# FEC for 100GBASE-SR4

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Jonathan King and John Petrilla

# Outline

- Background
- Outline of method for link budget model with FEC
  - Fibre Channel starting point, and Ethernet initial parameters
- Summary results
  - Compared to earlier estimates
  - Observations on the impact of FEC on noise penalties
- Jitter through the optical link, and sensitivity analysis
- Conclusions

# Background-1

- 802.3bj :
  - has adopted auto-negotiated FEC for NRZ backplane (*gustlin_01_0312*)
  - has adopted the same FEC for Cu (FEC required for 5m reach)
  - auto-negotiation not yet decided upon for shorter Cu reaches, but has several advantages
    - ‘Always encoding and not decoding’ increases the risk of MTTFPA (*cideciyan_01_0512*) - 64B/66B encoding has lower risk than uncorrected 256B/257B
    - Avoiding transcoding and FEC encoding and decoding can yield lowest latency and power (*dudek_02a_0312*)
    - 256B/257B transcoding precludes hosts which include MLGs (which rely on 64B/66B encoding), or links where 802.3bj and 802.3ba hosts are connected by legacy and Next Gen LR4 optics) - *Petrilla_01_0712*

# Background-2

- It is highly desirable that 100GBASE-SR4 and 100GBASE-CR4 can plug into a common host port (*dudek_01_1111*)
  - The common CR4/SR4 host port would have FEC capability
  - Using available FEC for Next Gen 100G Optics dramatically improves the performance vs cost ratio of 100GBASE-SR4 (*king_01_1111*)
- Auto-negotiation of FEC for the common 100GBASE-CR4 and SR4 port is *a very good thing*
  - Matches backplane use
  - Better MTTFPA, power, latency for CR4
  - Allows benefits of FEC for 802.3bj compliant ports, and backward compatibility with 802.3ba, OIF-CEI-02.0 25G compliant ports without FEC capability
- Adoption of auto-negotiated FEC for the common port would suggest the need to specify 100G-SR4 reach with and without FEC enabled

# Spreadsheet link modeling with and without FEC

- An update of earlier link modeling…
  - e.g. *king_01_1111, king_02_0112, petrilla_01_0112*

… drawing on Fibre Channel work (single channel of 28.05 Gb/s), and tweaking parameter values where required to suit Ethernet (four lanes of 25.78 Gb/s)

… and with reference to the preferred FEC scheme adopted by 802.3bj , in *gustlin_01_0312*

*… some observations on the impact of FEC on noise penalties, and a look at link margin and eye opening vs link parameters.*

# Fibre Channel

Fibre Channel is slightly ahead of Ethernet in specifying it's next rate (32G-FC)

- T11 has adopted FEC for 28.05 Gb/s single lane link
  - Relaxes the demands on component performance
  - Enables robust, low cost, 100 m OM4 links, and relaxes specs on host electrical traces
  - Though the precise link model parameters are still in development, link modeling shows:
    - Retiming and simple equalization do not enable 100 m reach.
    - FEC enables a retimed module to achieve 100 m reach without the need for active equalization.
      - Since an SRS test is expected, it can be left to the designer to decide if a fixed equalizer is included in the receiver

# Initial link model values for Fibre Channel, and Ethernet:

| Parameter | FC: 28 Gb/s single lane | IEEE: 25.8 Gb/s four lanes | Remarks |
|---|---|---|---|
| VCSEL fall time | 21 ps | | Effective, after Tx chain EQ |
| $RIN_{OMA}$ | -128 dB/Hz | -130 dB/Hz* | *Value for IEEE assumes usual trade off between jitter, rise time, and RIN |
| Wavelength range | 840 to 860 nm | | |
| RMS spectrum | 0.59 nm* | 0.6 nm | *Compatible with 16GFC |
| Min OMA | -2 dBm | -2 dBm | |
| Rx sensitivity, equiv. at $BER=10^{-12}$ | -8.5 dBm | -7.8 dBm* | *0.7 dB margin for multi-lane impairments and bit rate. Jitter calculations assume noise limited sensitivity is 1 dB lower than this. |
| Target Q* | *5 | *4.5 | *with FEC; 7.04 without FEC (for $BER=10^{-12}$) |
| Uncorrected BER, Corrected BER | $2.7x10^{-7}$, $10^{-18}$ | $4.7x10^{-6}$*, $10^{-15}$ | *From *gustlin_01_0312* |
| TJ/DCD | 8.6/2.1 ps | 4.7/2.1 ps | |
| Rx bandwidth | 19 GHz | 19 GHz | |

… a lot in common

# Calculating FEC and non-FEC reach for 100G-SR4

- 10GE spreadsheet modified for rate, using values from slide 6
    - No explicit Rx chain equalization
  - Channel: OM4, 4400 MHz.km, 1.5 dB total connector loss
- FEC characteristics from *gustlin_01_0312*

| Option | FEC Code RS(n, k, t, m) | Trans-coding | Effective Gain BER= $10^{-15}$ | Overall Latency | Total Area (40nm gates) | Total Power | Input BER for $10^{-15}$ BER | Input BER for $10^{-12}$ BER |
|---|---|---|---|---|---|---|---|---|
| 1 | RS(528, 514, 7, 10) | 256b/257b | 4.87 dB | 94.3 ns | 244k | 90 mW | $4.68\times10^{-6}$ | $2.34\times10^{-5}$ |

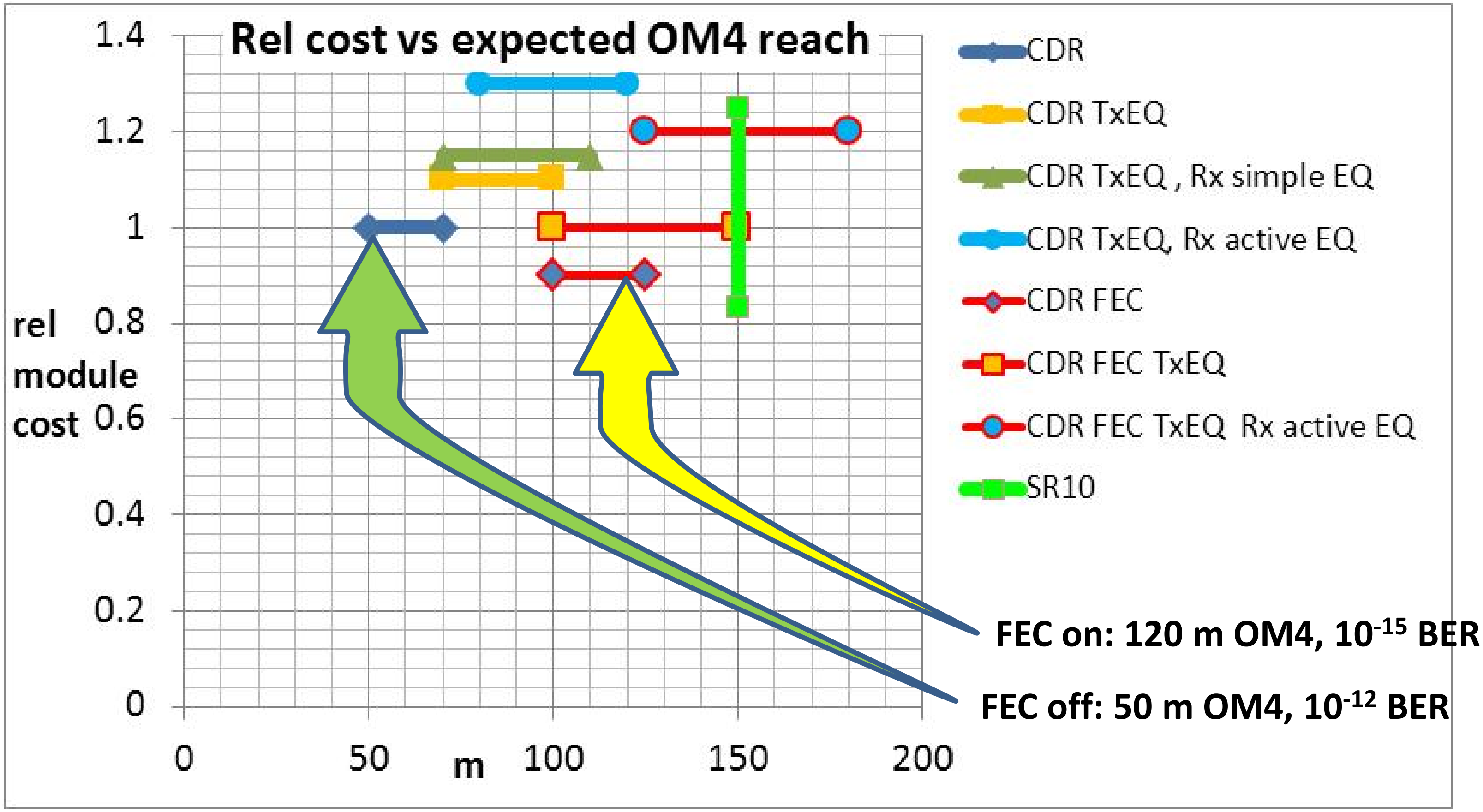
  - Target corrected error rate of $10^{-15}$, requires input BER of $4.68\times10^{-6}$, corresponds to Q of ~4.5
  - Rx sensitivity at Q = 4.5 is -9.7 dBm

# Summary results

| | Reach limit | OM4 reach | OM3 reach | Notes |
|---|---|---|---|---|
| 25.8 GBd, no FEC | power budget | 50 m | 50 m | ~2.6 dB VCEP $10^{-12}$ BER |
| 25.8 GBd, FEC | 3.6 dB VECP | 120 m | 80 m | ~1 dB margin $10^{-15}$ corrected BER |

- Without FEC, expected link budget for 100GBASE-SR4 is 5.7 dB
    - compares to >7 dB for 10GBASE-SR, 40GBASE-SR4
  - link budget closes at shorter reaches
- FEC raises link budget to 7.6 dB
  - enables >100m reach on OM4
  - simultaneously guarantees worst case corrected BER ≤ $10^{-15}$

# How these results compare to earlier relative cost vs reach estimates - from *king_02_0112*

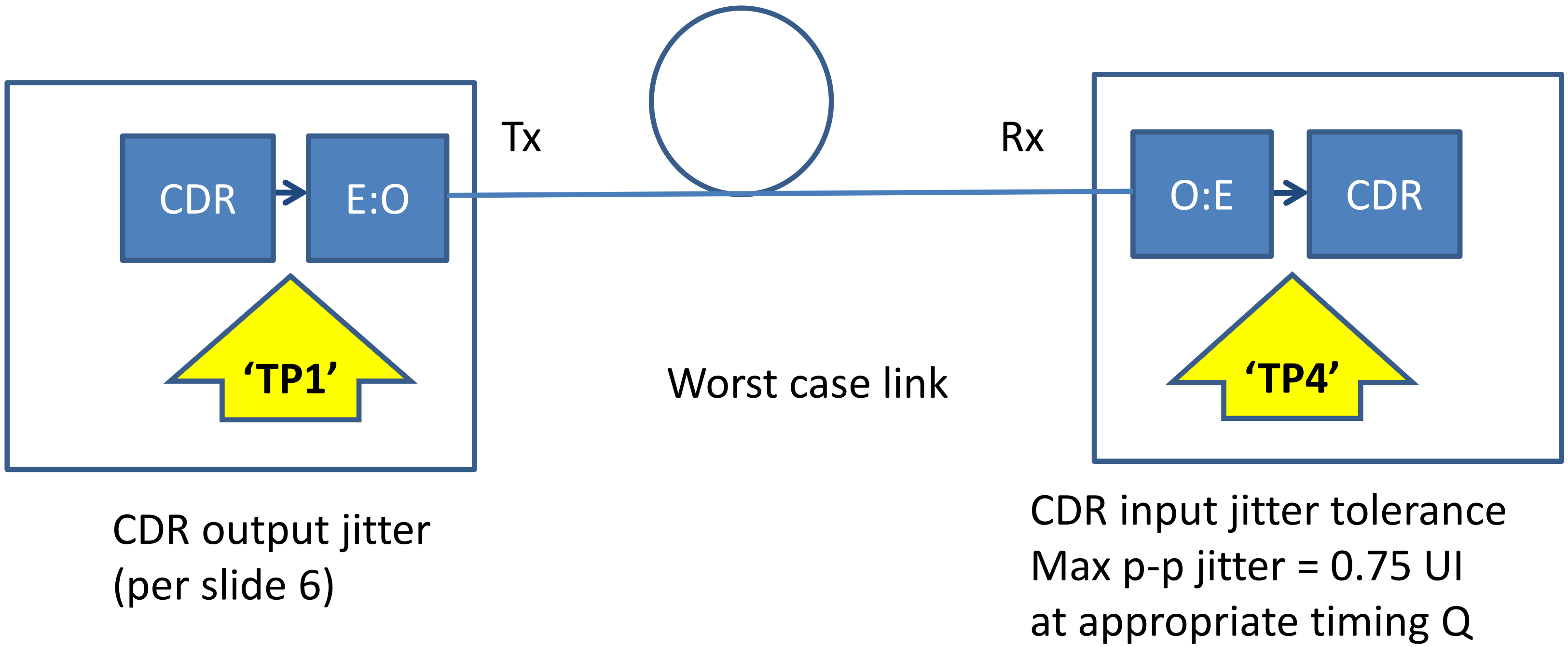


# Observations on the effect of FEC on noise penalties

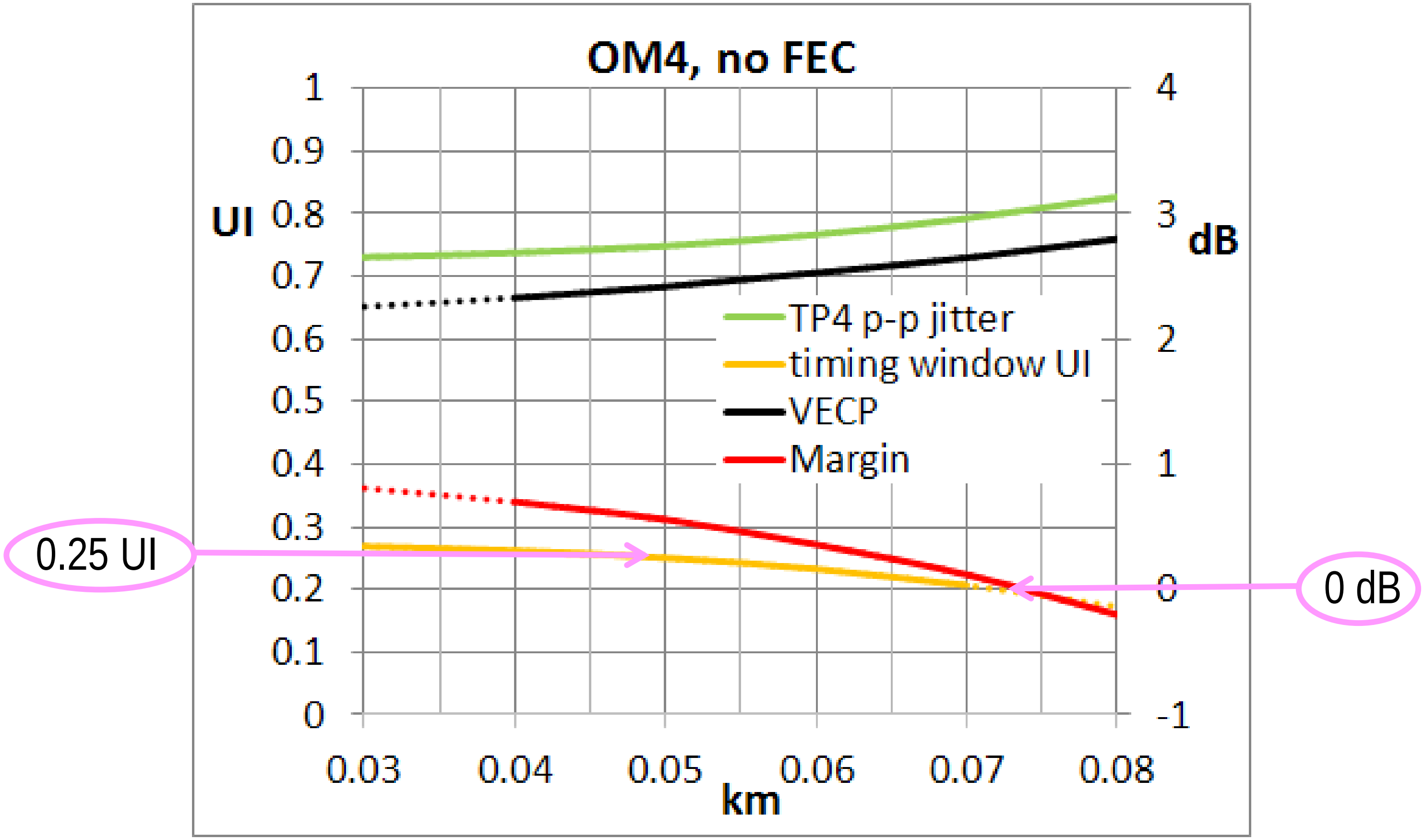
- FEC significantly reduces the penalties due noise terms as a result of the lower system Q required:
  - E.g., a system Q reduction from 7.04 (~ BER=$10^{-12}$, no FEC) to 4.5 (~raw BER = $4.68 \times 10^{-6}$, FEC corrected BER=$10^{-15}$) more than halves the MPN and RIN penalties.
    - Precise modeling of these effects becomes much less critical.
    - FEC corrected error rates can be significantly better than intrinsic noise floors would allow.
- FEC also allows relaxed design specs for the host electrical lanes, with negligible detriment to the FEC gain available for the optical link.
  - E.g., if the optical link contributes a raw BER of ~$4 \times 10^{-6}$, then designing the electrical lanes for BER ~$10^{-8}$ doesn't significantly impact the FEC gain available for the optics; but it does significantly reduce the Q (in amplitude and time domain) required from the electrical channel. Fibre Channel is currently studying this.

# Jitter through the optical link

- Although these are retimed links, the worst case link jitter budget from the module input CDR (‘TP1’) to output CDR (‘TP4’) needs to be considered.

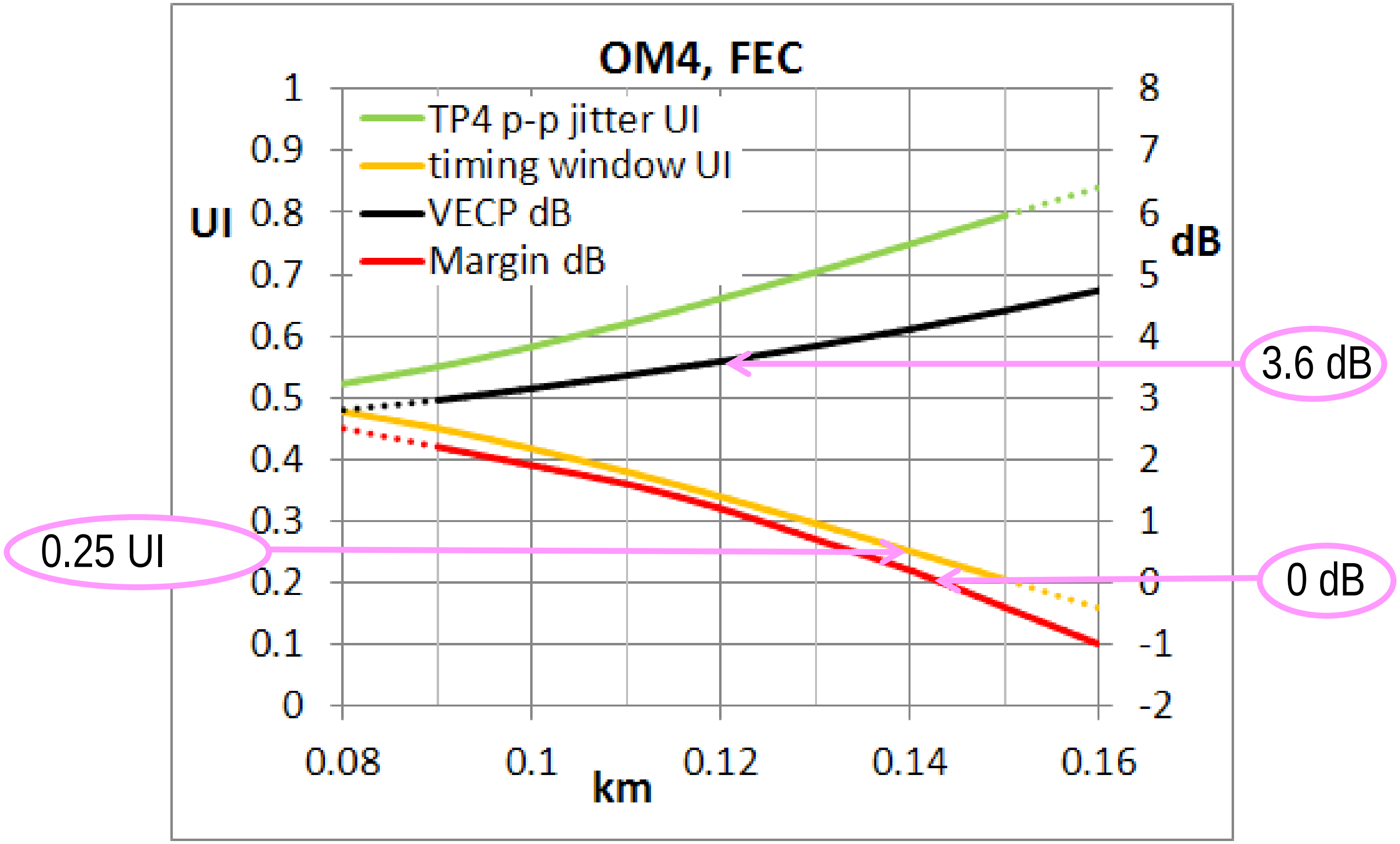


# Reach vs 'TP4' jitter: OM4, no FEC




- 50 m reach set by min 0.25 UI timing window

# Reach vs TP4 jitter: OM4, FEC




- 120 m reach set by max 3.6 dB VECP

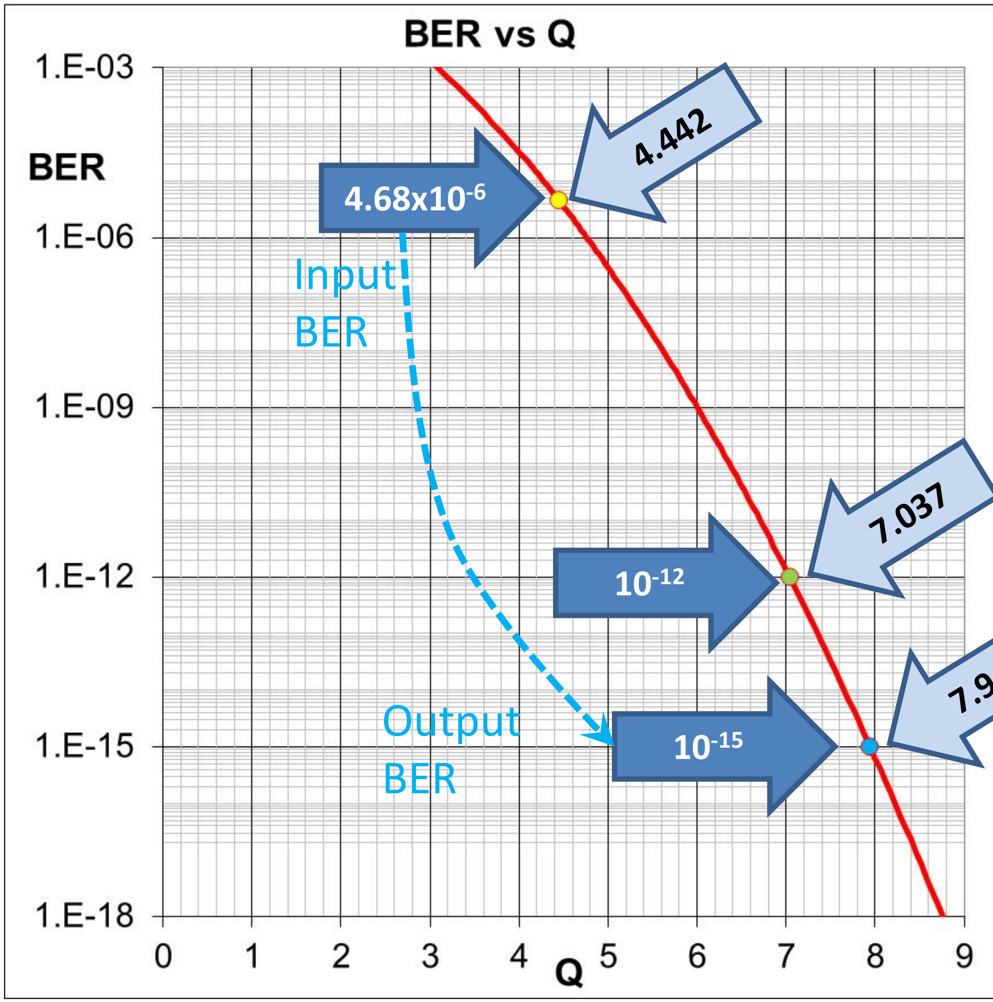
# Conclusions

- 100GBASE-SR4 can benefit substantially from the FEC available at a common 100GBASE-CR4/SR4 port
  - Enables 120 m on OM4 with FEC enabled
  - Enables $10^{-15}$ corrected BER rate
  - Lowest module cost vs reach

- With FEC disabled, the same module would be capable of 50 m on OM4 (at BER = $10^{-12}$ )

# Back up

# BER vs Q




For RS(528,524,7,10)

- Uncorrected BER = 4.68 x $10^{-6}$ yields corrected BER = $10^{-15}$
- Uncorrected Q = 4.442 , corrected Q ≡ 7.943
- (Q = 7.037 for BER = $10^{-12}$)
  (Q = 7.943 for BER = $10^{-15}$)

# Model snapshot: 25.8Gb/s, OM4, with FEC

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Spreadsheet by Del Hanson, David Cunningham, Piers Dawe, David Dolfi Agilent Technologies | | | | | | | | | Rev. 3.2/3 | | | This file | 10GEPBud3_1_16a.xls | | of | 17-Oct-01 | |
| *Basics* Input= | **Bold** | | Ts(20-80) | 21 | ps | Case: 850nm serial | **50MMF** | | Attenuation= | **3.5** | dB/km | Model/format rev | 3.1.16a | | of | 31-Oct-01 | |
| Q= | **4.50** | | Ts(10-90) | 32 | ps | *Target* Target reach | **0.120** | km | *Fiber* at | 850 | nm | NomSens OMA | **-9.70** | dBm | Margin | 1.13 | dB at |
| Base Rate= | **25781** | MBd | RIN(OMA) | **-130** | dB/Hz | *and* L_start= | **0.036** | km | C_att= | 1.00 | | *Receive* Refl Rx | **-12** | dB | *Answer!* | 0.12 | km |
| *Transmitter* | | | RIN at MinER | -138.0 | dB/Hz | *graph* L_inc= | **0.008** | km | Attenuation= | 3.62 | dB/km | Rec_BW= | ##### | MHz | est Rx BW | **18750** | MHz |
| Wavelength Uc | **840** | nm | RIN_Coef= | **0.70** | | Power Budget P= | 7.70 | dB | at | 840 | nm | c_rx | **329** | ns.MHz | | | |
| Uw (see notes) | **0.60** | nm | Det.Jitter | **4.7** | ps inc. DCD | Connections etc | **1.5** | dB | Disp. min. Uo= | **1316** | nm | T_rx(10-90) | 17.3 | ps | Test Source ER= | | |
| Tx pwr OMA= | **-2.00** | dBm | DCD_DJ= | **2.14** | ps TP3 | Pwr.Bud.-Conn.Loss | 6.2 | dB | Disp. So= | **0.1028** | ps/nm^2*km | TP4 Eye | 8 | ps | *Test Tx* | **6.5** | dB |
| Min. Ext Ratio= | 3.65 | dB | Effect. DJ= | 0.07 | (UI) ex DCD | C1= | **480** | ns.MHz | Disp. D1= | -108.41 | ps/(nm.km) | Opening | | (=Tx ey | TestERper | 1.98 | dBo |
| Worst"ave.TxPwr | **-1.0** | dBm | MPN k(OMA) | **0.3** | | Reflection Noise factor | **0** | no units | | | | RMS Baseline wander SD | **0.013** | fraction of 1/2 eye | | | |
| Ext. ratio penalty | 4.01 | dBo | Tx eye height | 43.8% | | Effective Rate | 27287 | MBd | (not in use) | **10** | | | | | V.E.C.P. | 3.61 | dBo |
| Tx mask X1= | **0.3** | UI | Refl Tx | **-12** | dB | Tb_eff= | 37 | ps | BWm= | **4400** | MHz*km | P_BLW (no ISI) | 0.01 | dB | | | Stressed |
| X2= | **0.4** | UI | ModalNoisePen | **0.3** | dB | Effective Rec Eye | 0.21 | UI | Eff. BWm= | ###### | MHz*km | P_BLW | 0.01 | dB | | | Rx sens |
| Y1= | **0.25** | | Tx mask top | 0.2 | UI | | | | | | | | | | | | |

| L | Patt | Ch IL | D1.L | D2.L | BWcd | effBWm | Te | Tc | Pisi central | P Eye corners | P_DJ central | P_DJ corners | Preflection central | Beta | SDmpn | Pmpn | Prin | Pcross central | Ptotal central | <Ptotal corners | LP Pen central | Margin | OMA central |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (km) | (dB) | (dB) | ps/nm | ps/nm | (MHz) | (MHz) | (ps) | (ps) | J=0, dB | (dB) | (dB) | (dB) | (dB) | | | (dB) | (dB) | (dB) | (dB) | (dB) | (dB) | (dB) | (dBm) |
| 0.002 | 0.01 | 1.51 | -0.22 | 0.00 | 1E+06 | ###### | 32 | 36 | 2.15 | 0.24 | 0.03 | 0.19 | | -1E-02 | 0.00 | 0.00 | | 0.02 | 2.51 | 2.92 | 2.5 | 3.7 | -4.9 |
| **0.036** | **0.13** | **1.63** | **-3.9** | **0.00** | **79,857** | **######** | **33** | **37** | **2.28** | **0.24** | **0.03** | **0.19** | **0** | **-0.20** | **0.01** | **0.00** | **0.24** | **0.06** | **3.0** | **3.4** | **2.9** | **3.2** | **-5.3** |
| 0.044 | 0.16 | 1.66 | -4.8 | 0.00 | 64,749 | 99,099 | 33 | 37 | 2.34 | 0.25 | 0.03 | 0.20 | 0 | -0.25 | 0.01 | 0.01 | 0.24 | 0.06 | 3.1 | 3.5 | 3.0 | 3.1 | -5.4 |
| 0.053 | 0.19 | 1.69 | -5.7 | 0.00 | 54,448 | 83,333 | 34 | 38 | 2.42 | 0.25 | 0.03 | 0.20 | 0 | -0.29 | 0.02 | 0.01 | 0.24 | 0.06 | 3.3 | 3.7 | 3.1 | 2.9 | -5.4 |
| 0.061 | 0.22 | 1.72 | -6.6 | 0.00 | 46,975 | 71,895 | 34 | 38 | 2.52 | 0.25 | 0.03 | 0.20 | 0 | -0.34 | 0.02 | 0.02 | 0.24 | 0.07 | 3.4 | 3.8 | 3.2 | 2.8 | -5.4 |
| 0.07 | 0.25 | 1.75 | -7.5 | 0.00 | 41,305 | 63,218 | 35 | 39 | 2.62 | 0.25 | 0.03 | 0.20 | 0 | -0.39 | 0.03 | 0.04 | 0.24 | 0.07 | 3.5 | 4.0 | 3.3 | 2.7 | -5.5 |
| **0.078** | **0.28** | **1.78** | **-8.5** | **0.00** | **36,857** | **56,410** | **35** | **39** | **2.74** | **0.25** | **0.03** | **0.20** | **0** | **-0.43** | **0.04** | **0.06** | **0.24** | **0.08** | **3.7** | **4.2** | **3.5** | **2.5** | **-5.6** |
| 0.086 | 0.31 | 1.81 | -9.4 | 0.00 | 33,274 | 50,926 | 36 | 40 | 2.88 | 0.25 | 0.03 | 0.20 | 0 | -0.48 | 0.04 | 0.09 | 0.24 | 0.09 | 3.9 | 4.4 | 3.6 | 2.3 | -5.6 |
| 0.095 | 0.34 | 1.84 | -10.3 | 0.00 | 30,325 | 46,414 | 37 | 41 | 3.03 | 0.25 | 0.03 | 0.20 | 0 | -0.53 | 0.05 | 0.12 | 0.25 | 0.11 | 4.2 | 4.6 | 3.8 | 2.0 | -5.7 |
| 0.103 | 0.37 | 1.87 | -11.2 | 0.00 | 27,857 | 42,636 | 38 | 42 | 3.19 | 0.25 | 0.03 | 0.20 | 0 | -0.58 | 0.06 | 0.16 | 0.26 | 0.13 | 4.4 | 4.9 | 4.1 | 1.8 | -5.8 |
| 0.112 | 0.40 | 1.90 | -12.1 | 0.00 | 25,760 | 39,427 | 39 | 43 | 3.37 | 0.25 | 0.03 | 0.20 | 0 | -0.62 | 0.07 | 0.21 | 0.27 | 0.16 | 4.7 | 5.2 | 4.3 | 1.5 | -5.9 |
| **0.12** | **0.43** | **1.93** | **-13.0** | **0.01** | **23,957** | **36,667** | **40** | **43** | **3.56** | **0.25** | **0.03** | **0.20** | **0** | **-0.67** | **0.08** | **0.27** | **0.28** | **0.19** | **5.1** | **5.5** | **4.6** | **1.1** | **-6.0** |

- Reach allowed by 3.6 dB vertical eye closure is 120 m on OM4
  - For a timing Q of 4.5, the p-p jitter at the input to the optical receiver CDR is 0.66 UI

# Model snapshot: 25.8Gb/s, OM4, no FEC

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Spreadsheet by Del Hanson, David Cunningham, Piers Dawe, David Dolfi Agilent Technologies | | | | | | | | | Rev. | 3.2/3 | | This file | 10GEPBud3_1_16a.xls | | | of | 17-Oct-01 | | |
| *Basics* | Input= | **Bold** | Ts(20-80) | 21 | ps | Case: 850nm serial | | 50MMF | Attenuation= | 3.5 | dB/km | Model/format rev | 3.1.16a | | | of | 31-Oct-01 | | |
| | Q= | 7.04 | Ts(10-90) | 32 | ps | *Target* | Target reach | 0.050 | km | *Fiber* | at | 850 | nm | NomSens OMA | -7.80 | dBm | Margin | 0.54 | dB at |
| | Base Rate= | 25781 | MBd | RIN(OMA) | -130 | dB/Hz | *and* | L_start= | 0.036 | km | C_att= | 1.00 | | *Receive* | Refl Rx | -12 | dB | *Answer!* | 0.05 km |
| *Transmitter* | | | RIN at MinER | -138.0 | dB/Hz | *graph* | L_inc= | 0.001 | km | | Attenuation= | 3.62 | dB/km | Rec_BW= | ##### | MHz | est Rx BW | 18750 | MHz |
| Wavelength Uc | 840 | nm | RIN_Coef= | 0.70 | | Power Budget P= | 5.80 | dB | | at | 840 | nm | | c_rx | 329 | ns.MHz | | | |
| Uw (see notes) | 0.60 | nm | Det.Jitter | 4.7 | ps inc. DCD | Connections etc | 1.5 | dB | Disp. min. Uo= | 1316 | nm | T_rx(10-90) | 17.3 | ps | Test Source ER= | | | | |
| Tx pwr OMA= | -2.00 | dBm | DCD_DJ= | 2.14 | ps TP3 | Pwr.Bud.-Conn.Loss | 4.3 | dB | Disp. So= | 0.1028 | ps/nm^2*km | TP4 Eye | 8 | ps | *Test Tx* | 6.5 | dB | | |
| Min. Ext Ratio= | 3.65 | dB | Effect. DJ= | 0.07 | (UI) ex DCD | C1= | 480 | ns.MHz | Disp. D1= | -108.41 | ps/(nm.km) | Opening | | (=Tx ey | TestERpe | 1.98 | dBo | | |
| 'Worst"ave.TxPwr | -1.0 | dBm | MPN k(OMA) | 0.3 | | Reflection Noise factor | 0 | no units | | | | RMS Baseline wander SD | 0.013 | fraction of 1/2 eye | | | | | |
| Ext. ratio penalty | 4.01 | dBo | Tx eye height | 43.8% | | Effective Rate | 27287 | MBd | (not in use) | 10 | | | | | V.E.C.P. | 2.44 | dBo | | |
| Tx mask X1= | 0.3 | UI | Refl Tx | -12 | dB | Tb_eff= | 37 | ps | BWm= | 4400 | MHz*km | P_BLW(no ISI) | 0.02 | dB | Stressed | | | | |
| X2= | 0.4 | UI | ModalNoisePen | 0.3 | dB | Effective Rec Eye | 0.21 | UI | Eff. BWm= | ###### | MHz*km | P_BLW | 0.02 | dB | Rx sens | | | | |
| Y1= | 0.25 | | Tx mask top | 0.2 | UI | | | | | | | | | | | | | | |

| L (km) | Patt (dB) | Ch IL (dB) | D1.L ps/nm | D2.L ps/nm | BWcd (MHz) | effBWm (MHz) | Te (ps) | Tc (ps) | Pisi central J=0, dB | P Eye corners (dB) | P_DJ central (dB) | P_DJ corners (dB) | Preflection central (dB) | Beta | SDmpn | Pmpn (dB) | Prin (dB) | Pcross central (dB) | Ptotal central (dB) | <Ptotal corners (dB) | LP Pen central (dB) | Margin (dB) | OMA central (dBm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.002 | 0.01 | 1.51 | -0.22 | 0.00 | 1E+06 | ###### | 32 | 36 | 2.15 | 0.24 | 0.03 | 0.19 | | -1E-02 | 0.00 | 0.00 | | 0.05 | 2.53 | 2.95 | 2.5 | 1.8 | -4.4 |
| **0.036** | **0.13** | **1.63** | **-3.9** | **0.00** | **79,857** | **######** | **33** | **37** | **2.28** | **0.24** | **0.03** | **0.19** | **0** | **-0.20** | **0.01** | **0.01** | **0.64** | **0.18** | **3.6** | **4.0** | **3.4** | **0.7** | **-5.2** |
| 0.037 | 0.14 | 1.64 | -4.1 | 0.00 | 76,867 | ###### | 33 | 37 | 2.29 | 0.24 | 0.03 | 0.20 | 0 | -0.21 | 0.01 | 0.01 | 0.64 | 0.18 | 3.6 | 4.0 | 3.4 | 0.7 | -5.2 |
| 0.039 | 0.14 | 1.64 | -4.2 | 0.00 | 74,094 | ###### | 33 | 37 | 2.30 | 0.24 | 0.03 | 0.20 | 0 | -0.22 | 0.01 | 0.01 | 0.64 | 0.18 | 3.6 | 4.0 | 3.5 | 0.7 | -5.2 |
| 0.04 | 0.15 | 1.65 | -4.4 | 0.00 | 71,513 | ###### | 33 | 37 | 2.31 | 0.24 | 0.03 | 0.20 | 0 | -0.22 | 0.01 | 0.01 | 0.64 | 0.18 | 3.6 | 4.0 | 3.5 | 0.7 | -5.2 |
| 0.042 | 0.15 | 1.65 | -4.5 | 0.00 | 69,107 | ###### | 33 | 37 | 2.32 | 0.24 | 0.03 | 0.20 | 0 | -0.23 | 0.01 | 0.01 | 0.64 | 0.19 | 3.6 | 4.0 | 3.5 | 0.7 | -5.2 |
| **0.043** | **0.16** | **1.66** | **-4.7** | **0.00** | **66,857** | **######** | **33** | **37** | **2.33** | **0.24** | **0.03** | **0.20** | **0** | **-0.24** | **0.01** | **0.02** | **0.63** | **0.19** | **3.7** | **4.1** | **3.5** | **0.6** | **-5.2** |
| 0.044 | 0.16 | 1.66 | -4.8 | 0.00 | 64,749 | 99,099 | 33 | 37 | 2.34 | 0.25 | 0.03 | 0.20 | 0 | -0.25 | 0.01 | 0.02 | 0.63 | 0.19 | 3.7 | 4.1 | 3.5 | 0.6 | -5.2 |
| 0.046 | 0.17 | 1.67 | -5.0 | 0.00 | 62,769 | 96,070 | 33 | 37 | 2.36 | 0.25 | 0.03 | 0.20 | 0 | -0.26 | 0.01 | 0.02 | 0.63 | 0.19 | 3.7 | 4.1 | 3.5 | 0.6 | -5.3 |
| 0.047 | 0.17 | 1.67 | -5.1 | 0.00 | 60,908 | 93,220 | 33 | 37 | 2.37 | 0.25 | 0.03 | 0.20 | 0 | -0.26 | 0.01 | 0.02 | 0.63 | 0.19 | 3.7 | 4.1 | 3.5 | 0.6 | -5.3 |
| 0.049 | 0.18 | 1.68 | -5.3 | 0.00 | 59,153 | 90,535 | 33 | 38 | 2.38 | 0.25 | 0.03 | 0.20 | 0 | -0.27 | 0.02 | 0.02 | 0.63 | 0.19 | 3.7 | 4.1 | 3.6 | 0.6 | -5.3 |
| **0.05** | **0.18** | **1.68** | **-5.4** | **0.00** | **57,497** | **88,000** | **33** | **38** | **2.39** | **0.25** | **0.03** | **0.20** | **0** | **-0.28** | **0.02** | **0.03** | **0.63** | **0.20** | **3.8** | **4.2** | **3.6** | **0.5** | **-5.3** |

- Reach limited by power budget and jitter: 50 m on OM4
  - max TJ = 0.75 UI at the input to the optical receiver CDR

# Model snapshot: 25.8Gb/s, OM3, with FEC

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Spreadsheet by Del Hanson, David Cunningham, Piers Dawe, David Dolfi Agilent Technologies | | | | | | | | | Rev. | 3.2/3 | This file | 10GEPBud3_1_16a.xls | | | of | 17-Oct-01 | |
| *Basics* Input= | **Bold** | | Ts(20-80) | 21 | ps | Case: 850nm serial | **newMMF** | | Attenuation= | **3.5** | dB/km | Model/format rev | 3.1.16a | | of | 31-Oct-01 | |
| Q= | **4.50** | | Ts(10-90) | 32 | ps | *Target* Target reach | **0.08** | km | *Fiber* at | 850 | nm | NomSens OMA | **-9.70** | dBm | Margin | 1.64 | dB at |
| Base Rate= | **25781** | MBd | RIN(OMA) | **-130** | dB/Hz | *and* L_start= | **0.001** | km | C_att= | 1.00 | | *Receive* Refl Rx | **-12** | dB | *Answer!* | 0.08 | km |
| *Transmitter* | | | RIN at MinER | -138.0 | dB/Hz | *graph* L_inc= | **0.008** | km | Attenuation= | 3.62 | dB/km | Rec_BW= | **#####** | MHz | est Rx BW | **18750** | MHz |
| Wavelength Uc | **840** | nm | RIN_Coef= | **0.70** | | Power Budget P= | 7.70 | dB | at | 840 | nm | c_rx | **329** | ns.MHz | | | |
| Uw (see notes) | **0.60** | nm | Det.Jitter | **4.7** | ps inc. DCD | Connections C | **1.5** | dB | Disp. min. Uo= | **1316** | nm | T_rx(10-90) | 17.3 | ps | Test Source ER= | | |
| Tx pwr OMA= | **-2.00** | dBm | DCD_DJ= | **2.14** | ps TP3 | Pwr.Bud.-Conn.Loss | 6.2 | dB | Disp. So= | **0.1028** | ps/nm^2*km | TP4 Eye | 8 | ps | *Test Tx* | **6.5** | dB |
| Min. Ext Ratio= | 3.65 | dB | Effect. DJ= | 0.07 | (UI) ex DCD | C1= | **480** | ns.MHz | Disp. D1= | -108.41 | ps/(nm.km) | Opening | | (=Tx ey | TestERpei | 1.98 | dBo |
| 'Worst"ave.TxPwr | **-1.0** | dBm | MPN k(OMA) | **0.3** | | Reflection Noise factor | **0** | no units | | | | RMS Baseline wander SD | **0.013** | fraction of 1/2 eye | | | |
| Ext. ratio penalty | 4.01 | dBo | Tx eye height | 43.8% | | Effective Rate | 27287 | MBd | (not in use) | **10** | | | | | V.E.C.P. | 3.55 | dBo |
| Tx mask X1= | **0.3** | UI | Refl Tx | **-12** | dB | Tb_eff= | 37 | ps | BWm= | **2000** | MHz*km | P_BLW (no ISI) | 0.01 | dB | | | Stressed |
| X2= | **0.4** | UI | ModalNoisePen | **0.3** | dB | Effective Rec Eye | 0.21 | UI | Eff. BWm= | ###### | MHz*km | P_BLW | 0.01 | dB | | | Rx sens |
| Y1= | **0.25** | | Tx mask top | 0.2 | UI | | | | | | | | | | | | |

| L (km) | Patt (dB) | Ch IL (dB) | D1.L ps/nm | D2.L ps/nm | BWcd (MHz) | effBWm (MHz) | Te (ps) | Tc (ps) | Pisi central J=0, dB | P Eye corners (dB) | P_DJ central (dB) | P_DJ corners (dB) | Preflection central (dB) | Beta | SDmpn | Pmpn (dB) | Prin (dB) | Pcross central (dB) | Ptotal central (dB) | <Ptotal corners (dB) | LP Pen central (dB) | Margin (dB) | OMA central (dBm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.002 | 0.01 | 1.51 | -0.22 | 0.00 | 1E+06 | ###### | 32 | 36 | 2.15 | 0.24 | 0.03 | 0.19 | | -1E-02 | 0.00 | 0.00 | | 0.02 | 2.51 | 2.92 | 2.5 | 3.7 | -5.5 |
| **0.001** | **0.00** | **1.50** | **-0.1** | **0.00** | **#####** | **######** | **32** | **36** | **2.15** | **0.24** | **0.03** | **0.19** | **0** | **-0.01** | **0.00** | **0.00** | **0.24** | **0.06** | **2.8** | **3.2** | **2.8** | **3.4** | **-5.7** |
| 0.009 | 0.03 | 1.53 | -1.0 | 0.00 | ##### | ###### | 32 | 36 | 2.17 | 0.24 | 0.03 | 0.19 | 0 | -0.05 | 0.00 | 0.00 | 0.24 | 0.06 | 2.8 | 3.2 | 2.8 | 3.4 | -5.7 |
| 0.017 | 0.06 | 1.56 | -1.8 | 0.00 | ##### | ###### | 32 | 37 | 2.21 | 0.24 | 0.03 | 0.19 | 0 | -0.09 | 0.00 | 0.00 | 0.24 | 0.06 | 2.9 | 3.3 | 2.8 | 3.3 | -5.8 |
| 0.025 | 0.09 | 1.59 | -2.7 | 0.00 | ##### | 80,972 | 33 | 37 | 2.28 | 0.24 | 0.03 | 0.19 | 0 | -0.14 | 0.00 | 0.00 | 0.24 | 0.06 | 3.0 | 3.4 | 2.9 | 3.2 | -5.8 |
| 0.033 | 0.12 | 1.62 | -3.5 | 0.00 | 88,185 | 61,350 | 33 | 38 | 2.37 | 0.25 | 0.03 | 0.20 | 0 | -0.18 | 0.01 | 0.00 | 0.24 | 0.06 | 3.1 | 3.5 | 3.0 | 3.1 | -5.8 |
| **0.041** | **0.15** | **1.65** | **-4.4** | **0.00** | **70,984** | **49,383** | **34** | **38** | **2.49** | **0.25** | **0.03** | **0.20** | **0** | **-0.23** | **0.01** | **0.00** | **0.24** | **0.06** | **3.3** | **3.7** | **3.1** | **2.9** | **-5.9** |
| 0.048 | 0.18 | 1.68 | -5.2 | 0.00 | 59,398 | 41,322 | 35 | 39 | 2.64 | 0.25 | 0.03 | 0.20 | 0 | -0.27 | 0.01 | 0.01 | 0.24 | 0.06 | 3.5 | 3.9 | 3.3 | 2.7 | -5.9 |
| 0.056 | 0.20 | 1.70 | -6.1 | 0.00 | 51,063 | 35,524 | 36 | 40 | 2.81 | 0.25 | 0.03 | 0.20 | 0 | -0.31 | 0.02 | 0.02 | 0.24 | 0.07 | 3.7 | 4.1 | 3.5 | 2.5 | -5.9 |
| 0.064 | 0.23 | 1.73 | -7.0 | 0.00 | 44,779 | 31,153 | 37 | 41 | 3.01 | 0.25 | 0.03 | 0.20 | 0 | -0.36 | 0.03 | 0.03 | 0.25 | 0.08 | 3.9 | 4.3 | 3.7 | 2.3 | -6.0 |
| 0.072 | 0.26 | 1.76 | -7.8 | 0.00 | 39,873 | 27,739 | 38 | 42 | 3.24 | 0.25 | 0.03 | 0.20 | 0 | -0.40 | 0.03 | 0.04 | 0.26 | 0.09 | 4.2 | 4.6 | 4.0 | 2.0 | -6.0 |
| **0.08** | **0.29** | **1.79** | **-8.7** | **0.00** | **35,936** | **25,000** | **40** | **43** | **3.50** | **0.25** | **0.03** | **0.20** | **0** | **-0.45** | **0.04** | **0.07** | **0.27** | **0.11** | **4.6** | **5.0** | **4.3** | **1.6** | **-6.1** |

- Reach allowed by 3.6 dB vertical eye closure is 80 m on OM3
  - For a timing Q of 4.5, the p-p jitter at the input to the optical receiver CDR is 0.53 UI

# Model snapshot: 25.8Gb/s, OM3, no FEC

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Spreadsheet by Del Hanson, David Cunningham, Piers Dawe, David Dolfi Agilent Technologies | | | | | | | | | Rev. 3.2/3 | | This file | 10GEPBud3_1_16a.xls | | | of | 17-Oct-01 | |
| *Basics* Input= | Bold | | Ts(20-80) | 21 | ps | Case: 850nm serial | newMMF | | Attenuation= | 3.5 | dB/km | Model/format rev | 3.1.16a | | of | 31-Oct-01 | |
| Q= | 7.04 | | Ts(10-90) | 32 | ps | *Target* Target reach | 0.05 | km | *Fiber* at | 850 | nm | NomSens OMA | -7.80 | dBm | Margin | 0.25 | dB at |
| Base Rate= | 25781 | MBd | RIN(OMA) | -130 | dB/Hz | *and* L_start= | 0.001 | km | C_att= | 1.00 | | *Receive* Refl Rx | -12 | dB | *Answer!* | 0.05 | km |
| *Transmitter* | | | RIN at MinER | -138.0 | dB/Hz | *graph* L_inc= | 0.005 | km | Attenuation= | 3.62 | dB/km | Rec_BW= | ##### | MHz | est Rx BW | 18750 | MHz |
| Wavelength Uc | 840 | nm | RIN_Coef= | 0.70 | | Power Budget P= | 5.80 | dB | at | 840 | nm | c_rx | 329 | ns.MHz | | | |
| Uw (see notes) | 0.60 | nm | Det.Jitter | 4.7 | ps inc. DCD | Connections C | 1.5 | dB | Disp. min. Uo= | 1316 | nm | T_rx(10-90) | 17.3 | ps | Test Source ER= | | |
| Tx pwr OMA= | -2.00 | dBm | DCD_DJ= | 2.14 | ps TP3 | Pwr.Bud.-Conn.Loss | 4.3 | dB | Disp. So= | 0.1028 | ps/nm^2*km | TP4 Eye | 8 | ps | *Test Tx* | 6.5 | dB |
| Min. Ext Ratio= | 3.65 | dB | Effect. DJ= | 0.07 | (UI) ex DCD | C1= | 480 | ns.MHz | Disp. D1= | -108.41 | ps/(nm.km) | Opening | | (=Tx ey | TestERper | 1.98 | dBo |
| Worst"ave.TxPwr | -1.0 | dBm | MPN k(OMA) | 0.3 | | Reflection Noise factor | 0 | no units | | | | RMS Baseline wander SD | 0.013 | fraction | of 1/2 eye | | |
| Ext. ratio penalty | 4.01 | dBo | Tx eye height | 43.8% | | Effective Rate | 27287 | MBd | (not in use) | 10 | | | | | V.E.C.P. | 2.72 | dBo |
| Tx mask X1= | 0.3 | UI | Refl Tx | -12 | dB | Tb_eff= | 37 | ps | BWm= | 2000 | MHz*km | P_BLW(no ISI) | 0.02 | dB | | | Stressed |
| X2= | 0.4 | UI | ModalNoisePen | 0.3 | dB | Effective Rec Eye | 0.21 | UI | Eff. BWm= | ###### | MHz*km | P_BLW | 0.02 | dB | | | Rx sens |
| Y1= | 0.25 | | Tx mask top | 0.2 | UI | | | | | | | | | | | | |

| L | Patt | Ch IL | D1.L | D2.L | BWcd | effBWm | Te | Tc | Pisi central | P Eye corners | P_DJ central | P_DJ corners | Preflection central | Beta | SDmpn | Pmpn | Prin | Pcross central | Ptotal central | <Ptotal corners | LP Pen central | Margin | OMA central |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (km) | (dB) | (dB) | ps/nm | ps/nm | (MHz) | (MHz) | (ps) | (ps) | J=0, dB | (dB) | (dB) | (dB) | (dB) | | | (dB) | (dB) | (dB) | (dB) | (dB) | (dB) | (dB) | (dBm) |
| 0.002 | 0.01 | 1.51 | -0.22 | 0.00 | 1E+06 | ####### | 32 | 36 | 2.15 | 0.24 | 0.03 | 0.19 | | -1E-02 | 0.00 | 0.00 | | 0.05 | 2.53 | 2.95 | 2.5 | 1.8 | -4.1 |
| **0.001** | **0.00** | **1.50** | **-0.1** | **0.00** | **#####** | **######** | **32** | **36** | **2.15** | **0.24** | **0.03** | **0.19** | **0** | **-0.01** | **0.00** | **0.00** | **0.65** | **0.17** | **3.3** | **3.7** | **3.3** | **1.0** | **-4.8** |
| 0.006 | 0.02 | 1.52 | -0.6 | 0.00 | ##### | ####### | 32 | 36 | 2.16 | 0.24 | 0.03 | 0.19 | 0 | -0.03 | 0.00 | 0.00 | 0.65 | 0.17 | 3.3 | 3.7 | 3.3 | 1.0 | -4.8 |
| 0.011 | 0.04 | 1.54 | -1.2 | 0.00 | ##### | ####### | 32 | 36 | 2.18 | 0.24 | 0.03 | 0.19 | 0 | -0.06 | 0.00 | 0.00 | 0.65 | 0.17 | 3.4 | 3.8 | 3.3 | 0.9 | -4.8 |
| 0.016 | 0.06 | 1.56 | -1.7 | 0.00 | ##### | ####### | 32 | 37 | 2.20 | 0.24 | 0.03 | 0.19 | 0 | -0.09 | 0.00 | 0.00 | 0.65 | 0.17 | 3.4 | 3.8 | 3.4 | 0.9 | -4.8 |
| 0.021 | 0.07 | 1.57 | -2.2 | 0.00 | ##### | 97,087 | 32 | 37 | 2.24 | 0.24 | 0.03 | 0.19 | 0 | -0.11 | 0.00 | 0.00 | 0.64 | 0.18 | 3.5 | 3.9 | 3.4 | 0.8 | -4.9 |
| **0.026** | **0.09** | **1.59** | **-2.8** | **0.00** | **#####** | **78,431** | **33** | **37** | **2.29** | **0.24** | **0.03** | **0.20** | **0** | **-0.14** | **0.00** | **0.00** | **0.64** | **0.18** | **3.5** | **3.9** | **3.4** | **0.8** | **-4.9** |
| 0.03 | 0.11 | 1.61 | -3.3 | 0.00 | 94,567 | 65,789 | 33 | 37 | 2.34 | 0.25 | 0.03 | 0.20 | 0 | -0.17 | 0.01 | 0.00 | 0.63 | 0.18 | 3.6 | 4.0 | 3.5 | 0.7 | -4.9 |
| 0.035 | 0.13 | 1.63 | -3.8 | 0.00 | 81,440 | 56,657 | 34 | 38 | 2.41 | 0.25 | 0.03 | 0.20 | 0 | -0.20 | 0.01 | 0.01 | 0.63 | 0.18 | 3.7 | 4.1 | 3.6 | 0.6 | -4.9 |
| 0.04 | 0.15 | 1.65 | -4.4 | 0.00 | 71,513 | 49,751 | 34 | 38 | 2.49 | 0.25 | 0.03 | 0.20 | 0 | -0.22 | 0.01 | 0.01 | 0.63 | 0.19 | 3.8 | 4.2 | 3.6 | 0.5 | -4.9 |
| 0.045 | 0.16 | 1.66 | -4.9 | 0.00 | 63,744 | 44,346 | 34 | 39 | 2.58 | 0.25 | 0.03 | 0.20 | 0 | -0.25 | 0.01 | 0.02 | 0.63 | 0.20 | 3.9 | 4.3 | 3.7 | 0.4 | -5.0 |
| **0.05** | **0.18** | **1.68** | **-5.4** | **0.00** | **57,497** | **40,000** | **35** | **39** | **2.67** | **0.25** | **0.03** | **0.20** | **0** | **-0.28** | **0.02** | **0.03** | **0.63** | **0.21** | **4.1** | **4.5** | **3.9** | **0.2** | **-5.0** |

- Reach limited by power budget and jitter: 50 m on OM3
  - max TJ = 0.75 UI at the input to optical receiver CDR (‘TP4’)