Power Electronics for Automotive

ICT for Automotive Industry

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Contacts

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- Competences:
  - Smart Power IC
  - Power Management
  - System supply
  - Safety

About Infineon

Energy Efficiency | **Mobility** | **Security**

Automotive

Industrial Power Control

Power Management & Multimarket

Chip Card & Security

Agenda

- Automotive trends
- The CO2 revolution
- Power electronics main building blocks
- Automotive: harsh environment with lot of challenges
- Safety a “shall” requirement for Automotive

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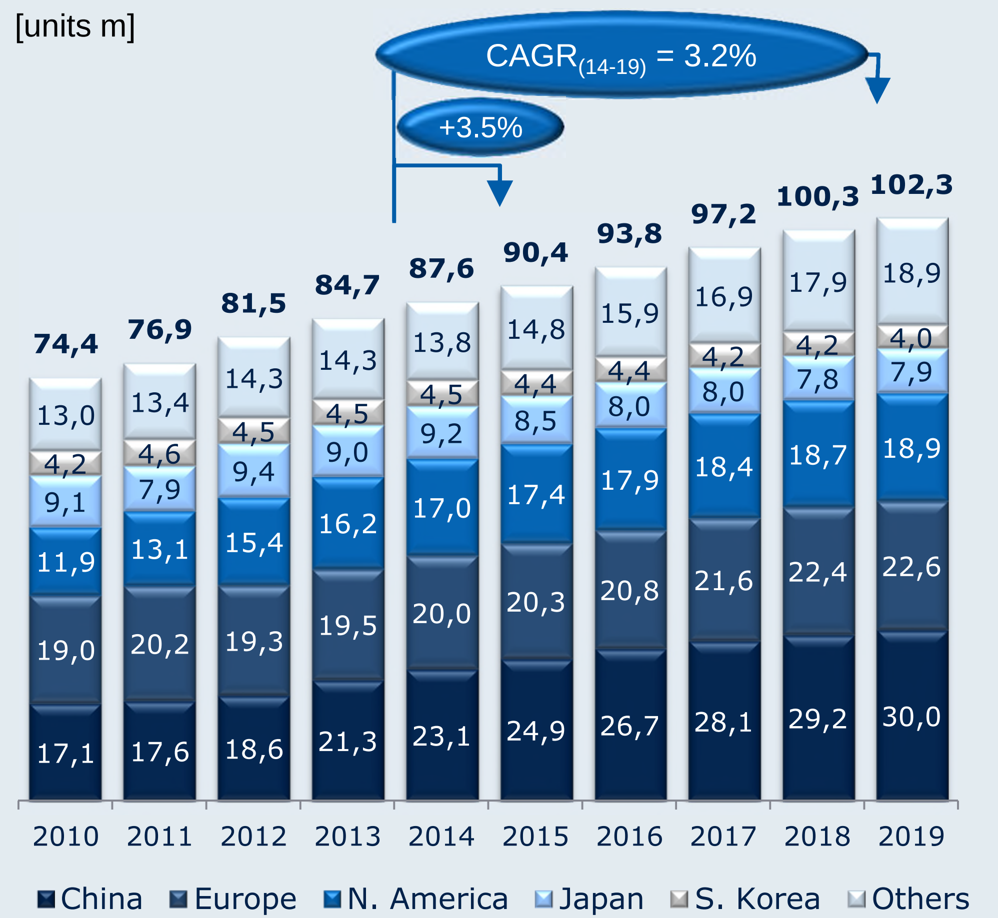
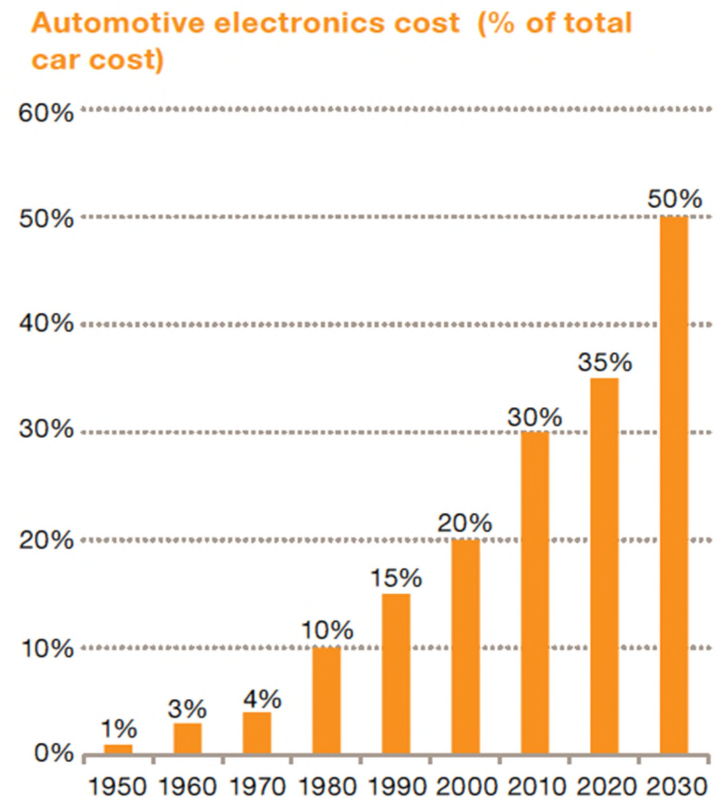
Car production and electronics content

Global car production (cars ≤ 6t)



CAGR$_{14-19}$	CAGR$_{14-19}$	CAGR$_{14-19}$	CAGR$_{14-19}$	CAGR$_{14-19}$	CAGR$_{14-19}$
5.3%	2.8%	1.6%	-3.0%	-1.5%	6.6%



Source: PwC analysis

Key Market Drivers

CO_2 Reduction

Communication

Safety

Affordable Car

 Courtesy Dr. Afons Graf

Segments & Applications

- **Powertrain**
  - Engine Management
  - Transmission
  - Starter/Alternator
  - Pumps
  - Cooling Fan

- **xEV**
  - Battery Management
  - Inverter
  - DC/DC
  - Charger

Segments & Applications

- Safety
  - Airbag
  - Electrical Power Steering
  - Braking/ESP/ABS
  - Active Suspension
  - Chassis Control
  - Domain Control
  - Tire Pressure Monitoring
  - ADAS Domain Control


Segments & Applications

- Body
  - Body Control Module
  - Gateway
  - HVAC
  - Power Distribution
  - Power Operated Systems
  - Lightning
  - Dashboard
  - Security Systems
- Infotainment
  - Car Audio
  - Navigation
  - Multimedia
  - Telematics/eCall

New Electronic Systems Drive Semiconductor Content in Cars

...

Electr
injecti
Electr
ignitio
Check
Speed
Centra
syster
Car ra
...

"They shouldn't allow humans to drive!"

C Stop&Go
C + Navigation
ht Vision
S I +II
GS
ernet Portal
ematics
ine services
etooth
office
al hazard
ning
egr. Safety
tems
ke-by-Wire
er-by-Wire
rive
l cell

e change assist
sonalization
-Update
ce Feedback
dal

1930 | 1970 | 1980 | 1990 | 2000 | 2010

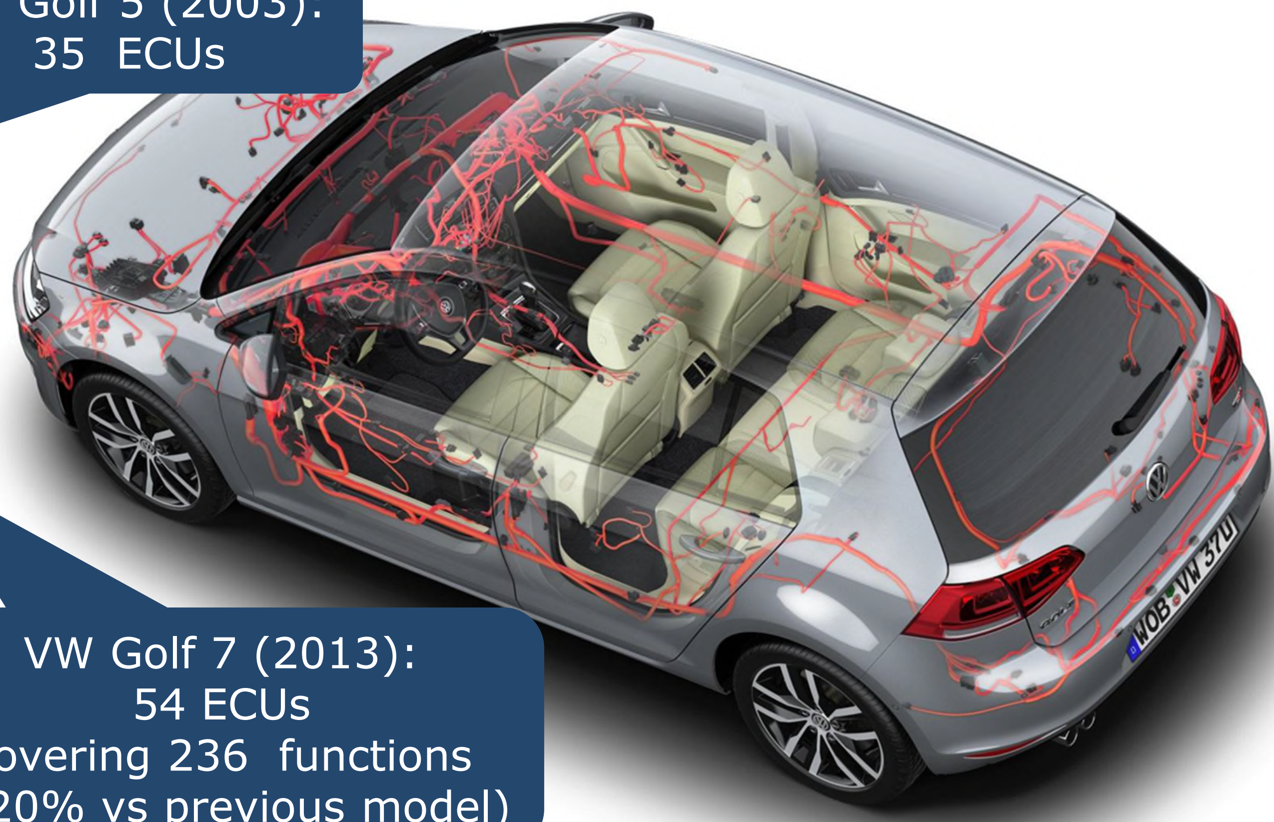
Electric/Electronic In Automotive

Evolution (compact car):

VW Golf 3 (1993): 8 ECUs

VW Golf 5 (2003): 35 ECUs

Mid range cars: 70-90 ECUs
High end cars: 100-120 ECUs



VW Golf 7 (2013): 54 ECUs covering 236 functions (+20% vs previous model)

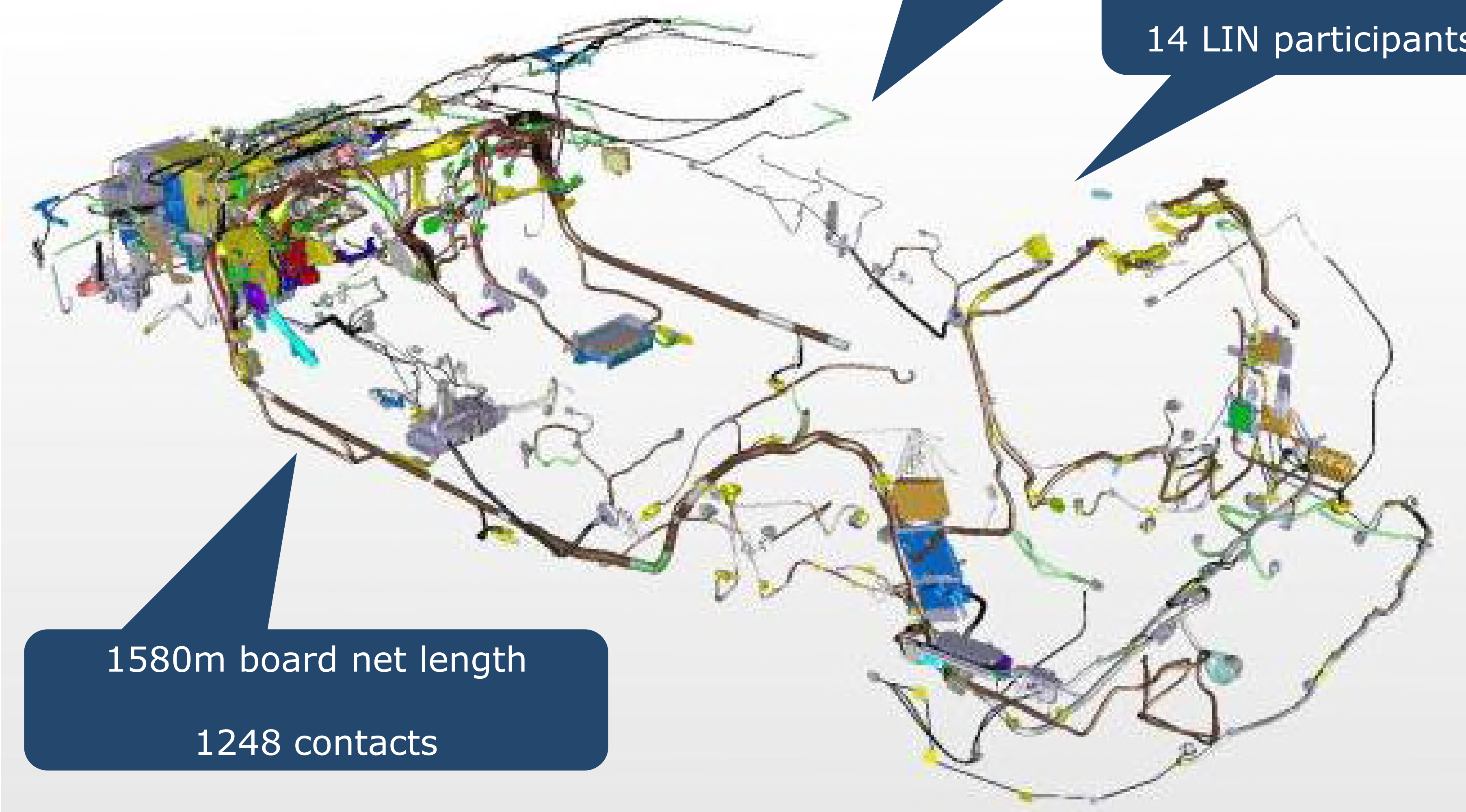
Electric/Electronic In Automotive

e.g. VW Golf 7 (2013)

20-30 electric motors/pumps

30 CAN notes

14 LIN participants



1580m board net length

1248 contacts

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- Safety a “shall” requirement for Automotive

Who prevents us from the CO_2 catastrophe

„Wie wär's mit Rudern, Kollege?"

Zeichnung: Tomicek

Cars Still Have Many **None** Demand-oriented Consumers

- **Reasons for none demand-oriented automotive systems**
  - History, mechanically driven, on-off control
  - Easy to realize, no electronic, no sensor
  - Oriented to minimum component cost
  - No direct customer value visible

What is new?

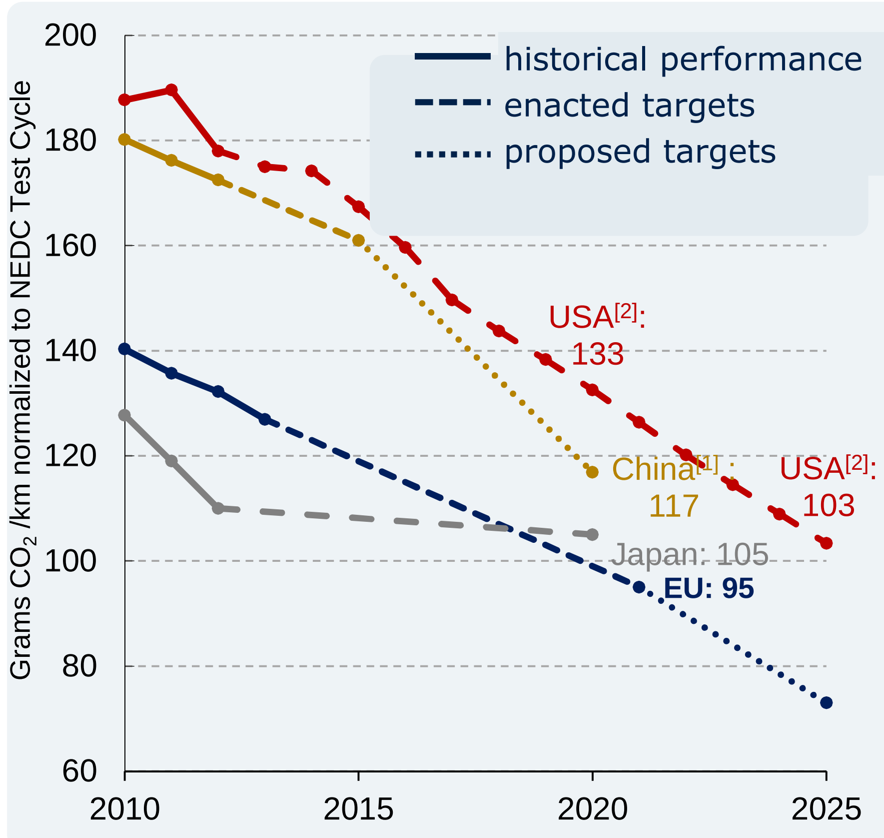
- **New assessment of value**
  - Political and social pressure to reduce CO_2 (fuel consumption)
  - Average fuel economy penalty for OEMs
  - High fuel price leads to payback
  - CO_2-based automotive tax leads to additional payback
  - Pressure also on none drive cycle relevant systems
    e.g. Climate Control (ADAC motorwelt 7/2007)

Global CO_2 Targets

EU Legislative Resolution
EU Parliament Dec. 17, 2008
Cars: 120 gCO_2/km beginning 2012
+10 g credit for biofuels, tires etc.....

CAFE & Clean Air Act: 35.5 mpg
NHTSA and EPA 2007-2010, Aug. 2012
2016 35.5mpg: Cars 39mpg, Trucks 30mpg
2025 54.5mpg: Cars 62mpg, Trucks 44mpg

Historical national fleet emissions performance and future targets



Source: The International Council for Clean Transportation

European Automotive CO_2 Targets

CO_2 target for average new car of manufacturer fleet:

2012 → 130 g CO_2/km for 65% of fleet
2013 → 130 g CO_2/km for 75% of fleet
2014 → 130 g CO_2/km for 80% of fleet
2015-2019 → 130 g CO_2/km for 100% of fleet

2020 → 95 g CO_2/km as proposal

CO_2 penalty payment for car manufacturer (per new car)**:**

5 €	**for**	**<1 g CO_2/km over target**
15 €	**for**	**<2 g CO_2/km over target**
25 €	**for**	**<3 g CO_2/km over target**
95 €	**for**	**≥4 g CO_2/km over target**

Example: penalty for 134.1 gCO_2/km = 5 + 15 + 25 + 2×95 € = 235 € per new car

Source: European Parliament Legislative Resolution, December 17, 2008

 Courtesy Dr. Afons Graf

The Cost of CO_2 over 10 Years
1 gCO_2/km ⇔ 225 €

90€

Fuel consumption
(1.40 €/ℓ, 15000 km/y)

1 g CO_2/km ⇔ 8.90 €/y

20€

CO_2 Car taxation
(depends on the country, see graph)

1 g CO_2/km ⇔ 1.5 to 3 €/y

20€

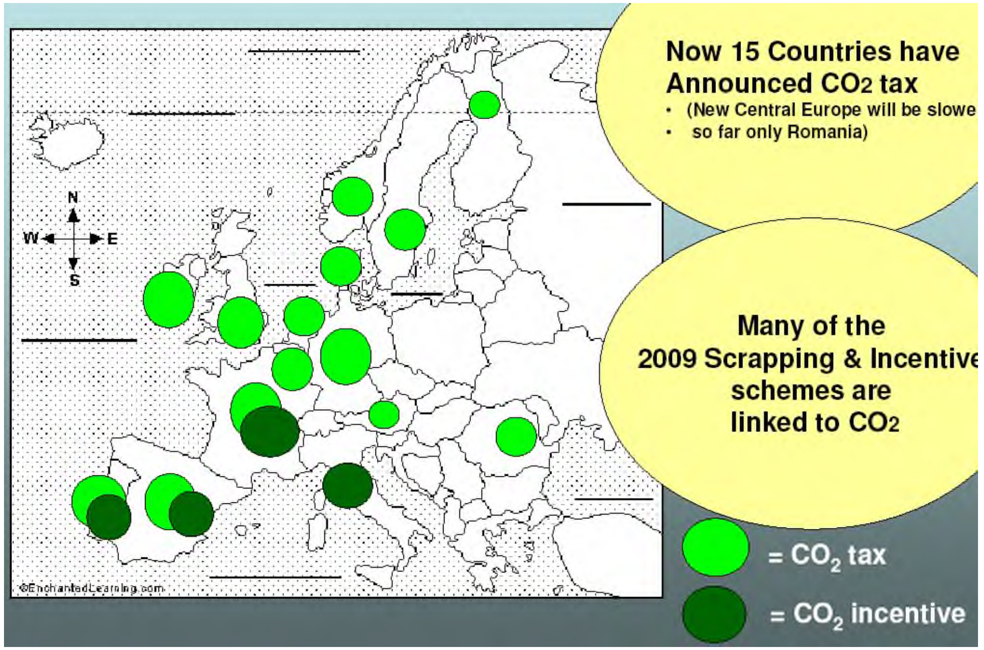
Car reputation
(5% discount, 1000 €, for 50 gCO_2/km)

1 g CO_2/km ⇔ 20 €/car

95€

Car manufacturer penalty
(EU Resolution December 2008, 120 gCO_2/km)

1 g CO_2/km ⇔ 5-95 €/car



Source: Global Insight, Munich June 9, 2009

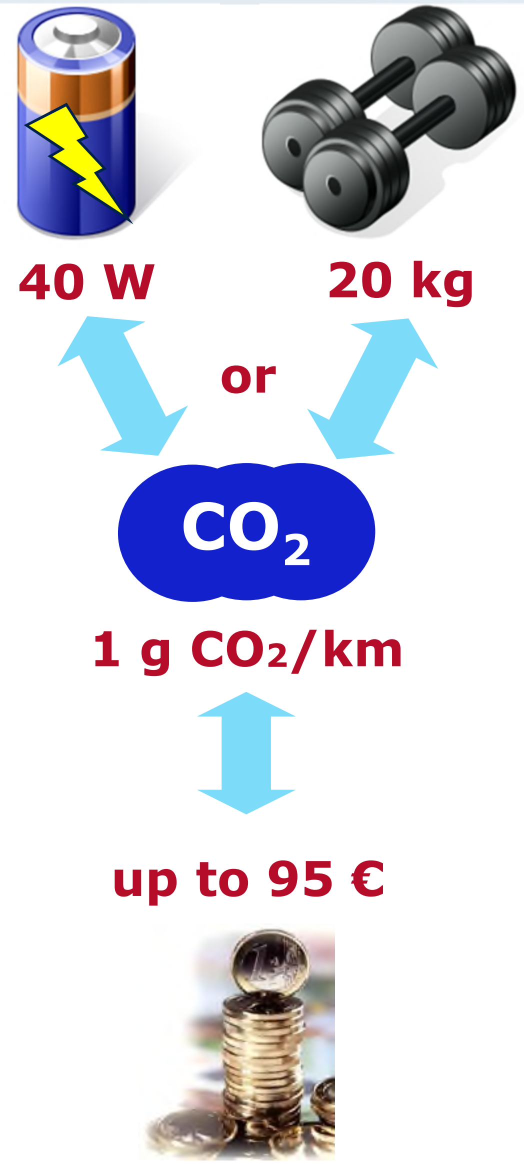
Efficiency and Losses are Equivalent to CO_2 Impacts of Electrical Power & Weight

100 W electricity	⇔	**0.1 ℓ/100km**
50 kg	⇔	**0.1 ℓ/100km**

1 ℓ/100km Gasoline	⇔	**23.6 g CO_2/km**
1 ℓ/100km Diesel	⇔	**26.5 g CO_2/km**

1 g CO_2/km	⇔	**40 W electricity**
1 g CO_2/km	⇔	**20 kg**

1 g CO_2/km	⇔	**5-95 € penalty**



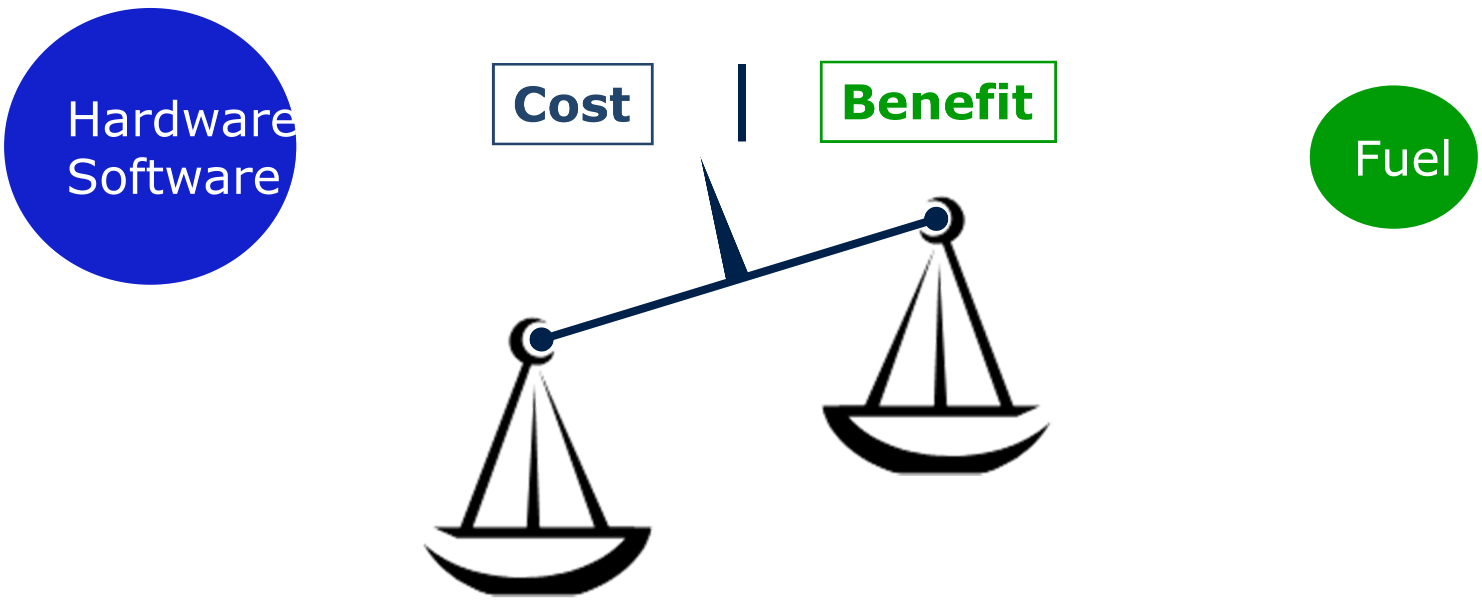
Source: VDI-Tagung Elektronik im Kfz, Baden-Baden 2007

 Courtesy Dr. Afons Graf

CO_2-Emission
Changing of Cost-Benefit Situation

Cost-Benefit-Balance

In the Past

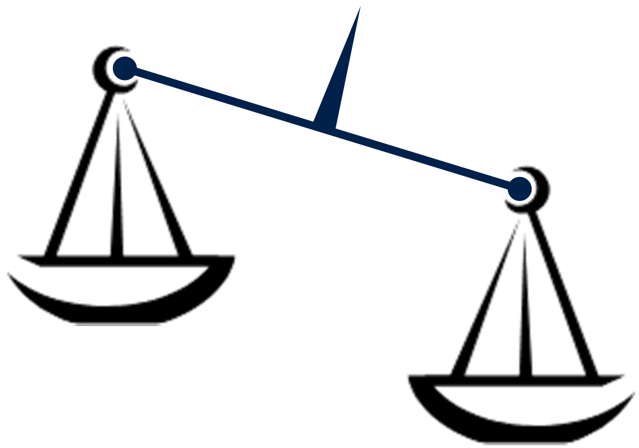


Cost-Benefit-Balance

In the Future

Hardware
Software

Cost | **Benefit**



Tax

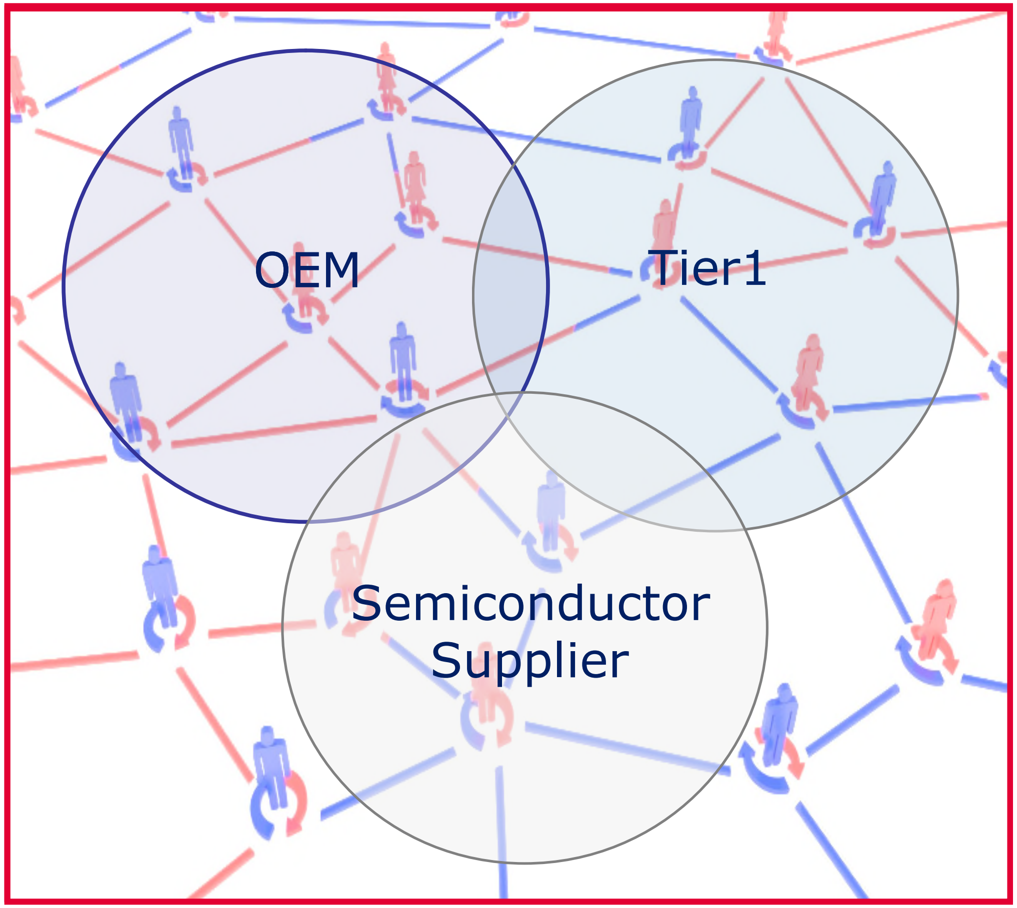
Fuel

Penalty

Repu-
tation

40 W (electrical) ⇔ 1 gCO_2/km ⇔ <95 €

Only an Integrated Approach can Successfully meet the Challenges of Tomorrow



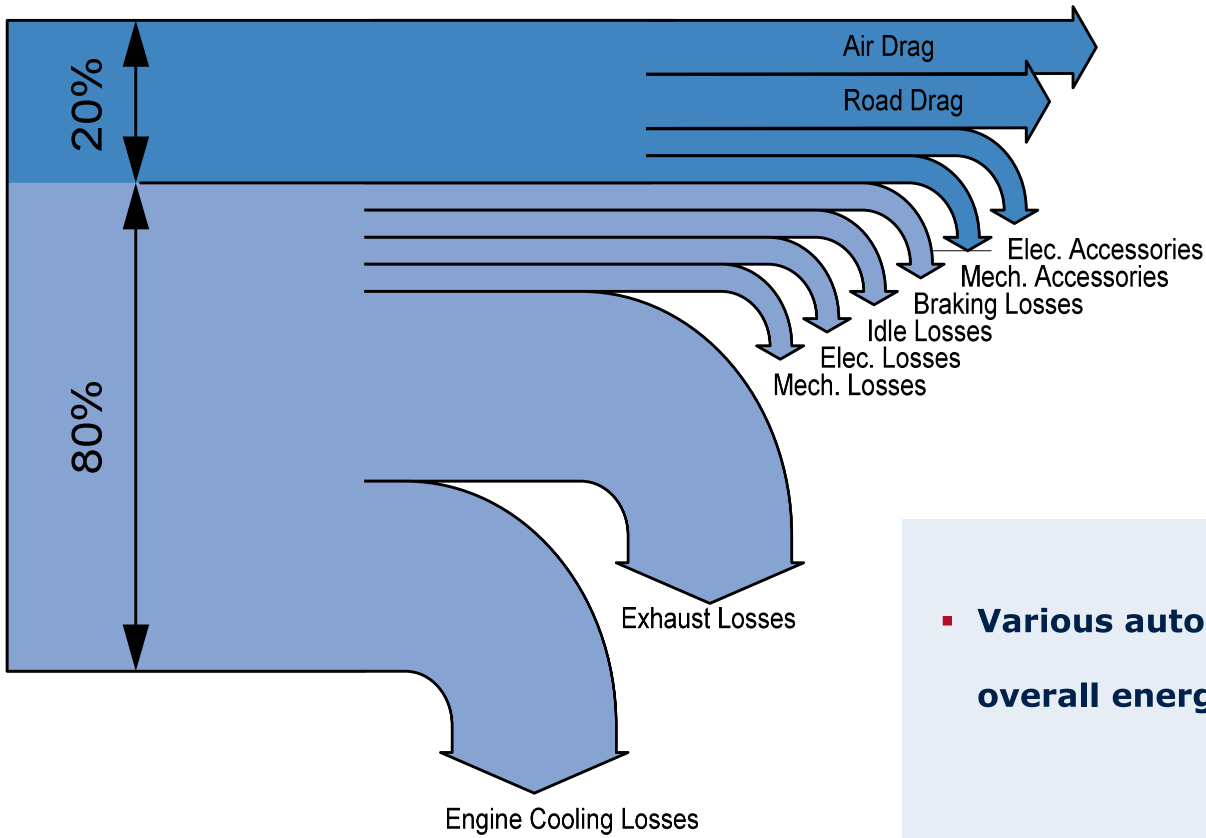
Parallel and joint structure instead of sequential approach

Networks, strategic and development partnerships with longterm horizon are key to success

Suppliers will become true system partners

 Courtesy Dr. Afons Graf

Energy Efficiency has many Facets



- **Various automotive areas contribute to the overall energy consumption**
- **Energy Efficiency will be improved in many small steps, mainly driven by electronics**

Emission Reduction can be Achieved by Optimizing Different Areas in the Car

Engine

Gasoline Engine

30% CO_2 reduction

Diesel Engine

10% CO_2 reduction

Air Drag

Radiator air flaps

2% CO_2 reduction

Friction

Tire rolling resistance

1% CO_2 reduction

Transmission

MT Shift point assistance

2% CO_2 reduction

High efficient AMT or DCT

2% CO_2 reduction

Hybridization

Stop/Start

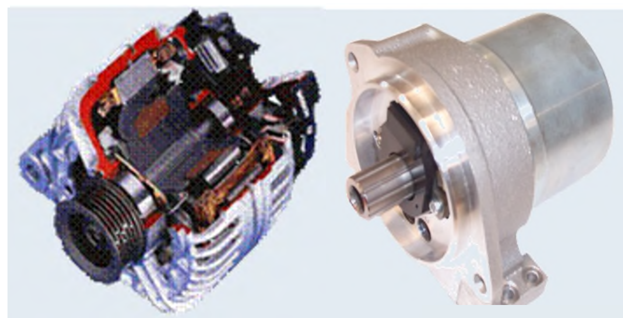
3% CO_2 reduction

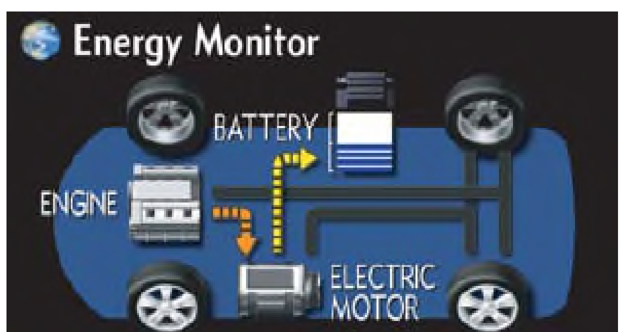
Mild Hybrid

20% CO_2 reduction

Full Hybrid

30% CO_2 reduction





Energy management
Energy efficiency
Energy on demand

1.0% CO_2 Lightning

1.0% CO_2 Infotainment

3.0% CO_2 EPS

1.0% CO_2 HVAC

1.0% CO_2 Fuel pump

3.0% CO_2 Water pump

6.0% CO_2 High Efficiency Generator

16% CO_2 reduction

 Courtesy Dr. Afons Graf

Example 1: improve engine

Engine

Gasoline Engine

30% CO_2 reduction

Diesel Engine

10% CO_2 reduction

- Electronics impact on control/sensing/actuation of the ICE
  - Injectors control
  - Valve control
- Combustion chamber pressure will bring even more advantage

Example 2: electrification of engine accessories

Energy management
Energy efficiency
Energy on demand

- 1.0% CO_2 Lightning
- 1.0% CO_2 Infotainment
- 3.0% CO_2 EPS
- 1.0% CO_2 HVAC
- 1.0% CO_2 Fuel pump
- 3.0% CO_2 Water pump
- 6.0% CO_2 High Efficiency Generator

16% CO_2 reduction

CO_2 reduction through motor electrification

Water pump (cooling)

Saves ~4g CO_2/km

Vacuum pump (braking)

Saves ~1.5g CO_2/km

Source: Infineon estimates

Example 3: Tire pressure monitoring system

Air Drag

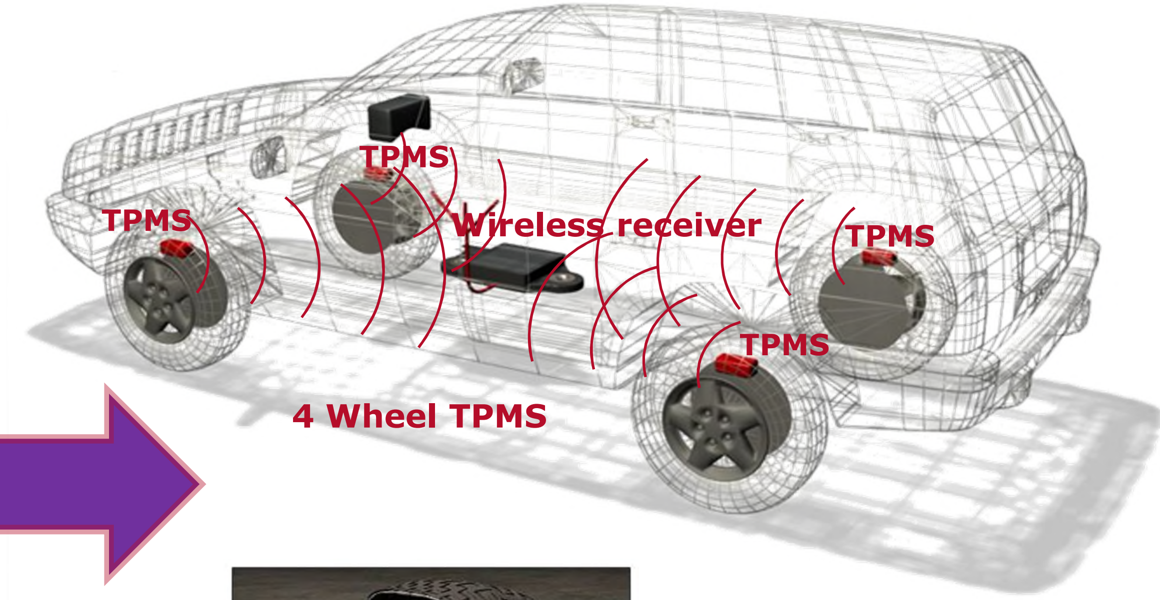
Radiator air flaps

2% CO_2 reduction

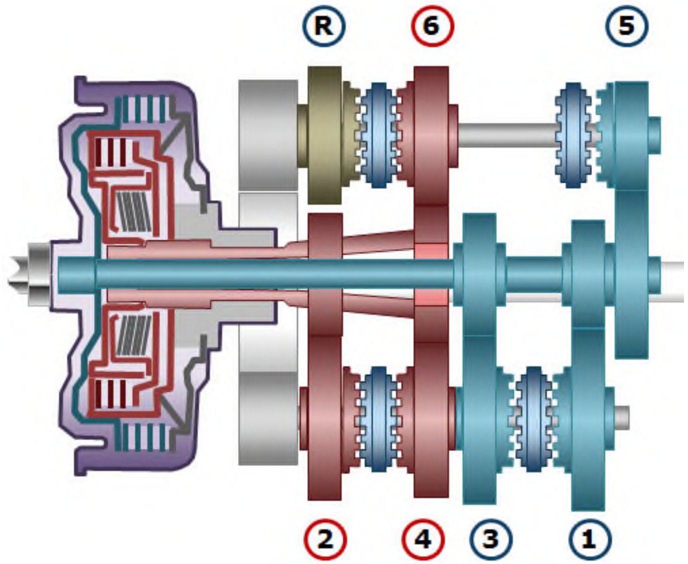
Friction

Tire rolling resistance

1% CO_2 reduction



Example 4: Dual clutch control



Transmission

MT Shift point assistance

2% CO_2 reduction

High efficient AMT or DCT

2% CO_2 reduction

Penetration rate in EU: 2020 28% 2010 5%

CO_2 savings: 4 g/km.

Example 5: Hybrid solution

Hybridization

Stop/Start

3% CO_2 reduction

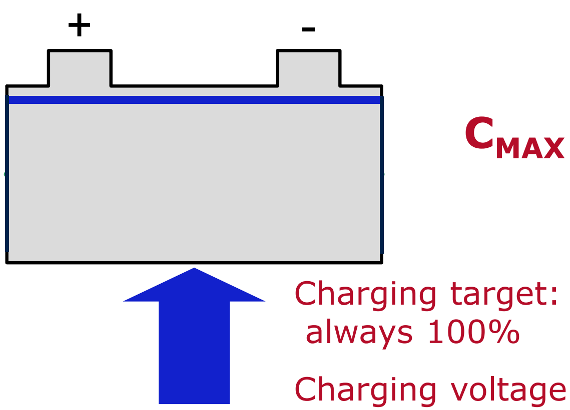
Mild Hybrid

20% CO_2 reduction

Full Hybrid

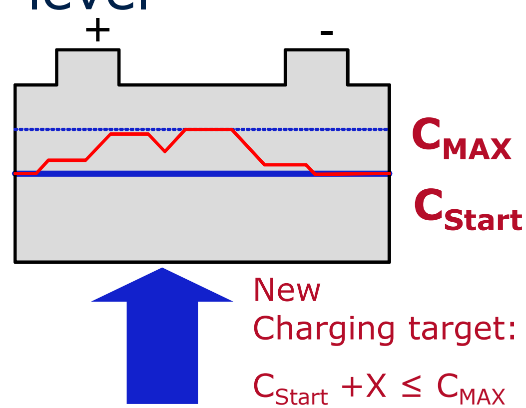
30% CO_2 reduction

- uC → Start and Stop + small braking energy recovery
- Mild hybrid → support electric motor + additional medium voltage battery network (48V)
- Full hybrid → electric motor capable to substitute the ICE and a smart engine management is done at higher level



Charging target: always 100%

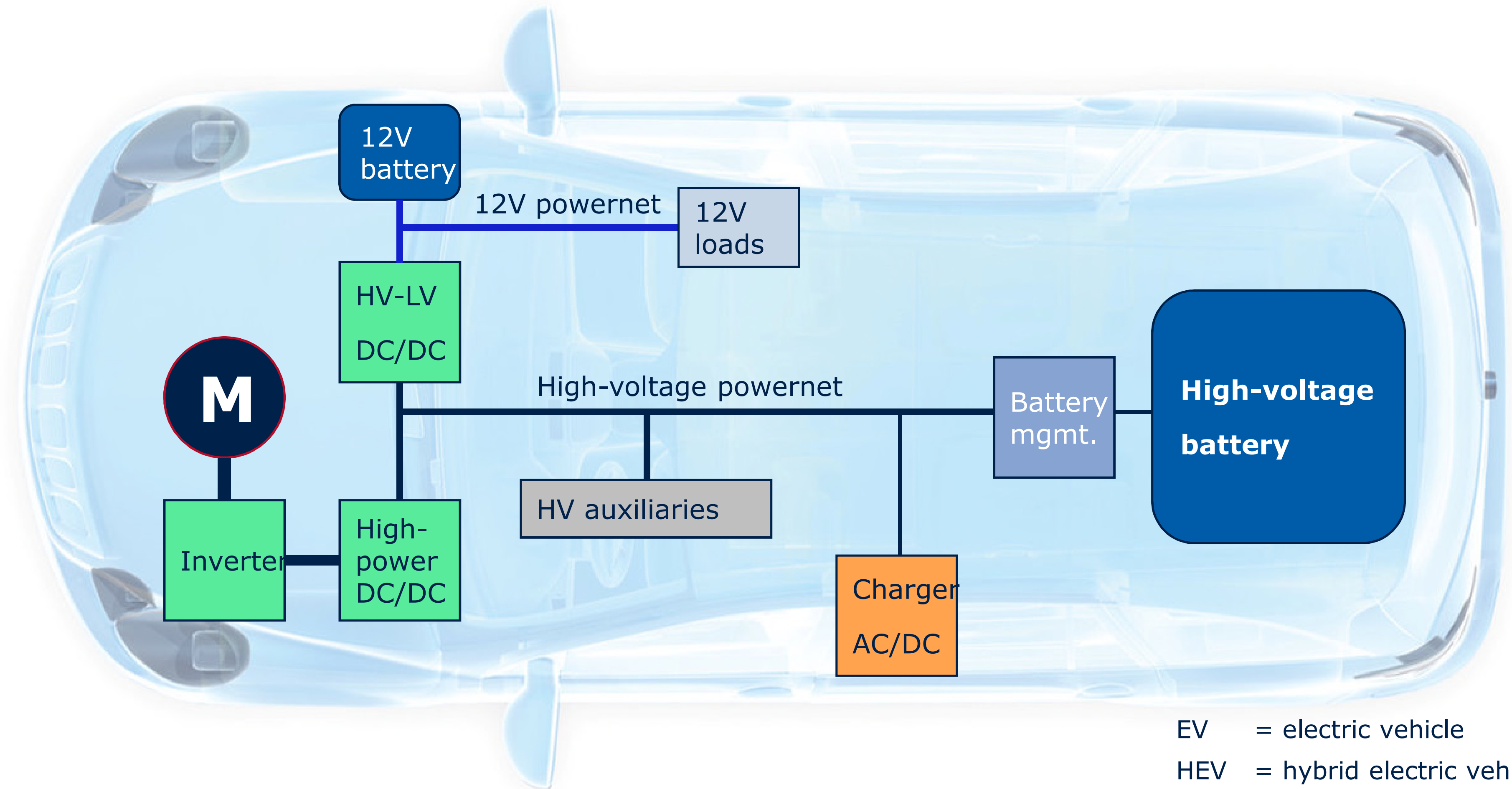
Charging voltage: Vset = f (Temp)



New Charging target:

$C_{Start} + X \leq C_{MAX}$

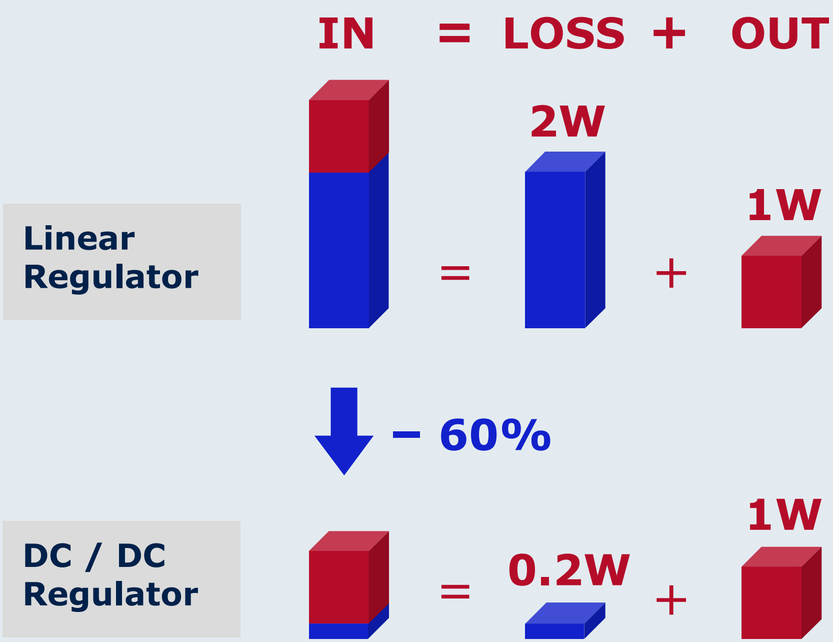
EV Architecture → the CO2 emission killer



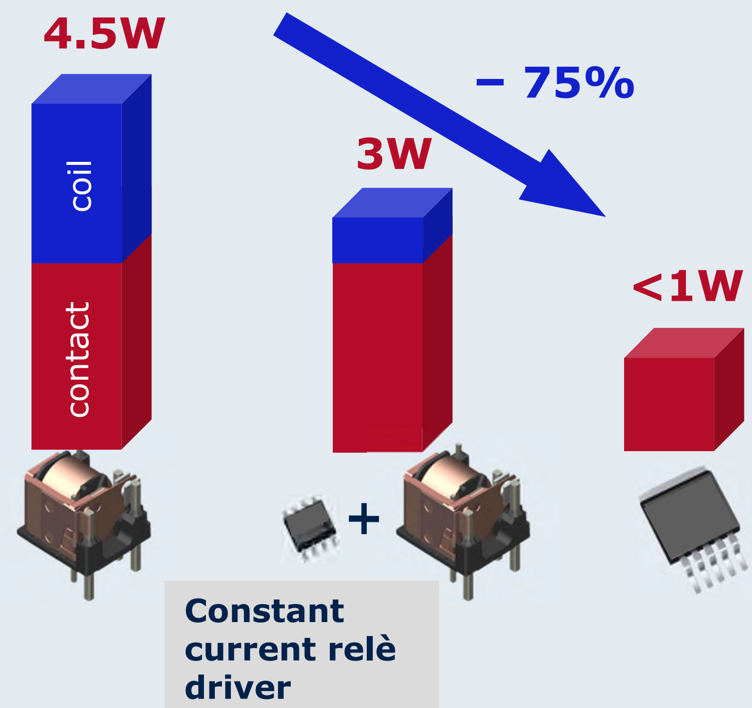
EV = electric vehicle
HEV = hybrid electric vehicle
HV = high voltage
LV = low voltage
AC = alternating current
DC = direct current

Almost all ECU can be improve in term of efficiency

Voltage Supply Efficiency
e.g. 5V, 200mA
60% lower input power



Power Switching Efficiency
e.g. 14V, 20A
75% lower switching losses



Efficiency Improvement with Reduced Current Consumption, especially in Driving-Mode

Source: http://images.google.de

IGN off – Car in Sleep/Park Mode

- Target: Sleep mode current <100 µA per ECU
- No Bus traffic, Wakeup events possible
  - Remote Keyless Entry
  - Inquiry of Switch Panels

Total Car Current Consumption:

~ 5..20 mA

Source:Infineon AG

IGN on – Car runs

- Target Parameter Performance / Functionality
- Current Consumption – Not Yet a Constraint
- ECU Power Supplies with Losses
- Permanent Network Traffic

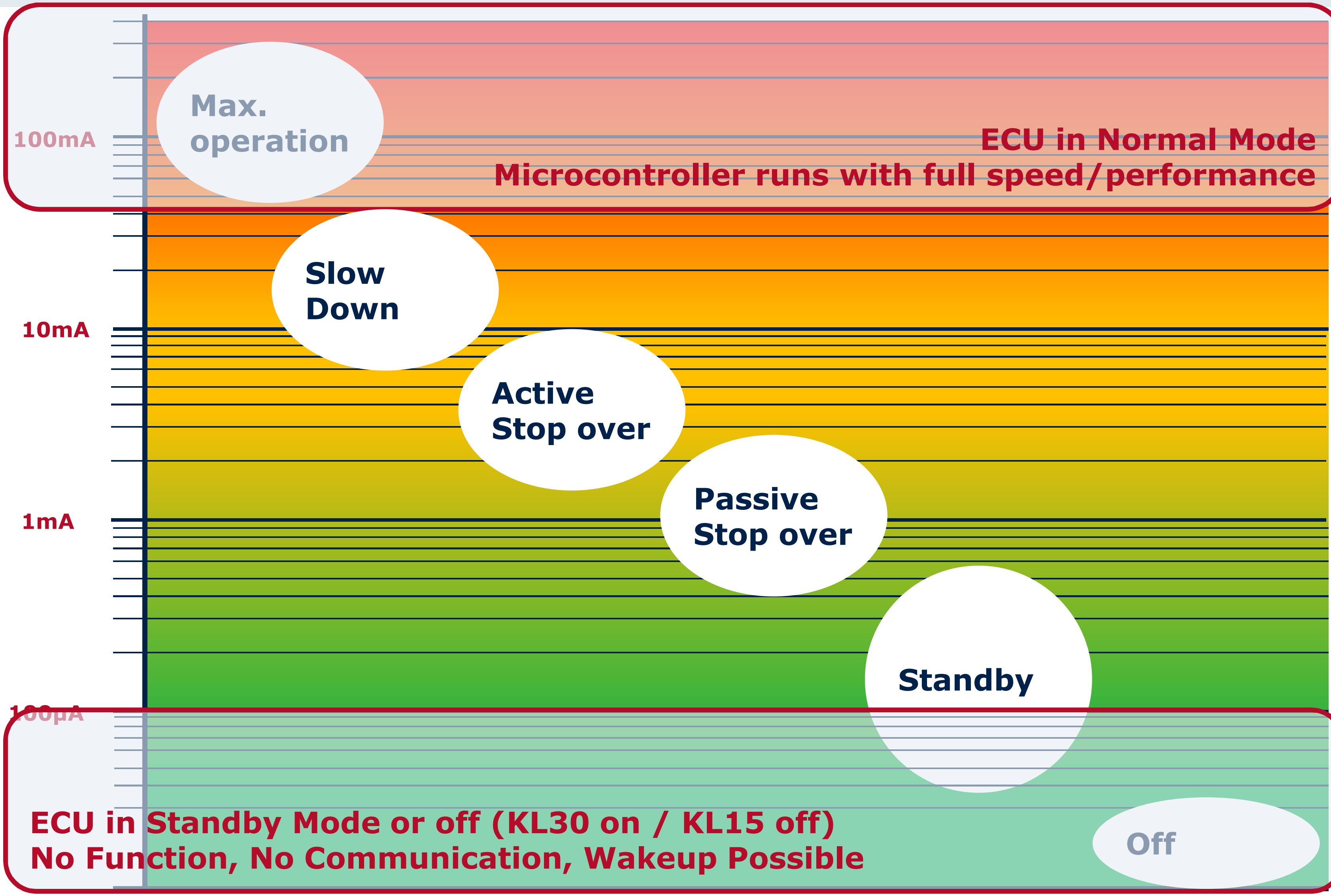
Total Car Current Consumption:

~ > 10 Amps
(without any loads)

How To Enhance Vehicle Efficiency when Car Drives

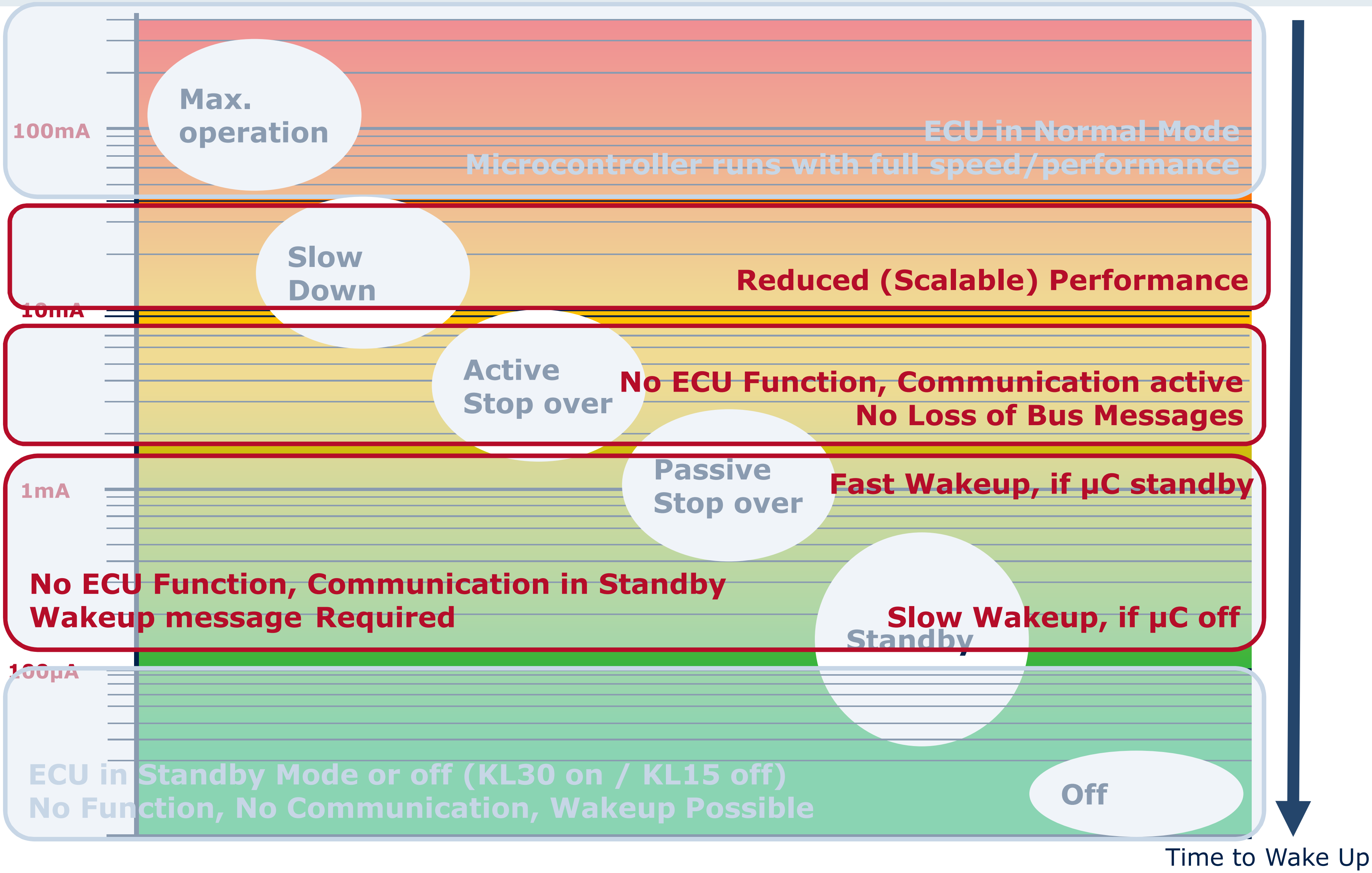
Improved Consumers	DC/DC Voltage Regulators, Relay Replacement
Partial Node Deactivation	Complete Deactivation of unused ECU's
Scalable Functionality	Dynamical Adaptation of ECU Performance

Current Operating Modes
No Current Saving while Car is Running



 Courtesy Dr. Afons Graf

New Operating Modes
Reducing Energy Consumption



 Courtesy Dr. Afons Graf

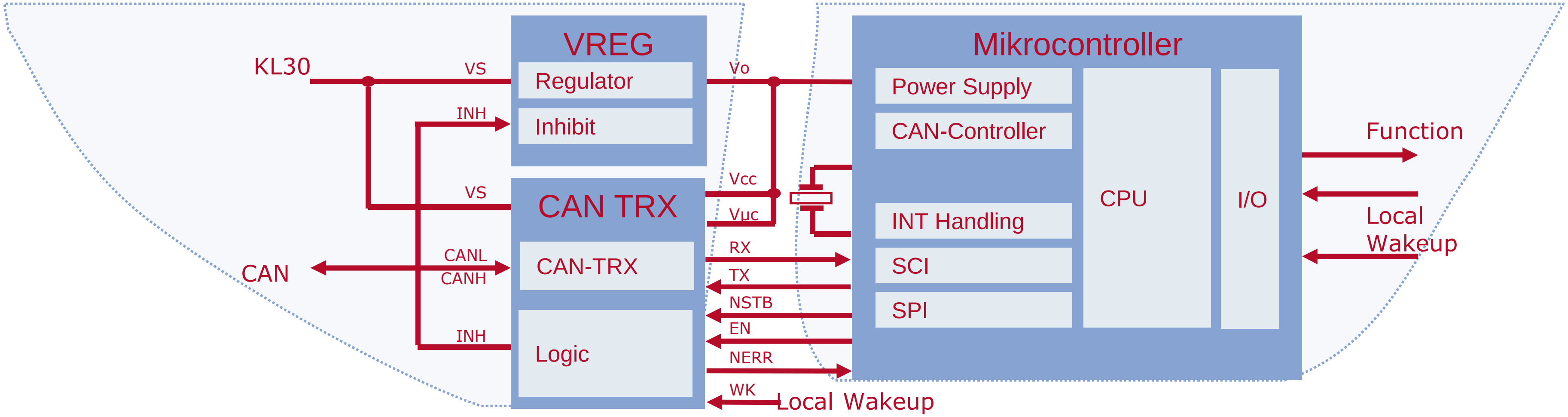
Energy Efficient Automotive Networks
Ways to Save Energy

Partial Node Deactivation

- *Partial Network Operation*
  - OEM HW Initiative “SWITCH”
- *AUTOSAR Concept Group CGEEM*
  - Concept Proposal “Partial Network Operation”
  - Accepted by AUTOSAR Core Members
  - Intended for AUTOSAR Rel. 4.1
  - In Discussion for AUTOSAR Rel. 3.2

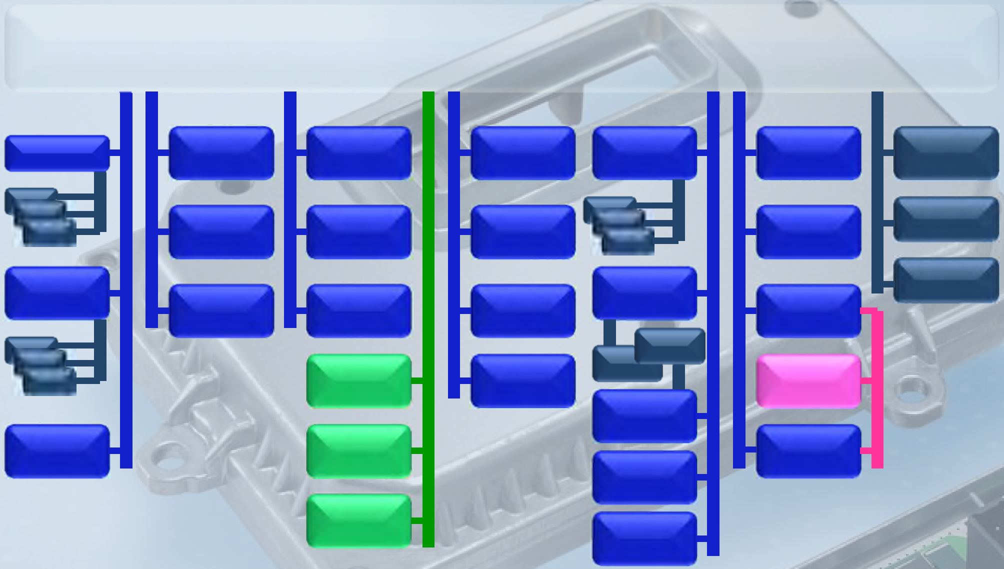
Scalable Functionality

- *AUTOSAR Concept Group CGEEM* (Concept Group Energy Efficiency Management)
  - Concept Proposal “Pretended Networking”
  - Concept Proposal “ECU Degradation”
  - Accepted by AUTOSAR Core Members
  - Intended for AUTOSAR Rel. 4.1



 Courtesy Dr. Afons Graf

Example Calculation / Use Case Analysis Starting Point

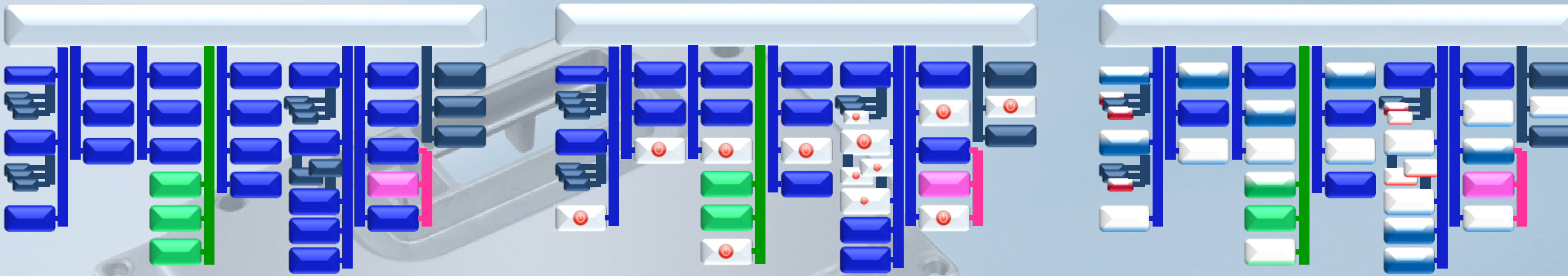


Total Current Consumption E/E Network

Starting Point:

- Number of Network Nodes 40
- Average Current Consumption per node (without loads) 200 mA

Example Calculation / Use Case Analysis
Total Current Consumption

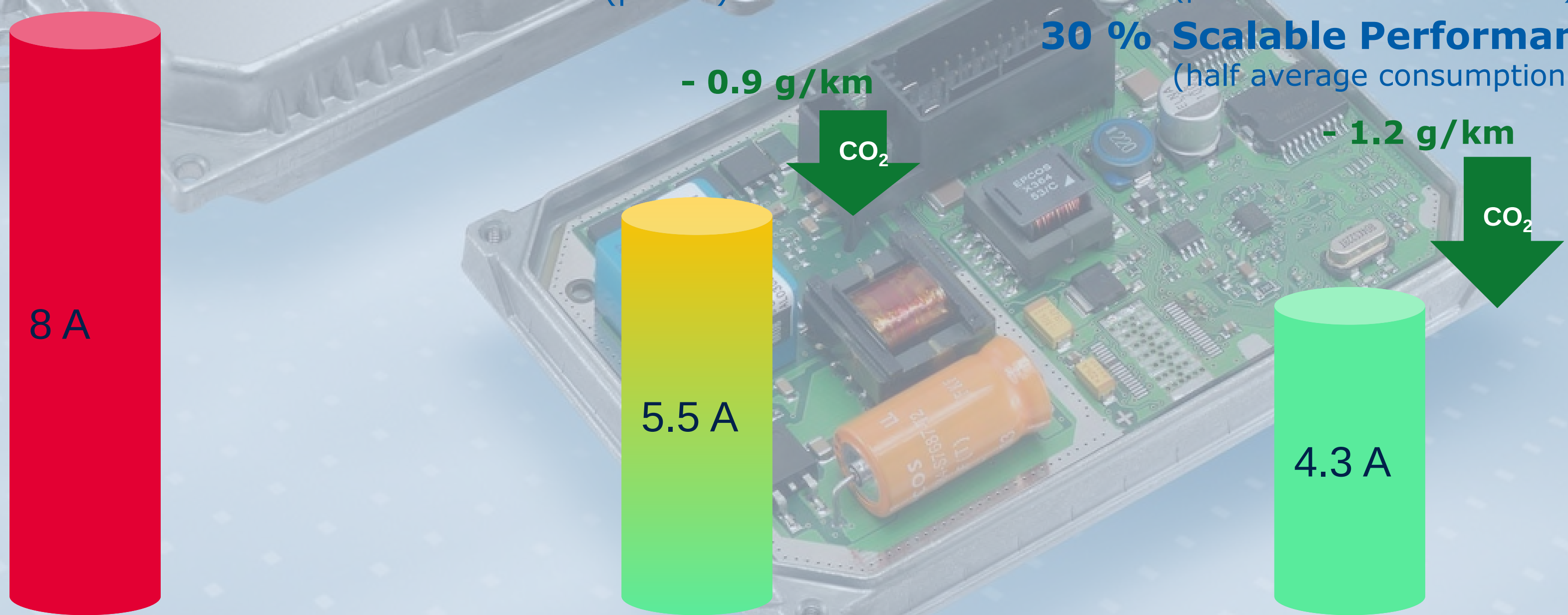


Status Quo
All ECUs run w/ full performance

30 % ECU capable of Partial Network
(µC off)

30 % ECU capable of Pretended Network
(µC in STOP or IDLE mode)

30 % Scalable Performance
(half average consumption)



Assumptions: Network with 40 ECUs. Average current consumption per ECU is 200mA. ECUs with scalable performance save 50 % (half of the average current consumption). Partial Network Mode: Capable ECUs remain 95% of the run time in partial network mode with a current consumption of 1mA (µC off) respectively 10mA (µC in STOP or IDLE).

 Courtesy Dr. Afons Graf

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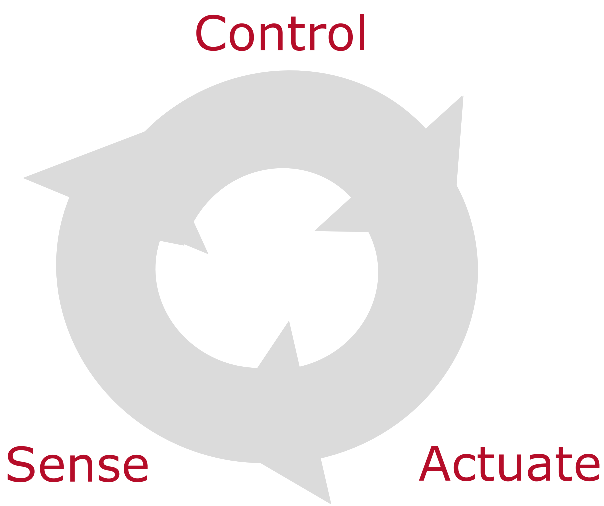
- Automotive: harsh environment with lot of challenges
- Safety a “shall” requirement for Automotive

Power electronics

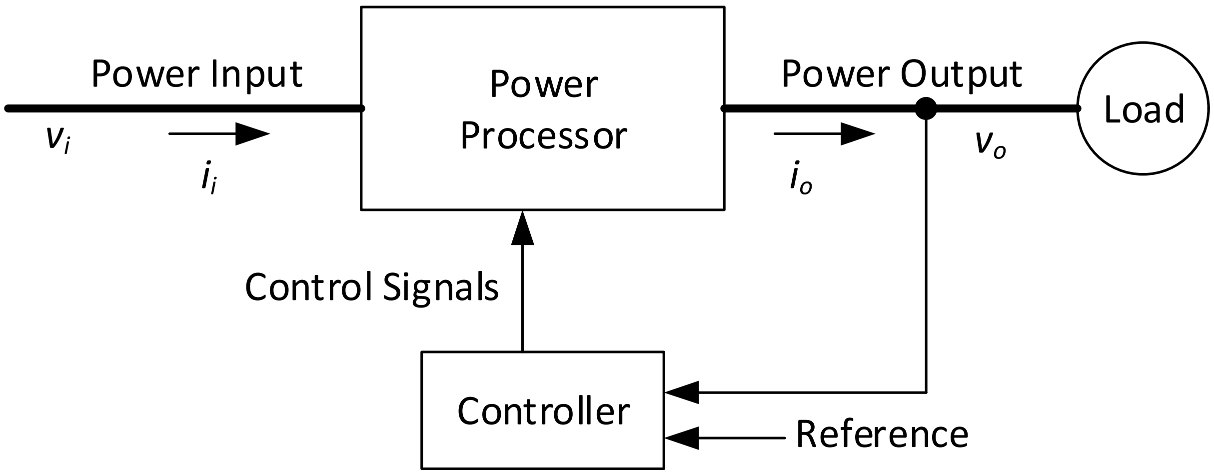
The power electronics focus is:

Control and process electrical energy efficiently



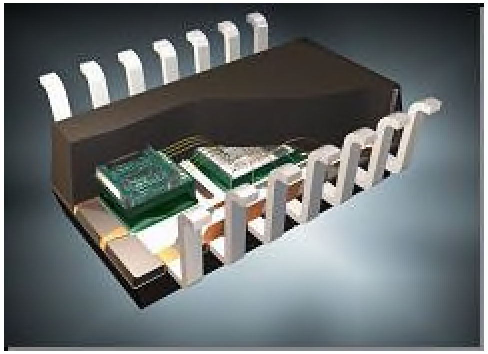
Efficiency is the good parameter to measure performances of the converter

$$\eta = \frac{P_{out}}{P_{in}}$$

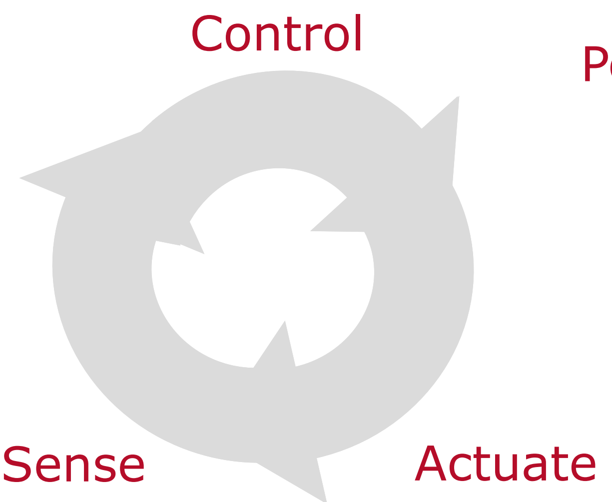


Power electronics for automotive

Silicon Sensors



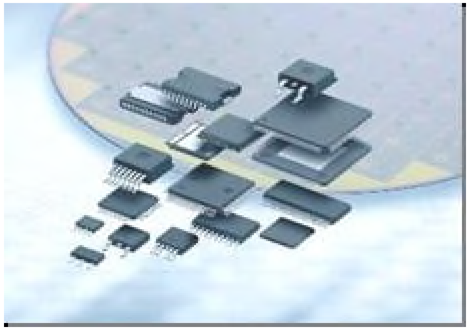
Special processes
High Precision
Robustness



Microcontrollers

High frequency
High complexity
Big flash size

Power Semiconductor



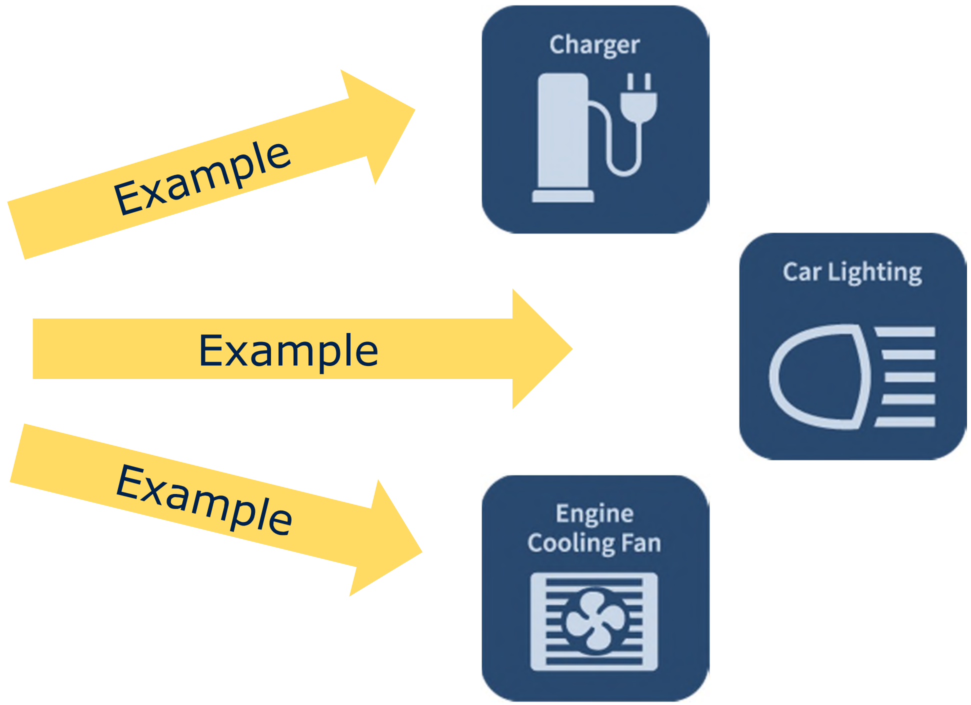
High current
High voltage
High temperatures

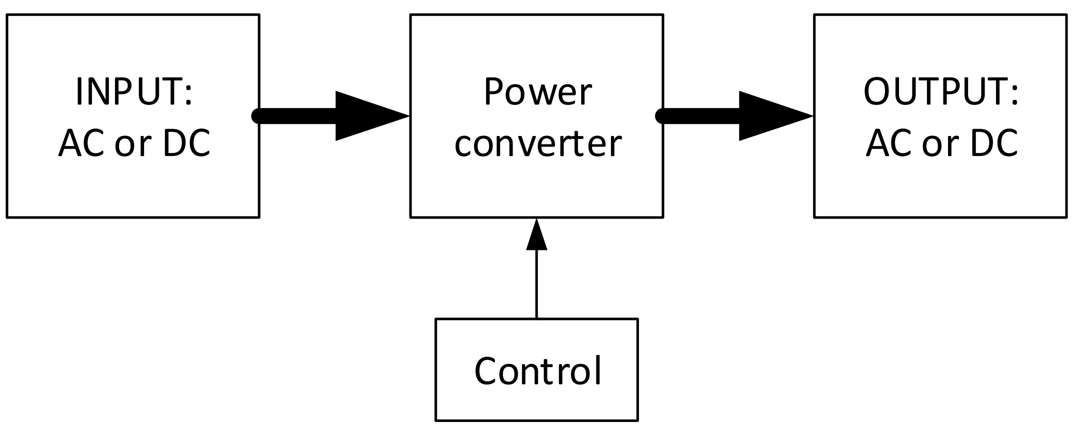
Smart Sensors

Smart Power

Major power converters in Automotive

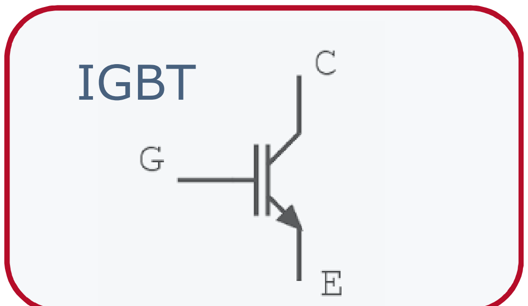
- AC-DC (rectifier)
- DC-DC
- DC-AC (inverter)

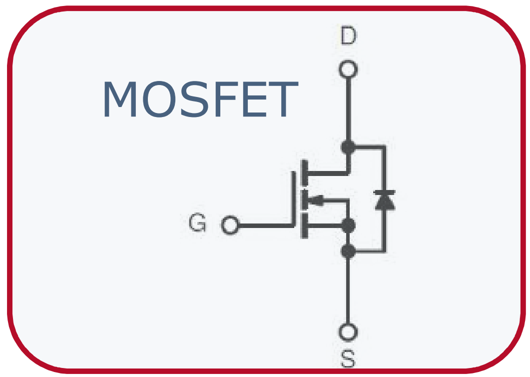


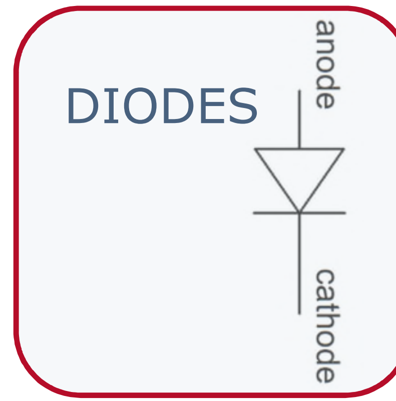


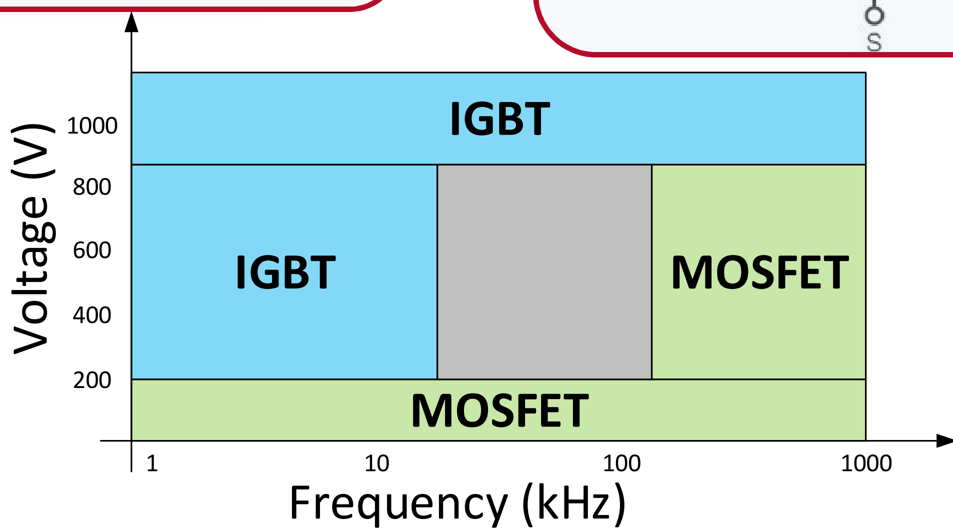
Key building blocks: power semiconductors

- The key element to build an efficient power converter is the **switch**
- The most used switches in automotive are



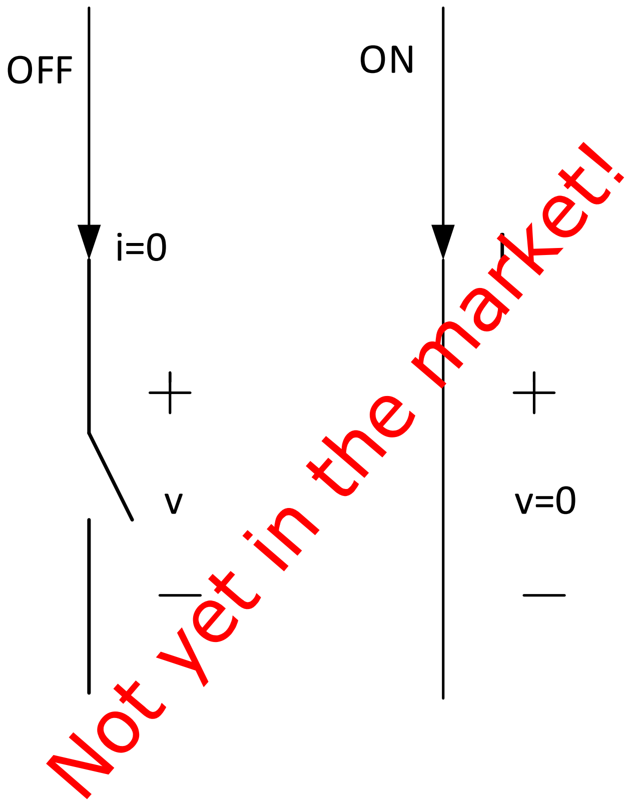




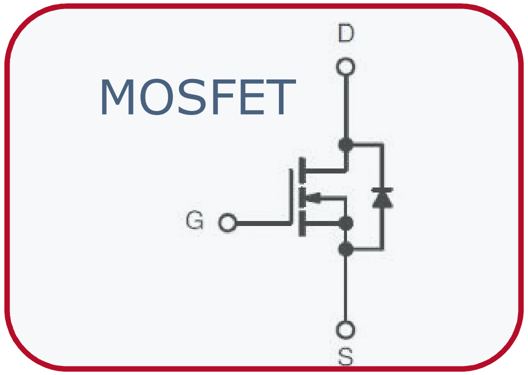


The ideal switch

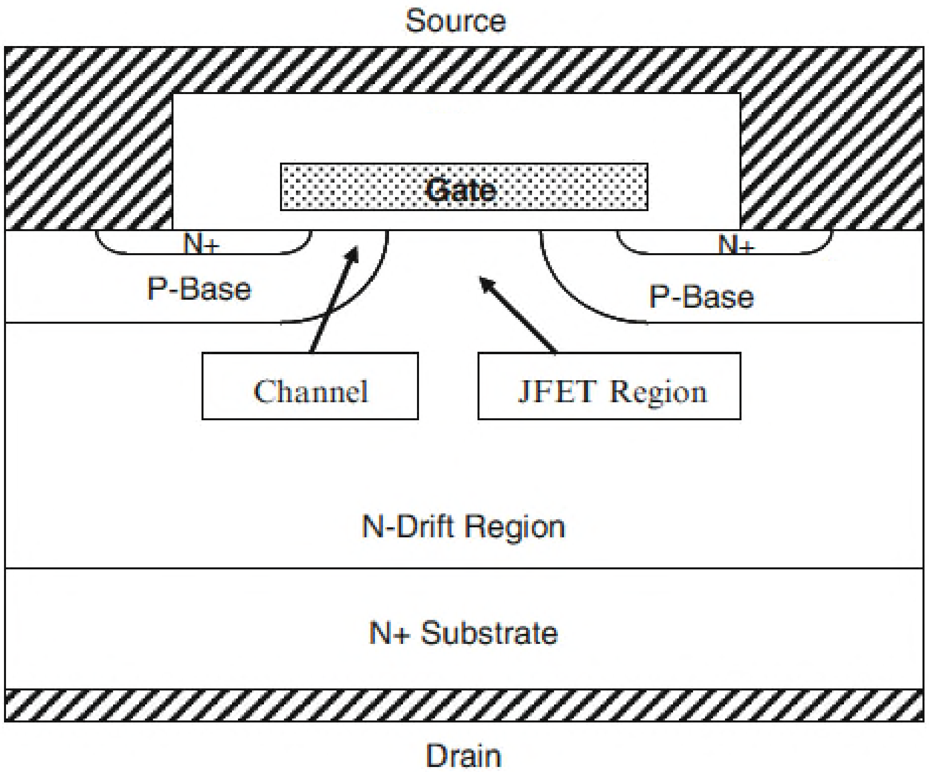
- Ideally the switch
  - Has no losses
  - Can sustain every voltages in off state
  - Is easy control
  - Has no driving losses



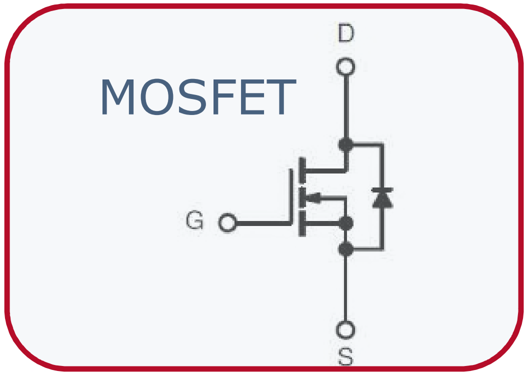
Power MOSFET → DMOS



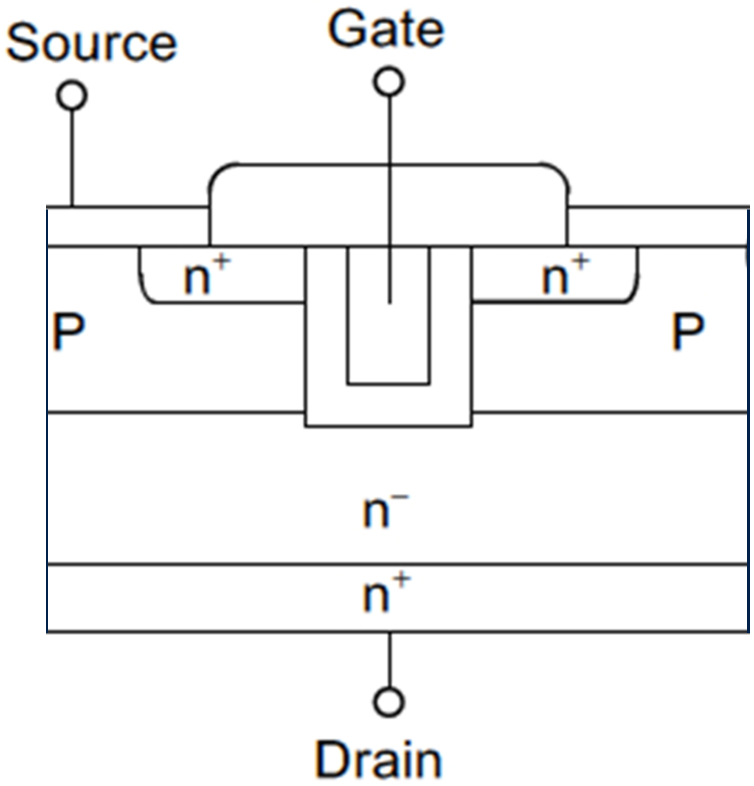
- First big step in the power MOSFET was the DMOS (Double diffusion MOS)
  - Better Ron (due to lower channel length) with respect to classical MOSFET structure
  - Fast switching



Power MOSFET → trench DMOS

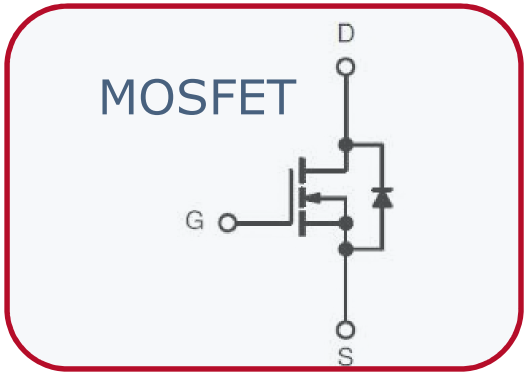


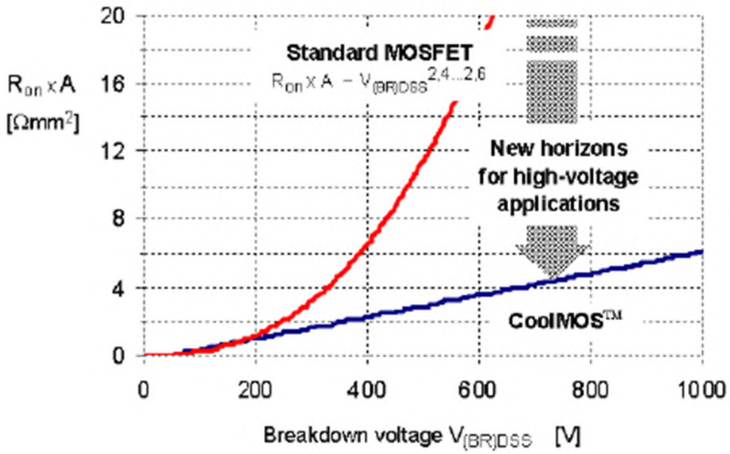
- Second big step is due to the introduction of trench concept
  - Removal of Jfet resistor and full vertical structure results in a reduced Ron
  - Higher density of channel per silicon unit

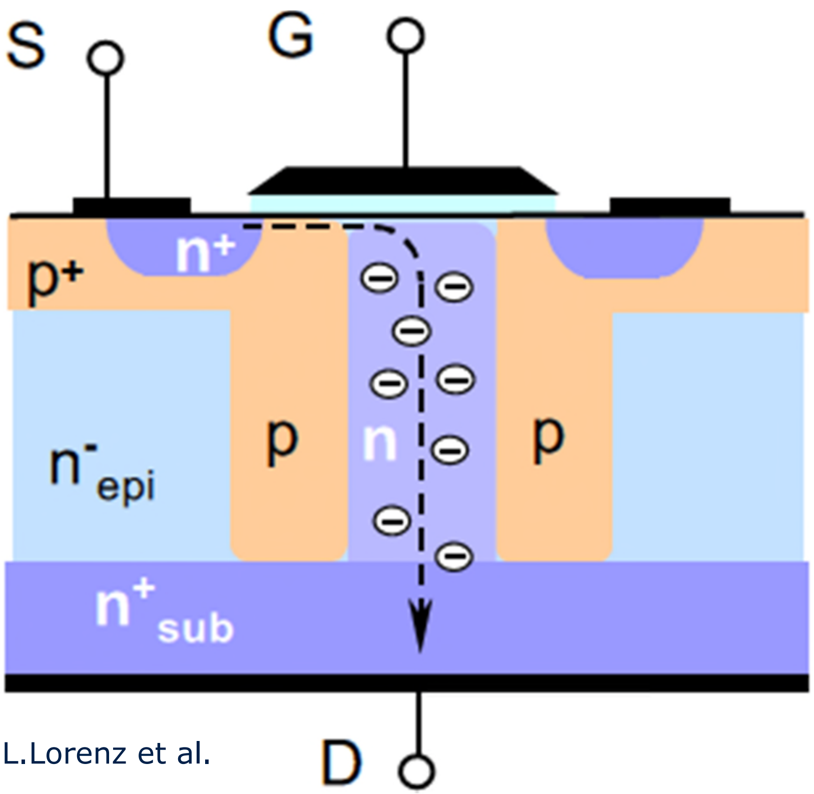


Power MOSFET → Super Junction

- Third big step is the introduction of the concept of charge balance:
  - Lower Ron through the increase doping of drift area together with the reduction of its depth
  - Full depleted P/N area allows for higher breakdown voltage
  - Area reduction allows for smaller caps → higher speed



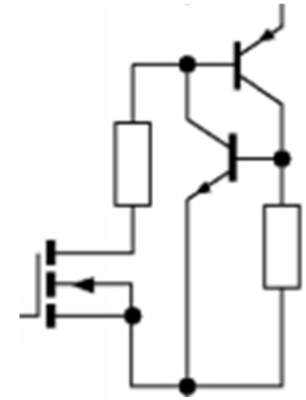


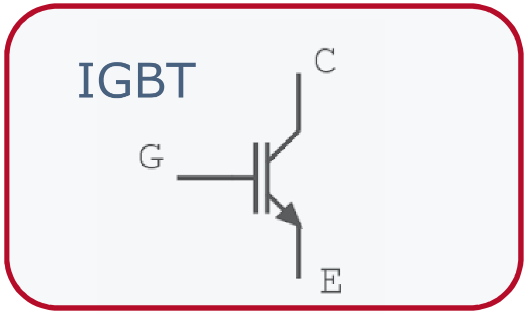


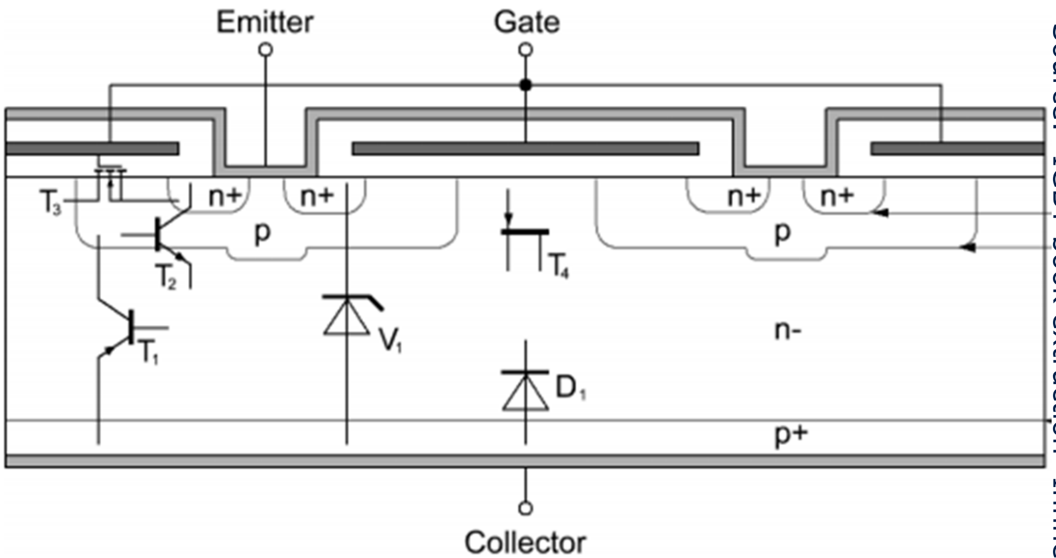
Source: "Second generation of Coolmos," L.Lorenz et al.

IGBT

- IGBT is a device that aim to bring the benefit of the combination of MOS + BJT
  - Input gate electrode, but conduction given by both electrons and holes (as consequence it is slow)
  - Suitable for very high voltage application







Source: "IGBT book extraction" Infineon

What’s next?

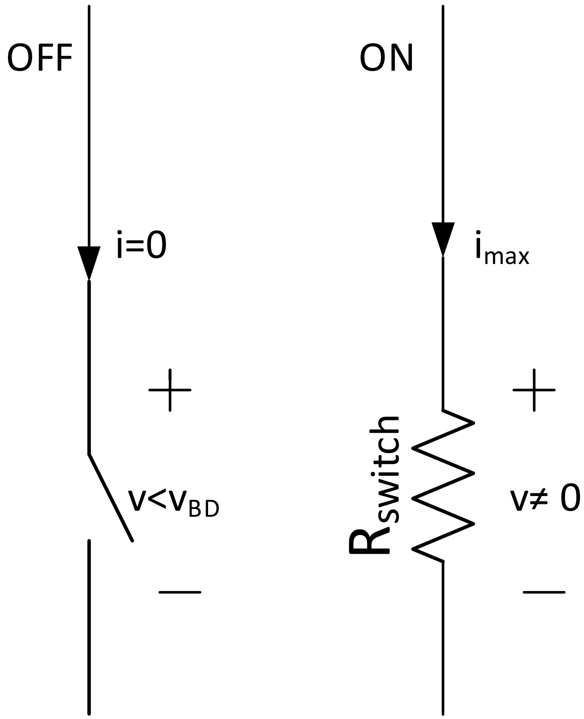
- There is a lot of movement in the last years around the “Wide BG devices”
  - Faster switching
  - Lower Ron
  - Work at higher junction temperature

- Not yet so diffused and still studies around them because
  - Still not very mature technology
  - Driving concept needs to change and currently the devices are not so well known by end user (design inertia)

Real switch → static

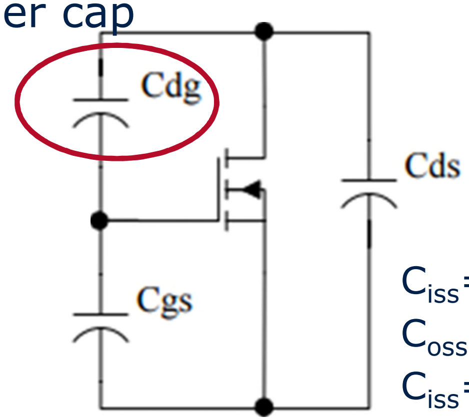
- Real switch
  - In ON state shows some resistance → it produce conduction loss
  - In ON state has a maximum current rating
  - In off state it can sustain a maximum voltage (breakdown will start)

$$\boxed{P_{cond} = R_{switch} \cdot i_{max}{}^{2}}$$

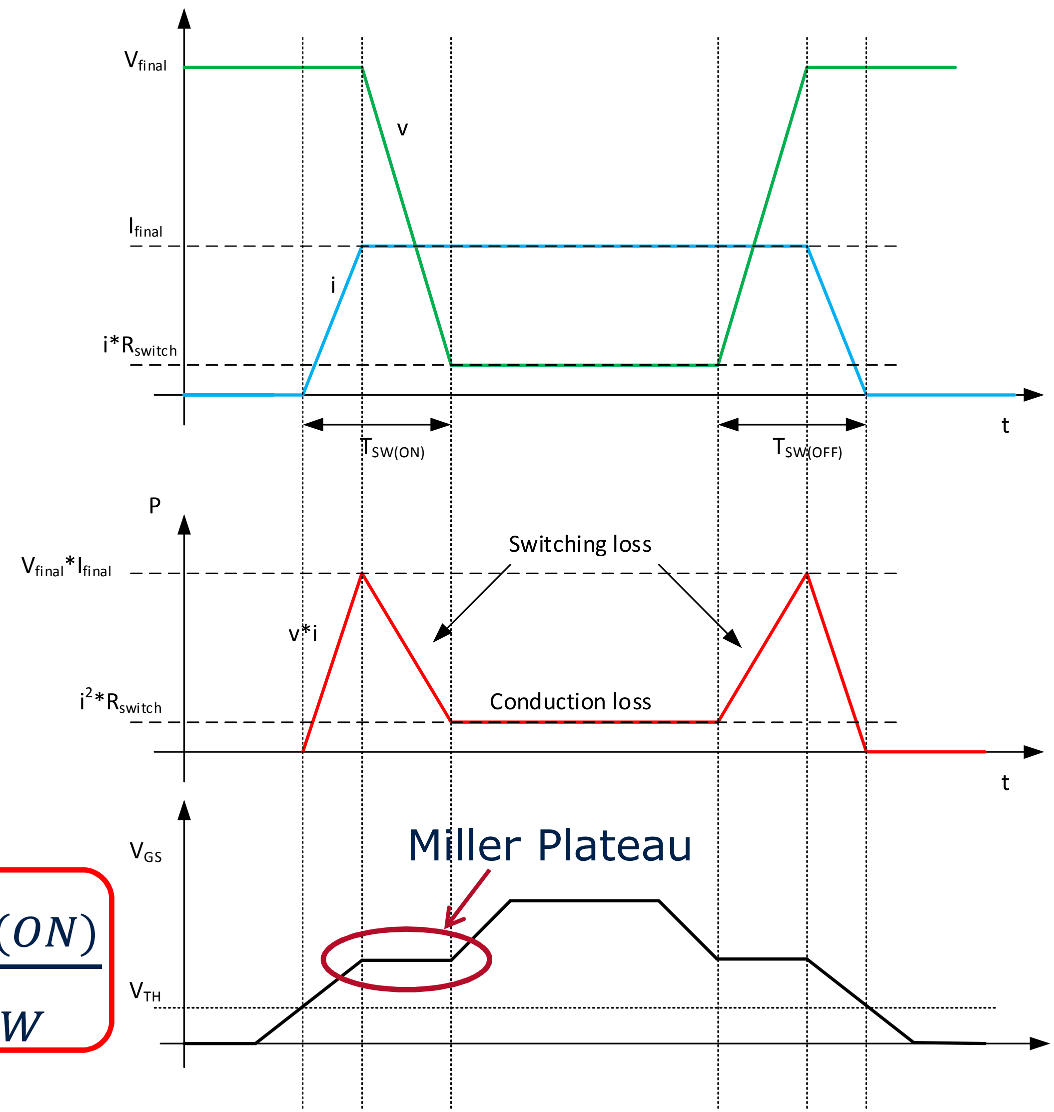


Real switch → dynamic

- Real switch
  - Driving losses caused by switch speed limitation



$C_{iss}=C_{gs}+C_{dg}$
$C_{oss}=C_{dg}+C_{ds}$
$C_{iss}=C_{gd}$

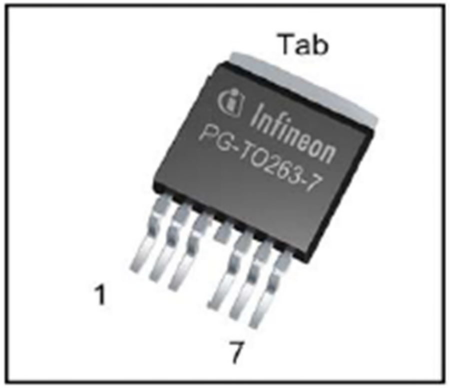


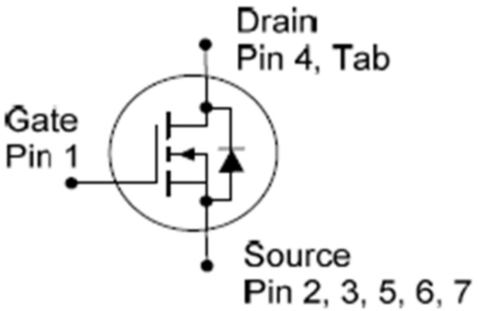
$$P_{switching} = \frac{V_{final} \cdot I_{final}}{2} \cdot \frac{T_{SW(ON)}}{T_{SW}}$$

Package

- One limitation of power handling is the package
- Vertical power mos structure helps, with proper power package to extract the heat
- Normally the heat is collected out of the drain contact
- New packages are moving towards leadless solution to reduce parasitics

PG-TO263-7-3

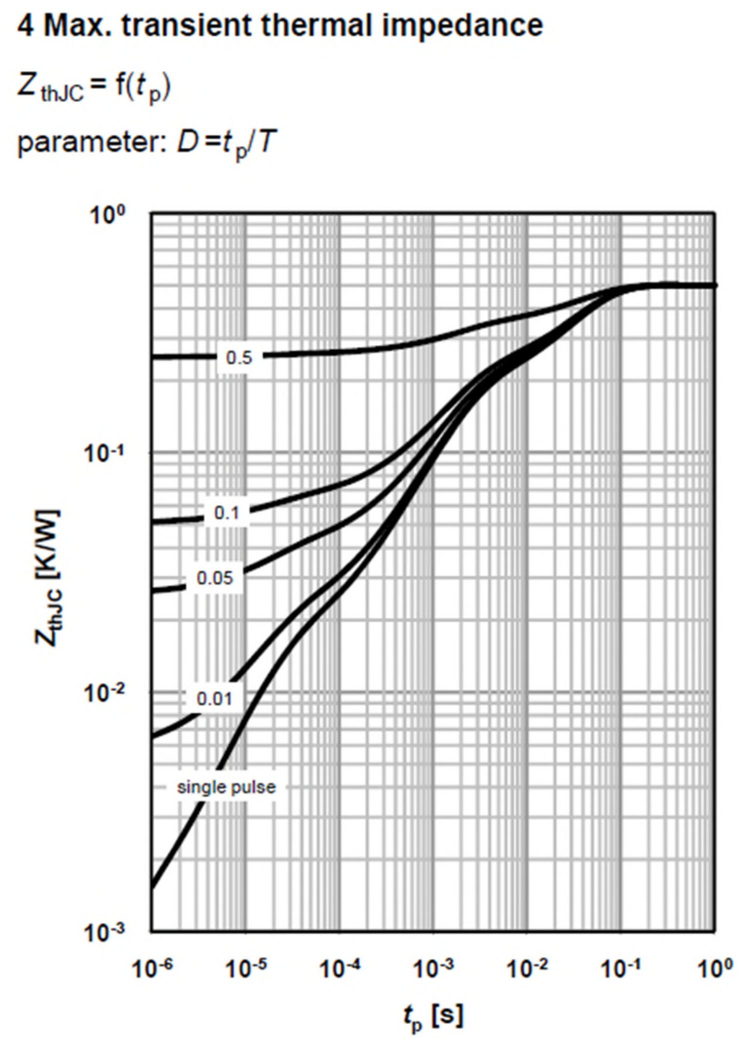




Source:IPB180N10S4-02
VDSmax=100V
Ron= 2,5mOhm

Package → ZthJC

- The important parameter to look at is the Rthjc (thermal resistance from Case to Junction).
- The max junction temperature allowed for Automotive products is generally from 150C to 175C
- Designer should calculate according to ambient temperature proper power size for the switch and proper heat sink if necessary



Source:IPB180N10S4-02
VDSmax=100V
Ron= 2,5mOhm

Switches in the market, main option

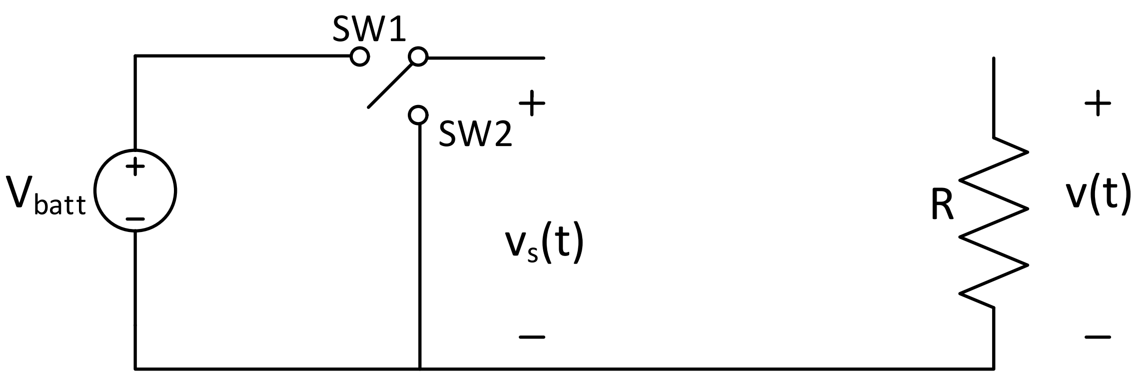
Increased Functions

- Standalone solutions in special package modules optimize for high power application
- Discrete solution
- Smart solution with driver and diagnostic → additional functions
- Smart solution with multichannel switches (and capability of control them independently → additional functions and integration capabilities
- DrMOS solution (half bridge solution with power + driver and synchronous rectifier management for VRMs solution) → dedicated solution for special topologies

Increase POWER

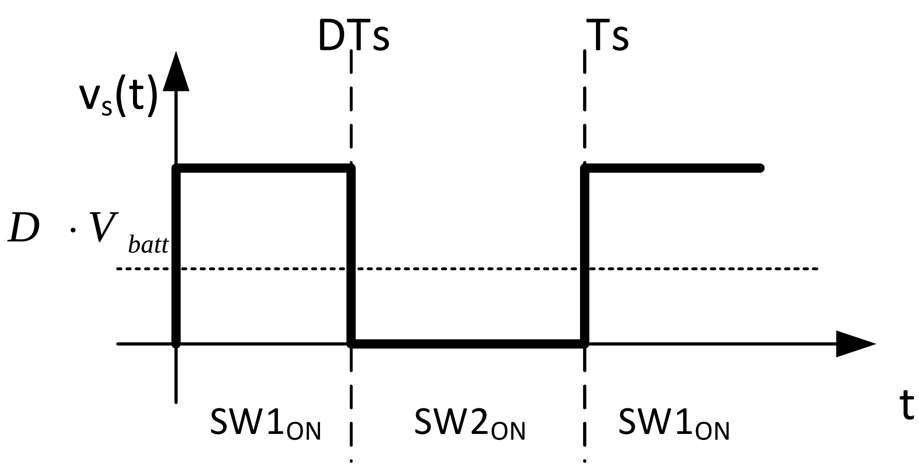
DCDC → Buck converter

- The switch is the basic building block of the power processors
- The topology (the way the switches are connected and managed) define the behavior of the converter



The average (DC component of Fourier analysis) is

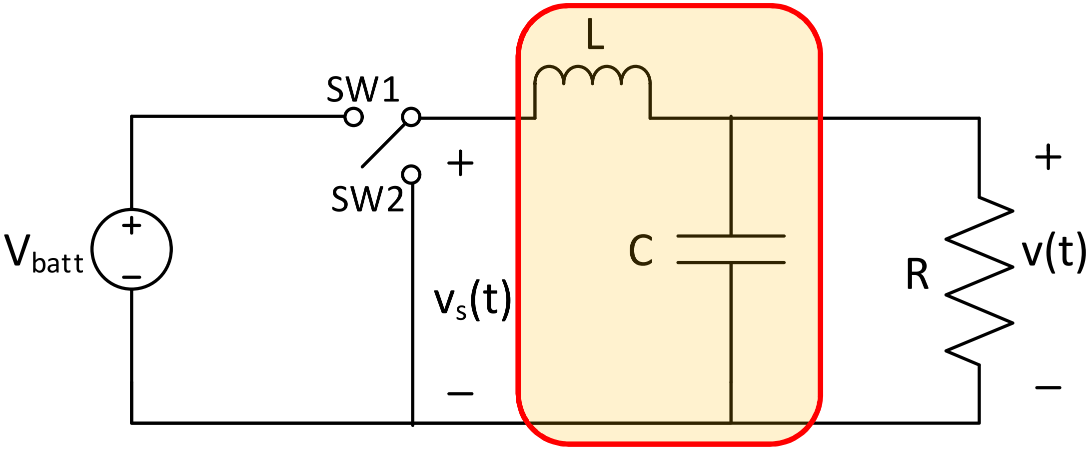
$$\boxed{\langle v_s \rangle = D \cdot V_{batt}}$$



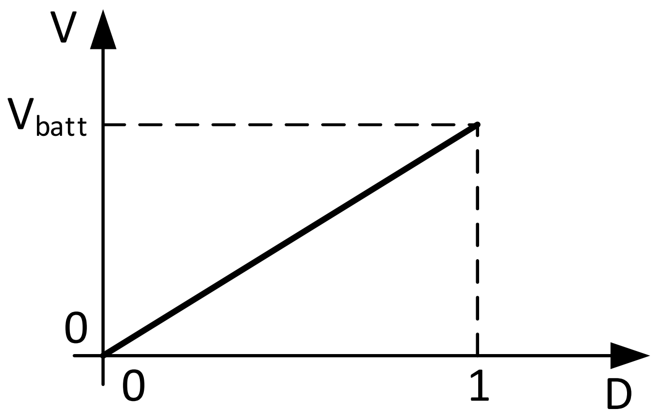
D=Duty cycle (0….1)

DCDC → Buck converter

- A low pass filter will average the switching voltage approximating the output voltage v(t) to the average



Buck converter, also known as step done converter



$$v \cong \langle v_s \rangle = D \cdot V_{batt}$$

DCDC → Buck converter: steady state

- In the assumption the power converter is in steady state condition and that the voltage ripple in the output cap is small the following rules can be applied:
  - For Capacitor: average current is zero

$$i_C(t) = C\frac{dv_C(t)}{dt}$$

$$\langle i_C \rangle = \frac{1}{T_s}\int_0^{T_s} i_C(t)dt = 0$$

→ Charge balance

  - Or Inductance: average voltage is zero

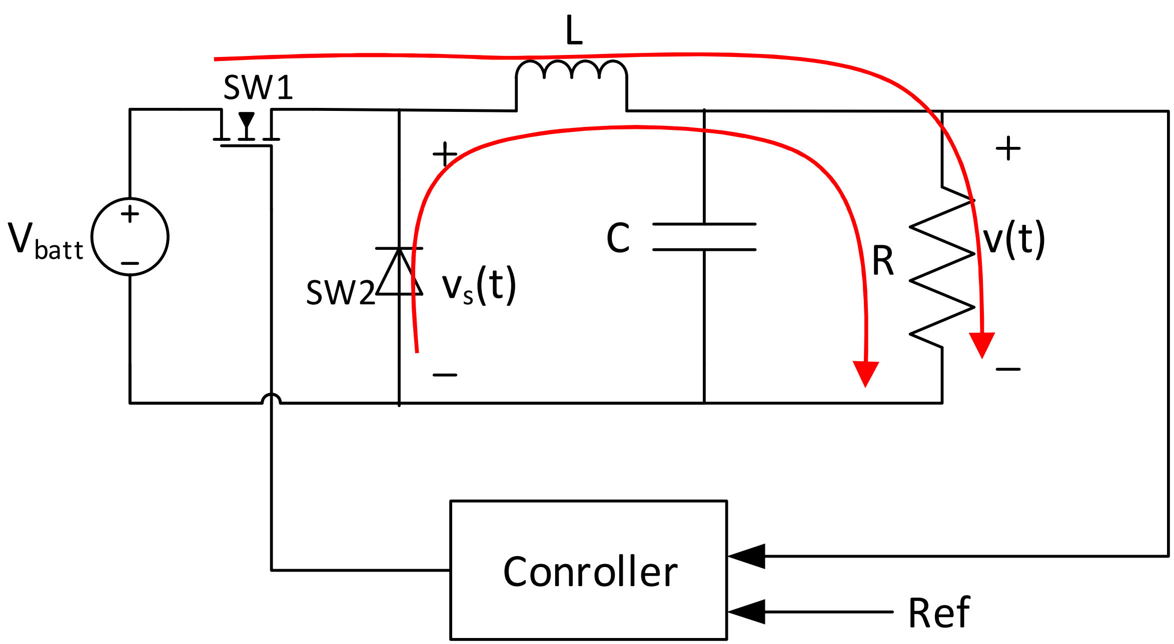
$$v_L(t) = L\frac{di_L(t)}{dt}$$

$$\langle v_L \rangle = \frac{1}{T_s}\int_0^{T_s} v_L(t)dt = 0$$

→ Volt-second balance

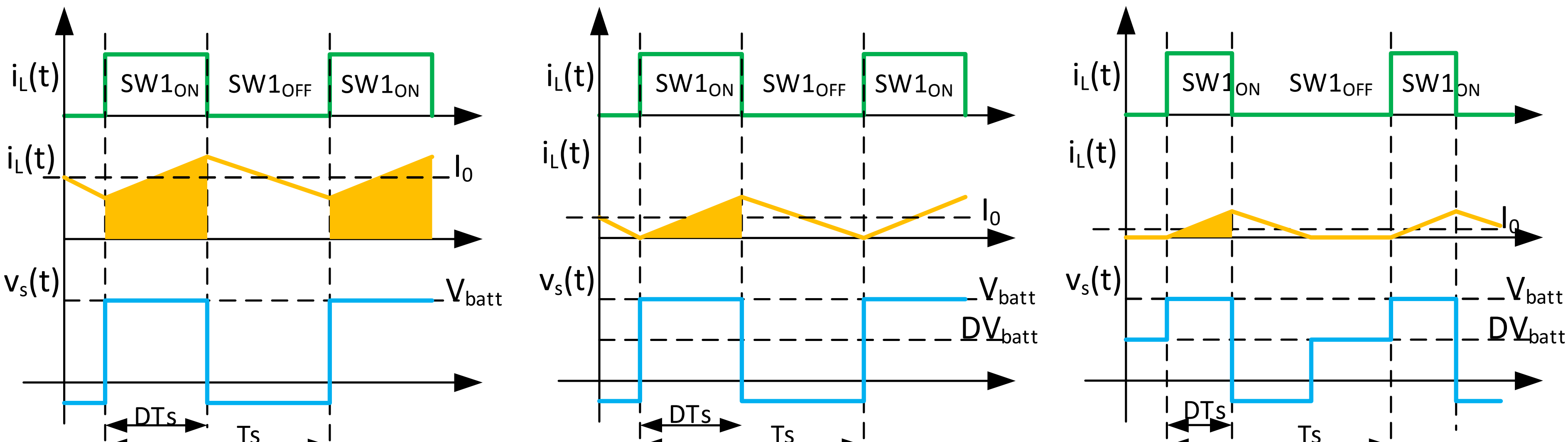
DCDC → Buck converter with real switches

- Buck with freewheeling diode:
  - SW1 is a MOS that is properly modulated by the controller
  - The modulation is normally a PWM where the frequency is fixed and the duty cycle ($SW1_{ON}/Ts$) is modulated
  - SW2 could be a diode. It creates a path for the current in the inductor whenever the SW1 is opened



DCDC → Buck converter: CCM → DCM

- When the current reduces it will arrive to a point where the controller has to modify the duty cycle to keep regulation
- At light load the converter enters into DCM and for an additional phase is present in the modulation (diode not conducting)



$$V_0 = V_{batt} D$$

$$V_0 = V_{batt}\left(\frac{2}{1+\sqrt{1+\frac{8\tau_L}{D^2}}}\right)$$

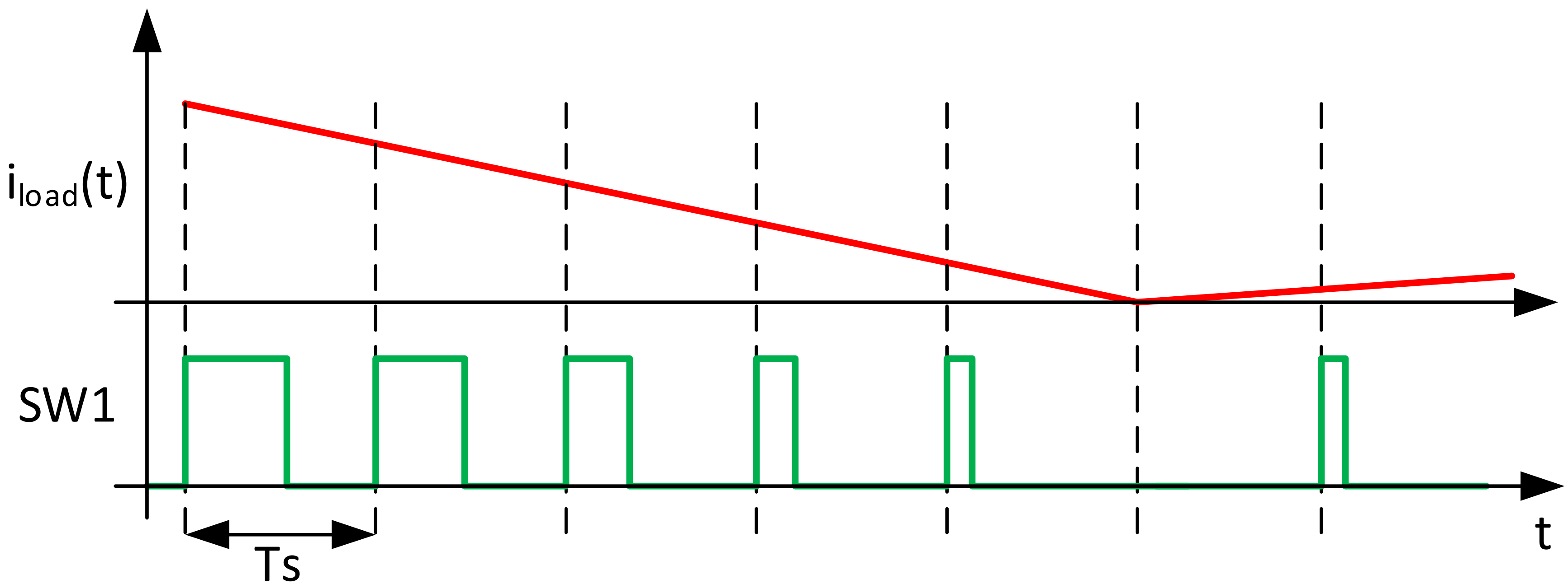
$$\tau_L = \frac{L}{RT_s}$$

DCDC → Buck converter: CCM → DCM

- The movement from CCM and DCM change radically the properties of the converter
  - Duty cycle depends on load
  - Output impedance change
  - Dynamics can also change
  - Compensator implemented to optimize the CCM mode could create instability in DCM

DCDC → Buck converter: light load

- In case of light load the duty cycle could be zero (if controller supported it)



Skipping mode

DCDC → Buck converter efficiency

- The main losses associated with the buck are:
  - Conduction losses of the switches, inductor and capacitance
  - Switching losses mainly due to the switching behavior and associated to the switches

$$P_{COND\_SW1} = R_{SW1} \cdot \frac{T_{ON}}{T_s}\left(I_o{}^2 + \frac{\Delta I_L{}^2}{12}\right)$$

$$P_{COND\_SW2} = \frac{T_{OFF}}{T_s}(V_D \cdot I_o)$$

$$P_{COND\_L} = R_L\left(I_o{}^2 + \frac{\Delta I_L{}^2}{12}\right)$$

$$P_{COND\_C} = \frac{R_C \Delta I_L{}^2}{12}$$

I_0 = output current
ΔI_L =inductor current ripple
V_D =diode forward voltage
R_L =equivalent series resistance inductor
R_C =equivalent series resistance inductor

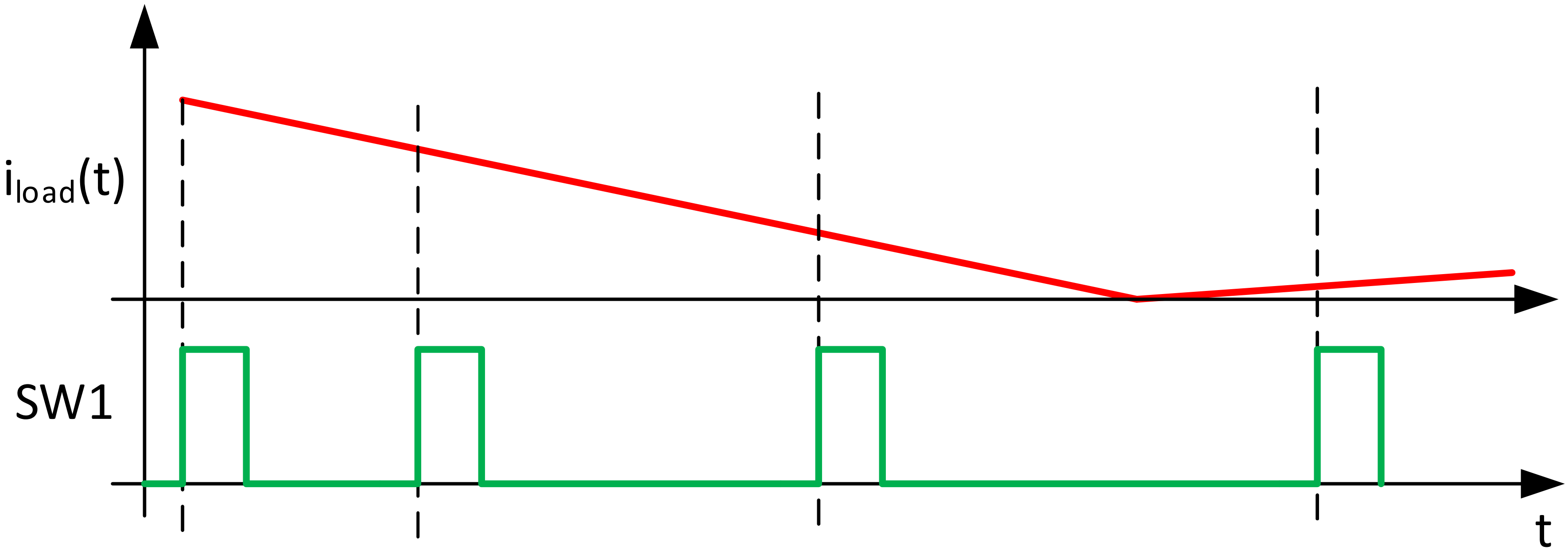
  - Driving losses due to the driver

$$P_{DRV\_SW1} = \frac{C_{iss} \cdot V_{gs} \cdot V_{batt}}{T_s}$$

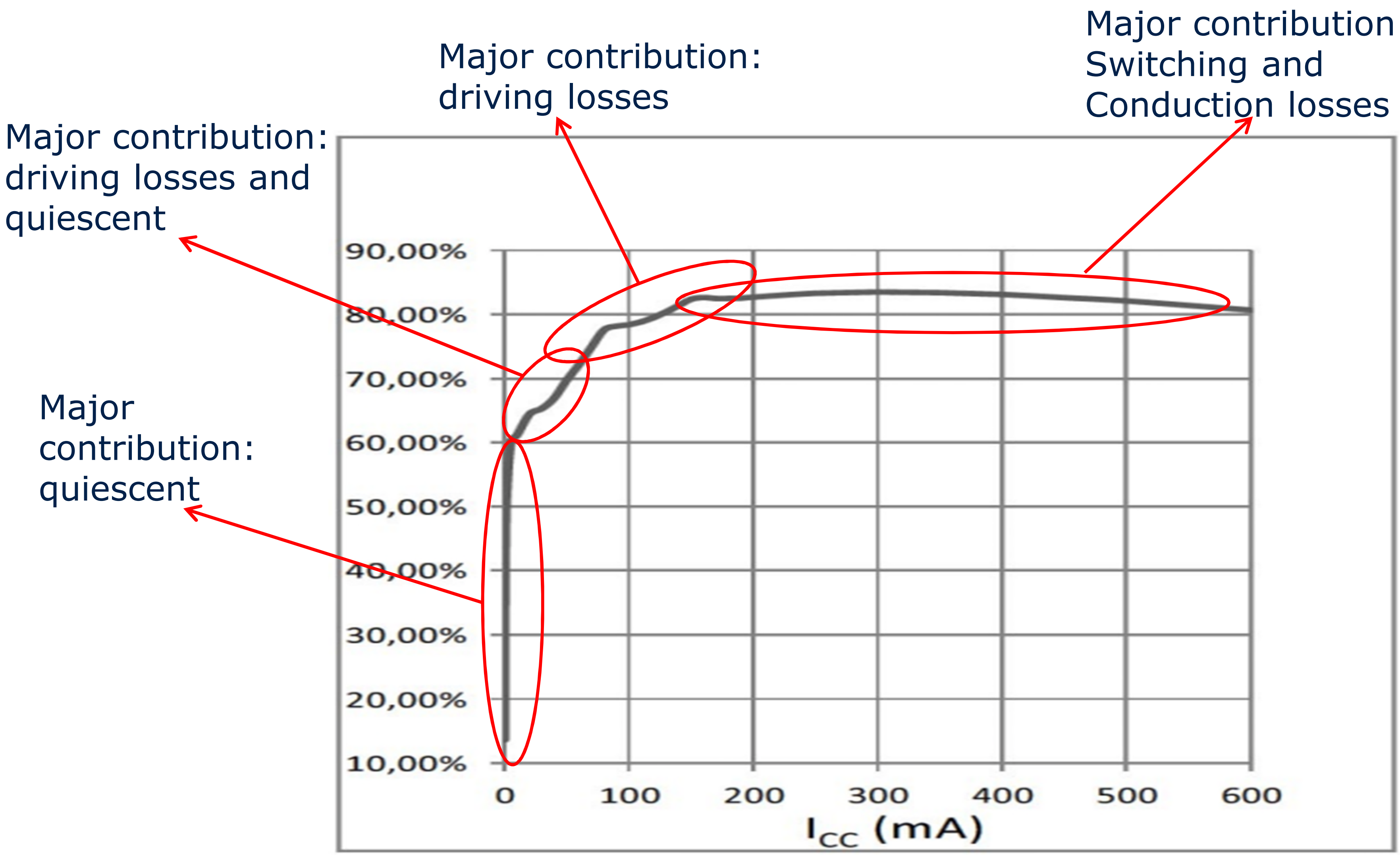
  - Quiescent losses normally constant and associated mainly to controller, reference generator….

DCDC → Buck converter PFM

- In order to optimize the efficiency for all the allowable load current (0 to max) a new modulation technique need to be addresses: PFM
- The modulation technique varies the frequency of the SW1 switch according to the load
- Several PFM modulation are available. COT is the most diffused



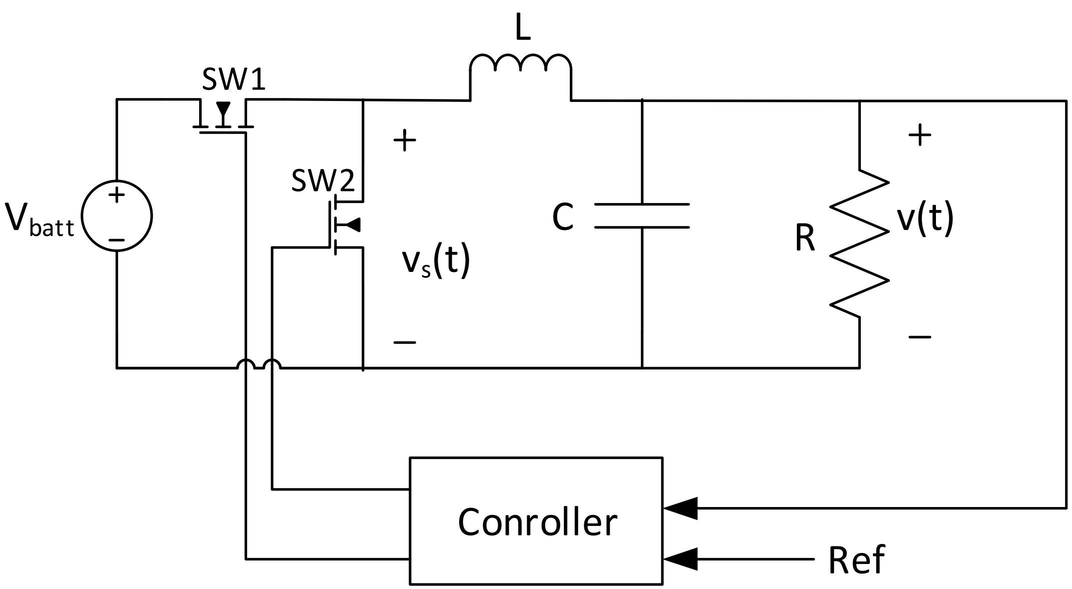
DCDC → Buck converter efficiency

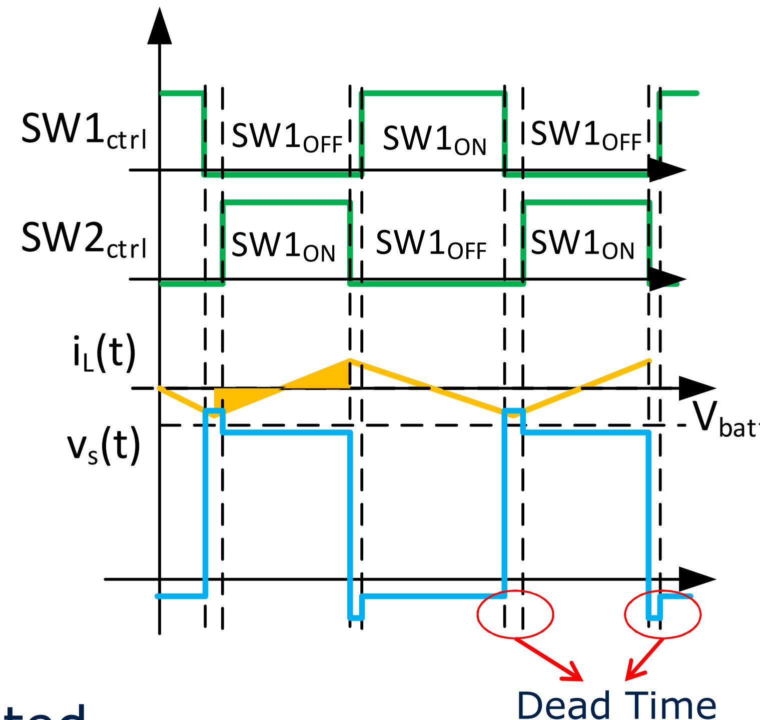


TLF50201EL, 2MHz switching; PWM/PFM; low quiescent

DCDC → synchronous buck

- On source of losses is the diode forward voltage
- To optimize the diode switches losses one solution is to add a second mosfet switch as SW2

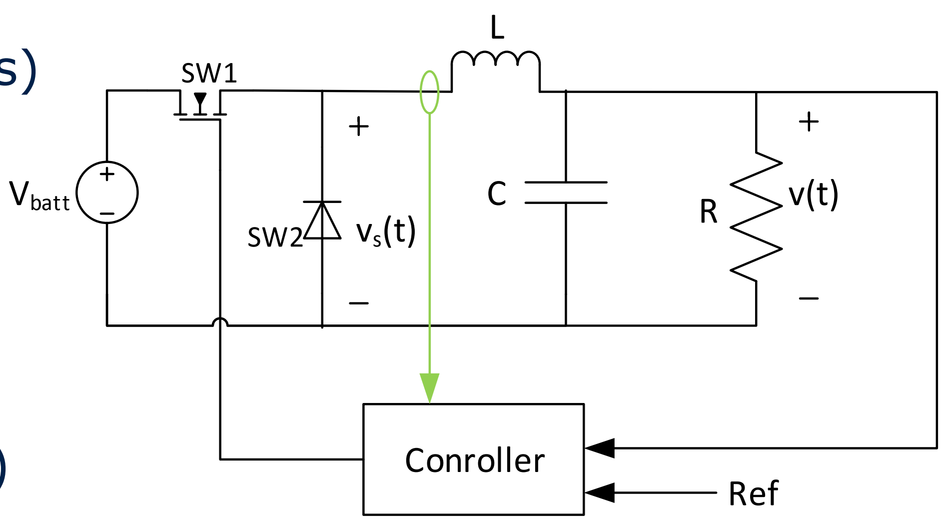




- The controller become more complicated
- At light load efficiency is degrade respect to the async.
- The advantage strongly depends on duty cycle

DCDC → controller

- The most popular controller are
  - voltage mode (easy and good for load variation)
  - Voltage mode plus feedforward (good line and load dynamics)
  - Current mode
    - Peak/valley current (simplify the stabilization, good line rejection)
    - Average Current (not as fast as the peak current control, less prone to noise)
    - V2 control (very fast dynamics)



  - PFM COT (Constant ON Time)
- Digital controller is also becoming a solution for some applications

DCDC → increase frequency

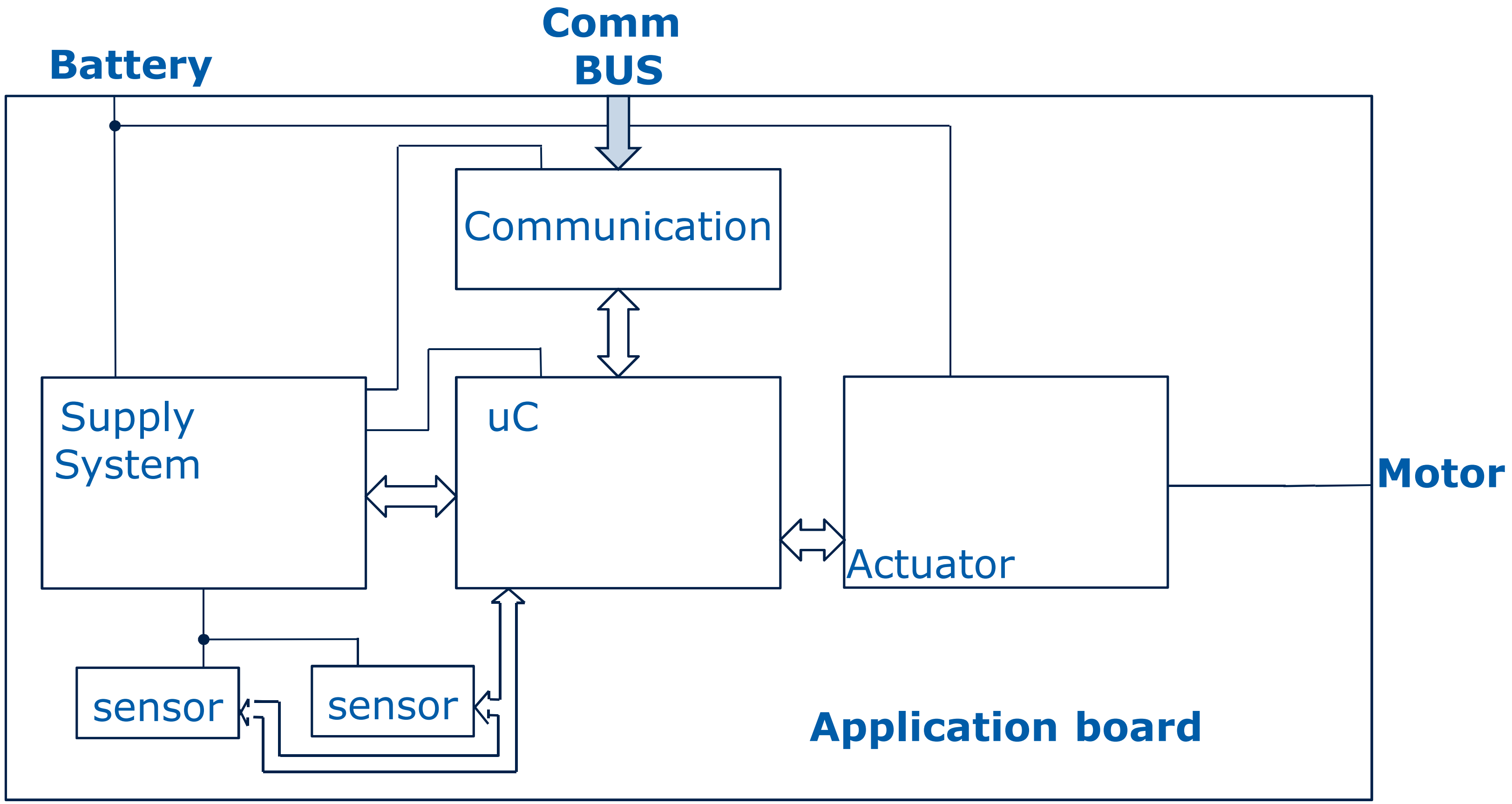
- The trend is to increase power density
  - Reduce impact of external component (LC)
  - The slew rate of the inductor should be fast enough to follow the current demand
  - The bandwidth of the loop should be maximize to increase the speed of the loop reaction at variation of the load without using big capacitor at the output

↓

Increase switching frequency

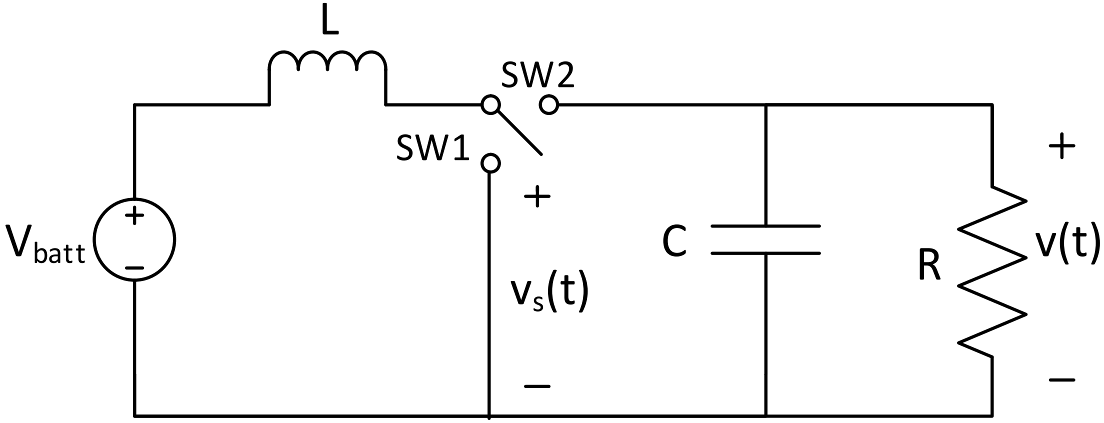
DCDC → Buck application → System supply

- Each ECU need to be supplied from the battery. The most efficient way is to use a System supply that is distributing the power over the single components



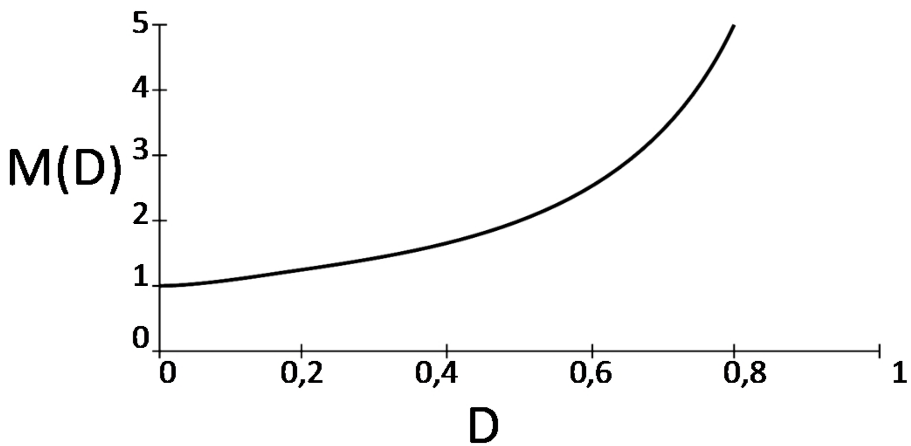
DCDC → other useful topologies → BOOST

- Boost topology (also known as set up converter) is used whenever the voltage to provide is bigger than the battery one

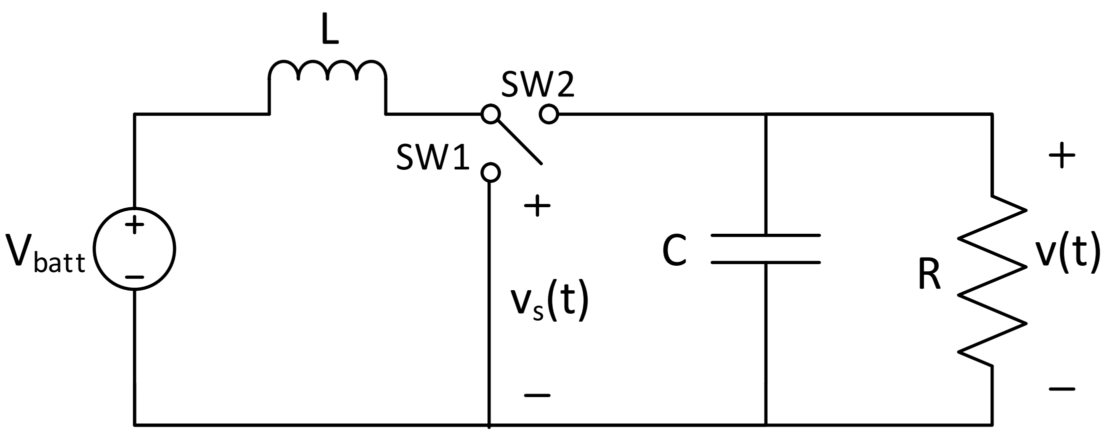


$$\boxed{M(D) = \frac{1}{1-D}}$$

$M(D) = V_0/V_{batt}$



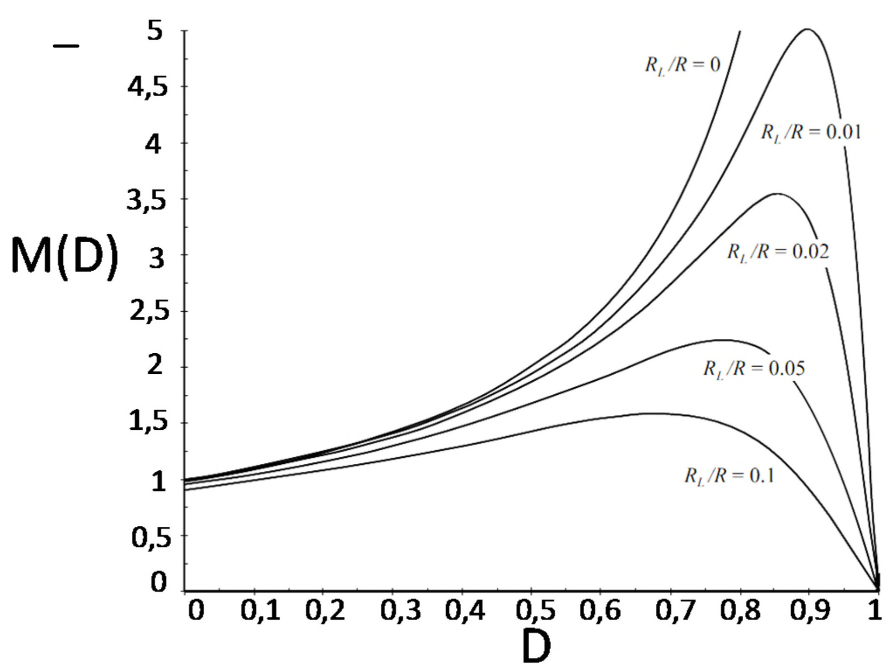
- Parasitic component put some limitations



$$M(D)=\frac{1}{1-D}\cdot\frac{1}{\left(1+\frac{R_L}{R(1-D)^2}\right)}$$

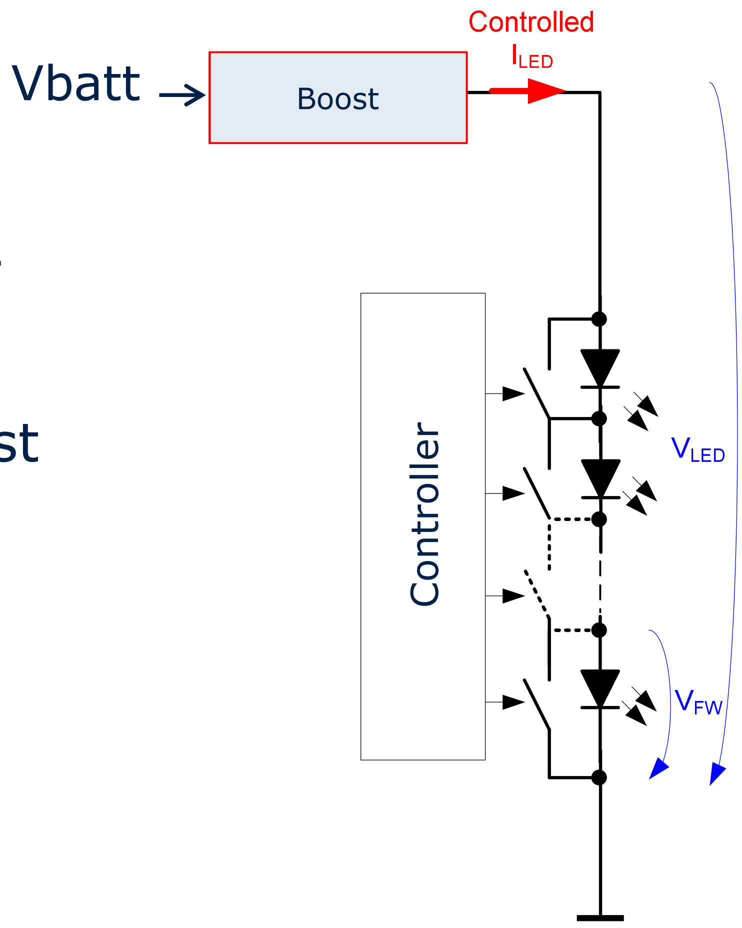
$M(D) = V_0/V_{batt}$

R_L=inductor par. res.

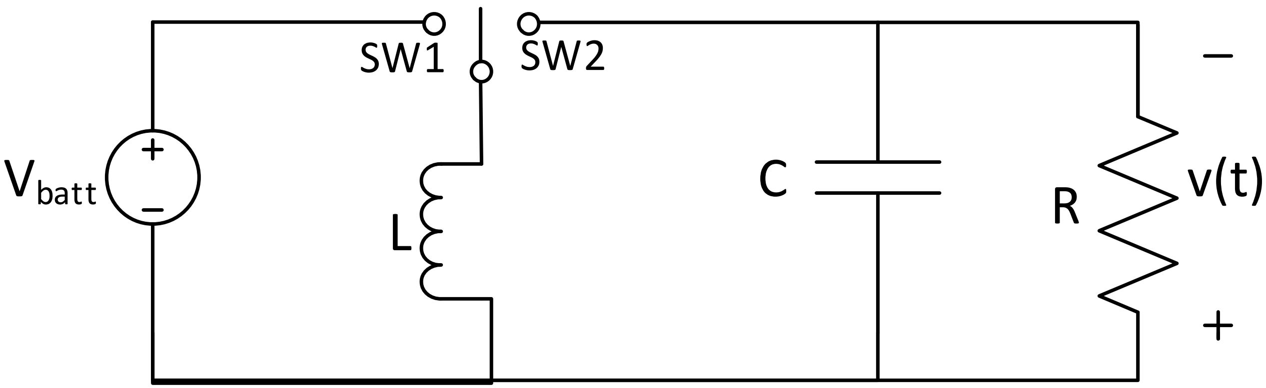


DCDC → Boost application → LED driver

- LED application needs the boost especially for very long chains of LED
- The main control they need is just the current as this is the most important control variable for properly driving the LED

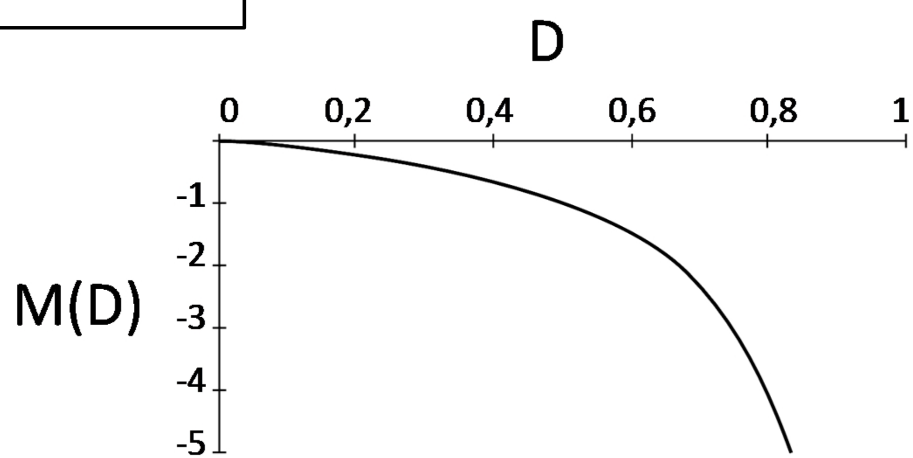


- Buck boost behaves as a buck or as a boost according to the condition of the battery



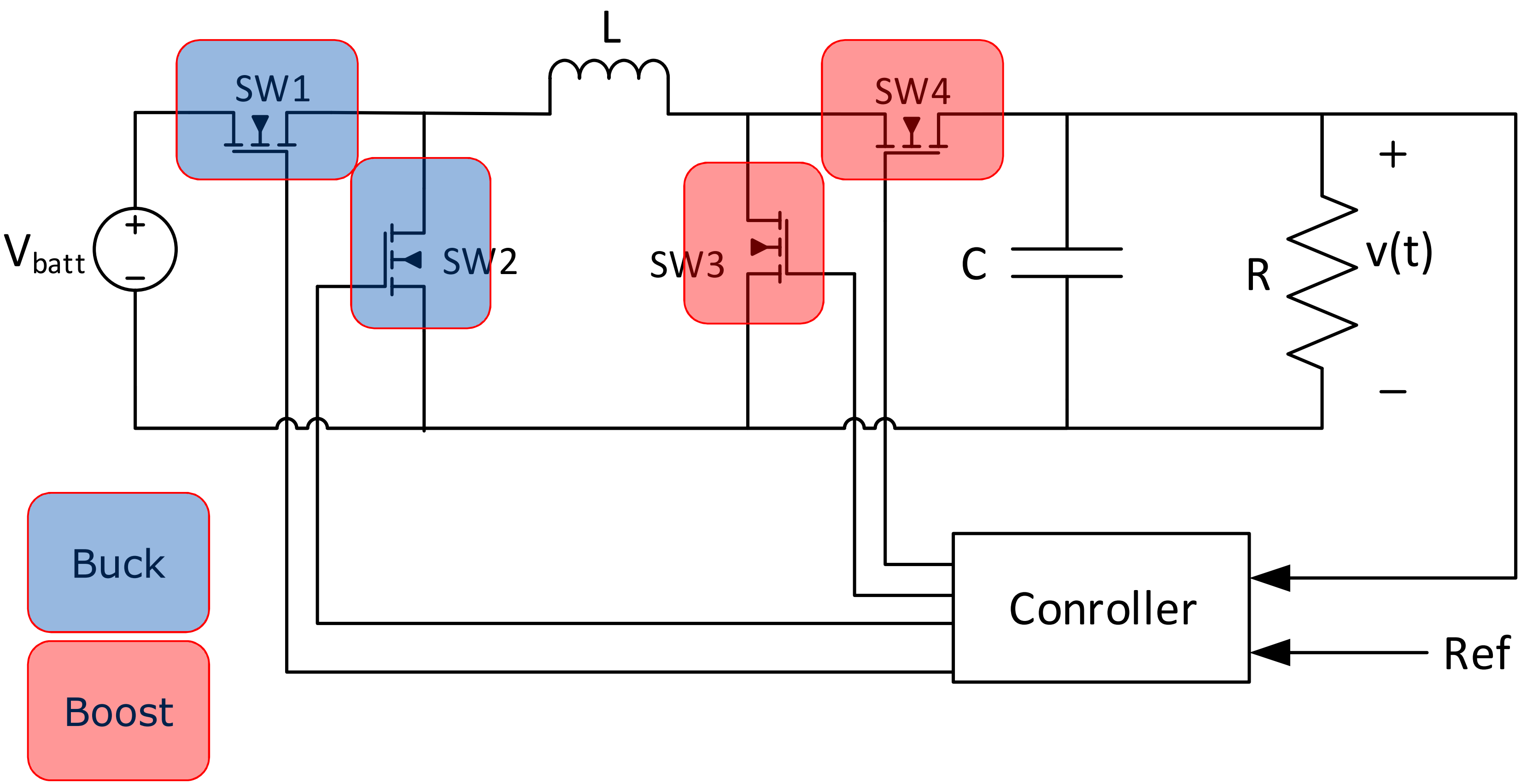
$$\boxed{M(D) = -\frac{1}{1-D}}$$

$$M(D) = V_0/V_{batt}$$

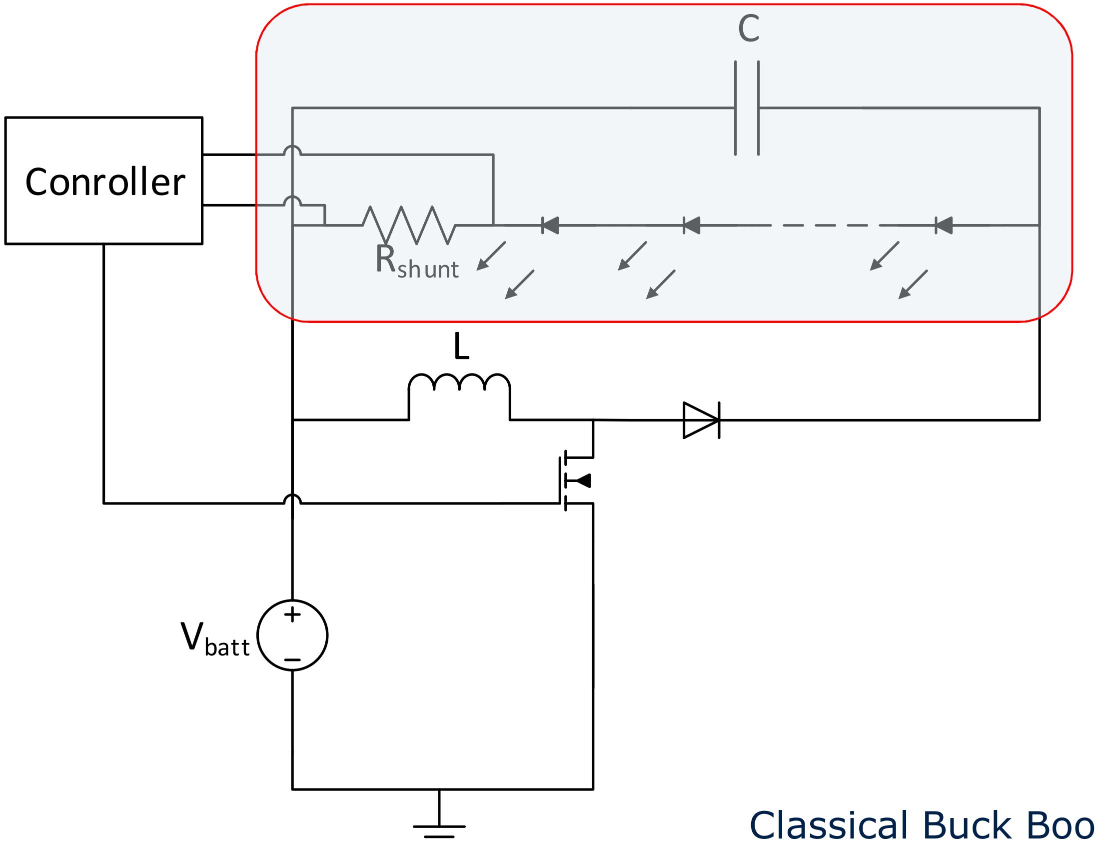


DCDC → other useful topologies → BUCK/BOOST

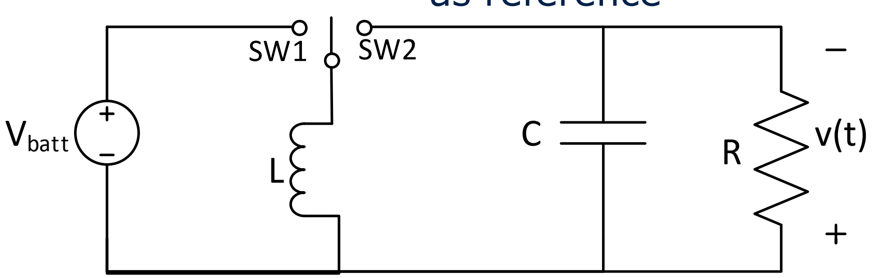
- Non inverting buck boost normally is use as a buck or as a boost with a “topology management” control



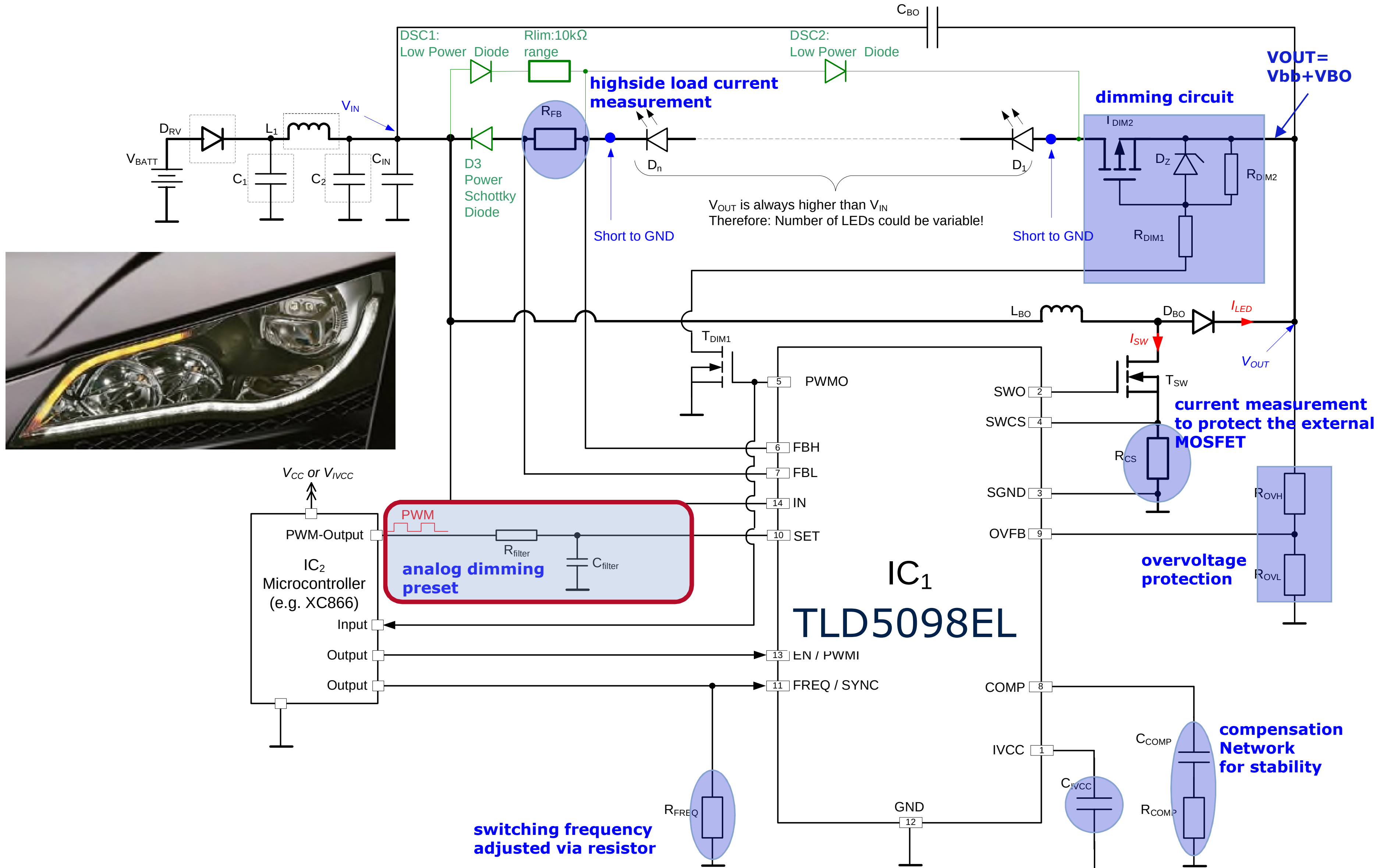
- System supply needs also a boost in the case the requirement on the minimum battery is to keep operation of the ECU eve during cranking
- The most flexible LED driver is the buck boost especially if the LED chain can be configured



Classical Buck Boost as reference



DCDC → Buck Boost → application example



 Courtesy Dr. Afons Graf

Agenda

- Automotive trends
- The CO2 revolution
- Power electronics main building blocks
- Automotive: harsh environment with lot of challenges
- Safety a “shall” requirement for Automotive

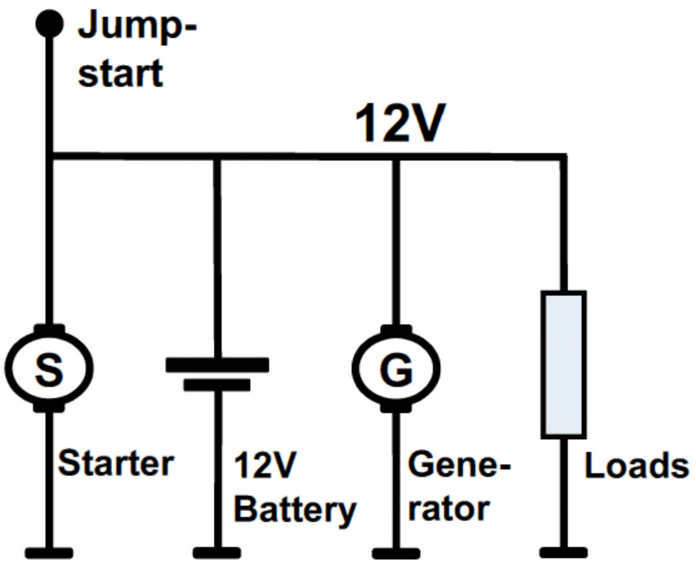
Automotive: harsh environment with lot of challenges

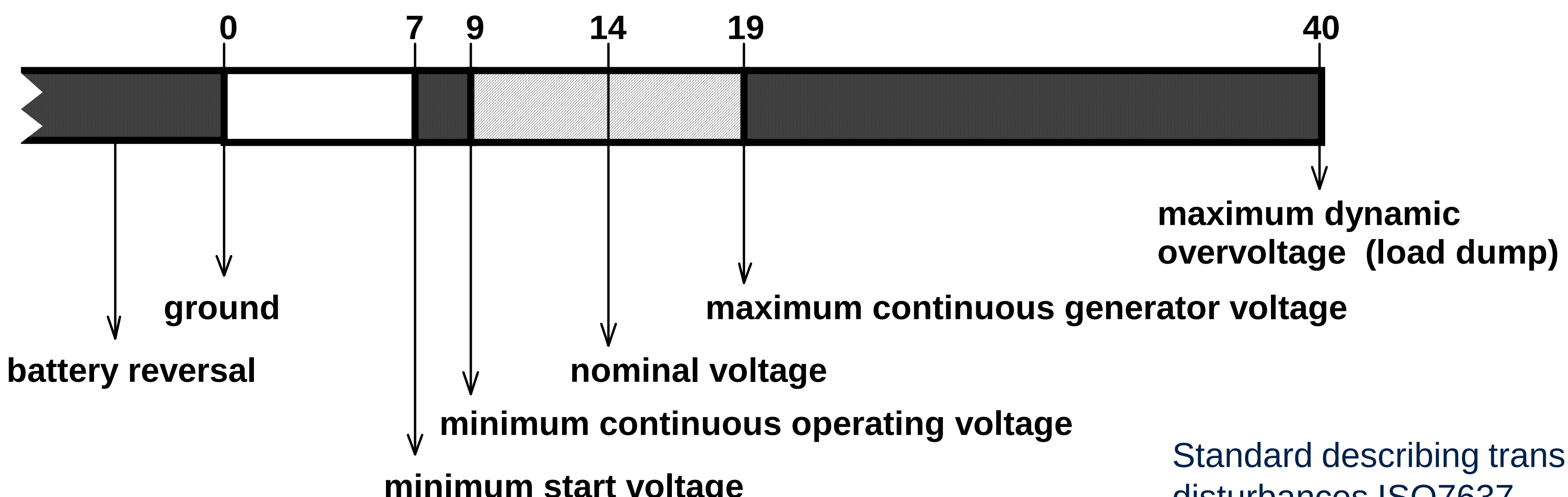
- The automotive environment is not an "easy place" for electronics systems (especially for power electronics) because of:
  - High voltage battery requirements
  - High temperature requirements
  - EMC and transient requirements
  - Reliability requirements

- Huge volume to provide keeping under control the quality of the provided systems

High voltage battery requirements

- Currently the car electronics is based on a 12V Architecture (2X12 in trucks)
- All the electronics connected directly to the battery (e.g. all the power supply module of ECU) shall work over a wide spread of voltages





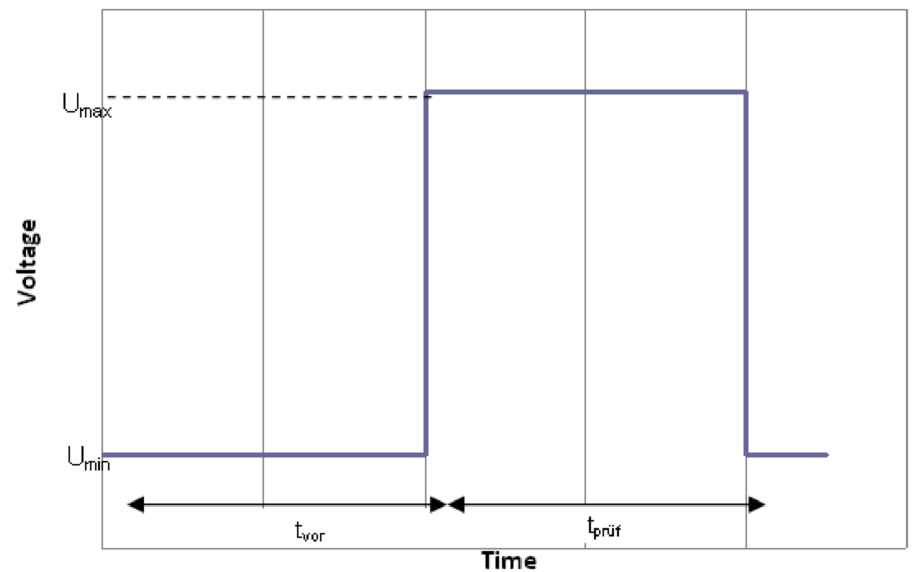
Standard describing transient disturbances ISO7637

High voltage battery requirements

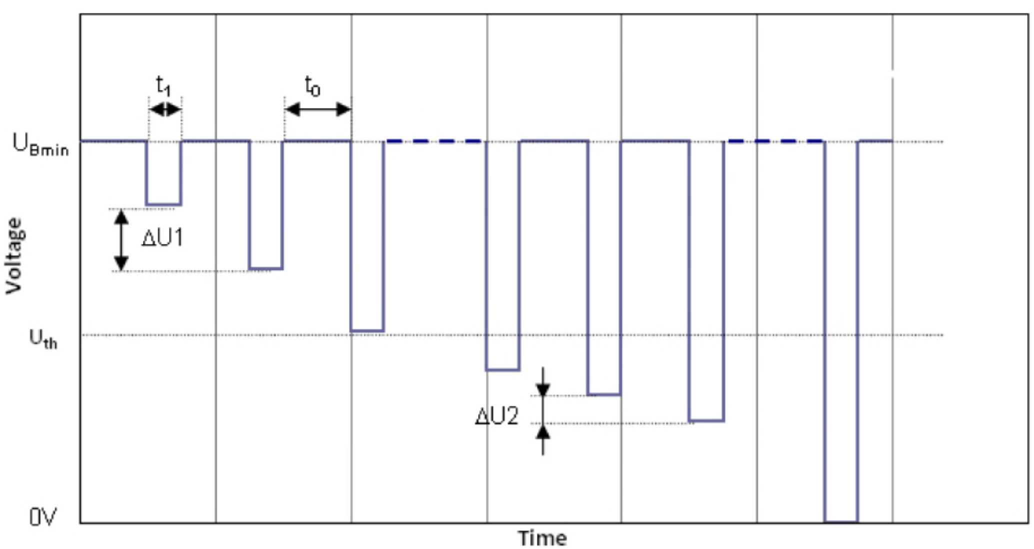
- German OEM (Original Equipment Manufacturer) Initiative: LV124:
  - *"This document specifies requirements, test conditions, and tests for electric, electronic, and mechatronic components and systems for use in motor vehicles with a 12 V electric system."*

- The LV124 define also the acceptance criteria based of the different system in the car

High voltage battery requirements → examples



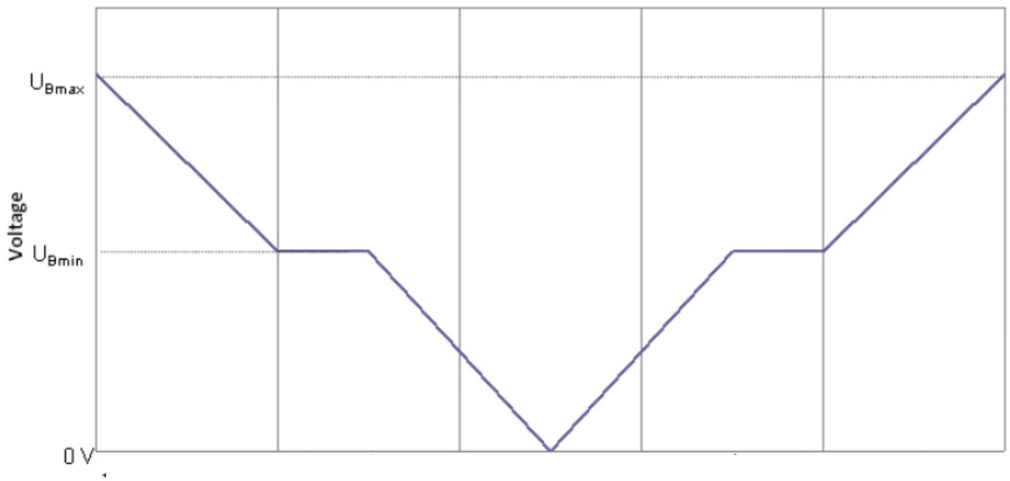
- jump starting of the vehicle (up to 27V)
- Device with the maximum load to take into account self heating

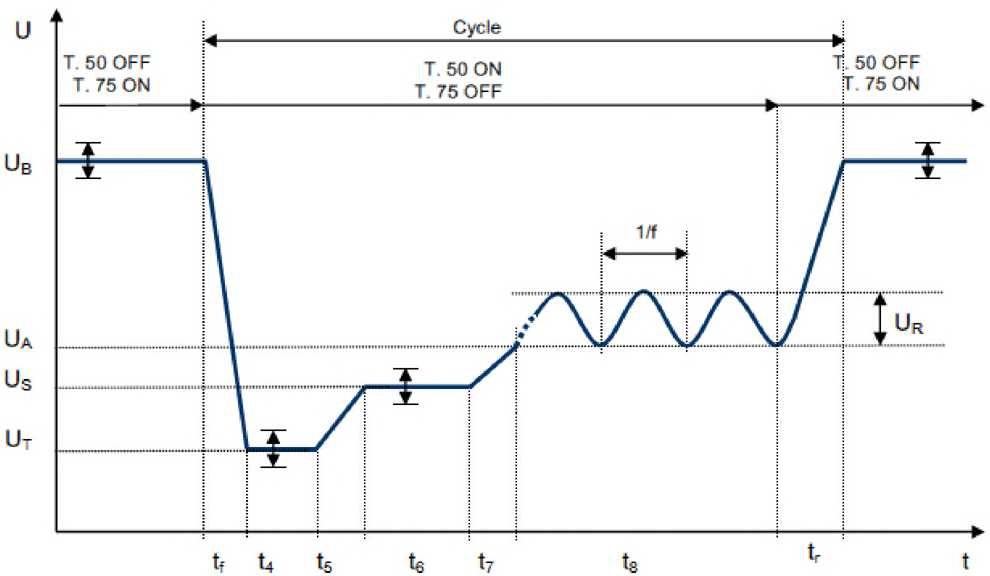


- reset behavior
- No undefined condition in all the other voltages

High voltage battery requirements → examples

- slow charging and discharging of the battery
- Device shall function within its specified range. Out of specified range the device shall not be undefined





- battery drop at startup
- Lowest voltage can be 3V in severe cold crank, 7V for warm crank.

High voltage battery requirements → 48V

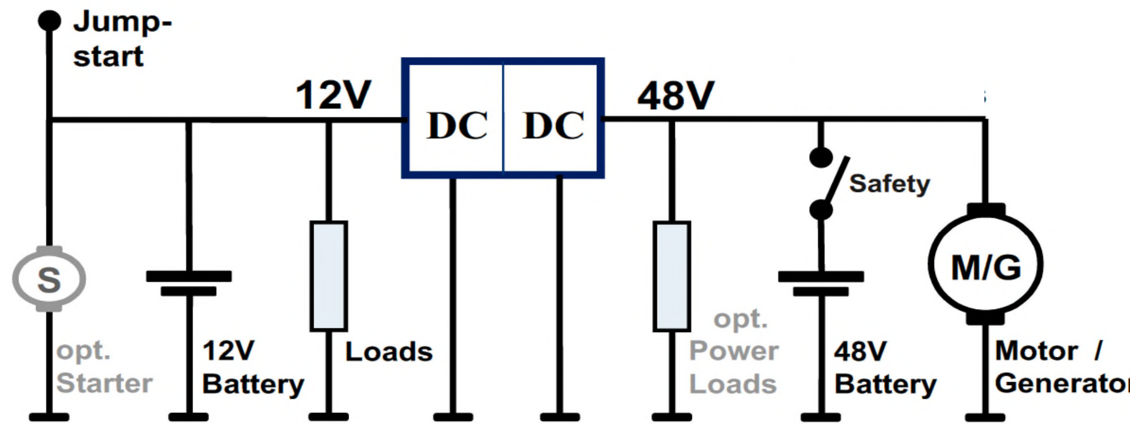
- It is needed to maximize the energy efficiency of the existing system and to answer to the request additional power for new application in the car
- Higher voltage allows to reduce cable diameter
- Beyond 60V DC special measures for protected humans are needed

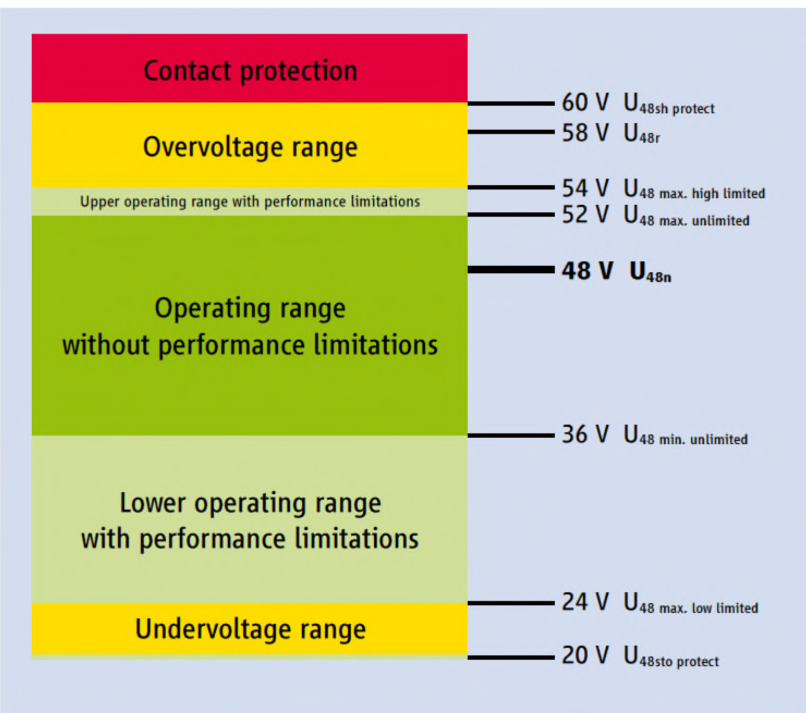
↓

48V battery architecture

- This new level is intended to supply electrical components of more than 3 kW power, such as the start-stop feature (boost and energy recuperation), air conditioning compressors, electrical heaters, pumps, steering drives

High voltage battery requirements → 48V





Source ZVEI Voltage Classes for electric mobility

- 12V powernet will be almost the same
- 48V is an extension of the 12V

High temperature requirements

- Cars should be able to work in Nordic countries (e.g. Alaska)
  - → temperature to sustain are -40C (typical problem is the startup)
- According to the location of the electronics components high operative temperature could be required
  - Engine compartments, transmission control units
  - Current requirements are 85C max for application below the dashboard; 105C where it could be sun radiation (wind screen where it is hosted rain sensor…); 125C or more for application in power train (EPS, Engine…)
- Requirements are increasing

High temperature requirements

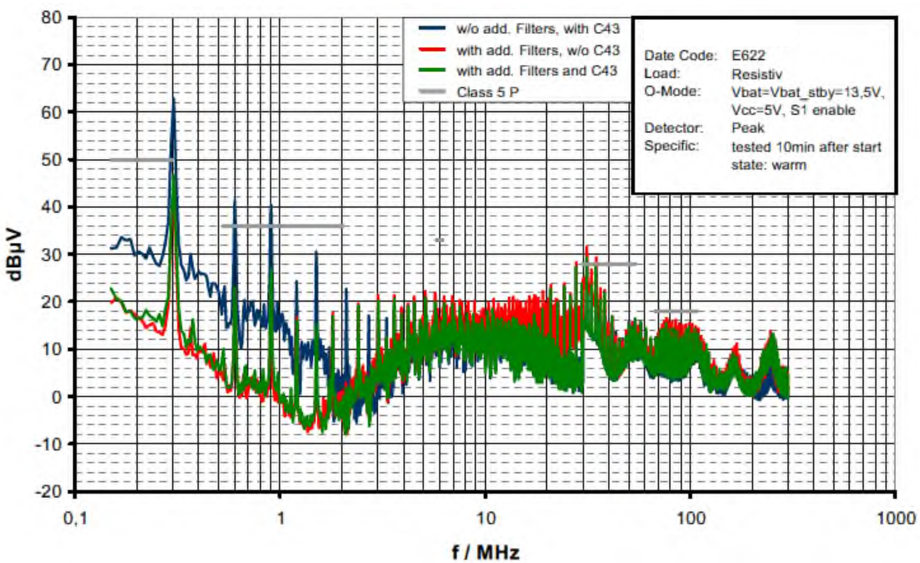
- Power electronics, smart ICs at high temperature may suffer of:
  - Increase of leakage (in smart Ics bandgaps could be affected)
  - Decrease of speed (mobility decrease)
  - MOS gates start also to leak
  - Electro migration starts to become critical at high temperature and to reduce the problem bigger metals (better copper metal) shall be used as well as contacts
  - Wire bonding is one of the major failure mechanism (due e.g. thermo-mechanical stress)

EMC requirements

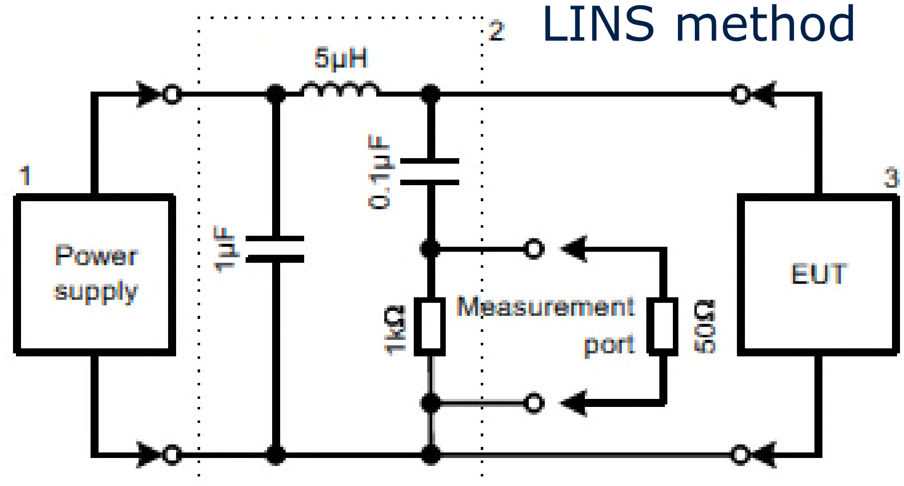
- In the automotive there are applications
  - that could generate disturbances (switching of heavy inductive loads, fast switching circuits)
  - That could be prone to disturbances coming from elsewhere and need to be not affected especially if the function is safety critical
- EMC is normally a hard topic to deal with especially in a later stage of the design.
  - It is important to “design for EMC” since the beginning
- Standards:
  - DPI (e.g. IEC 62132)
  - Conducted emission - 150 Ohm method (e.g. IEC 61967)
  - Conducted emission - LINS method (e.g. IEC CISPR)
  - Conducted immunity (ISO 7637, LV124)
  - …….

EMC requirements → conducted emission

- Fast and high power switching regulators can creates often issues
  - Hard switching is good for efficiency, but is critical for emission
  - technique to solve hard switching problems are:
    - Filters (expensive and require board space)
    - Shaping currents (most of the time at a price of efficiency)
    - Spread spectrum technique (where allowed)

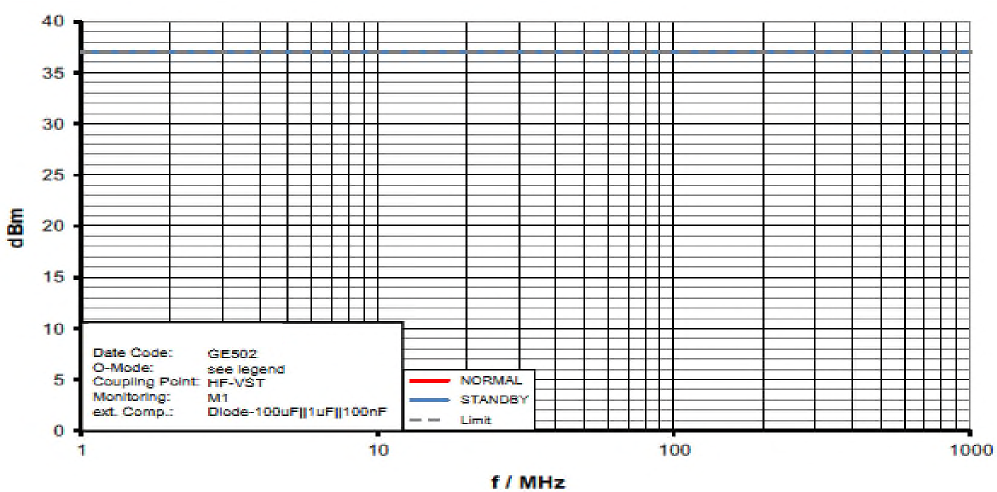


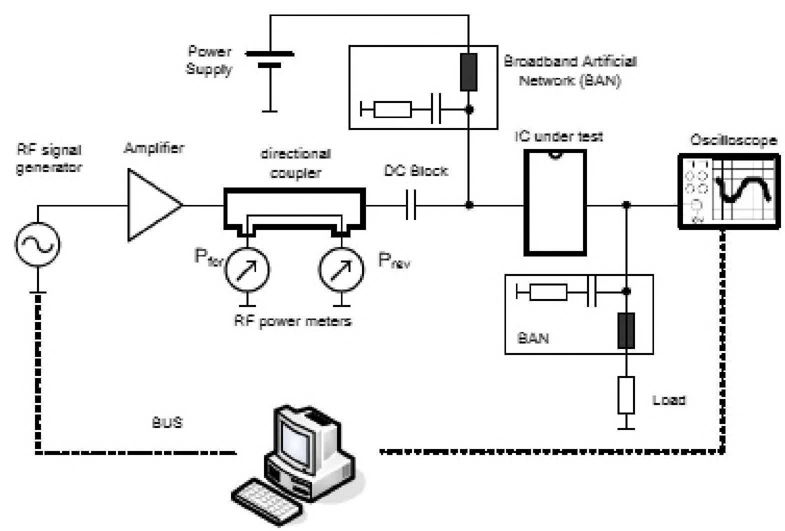
LINS method



EMC requirements → susceptibility

- For semiconductor IC the pins are divided into
  - Local pin (requirement to be in spec up to 17dBm power injected)
  - Global pin (requirement to be in spec up to 37dBm power injected)
- Most common problem is rectification of the signal and induced offset





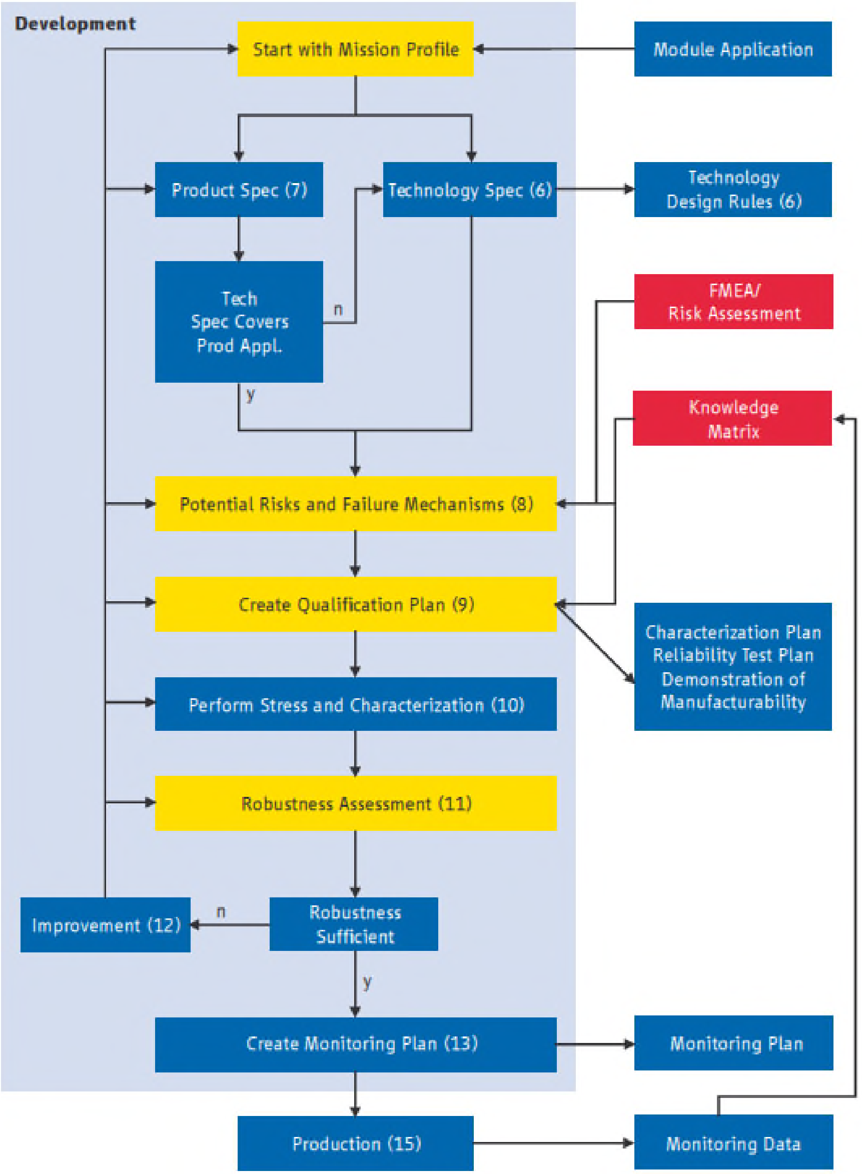
Reliability requirements

- The key word for automotive industry, and especially for semiconductor industry is: ZERO DEFECT
- Reliability is the probability that an item will perform
  - a required function
  - under stated conditions
  - for a stated period of time.
- Semiconductor industry use normally the AEC Q100 standard as reference of quality test to perform
  - *"This document contains a set of failure mechanism based stress tests and defines the minimum stress test driven qualification requirements and references test conditions for qualification of integrated circuits (ICs)……"*

Reliability requirements

- Most of the cars actually drive less than 10000hrs over a car lifespan of up to 15 year
- Most of the electronics are also required to work 10000hrs, but some are powers all the time…
- The zero defect campaign means to keep the defect to a level as much as possible lower than 1ppm
- In order to proper setup the proper qualification plan for a product the mission profile is necessary (ie "*collection of relevant environmental load/stress and operation conditions to which a component will be exposed during its full lifecycle*")
- Reliability test done at qualification are not enough
  - Additional test in production are needed (IDDQ, Voltage stress, different temperature)
  - Design for 6 sigma approach is also very important

Reliability requirements



Source: ZVEI Handbook for robustness validation

- Some AEC Q100 tests:
  - Latchup
  - ESD
  - THB (temperature Humidity Bias) to check material (die, package) stability against humidity
  - HTOL (High Temperature Operating Lifetime) accelerated test for checking lifetime of the product
  - PTC (power temperature cycling) to check material and interfaces stability
  - ....

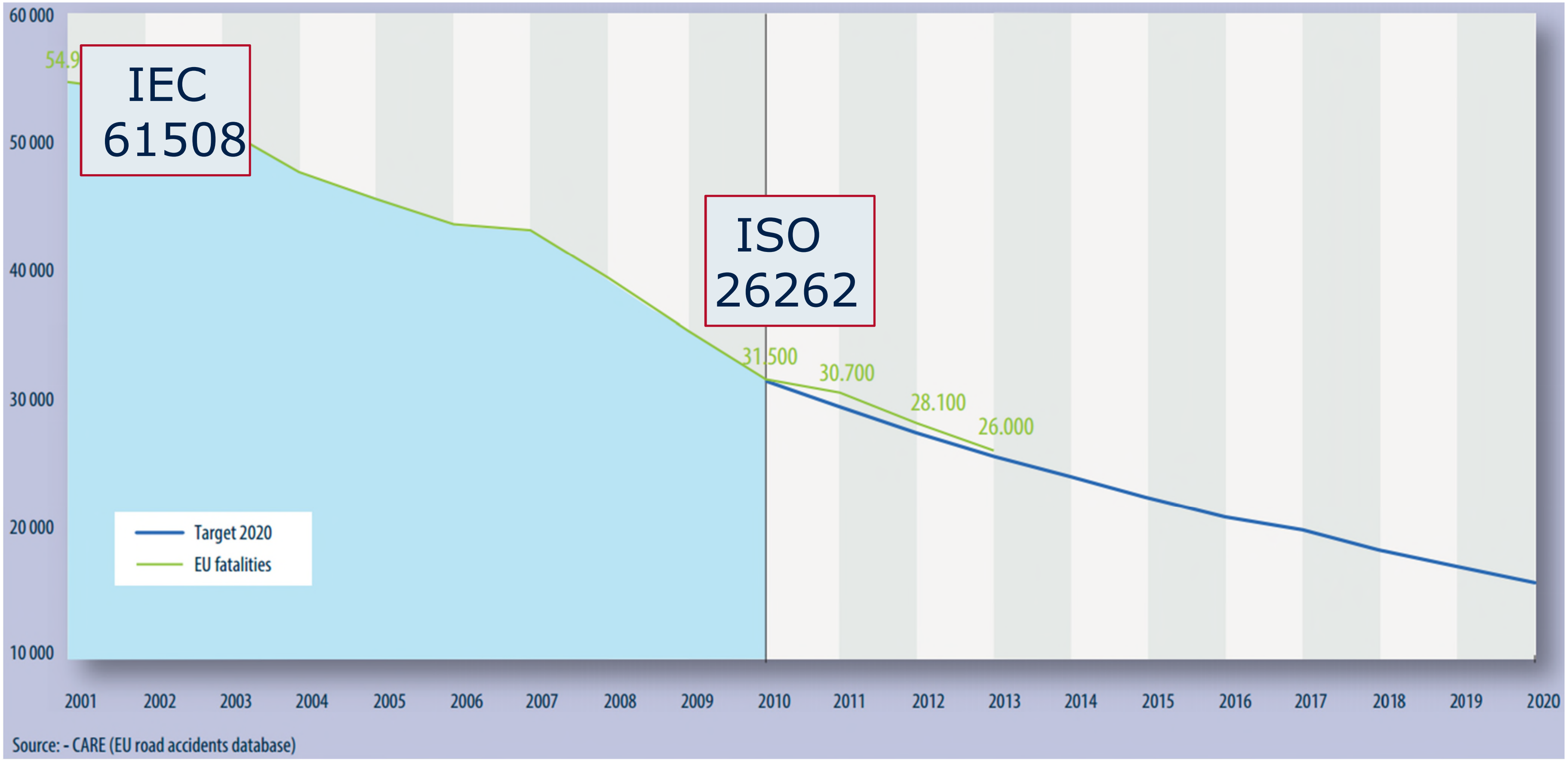
Agenda

- Automotive trends
- The CO2 revolution
- Power electronics main building blocks
- Automotive: harsh environment with lot of challenges
- Safety a “shall” requirement for Automotive

Standard help on the quality side

Objective: EU commission July 2010 has set the target to reduce traffic fatalities by 50% within the next ten years.

Standards have been a positive factor to control product Quality

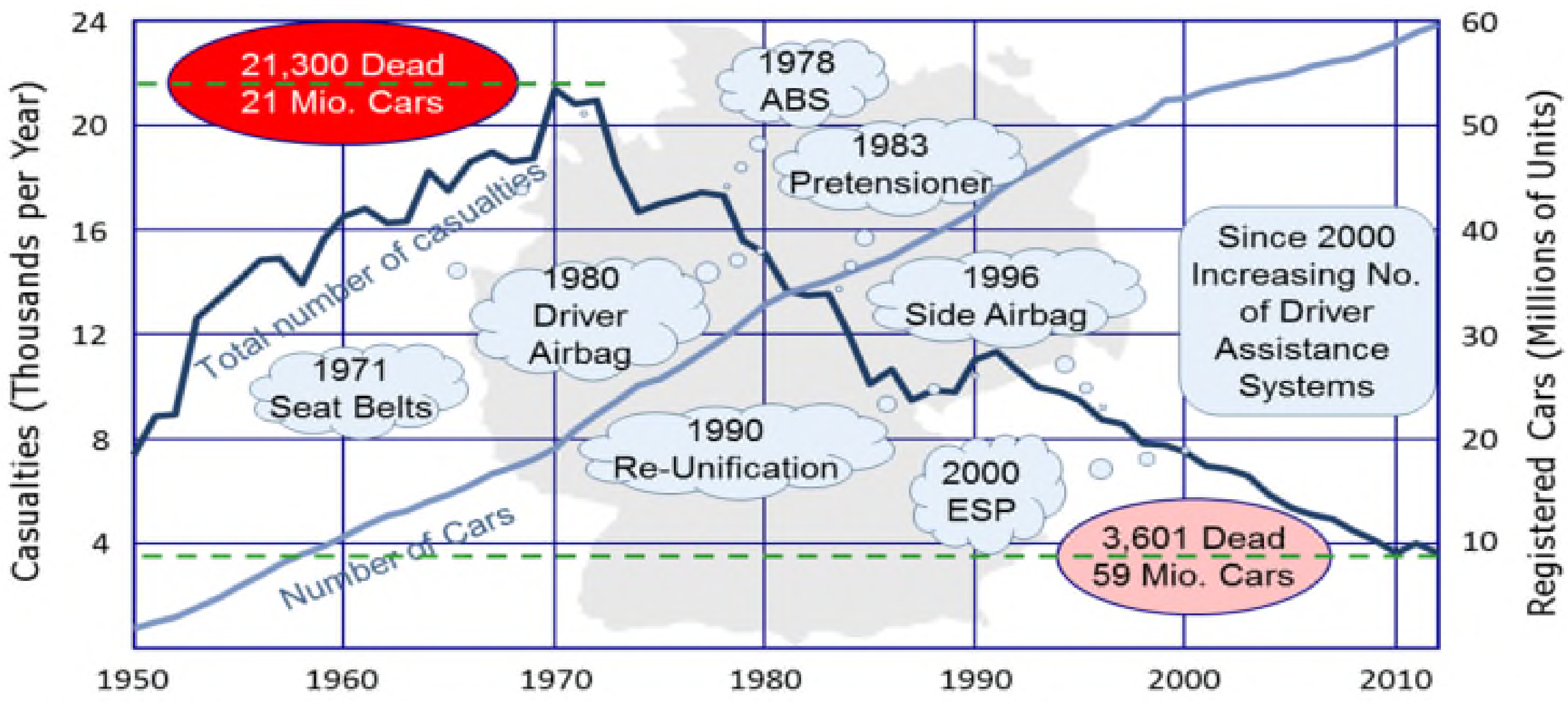


http://ec.europa.eu/transport/road_safety/pdf/observatory/move_affiche_hoz_en_2014_sansdebord.pdf

Why safety is important

- Safety mechanisms inserted in the cars demonstrate to be effective in saving lives

Safety



Source: Statistisches Bundesamt, Bosch 01/2013
Presented in WSC, Market Committee Report 05/2013

Safety in the car

- Safety systems in the cars can be grouped as
  - Passive safety → the aim is to reduce the accident consequence protecting vehicle occupant, but not reduce the accident probability
    - Restraint systems, Ecall…..
  - Active Safety → enhance the possibility to avoid accident, giving to drivers still the highest control of the vehicle
    - ABS, ESP….
  - Preventing Safety → prevent the condition that can lead to an accident
    - ADAS (Lane assist, blind spot detection, adaptive head lights…)

ISO 26262 Scope

- ISO 26262 **does Address**
  - E/E systems in mass production passenger cars
  - max gross weight up to 3.5 ton
  - possible hazards caused by malfunctioning E/E systems. E.g. Harm to:
    - Vehicle drivers / passengers
    - Others in locality of vehicle

- ISO 26262 **does not** address
  - Systems developed prior to the publication date
  - performance
  - does not address special purpose vehicles
    - designed for drivers with disabilities
  - Hazards due to
    - electric shock, Fire, Smoke, Heat, Radiation, Toxicity, Flammability, Reactivity, Corrosion, release of energy, etc.
    - unless directly caused by malfunctioning behaviour

ISO26262 as STATE OF THE ART

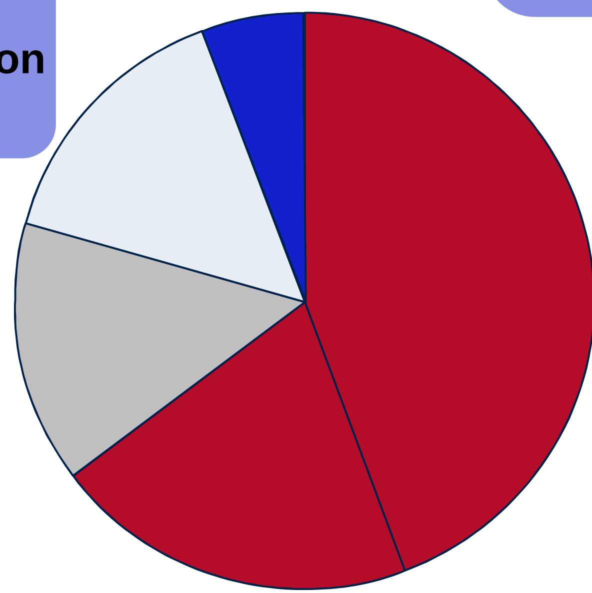
- It will be mandatory in Europe
  - Issued June 2011 as draft International Standard
    - stage 60.00 (standard under publication)
  - Issued Nov 2011 as International Standard
    - stage 60.60 (published)
  - First systems to comply by 2013
  - All systems to comply by 2015

- It is a new automotive industry "**State of the Art**"

- It will be viewed as 'best practice' in law
  - Not statutory requirements as yet…
  - Will be enforced by private legal actions

System failure – Example industry

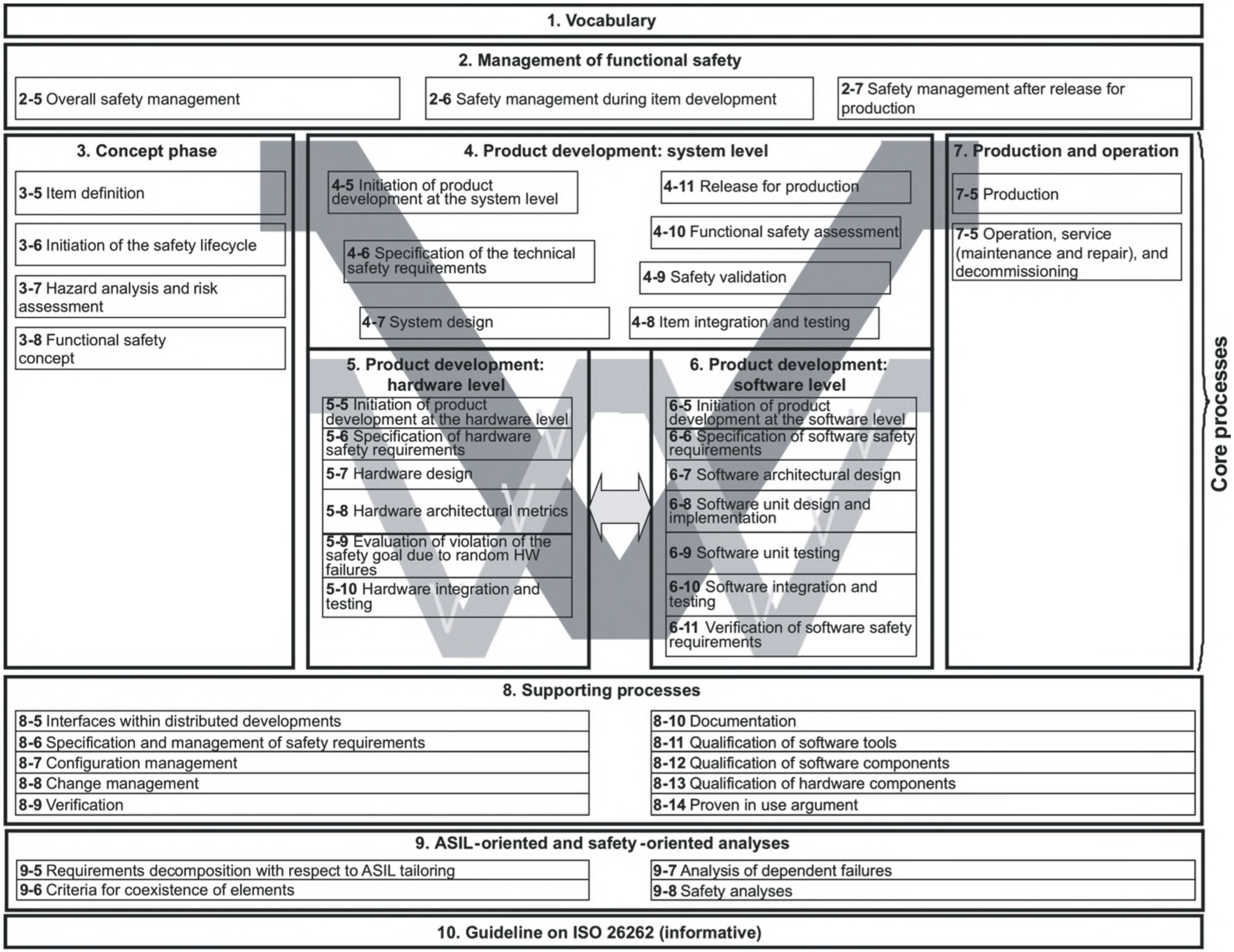
Over 80% off all failures are caused before any user touches installations



Only 15% of failures happen during operation and maintenance

Source: HSE UK report 1999, based on industrial accidents based on 34 incidents

ISO 26262 the lifecycle



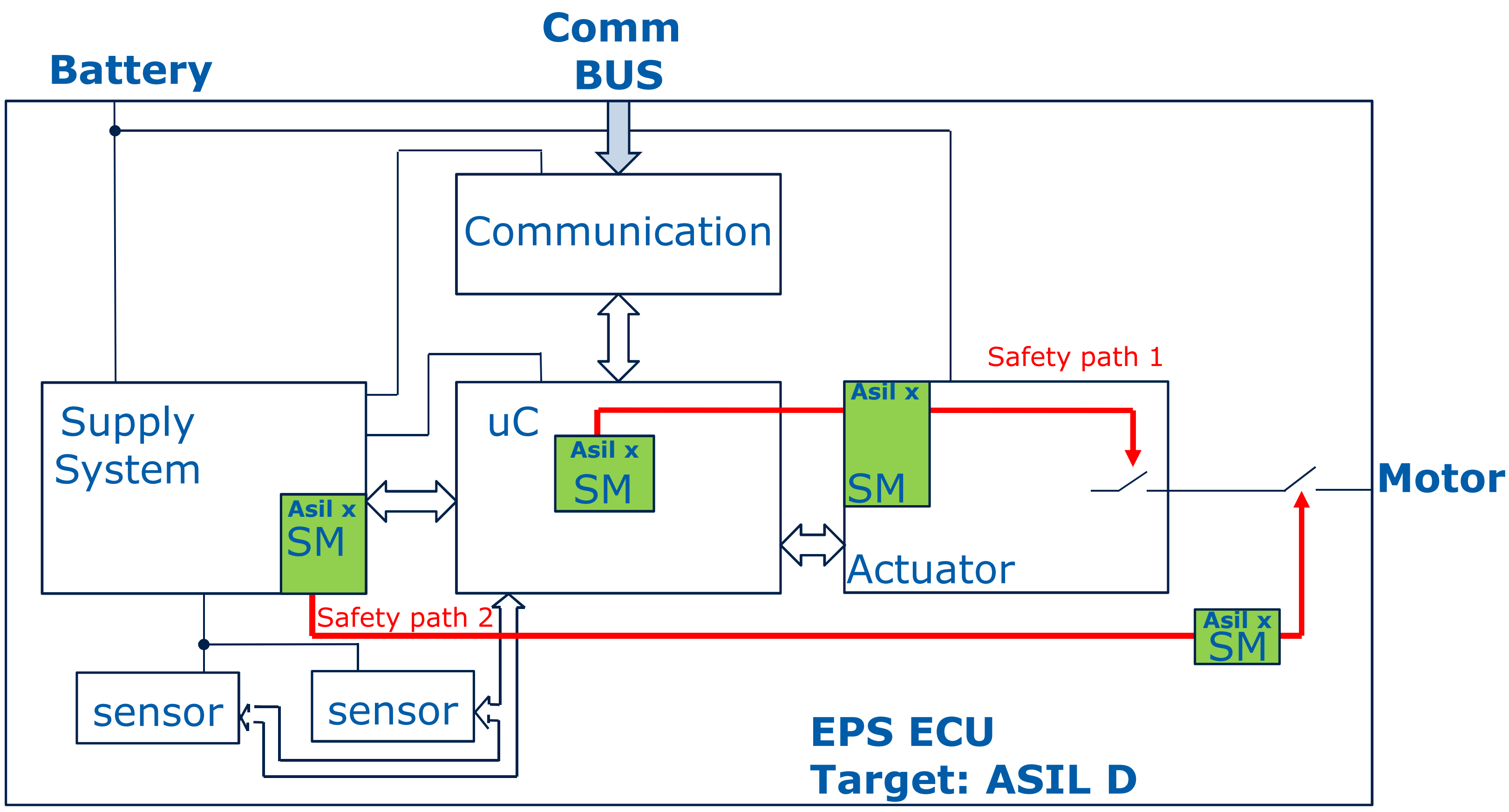
ISO 26262 → Vocabulary

- **Harm** = physical injury or damage to the health of people either directly, or indirectly as a result of damage to property or to the environment
- **Hazard** = potential source of harm
- **Hazardous Event** =hazardous situation which results in harm. Combination of a hazard and an operational situation
- **Risk** = Combination of probability and severity of a potential harm
- **Tolerable Risk** = risk which is accepted in a given context based on the current values of society
- **Safety** = Freedom from unacceptable risk
- **Safety Function** = Function to achieve or maintain a safe state
- **Safety Integrity** = Certainty that the safety functions are correctly performed

ISO 26262 → Vocabulary

- **Safe State** = operating mode of an item without an unreasonable level of risk
- **ASIL**= **A**utomotive **S**afety **I**ntegrity **L**evel
- **Cascading Failure=** Failure causing other elements of the same item to fail
- **Cascading Failure =** failure of two or more elements due to a single event or root cause
- **Redundancy=** existence of means in addition to the means that would be sufficient for an element (1.32) to perform a required function or to represent information
- **Diversity=** different solutions satisfying the same requirement with the aim of independence

Example of safe state in a EPS
2 power switch in series



Failures

- **Systematic failure=**

  failure, related in a deterministic way to a certain cause, that can only be eliminated by a change of the design or of the manufacturing process, operational procedures, documentation or other relevant factors

- **Random hardware failure =**

  failure that can occur unpredictably during the lifetime of a hardware element and that follows a probability distribution

- **Single-Point failure =**

  fault in an element that is not covered by a safety mechanism and that leads directly to the violation of a safety goal

- **Latent fault =**

  multiple-point fault whose presence is not detected by a safety mechanism nor perceived by the driver within the multiple-point fault detection interval

- **Safety Mechanism =**

  technical solution implemented by E/E functions or elements, or by other technologies, to detect faults or control failures in order to achieve or maintain a safe state

ISO 26262 → Vocabulary

- **ASIL**= **A**utomotive **S**afety **I**ntegrity **L**evel

  one of the four levels to specify the item's necessary requirements of ISO 26262 and safety measures for avoiding an unreasonable residual risk, with D representing the most stringent and A the least one

ASIL metrics → relative metrics

- For ASILB, ASILC and ASILD the single and multipoint faults metrics must be shown to meet the requirements in ISO26262 part 5 table F1

Single Point Fault Metric

$$= 1 - \frac{\boxed{\sum_{\text{Safety related HW elements}} (\lambda_{SPF} + \lambda_{RF})}}{\boxed{\sum_{\text{Safety related HW elements}} \lambda}}$$

Latent Fault metric

$$= 1 - \frac{\boxed{\sum_{\text{safety related HW elements}} (\lambda_{MPF\ Latent})}}{\boxed{\sum_{\text{safety related HW elements}} (\lambda - \lambda_{SPF} - \lambda_{RF})}}$$

	ASIL B	ASIL C	ASIL D
Single point faults metric	> 90 %	> 97 %	> 99 %
Latent faults metric	> 60 %	> 80 %	> 90 %

ASIL metrics → absolute metrics

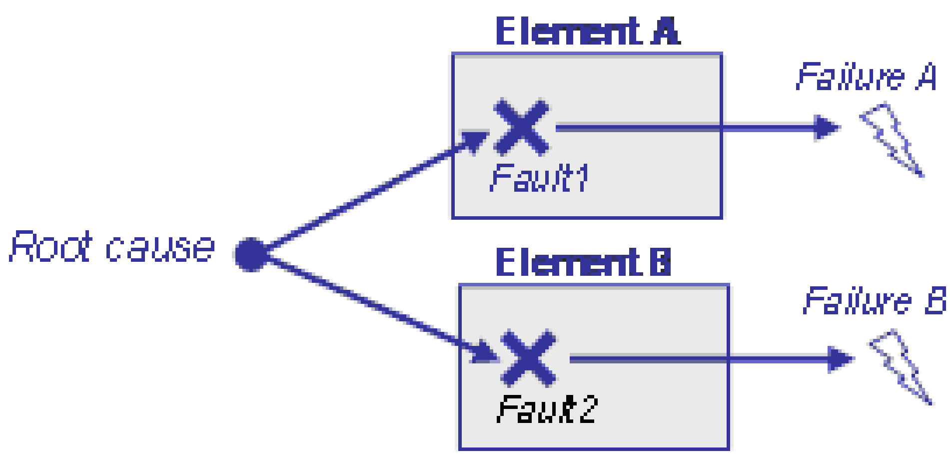
ASIL Level	Random HW failure target values
D	< *10-8/h* ++
C	< *10-7/h* ++
B	< *10-7/h* +
A	o

- **Cascading Failure =**

  Failure causing other elements of the same item to fail

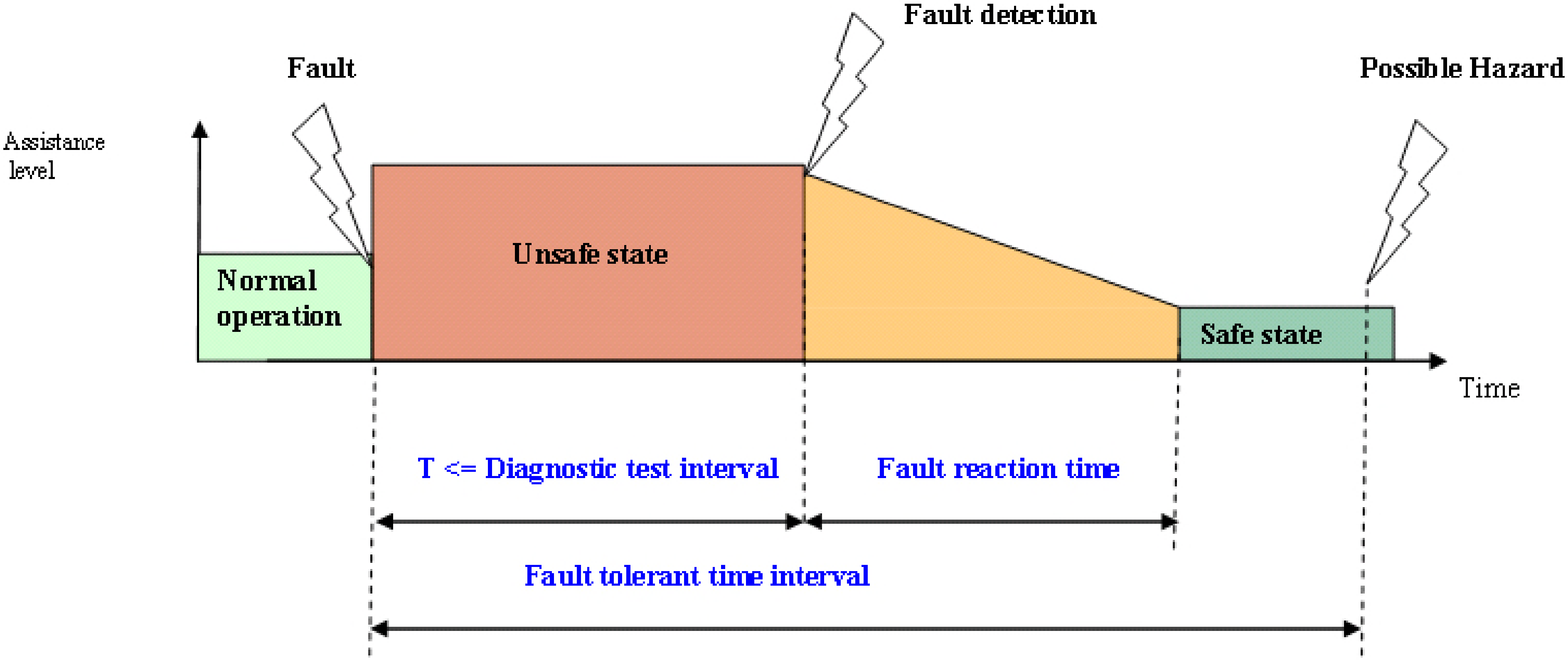
- **Common cause Failure =**

  failure of two or more elements due to a single event or root cause



Reaction time

Fault Reaction Time



Requirement Safety Flow

SeooC= Safety Element Out Of Contest

(in case of element development for different customert, eg ECU)

ITEM LEVEL
→ HARA to identify Safety Goal
→ Functional safety requirement allocated to System, external….

OEM

SeooC

SYSTEM LEVEL
→ Technical Safety Requirements allocated to HW/SW

Tier 1

SeooC

SeooC

HW LEVEL
→ Hardware Safety Requirements

Tier 2

SW LEVEL
→ Software Safety Requirements

HARA: Hazard Analysis and Risk Assessment

- Potential severity
  - S0: no injuries
  - S1: light and moderate injuries
  - S2: severe and life-threatening injuries –survival probable
  - S3: life-threatening injuries –survival uncertain

- Probability of exposure
  - E1: extremely low probability
  - E2: low probability
  - E3: medium probability
  - E4: high probability

- Controllability through the driver
  - C1: simply controllable
  - C2: normally controllable
  - C3: difficult to control or uncontrollable

		C1	C2	C3
S1	E1	QM	QM	QM
	E2	QM	QM	QM
	E3	QM	QM	ASIL A
	E4	QM	ASIL A	ASIL B
S2	E1	QM	QM	QM
	E2	QM	QM	ASIL A
	E3	QM	ASIL A	ASIL B
	E4	ASIL A	ASIL B	ASIL C
S3	E1	QM	QM	ASIL A
	E2	QM	ASIL A	ASIL B
	E3	ASIL A	ASIL B	ASIL C
	E4	ASIL B	ASIL C	ASIL D

Example: safety goals for airbag
SG1: avoid inadvertent airbag deployment

		C1	C2	C3
S1	E1	QM	QM	QM
	E2	QM	QM	QM
	E3	QM	QM	ASIL A
	E4	QM	ASIL A	ASIL B
S2	E1	QM	QM	QM
	E2	QM	QM	ASIL A
	E3	QM	ASIL A	ASIL B
	E4	ASIL A	ASIL B	ASIL C
S3	E1	QM	QM	ASIL A
	E2	QM	ASIL A	ASIL B
	E3	ASIL A	ASIL B	ASIL C
	E4	ASIL B	ASIL C	ASIL D

Example: safety goals for airbag
SG1: avoid inadvertent airbag deployment

		C1	C2	C3
S1	E1	QM	QM	QM
	E2	QM	QM	QM
	E3	QM	QM	ASIL A
	E4	QM	ASIL A	ASIL B
S2	E1	QM	QM	QM
	E2	QM	QM	ASIL A
	E3	QM	ASIL A	ASIL B
	E4	ASIL A	ASIL B	ASIL C
S3	E1	QM	QM	ASIL A
	E2	QM	ASIL A	ASIL B
	E3	ASIL A	ASIL B	ASIL C
	E4	ASIL B	ASIL C	ASIL D

Example: safety goals for airbag
SG2: avoid non deployment during a crash event

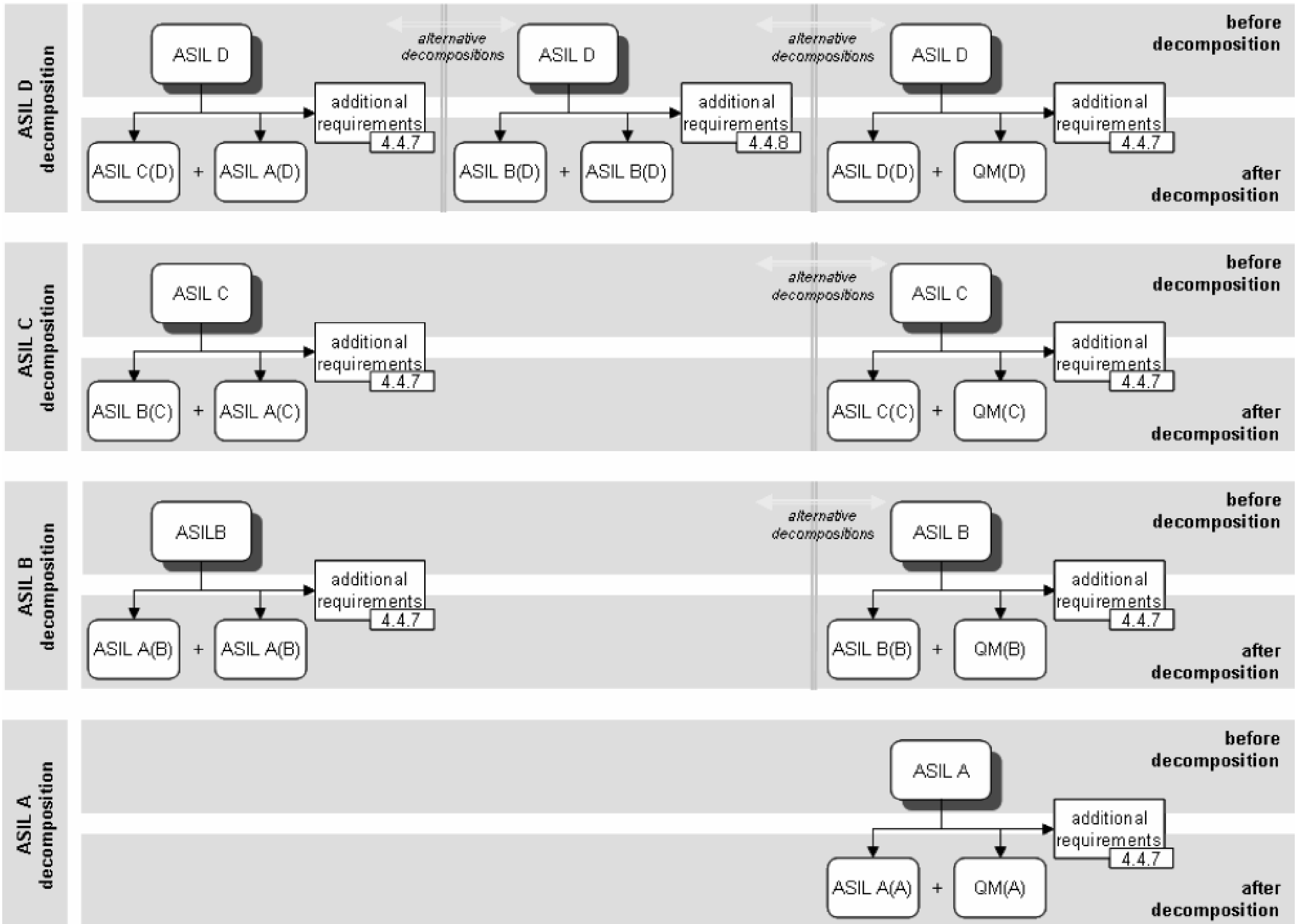
		C1	C2	C3
S1	E1	QM	QM	QM
	E2	QM	QM	QM
	E3	QM	QM	ASIL A
	E4	QM	ASIL A	ASIL B
S2	E1	QM	QM	QM
	E2	QM	QM	ASIL A
	E3	QM	ASIL A	ASIL B
	E4	ASIL A	ASIL B	ASIL C
S3	E1	QM	QM	ASIL A
	E2	QM	ASIL A	ASIL B
	E3	ASIL A	ASIL B	ASIL C
	E4	ASIL B	ASIL C	ASIL D

Example: safety goals for airbag
SG2: avoid non deployment during a crash event

		C1	C2	C3
S1	E1	QM	QM	QM
	E2	QM	QM	QM
	E3	QM	QM	ASIL A
	E4	QM	ASIL A	ASIL B
S2	E1	QM	QM	QM
	E2	QM	QM	ASIL A
	E3	QM	ASIL A	ASIL B
	E4	ASIL A	ASIL B	ASIL C
S3	E1	QM	QM	ASIL A
	E2	QM	ASIL A	ASIL B
	E3	ASIL A	ASIL B	ASIL C
	E4	ASIL B	ASIL C	ASIL D

ASIL decomposition

- The ASIL level can be decomposed between 2 independent element implemented the same safety goal



Redundancy Versus Diversity

- Redundant

(& Independent)

- Diverse

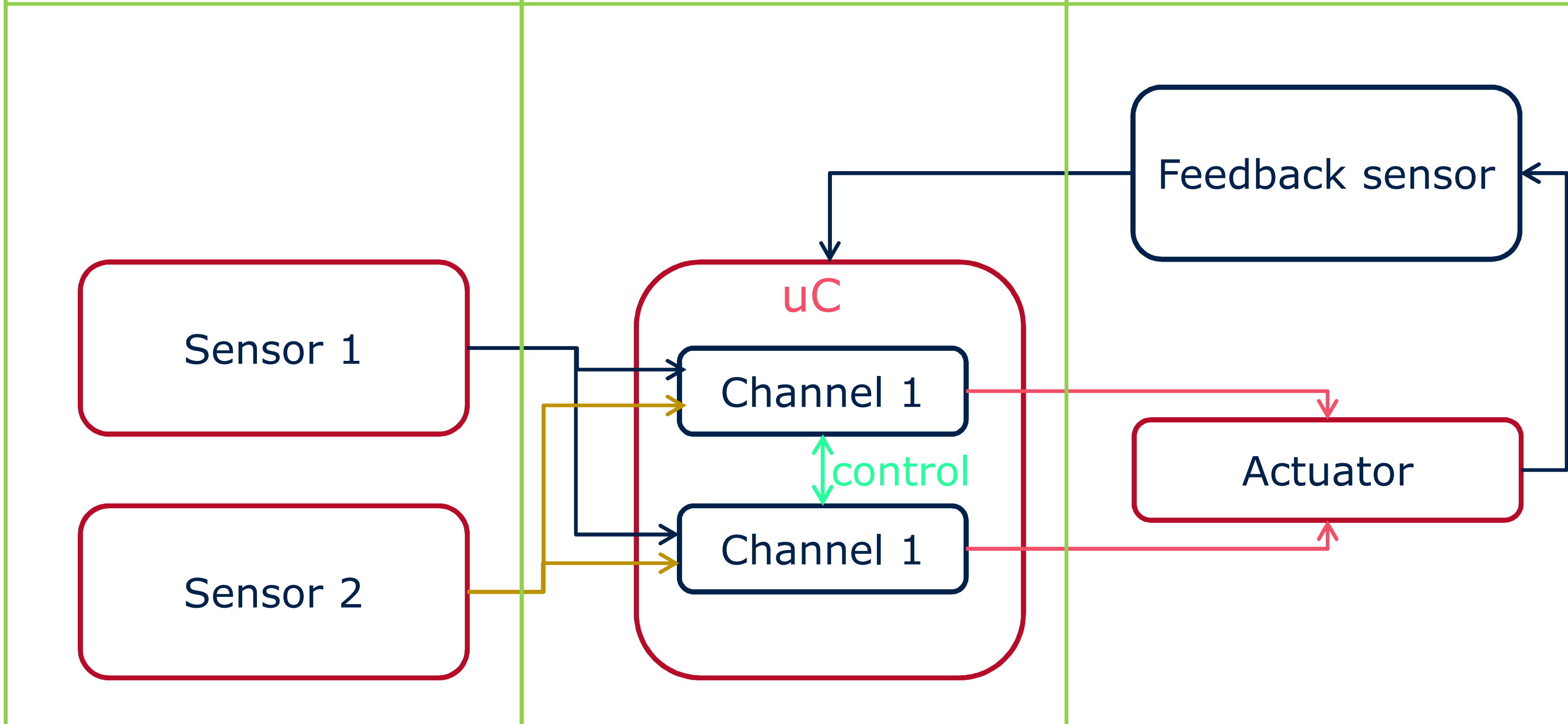
(& Independent)

Courtesy: Simon Brewertone

From system to HW

Safety Goal: e.g. “avid malfunctions of vehicle dynamics”
ASIL D

2 X ASIL B(D)	ASIL D	ASIL D



Redundancy (1oo2)	Redundancy within the uC (1oo2) + monitoring	Activation on dual demand

Coexistence and Freedom from interference

- Within the same system/HW function with different ASIL level can Coexist provided that they don't interfere directly or indirectly between each other.
  - If they interact, proper safety mechanism shall be provided to monitor and react in case the interaction compromise the ASIL function.

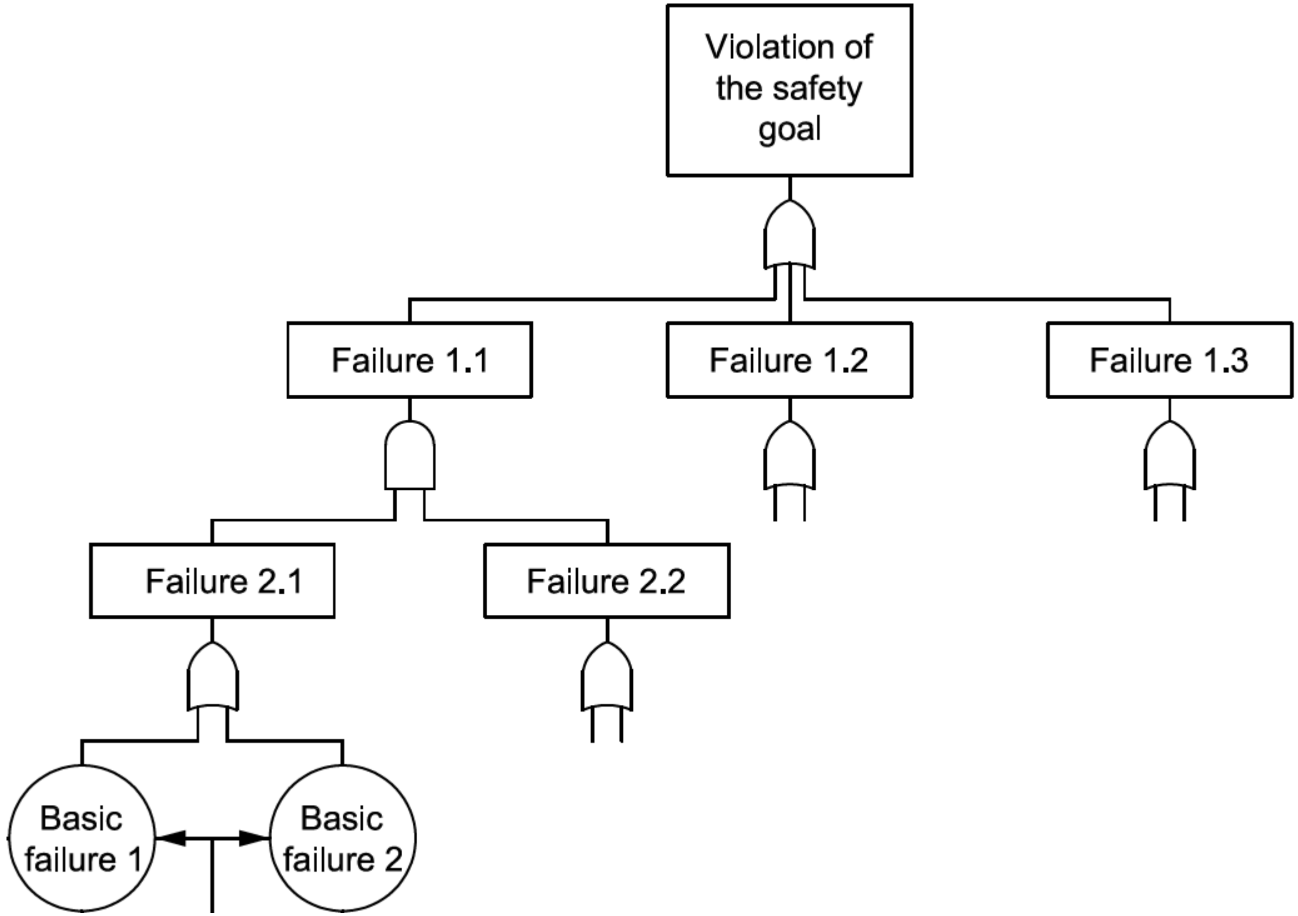
- Freedom from interference concept: the monitored function and the monitor shall be independent

Safety requires evidence

- Evidence and completeness is a key requirement for ISO 26262
- At each phase evidence shall be provided to prove that the TSRs are respected
- The most common safety analysis used to prove the effectiveness of the design are
  - Deductive analysis (e.g. Fault Tree Analysis (FTA) that is Top Down analysis) → especially at concept phase
  - Inductive analysis (e.g. Failure Mode Effect and Diagnostic Analysis (FMEDA) that is a Bottom Up analysis) → especially at the end of the design
  - Dependency Failure Analysis (DFA) to check the freedom from interference. It will analyse also the effect of common cause initiator (temperature, EMC, vibration….)

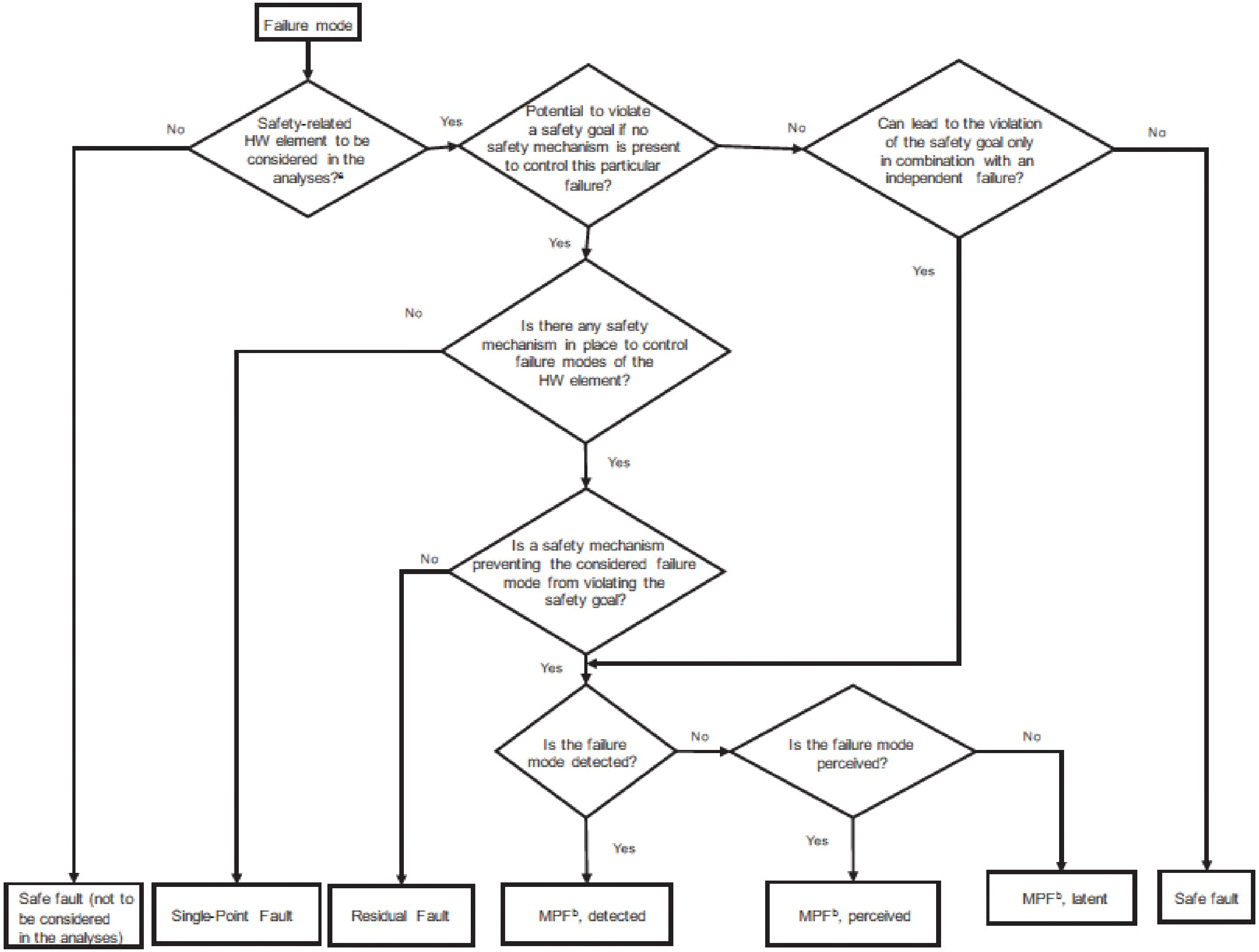
FTA → safety analysis to prove the concept

- Fault tree analysis (FTA) is very helpful especially in the concept phase to analyze the possible failure mode of the design



FMEDA → safety analysis of the design

- Failure Mode Effect and Diagnostic Analysis (FMEDA) is very helpful to quantify the failure contribution



FMEDA → safety analysis evaluate FIT rate

- Example of the analysis of a regulator within IC
- Generally the industry use the Siemens standard (SN 29500) to associate a FIT number to the design
- Diagnostic Coverage (DC) could be proved by fault injection

Name	Component	Qty	Function	Failure Mode	FM-Distribution	FM-Effect	Behavior	Lambda	Diagnostics	DC	Reference	Remarks
Linear Regulator	Regulator_Linear - Regulator all technologies =< 1 Watt (>30-300 transistors) --- No further functionality specified	1	5V supply	Input to output short	30,0%	Overvoltage	Dangerous	2,0E-08	Overvoltage supervision	99%		
				Input to output open	30,0%	No supply	Safe	2,0E-08	-	-		
				Change value high (up to 20%)	15,0%	Overvoltage	Dangerous	2,0E-08	Overvoltage supervision	99%		
				Change value low (up to 20%)	15,0%	Undervoltage	Dangerous	2,0E-08	Undervoltage supervision	60%		
				Output oscillates	10,0%	No effect	Safe	2,0E-08	-	-		

DFA → safety analysis to check common cause

Table A.7 — Topics for dependent failures evaluation, potential initiators and related measures

Topics of ISO 26262-9:2011, 7.4.2.3	Examples for potential initiators and coupling mechanisms	Examples for measures
Hardware failures	Physical defects able to influence both a part and its safety mechanism in such a way that a violation of the safety goal can occur	Can be addressed by measures like physical separation, diversity, production tests, etc.
Development faults	Faults introduced within development which have the capability to cause a dependent failure, for example, crosstalk, incorrect implementation of functionality, specification errors, wrong microcontroller configuration, etc. (see also A.3.7)	Can be addressed by measures like development process definition, diversity, design rules, configuration protection mechanisms, etc.
Manufacturing faults	Faults introduced within manufacturing which have the capability to cause a dependent failure, for example, masks misalignment faults	Can be addressed by a thorough production test of the microcontroller
Installation faults	Faults introduced during installation which have the capability to cause a dependent failure, for example, microcontroller PCB connection, interference of adjacent parts, etc.	Can be addressed by production test of ECU, installation manuals, etc.
Repair faults	Faults introduced during repair which have the capability to cause a dependent failure, for example, faults in memory spare columns/rows	Can be addressed by production tests, repair manuals, etc.
Environmental factors	Typical environmental factors are temperature, EMI, humidity, mechanical stress, etc.	Can be addressed by measures like qualification tests, stress tests, dedicated sensors, diversity, etc.
Failures of common internal and external resources	For a microcontroller, typical shared resources are clocks, reset and power supply, including power distribution	Can be addressed by measures like clock supervision, internal or external supply supervision, diverse distribution, etc.
Stress due to specific situations, e.g. wear, ageing.	Ageing and wear mechanisms are, for example, electro migration, etc.	Can be addressed by design rules, qualification tests, diversity, start-up tests, etc.

Safety Case

- Safety Case aims to provide the evidence that all the safety requirements are complete and satisfied!

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