Reliability Assessment of VCSEL Devices for 5 Gbit/s Data Transmission in Automotive Environments

Interconnectivity, Tokyo, November 14th, 2013

Jörg Angstenberger

Head of Technology Assessment

Agenda

1. Introduction
2. Automotive Robustness Requirements
3. Automotive Environment Requirements
4. Reliability Assessment
5. Summary

Reliability Assessment of VCSEL Transmitters

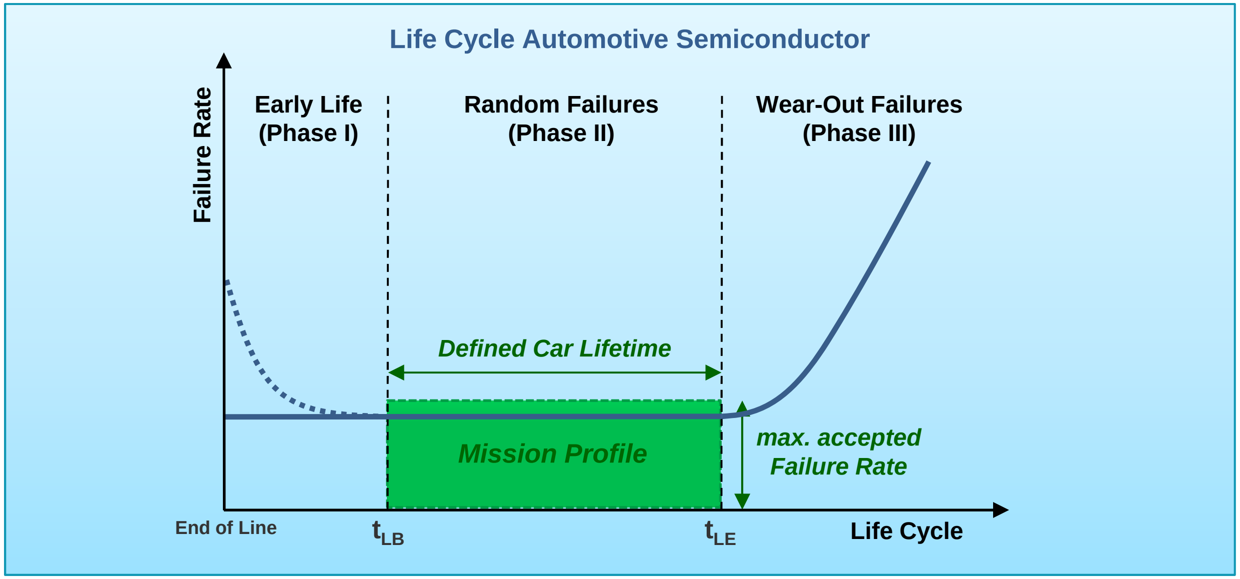
- VCSEL transmitters are able to provide Data Rates >5 Gbit/s and could be an option for further optical Physical Layer Data Links
- VCSEL devices are well established in DataCom Applications but so far have not been introduced to Automotive Applications
- VCSEL devices show good performance reliability in DataCom Application Environments

→ Reliability Assessment of VCSEL devices to determine whether the demanding reliability requirements for automotive can be achieved

Agenda

1. Introduction
2. Automotive Robustness Requirements
3. Automotive Environment Requirements
4. Reliability Assessment
5. Summary

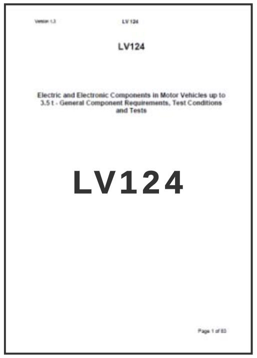
Required Lifetime and Reliability for Automotive



Failure rate of a semiconductor

- depends on lifetime and the relation to a defined car mission profile
- has to be below the max. accepted failure rate over the defined car lifetime

Mission Profile of the Automotive Application



Version 1.3
LV 124

LV124

Electric and Electronic Components in Motor Vehicles up to 3.5 t - General Component Requirements, Test Conditions and Tests

LV124

Page 1 of 83

The mission profile is principally defined by the required lifetime of the device in a specific compartment area of the vehicle.

In terms of motor vehicles from main German manufacturers, this information can be found in the LV124[1] specification

Required Life Time:

Criteria	Requirement
Service Life	15 years
Operating Hours	8000 h
Milage	300.000 km

Required Failure Rate during Lifetime:

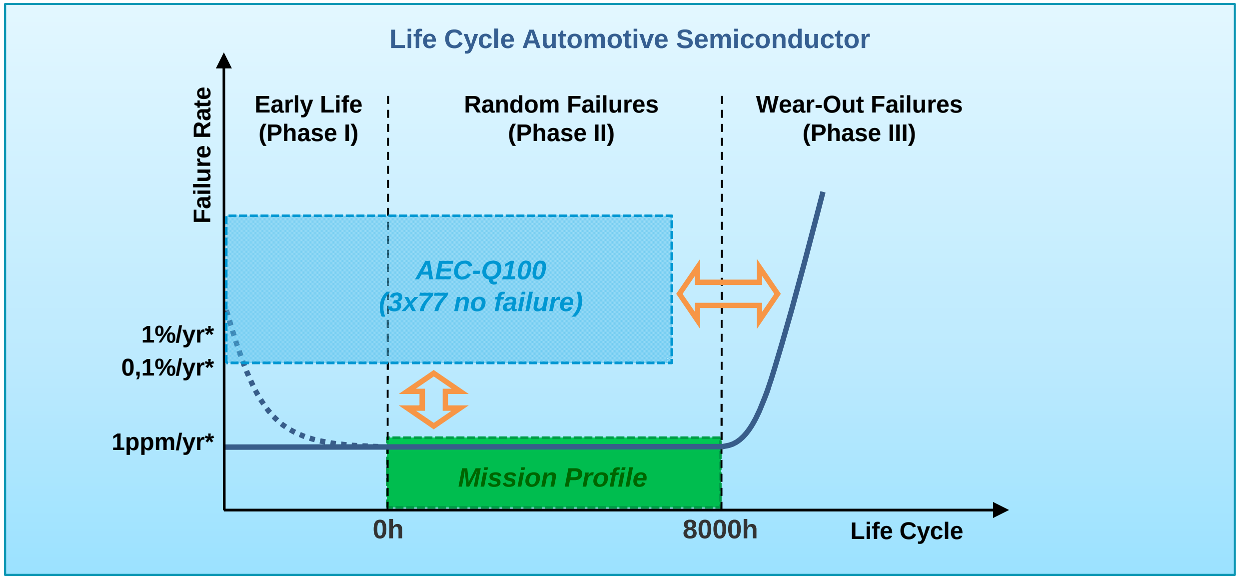
For automotive semiconductor devices, random failure rates in the magnitude of **~10FIT** with a confidence level of 90% are assumed and accepted.(≙5ppm/yr @500 operating hours/yr)

---

[1] **LV124** Electric and Electronic Components in Motor Vehicles up to 3.5t - General Component Requirements, Test Conditions and Tests.

Automotive Robustness Requirements

AEC-Q100 exclusively is not sufficient for today’s semiconductors

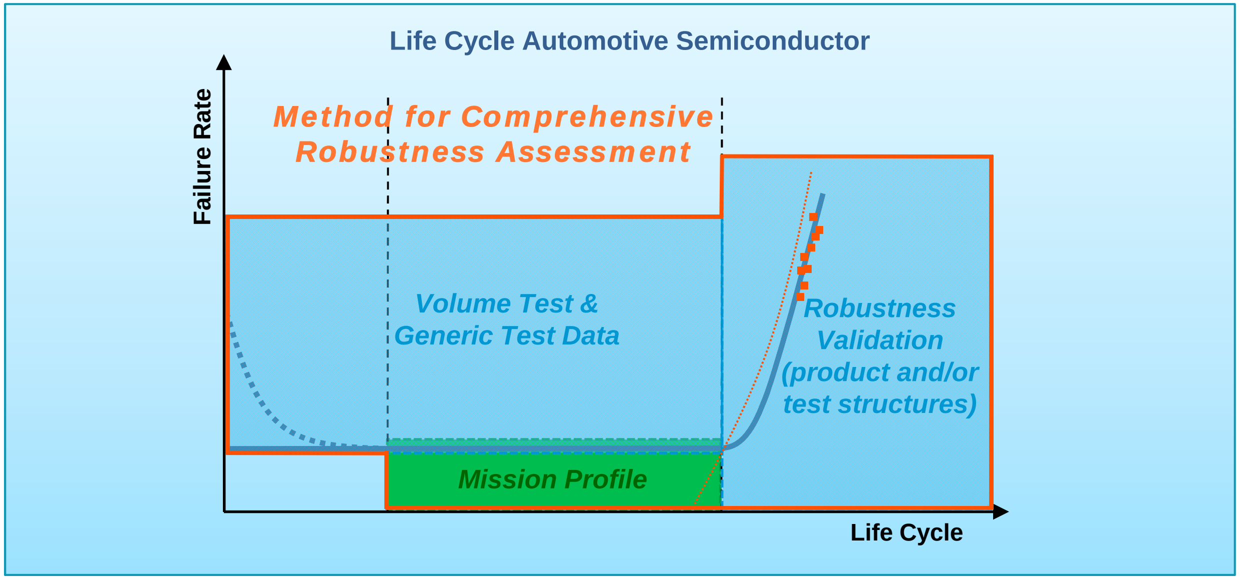


- Today, single-digit failure rates (ppm/yr) are expected (0ppm goal)
- With AEC-Q100 there is a significant coverage gap
- No transparency of robustness margin
- AEC-Q100 exclusively is not sufficient for today’s semiconductors

Automotive Robustness Requirements

RUETZ
SYSTEM SOLUTIONS

Unified Method for comprehensive Robustness Assessment

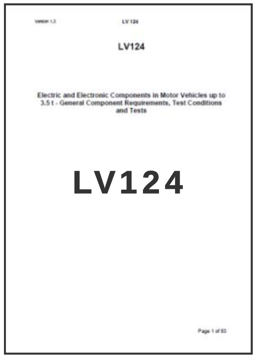


- Robustness Validation Method to cover wear-out failure mechanisms
- High Volume/Generic Test Data to cover random failures
- Integrated Method based on Physics of Failures and today’s experiences for a comprehensive Robustness Assessment

Agenda

1. Introduction
2. Automotive Robustness Requirements
3. Automotive Environment Requirements
4. Reliability Assessment
5. Summary

Temperature Conditions in Automotive Applications



Version 1.3 LV 124

LV124

Electric and Electronic Components in Motor Vehicles up to 3.5 t - General Component Requirements, Test Conditions and Tests

LV124

Page 1 of 83

For MOST applications, only installation locations 1 and 2 have to be taken into account.

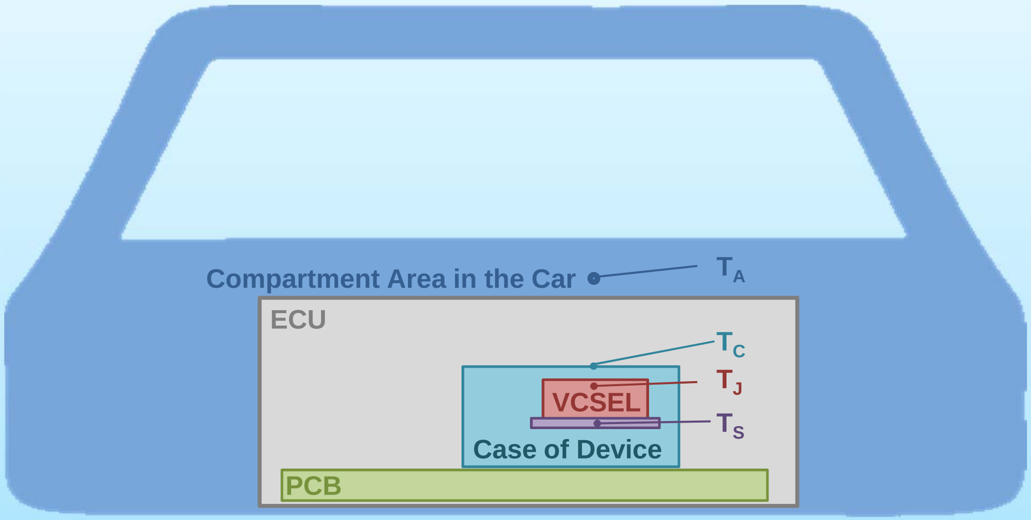
Installation location of the component	**Temperature Profile No.**
Interior, without special requirement	1
Body-mounted part, without special requirements	1
Interior exposed to sun radiation	2
Body-mounted part, roof	2
Engine compartment, but not on the engine	3
On the radiator	3
Engine-mounted parts	4
Gearbox-mounted parts	4

Temperature Profile 1	**Temperature Profile 2**	**Percentage**	**Operating Hours**
-40 °C	-40 °C	6 %	480h
23 °C	23 °C	20%	1600h
40 °C	50 °C	65%	5200h
75 °C	100 °C	8%	640h
80 °C	105 °C	1%	80h
Operating Hours complete:			8000h

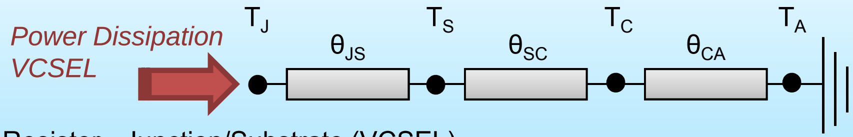
Worst Case Temperature Profile

Automotive Environment Requirements

Temperature Model



T_A	Temperature Ambient (Temperature Profile compartment area)
T_C	Temperature Case (Surface of the VCSEL package)
T_S	Temperature Substrate of VCSEL
T_J	Junction Temperature VCSEL



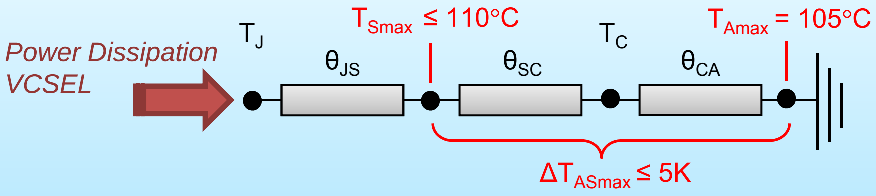
θ_{JS}	Thermal Resistor - Junction/Substrate (VCSEL)
θ_{SC}	Thermal Resistor - Substrate/Case (Substrate VCSEL/Surface Package of device
θ_{CA}	Thermal Resistor - Case/Ambient (Surface Package of device/compartment area)

Agenda

RUETZ
SYSTEM SOLUTIONS

1. Introduction
2. Automotive Robustness Requirements
3. Automotive Environment Requirements
4. Reliability Assessment
5. Summary

Test Temperature to Cover All Possible Failure Mechanisms

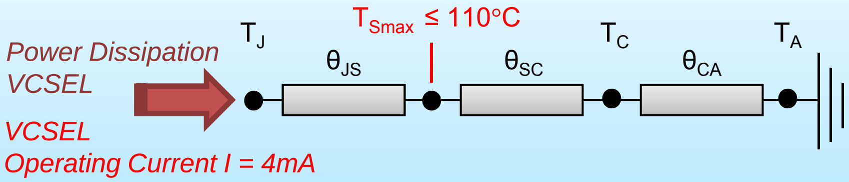


θ_{JS}	Thermal Resistor - Junction/Substrate (VCSEL)
θ_{SC}	Thermal Resistor - Substrate/Case (Substrate VCSEL/Surface Package of device
θ_{CA}	Thermal Resistor - Case/Ambient (Surface Package of device/compartment area)

Minimum Test Temperature ($T_{JTestmin}$)
Minimum test temperature (Junction) of the VCSEL has to be at least the maximum possible temperature under application conditions

Maximum Test Temperature ($T_{JTestmax}$)
The maximum test temperature is limited by maximum power dissipation of the VCSEL and has to be estimated by the manufacturer.

Thermal Model of a VCSEL



Power Dissipation VCSEL

VCSEL
Operating Current I = 4mA

θ_{JS}	Thermal Resistor - Junction/Substrate (VCSEL)
θ_{SC}	Thermal Resistor - Substrate/Case (Substrate VCSEL/Surface Package of device)
θ_{CA}	Thermal Resistor - Case/Ambient (Surface Package of device/compartment area)

Example of a thermal model of a virtual VCSEL-device:

Substrate Temperatur T_S **[°C]**	**Operating Current I [mA]**									
	3	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
70	81	84	88	91	95	98	102	106	109	113
85	96	99	103	106	110	113	117	121	124	128
90	101	104	108	111	115	118	122	126	129	133
100	111	114	118	121	125	128	132	136	139	143
105	116	119	123	126	130	133	137	141	144	148
110	121	124	128	131	135	138	142	146	149	153
120	131	134	138	141	145	148	152	156	159	163
130	141	144	148	151	155	158	162	166	169	173

The thermal model of a VCSEL describes the correlation between substrate temperature, operating current, and junction temperature.

Lifetime Test

Lifetime Test

In this Reliability Assessment, there are two basic intentions for lifetime testing:

1. Robustness Validation: Determination of the point in time when the wear-out phase of the device begins

2. Volume Test: Prediction of the expected random failure rate of the device during the specified car lifetime

⇨ 2 different test setups for **Wear-Out** and **Random Failure** Rate

Lifetime Test

Robustness Validation for Wear-Out

- HTOL test with high acceleration factor[2]
- Limited number of samples
- Generation of a significant number of failures (e.g. 50%) in a limited time frame

$$A_f = \left(\frac{I_1}{I_2}\right)^N \cdot e^{-\frac{E_A}{k}\left(\frac{1}{273{,}15°C+T_1}-\frac{1}{273{,}15°C+T_2}\right)}$$

E_A	Activation Energy ([2]typical value for wear-out 0.7V or empirical determined)
k	Boltzmann Constant
A_f	Acceleration Factor
I_1	Current at Test
I_2	Operating Current
T_1	Test Temperature (Junction Temperature T_J)
T_2	Temperature at operating condition (Junction Temperature T_J)
N	Current acceleration exponent ([2]typical value N=2)

---

2. **GR-468-CORE Issue 2.** *Generic Reliability Assurance Requirements for Optoelectronic Devices* s.l. : Telcordia Technologies, September 2004.

Lifetime Test

Volume Test for Random Failure Rate

- HTOL test with moderate acceleration factor[2]
- High number of samples to prove a failure rate of ~10FIT with a CL of 90%
- Conservative (low) activation energy according to GR-468-CORE to cover all possible failure mechanisms

$$A_f = e^{-\frac{E_A}{k}\left(\frac{1}{273{,}15°C+T_1}-\frac{1}{273{,}15°C+T_2}\right)}$$

E_A	Activation Energy (^{2}typical value for random failure 0.35eV)
k	Boltzmann Constant
A_f	Acceleration Factor
T_1	Test Temperature (Junction Temperature T_J)
T_2	Temperature at operating condition (Junction Temperature T_J)

---

[2] **GR-468-CORE Issue 2.** *Generic Reliability Assurance Requirements for Optoelectronic Devices* s.l. : Telcordia Technologies, September 2004

Random Failure Rate Calculation

Calculation of the corresponding device hours under application conditions based on the collected device hours from test

$$D(T_{JApp}) = nt \cdot e^{-\frac{E_A}{k}\left(\frac{1}{273{,}15°C+T_{JTest}} - \frac{1}{273{,}15°C+T_{JApp}}\right)}$$

$D(T_{JApp})$	Device hours at Application Condition
n	Number of tested devices
t	Number of test hours at test condition T_{JTest}
T_{JTest}	Temperature Test Condition (Junction Temperature)
T_{JApp}	Temperature Application Condition (Junction Temperature)
E_A	Activation Energy
k	Boltzmann Constant

Calculation of the approved random failure rate under application conditions based on the corresponding device hours

$$\lambda(T_{JApp}) \leq \frac{\chi^2(CL, 2r+2)}{2D(T_{JApp})}$$

$\lambda(T_{JApp})$	approved random failure rate for corresponding application condition
T_{JApp}	Junction Temperature (Application condition)
$D(T_{JApp})$	Tested Device hours at application condition T_{JApp}
CL	Confidence Level (e.g. 90%)
r	Number of Failures
$\chi^2(CL,2r+2)$	Bound of χ^2 distribution

Calculation Example for Random Failure Rate (virtual VCSEL)

Example: Virtual VCSEL						
Operating Current I [mA]	3	4	5	6	7	8
T_{cmax} [°C]	110	110	110	110	110	110
ΔT_{SC} [k]	0	0	0	0	0	0
ΔT_{JS} [K]	11	14	18	21	25	28
T_{Jmin} [°C]	-24	-21	-17	-14	-10	-7
T_{Jmean} [°C]	66	69	73	76	80	83
T_{Jmax} [°C]	121	124	128	131	135	138
Test Data T_{JTest}=140°C (5000h x 3000)	used	used	used	used	used	used
Test Data T_{JTest}=124°C (6000h x 2500)	used	used				
Test Data T_{JTest}= 100°C (6000h x 500)						
FIT (CL 90%) calulated for T_{jmean}	<11	<12	<23	<25	<29	<32
FIT (CL 90%) calculated for temperature profile	<12	<14	<26	<28	<32	<35

Random Failure Rate calculated for the mean temperature T_{jmean} of the distribution: <12FIT(CL90%, T_{jmean}=69°C)

Random Failure Rate calculated for the complete temperature profile of the distribution: <14FIT(CL90%, $T_{jprofile}$=[-24°C,69°C,124°C])

Agenda

1. Introduction
2. Automotive Robustness Requirements
3. Automotive Environment Requirements
4. Reliability Assessment
5. Summary

Summary

RUETZ SYSTEM SOLUTIONS

Reliability Assessment Method

- Automotive Robustness Requirements have been discussed
- AEC-Q100 exclusively is not sufficient to prove automotive suitability of todays semiconductors
- A temperature profile was calculated that considers the thermal worst case scenario for the VCSEL transmitter device
- Two different test setups were introduced to evaluate the wear-out behavior and the random failure rate of the VCSEL device
- A calculation method according to established reliability methods was introduced to predict the random failure rate

Status of Lifetime Test from VCSEL Manufacturer

- A reliability study based on the introduced evaluation method was started in 2012 on 3 VCSEL devices from different manufacturers
- The selected devices fulfill the basic functional requirements of a potential further optical MOST Physical Layer
- Test results show that the requirement of more the 8000h lifetime can be achieved without running into wear-out
- Test results demonstrate that a random failure rate of around 10FIT is realistic and feasible

Thank you for your attention!

Jörg Angstenberger

RUETZ
SYSTEM SOLUTIONS

Walter-Gropius-Straße 17
80807 München
Germany

T +49 / 89 / 200 04 13-0
F +49 / 89 / 200 04 13-99
info@ruetz-system-solutions.com