GI-POF Link and VCSEL Reliability Calculations

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Multi-Gigabit Automotive Ethernet over Plastic Optical Fiber

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Overview

1. The goal of 802.3dh is to write a robust link specification for the GI POF channel.
   802.3dh is getting into evaluating and ruling on components.

2. A wide band for center wavelength is favored by VCSEL manufacturers who serve the majority of the 25G and higher speed datacom market. Why? Because in their analysis, the wavelength of light does not impact the ability to make the link.

3. This presentation will clarify the VCSEL reliability.

Outline

- 850 nm VCSEL Reliability Statement
- Reliability Statistics
- Application to VCSEL
- Summary

850 nm VCSEL Reliability

1. Time to 1% failure exceeds automotive requirement by a wide margin (murty_3dh_01a_220713.pdf)

2. Field experience of over 100M units has demonstrated random failure rate lower than 1 FIT

3. Hazard rate for wear out at EOL is very small (this presentation)

See a similar statement on 850 and 910 nm reliability in Hoser_3dh_220824.pdf.

Calculations reported in Refs. [1] and [2]

There are three main results here. There is agreement that two of the calculations are incorrect: ppm value and TTF_5 FIT.

The third, failure rate (= 118 FIT), is also incorrect and will be shown in the next several slides.

$\lambda(t)$ in the expression is the same as the hazard rate h(t) defined on slide 5.

$$T_J = T_S + \frac{I_{BIAS}(mA)}{7.5} \cdot \Delta T_{SJ@7.5mA}$$

$$TTF_{5FIT} = \exp\left(\mu' + \sigma' \cdot \Phi^{-1}\left(\frac{5 \cdot 32000}{1000} 10^{-9}\right)\right)$$

$$\lambda(t) = -\frac{d\ln(1-F(t))}{dt}$$

$$ppm = \frac{\lambda(t) \cdot 32000}{1000}$$

a) Expression is not valid for wear out lognormal failure distribution.
b) Vastly overstates failure.

Reliability result

	Temperature profile						Failure rate					
	Percentage	Operation time per Temperature (h)	T_A (ºC)	T_S (ºC)	T_J (ºC)	TTF x% (hours)	TTF_{5FIT} (hours)	Equivalent time in max T (hours)	Log-normal mu', ln (hours)	Failure-rate wear out (FIT)	Failure-rate maverick (FIT)	ppm
T0	6 %	1920	-40	-20.00	5.0	1.084E+11	11684618447	0.00	27.2706			
T1	20 %	6400	23	43.00	68.0	1.539E+07	1658406	3.27	18.4104			
T2	65 %	20800	50	70.00	95.0	8.736E+05	94131	187.00	15.5415			
T3	8 %	2560	100	120.00	145.0	1.145E+04	1234	1755.75	11.2070	$\lambda(t)$		
T4	1 %	320	105	125.00	150.0	7.854E+03	846	320.00	μ' 10.8[illegible]			ppm
Cummulative	100 %	32000						t 2266.01	10.8298	118.4411	5.0	3950

> 10 FIT !

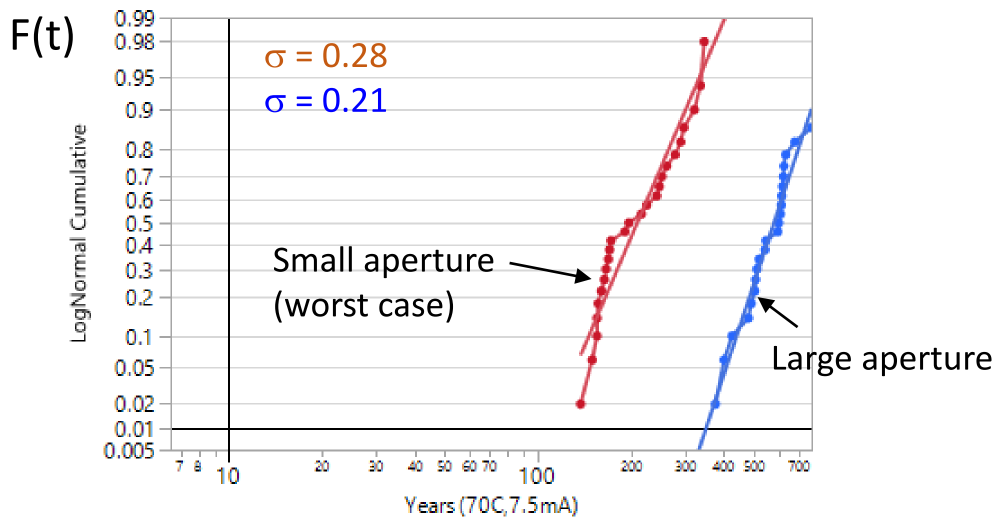
Incorrect value

Incorrect values even for the composite line.

The inputs to this calculation are incorrect.
a) Calculated with an extrapolation of the composite line that leads to an incorrect answer.
b) This is calculated for Δt at 125°C (100%, not 1% as in the mission profile), see Appendix.

[1] Ruben Perez-Aranda, perezaranda_3dh_01a_221005_vcsels.pdf
[2] Ruben Perez-Aranda and David Ortiz, perezaranda_3cz_01b_080621_vcsel_reliability.pdf

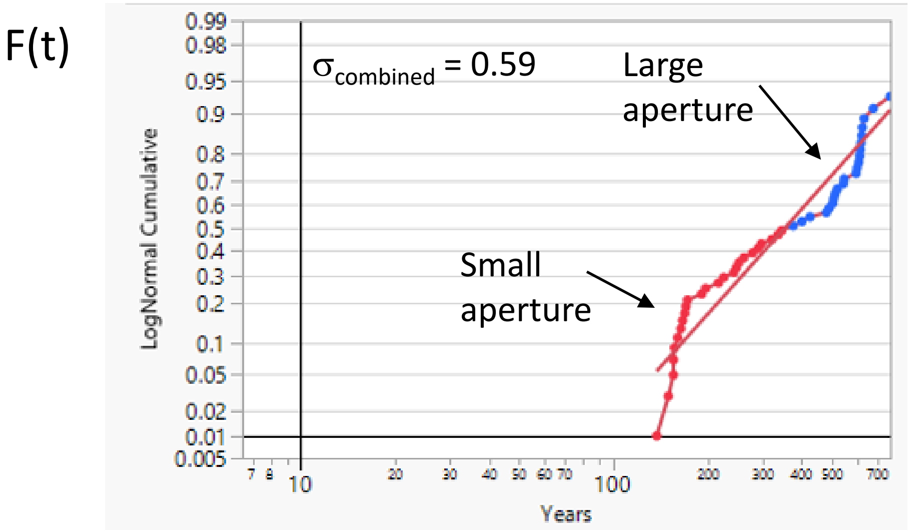
VCSEL Failure Distribution



Spread $\sigma = \sigma_{\text{intrinsic}}$

Large aperture VCSEL operates at a lower junction temperature.

Combined (same data as the left plot)



Spread $\sigma_{\text{combined}} \approx \sqrt{\sigma^2_{\text{intrinsic}} + \sigma^2_{\text{heterogeneity}}}$

a) When you combine all VCSELs, you get a larger σ

b) σ_{combined} increases with heterogeneity

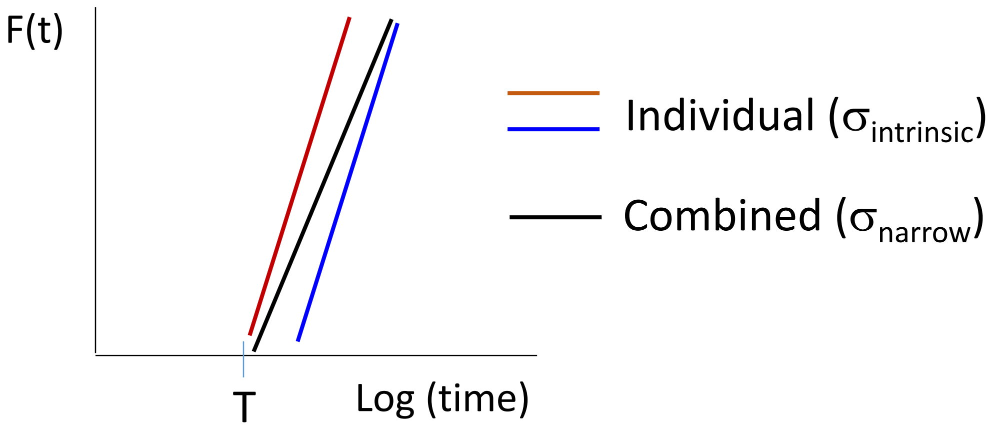
Lognormal distribution

$$f(t) = \frac{1}{\sigma t\sqrt{2\pi}}\exp\left(-\frac{(\ln t - \mu)^2}{2\sigma^2}\right) \quad \text{pdf}$$

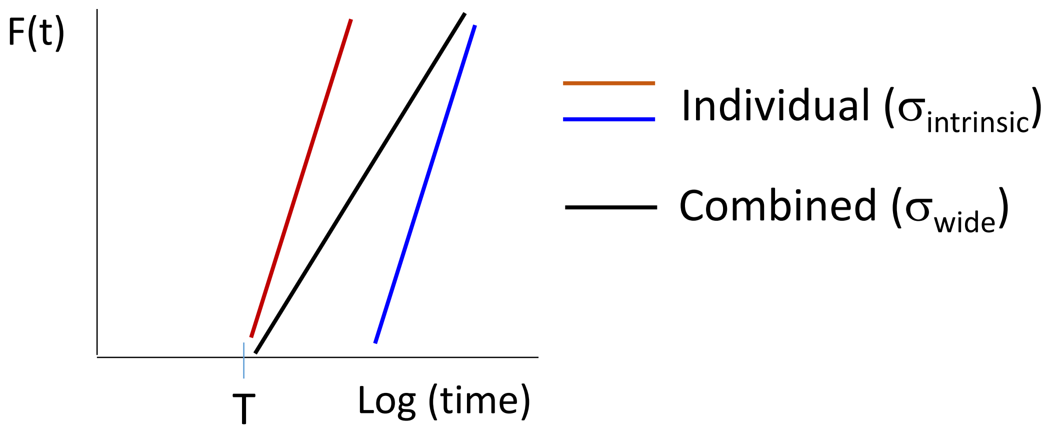
$$F(t) = \frac{1}{2}\left(1 + \text{erf}\left(\frac{\ln t - \mu}{\sigma\sqrt{2}}\right)\right) \quad \text{cdf}$$

σ Increases with Heterogeneity

Narrow distribution of aperture size



Wide distribution of aperture size



$\sigma_{wide} > \sigma_{narrow}$

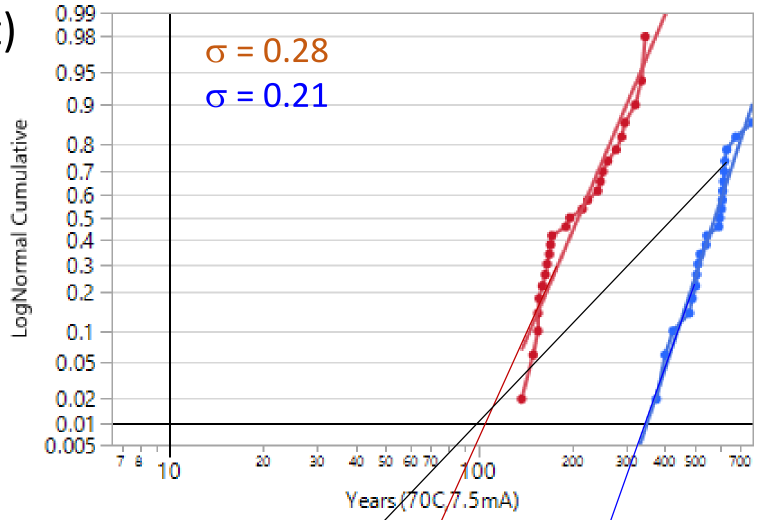
Does more heterogeneity (a wide distribution of apertures) make the VCSEL less reliable?
Answer: No, if the leftmost curve does not move.

The math in Ref. [1] punishes the 850 nm VCSEL because of a wide distribution of aperture sizes!
It predicts a higher failure rate for a wider distribution of aperture size.

[1] Ruben Perez-Aranda, perezaranda_3dh_01a_221005_vcsels.pdf

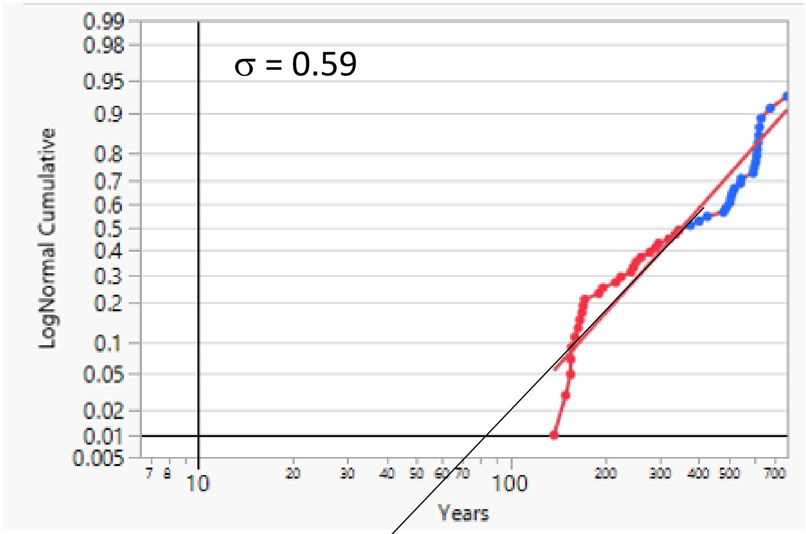
Extrapolate the Failure Distribution

F(t)



Combined

F(t)

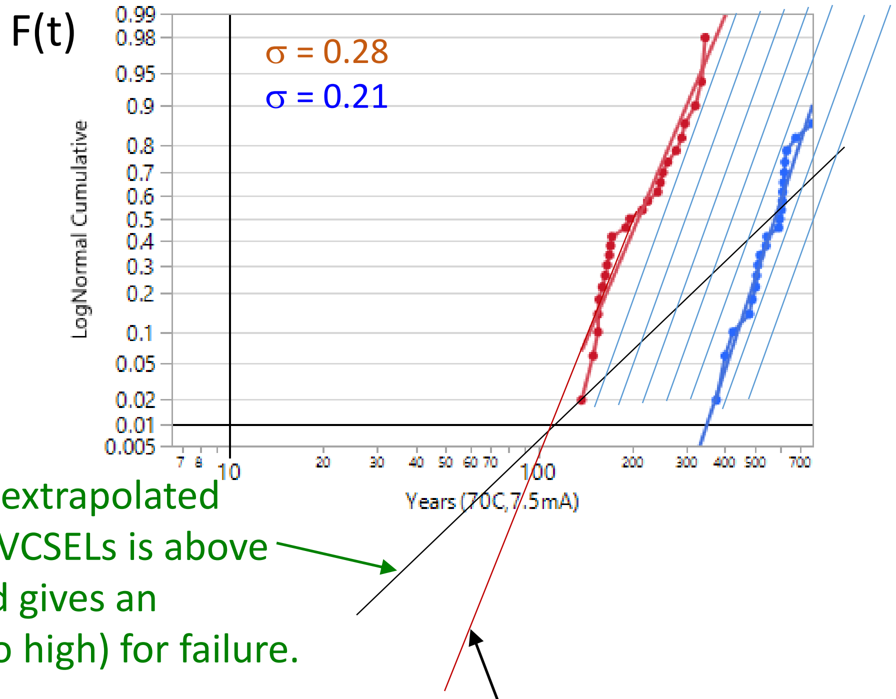


This section of the extrapolated line from the combined plot is above the orange curve **(=> the extrapolated portion is incorrect because it predicts higher failure than the orange line)**

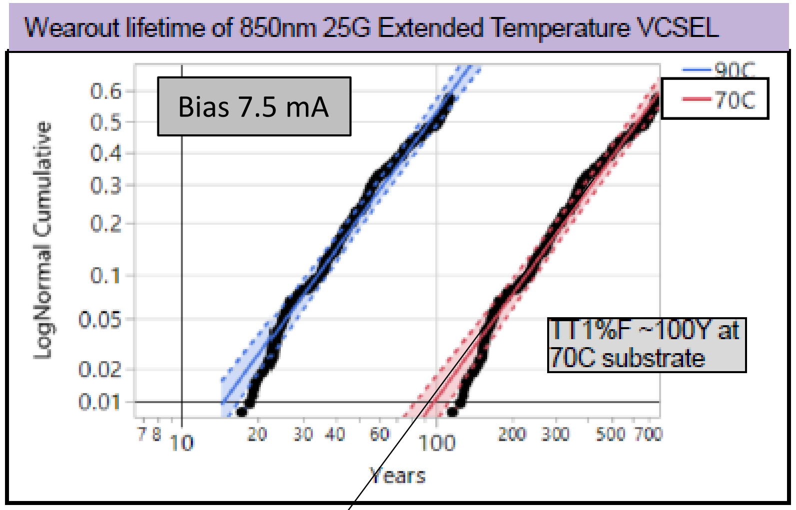
Extrapolated failure distribution for combined plot (this is translated to the left figure)

Failure cannot be higher than this line because it represents worst case.

850 nm VCSEL



Combined failure distribution for all 850 nm VCSELs (murty_3dh_01a_220713.pdf)



This section of the extrapolated line for all 850 nm VCSELs is above the orange line and gives an incorrect value (too high) for failure.

Extrapolated failure distribution for all 850 nm VCSELs ($\sigma_{composite} > \sigma_{intrinsic}$)

Facts about VCSELs:

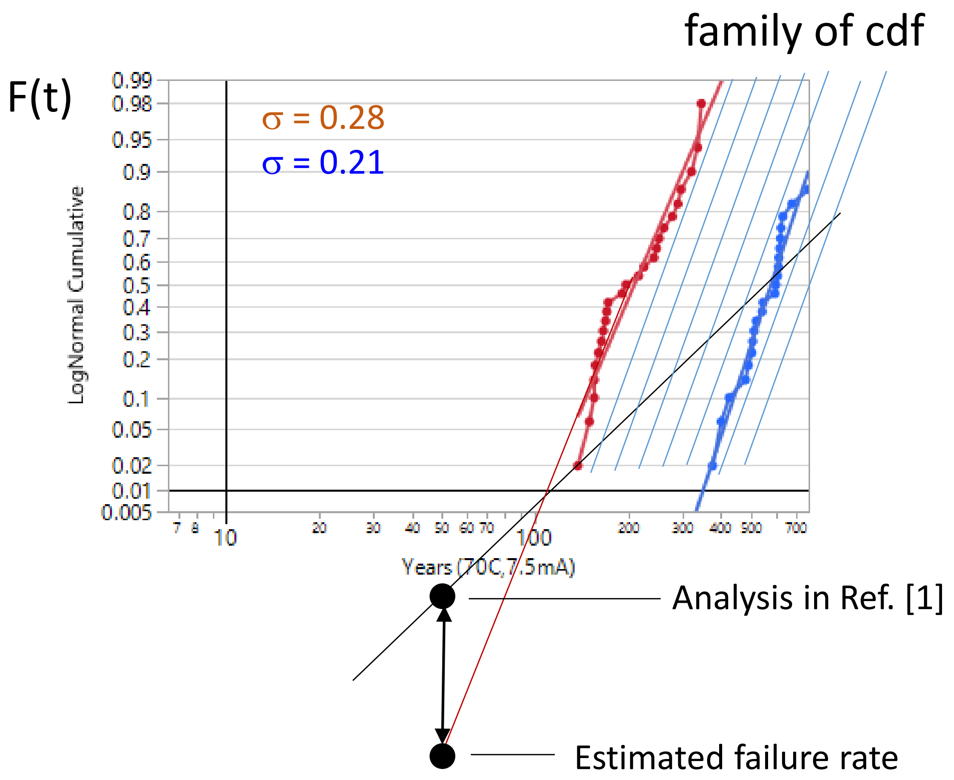
a) Extrapolated leftmost failure distribution. VCSELs do not fall to the left of this line because they are screened. [VCSEL aperture sizes don't follow a Gaussian distribution.]

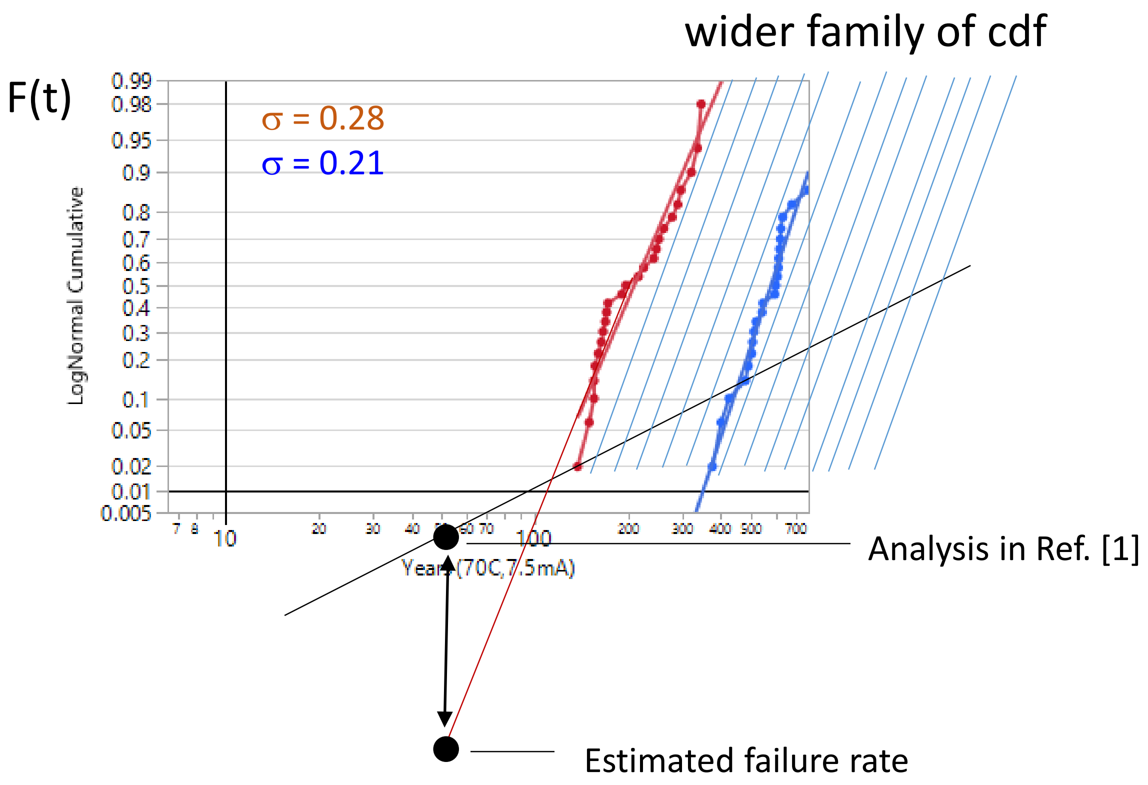
b) Failure will not exceed this line.

The extrapolated failure distribution for all 850 nm VCSELs lies above the orange curve! It vastly overestimates the failure rate. This is why the failure rate estimate (it is called hazard rate) is so high in Ref. [1].

[1] Ruben Perez-Aranda, perezaranda_3dh_01a_221005_vcsels.pdf

Analysis in Ref. [1] punishes wide distribution of VCSELs



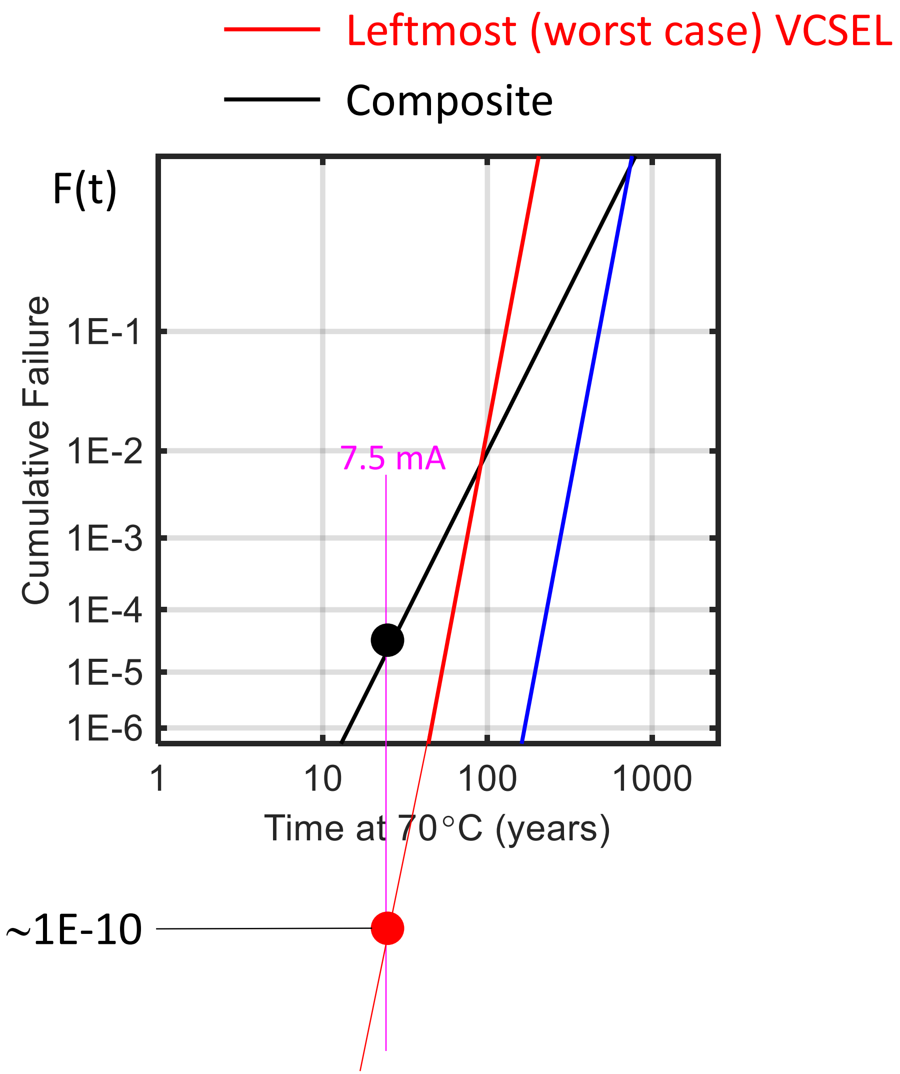


Predicted failure is higher for the wider distribution of VCSELs.

This does not agree with expectation that failure rate should not depend on the distribution of apertures (when worst case [orange line] is controlled).

[1] Ruben Perez-Aranda, perezaranda_3dh_01a_221005_vcsels.pdf

Estimate for Hazard Rate for Wear Out



Invalid extrapolation

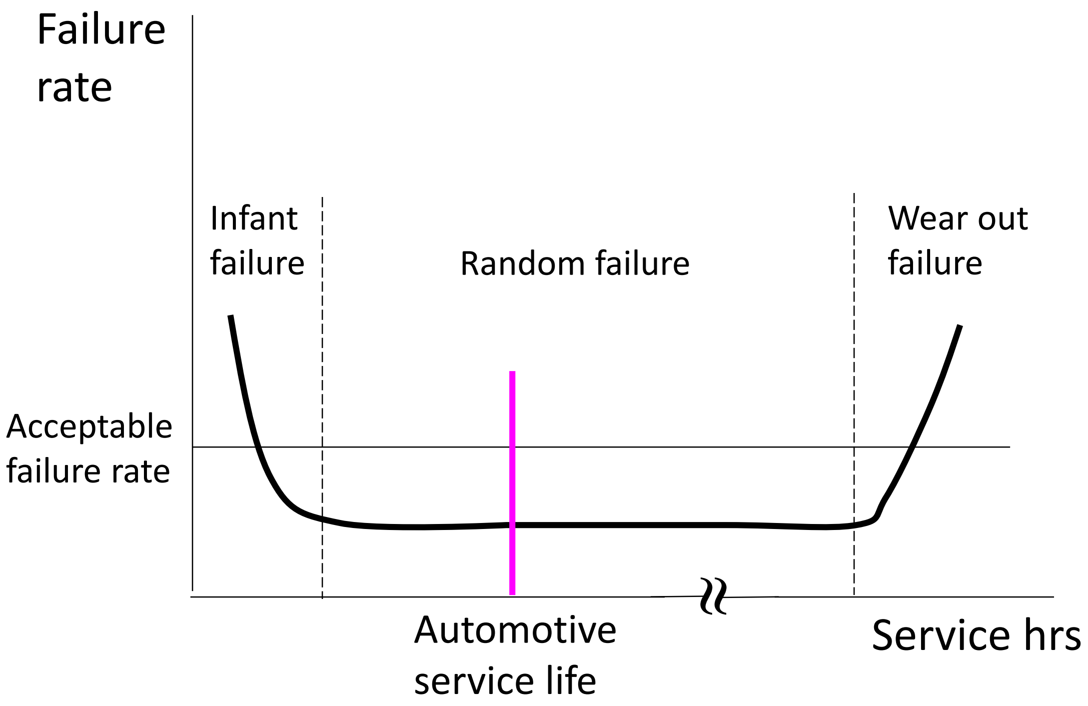
Bias	Item	Worst case VCSEL ✓	Composite ✗
7.5 mA	Hazard rate (FIT)	<< 1	~100*

- **The hazard rate for wear out is very small**
- Hazard rate is the derivative of F(t) [for F(t) << 1]

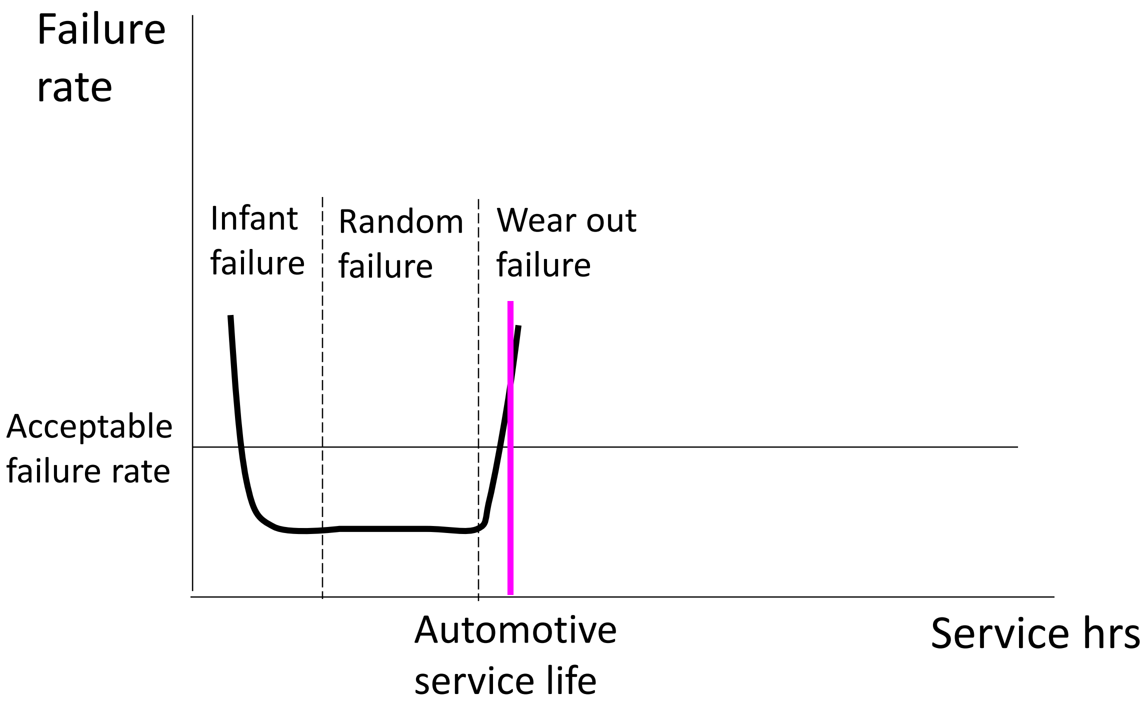
* See Appendix. Actual value is a 10X smaller.

Failure Rate and Automotive Service Life

Correct Picture



Claim in Ref [1]
This is incorrect.



[1] Ruben Perez-Aranda and David Ortiz, "VCSEL reliability comparison," perezaranda_3cz_01b_080621_vcsel_reliability.pdf.

Multi-Wavelength Links

Multi-wavelength VCSEL-based links are becoming increasingly common for two reasons:

a) Increase the data rate, or
b) Enable multiple VCSEL suppliers to participate

1. 802.3cm Bidirectional link 844 – 863 nm, 900 – 918 nm

2. SWDM Four wavelengths covering 840 – 950 nm

3. 802.3db 50 m OM4 link, source can be any wavelength 842 – 948 nm

From Vipul Bhatt (Coherent, formerly II-VI)

“Our long experience with commercial implementation of SWDM4 transceiver modules has proven that there is no adverse impact on manufacturing or testing cost for receivers designed to accept a wide range of wavelengths. On the contrary, a common design that works for a variety of transmitters helps leverage economies of scale.”

Summary

- 850 nm VCSEL for the automotive mission profile:
  - Time to 1% Failure for wear out exceeds the total 3.7 service year requirement of the automotive mission profile by a wide margin
  - Can leverage the the established high volume, multi-vendor manufacturing eco-system to maintain low random failure rate
  - Low hazard rate at EOL
- Adopting a wide wavelength band (840 – 9xx nm) will enable a wide range on suppliers
- Time to move to developing a robust specifications for GI POF links

Appendix

Calculating Hazard Rate

Hazard rate at EOL is a function of temperature, and the automotive mission profile shows five different temperatures. The method for calculating hazard rate is described here.

$$\Delta F = \int_{t_1}^{t_2} \langle h(\tau) \rangle \, d\tau$$

ΔF	cumulative failure in a finite interval of time
h(t)	hazard rate

1. The automotive mission profile shows the probability of a vehicle being at each of five different temperatures. Each vehicle may take a different path through the temperature profile.

2. Hazard rate is meaningful only as a statistical average $\langle h(t) \rangle$ because the goal is to estimate the failure rate of an ensemble (fleet) of vehicles.

3. A Monte Carlo simulation can be used to simulate temperature history and determine $\langle h(t) \rangle$. The simulation should be run many times and $\langle h(t) \rangle$ determined by taking the average. Spikes in h(t) for a brief time in any one Monte Carlo run do not carry much meaning by themselves because it is the resulting failures that count, not the value of h(t) itself. The resulting failures depend on $\langle h(t) \rangle$.

4. Alternatively, de-rating the hazard rate at EOL by the fraction of time at each of the five temperatures will give the same value of $\langle h(t) \rangle$ as the Monte Carlo simulation.