# Reliability constrained link budget assessment for 25 and 10 Gb/s

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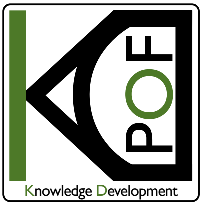
IEEE 802.3cz Task Force - 22nd Dec 2020 Adhoc Meeting

# Introduction & objectives

- This contribution is based on the reliability criteria and reliability models presented in [1], which are consistent with the ones considered in [2]
- It is also based on the mission profile proposal of [3]
- The objectives of this contribution are:
  - Exploration of the maximum operation bias current at maximum temperature based on wear out reliability criteria
  - Link budget assessment based on max bias current
- As explained in [2], 5 FIT target of maverick failures have not been verified so far. The presented reliability analysis will only be based on the wear out / fatigue failures
- Only TRUMPF 850nm 25G VCSEL will be considered, because reliability data and oxide aperture of the tested devices are known
  - Smallest oxide aperture diameter corner will be considered for the reliability calculation
  - Smallest and largest aperture will be considered for link budget analysis

# VCSEL wear out reliability models [1]

# VCSEL wear out statistics — lognormal PDF




- VCSEL aging failures are collected in time according to a lognormal distribution
  - This is very different of the general consideration of exponential distribution used in complex CMOS integrated circuits (λ is constant)
- Because VCSEL lifetime statistics follow a lognormal distribution, λ is not constant
- Lognormal PDF is defined as:

$$f(t') = \frac{1}{\sigma'\sqrt{2\pi}} \exp\left(-\frac{1}{2}\left(\frac{t'-\mu'}{\sigma'}\right)^2\right)$$

where:

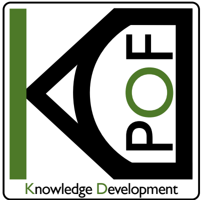
  - $t'$ is the natural logarithm of the time to failure
  - $\mu'$ mean of the natural logarithms of the time to failure
  - $\sigma'$ standard deviation of the natural logarithms of the time to failure

- Therefore, the unreliability function is:

$$F(t) = \Phi\left(\frac{\ln(t) - \mu'}{\sigma'}\right)$$

where $\Phi$ is the standard normal distribution (i.e. $N(0,1)$)

# VCSEL wear out reliability model




- Reliability model is as follows. The time to failure is reduced with temperature (T) according to Arrhenius's equation and with a negative power of the average current density (J):

$$TTF_{x\%} = C \cdot J^{-n} \cdot \exp\left(\frac{E_a \cdot e}{k_B \cdot T}\right)$$

where:

  - $E_a$ is the activation energy of failure mechanism (eV)
  - $e$ is the electron charge (SI units)
  - $k_B$ is the Boltzmann's constant (SI units)
  - $T$ is absolute temperature (Kelvin)
  - $C$ is a constant
  - $TTF_{x\%}$ is the time to x% failures (e.g. in hours)

- Reliability model can be built on $T_J$ (junction or active region temperature) or it can be built on $T_S$ (substrate or heat-sink temperature, direct to measure)

# VCSEL wear out reliability analysis results

# VCSEL reliability analysis based on extracted model from [4]

Reliability parameters

| Operation | Operation total time (h) | 32000 | Reliability model | Wear out Ea (eV) @ $T_J$ | 1.075 |
|---|---|---|---|---|---|
| | Service life (years) | 15 | | Wear out n @ $T_J$ | 6.084 |
| | Min oxide aperture diam. (um) | 6.5 | | Arrhenius C factor (hours) @ $T_J$ | 1.070547E-02 |
| | $I_{OP}$ (mA) max | 4.4770 | | TTF x% | 50 |
| | $J_{OP}$ (kA/cm²) | 13.50 | | Log-normal σ', ln (hours) | 0.32 |
| | $V_F$ (V) w/c | 2.0 | | Qe | 1.6022E-19 |
| | $P_{opt}$ (mW) w/c | 0 | | $K_B$ | 1.3806E-23 |
| | $P_{DIS}$ (mW) | 8.9540 | | Qe/$K_B$ | 1.1605E+04 |
| | $R_{JS}$ (K/W) w/c | 2500 | | ºC to Kelvin | 273.15 |
| | $\Delta T_{AS}$ (ºC) | 20 | | | |

## Calculation according to [1], slide 18. Model extracted from [4].

Reliability result

| | Temperature profile | | | | | Failure rate | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Percentage | Time per Temperature (h) | $T_A$ (ºC) | $T_S$ (ºC) | $T_J$ (ºC) | TTF x% (hours) | TTF x% (years) | Equivalent time in max T (hours) | Log-normal mu', ln (hours) | Failure-rate wear out (FIT) | Failure-rate maverick (FIT) | Total ppm |
| $T_0$ | 6 % | 1920 | -40 | -20 | 2.4 | 6.652E+10 | 7.594E+06 | 0.00 | 24.9208 | | | |
| $T_1$ | 20 % | 6400 | 23 | 43 | 65.4 | 1.454E+07 | 1.659E+03 | 4.84 | 16.4921 | | | |
| $T_2$ | 65 % | 20800 | 50 | 70 | 92.4 | 9.548E+05 | 1.090E+02 | 239.28 | 13.7692 | | | |
| $T_3$ | 8 % | 2560 | 100 | 120 | 142.4 | 1.570E+04 | 1.792E+00 | 1791.29 | 9.6612 | | | |
| $T_4$ | 1 % | 320 | 105 | 125 | 147.4 | 1.098E+04 | 1.254E+00 | 320.00 | 9.3042 | | | |
| Cummulative | 100 % | 32000 | | | | | | 2355.40 | 9.3042 | 5.0 | 5.0 | 319.21 |

## Original mission profile

# VCSEL reliability analysis based on extracted model from [4]

Reliability parameters

| Operation | Operation total time (h) | 12000 | Reliability model | Wear out Ea (eV) @ $T_J$ | 1.075 |
|---|---|---|---|---|---|
| | Service life (years) | 15 | | Wear out n @ $T_J$ | 6.084 |
| | Min oxide aperture diam. (um) | 6.5 | | Arrhenius C factor (hours) @ $T_J$ | 1.070547E-02 |
| | $I_{OP}$ (mA) max | 4.7960 | | TTF x% | 50 |
| | $J_{OP}$ (kA/cm$^2$) | 14.46 | | Log-normal σ', ln (hours) | 0.32 |
| | $V_F$ (V) w/c | 2.0 | | Qe | 1.6022E-19 |
| | $P_{opt}$ (mW) w/c | 0 | | $K_B$ | 1.3806E-23 |
| | $P_{DIS}$ (mW) | 9.5920 | | Qe/$K_B$ | 1.1605E+04 |
| | $R_{JS}$ (K/W) w/c | 2500 | | ºC to Kelvin | 273.15 |
| | $\Delta T_{AS}$ (ºC) | 20 | | | |

## Calculation according to [1], slide 18. Model extracted from [4].

Reliability result

| | Temperature profile | | | | | Failure rate | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Percentage | Time per Temperature (h) | $T_A$ (ºC) | $T_S$ (ºC) | $T_J$ (ºC) | TTF x% (hours) | TTF x% (years) | Equivalent time in max T (hours) | Log-normal mu', ln (hours) | Failure-rate wear out (FIT) | Failure-rate maverick (FIT) | Total ppm |
| $T_0$ | 6 % | 720 | -40 | -20 | 4.0 | 3.372E+10 | 3.849E+06 | 0.00 | 24.2413 | | | |
| $T_1$ | 20 % | 2400 | 23 | 43 | 67.0 | 8.045E+06 | 9.183E+02 | 1.93 | 15.9005 | | | |
| $T_2$ | 65 % | 7800 | 70 | 90 | 114.0 | 9.353E+04 | 1.068E+01 | 538.67 | 11.4461 | | | |
| $T_3$ | 8 % | 960 | 100 | 120 | 144.0 | 9.206E+03 | 1.051E+00 | 673.55 | 9.1276 | | | |
| $T_4$ | 1 % | 120 | 105 | 125 | 149.0 | 6.459E+03 | 7.374E-01 | 120.00 | 8.7733 | | | |
| Cummulative | 100 % | 12000 | | | | | | 1334.15 | 8.7733 | 5.0 | 5.0 | 119.54 |

## New mission profile

# VCSEL reliability analysis based on extracted model from [5]

Reliability parameters

| Operation | Operation total time (h) | 32000 | Reliability model | Wear out Ea (eV) @ $T_S$ | 1.225 |
|---|---|---|---|---|---|
| | Service life (years) | 15 | | Wear out n @ $T_S$ | 6.588 |
| | Min oxide aperture diam. (um) | 6.5 | | Arrhenius C factor (hours) @ $T_S$ | 4.044972E-05 |
| | $I_{OP}$ (mA) max | 4.5840 | | TTF x% | 1 |
| | $J_{OP}$ (kA/cm$^2$) | 13.82 | | Log-normal σ', ln (hours) | 0.37 |
| | $V_F$ (V) w/c | 2.0 | | Qe | 1.6022E-19 |
| | $P_{opt}$ (mW) w/c | 0 | | $K_B$ | 1.3806E-23 |
| | $P_{DIS}$ (mW) | 9.1680 | | Qe/$K_B$ | 1.1605E+04 |
| | $R_{JS}$ (K/W) w/c | 2500 | | ºC to Kelvin | 273.15 |
| | $\Delta T_{AS}$ (ºC) | 20 | | | |

## Calculation according to [1], slide 23. Model extracted from [5].

Reliability result

| | Temperature profile | | | | | Failure rate | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Percentage | Time per Temperature (h) | $T_A$ (ºC) | $T_S$ (ºC) | $T_J$ (ºC) | TTF x% (hours) | TTF x% (years) | Equivalent time in max T (hours) | Log-normal mu', ln (hours) | Failure-rate wear out (FIT) | Failure-rate maverick (FIT) | Total ppm |
| $T_0$ | 6 % | 1920 | -40 | -20 | 2.9 | 3.071E+12 | 3.506E+08 | 0.00 | 29.6139 | | | |
| $T_1$ | 20 % | 6400 | 23 | 43 | 65.9 | 4.229E+07 | 4.827E+03 | 0.61 | 18.4207 | | | |
| $T_2$ | 65 % | 20800 | 50 | 70 | 92.9 | 1.228E+06 | 1.402E+02 | 67.93 | 14.8818 | | | |
| $T_3$ | 8 % | 2560 | 100 | 120 | 142.9 | 6.317E+03 | 7.212E-01 | 1625.49 | 9.6118 | | | |
| $T_4$ | 1 % | 320 | 105 | 125 | 147.9 | 4.011E+03 | 4.579E-01 | 320.00 | 9.1576 | | | |
| Cummulative | 100 % | 32000 | | | | | | 2014.03 | 9.1576 | 5.0 | 5.0 | 320.05 |

## Original mission profile

# VCSEL reliability analysis based on extracted model from [5]

Reliability parameters

| Operation | Operation total time (h) | 12000 | Reliability model | Wear out Ea (eV) @ $T_S$ | 1.225 |
|---|---|---|---|---|---|
| | Service life (years) | 15 | | Wear out n @ $T_S$ | 6.588 |
| | Min oxide aperture diam. (um) | 6.5 | | Arrhenius C factor (hours) @ $T_S$ | 4.044972E-05 |
| | $I_{OP}$ (mA) max | 5.0775 | | TTF x% | 1 |
| | $J_{OP}$ (kA/cm²) | 15.31 | | Log-normal σ', ln (hours) | 0.37 |
| | $V_F$ (V) w/c | 2.0 | | Qe | 1.6022E-19 |
| | $P_{opt}$ (mW) w/c | 0 | | $K_B$ | 1.3806E-23 |
| | $P_{DIS}$ (mW) | 10.1550 | | Qe/$K_B$ | 1.1605E+04 |
| | $R_{JS}$ (K/W) w/c | 2500 | | °C to Kelvin | 273.15 |
| | $\Delta T_{AS}$ (°C) | 20 | | | |

## Calculation according to [1], slide 23. Model extracted from [5].

Reliability result

| | Temperature profile | | | | | Failure rate | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Percentage | Time per Temperature (h) | $T_A$ (°C) | $T_S$ (°C) | $T_J$ (°C) | TTF x% (hours) | TTF x% (years) | Equivalent time in max T (hours) | Log-normal mu', ln (hours) | Failure-rate wear out (FIT) | Failure-rate maverick (FIT) | Total ppm |
| $T_0$ | 6 % | 720 | -40 | -20 | 5.4 | 1.566E+12 | 1.788E+08 | 0.00 | 28.9403 | | | |
| $T_1$ | 20 % | 2400 | 23 | 43 | 68.4 | 2.156E+07 | 2.461E+03 | 0.23 | 17.7471 | | | |
| $T_2$ | 65 % | 7800 | 70 | 90 | 115.4 | 6.392E+04 | 7.296E+00 | 249.59 | 11.9261 | | | |
| $T_3$ | 8 % | 960 | 100 | 120 | 145.4 | 3.221E+03 | 3.677E-01 | 609.56 | 8.9382 | | | |
| $T_4$ | 1 % | 120 | 105 | 125 | 150.4 | 2.045E+03 | 2.335E-01 | 120.00 | 8.4840 | | | |
| Cummulative | 100 % | 12000 | | | | | | 979.38 | 8.4840 | 5.0 | 5.0 | 119.61 |

## New mission profile

# VCSEL reliability analysis based on TRUMPF data [2]

Reliability parameters

| | | | | | |
|---|---|---|---|---|---|
| **Operation** | **Operation total time (h)** | 32000 | **Reliability model** | **Wear out Ea (eV) @ $T_J$** | 1.180 |
| | **Service life (years)** | 15 | | **Wear out n @ $T_J$** | 1.640 |
| | **Min oxide aperture diam. (um)** | 6.5 | | **TTF x%, location** | 50.0 |
| | **$I_{OP}$ (mA) max** | 5.6820 | | **Log-normal σ', ln (hours)** | 0.5 |
| | **$J_{OP}$ (kA/cm²)** | 17.13 | | **$J_0$ (kA/cm²)** | 19.49 |
| | **$J_{OP}$ (mA/um²)** | 0.17 | | **$T_{J0}$ (ºC)** | 193 |
| | **$\Delta T_{AS}$ (ºC)** | 20.0 | | **$TTF_0$ x% (hours)** | 965 |
| **VCSEL model fitting** | **$R_{JS}$ (K/W) @ room Ts reference** | 1950 | | **Arrhenius C factor (hours) @ $T_J$** | 2.198993E-08 |
| | **$R_{JS}$ factor** | 100 % | | **Qe** | 1.6022E-19 |
| | **$R_{JS}$ (K/W) @ room Ts** | 1950 | | **$K_B$** | 1.3806E-23 |
| | **$R_{JS}$ room Ts (ºC)** | 20.0 | | **Qe/$K_B$** | 1.1605E+04 |
| | **$R_{JS}$ Exponent** | 1.067 | | **ºC to Kelvin** | 273.15 |
| | **$R_{JS}$ Current fitting p0** | 0.01754 | **VCSEL model fitting** | **$P_{DIS}$ poly-fitting p11** | -0.006889 |
| | **$R_{JS}$ Current fitting p1** | 0.9636 | | **$P_{DIS}$ poly-fitting p02** | -5.203E-05 |
| | **$P_{DIS}$ poly-fitting p00** | -0.3481 | | **$P_{DIS}$ poly-fitting p21** | 0.0001612 |
| | **$P_{DIS}$ poly-fitting p10** | 1.291 | | **$P_{DIS}$ poly-fitting p12** | 3.641E-05 |
| | **$P_{DIS}$ poly-fitting p01** | 0.01552 | | **$P_{DIS}$ poly-fitting p03** | 1.736E-15 |
| | **$P_{DIS}$ poly-fitting p20** | 0.05763 | | | |

Reliability result

| | Temperature profile | | | | | | | Failure rate | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Percentage** | **Operation time per Temperature (h)** | **$T_A$ (ºC)** | **$T_S$ (ºC)** | **$R_{JS}$ (K/W)** | **$P_{DIS}$ (mW)** | **$T_J$ (ºC)** | **TTF x% (hours)** | **TTF x% (years)** | **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** | -20.0 | 1772.9 | 9.28 | -3.6 | 2.384E+12 | 2.721E+08 | 0.00 | 28.4996 | | | |
| **T1** | **20 %** | 6400 | **23** | 43.0 | 2247.4 | 8.34 | 61.7 | 1.192E+08 | 1.361E+04 | 1.19 | 18.5963 | | | |
| **T2** | **65 %** | 20800 | 50 | 70.0 | 2452.7 | 8.32 | 90.4 | 4.751E+06 | 5.423E+02 | 97.41 | 15.3738 | | | |
| **T3** | **8 %** | 2560 | **100** | 120.0 | 2835.9 | 8.87 | 145.1 | 3.434E+04 | 3.920E+00 | 1658.43 | 10.4442 | | | |
| **T4** | **1 %** | 320 | **105** | 125.0 | 2874.4 | 8.97 | 150.8 | 2.225E+04 | 2.540E+00 | 320.00 | 10.0100 | | | |
| **Cummulative** | 100 % | 32000 | | | | | | | | **2077.03** | **10.0100** | **5.0** | **5.0** | **320.54** |

**Original mission profile**

# VCSEL reliability analysis based on TRUMPF data [2]

Reliability parameters

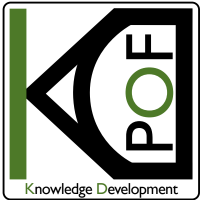
| | | | | | |
|---|---|---|---|---|---|
| Operation | Operation total time (h) | 12000 | Reliability model | Wear out Ea (eV) @ $T_J$ | 1.180 |
| | Service life (years) | 15 | | Wear out n @ $T_J$ | 1.640 |
| | Min oxide aperture diam. (um) | 6.5 | | TTF x%, location | 50.0 |
| | $I_{OP}$ (mA) max | 6.5200 | | Log-normal σ', ln (hours) | 0.5 |
| | $J_{OP}$ (kA/cm²) | 19.66 | | $J_0$ (kA/cm²) | 19.49 |
| | $J_{OP}$ (mA/um²) | 0.20 | | $T_{J0}$ (ºC) | 193 |
| | $\Delta T_{AS}$ (ºC) | 20.0 | | $TTF_0$ x% (hours) | 965 |
| VCSEL model fitting | $R_{JS}$ (K/W) @ room Ts reference | 1950 | | Arrhenius C factor (hours) @ $T_J$ | 2.198993E-08 |
| | $R_{JS}$ factor | 100 % | | Qe | 1.6022E-19 |
| | $R_{JS}$ (K/W) @ room Ts | 1950 | | $K_B$ | 1.3806E-23 |
| | $R_{JS}$ room Ts (ºC) | 20.0 | | Qe/$K_B$ | 1.1605E+04 |
| | $R_{JS}$ Exponent | 1.067 | | ºC to Kelvin | 273.15 |
| | $R_{JS}$ Current fitting p0 | 0.01754 | VCSEL model fitting | $P_{DIS}$ poly-fitting p11 | -0.006889 |
| | $R_{JS}$ Current fitting p1 | 0.9636 | | $P_{DIS}$ poly-fitting p02 | -5.203E-05 |
| | $P_{DIS}$ poly-fitting p00 | -0.3481 | | $P_{DIS}$ poly-fitting p21 | 0.0001612 |
| | $P_{DIS}$ poly-fitting p10 | 1.291 | | $P_{DIS}$ poly-fitting p12 | 3.641E-05 |
| | $P_{DIS}$ poly-fitting p01 | 0.01552 | | $P_{DIS}$ poly-fitting p03 | 1.736E-15 |
| | $P_{DIS}$ poly-fitting p20 | 0.05763 | | | |

Reliability result

| | Temperature profile | | | | | | | Failure rate | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Percentage | Operation time per Temperature (h) | $T_A$ (ºC) | $T_S$ (ºC) | $R_{JS}$ (K/W) | $P_{DIS}$ (mW) | $T_J$ (ºC) | TTF x% (hours) | TTF x% (years) | Equivalent time in max T (hours) | Log-normal mu', ln (hours) | Failure-rate wear out (FIT) | Failure-rate maverick (FIT) | ppm |
| T0 | 6 % | 720 | -40 | -20.0 | 1797.5 | 11.04 | -0.1 | 1.010E+12 | 1.153E+08 | 0.00 | 27.6412 | | | |
| T1 | 20 % | 2400 | 23 | 43.0 | 2278.4 | 9.89 | 65.5 | 6.019E+07 | 6.871E+03 | 0.48 | 17.9130 | | | |
| T2 | 65 % | 7800 | 70 | 90.0 | 2641.6 | 9.99 | 116.4 | 3.071E+05 | 3.506E+01 | 306.88 | 12.6349 | | | |
| T3 | 8 % | 960 | 100 | 120.0 | 2875.1 | 10.48 | 150.1 | 1.863E+04 | 2.127E+00 | 622.63 | 9.8324 | | | |
| T4 | 1 % | 120 | 105 | 125.0 | 2914.1 | 10.60 | 155.9 | 1.208E+04 | 1.379E+00 | 120.00 | 9.3995 | | | |
| Cummulative | 100 % | 12000 | | | | | | | | 1049.99 | 9.3995 | 5.0 | 5.0 | 119.77 |

**New mission profile**

# Conclusions on max $I_{BIAS}$




- For the original mission profile presented in [1], i.e. 32000 hours:
  - According to models considered in [1]: max current density is between 13.5 and 13.8 kA/cm$^2$
    - max $I_{BIAS}$ between 4.5 and 4.6 mA, for 6.5 um aperture
  - TRUMPF 850 nm 25G VCSEL: max current density is 17.1 kA/cm$^2$
    - max $I_{BIAS}$ is 5.7 mA, for 6.5 um aperture

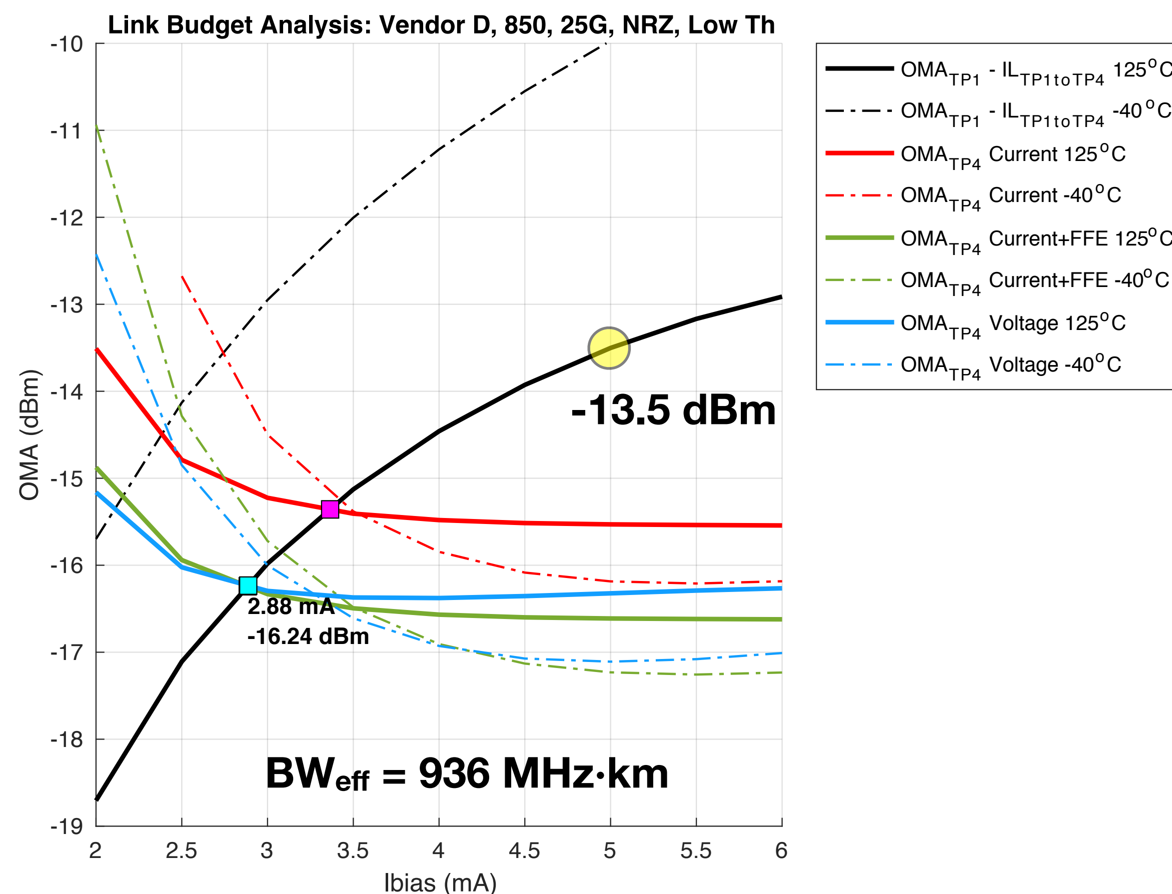
- Considering the new mission profile proposed in [3], which is more suitable for multi-gigabit applications, i.e. 12000 hours:
  - According to models considered in [1]: max current density is between 14.5 and 15.3 kA/cm$^2$
    - max $I_{BIAS}$ between 4.8 and 5.1 mA, for 6.5 um aperture
  - TRUMPF 850 nm 25G VCSEL: max current density is 19.7 kA/cm$^2$
    - max $I_{BIAS}$ is 6.5 mA, for 6.5 um aperture

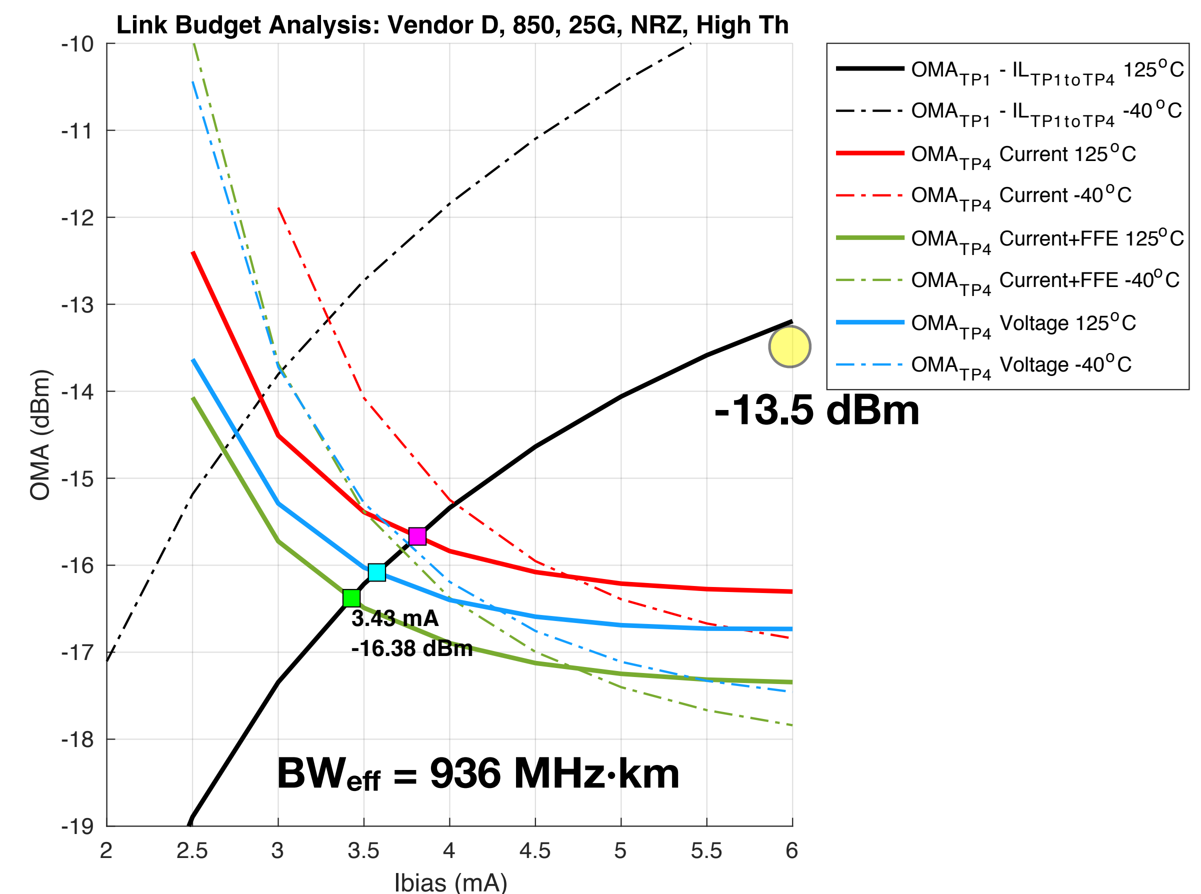
- Let's consider a conservative (i.e. 5 FIT random failures not verified so far) max current density of 15.2 kA/cm$^2$ for TRUMPF 850nm 25G VCSELs:
  - $I_{BIAS}$ = 5 mA for low threshold devices, 6.5 um aperture
  - $I_{BIAS}$ = 6 mA for high threshold devices, 7.5 um aperture

# Reliability constrained link budget assessment

# Link budget assessment for 25 Gb/s

- From [6], we have $IL_{TP1\text{-}to\text{-}TP4}$ = 11.84 dB, so based on the following curves we can calculate $OMA_{TP1}$ for ER = 3dB



# Link budget assessment for 25 Gb/s

- Proposal considering ER = 3 dB:
  - $(OMA_{TP1} - IL_{TP1\text{-to-}TP4})_{min}$ = -13.5 dBm
  - $OMA_{TP1,min}$ = -13.5 + 11.84 = -1.7 dBm
  - $IL_{TP1\text{-to-}TP2,max}$ = 4.0 dB = 0.5 + 1.0 + 2.5 (SE variation + aging + coupling loss)
  - $OMA_{TP2,min}$ = -1.7 - 4.0 = **-5.7 dBm**
  - $OMA_{TP4,max}$ = -16.5 dBm
  - $IL_{TP3\text{-to-}TP4,\ max}$ = 2.5 dB (more realistic with actual knowledge)
  - $OMA_{TP3,max}$ = -16.5 + 2.5 = **-14.0 dBm**
  - Power Budget = **-5.7 + 14.0 = 8.3 dB**
- For $I_{BIAS}$ >= 5 mA, it is reasonable to increase the ER to 4 dB without receiver sensitivity degradation caused by VCSEL non-linear response, therefore:
  - $OMA_{TP2,min}$ = -5.7 + 1.125 = **-4.6 dBm**
    - Where $10\cdot\log10((10^{(3/10)} + 1)/(10^{(3/10)} - 1)\cdot(10^{(4/10)} - 1)/(10^{(4/10)} + 1))$ = 1.125 dB
  - $OMA_{TP3,max}$ = = **-13.5 dBm**
    - With extra OMA at TP2, we give margin 0.5 dB to the RX implementation, equivalent to $OMA_{TP4,max}$ = -16 dBm
  - Power budget = **-4.6 + 13.5 = 8.9 dB**
- Channel attenuation = 8.28 dB (fiber att. + 0.2 dB bending + 4×2dB inline connections)
- Unallocated margin = 8.9 - 8.28 = **0.62 dB**

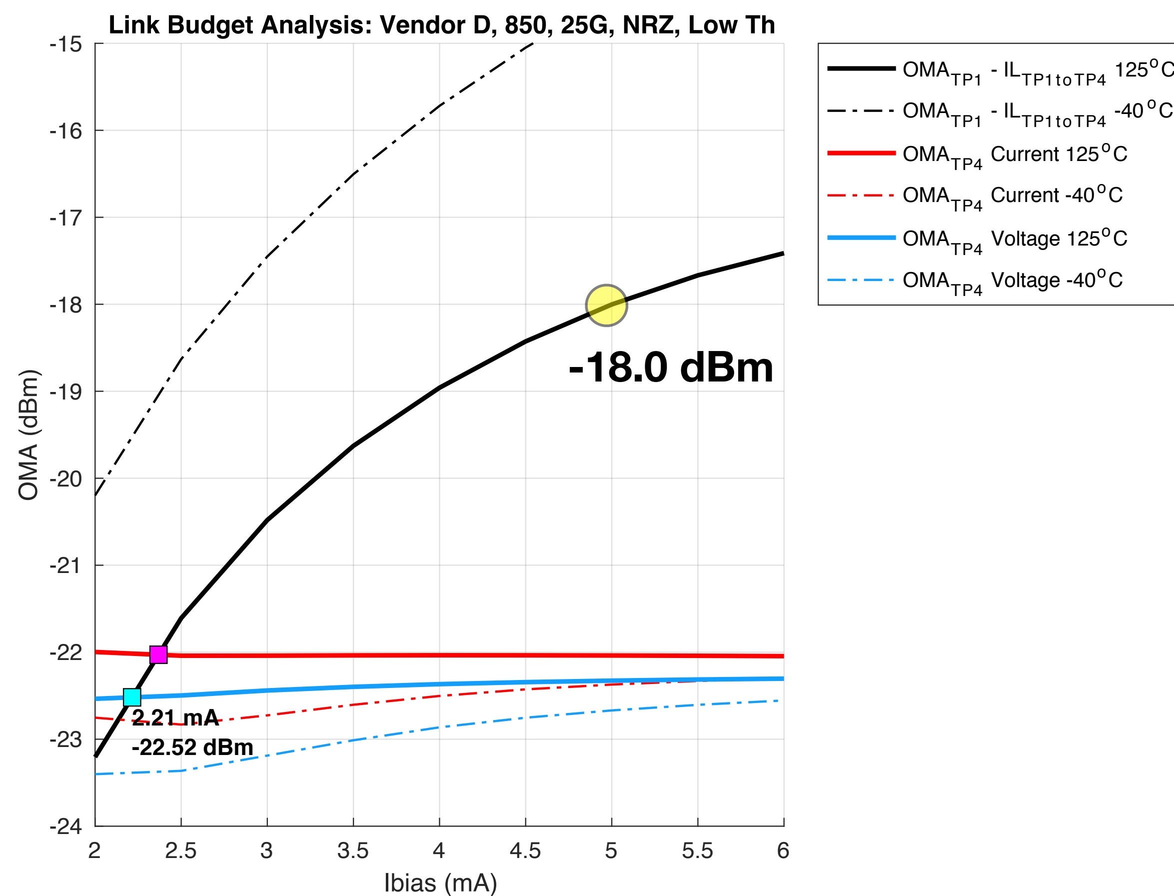
# Link budget assessment for 25 Gb/s

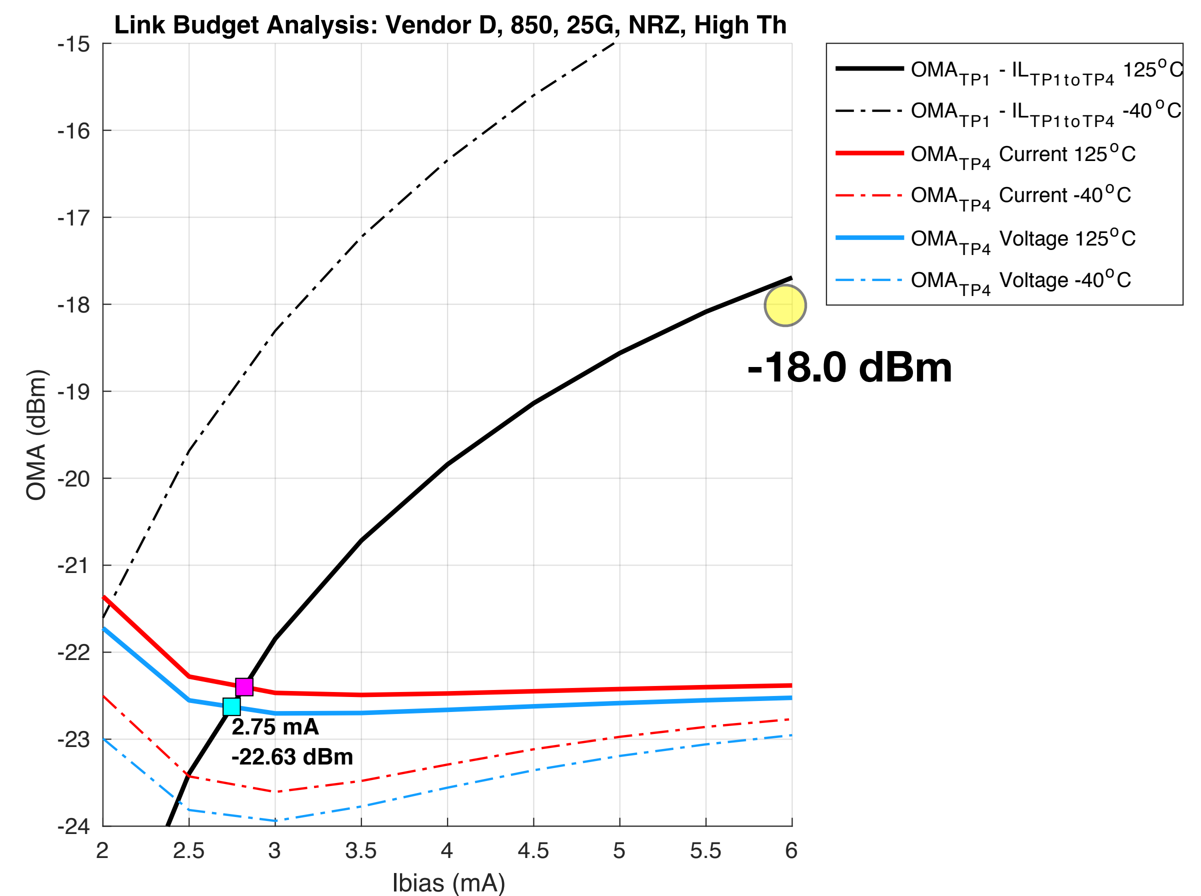
25 Gb/s link budget assessment (ERmin = 4 dB)

| Parameter | Value | |
|---|---|---|
| **VCSEL SE variation in the same bin (dB)** | 0.50 | **A** |
| **VCSEL aging (dB)** | 1.00 | **B** |
| **VCSEL to TP2 max coupling loss (dB)** | 2.50 | **C** |
| **$IL_{TP1\text{-to-}TP2}$, max (dB)** | **4.00** | **D = A + B + C** |
| **$IL_{TP3\text{-to-}TP4}$, max (dB)** | **2.50** | **E** |
| **Insertion loss per inline connection, $IL_{IC}$ max (dB)** | **2.00** | **F** |
| **Number of inline connections ($N_{IC}$)** | **4** | **G** |
| **Macrobend insertion loss, max (dB)** | 0.20 | **H** |
| **Microbend insertion loss, max (dB)** | 0.00 | **I** |
| **Bending insertion loss, $IL_{BEND}$ max (dB)** | 0.20 | **J = H + I** |
| **Fiber attenuation (dB/km)** | 2.00 | **K** |
| **Channel attenuation, $IL_{TP2\text{-to-}TP3}$, max (dB)** | **8.28** | **L = (F × G) + J + (40/1000 × K)** |
| **$IL_{TP1\text{-to-}TP4}$, max (dB)** | **14.78** | **M = D + E + L** |
| **$OMA_{TP1}$ min (dBm)** | **-0.60** | **N** |
| **$OMA_{TP2}$ min (dBm)** | **-4.60** | **O = N - D** |
| **$OMA_{TP4}$ max (dBm)** | **-16.00** | **P** |
| **$OMA_{TP3}$ max (dBm)** | **-13.50** | **Q = P + E** |
| **Power budget (dB)** | **8.90** | **R = O - Q** |
| **Unallocated margin (dB)** | **0.62** | **S = R - L** |

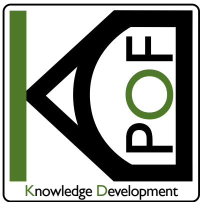
# Link budget assessment for 10 Gb/s

- From [7], we have $IL_{TP1\text{-to-}TP4}$ = 16.34 dB, so based on the following curves we can calculate $OMA_{TP1}$ for ER = 3dB



# Link budget assessment for 10 Gb/s



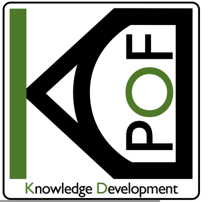

- Proposal considering ER = 3dB:
  - $(OMA_{TP1} - IL_{TP1\text{-to-}TP4})_{min}$ = -18.0 dBm
  - $OMA_{TP1,min}$ = -18.0 + 16.34 = -1.7 dBm
  - $IL_{TP1\text{-to-}TP2,max}$ = 5.0 dB = 0.5 + 1.0 + 3.5 (SE variation + aging + relaxed coupling loss)
  - $OMA_{TP2,min}$ = -1.7 - 5.0 = **-6.7 dBm**
  - $OMA_{TP4,max}$ = -22.0 dBm
  - $IL_{TP3\text{-to-}TP4,\ max}$ = 3.5 dB (relaxed design of receiver coupling elements)
  - $OMA_{TP3,max}$ = -22.0 + 3.5 = **-18.5 dBm**
  - Power budget = **-6.7 + 18.5 = 11.8 dB**
- Channel attenuation = 11.28 dB (fiber att. + 0.2 dB bending + 4×2.75dB inline connections)
- Unallocated margin = 11.8 - 11.28 = **0.52 dB**

# Link budget assessment for 10 Gb/s

10 Gb/s link budget assessment (ERmin = 3 dB)

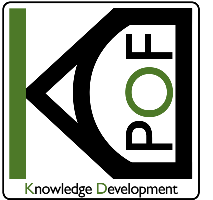
| Parameter | Value | |
|---|---|---|
| VCSEL SE variation in the same bin (dB) | 0.50 | A |
| VCSEL aging (dB) | 1.00 | B |
| VCSEL to TP2 max coupling loss (dB) | 3.50 | C |
| $IL_{TP1\text{-}to\text{-}TP2}$ , max (dB) | 5.00 | D = A + B + C |
| $IL_{TP3\text{-}to\text{-}TP4}$ , max (dB) | 3.50 | E |
| Insertion loss per inline connection, $IL_{IC}$ max (dB) | 2.75 | F |
| Number of inline connections ($N_{IC}$) | 4 | G |
| Macrobend insertion loss, max (dB) | 0.20 | H |
| Microbend insertion loss, max (dB) | 0.00 | I |
| Bending insertion loss, $IL_{BEND}$ max (dB) | 0.20 | J = H + I |
| Fiber attenuation (dB/km) | 2.00 | K |
| Channel attenuation, $IL_{TP2\text{-}to\text{-}TP3}$ , max (dB) | 11.28 | L = (F × G) + J + (40/1000 × K) |
| $IL_{TP1\text{-}to\text{-}TP4}$ , max (dB) | 19.78 | M = D + E + L |
| $OMA_{TP1}$ min (dBm) | -1.70 | N |
| $OMA_{TP2}$ min (dBm) | -6.70 | O = N - D |
| $OMA_{TP4}$ max (dBm) | -22.00 | P |
| $OMA_{TP3}$ max (dBm) | -18.50 | Q = P + E |
| Power budget (dB) | 11.80 | R = O - Q |
| Unallocated margin (dB) | 0.52 | S = R - L |

# Conclusions




- VCSEL wear out reliability analysis for proposed mission profile in [3] has been presented to determine max bias current that might be used to meet the reliability requirements
- Specifically, reliability analysis for TRUMPF 850nm 25G VCSEL has been presented
- Based on max bias current, link budget assessment has be presented for 25 and 10 Gb/s operations

# References





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Thank you!