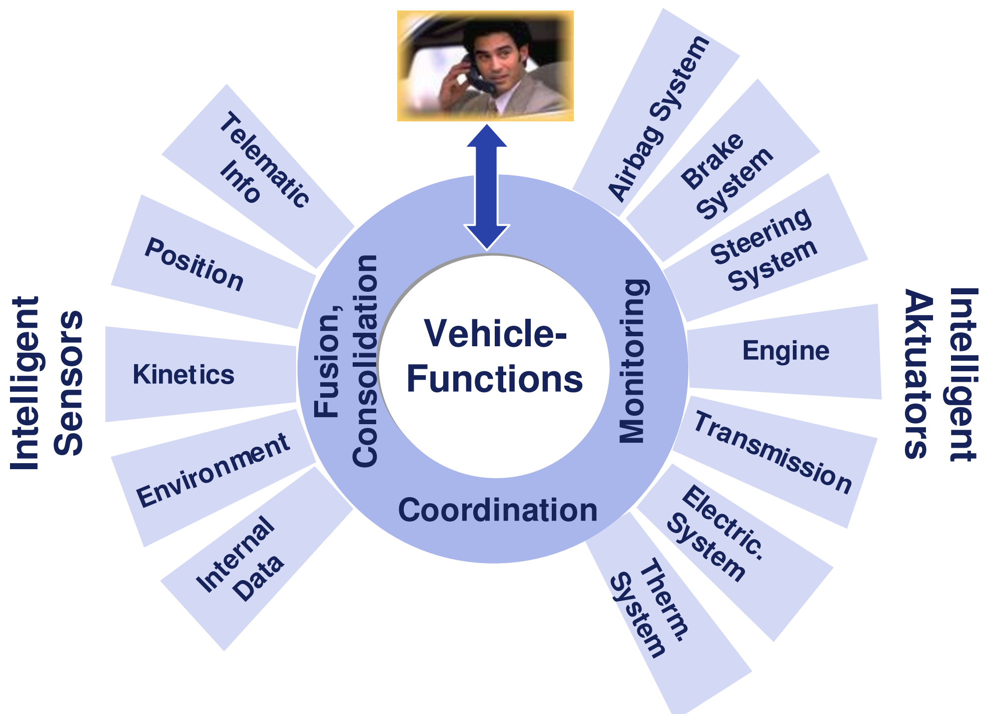
Notes

- The relative significance of software is increasing rapidly
- Software will in future be sold to customers as a separate and independent product
- Its share of value creation is growing four times as quickly as electronics
- The aim of car suppliers is a network with 20 control units the functions of which is centrally controlled by 5-7 main computers
- To better contain complexity standards remain to be defined

Source: Bayern Innovativ, ADL Research

Integration of power electronics in system components is expanding functionality primarily in the direction of intelligent sensors and actuators

Trend: Decentralisation of Intelligence



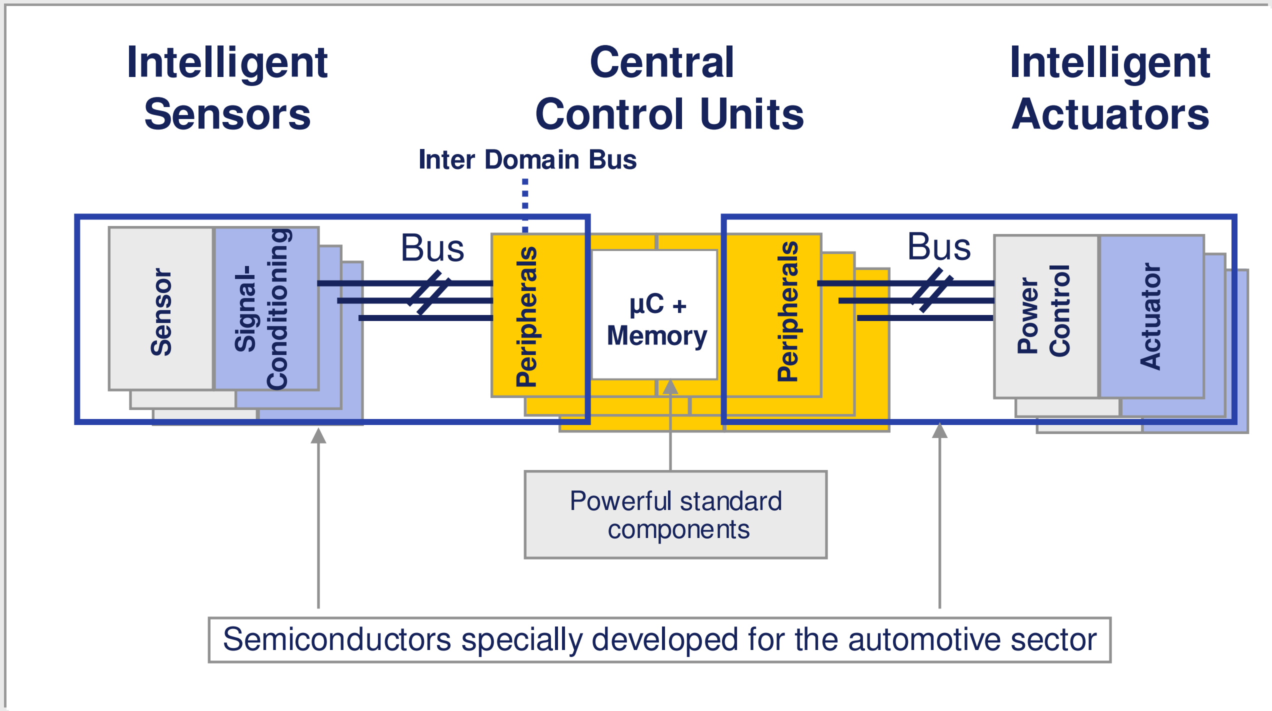
Source: Bosch

Notes

- Through interplay of intelligent sensors and actuators the driver can access vehicle data at any time
- In addition the vehicle can implement systems corrections autonomously
- Such systems can only be realised by use of corresponding power electronics. Primarily where the safety of the road user is to be increased are semiconductors coming into use
- This is reflected in high sales figures for the following years:
  - by 2008 sales volumes of 232 thousand million $ are anticipated (in 2003 it was 13.7 thousand million)

By using intelligent sensors and powerful semiconductors a great many analysis/evaluation programmes can be directly integrated into sensors

Trend: Use of Domain-Based Systems Architectures



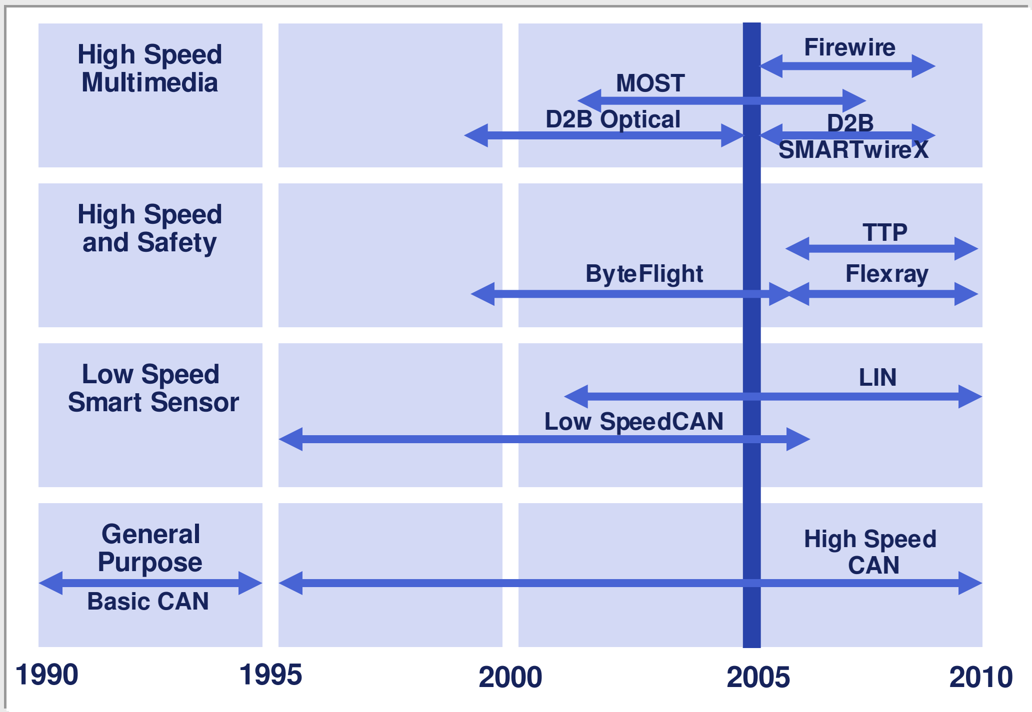
Source: Bosch, ADL Research

Notes

- Future systems architecture is in the main based on the use of intelligent sensors and actuators
- Diagnosis, monitoring, data evaluation and signal processing are relocated away from the central control unit towards the actual sensor
- This then permits communication by the sensor directly via the bus system

MOST and FlexRay will become the most commonly used bus systems due to increasing use of multimedia and by-wire solutions

Trend: In-Vehicle Network Architecture 2010



Notes

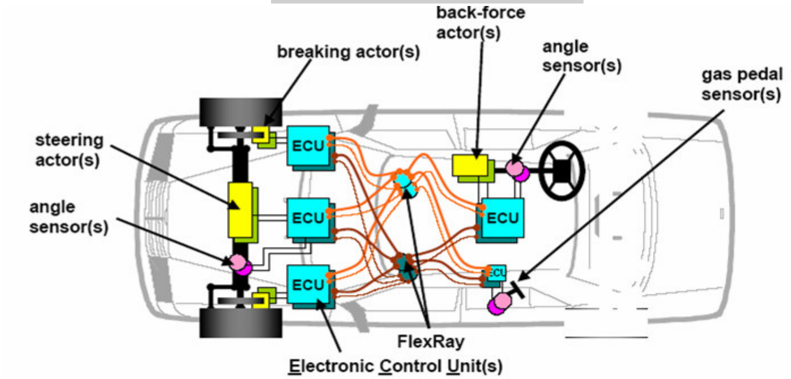
- Due to the increased prevalence of Infotainment/Multimedia solutions the MOST **(Media Orientated Systems Transport)** bus sytem is used more and more frequently
- **FlexRay** is a high-speed application bus system spanning manufacturers. Development of FlexRay is being undertaken by BMW and DaimlerChrysler in cooperatio with semiconductor producers

Protocol	Data rate
LIN	20 kBit/s
CAN	1 MBit/s
FlexRay	3-10 Mbit/s
MOST 1	25 Mbit/s
MOST 2	150 Mbit/s

Source: Delphi

With the FlexRay bus communications system safety-related applications can be electronically controlled

Steer-by-Wire



Notes

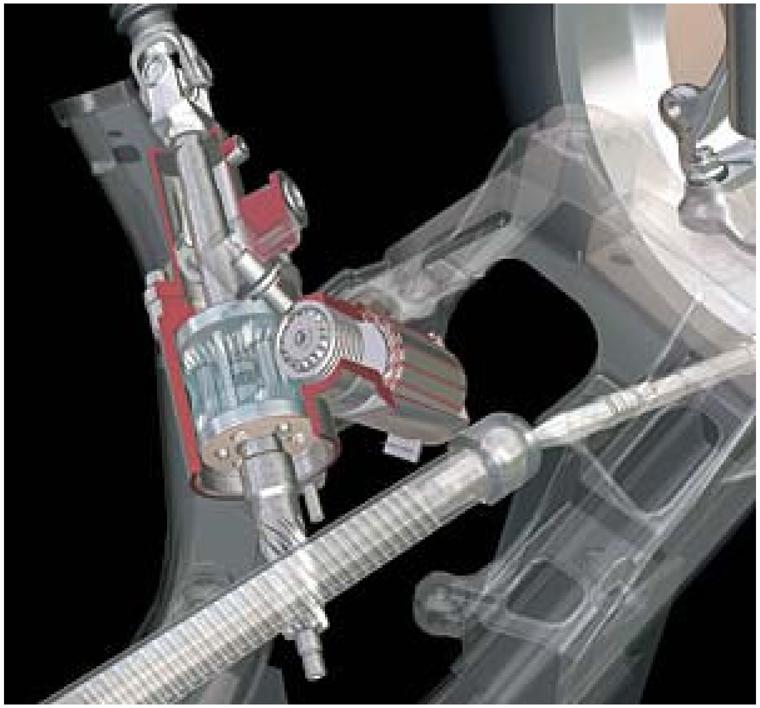
- As early as 2008 an increase in vehicle data rate to approximately **1.5 Mbit/s** is anticipated. For that reason increasing significance will be attached primarily to Flex-Ray in future with a network data rate of **5Mbit/sec**
- FlexRay makes possible new functions through improved packaging such as for example convoy driving
- **Steer-by-Wire** will be supported by FlexRay using a simple communications structure
- All sensors, actuators and control units are redundantly designed -> increased availability

Source: FHT Esslingen

Agenda

Arthur D Little

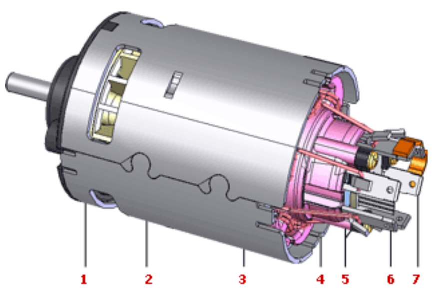
The electrically assisted steering transmission system increases driving comfort and road safety

Active Steering	Notes
	■ The basic active steering layout consists of – a modified **rack and pinion steering mechanism**, – a **dual epicyclic gear** and – an **EC motor** ■ In this design servo-assisted steering is supported by an overriding drive. ■ The EC motor forms the core of the active steering system which depending on speed guarantees an appropriate steering and wheel angle

Source: BMW

The EC motor-assisted system ensures optimum steering transmission on the road

EC-Motors for Vehicle Use



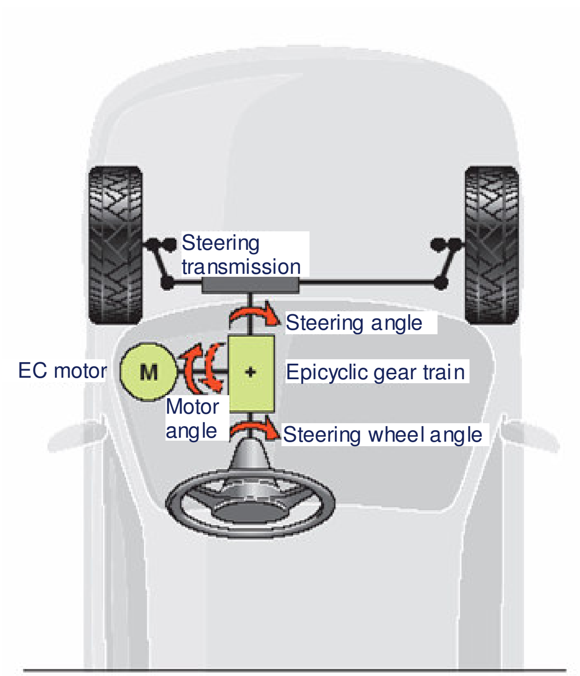
Source: BMW, ebm-papst

Notes

- EC motors represent an adequate replacement for hydraulic systems where a high degree of energy efficiency, longevity, low noise ratio and comfort are required.
- Prime consideration in the design of active steering was the need for steering precision and refinement of direct steering
- The EC motor generates the optimum steering transmisiion under changing loads and under extreme temperature fluctuation n (-40°C bis 125 °C).
- With a specified service live of 15 000 hrs the engine must function unfailingly over the the entire life of the vehicle

Lateral and yaw acceleration sensors provide the basis for precise vehicle driving reaction

Active Steering Control Unit

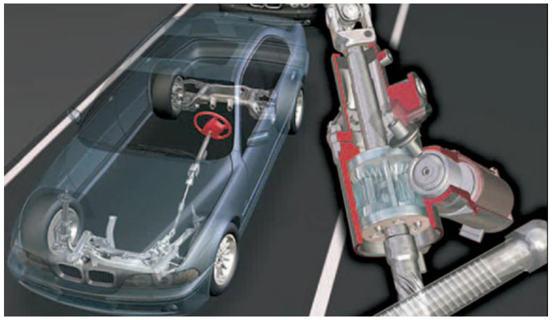


Notes

- Depending on speed even slight steering movements are sufficient to achieve a large steering radius and vice versa
- Lateral and yaw acceleration sensors determine the vehicle's driving reaction and from this stabilising steering actions are derived
- In the event of electrical system failure a full hydraulic system can be switched in.

Source: FHT Esslingen

On the BMW 3 Series active steering now moves into the medium-size class – an intermediate stage to a full electronic steer-by wire system

Active Steering Systems in Operation	Notes
 	■ These systems are currently in use in the BMW 5 and 6 Series ■ The system has also been adopted in the new 3 Series wurde das System ■ An independent Steer-by-Wire System is only being introduced in stages, i.e. Irrespective of reliability there will be a parallel mechanically operated system which comes into play in the event of electronics failure

Source: BMW

Agenda

The IDS+System is enabling Opel to make the transition from mechanical-hydraulic to a mechatronic chassis

Opel Astra with IDS+ System

Notes

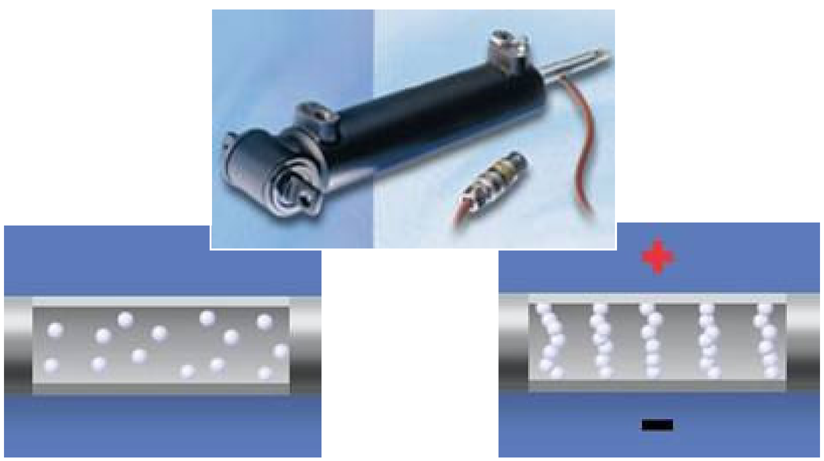
- IDS+ chassis system with CDC electronic damper system on the Opel Astra
- The IDS+ system comprises a network of sensors and control units for all driving dynamics systems parameters
- This ensures optimum vehicle handling
  - Example: on curved stretches of road damping is hard and on long straights it is soft
- With CATS (Computer Active Technology Suspension) Jaguar markets a similar electronically control chassis control system

Source: Opel

Additional electronically controlled chassis control systems are being developed by Fludicon and Volvo

Electrorheological Fluid (ERF)

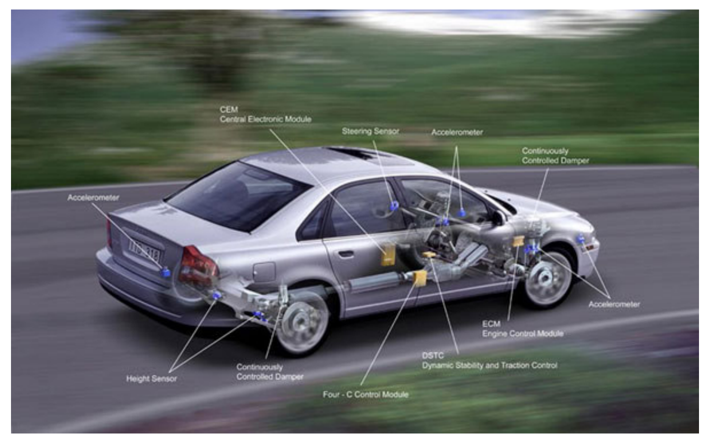
- ERF changes when subject to an electrical potential and is infinitely reversible from liquid to solid form
- It permits extremely short response times and absence of valve wear



Source: Fludicon

Volvo Four C

- Four C (Continously Controlled Chassis Concept): shock absorbers with integral magnetic valves whose opening and closing impulses are coordinated by a central control module (SUM, Suspension Module)



Source: Volvo

An additional contribution to improvement of driving dynamics is the Bosch-developed ACC (Active Cruise Control) radar sensor

Radar Sensor	Notes
	■ The 77 GHz radar sensor determines the interval distance to the car ahead and can therefore constantly calculate **relative speed** and **lateral position** in relation to the driver's car ■ Using the sensor information thus obtained the driver's track position can be precisely determined ■ Energetic driver actions, for example in driving queues, can therefore be minimised ■ Systems on the horizon can regulate car interval until stop ■ Already as a customer option solutions can be implemented which make possible autonomous driving off and braking ■ Proximity measurement can be realised by additionally supplementing the ACC sensors with 24-GHz radar sensors ergänzt

Source: Bosch

The Conti-Temic ACC solution is very lucrative particularly in medium-sized cars

Driver In-Car Support Systems

Video

- Rear zone
- Horizontal aperture angle ± 60°

Ultrasound

- Ultra-proximity zone ≤ 3m
- Horizontal aperture angle ± 60°

Infrared

- Near vision zone ≤ 150 m
- Horizontal aperture angle ± 10 °

Video

- Intermediate zone ≤ 80 m
- Horizontal aperture angle : ± 22°

77 GHz Long Range Radar

- Long range ≥ 150 m
- Horizontal aperture angle: ± 8°

Source: Bosch

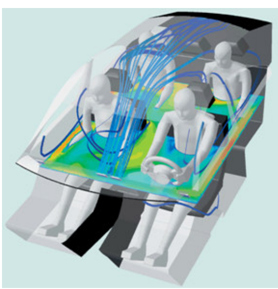
Notes

- The infra red solution is more cost-effective than radar-based ACC solutions so they are used in the small to compact class car segment
- In years to come development of driver support systems primarily for increased safety will gain in significance
- Currently available systems are:
  - Infrared systems
  - Video systems
  - Ultrasonic sensors (range 2.5 m)
  - Long range 77 Ghzradar (range up to 150m)
  - Close range 24 GHz sensors (range up to 5m)

The roof complex is being developed as a central signals processing unit for driver support systems

Trend: Further development of the roof complex for central control and signal processing unit

Sunroof



Climate Control

Anti-glare interior mirror

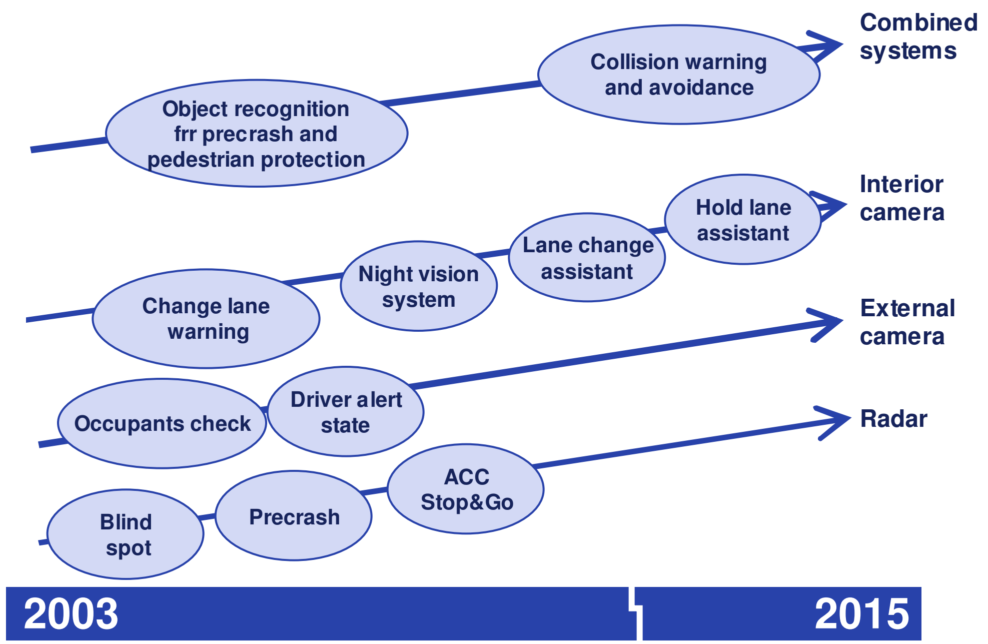
Notes

- The roof complex is increasingly becomiont the central unit for control of safety and comfort functions:
- In addition to light sensoring this includes a great many additional functions:
  - Control of automatic anti-glare interior mirror
  - Memory function enables storage of individual requirement settings
  - Control of sliding and elevating roof with crush protection
  - Interior temperature recording using ventilated sensor
    - Relay of information to climate control automatic system
  - Automatic wiper activation using a rain sensor
- In future this unit will be further expanded by sensors and signal processing units for vehicle driver support systems (ACC unit, cameras and other sensors)

Quelle: Hella

Combined systems consisting of cameras, sensors and radar systems will make a crucial contribution to anticipatory driving behaviour

Driver Support System Development



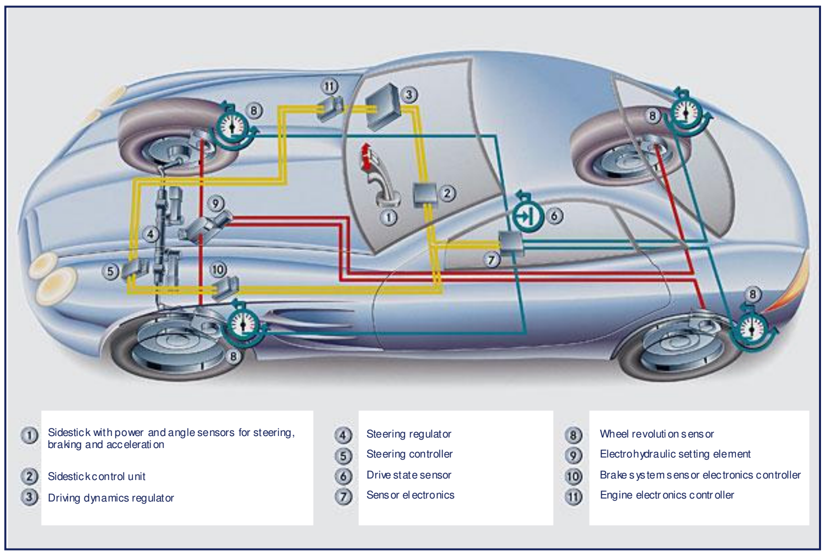
Notes

- The market for driver support sytems will grown from the present 29 thousan million Euro to 11.6 thousand million Euro in 2010. In 2015 saturation will be reached at 15 thousand million Euro.
- Long range radar, close range radar and camera systems will in future be increasingly combined.
- From 2011 systems are anticipated which will automatically give the driver collision warnings and initiate action independently

Source: Bosch, Siemens VDO, Bayern Innovativ

The first drive-by-wire solutions to gain customer acceptance will capture the market from 2012

Drive-by-Wire Solution



Notes

- Car manufacuters are making great development efforts to overcome practical problems associated for example with steer-by-wire solutions
- With its fault tolerance or fail-safe modes FlexRay is the key to development of fault-free functioning by-wire solutions
- Initial prototypes are aleady being trialled and will come on the market in 2006
- To be able to test by-wire solutions in practice initially, as is currently the case with new steering systems, mechanical controls are added in parallel. These come into play in the event that the electronics fail

Source: DaimlerChrysler

The DaimlerChrysler SL Class rolling research vehicle for Drive-by-Wire solutions

SL Class	Notes
	▪ Steering wheel and pedals are no longer necessary in DaimlerChrysler test vehicles ▪ Steering, braking and acceleration are controlled via a sidestick which can control precise manoeuvering ▪ This is via an onboard computer which evaluates the driver's commands so that critical situations can be overcome

Source: DaimlerChrysler

Agenda

Agenda

Future seating functions and seat designs in the car are increasingly marked by individual solutions

Seating Functions

Ergonomics

Psychology

Industrial Standards

Seat Climate Control

Vibration effects

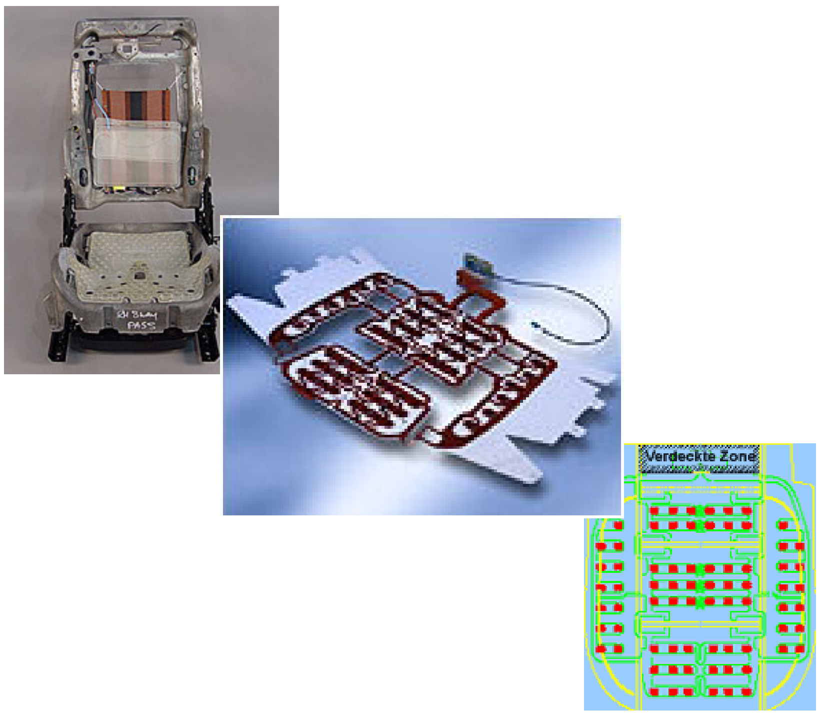
Orthopaedic aspects

Erläuterungen

- In addition to seating functions comfort and design considerations are more and more central
- In developing seating systems more and more factors are considered:
  - Ergonomcs
  - Seat climate control
  - Orthopaedic aspects
  - Vibration reduction
  - Industrial Standards
  - Optical aspects

Source: ContiTemic

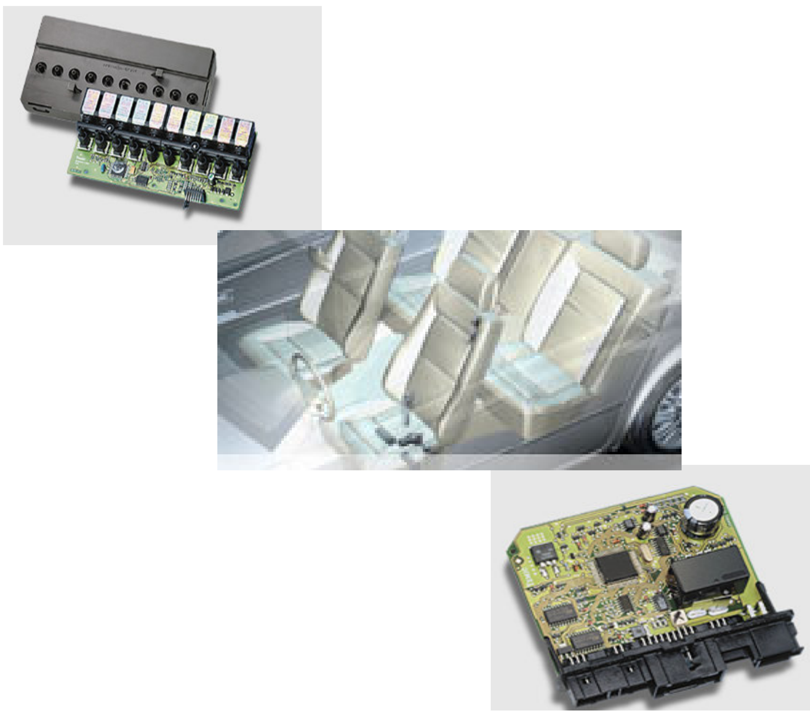
The Siemens VDO Occupant Classification System (OCS) provides situation-oriented seating adjustment

Intelligent Seats	Notes
	■ Based on a sensor mat integral to the seat seat pressure distribution is registered ■ Software analyses the data and relays derived commands to the control unit ■ Depending on the passenger - child or adult - the seat restraint system is adjusted and optimised accordingly

Source: ContiTemic, Bosch, BMW

The ContiTemic multi-contour backrest provides driver and passenger with optimum adjustment options

Multi-Contour Backrest



Notes

- The ContiTemic multi-contour backrest meets the requirement for individual settings
- Up to 7separate air cusions adapt to the body and so register the optimum seat adaptation for the passenger
- On registering the optimum seat configuration this can be individually stored in memory and called up as and when required
- To minimise use of motors these are replaced or supplemented by pneumatic activators
- A further variant is design of a central pressure unit via which pressure can be distributed via a pressure reducer

Source: Conti Temic

Already in the BMW 7 Series 13 electromotors for seat adjustment, heating and cooling require to be controlled by power electronics

The Dynamic Seat	Notes
 	■ In general greater demands will be placed on springing and comfort ■ In the medium-sized car segment in particular an increase in seating comfort functions will be registered in years to come ■ Future developments will take place in the following areas *inter alia*: – Massage functions – Improved side support when negotiating bends – Ergonomic relief of the back muscle structure

Source: ContiTemic, Bosch, BMW

Rapid increase in seat functionality requires ever more complex control electronics

VW Phaeton Seating System	Notes

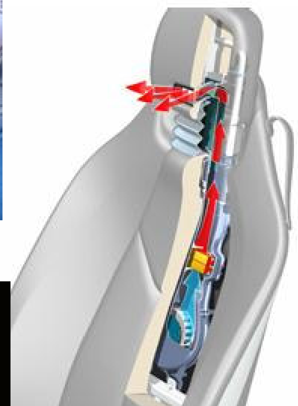
Notes

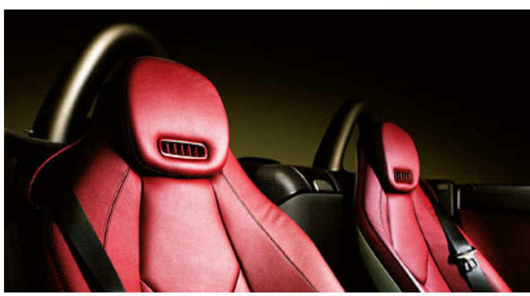
- A 12-way system adjusts length, height and rake parameters to the body
- An additonal Phaeton function is an 18-way system, where in additon the top of the backrest, headrest and seat depth can be adjusted
- Climate control and massage function complete the function portfolio
- With a 12-way system for the rear seats Volkswagen was the first car manufacturer with elecrically adjustable seats in the rear of the car

Source: VW, AGR

PTC auxiliary heaters in the Mercedes SLK warm up the car interior immediately on starting the engine

PTC Auxiliary Heater





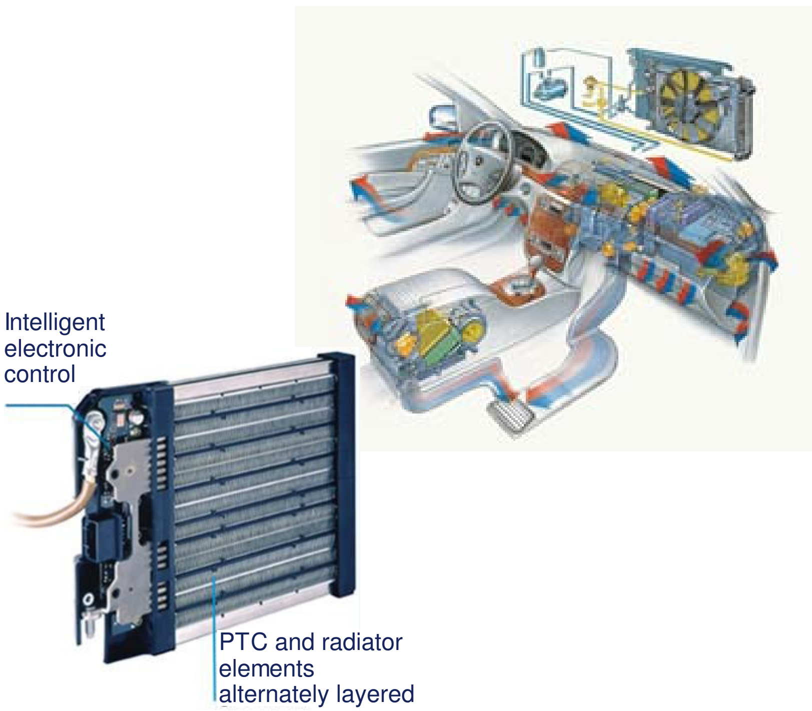
Notes

- PTC auxiliary heaters warm the car interior immediately on starting the engine – example: PTC auxiliary heater for neck heating in the new Mercedes SLK (Air Scarf)
- 95% of the electrical energy is passed to the air strem to the vehicle interior
- The BMW 520d rear seating air flow cab even now be separately electronically controlled by an electronic auxiliary heating system
- Using semiconductor circuitry the power electronics controls the PTC element heating times; typical values for PTC auxiliary heaters power consumption are approximately 1000 W
- Vehicle electrical system overload is avoided by an intelligent PTC element circuit
- With improved motor efficiency more auxiliary heaters will increasingly be required

Source: DaimlerChrysler

Behr 4-zone climate control based on an intelligent control unit makes possible comprehensive management of interior climate

4-Zone Climate Control



Notes

- Use of a 4-quadrant solar sensor for automatic temperature adjustment under direct solar radiation
- Humidity management prevents screen condensation and rises simultaneously if interior air is too dry
- An air quality system with one particle and two active carbon filters, a corrosive gas sensor and an automatic recirculation air circuit cleans the car interior air
- An additional large air jet right and left for draught-free ventilation of the head area can be manually directed with reducible mid-jet temperature
- Full control of the 4-zone climate control is possible via a control unit
- PTC air heaters with integral power electronics provide immediate rear passenger compartment warm air heating even when the engine is cold

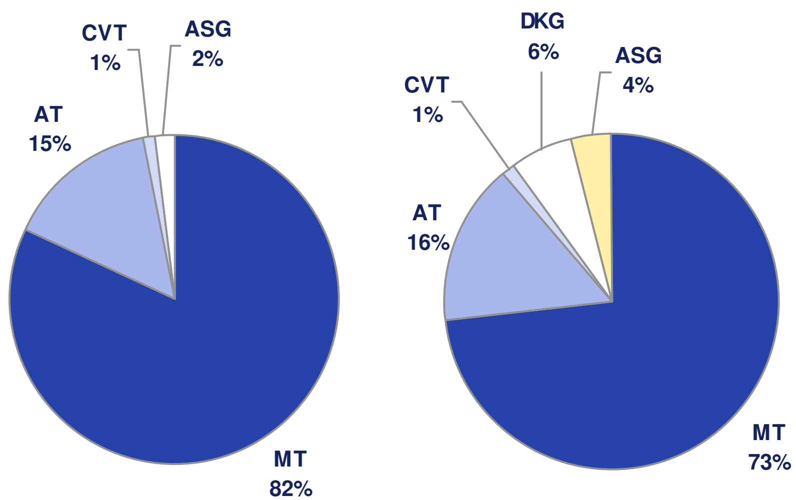
Source: Behr AG, Catem

Agenda

Twin-clutch and autochanger gearboxes will achieve significant market shares (1)

European Market Shares (cars and HGVs <6 t)

2002	2012



Vehicle Class Penetration

Vehicle Classes	ASG	DKG
A/B	full	none
C	partial	full
D	none	full
E	none	none
Sport	partial	full
HGV	full	none

Penetration depth

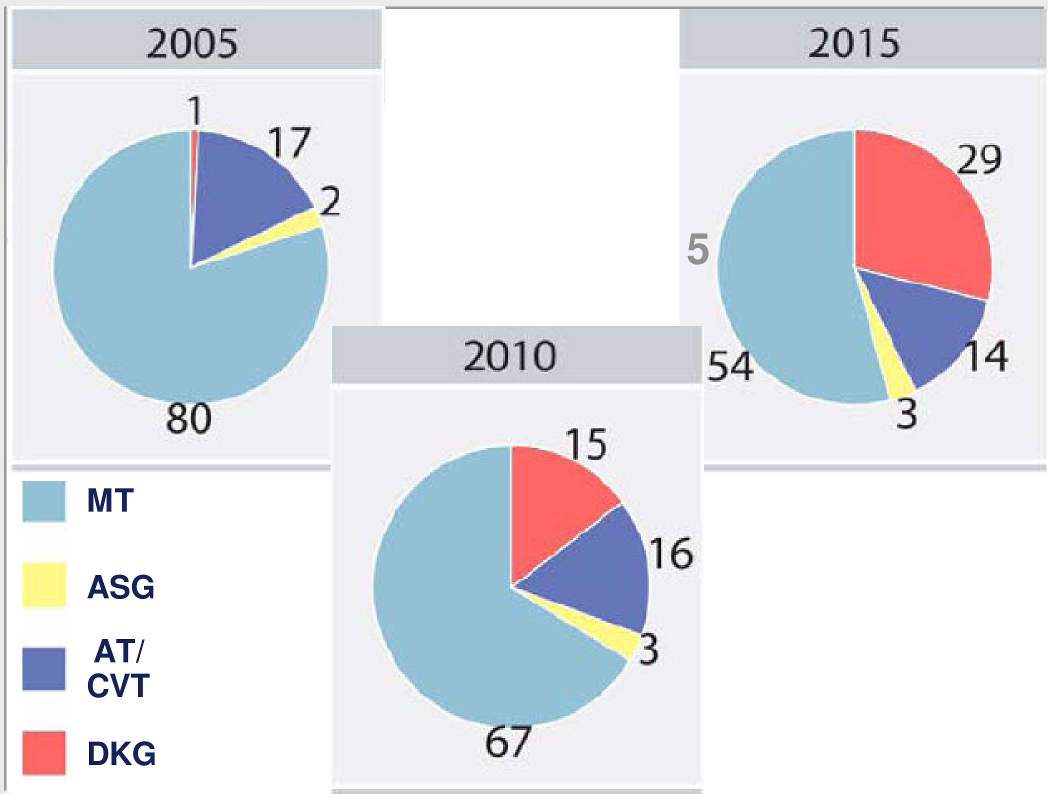
full · majority · partial · low · none

Source: ZF

DKG: Twin-clutch gearbox, ASG: autochanger gearbox

Twin-clutch and autochanger gearboxes will achieve significant market shares(2)

European [%] Gearbox Market Shares (cars, HGV <6 t)



*Source: Getrag Presseinformationen IAA 2005

Market Segment Penetration

Vehicle classes	ASG	DKG
A/B	●	●
C	○	●
D	○	●
E	○	●
Sport	●	●
LCV	●	●
Manufacturer focus:	F	D

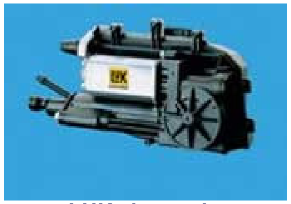
Agenda

10	Transmission Systems
10.1	Autochanger Gearbox
10.2	Twin-Clutch Gearbox

Autochanger gearboxes combined with electronic clutch systems contribute greatly to fuel economy and are considerably more cost-effectve than an automatic gearbox

Autochanger Gearbox

ZF autochanger gearbox



LUK electronic clutch management

Siemens VDO autochanger and electronic clutch drive motors

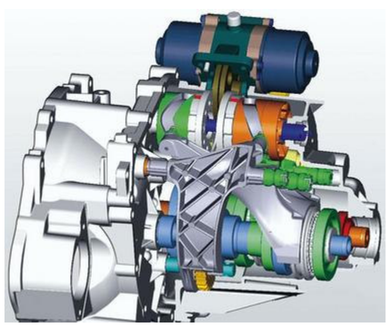
Notes

- Actuation in automatic clutch movements and gear changes is by electromotor actuators
- The EC motors used by Siemens VDO operate in the 50-25- Watt output spectrum
- Electronic clutch management makes possible gear changing without a clutch pedal
- Further advantages as against an automatic gearbox flow from the lower costs, lower weight and small size
- For that reason automatic gear changing will gain increasingly in significance in Europe in coming years

Source:Siemens VDO, ZF Sachs, LUK

The autochanger gearbox in the Smart Forfour can be operated in either automatic or manual change mode

Autochanger Gearbox in the Smart Forfour



Automatisiertes 6-Gang Schaltgetriebe des Smart forfour

Notes

- In manual change mode it is only necessary to move the gear lever forward or back
- The control electronics used recognises the driver's gearchange intention and operates the clutch via the actuator motors
- The combination of onboard electronics and electronic stabiliser program (ESP) has made it possible to incorporate a clutch-slip creep function in the gearbox
- The main deciding factors for the advantages as against the fully automatic gearboxwere the low weight (some 36 kilograms for the 1.5 petrol engine and 41 kilograms for the diesel unit) . Fully automatic gearboxes would be double the weight.

➔ Fuel savings of approximately 1 litre per 100 kms

Source: DaimlerChrysler

The demand for high temperature electronics for transmission system contol continues to rise

Twin-Clutch Gearbox and Control Unit

Notes

- The twin-clutch gearbox in the new VW Passat operates with two clutches. The first one disengages to change up and the second one closes for the next higher gear – so acceleration continues smoothly without a "jerk" "
- Amechatronic control system takes over coordination and control
- Control modules with power electronics are fitted direclty inside gearbox
- Technical specifications of the control unit developed by Conti Temic for hybrid technology are:
  - Temperature range - 40°C bis + 145°C
  - Acceleration: 20 g
  - The controller contains inter alia:
    4 revolution sensors, displacement transducer, 2 pressure sensors, a temperature sensor and 11 partially integral actuators

Source: Continental / VW

The twin-clutch gearbox is very likely to replace the fully automatic gearbox in many areas

Clutch Gearbox Controller

VW Passat 2.0 TDI PT

ContiTemic Local Controller

Notes

- The electronic control used here enables gearchanges to be made in 0.2 seconds
- The DSG twin-clutch gearbox perfectly combines the acceleration and fuel consumption characteristics of a manual shift with the comfort of automatic transmission
- In Austria already every tenth Golf V sold and every fourth Touran is fitted with the DSG twin-clutch gearbox. The new Passat adds yet another car segment

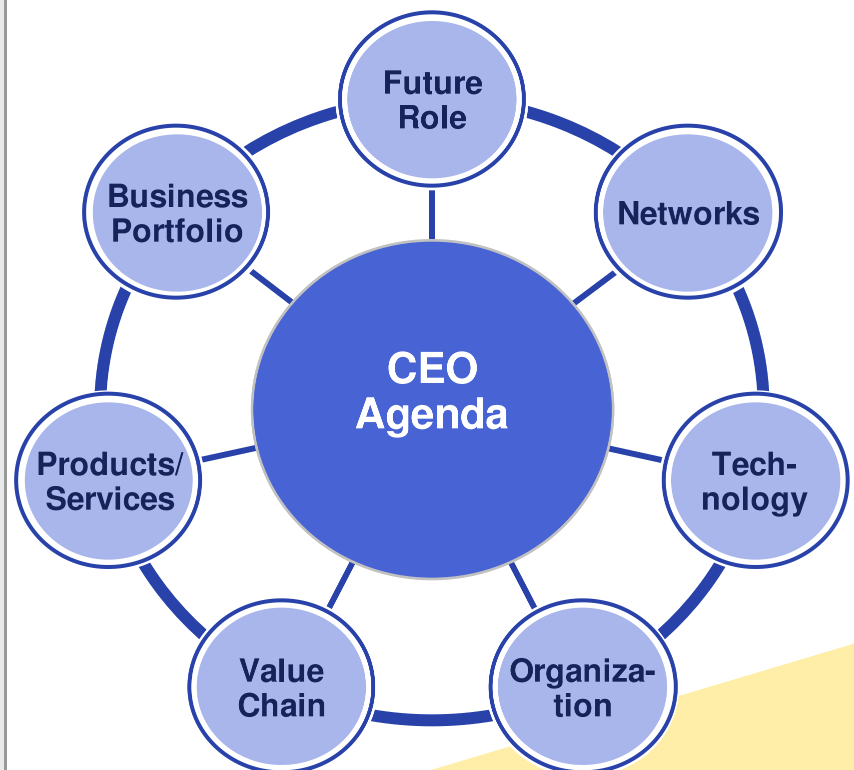
Source: ContiTemic, ADL Research

Agenda

Your Partner brings you both industry-specific and functional experience

Arthur D. Little GmbH

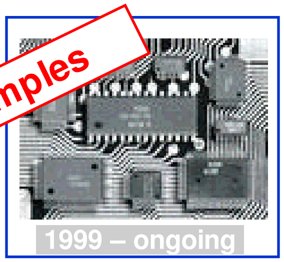
- Founded 1886
- Arthur D. Little provides a thorough consultancy service from strategy development through to action implementation
- Our teams work in a pragmatic and client-oriented manner at every project phase. Is is an advantage here that our consultants have pronounced industry and technological sector knowledge.
- We advise our clients inter alia from the automotive sector (OEMs and suppliers) and TIME industry (Telecommunications, Information, Media, Electronics) plus the machine tool and plant construction industries



Arthur D. Little – Thoughtleader in Innovating Business and Mastering Complexity

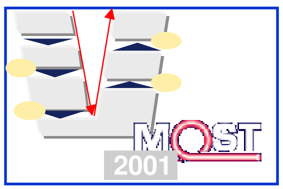
Arthur D. Little Projects in the field of Automotive Electronics and Software

Examples



Support of a leading German OEM in Process Redesign of E/E product development, logistics and service business. Realisation of Implementation Management of necessary **IT Systems** and Tools including restructuring the **Organisation** for more secure and hazard-free **Downloading of Software** in vehicles and increased efficiency of **Diagnoses**

For **one of the largest HGV vehicle manufacturers -** following initial situation definition - we provided support in the form of consultancy and action in implementation of a new strategy and organisation for development of installed electronics which also included associated services, technologies and supplier/partner relationships

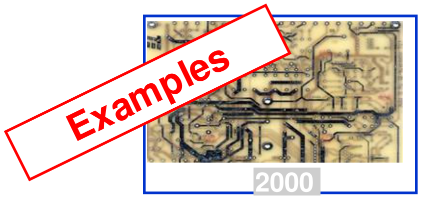


We carried out an **Audit** for Project Management, software architecture and technologies including software development processes of a leading **Telematics Supplier** on behalf of the OEM client

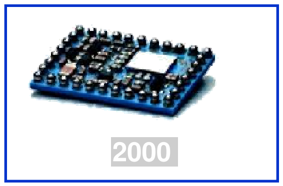
We collaborated in developing the most innovative car which the OEM has placed on the market in the last 2 years in the course of the **Telematics Systems Project and Supplier Management**

We cooperated in support of a global car and HGV manufacturer in defining and implementing a **common Electrics and Electronics platform** by focussing on the **Redesign of EE Development Processes** and setting up the **target cost processes and project organisation**

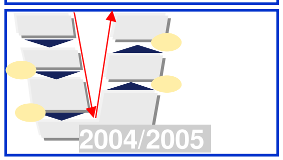
Arthur D. Little Projects in the field of Automotive Electronics and Software



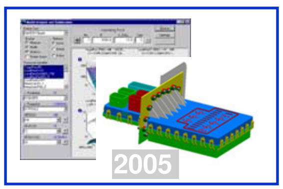
Strategy Development for leading **FPC** manufacturers: We support a leading German-Japanese Joint Venture for flexible and rigid-flexible PCBs in restructuring their market and production strategy in order to enable them to better serve their customers in the telecommunications and automobile industry



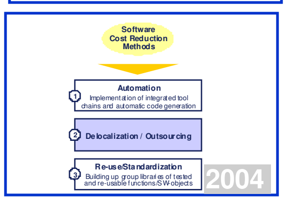
Strategic Study in the context of **42V Power Distribution** for a silicon manufacturer: We evaluated market trends (opportunities and risks) and had access to in-house competences (strengths and weaknesses compared to competitors) and developed a strategy in relation to the development of power electronics for the automotive sector ("Don´t go for 42V")



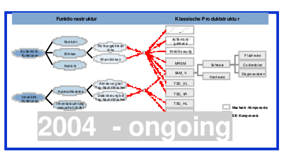
On behalf of an automotive OEM and a semiconductor manufacturer we carried out an audit of a subsidiary company active in the field of **Software and Software Tool Development for Vehicle Installed Systems**



We developed a strategy for additional competence building for electronics in the machine-tool branch of a supplier active in the field of **automotive power electronics** using analyses and evaluations of current market trends and associated opportunities



For a major Tier 1 player we assessed opportunities for raising efficiency in development of installed systems using **automation and delocalisation of software development in installed systems.**



For a leading OEM, we carried out a large-scale structural conversion programme embracing engineering, production and after-sales in order to optimise **E/E engineering, change management and release processes**.

Agenda

What problems confronted the participants in the study?

Extract

Topics Investigated in the Study

- Serious future changes in propulsion technology and vehicle safety and comfort systems militate in favour of the use of power electronics. What trends do you discern here??
- In what segments of the automotive sector and in what systems or subsystems are power electronics already used today?
- Where in the vehicle currently is there use of power electronics under environmentaly conditions involving high temperatures (>100°C) and/or high amperages (>100A)?
- How do youy assess the following 5 power electronics development avenues?

Miniaturisation Systems integration	**Assemblies/ (System level)**	**Elements/ (Component level)**	**Material level (Developmental foci)**	**Production technology**

- How will the power consumption in vehicle electrical systemts be in the future?
- What solutions are being developed to compensate for or counter increasing power consumption?
- What customer benefits and what differentiation options in relation to competitors do power electronics offer and which you use?
- How do you proceed with regard to market launch of power electronics systems?