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

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Jörg Angstenberger

Head of Technology Assessment

Agenda

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

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Optical Data Transmission with VCSEL Transmitter

- LED/PMMA based transmission layers are limited to a bandwidth of 100-200 Mbit/s,
- Data rates of 5Gbit/s are achievable by using VCSEL transmitters
- VCSEL devices are well established in DataCom Applications but not introduced to Automotive Applications so far
- VCSEL devices show a good reliability performance in DataCom Application Environments

The Reliability Assessment of VCSEL semiconductors is necessary to demonstrate if the high demanding reliability requirements of the automotive industry can be achieved.

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Scope of Reliability Assessment

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Transceiver Module for MOST25/MOST150 (FOT/Pigtail)

Reliability of LED/RCLED	*Reliability of Driver Chip*	*Reliability of Receiver Chip*	*Reliability of PD Chip*

Reliability of Packaging Technology

Reliability of Optomechanical Construction/Optical Path

Scope of this Assessment is the reliability of VCSEL Chip itself.

Reliability of all other elements is assumed to be similar to existing devices for automotive or have to be investigated in a separate reliability assessment.

Transceiver Module for MOST 5Gbit/s

Reliability of VCSEL Chip	*Reliability of Driver Chip*	*Reliability of Receiver Chip*	*Reliability of PD Chip*

Reliability of Packaging Technology

Reliability of Optomechanical Construction/Optical Path

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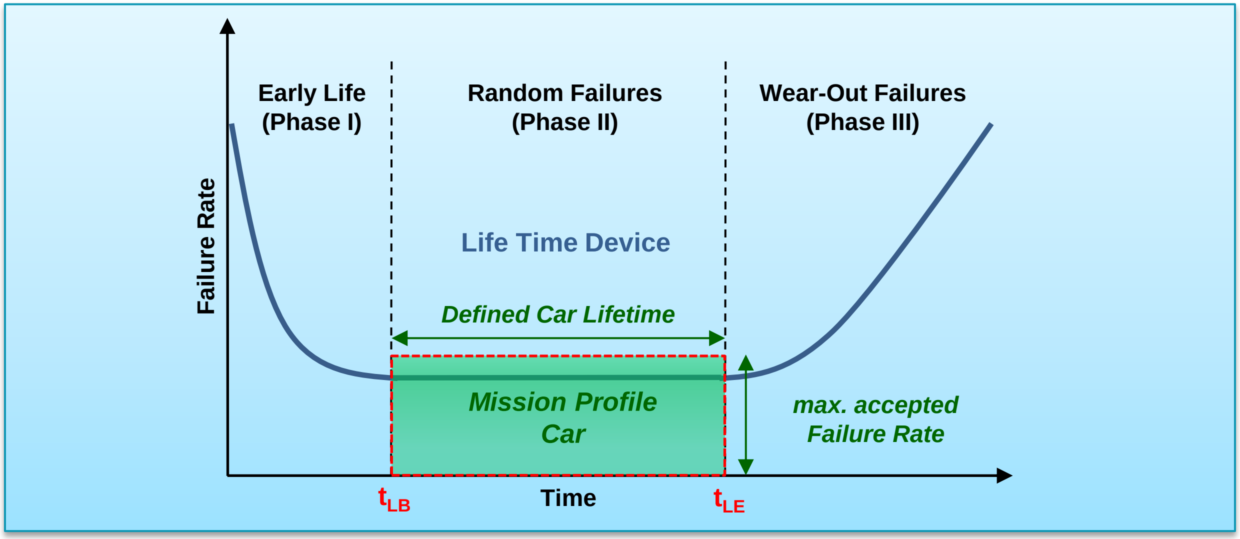
Required Life Time and Reliability for Automotive



Failure rate of an electronic semiconductor device dependent on life time and the relation to a defined car mission profile. To assure that the electronic device is able to fulfill the mission profile of the car, the failure rate of the device has to be below the maximum accepted failure rate over the defined car lifetime.

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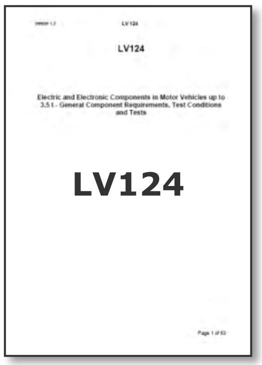
Mission Profile of the Automotive Application


LV124

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

LV124

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 published by Audi, BMW, Daimler, Porsche, and Volkswagen.

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

There is no general definition for a maximum accepted failure rate during car life in the automotive area. Nevertheless for a less complex automotive semiconductor device, random failure rates of **~10FIT** with a confidence level of 90% are assumed and accepted.

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

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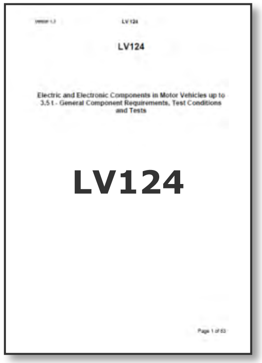
Temperature Conditions in Automotive Applications


LV 124

LV124

Electric and Electronic Components in Motor Vehicles up to 3,5 t - General Component Requirements, Test Conditions and Tests

LV124

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For MOST Applications, only installation location 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

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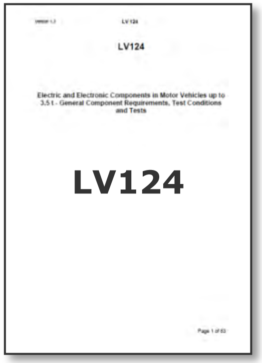
Temperature Profile Automotive Compared to DataCom

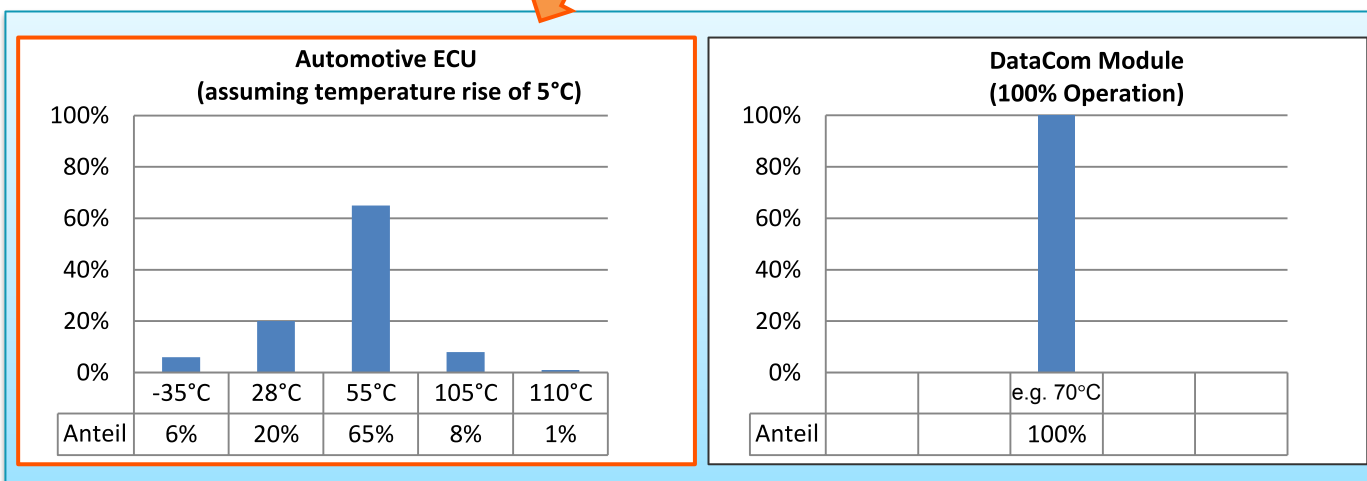

LV124

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

LV124

Automotive Profile involves higher temperature but most common temperature is in about the same range

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



Automotive Environment Requirements

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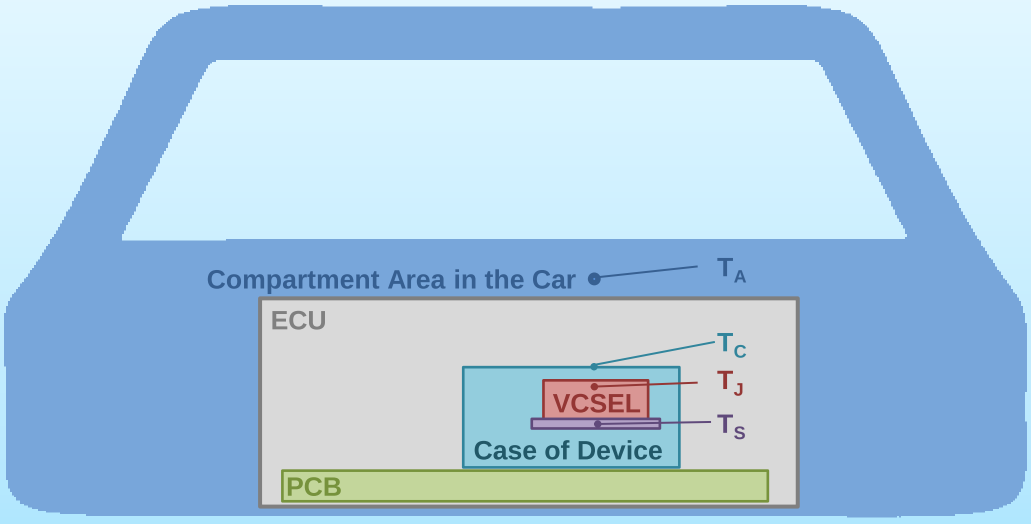
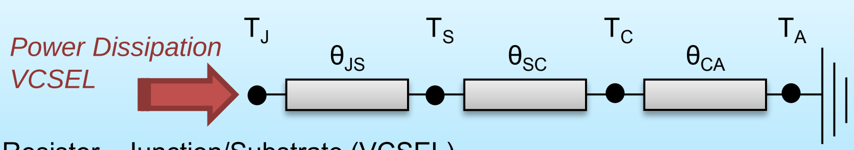
Temperature Model



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)

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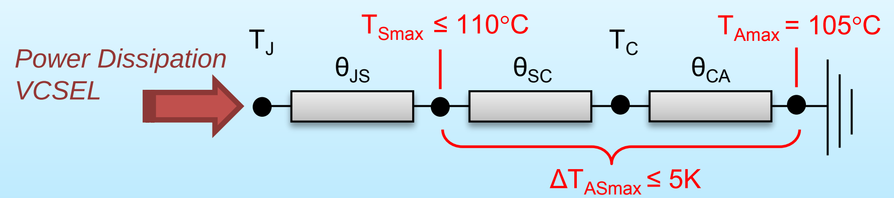
Test Temperature to Cover All Possible Failure Mechanisms



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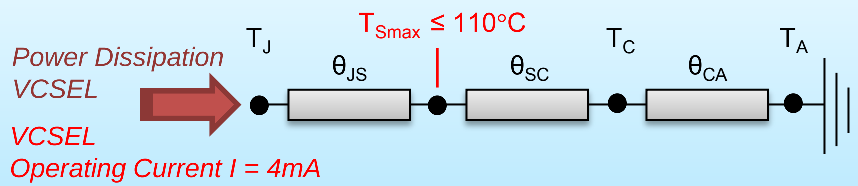
θ_{CA} Thermal Resistor - Case/Ambient (Surface Package of device/compartment area)

Minimum Test Temperature ($T_{JTestmin}$)
To ensure that all possible failure mechanisms are addressed by the test setup, the minimum test temperature (Junction) of the VCSEL has to be at least the maximum possible temperature under application conditions (corresponding temperature profile of the compartment area).

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



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

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Life Time Test

In this reliability assessment, there are basically two intentions for life time testing:

1. Determination of the point of time where the Wear-Out phase of the device begins

2. Prediction of the expected random failure rate of the device during the specified car life time

Unfortunately, 1. requires a test scenario with high acceleration (high test temperatures) to get useful results in a realistic time frame while 2. captures the risk of failures caused by excessive thermal stress outside of the specified temperature range.

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

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Wear-Out Test

- HTOL test with high acceleration factor
(test for fail - can be achieved by increasing the test temperature and the test current beyond the maximum specified application temperature[2])
- Limited amount of samples
- Generation of a significant amount 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 in 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.

Life Time Test

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Random Test

- HTOL test with moderate acceleration factor
  (test for survive - realized by using a test temperature slightly above the maximum specified application temperature[2])
- High amount 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 in 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

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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

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

$\lambda(T_{JApp})$	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

3. **Qualitäts- und Zuverlässigkeitssicherung elektronischer Bauelemente und Systeme.** *Gottschalk, Armin.* s.l. : expert Verlag, 2010.

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])

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Reliability Assessment Method

- Automotive Requirements according to LV124 have been discussed
- A temperature profile was calculated that considers the thermal worst case scenario for the VCSEL transmitter device
- Two different test setups were introduced according to GR-468-CORE 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

Summary

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Status of Life Time Test from VCSEL Manufacturer

- A reliability study based on the introduced evaluation method has been started on 3 VCSEL devices from different manufacturers in 2012
- The selected devices fulfill the basic functional requirements of a potential further optical MOST Physical Layer
- First test results show that the requirement of more the 8000h lifetime can be achieved without running into wear-out
- First test results demonstrate that a random failure rate of around 10FIT is realistic and feasible
- Some tests are still running and planned to be finished by mid of 2013.

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

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Wear-Out Diagramm Example (virtual VCSEL)