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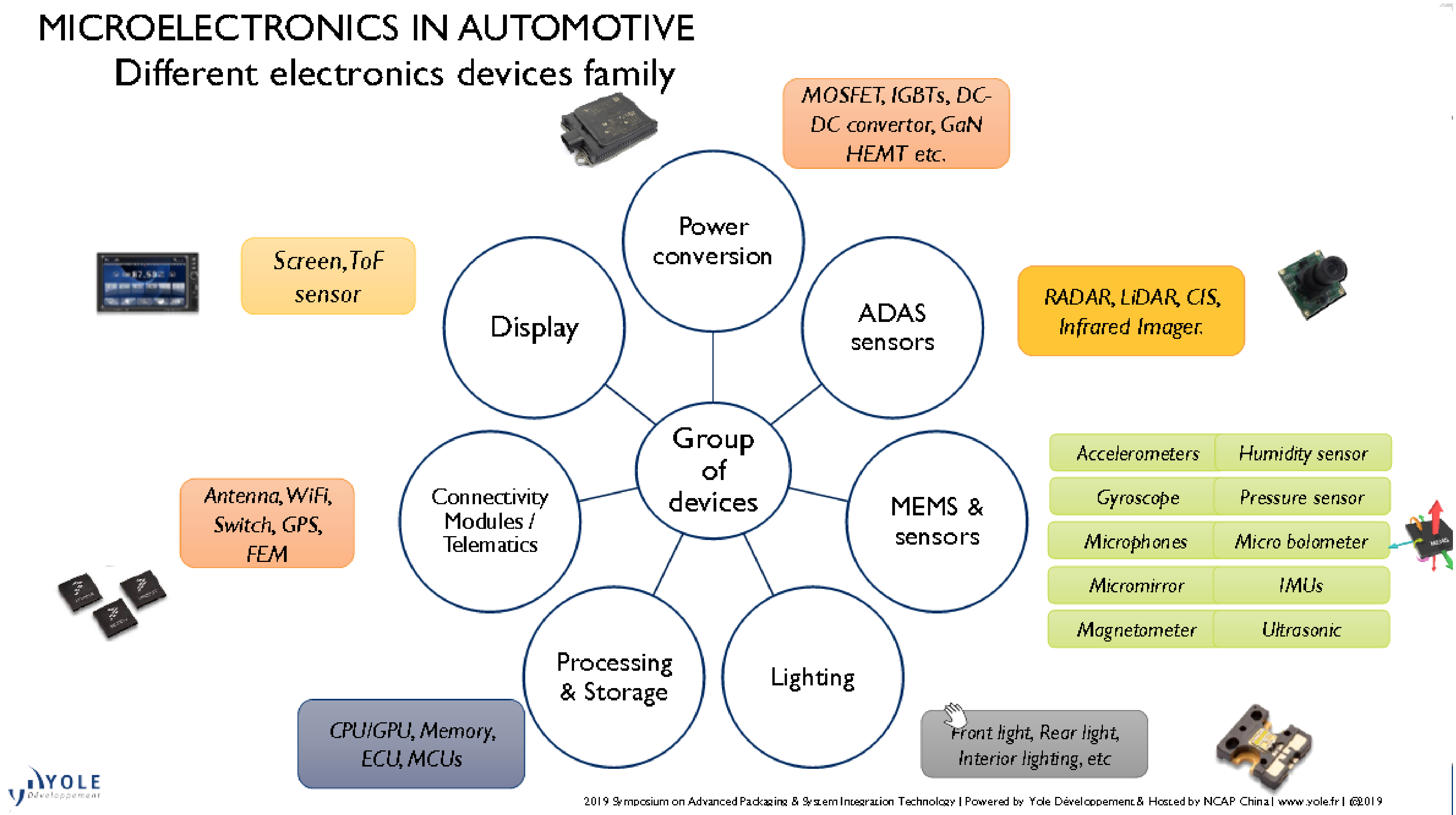
Automotive Packaging Trends
- Challenges and Solutions

EungSan Cho
Thorsten Meyer
Infineon Technologies

IMAPS Device Packaging
Mar 3rd 2020
T-AM3: 064

Microelectronics in Automotive

Up to 80% of all Innovations enabled by Semiconductor



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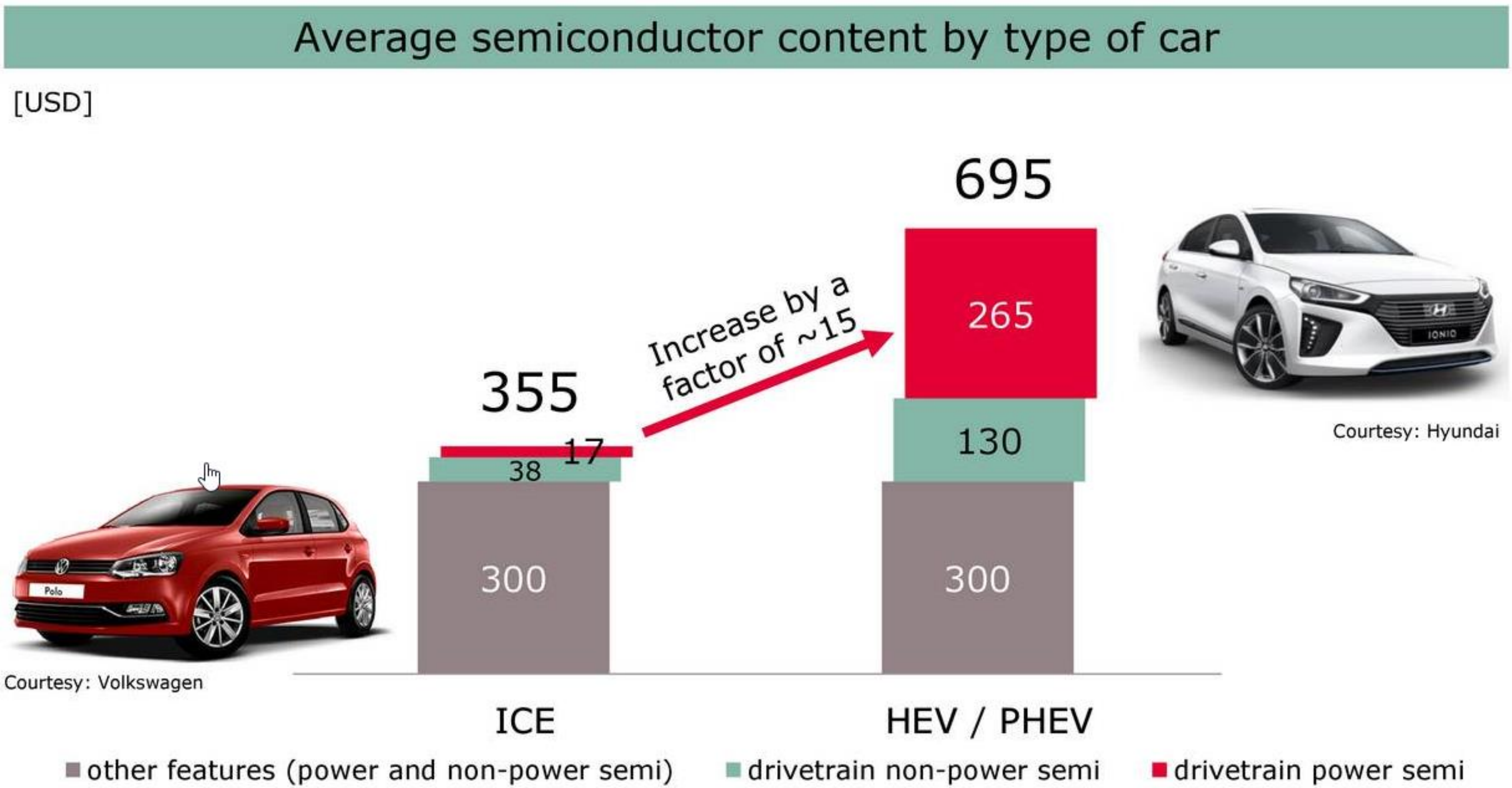
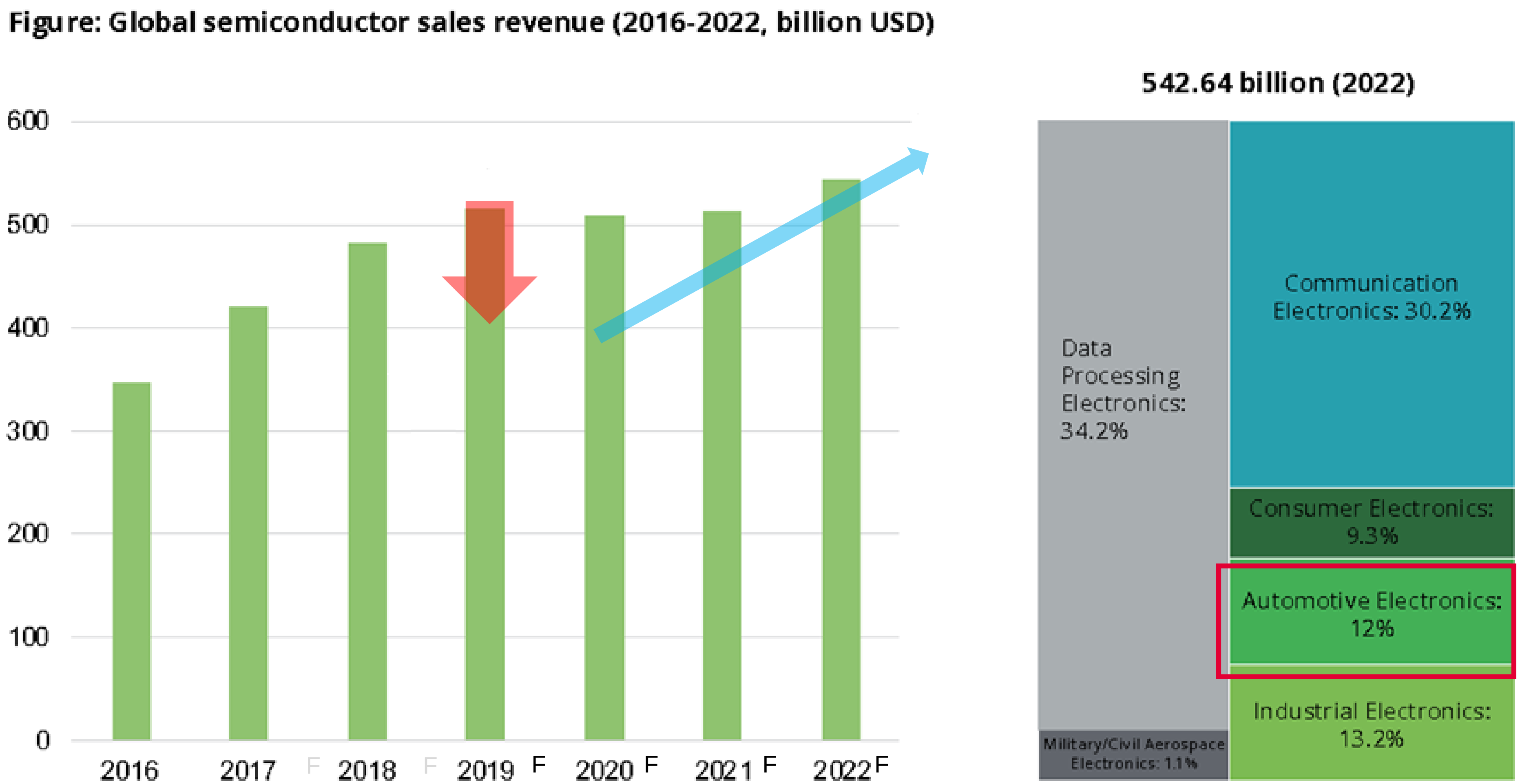
From ICE to EV

Power Semiconductor in Powertrain increases by ~15x



Semiconductors in Automotive Applications
Trend

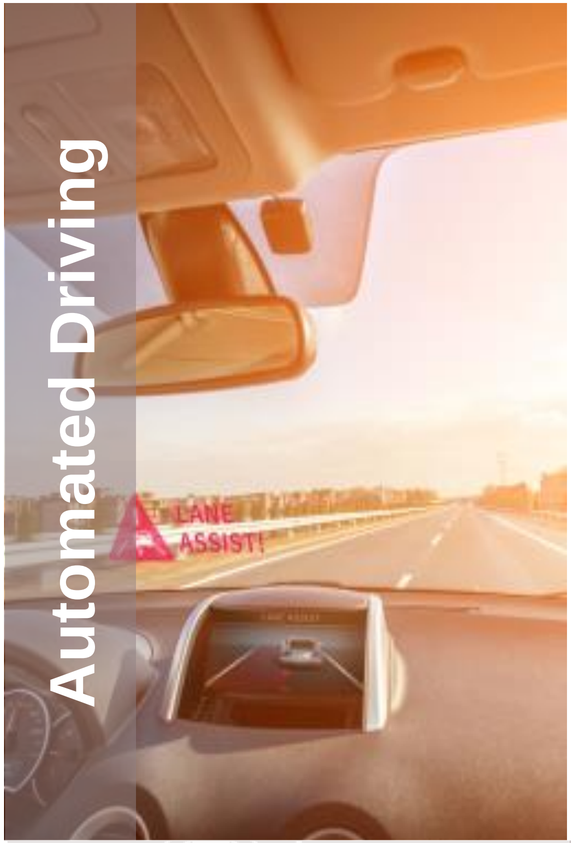


- 12% of Semiconductor Market in Automotive
- 80% of all ATV Innovations supported by semiconductors

Source: McKinsey & Company, 2016

Megatrends are Shaping the Automotive Market

Significant Increase of Semi Content per Car



Enabling safety towards Vision Zero

Enabling CO_2 reduction

Enabling the communication of cars

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ATV Drivers to Package Technical Requirements
Translation

Automated cars

e-Mobility

Connectivity

- Functional safety
- Increased features (redundancy, storage, performance)
- Extended profiles (charging, car sharing)
- High power (48V, SiC)
- Competitive environment

Miniaturisation ⟺ Higher functional integration ⟺ Enhanced electrical and thermal performance ⟺ Longer reliability assessments

- Reduced package costs
- Reduced development time (t2m)

- System in package
- Thermally enhanced solutions*
- High power density packages
- Robust packages

* Integration on system-level with customer

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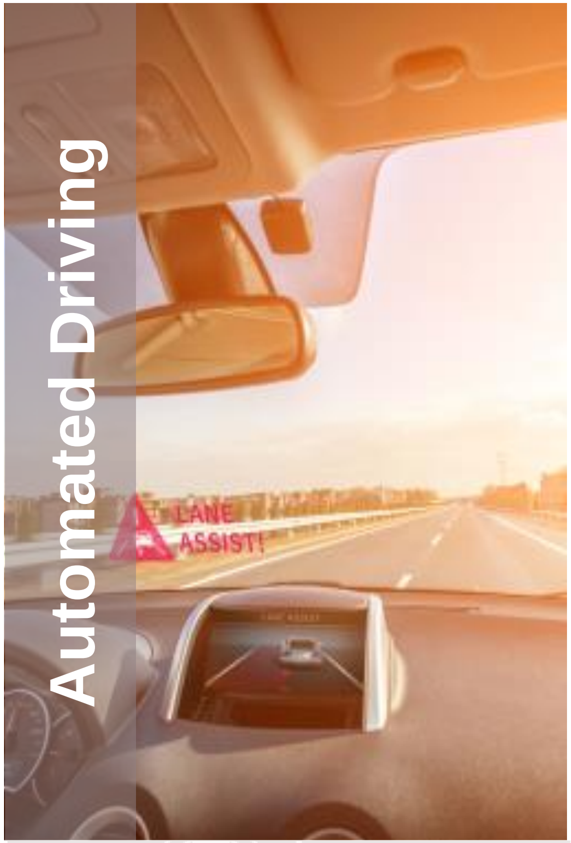
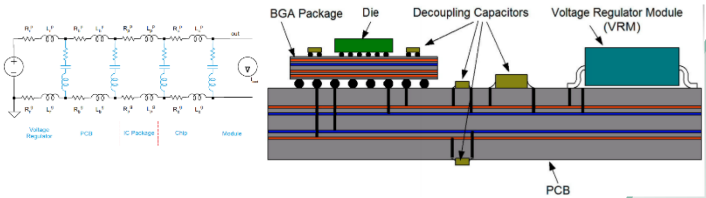


Enabling safety towards Vision Zero

Enabling CO_2 reduction

Enabling the communication of cars

Automotive Requirements
More Computation Power/ Higher Integration

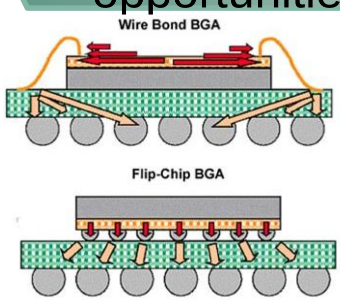


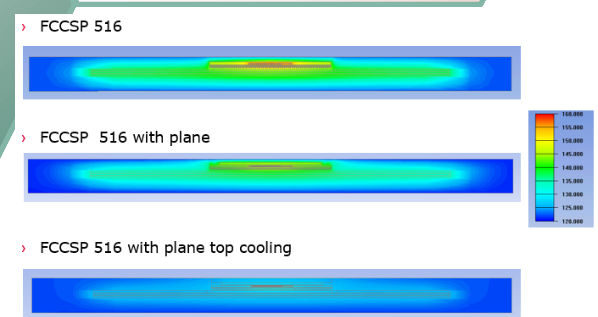
High frequency
⇩
Dynamic load & EMI criticality increases
⇩
Passive on package required

IR-drop and power integrity becomes critical
⇩
Short interconnect mandatory
⇩
Flip Chip technologies offer opportunities

…While keep automotive requirements (reliability, quality)…

Advanced cooling solutions
(+ customer system integration)
⇧
Bottom & Top cooling necessary
⇧
High power
(5W or more)





Definition of the Harsh Environment

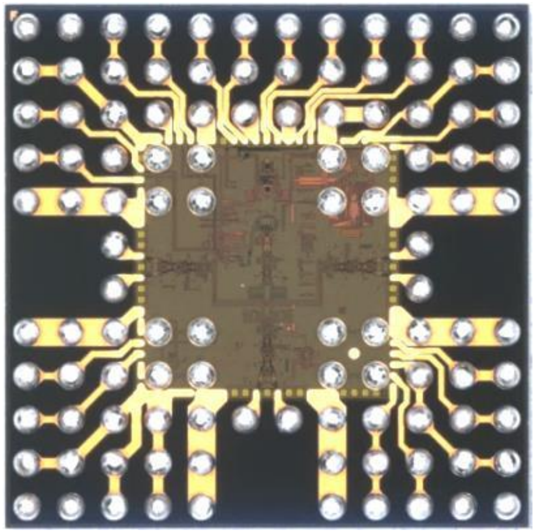
Based on Expertise

- For automotive products the Q 100/101 is a minimum mandatory qualification requirement
- Additionally IFX has defined a clear and quantitative minimum outgoing quality requirement that shall be achieved for automotive molded packages
- There is a trend towards Grade 0 / Q006 / robust validation
- For applications in other harsh environments there are special test requirements applied, e.g.
  - Applications in exhaust gas system: Iodid, Diiodmethan, corrosive gases
  - Applications in gear boxes: hot oil
  - Sensors: Shock Tests, several media tests

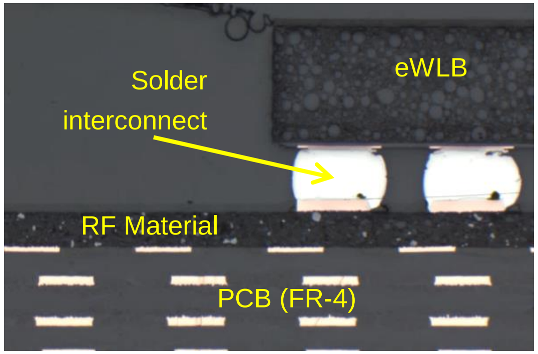
- But with the change to electric drives, some of these applications will vanish
- May open a path for consumer packages to automotive

eWLB Radar

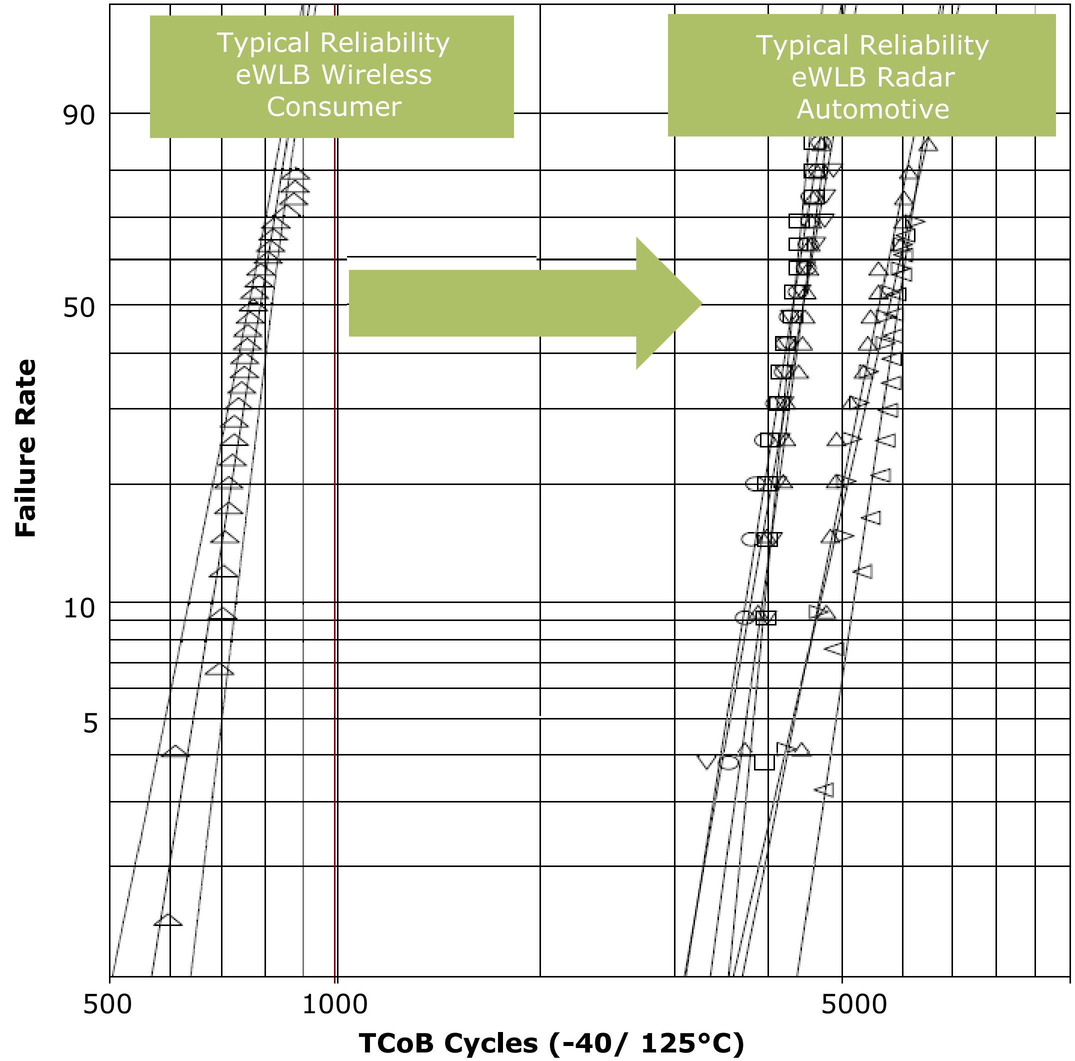
Serving Automotive Market



eWLB Radar



eWLB Radar
Cross section on board

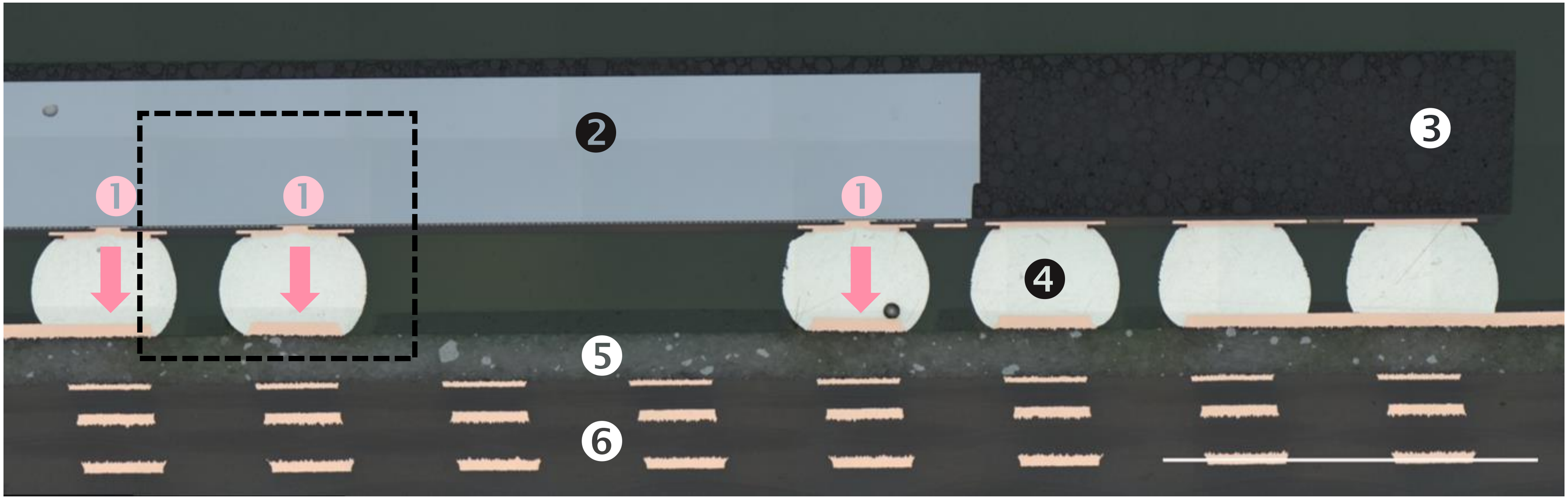


- TCoB performance increase for Automotive
- Redundant electrical connections concept

Consumer Package for Automotive

eWLB Radar - Summary

eWLB Radar cross-section

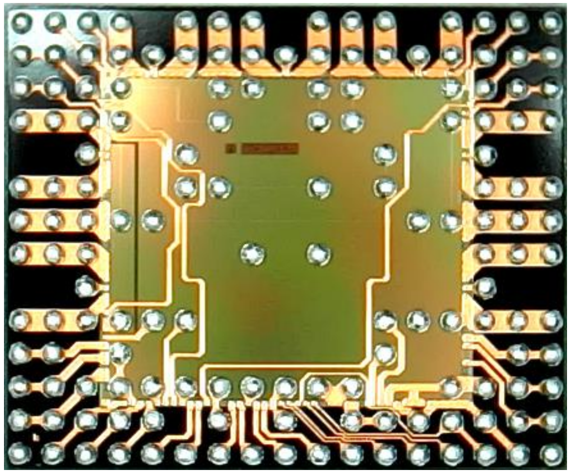


❶ Thermal ball
❷ Silicon
❸ Mold compound
❹ Solder balls
❺ RF-sheet
❻ FR4-layers

- Typical fatigue modes after TCoB are solder ball, UBM, and RDL fatigue
- Solder fatigue has not reducing driving force and can cause end-of-life failure

- Use of consumer packages for automotive required adaptations in the package in order to achieve customer requirements

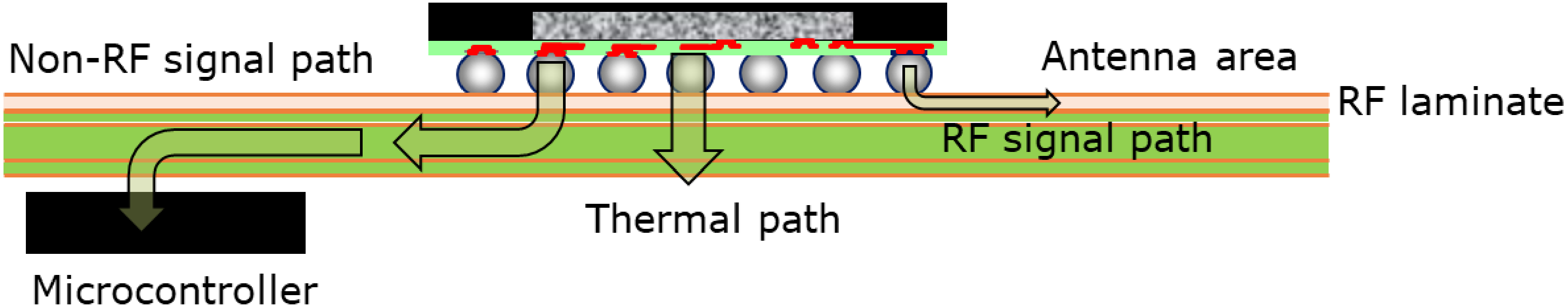
Consumer Package for Automotive
eWLB Radar - Summary



2nd generation eWLB Radar

Development trends

- Increased package sizes
- Variety of RF board materials
- Increased number of integrated RF-channels
- Increased out-put power and heat dissipation

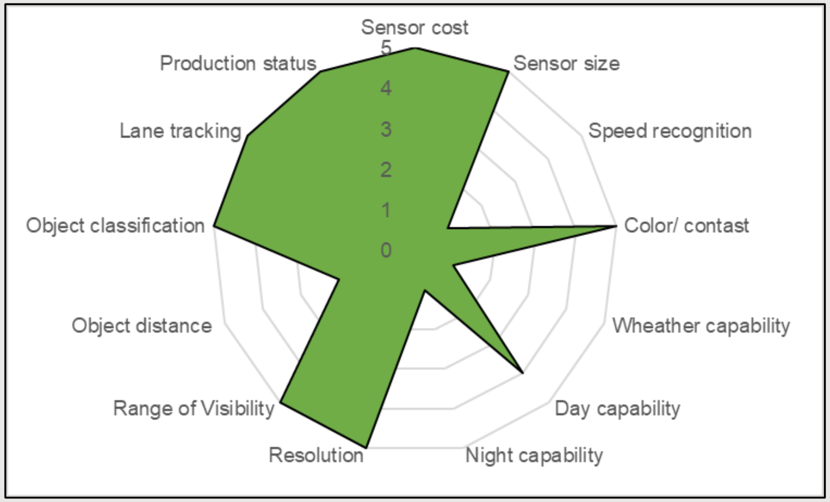


https://www.i-micronews.com/products/bosch-mid-range-radar-mrr-sensor/

ADAS Sensors

Assessment – Camera & Radar

CAMERA



Performance Overview of Camera

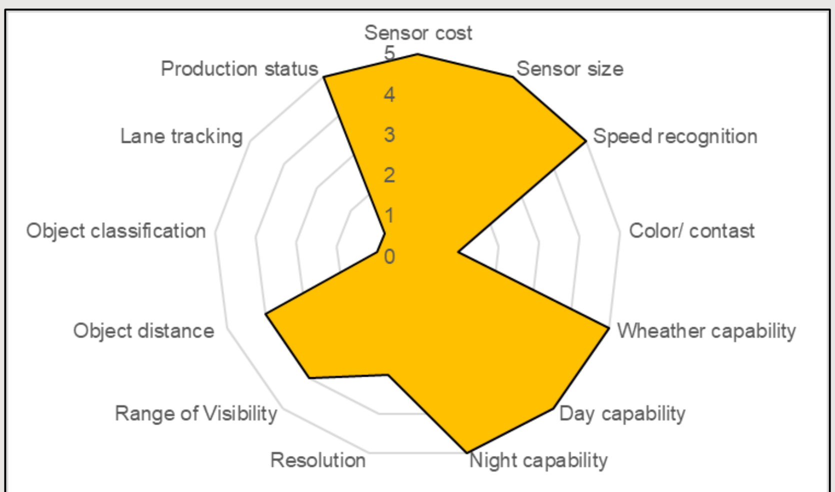
Advantages

- ❑ Low cost
- ❑ High resolution and range
- ❑ Color and contrast detection
- ❑ Availability

Trade-offs

- ❑ Wheather impact high
- ❑ Light dependence
- ❑ No speed recognition

RADAR



Performance Overview of Radar

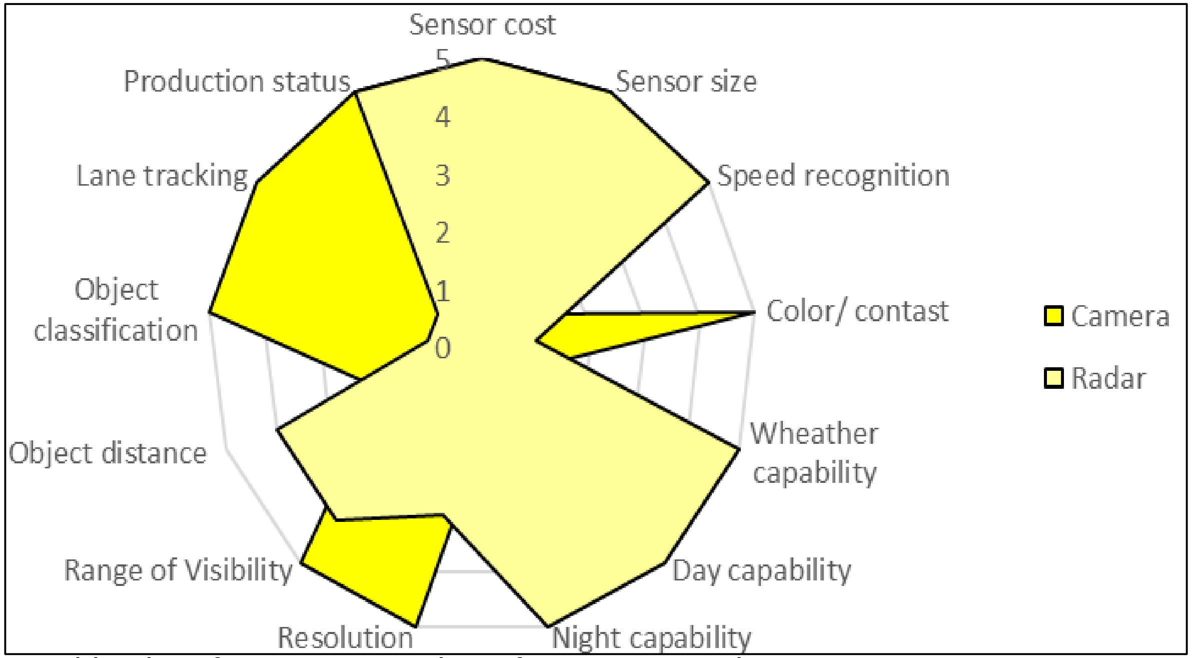
Advantages

- ❑ Low cost
- ❑ Accurate speed recognition
- ❑ No wheather issues
- ❑ Availability

Trade-offs

- ❑ Resolution
- ❑ No colors/ low contrast
- ❑ Object classification

ADAS Sensors
Assessment - Summary



Combined Performance Overview of Camera & Radar

Summary:

- ADAS sensors show advantages and trade-offs
- The combination of sensory allows coverage of needs
- Sensor Fusion will be likely for autonomous/ ADAS functions
- Lidar will require cost and dimension reduction for brought acceptance

Autonomous Driving
Reliability Requirements

Pictures: © Audi AG

Contributing factors

- Strong demand for **high performance computing power**
- Need for various **sensor technologies**, mostly for use in outside mounting places
- Driverless operation allows **extended use time**
- Conditionally and highly automated driving will reach SAE levels 3 and 4, following then also in complex traffic situations and will finally reach Level 5

Consequences

- Rising **gap between ambient and junction temperature** requirements (due to enhanced self heating)
- Mounting places (for sensors) with influence of **corrosive chemicals**
- **Increased operating time** (significantly increase from roughly 9,000 hours towards 50,000 hours and more (considering charging time for the HV/EV))

Courtesy of U. Abelein

Megatrends are shaping the Automotive Market

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Enabling safety towards Vision Zero

Enabling CO_2 reduction

Enabling the communication of cars

FHEV: Full hybrid EV

PHEV: Plug-in hybrid EV

BEV: Battery EV

eMobility
The Beginning in 1900s...

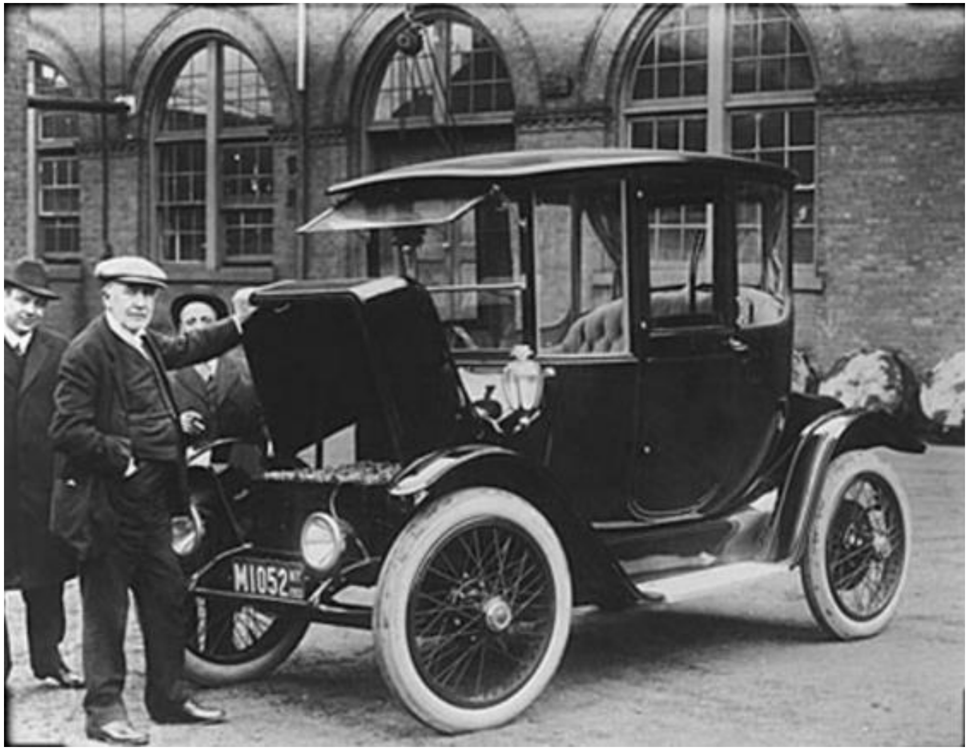

Photo of Thomas Edison with an electric car in 1913

Year 1899/ 1900

- Electric vehicles outsold all other types of cars
- 28 percent of all 4,192 cars produced in the US in 1900 were electric (source: American Census)
- And the total value of electric cars sold was more than gasoline and steam powered cars combined that year

Year 1912

- Electric cars peak

Year 1935

- Henry Ford's mass production of internal-combustion engines made gas-powered cars significantly cheaper than electric cars
- In 1912 an electric roadster priced at about $1,750, whereas a gas-powered car cost only $650

Source: Wikipedia

eMobility
The Continuation...

- In the 1960s and 1970s, the interest in electric cars began to grow again (even if car optics showed some improvement potential)

- 1970
- **RT1** electric car prototype
- Seattle, Washington

- 1974
- **Sebring Vanguard**
- Pyramid-shaped two passenger vehicle

- **Zagato Zele**
- Produced by Zagato (Italy)
- Sold in US by Elcar Corp.
- Speed 45 mph, range 60mi
- Cost $4,000-$4,500.

- The 1990 Clean Air Act Amendment and the 1992 Energy Policy Act helped spur investment again in electric vehicles
- The California Air Resources Board also passed new regulations that required automakers to make and sell a zero-emissions vehicle in order for them to market their cars in the state.

Source: Wikipedia

E-Mobility
Reliability Requirements

Operating Situation	Vehicle parked	Charging cable inserted	High-voltage battery pack charging	Power line comm active (if available)
Driving Operation	no	no	yes/ no	no
Charging Operation	yes	yes	yes	Yes
Preconditioning	yes	yes/ no	yes/ no	yes/ no
On-Grid Parking	yes	yes	no	yes
Off-Grid Parking or Parking	yes	no	no	no

Operating states for e-vehicles according to LV124

- Automotive lifetime requirements today
  - Life time 15 years
  - Operation time 10,000 h
  - Mileage 300,000 km

- Example requirements for electric vehicles
  - Driving operation 8,000 h
  - Charging operation 30,000 h
  - Off-grid parking 92,000 h

Note: These requirements apply to the (passenger) vehicle in a more or less private use, subsystems and ECUs within the vehicle already today face different lifetime requirements.
A different user profile may result in totally different lifetime requirements.

Note: 5,500 h comfort-preconditioning (e.g. heating the cabin) might be estimated although not required as a state in the table

Extended Mission Profiles

Today

Example:

Microcontroller for **use in a battery charging system**

- Lifetime (same like vehicle) 15 years
- Op. Ambient Temp. Range -40 °C to 125 °C
- Non-operating time 91,400 hours
- Operating time 40,000 hour

Is an AEC-Q100 qualification covering the lifetime?

Customer Mission Profile*

$T_{ambient}$ [°C]	Time [h]
Operating	
125	400
120	3,200
76	26,000
23	8,000
-40	2,400
Non Operating	
85	914
80	7,312
60	59,410
23	18,280
-40	5,484

*) Arbitrary chosen, corresponding to “Automotive Application Questionnaire for Electronic Control Units and Sensors”, ZVEI, October 2006

Extended Mission Profiles

AEC-Q100 qualification covering the lifetime?

Equivalent HTSL stress time

Assumptions:
Arrhenius Model with E_a=0.7 eV
Self heating: 20 °C

$$t_f = A \cdot \exp\left(\frac{E_a}{kT}\right)$$

Result:
$T_{stress,eq}$ @ 175 °C = 1,521 h
$T_{stress,eq}$ @ 150 °C = 4,437 h

AEC-Q100 stress test conditions (Grade 1)

500 hours @ 175 °C or
1000 hours @ 150 °C

<30% coverage

AEC-Q100 stress test conditions (Grade 0)

1000 hours @ 175 °C or
2000 hours @ 150 °C

~60% coverage

Customer Mission Profile*

$T_{ambient}$ [°C]	Time [h]
Operating	
125	400
120	3,200
76	26,000
23	8,000
-40	2,400
Non Operating	
85	914
80	7,312
60	59,410
23	18,280
-40	5,484

*) Arbitrary chosen, corresponding to "Automotive Application Questionnaire for Electronic Control Units and Sensors", ZVEI, October 2006

E_a: Activation Energy

E-Mobility
Reliability Requirements

Contributing factors

- **Additional operating states** beside driving and parking:
  - On-grid parking
  - Vehicle-Preconditioning (battery as well as driver comfort like cabin heating)
  - Charging

Table 45: Description General part

Operating situations

Operating situation	Vehicle parked	Charging cable inserted	High-voltage battery pack charging	Power line communication active (if available)
Driving operation	no	no	yes/no	no
Charging operation	yes	yes	yes	yes
Preconditioning	yes	yes/no	yes/no	yes/no
On-grid parking	yes	yes	no	yes
Off-grid parking or parking	yes	no	no	no

Consequences

- **Increase in operating times**
- Power electronics will increase the efficiency of power electronics (e. g. **SiC**)
- Max. **operational temperature** will **rise** (200°C and above)
  - New materials (e. g. encapsulating materials) required to fulfill these new requirements
  - Sensors and microelectronic components will be added to systems so that heterogeneity and complexity is increased
  - Systems will have to be developed in a shorter time and at lower cost

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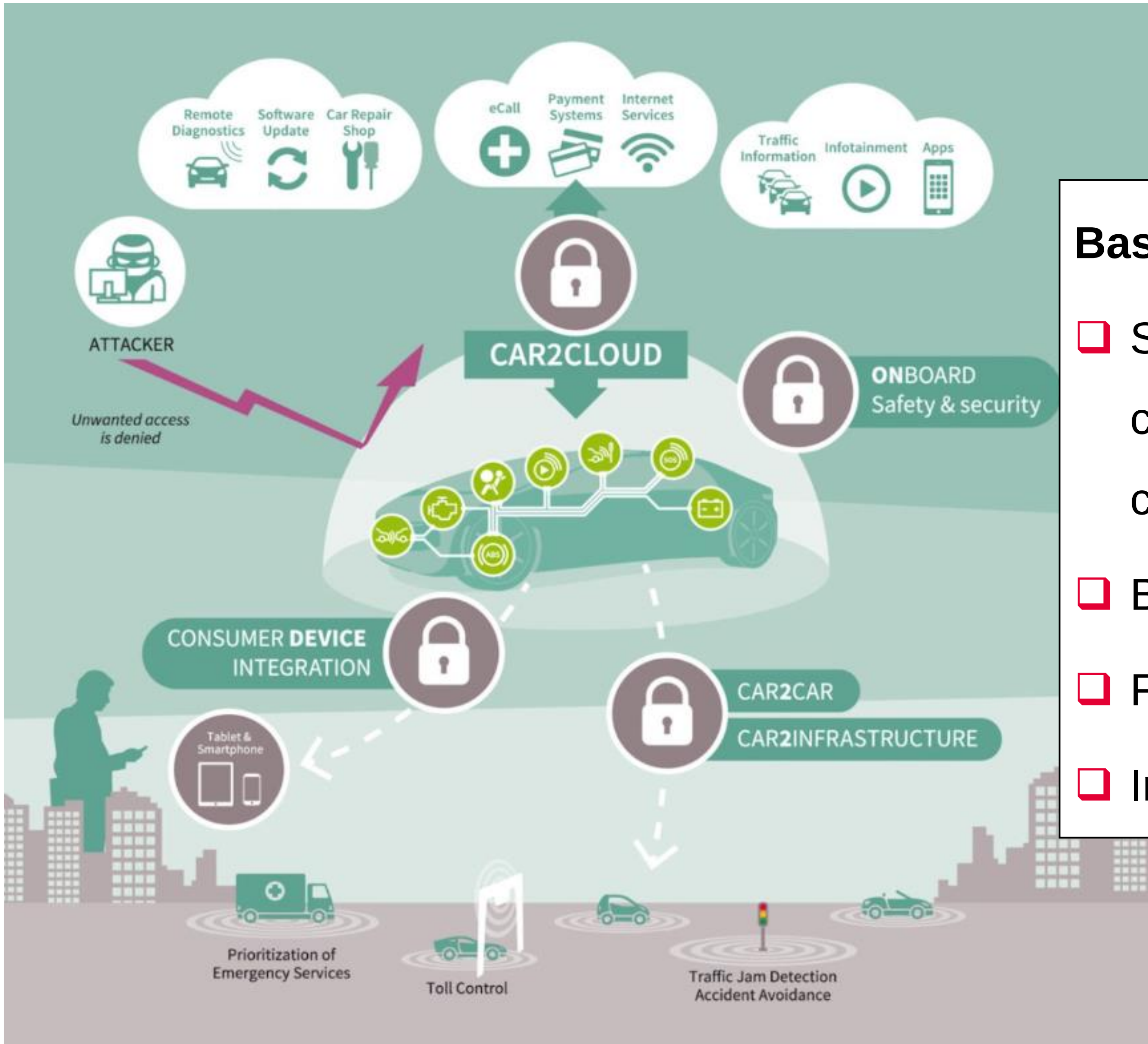
Enabling the communication of cars

Connected Cars
New Requirements



Basic Security Considerations

- Secure on-board, car-2-cloud, car-2-infrastructure and car-2-car communication
- Basic protection of single ECUs
- Firewall & Gateway
- Infotainment Protection

Connectivity
Reliability Requirements

© BMW Group

Contributing factors

- Will develop from connected infotainment to **car-to-x communication**
- Strong link to **autonomous driving** (swarm intelligence)
- **Software** update "**over the air**"
- Vehicle to be **permanently accessible** for any requests from backbone/ customer
- Advanced packaging, such as SiP with small node size technology, will be used
- Connectivity will be one of the main drives that increases the operational time of packages (and ECUs) in automotive (e. g. software update during parking using WLAN instead of GSM)

Consequences

- Vehicle might be **"always online**"
- **Increased operating** time up to 24/7
- Introduction of components to harsh environments that were originally designed for consumer electronics

The Role of Mission Profiles
Consequences of Extended Stress Test Durations

Comparison of suggested extended stress test durations with equivalent test times derived from a typical customer mission profile

Test	Condition	Standard	Ext. Level 1	Ext. Level 2
	Acc. AEC-Q100	Standard life electronics	E-mobility standard	E-mobility extended
HTSL	See test A6, Grade 1	1.000 h	4.000 h	10.000 h

** HTSL @ T_{stress} = 150 °C

Failure mode	E_a [eV]	ETT** [hours]
Cu-Al IMC growth	1.1	2176
<Standard>	0.7	4437
MC oxidation	0.45	10059

Customer Mission Profile*

$T_{ambient}$ [°C]	Time [h]
Operating	
125	400
120	3,200
76	26,000
23	8,000
-40	2,400
Non Operating	
85	914
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- Severe over- or under-stress possible, depending on the relevant failure mode
- Formally no way to avoid non application relevant high E_a fail mechanisms or generate application relevant robustness data for low E_a failure mechanisms

The Role of Mission Profiles

Standardized Mission Profiles

- Fulfilling requirements of today's standard mission profiles needs additional efforts in technology development and product design
- Adding unnecessary requirements by meaningless extended test conditions leads to prolonged time to market, blocking of technologies and additional development efforts
- Therefore the mission profile is an essential puzzle piece in development & qualification

Challenge: Using mission profiles in standards based qualification needs standardized reference profiles!

Advantages

- Usable in **established process** (today used for customer specific mission profiles)
- **Failure mode specific test** evaluation possible (non field application relevant qualification failures can be discarded on a solid base)
- Allows including a **knowledge based qualification** using a structured generic data approach (adapted Robustness Validation approach)➔ **Time to Market**

Challenges

- **User acceptance** needs to be developed
- Requires an **alignment** to a reasonable set of standard applications / **mission profiles**
- Requires **development** of **constraints and standardized methods** to evaluate relevant failure mechanisms
- Not applicable in case of a strong mission profile dependency on **user behavior**. (e.g. inverter in electric drivetrain)

Summary

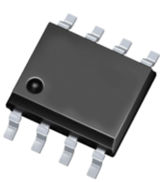
Automotive Packaging Trends

- Automotive arena provides a huge growth opportunity, and it is already happening…
- Automotive requirements are specific and will need adjustments for developing and enabling effective package solutions
- Current standards for semiconductors only provide customer specific qualification procedures to verify the fulfilment of these kind of lifetime requirements
- Recent megatrends in the automotive industry lead to significantly extended lifetime requirements for vehicle electronics
- Packaging technology will make the difference

Part of your life. Part of tomorrow.

Automotive Requirements
Zero Defects

- Zero Defect is a **prerequisit** for the automotive market
- Zero defect is expected from customer
- Zero Defect principle: No rework – first time right products
- Automotive knowledge and experience – technology, but also development, methodologies, … mindset – will be key to success



x 300

x 50

1ppm component defect

300ppm ECU(*) defect

15000 car defects out of 1Mio (1,5%)

(*) ECU: Electronic Control Unit

The Role of Mission Profiles

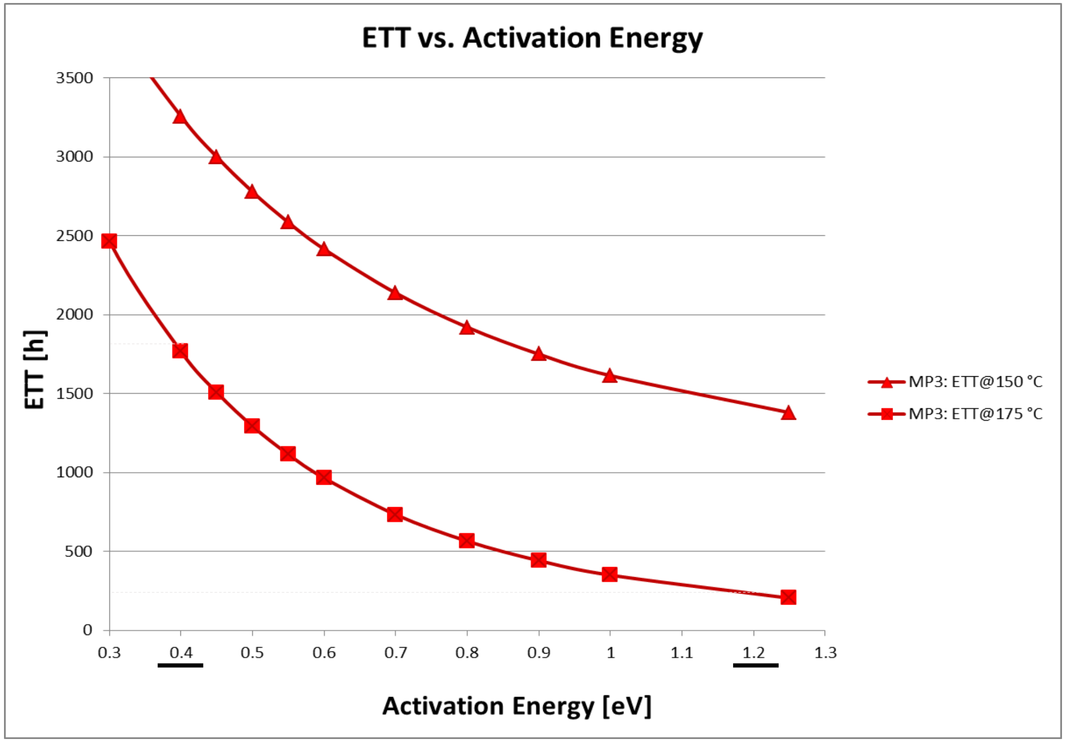
Extending Test Times

Straight forward approach: Extended test times as new reliability target

Risk: Coming from a mission profile,

- → Different failure mechanisms lead to different equivalent test times (ETT)
- → Setting test time as target leads to different lifetime requirements for each failure mechanism
- → (Failure modes not covered or unnecessary product robustness increase)

$T_{junction}$ [°C]	Time [h]
150	1,000
125	3,000
100	3,000
75	500
48	400
-15	100



Activation energy refers to the minimum amount of **energy** required to trigger a temperature-accelerated failure mechanism.

Source: Wikipedia

Source: Ulrich Abelein

Automotive Packaging Reliability

Requirements

Infotainment/ Comfort

Power train

Safety

Lightning

Connectivity





Grade 3 & 2
-40°C to +105°C

Grade 1 & 0
-40°C to +150°C

Grade 1
-40°C to +125°C

Grade 1 (ext)
-40°C to +125°C
Grade 3 & 2 (int)
-40°C to +105°C

Grade 3 & 2
-40°C to +105°C

- Five main application groups are showing very different needs & operating conditions
- In these five applications, you can find specific electronic devices (e. g. LEDs in lighting)
- Some electronic devices can be found in several groups with different specs (e. g. MCUs in safety vs. MCUs in infotainment)

Source: Yole Developmen

Reliability

Heterogeneous Integration Roadmap

- Reliability of electronics systems as a professional discipline is existing since the 1960s
- The first generation of reliability prediction relied on fixed sets of tests according to standards such as MIL Handbook 217 without accounting for the specifies of the individual product and application use case in detail
- In the 1980s, numerous organizations found this procedure to be inaccurate
- In the late 1990s, the 2nd generation of reliability prediction had been established based on **specific mission profiles**, the strength of the individual materials, and a detailed knowledge of the failure modes, degradation mechanisms and propagation speeds
- Using modeling and simulation of the degradation mechanisms as well as data-driven approaches, the characteristic end-of-life reliability of the new product can be estimated
- However, it does not capture the onset and the propagation of the degradation in an individual part