CMOS Reliability Integration and Engineering (Part-1)

Introduction to Automotive Reliability

Dr. Eitan Shauly,
Tower Semiconductor
(Tel) 972-4-6506570, eitansh@Towersemi.com

1

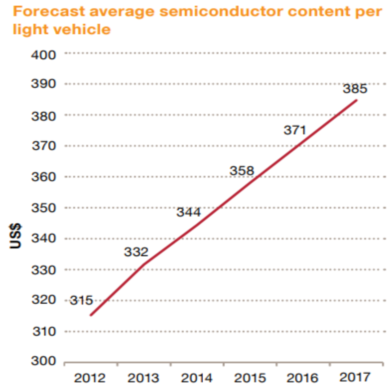
Topics

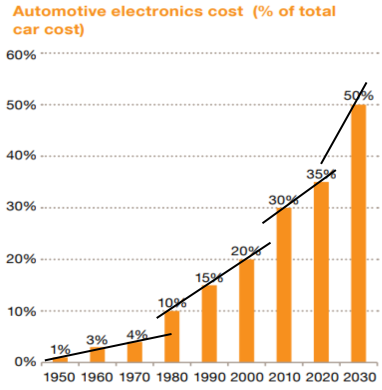
- The overall semiconductor Automotive market
- IoT, Automotive, connectivity. Examples for different Automotive applications
- Different requirements for Automotive
- Reliability for Automotive:
  - Cumulative failure and life-time
  - The mission profile
  - Environmental qualification and Burn-In
- Quality and Manufacturing for Automotive
  - Risk management,
  - The Zero-defect program,
  - Process Control for Automotive
  - Continuance Improvement plan,
  - 8D report, Failure Analysis capabilities
- DfA – Design For Automotive
  - Devices, rules, Guidelines and DfM
  - SPICE modeling – Aging
  - IPs, ISO26262
  - ASIL, Safety Function, Trace and tractability

2

Semiconductor Value in Automotive

- 7% CAGR through 2022,
- $6,000 Electronic in luxury car by 2022
- Estimated: ~60% of IC design have functional safety needs





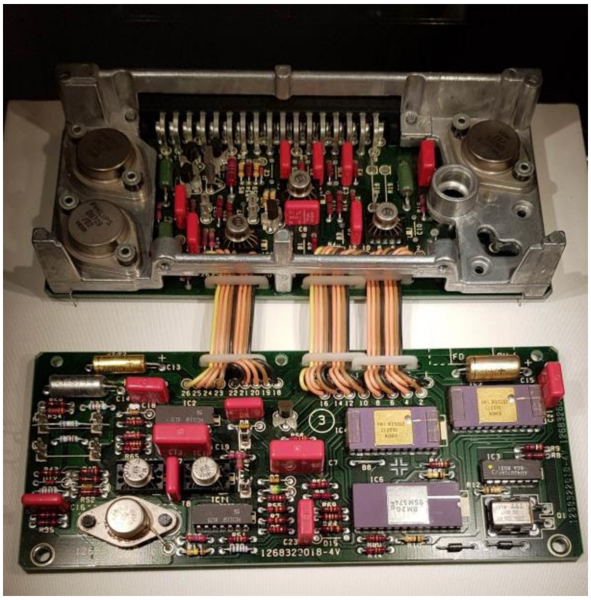
Source: PwC analysis

TOWER SEMICONDUCTOR LTD.

4

1978, automotive

- ABS-2 (Anti-lock braking system) controller from Robert Bosch GmbH, Germany, 1978.
- The computerized ABS controller in only part of the anti-lock brake system. It receives speed and acceleration information from wheel sensors and activates solenoids valves in the braking system.
- Picture was taken at the Computer Museum, CA, USA.



TOWER SEMICONDUCTOR LTD.

5

2018, automotive

Architecture complexity increases by 5 orders of magnitude in 2 yrs

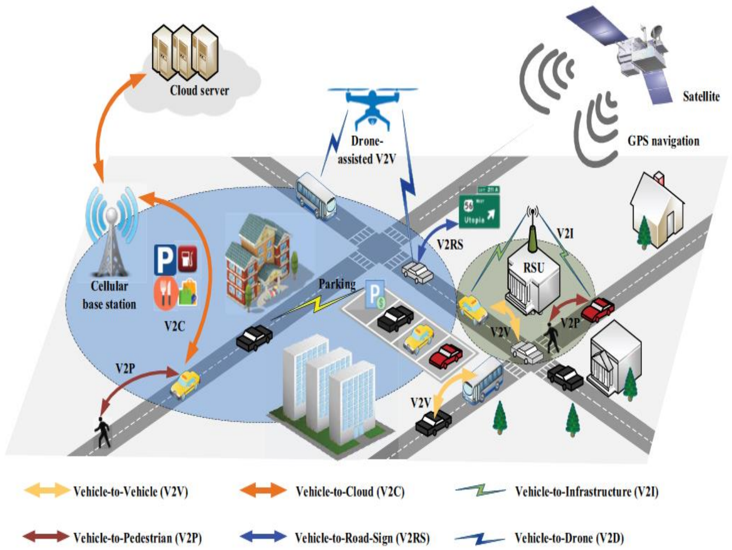
LINES OF CODE

- 2M Hubble Space Telescope
- 5M Mars Curiosity Rover
- 12M Smartphone OS
- 25M F-35 Fighter Jet
- Luxury car software 100M

- 6 radar beams
- 8 cameras
- 12 parking sensors
- 100+ electric motors
- 144 electronic control units
- 500 LEDs
- 734 wire harnesses
- 2,400 wires
- 5,000 meters of cables

source: Roland Berger
source: CarsGuide
Source: High volume global automotive platform

CASE: Connected - IoT on the road

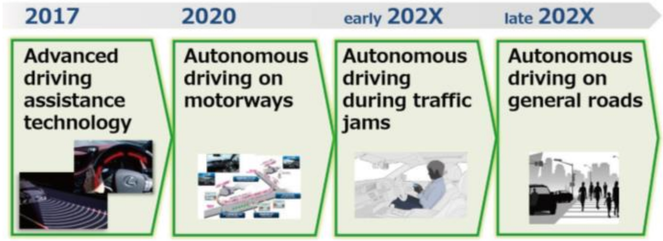


TOWER SEMICONDUCTOR LTD.

10

CASE: Autonomous

- Ask for advance monitoring and AI (artificial Intelligence) technology
- Automotive market + Google + Apple



The autonomous roadmap

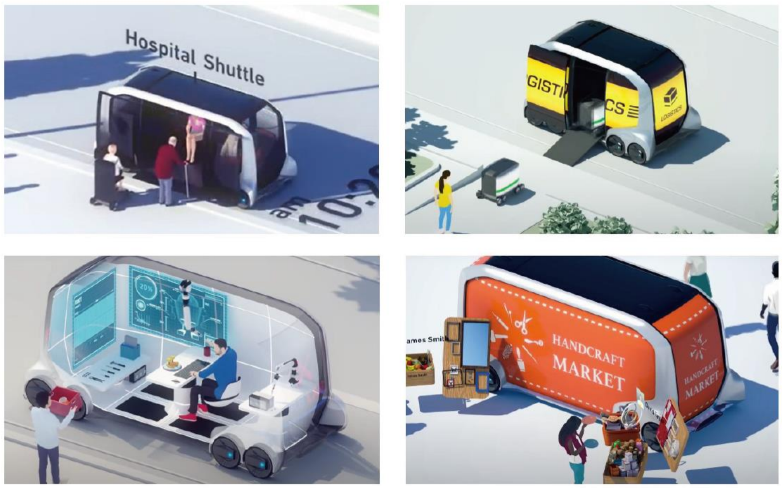
ADAS – Advanced Driver Assistance Systems.mp4 (Command Line)

Highlights of Mobileye's Autonomous Vehicle Driving the Streets of Munich.mp4 (Command Line)

TOWER SEMICONDUCTOR LTD.

11

CASE: Shared and Services



Source: TOYOTA MOTOR CORPORATION

TOWER SEMICONDUCTOR LTD.

12

Example for different Automotive Applications

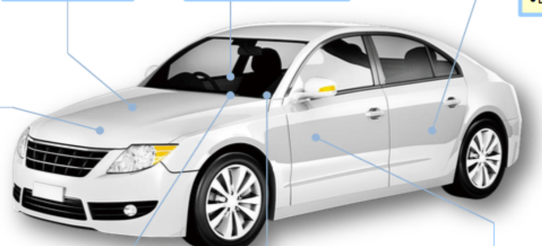
GaN, SiC

Power Train
- Engine control
  - Engine
  - Fuel injection
  - Knock control
- HEV/EV motor
- Transmission

Infotainment
- Dashboard
- Car audio
- Connectivity audio
- Entertainment
- ITS/GPS
- Car navigation display

Networking
- CAN
- LIN
- FlexRay
- SAFE-BY-WIRE
- MOST
- Bluetooth
- Ethernet

Chassis
- Steering/EPS
- Brake/ABS
- Traction control
- Suspension
- Chassis control



Safety
- Airbag
- TPMS
- Collision warning
- Parking assistance
- Back monitor
- Night vision

Body
- Power door
- Power window
- Climate control
- Seat control
- Mirror and wiper control

Electronic system
- Alternator, battery, and starter
- Lighting
- Diagnostics
- In-car data bus

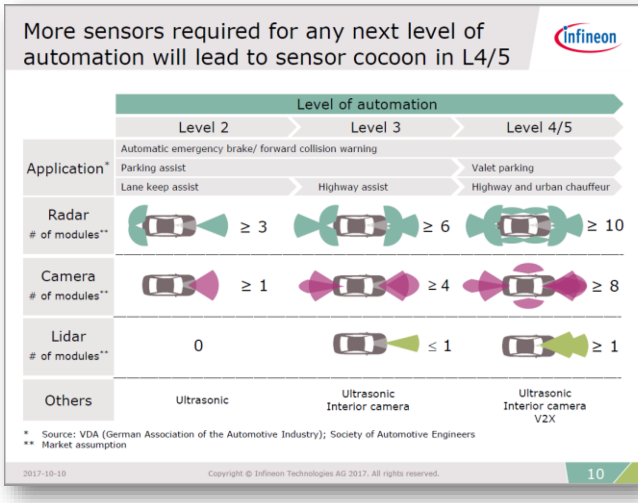
After: https://semiengineering.com/foundries-accelerate-auto-efforts/

TOWER SEMICONDUCTOR LTD.

14

Quality requirements for Automotive

- More ICs per System Requires Lower DPPM per IC

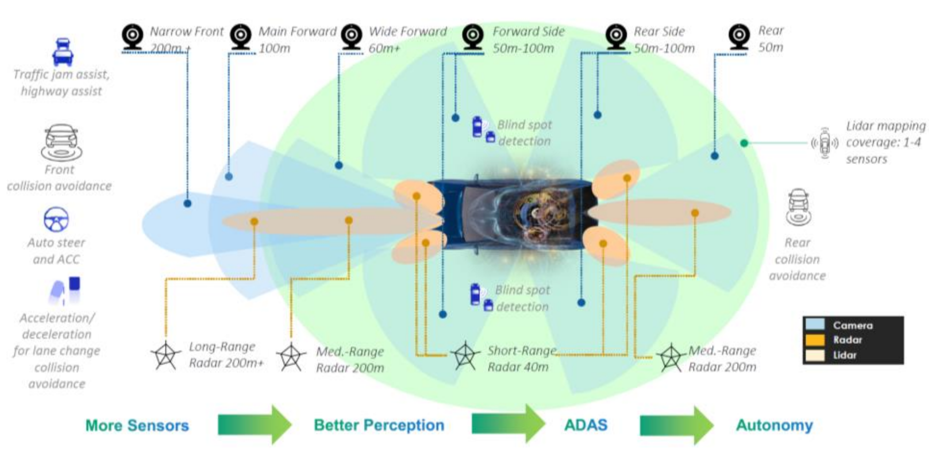


- ~5X module increase with fully autonomous vehicles

15

AI and more sensor for Autonomy

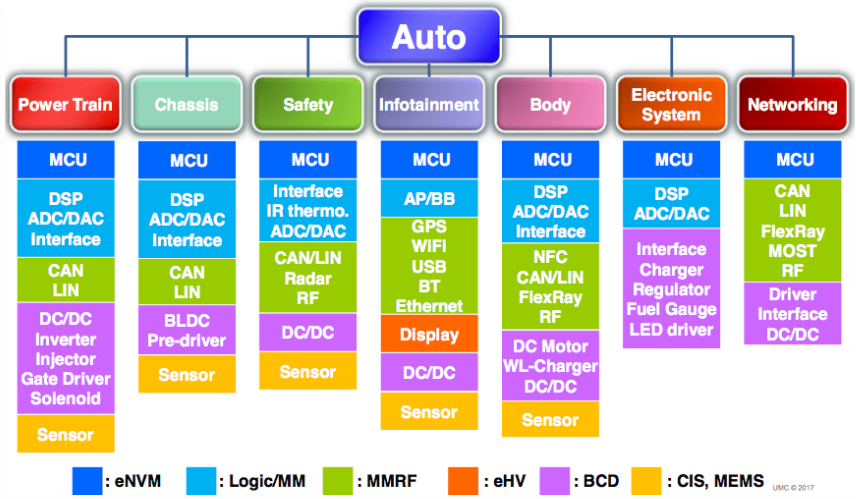
- The overall number of LiDars, Radars, Camera only goes up



After: Kos Gitchev, "LPDDR, GDDR, and HBM for Auto AI Applications," Automotive Electronics Forum, 2024 (JEDEC)

16

Automotive Domains



After: https://semiengineering.com/foundries-accelerate-auto-efforts/

17

CMOS Reliability Integration and Engineering (Part-1)

Reliability for Automotive

Dr. Eitan Shauly,
Tower Semiconductor
(Tel) 972-4-6506570, eitansh@Towersemi.com

21

AEC-Q100 Definition for Part Operating Grade

1.3.3 Definition of Part Operating Temperature Grade

The part operating temperature grades are defined below:

Grade 0: -40°C to +150°C ambient operating temperature range
Grade 1: -40°C to +125°C ambient operating temperature range
Grade 2: -40°C to +105°C ambient operating temperature range
Grade 3: -40°C to +85°C ambient operating temperature range
Grade 4: 0°C to +70°C ambient operating temperature range

- But temperature, is only a part of the overall MISSION PROFILE

Reliability Requirements for Automotive

Item \ Usage	Measuring instrument	Consumer electronic	Automobile	Aircraft	
Demand accuracy: [%]	0.1～1	Several	Several	0.1～1	Wafer foundry
Operating temperature: [℃]	0～40	-10～70	-40～150	-65～350	
Vibration [G]	～1	5	25	20	packaging
Power voltage variation [%]	±10	±10	±50	±10	Wafer foundry
Electromagnetic environment	Good	Good	Bad	Good	Car Mnfg.
Other tolerances	-	Moisture	Salt water, Exhaust gas	Salt water	

After: Toyota, IRPS 2014

Reliability Requirements for Automotive

Fab Automotive Protocol	Physical + Environmental Reliability

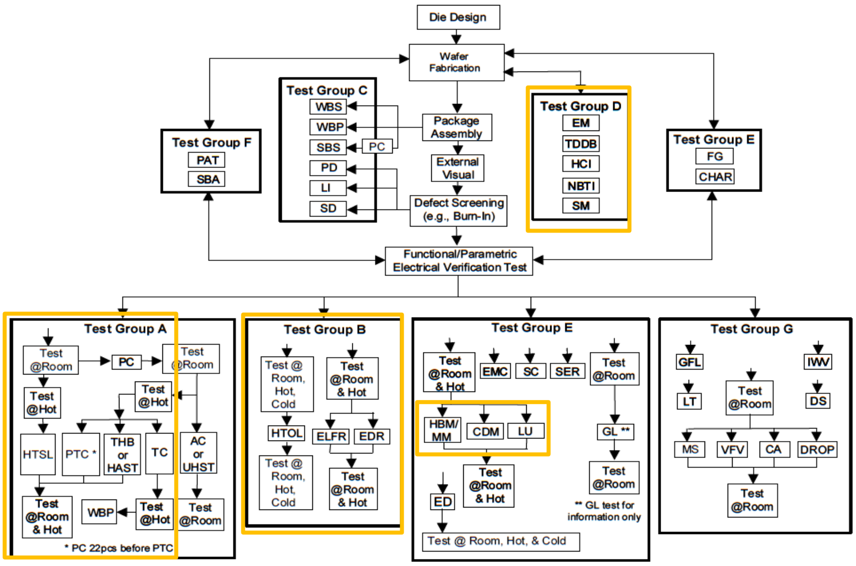
- Reliability testing, check for different potential failure mechanisms:
  - Gate Oxide integrity (Vramp / Qbd, TDDB),
  - Channels (HCI, NBTI)
  - Interconnects (EM, SM, IMD-TDDB)
- For each test, we calculate the "Life-Time" (LT) dependency on the physical and electrical conditions

$$LT = f(Temperature, Vapp, Area, CumF)$$

Grade / Mission Profile depended	Device depended	layout depended	Grade / Mission Profile depended

25

AEC Q100 - Qualification Test Flow



26

Reliability Requirements for Automotive

Reliability Life-Time – depends on mission Profile

Classification	Automotive Use A	Automotive Use C	General (Consumer)
Criteria for classification	Applications for Automotive use directly relating to safety (Failure may cause accident)	Applications for automotive use, not directly relating to safety	Applications other than for automotive use.
Example for application	Power trains Brakes, driving support systems, airbags	Navigation systems, car air-conditioners	Home electronics, toys
Annual operating hours	500hrs (driving hours). Differs depending on whether or not work with KEY ON/OFF	500hr's (driving hours)	Up to 8760 hours. Differs among applications
Useful life	15 Years (Cumulative failure probability 0.1%)	15 Years (Cumulative failure probability 0.1%)	Up to 10 Years (Cumulative failure probability 0.1%). Differs among applications
Operation conditions (Example)	Ta = -40C (min) / 85C (max) RH = 0(min) / 100% (max)		Ta = 0C (min) / 70C (max) RH = 10(min) / 80% (max)
Early failure rate	10ppm or below / Year	50ppm or below / Year	Up to 500ppm / Year. Differs among applications

After: JEITA EDR-4708 (Guidelines for LSI Reliability Qualification Plan)

TOWER SEMICONDUCTOR LTD.

27

Example – Cumulative Failure Calculation

- Reliability testing, provide information on the life-time (time-to-breakdown) and the distribution of the results,
- Example for LT calculation for MIM capacitor:

$$Lifetime_{target} = t_0 e^{-CV_{target}} e^{E_a / k_B T_{target}} \left(\frac{A_{test}}{A_{target}} \right)^{1/\beta} \left[\frac{Ln(1-F_{target})}{Ln(1-F_{63.2\%})} \right]^{1/\beta}$$

Modeling Parameters					Input Parameters				Output
C, 1/V	Ea (eV)	β	To, hrs	Atest, um2	V	Area,mm²	T,C	Fail rate,%	Life Time (hrs, Years)
1.67	0.40	1.36	2.24E+06	60000	5.928	3.60E+04	105	0.100%	24.25 Yeras

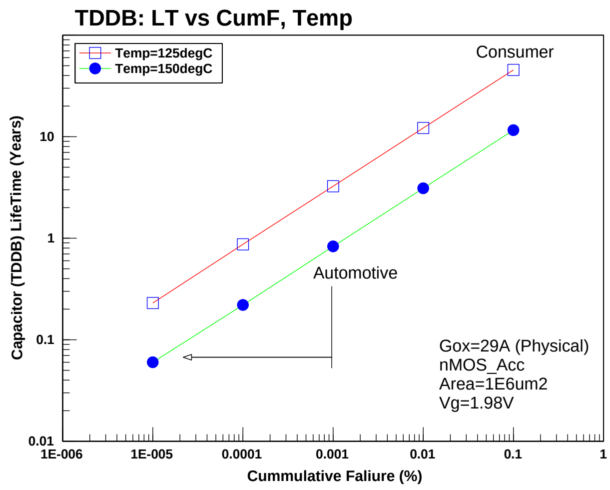
Example

Microsoft Excel 97-2003 Worksheet

TOWER SEMICONDUCTOR LTD.

28

GOX TDDB – CumF and Temp



TOWER SEMICONDUCTOR LTD.

29

Automotive Life-Time Setting

Over all car life-time: 15~20Y (1Year = 8760hrs)

Engine-on time: ~5hr's/day (Duty Cycle = 15~20%)

Engine in ideal-time: ~0.4hr/day (~2.3%)

Engine in Off-time: ~18.5hr's/day (~80%)

Average car speed: 30mph/50km/h

Overall mileage in car lifetime:
30m*5*365*15~20 =821,250~1,095,000miles

For Consumer qualification: use 100% Duty Cycle for >10 years
EFR (Early Failure Rate): 0.1%

For Automotive qualification: use >25% Duty Cycle for >10 years
EFR: 0.01% ~ 0.001%~0.0001%

→ This is the reason Zero-defect program is needed

See for example: AEC-Q101 Rev D; N. Nose and A. Mikami, IRPS 2014

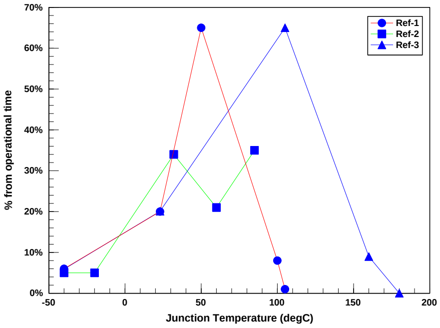
TOWER SEMICONDUCTOR LTD.

30

Mission Profile Performances Calculations

The examples below, are mission profiles as extracted from the literature

Ref1 Audi	Temp (degC)	-40	23	50	100	105
	Distribution	6%	20%	65%	8%	1%
Ref2 STMicro	Temp (degC)	-40	-20	32	60	85
	Distribution	5%	5%	34%	21%	35%
Ref3 NXP	Temp (degC)	-40	23	105	160	180
	Distribution	5.9%	20.08%	65%	9%	0.02%



[1] Audi, Spectrum 2 of VW, VW 80000 2013-06, Status Dec 22, 2016

[2] STMicroelectronic, R. Letor et al., "Life time prediction and design for Smart Power devices fro Automotive exterior lighting,"

[3] NXP process qualification Strategy Integrated TMR ABCD9 Process, 2017

The "effective" % of each segment of the profile, is depend on the device type

TOWER SEMICONDUCTOR LTD.

33

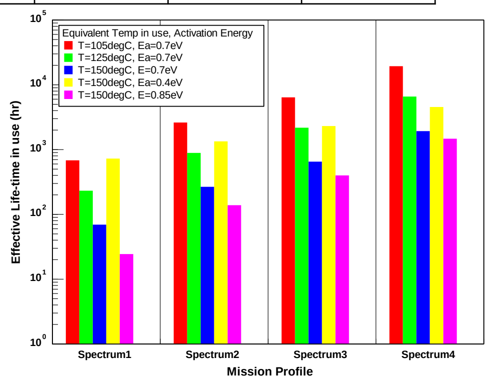
Example for Mission profile calculation

Time index	Duration (%)	Duration (hrs)	Temp. Spectrum 1	Temp. Spectrum 2	Temp. Spectrum 3	Temp. Spectrum 4
t1	6%	1,800	-40 °C	-40 °C	-40 °C	-40 °C
t2	20%	6,000	23 °C	23 °C	23 °C	23 °C
t3	65%	19,500	40 °C	50 °C	65 °C	85 °C
t4	8%	2,400	75 °C	100 °C	115 °C	135 °C
t5	1%	300	80 °C	105 °C	120 °C	140 °C
Sum	100%	30,000				

Above: Volkswagen example for 4 different mission profiles, for motor vehicles, up to 3.5t . Spectrum 2 is also used by Audi.

$$t_{equivalent} = \sum_{i=1}^{5} \frac{t_i}{\exp\left[\frac{E_a}{K_B}\left(\frac{1}{T_i} - \frac{1}{T_{equivalent}}\right)\right]}$$

Right: Equivalent stress time at different stress temperatures and activation energy's for the different mission profiles listed at the table above.



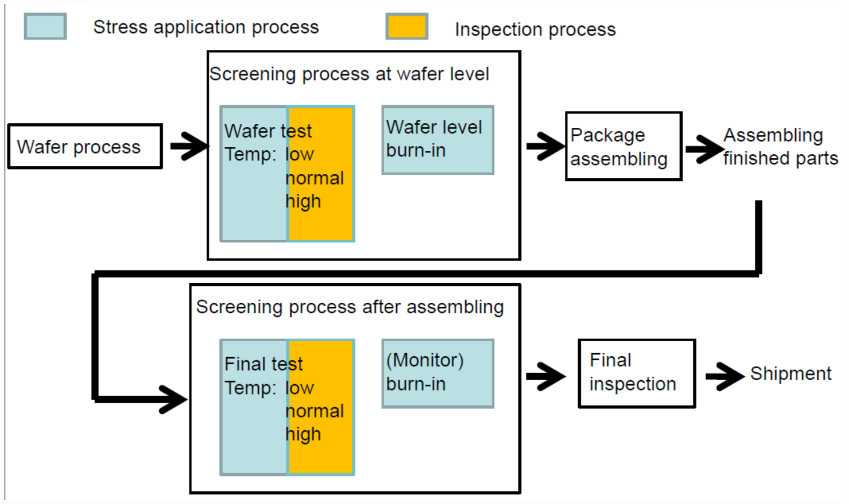
After: *Design Rules in a Semiconductor Foundry* Edited by Eitan N. Shauly, 2022 Jenny Stanford Publishing

TOWER SEMICONDUCTOR LTD.

34

Burn-In for Screening

- Screening is done by the customer, after packaging.
- Based on Voltage stress (high priority) or temperature stress or both



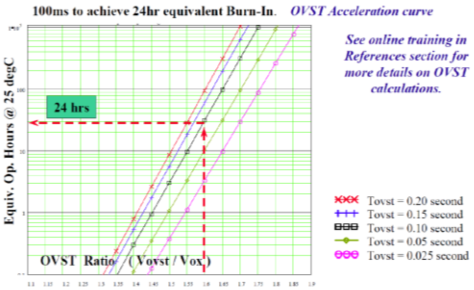
46

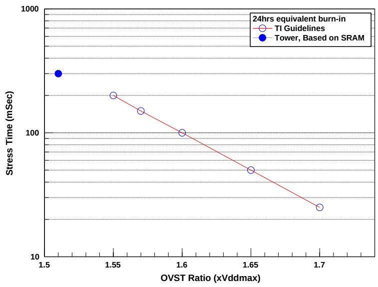
DVS (Dynamic Over Stress) with OVST=Over Stress, w/o temperature

- Reduce DPPM & customer returns due to random fab defects,
- Avoid need for burn-in, due to upstream detection of defects
- Shorter loop from probe test to fab if defects increase dramatically
- OVST test accelerates Oxide defect failures
- OVST required on any device that has oxide area > 10K µm2
- Provides equivalent of burn in without tube cost,
  TARGET : 24 Hrs (25°C Burn-in @Vop,max)
- OVST test sequence:
  - Measure current before stress (nom or max operating voltage)
  - Apply OVST stress voltage (and measure current during stress for info only)
  - Measure current after stress (same condition as step 1)
  - Calculate Delta current before and after stress. Need to be ~zero

47

OVST=Over Stress, w/o temperature





After: Automotive TFQ: A brief introduction of automotive test for quality (TI publications)

Table 10.9-1: Examples for Voltage Stress Conditions

Device	Volatge Stress Conditions
1.2V MOSFETs	2V for 300mSec
5V MOSFETs	6.93V for 300mSec
5V-based LDMOS	To be define by the designer based on device SOA (Self-Operational-Area) characteristics

CMOS Reliability Integration and Engineering (Part-1)

Quality and Manufacturing

Dr. Eitan Shauly,
Tower Semiconductor
(Tel) 972-4-6506570, eitansh@Towersemi.com

Certifications

Quality

ISO 9001

- Quality Management System
- Customer Satisfaction
- Resource Management
- Supplier Quality
- Management Responsibility
- Process Control
- Internal Audit
- CAR/PAR
- Document Control

Environmental

ISO 14001

- Environmental Commitment
- Community Feedback
- REACH Compliant
- RoHS Compliant
- JPGSSI Compliant
- Sony Green Partner

IP Security

BS/ ISO 27001

- Information Security
- Business Continuity
- International Cooperation

Safety

OHSAS 18001

- Health & Safety Commitment
- Community Feedback

Automotive

ISO IATF 16949

- Automotive Industry Quality Requirements
- SII/ROS

CAR: Corrective Action Report
PAR: Preventive Action Report
OHSMS (18001): Occupational Health and Safety Assessment Series
TPM: Total Productive Maintenance

TOWER SEMICONDUCTOR LTD.

51

IATF 16949

- Defines the requirements for a QMS (Quality Management System) of any organization within the automotive industry supply chain, to be more responsive to market demands
- Based on ISO 9001 (2016),

TOWER SEMICONDUCTOR LTD.

52

IATF 16949 – 5 Key Topics

Key topics

Key topics addressed by the IATF 16949 standard include:

Product safety: A product should perform to its designed or intended purpose without causing unacceptable harm or damage. Organisations must have processes in place to ensure product safety throughout the entire product lifecycle.

Risk management and contingency planning: IATF 16949 includes a number of specific risk-related requirements to minimise the likelihood of failure during new programme development, as well as maximise the potential of planned activities. This is intended to make businesses safer and more stable by identifying and mitigating risk.

Requirements for embedded software: The standard references embedded software in the requirements for product validation, warranty and troubleshooting of issues in the field. A product requiring embedded software may need to comply with a customer's sourcing-from-origin requirements.

Change and warranty management: The warranty management process must address and integrate all applicable customer-specific requirements, as well as warranty party analysis procedures to validate No Trouble Found (NTF). When applicable, decisions should be agreed with the customer.

Management of sub-tier suppliers: This outlines a progressive approach that goes from compliance to ISO 9001 via second-party audits, all the way to certification to IATF 16949 through third-party certification. The IATF website contains a document (Minimum Automotive Quality Management System Requirements for Sub-Tier Suppliers) to support specific requirements in this area.

53

Automotive Activities

- The content can be divided to Proactive and Reactive activities.
- The organization need to lead to proactive activities to prevent the failures and impact of the customers and quality events

Proactive	Reactive
• VOC / CSR • Management • Zero defect • NPI • Risk assessment • CIP • Systems • Tools automation • Maverick material management	• Problem Solving • Wide preventive actions • Global communication

VOC: Volatile Organic Compound
CSR: Customer Special Request/Report
NPI: New Product Introduction
CIP: Continues Improvement Plan

54

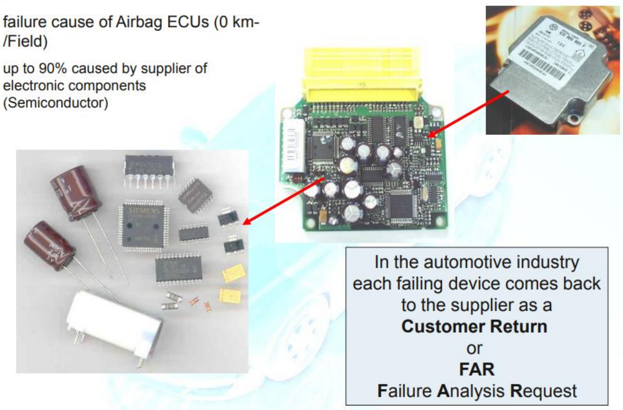
Risk and Cost

Customer Returns = FARs

infineon

failure cause of Airbag ECUs (0 km-/Field)

up to 90% caused by supplier of electronic components (Semiconductor)



In the automotive industry each failing device comes back to the supplier as a **Customer Return** or **FAR** Failure Analysis Request

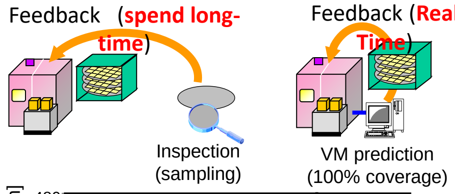
Example : Cost Explosion in case of a supplier quality event

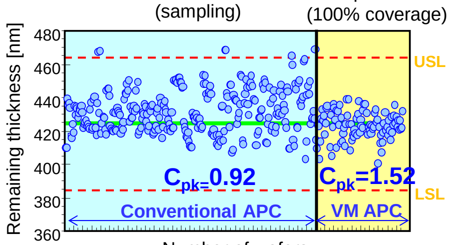
Failure analysis	Failure analysis Cost of Scrap	Cost of Scrap Cost of Overtime	e.g. 1 day linedown Controlled shipping	e.g. recall of 10,000 cars
~ 10 k€	~ 50 k€	~100k€	~1000k€	~10000 k€

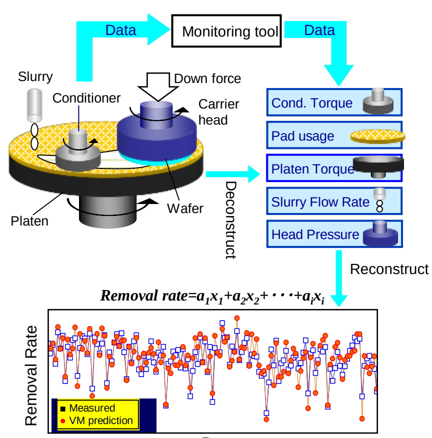
TOWER SEMICONDUCTOR LTD.

Virtual Metrology (VM) for Automotive Quality

- Shorter cycle time using Virtual Metrology Advanced Process Control (VM-APC) based for critical parameters
- Embedded into Zero-defect methodology for Automotive manufacturing

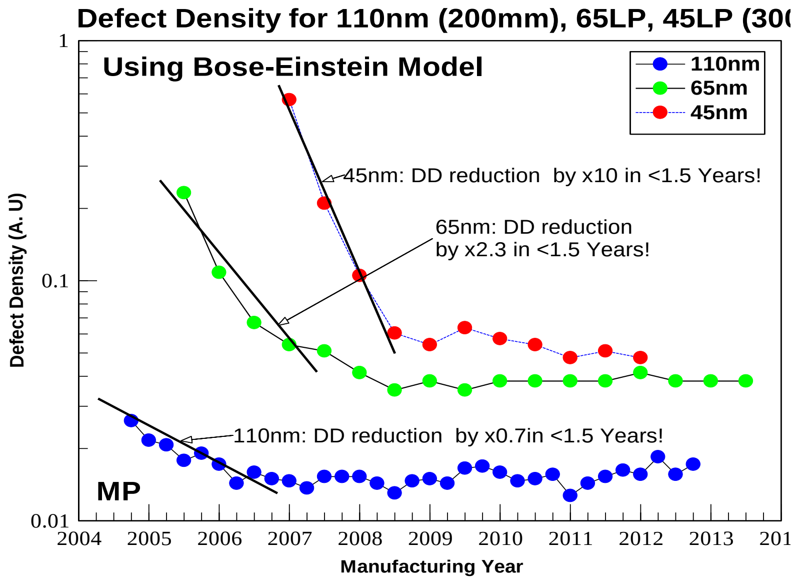






Predict the processing result at real time!

TOWER SEMICONDUCTOR LTD. 67



80

CAR – Respond Time Commit for Automotive Customers

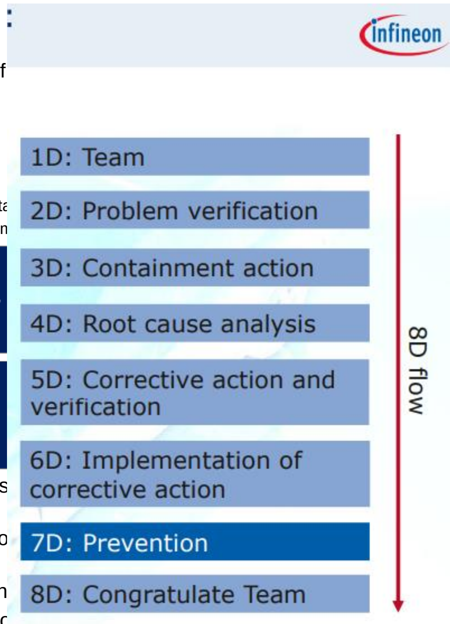
- Foundry will respond to an Automotive customer with result of initial investigation one business day after receipt of sufficient information to investigate.
- foundry will respond to an Automotive customer with an 8D-type root cause report and corrective / preventive action plan within 7 calendar days.
- Should any field failures occur, Foundry personnel will immediately form a cross-functional root cause analysis team to assist customer analysis of the failure.

CAR: Corrective Action report

81

Problem Solving (8D)

- Trigger problem solving teams fast based on the f
- High priority in the organization
- Work systematically for RC analysis
- Use Problem solving:
  - Is/ is not table
  - Possible root cause analysis (fishbone/ why in why out ta
  - 3X5 why analysis for root cause, detectability and systen
- Brainstorming with experts.



- High level 8D reports that elaborate the problem s data.
- Routine updates to the customers, send the 8D ro updates.
- Global knowledge sharing with follow up and man
- Preventive actions in other areas / processes / toc

TOWER SEMICONDUCTOR LTD.

82

CMOS Reliability Integration and Engineering (Part-1)

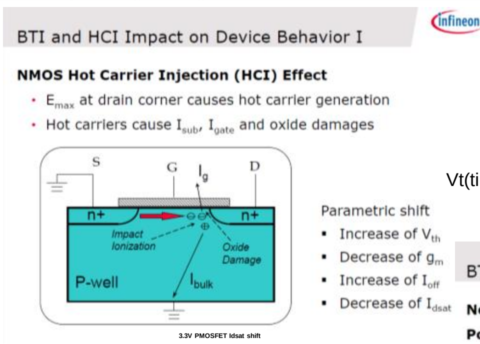
DfA - Design for Automotive

Dr. Eitan Shauly,
Tower Semiconductor
(Tel) 972-4-6506570, eitansh@Towersemi.com

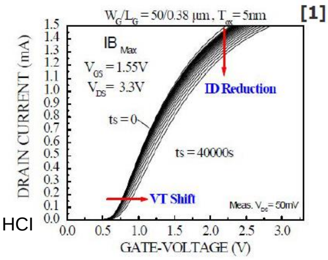
TOWER SEMICONDUCTOR LTD.

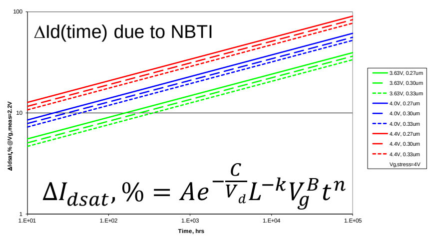
88

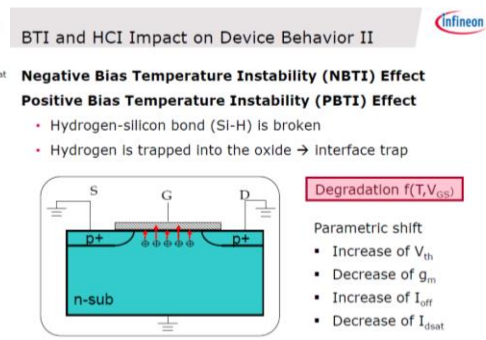
Why aging inside SPICE



Vt(time) due to HCI







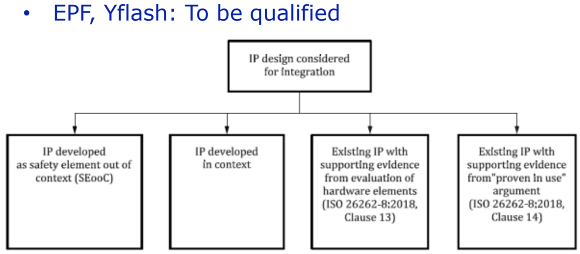
TOWER SEMICONDUCTOR LTD.

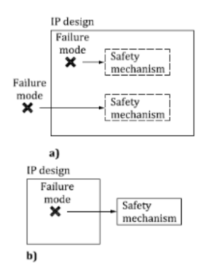
104

IPs

Dedicated IPs for Automotive

- Std Cells, IOs: Relatively easy to make. The IPs are with more relax M1-M1 space, and other Automotive rules
- Memory IPs: take the approach of "proven in use" argument, based on ISO 26262 Part-11
- EPF, Yflash: To be qualified





(left) Possible approaches for using IP in safety-related designs. [After: Road vehicles — Functional safety —Part 11: Guidelines on application of ISO 26262 to semiconductors]. (right) Types of IP with allocated safety requirements

TOWER SEMICONDUCTOR LTD.

107

Functional Safety Methodologies for Automotive Applications (ISO26262)

ISO 26262: Road Vehicles—Functional Safety is the automotive industry standard


INTERNATIONAL STANDARD

ISO 26262-11

First edition 2018-12

Road vehicles — Functional safety —

Part 11:
Guidelines on application of ISO 26262 to semiconductors

Véhicules routiers — Sécurité fonctionnelle —

Partie 11: Lignes directrices sur l'application de l'ISO 26262 aux semi-conducteurs

Reference number ISO 26262-11:2018(E)

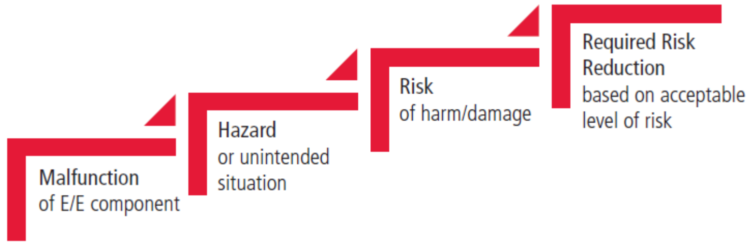
© ISO 2018

- Compliance to these requirements has been traditionally addressed by car manufacturers and system suppliers.
- However, with the increasing complexity, the industry is taking a divide-and-conquer approach, and all participants of the supply chain are no called to support and enable functional safety and reliability standards.
- These metrics are becoming an integral part of the semiconductor design flow.

109

ISO 26262 – Functional Safety

According to ISO 26262, functional safety is defined as the "absence of unreasonable risk due to hazards caused by malfunctioning behavior of electrical/electronic systems".



Malfunction classification:

- Systematic failures
- Random failures

110

ISO 26262 – ASIL: Automotive Safety Integrity Level

1FIT = 1fail after 1E9 operational hr's

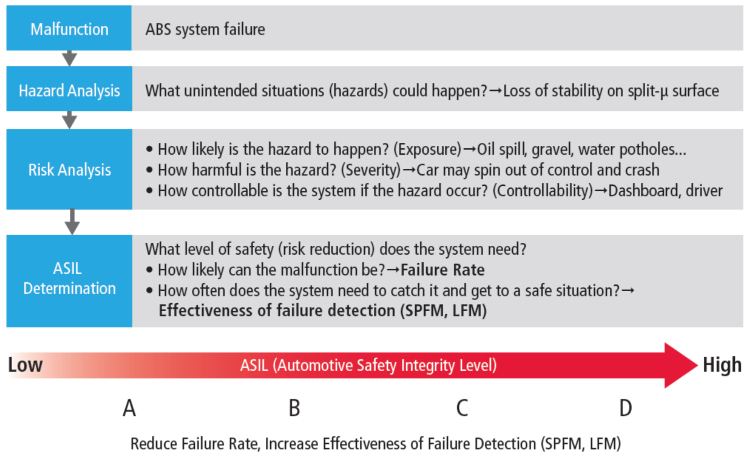


Figure 2: ABS example of ASIL determination based on hazard and risk analysis at the concept phase

ASIL	Fail rate
A	<1000 FIT
B	<100 FIT
C	<100 FIT
D	<10 FIT

After: Analog components advance functional safety development for automotive applications (TI)