MMF links, EQ and FEC

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Supporters and contributors

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Introduction

- Estimates of MMF link improvements possible with some known techniques are presented:
  - Tx equalization
  - FEC (two flavours)
  - Rx chain equalization (FFE and FFE/DFE)

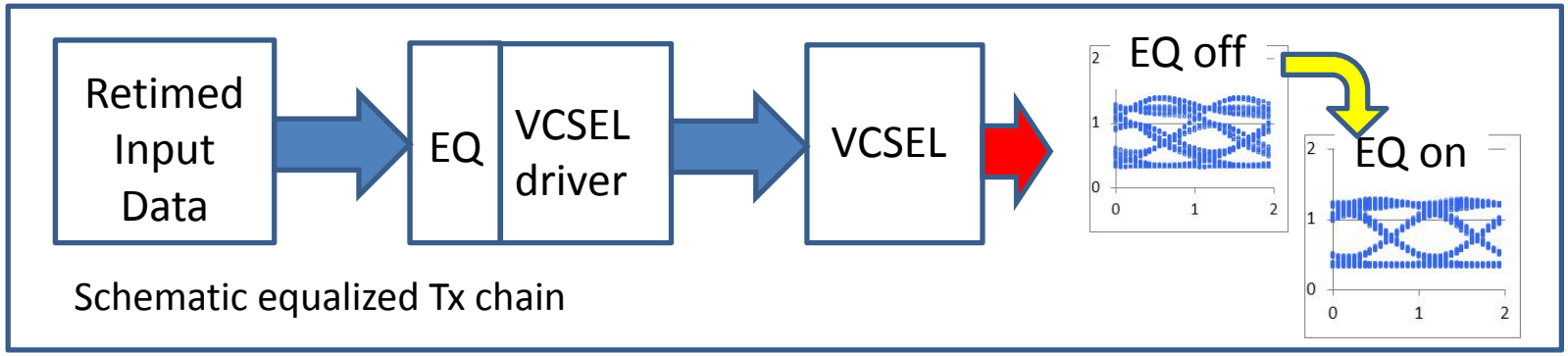
Tx equalization

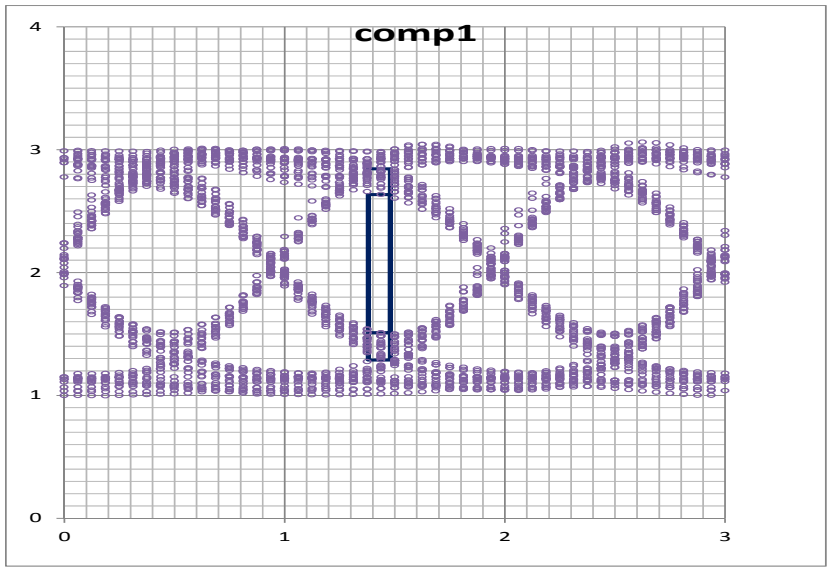
- The characteristic parameters of next generation 28 GBd VCSELs are not expected to scale with bit rate from 10 Gb/s or 14 Gb/s.
  - Rise/fall times expected to be around 20 ps
  - RIN_{OMA} expected to be ~-130 dB/Hz

- Public domain link models based on the 10GbE spreadsheet don't explicitly account for any Tx chain equalization, and predict significant constraints on maximum reach for 25.8 GBd to 28 GBd optical lane rates.

- Spreadsheet link models can be improved by setting an *equivalent rise/fall time* in the spreadsheet that produces worst case Tx eye closure matching the eye closure seen in simulations combining the design models of next generation VCSELs and drivers.

TxEQ: driver/equalizer + VCSEL simulation





Simulated output eye at 28 GBd
with Tx equalization activated
eye closure = 1.5 dB

(eye closure without Tx equalization = 2.6 dB)

Notes: The simulations used a transistor level design model of a low power (~30 mW per lane for the EQ functionality) Tx driver/EQ, and design specific rate equation model of a high speed VCSEL design operating at high temperature. Although the implementation details are not described, the indicated range of eye improvement is helpful for setting objectives.

Tx EQ: Simulation vs spreadsheet

	Simulation driver + VCSEL		**28G xls model fixed DJ**		
	Eye-closure dB	DJ, UI	Eye-closure dB	Added DJ, UI	Rise-time to match eye-closure, ps
No Tx EQ	2.6	0.3	2.6	0.12	**20**
Tx EQ	1.5	0.15	1.5	0.12	**16**

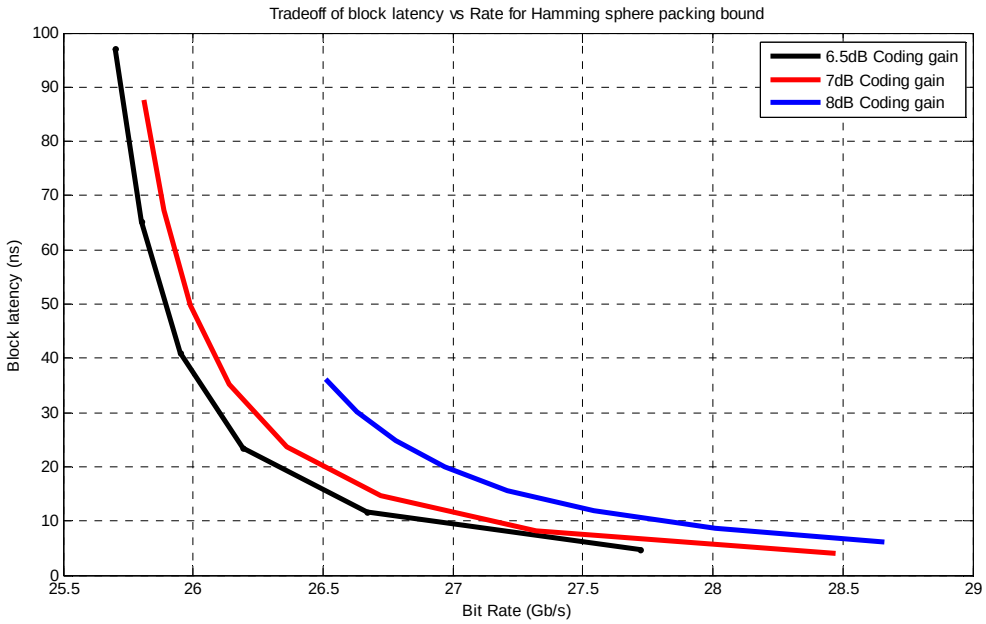
- Based on simulations, shorter equivalent rise/fall times need to be used in spreadsheet models to match the eye closure expected from an equalized driver + VCSEL transmitter chain
- In practice, Tx equalization is likely to give equivalent rise/fall times in the 16 ps to 20 ps range

FEC for SR4: Mandatory Vs. Optional?

- FEC encoder is simple
  - Similar to CRC-32 generation, adds parity to make a block of bits a “codeword”
  - Low complexity/latency
- FEC decoder involves 3 steps
  - Compute “Syndrome”
    - If syndromes are zero, then no errors have occurred. Nothing more to do
  - Solve “Key Equation” using Berlekamp Massey or Euclidean Algorithm
  - Chien Search
    - Forney for Reed Solomon codes
- Mandatory FEC means Transmitter always sends FEC encoded frames
- Mandatory FEC can still mean low latency. Rx can perform tradeoffs
  - Zero FEC latency: Ignore FEC parity bits at Rx
  - 1x block latency: Integrity check/Error Detection. Verify syndromes are zero
  - 2-3x block latency: Full FEC decode
- Optional FEC means host transmitter enables FEC based on reported capabilities of module and link partner

FEC Latency vs. overhead

- Choice of FEC parameters involves a triple tradeoff
  - Latency
  - Additional overhead causes over clocking (higher signaling rate) or reduced data rate
  - Coding gain
- The block latency increases sharply as the rate approaches 100GE-LR4 rate
- For lowest latency, higher overhead (28 vs. 25.8 GBd or 92 vs. 100 Gb/s) is preferred
- However, if mandatory FEC is desirable, 28 GBd might impose a burden on all ports
- Alternate transcoding, 512B/513B has been proposed to lower the FEC overhead



Spreadsheet link model with and without FEC

- Initial calculations of non-FEC and FEC enabled reach using modified '10GE spreadsheet' model - not exact, perhaps a compass
- Link assumptions:
  - Tx/VCSEL: two effective rise fall times used, 20 ps (simple Tx chain), and 16 ps (some Tx equalization)
    - Tx_OMA min of -2 dBm , 0.6 nm max RMS spectral width, -130 dB/Hz RIN_{OMA}, 840 nm worst case centre wavelength, 0.12 UI added DJ
  - Channel: OM4, 4400 MHz.km, 1.5 dB total connector loss
  - Receiver: -7.6 dBm sensitivity at 25.8 GBd, BER 10^{-12}
    - includes nominal 1 dB allowance for penalties due to multiple parallel channels
    - de-rated by the square root of the bit rate, and by 10.log(Q), to give -10 dBm for 25.8 GBd, BER=$3x10^{-5}$, and -10.2 dBm for 28.05 GBd, BER=$9.9x10^{-5}$
- FEC assumptions:
  - High and low latency FEC flavours, ~the bookends in Gustlin_02a_0311

Block size	Rate Gb/s	3x block latency	Raw coding gain, 10^{-15}	BER in for 10^{-15} out	Notes
9979 bits	25.8	~300 ns	5.9 dB	$3.06x10^{-5}$	'High latency', Q=~4
906 bits	28	~30 ns	6.6 dB	$9.96x10^{-5}$	'Low latency', Q=~3.8

Summary results 1

VCSEL effective rise fall time = 20 ps (no Tx equalization)

Rate/FEC	Reach limit definition	OM4 reach	Typ. latency: 50m fiber + FEC	Max. latency: max reach + FEC	Notes
25.8 GBd, no FEC	power budget	**70 m**	250 ns	350 ns	~2.5 dB VECP
25.8 GBd, high latency FEC	power budget	155 m	550 ns	1075 ns	high ~4.5dB VECP
25.8 GBd, high latency FEC	3.6 dB VECP	**125 m**	550 ns	925 ns	1.7 dB margin for spec relaxation
25.8 GBd, high latency FEC	3.0 dB VECP	**100 m**	550 ns	800 ns	2.6 dB margin for spec relaxation
28 GBd, low latency FEC	power budget	140 m	280 ns	730 ns	high ~4.8 dB VECP !
28 GBd, low latency FEC	3.6 dB VECP	**100 m**	280 ns	530 ns	2.0 dB margin for spec relaxation

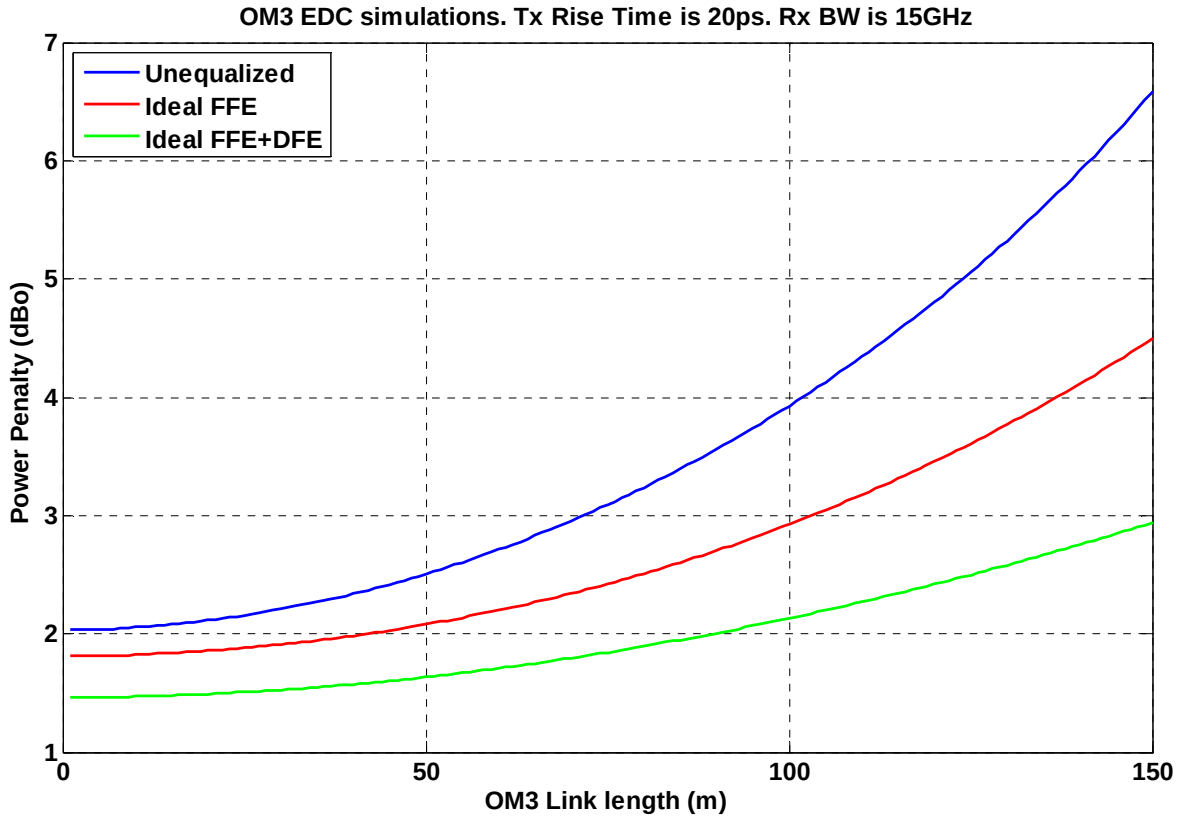
Summary results 2

VCSEL effective rise fall time = 16 ps (some Tx equalization)

Rate/FEC	Reach limit definition	OM4 reach	Typ. latency: 50m fiber + FEC	Max. latency: max reach + FEC	Notes
25.8 GBd, no FEC	power budget	**100 m**	250 ns	500 ns	~2.2 dB VECP
25.8 GBd, high latency FEC	power budget	170 m	550 ns	1150 ns	high ~4 dB VECP !
25.8 GBd, high latency FEC	3.6 dB VECP	**155 m**	550 ns	1075 ns	1.2 dB margin for spec relaxation
25.8 GBd, high latency FEC	3.0 dB VECP	**135 m**	550 ns	975 ns	2.2 dB margin for spec relaxation
28 GBd, low latency FEC	power budget	160 m	280 ns	830 ns	high ~4.5 dB VECP !
28 GBd, low latency FEC	3.6 dB VECP	**135 m**	280 ns	705 ns	1.7 dB margin for spec relaxation

Rx chain equalization

- PIE-L and PIE-D used to calculate equalized power penalty vs distance
  - The PIE metrics (Penalty for Ideal Equalizer) refer to FFE and FFE/DFE based equalizers of with infinite number of taps. In practice, an equalizer with a finite, modest number of taps can get very close to the ideal equalizer penalty
  - Tx/VCSEL: 20 ps rise fall times, Rx bandwidth 15 GHz, OM3 fibre



Concluding notes

Tx equalization

- Reduces Tx eye closure by about 1 dB
- May allow an effective rise time between 16 and 20 ps for spreadsheet modeling
- Power efficient: ~30 mW/lane inside the module

FEC

- Allows links to extend to their ISI limited reach,
    - about a 40% increase in distance - enables 100+ m links on OM4 for slow lasers
- … and can provide an extra 1 to 2 dB link budget margin
    - for example could be used to relax the Tx or Rx specs used here
- … can be power efficient ~50 mW/lane (depending on process) outside module

Notes: Link latency is dominated by the fibre - FEC adds the equivalent of 6 m to 60 m of fiber

- Greater overheads (higher bit-rates) reduce FEC latency, but reduce max reach

Rx equalization

- Reduces vertical eye closure penalty of a 100 m OM3 link by 1 to 2 dB (depending on complexity)
- Many choices are available. Continuous Time Linear Equalizer (CTLE), FFE or DFE
- Current power consumption estimates: 100 mW for linear TIA, 100-150 mW for EDC. Power consumption for EDC in 28 nm CMOS can be further reduced to 50-75 mW.

Summary table

Technology	Approximate power/lane	benefit	Notes
Full retiming in module	~500 mW	relaxed host specs, partitioned testing	per Tx Rx pair*
Tx EQ	~30 mW	~1 dB	
FEC	~50 mW	1 to 2.5 dB	latency vs overhead
Rx EQ	~150-200 mW	1 to 2 dB	for FFE/DFE
Rx chain CTLE or fixed peaking	<30 mW ?	~1 dB ?	power burn vs benefit TBD

* ~10mW per Gb/s per CDR, expected to reduce in next few years

Thank you !

back up

- Link models for 20ps rise/fall time

25.8 Gb/s 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)	**20**	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)	30	ps	*Target* Target reach	**0.070**	km	*Fiber* at	850	nm	NomSens OMA	**-7.61**	dBm	Margin	0.10	dB at
Base Rate=	**25781**	MBd	RIN(OMA)	**-130**	dB/Hz	*and* L_start=	**0.002**	km	C_att=	1.00		*Receive* Refl Rx	**-12**	dB	*Answer!*	0.07	km
Transmitter			RIN at MinER	-138.0	dB/Hz	*graph* L_inc=	**0.007**	km	Attenuation=	3.62	dB/km	Rec_BW=	**#####**	MHz	st Rx BW	**18750**	MHz
Wavelength Uc	**840**	nm	RIN_Coef=	**0.70**		Power Budget P=	5.61	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)	16.0	ps	Test Source ER=		
Tx pwr OMA=	**-2.00**	dBm	DCD_DJ=	**2.3273**	ps TP3	Pwr.Bud.-Conn.Loss	4.11	dB	Disp. So=	**0.103**	ps/nm^2*km	TP4 Eye	8	ps	*Test Tx*	**6.5**	dB
Min. Ext Ratio=	3.65	dB	Effect. DJ=	0.06	(UI) ex DCD	C1=	**480**	ns.MHz	Disp. D1=	#####	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	**0.025**	fraction of 1/2 eye			
Ext. ratio penalty	4.01	dBo	Tx eye height	46.6%		Effective Rate	27427	MBd	(not in use)	**10**					V.E.C.P.	2.47	dBo
Tx mask X1=	**0.3**	UI	Refl Tx	**-12**	dB	Tb_eff=	36	ps	BWm=	**4400**	MHz*km	P_BLW(no ISI)	0.07	dB			Stressed
X2=	**0.4**	UI	ModalNoisePen	**0.3**	dB	Effective Rec Eye	0.21	UI	Eff. BWm=	#####	MHz*km	P_BLW	0.07	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	######	30	34	1.85	0.24	0.02	0.17		-1E-02	0.00	0.00		0.16	2.33	2.73	2.3	1.8	-4.0
0.002	**0.01**	**1.51**	**-0.2**	**0.00**	**#####**	**######**	**30**	**34**	**1.85**	**0.24**	**0.02**	**0.17**	**0**	**-0.01**	**0.00**	**0.00**	**0.61**	**0.30**	**3.1**	**3.5**	**3.1**	**1.0**	**-4.7**
0.009	0.03	1.53	-1.0	0.00	#####	######	30	34	1.85	0.24	0.02	0.17	0	-0.05	0.00	0.00	0.61	0.31	3.1	3.5	3.1	1.0	-4.7
0.016	0.06	1.56	-1.7	0.00	#####	######	31	34	1.87	0.24	0.02	0.17	0	-0.09	0.00	0.00	0.60	0.31	3.2	3.6	3.1	1.0	-4.7
0.022	0.08	1.58	-2.4	0.00	#####	######	31	35	1.89	0.25	0.02	0.18	0	-0.13	0.00	0.00	0.60	0.31	3.2	3.6	3.1	0.9	-4.7
0.029	0.11	1.61	-3.2	0.00	98,453	######	31	35	1.93	0.25	0.02	0.18	0	-0.16	0.01	0.00	0.59	0.31	3.3	3.7	3.2	0.8	-4.8
0.036	**0.13**	**1.63**	**-3.9**	**0.00**	**79,857**	**######**	**31**	**35**	**1.97**	**0.25**	**0.02**	**0.18**	**0**	**-0.20**	**0.01**	**0.01**	**0.59**	**0.32**	**3.3**	**3.7**	**3.2**	**0.8**	**-4.8**
0.043	0.16	1.66	-4.6	0.00	67,169	######	32	35	2.02	0.25	0.02	0.18	0	-0.24	0.01	0.02	0.58	0.33	3.4	3.8	3.3	0.7	-4.8
0.05	0.18	1.68	-5.4	0.00	57,961	88,710	32	36	2.08	0.25	0.02	0.18	0	-0.28	0.02	0.03	0.57	0.35	3.5	3.9	3.4	0.6	-4.9
0.056	0.20	1.70	-6.1	0.00	50,972	78,014	32	36	2.15	0.25	0.02	0.18	0	-0.32	0.02	0.04	0.57	0.37	3.7	4.1	3.5	0.4	-4.9
0.063	0.23	1.73	-6.9	0.00	45,488	69,620	33	37	2.23	0.25	0.02	0.18	0	-0.35	0.02	0.07	0.57	0.40	3.8	4.2	3.6	0.3	-5.0
0.07	**0.25**	**1.75**	**-7.6**	**0.00**	**41,069**	**62,857**	**33**	**37**	**2.32**	**0.25**	**0.02**	**0.18**	**0**	**-0.39**	**0.03**	**0.10**	**0.57**	**0.45**	**4.0**	**4.4**	**3.8**	**0.1**	**-5.0**

- Reach limited by power budget: ~70 m OM4
  - ~2.5 dB vertical eye closure penalty

25.8 Gb/s 'high latency' FEC (power budget limit)

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)	**20**	ps	Case: 850nm serial	**newMMF**	Attenuation=	**3.5**	dB/km	Model/format rev	3.1.16a	of	31-Oct-01
	Q=	**4.04**		Ts(10-90)	30	ps	*Target* Target reach	**0.155** km	*Fiber* at	850	nm	NomSens OMA	**-10.03** dBm	Margin	0.14 dB at
	Base Rate=	**25781**	MBd	RIN(OMA)	**-130**	dB/Hz	*and* L_start=	**0.002** km	C_att=	1.00		*Receive* Refl Rx	**-12** dB	*Answer!*	0.155 km
Transmitter				RIN at MinER	-138.0	dB/Hz	*graph* L_inc=	**0.015** km	Attenuation=	3.62	dB/km	Rec_BW=	**#####** MHz	st Rx BW	**18750** MHz
	Wavelength Uc	**840**	nm	RIN_Coef=	**0.70**		Power Budget P=	8.03 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)	16.0 ps	Test Source ER=	
	Tx pwr OMA=	**-2.00**	dBm	DCD_DJ=	**2.33**	ps TP3	Pwr.Bud.-Conn.Loss	6.525 dB	Disp. So=	**0.103**	ps/nm^2*km	TP4 Eye	8 ps	*Test Tx*	**6.5** dB
	Min. Ext Ratio=	3.65	dB	Effect. DJ=	0.06	(UI) ex DCD	C1=	**480** ns.MHz	Disp. D1=	#####	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	**0.025** fraction of 1/2 eye		
	Ext. ratio penalty	4.01	dBo	Tx eye height	46.6%		Effective Rate	27429 MBd	(not in use)	**10**				V.E.C.P.	4.40 dBo
	Tx mask X1=	**0.3**	UI	Refl Tx	**-12**	dB	Tb_eff=	36 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	######	30	34	1.85	0.24	0.02	0.18		-1E-02	0.00	0.00		0.05	2.22	2.62	2.2	4.3	-4.0
0.002	**0.01**	**1.51**	**-0.2**	**0.00**	**#####**	**######**	**30**	**34**	**1.85**	**0.24**	**0.02**	**0.18**	**0**	**-0.01**	**0.00**	**0.00**	**0.18**	**0.07**	**2.4**	**2.8**	**2.4**	**4.1**	**-4.2**
0.017	0.06	1.56	-1.9	0.00	#####	######	31	34	1.87	0.24	0.02	0.18	0	-0.10	0.00	0.00	0.18	0.07	2.5	2.9	2.4	4.0	-4.2
0.033	0.12	1.62	-3.5	0.00	88,185	######	31	35	1.95	0.25	0.02	0.18	0	-0.18	0.01	0.00	0.18	0.08	2.6	3.0	2.5	3.9	-4.3
0.048	0.17	1.67	-5.2	0.00	60,018	91,858	32	36	2.07	0.25	0.02	0.18	0	-0.27	0.01	0.01	0.17	0.08	2.8	3.2	2.7	3.7	-4.3
0.063	0.23	1.73	-6.9	0.00	45,488	69,620	33	37	2.23	0.25	0.02	0.18	0	-0.35	0.02	0.02	0.17	0.09	3.1	3.5	2.8	3.5	-4.4
0.079	**0.28**	**1.78**	**-8.5**	**0.00**	**36,622**	**56,051**	**34**	**38**	**2.44**	**0.25**	**0.02**	**0.18**	**0**	**-0.44**	**0.04**	**0.05**	**0.17**	**0.11**	**3.4**	**3.8**	**3.1**	**3.1**	**-4.5**
0.094	0.34	1.84	-10.2	0.00	30,649	46,908	36	39	2.70	0.25	0.02	0.18	0	-0.53	0.05	0.09	0.18	0.14	3.8	4.2	3.4	2.8	-4.6
0.109	0.40	1.90	-11.8	0.00	26,351	40,330	37	41	3.01	0.25	0.02	0.18	0	-0.61	0.07	0.16	0.19	0.18	4.3	4.7	3.9	2.3	-4.8
0.124	0.45	1.95	-13.5	0.01	23,110	35,370	39	42	3.37	0.25	0.02	0.18	0	-0.70	0.08	0.25	0.20	0.24	4.8	5.2	4.4	1.7	-5.0
0.14	0.51	2.01	-15.1	0.01	20,579	31,496	41	44	3.77	0.26	0.02	0.19	0	-0.78	0.10	0.36	0.22	0.35	5.5	6.0	5.0	1.0	-5.2
0.155	**0.56**	**2.06**	**-16.8**	**0.01**	**18,547**	**28,387**	**43**	**46**	**4.24**	**0.26**	**0.02**	**0.19**	**0**	**-0.87**	**0.11**	**0.50**	**0.26**	**0.51**	**6.4**	**6.8**	**5.8**	**0.1**	**-5.5**

- Reach limited by power budget is 155 m OM4
  - ~4.4 dB vertical eye closure penalty (too high)

25.8 Gb/s ‘high latency’ FEC (ISI limit)

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	Q=	**4.04**	Ts(10-90)	30	ps	*Target*	Target reach	**0.125**	km	*Fiber* at	850	nm	NomSens OMA	**-10.03**	dBm	Margin	1.67	dB at
Base Rate=	**25781**	MBd	RIN(OMA)	**-130**	dB/Hz	*and*	L_start=	**0.002**	km	C_att=	1.00		*Receive* Refl Rx	**-12**	dB	*Answer!*	0.125 km	
Transmitter			RIN at MinER	-138.0	dB/Hz	*graph*	L_inc=	**0.012**	km	Attenuation=	3.62	dB/km	Rec_BW=	**#####**	MHz	st Rx BW	**18750**	MHz
Wavelength Uc	**840**	nm	RIN_Coef=	**0.70**			Power Budget P=	8.03	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)	16.0	ps	Test Source ER=		
Tx pwr OMA=	**-2.00**	dBm	DCD_DJ=	**2.33**	ps TP3		Pwr.Bud.-Conn.Loss	6.525	dB	Disp. So=	**0.103**	ps/nm^2*km	TP4 Eye	8	ps	*Test Tx*	**6.5**	dB
Min. Ext Ratio=	3.65	dB	Effect. DJ=	0.06	(UI) ex DCD		C1=	**480**	ns.MHz	Disp. D1=	######	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	**0.025**	fraction of 1/2 eye			
Ext. ratio penalty	4.01	dBo	Tx eye height	46.6%			Effective Rate	27429	MBd	(not in use)	**10**					V.E.C.P.	3.54	dBo
Tx mask X1=	**0.3**	UI	Refl Tx	**-12**	dB		Tb_eff=	36	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	######	30	34	1.85	0.24	0.02	0.18		-1E-02	0.00	0.00		0.05	2.22	2.62	2.2	4.3	-5.5
0.002	**0.01**	**1.51**	**-0.2**	**0.00**	**#####**	**######**	**30**	**34**	**1.85**	**0.24**	**0.02**	**0.18**	**0**	**-0.01**	**0.00**	**0.00**	**0.18**	**0.07**	**2.4**	**2.8**	**2.4**	**4.1**	**-5.7**
0.014	0.05	1.55	-1.6	0.00	#####	######	30	34	1.87	0.24	0.02	0.18	0	-0.08	0.00	0.00	0.18	0.07	2.5	2.9	2.4	4.0	-5.7
0.027	0.10	1.60	-2.9	0.00	#####	######	31	35	1.91	0.25	0.02	0.18	0	-0.15	0.00	0.00	0.18	0.07	2.6	3.0	2.5	3.9	-5.8
0.039	0.14	1.64	-4.2	0.00	73,903	######	31	35	1.99	0.25	0.02	0.18	0	-0.22	0.01	0.00	0.18	0.08	2.7	3.1	2.6	3.8	-5.8
0.051	0.19	1.69	-5.6	0.00	56,149	85,938	32	36	2.10	0.25	0.02	0.18	0	-0.29	0.02	0.01	0.17	0.08	2.9	3.3	2.7	3.7	-5.9
0.064	**0.23**	**1.73**	**-6.9**	**0.00**	**45,273**	**69,291**	**33**	**37**	**2.24**	**0.25**	**0.02**	**0.18**	**0**	**-0.36**	**0.03**	**0.02**	**0.17**	**0.09**	**3.1**	**3.5**	**2.8**	**3.5**	**-5.9**
0.076	0.27	1.77	-8.2	0.00	37,927	58,047	34	37	2.40	0.25	0.02	0.18	0	-0.42	0.04	0.04	0.17	0.10	3.3	3.7	3.0	3.2	-6.0
0.088	0.32	1.82	-9.6	0.00	32,632	49,943	35	39	2.60	0.25	0.02	0.18	0	-0.49	0.05	0.08	0.17	0.12	3.6	4.0	3.3	2.9	-6.1
0.10	0.36	1.86	-10.9	0.00	28,634	43,825	36	40	2.83	0.25	0.02	0.18	0	-0.56	0.06	0.12	0.18	0.15	4.0	4.4	3.6	2.6	-6.2
0.113	0.41	1.91	-12.2	0.00	25,509	39,042	38	41	3.09	0.25	0.02	0.18	0	-0.63	0.07	0.18	0.19	0.19	4.4	4.8	4.0	2.1	-6.3
0.125	**0.45**	**1.95**	**-13.6**	**0.01**	**22,999**	**35,200**	**39**	**42**	**3.38**	**0.25**	**0.02**	**0.18**	**0**	**-0.70**	**0.08**	**0.25**	**0.20**	**0.25**	**4.9**	**5.3**	**4.4**	**1.7**	**-6.5**

- Reach limited by ~3.6 dB vertical eye closure is ~125 m OM4

25.8 Gb/s ‘high latency’ FEC (ISI limit)

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** — Q= **4.04** — Base Rate= **25781** MBd

Transmitter

Wavelength Uc	**840**	nm
Uw (see notes)	**0.60**	nm
Tx pwr OMA=	**-2.00**	dBm
Min. Ext Ratio=	3.65	dB
Worst"ave.TxPwr	**-1.0**	dBm
Ext. ratio penalty	4.01	dBo
Tx mask X1=	**0.3**	UI
X2=	**0.4**	UI
Y1=	**0.25**	

Ts(20-80)	**20**	ps
Ts(10-90)	30	ps
RIN(OMA)	**-130**	dB/Hz
RIN at MinER	-138.0	dB/Hz
RIN_Coef=	**0.70**	
Det.Jitter	**4.7**	ps inc. DCD
DCD_DJ=	**2.33**	ps TP3
Effect. DJ=	0.06	(UI) ex DCD
MPN k(OMA)	**0.3**	
Tx eye height	46.6%	
Refl Tx	**-12**	dB
ModalNoisePen	**0.3**	dB
Tx mask top	0.2	UI

Case: 850nm serial	**newMMF**	
Target Target reach	**0.100**	km
and L_start=	**0.002**	km
graph L_inc=	**0.01**	km
Power Budget P=	8.03	dB
Connections C	**1.5**	dB
Pwr.Bud.-Conn.Loss	6.525	dB
C1=	**480**	ns.MHz
Reflection Noise factor	**0**	no units
Effective Rate	27429	MBd
Tb_eff=	36	ps
Effective Rec Eye	0.21	UI

Attenuation=	**3.5**	dB/km
Fiber at	850	nm
C_att=	1.00	
Attenuation=	3.62	dB/km
at	840	nm
Disp. min. Uo=	**1316**	nm
Disp. So=	**0.103**	ps/nm^2*km
Disp. D1=	#####	ps/(nm.km)
(not in use)	**10**	
BWm=	**4400**	MHz*km
Eff. BWm=	#####	MHz*km

NomSens OMA	**-10.03**	dBm
Receive Refl Rx	**-12**	dB
Rec_BW=	#####	MHz
c_rx	**329**	ns.MHz
T_rx(10-90)	16.0	ps
TP4 Eye	8	ps
Opening		(=Tx ey
RMS Baseline wander SD	**0.025**	fraction
P_BLW(no ISI)	0.02	dB
P_BLW	0.02	dB

Model/format rev 3.1.16a of 31-Oct-01

Margin 2.57 dB at *Answer!* 0.1 km

st Rx BW **18750** MHz

Test Source ER=

Test Tx **6.5** dB

TestERpe 1.98 dBo

V.E.C.P. 2.98 dBo

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	Stressed Rx sens 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	######	30	34	1.85	0.24	0.02	0.18		-1E-02	0.00	0.00		0.05	2.22	2.62	2.2	4.3	-6.4
0.002	**0.01**	**1.51**	**-0.2**	**0.00**	#####	######	**30**	**34**	**1.85**	**0.24**	**0.02**	**0.18**	**0**	**-0.01**	**0.00**	**0.00**	**0.18**	**0.07**	**2.4**	**2.8**	**2.4**	**4.1**	**-6.6**
0.012	0.04	1.54	-1.3	0.00	#####	######	30	34	1.86	0.24	0.02	0.18	0	-0.07	0.00	0.00	0.18	0.07	2.5	2.9	2.4	4.0	-6.6
0.022	0.08	1.58	-2.3	0.00	#####	######	31	35	1.89	0.25	0.02	0.18	0	-0.12	0.00	0.00	0.18	0.07	2.5	2.9	2.5	4.0	-6.7
0.031	0.11	1.61	-3.4	0.00	91,555	######	31	35	1.94	0.25	0.02	0.18	0	-0.18	0.01	0.00	0.18	0.07	2.6	3.0	2.5	3.9	-6.7
0.041	0.15	1.65	-4.5	0.00	69,778	######	31	35	2.01	0.25	0.02	0.18	0	-0.23	0.01	0.00	0.17	0.08	2.7	3.1	2.6	3.8	-6.7
0.051	**0.18**	**1.68**	**-5.5**	**0.00**	**56,369**	**86,275**	**32**	**36**	**2.10**	**0.25**	**0.02**	**0.18**	**0**	**-0.29**	**0.02**	**0.01**	**0.17**	**0.08**	**2.9**	**3.3**	**2.7**	**3.7**	**-6.8**
0.061	0.22	1.72	-6.6	0.00	47,284	72,368	33	36	2.20	0.25	0.02	0.18	0	-0.34	0.02	0.02	0.17	0.09	3.0	3.4	2.8	3.5	-6.8
0.071	0.26	1.76	-7.7	0.00	40,720	62,323	33	37	2.33	0.25	0.02	0.18	0	-0.40	0.03	0.03	0.17	0.10	3.2	3.6	3.0	3.3	-6.9
0.08	0.29	1.79	-8.7	0.00	35,757	54,726	34	38	2.47	0.25	0.02	0.18	0	-0.45	0.04	0.05	0.17	0.11	3.4	3.8	3.1	3.1	-6.9
0.09	0.33	1.83	-9.8	0.00	31,872	48,780	35	39	2.64	0.25	0.02	0.18	0	-0.51	0.05	0.08	0.17	0.13	3.7	4.1	3.3	2.9	-7.0
0.10	**0.36**	**1.86**	**-10.8**	**0.00**	**28,748**	**44,000**	**36**	**40**	**2.82**	**0.25**	**0.02**	**0.18**	**0**	**-0.56**	**0.06**	**0.12**	**0.18**	**0.15**	**4.0**	**4.4**	**3.6**	**2.6**	**-7.1**

- Reach limited by ~3.0 dB vertical eye closure is 100 m OM4

28 Gb/s ‘low latency’ FEC (power budget limit)

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)	**20**	ps	Case: 850nm serial	**newMMF**		Attenuation=	**3.5**	dB/km	Model/format rev	3.1.16a		of	31-Oct-01	
Q=	**3.74**		Ts(10-90)	30	ps	*Target* Target reach	**0.140**	km	*Fiber* at	850	nm	NomSens OMA	**-10.18**	dBm	Margin	0.08	dB at
Base Rate=	**28050**	MBd	RIN(OMA)	**-130**	dB/Hz	*and* L_start=	**0.002**	km	C_att=	1.00		*Receive* Refl Rx	**-12**	dB	*Answer!*	0.14	km
Transmitter			RIN at MinER	-138.0	dB/Hz	*graph* L_inc=	**0.014**	km	Attenuation=	3.62	dB/km	Rec_BW=	**#####**	MHz	st Rx BW	**20400**	MHz
Wavelength Uc	**840**	nm	RIN_Coef=	**0.70**		Power Budget P=	8.18	dB	at	840	nm	c_rx	**329**	ns.MHz			
Uw (see notes)	**0.60**	nm	Det.Jitter	**4.3**	ps inc. DCD	Connections C	**1.5**	dB	Disp. min. Uo=	**1316**	nm	T_rx(10-90)	14.7	ps	Test Source ER=		
Tx pwr OMA=	**-2.00**	dBm	DCD_DJ=	**2.139**	ps TP3	Pwr.Bud.-Conn.Loss	6.676	dB	Disp. So=	**0.103**	ps/nm^2*km	TP4 Eye	7	ps	*Test Tx*	**6.5**	dB
Min. Ext Ratio=	3.65	dB	Effect. DJ=	0.06	(UI) ex DCD	C1=	**480**	ns.MHz	Disp. D1=	#####	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	**0.025**	fraction of 1/2 eye			
Ext. ratio penalty	4.01	dBo	Tx eye height	40.8%		Effective Rate	29840	MBd	(not in use)	**10**					V.E.C.P.	4.77	dBo
Tx mask X1=	**0.3**	UI	Refl Tx	**-12**	dB	Tb_eff=	34	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	######	30	34	2.26	0.25	0.02	0.18		-1E-02	0.00	0.00		0.06	2.64	3.05	2.6	4.0	-3.9
0.002	**0.01**	**1.51**	**-0.2**	**0.00**	**#####**	**######**	**30**	**34**	**2.26**	**0.25**	**0.02**	**0.18**	**0**	**-0.01**	**0.00**	**0.00**	**0.21**	**0.08**	**2.9**	**3.3**	**2.9**	**3.8**	**-4.1**
0.016	0.06	1.56	-1.7	0.00	#####	######	31	34	2.29	0.25	0.02	0.18	0	-0.10	0.00	0.00	0.20	0.08	3.0	3.4	2.9	3.7	-4.2
0.03	0.11	1.61	-3.2	0.00	97,123	######	31	34	2.36	0.25	0.02	0.18	0	-0.18	0.01	0.00	0.20	0.09	3.1	3.5	3.0	3.6	-4.2
0.043	0.16	1.66	-4.7	0.00	66,241	######	32	35	2.48	0.25	0.02	0.18	0	-0.26	0.01	0.01	0.20	0.09	3.2	3.7	3.1	3.4	-4.3
0.057	0.21	1.71	-6.2	0.00	50,259	76,923	32	36	2.64	0.25	0.02	0.18	0	-0.35	0.02	0.02	0.19	0.10	3.5	3.9	3.3	3.2	-4.4
0.071	**0.26**	**1.76**	**-7.7**	**0.00**	**40,491**	**61,972**	**34**	**37**	**2.84**	**0.25**	**0.02**	**0.18**	**0**	**-0.43**	**0.04**	**0.04**	**0.19**	**0.12**	**3.8**	**4.2**	**3.5**	**2.9**	**-4.4**
0.085	0.31	1.81	-9.2	0.00	33,901	51,887	35	38	3.10	0.25	0.02	0.18	0	-0.52	0.05	0.08	0.20	0.14	4.1	4.6	3.8	2.5	-4.5
0.099	0.36	1.86	-10.7	0.00	29,157	44,625	36	39	3.40	0.25	0.02	0.18	0	-0.60	0.06	0.13	0.21	0.18	4.6	5.0	4.2	2.1	-4.7
0.112	0.41	1.91	-12.2	0.00	25,577	39,146	38	40	3.74	0.26	0.02	0.18	0	-0.69	0.08	0.20	0.23	0.24	5.1	5.6	4.7	1.5	-4.8
0.126	0.46	1.96	-13.7	0.01	22,780	34,865	39	42	4.14	0.26	0.02	0.19	0	-0.77	0.09	0.29	0.25	0.33	5.8	6.2	5.3	0.9	-5.0
0.14	**0.51**	**2.01**	**-15.2**	**0.01**	**20,535**	**31,429**	**41**	**44**	**4.60**	**0.27**	**0.02**	**0.19**	**0**	**-0.85**	**0.11**	**0.40**	**0.29**	**0.48**	**6.6**	**7.0**	**6.1**	**0.1**	**-5.3**

- Reach allowed by power budget is ~140 m OM4
  - but ~4.8 dB vertical eye closure (too high)

28 Gb/s ‘low latency’ FEC (ISI limit)

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 — Model/format rev 3.1.16a of 31-Oct-01

Basics	Input=	**Bold**		Ts(20-80)	**20**	ps	Case: 850nm serial	**newMMF**		Attenuation=	**3.5**	dB/km	NomSens OMA	**-10.18**	dBm	Margin	2.03	dB at													
	Q=	**3.74**		Ts(10-90)	30	ps	*Target* Target reach	**0.100**	km	*Fiber* at	850	nm	*Receive* Refl Rx	**-12**	dB	*Answer!*		0.1 km												
	Base Rate=	**28050**	MBd	RIN(OMA)	**-130**	dB/Hz	*and* L_start=	**0.002**	km	C_att=	1.00		Rec_BW=	**#####**	MHz	st Rx BW	**20400**	MHz												
Transmitter				RIN at MinER	-138.0	dB/Hz	*graph* L_inc=	**0.01**	km	Attenuation=	3.62	dB/km	c_rx	**329**	ns.MHz																
Wavelength Uc		**840**	nm	RIN_Coef=	**0.70**		Power Budget P=	8.18	dB	at	840	nm	T_rx(10-90)	14.7	ps	Test Source ER=														
Uw (see notes)		**0.60**	nm	Det.Jitter	**4.3**	ps inc. DCD	Connections C	**1.5**	dB	Disp. min. Uo=	**1316**	nm	TP4 Eye	7	ps	*Test Tx*	**6.5**	dB												
Tx pwr OMA=		**-2.00**	dBm	DCD_DJ=	**2.139**	ps TP3	Pwr.Bud.-Conn.Loss	6.676	dB	Disp. So=	**0.103**	ps/nm^2*km	Opening		(=Tx ey	TestERpe	1.98	dBo												
Min. Ext Ratio=		3.65	dB	Effect. DJ=	0.06	(UI) ex DCD	C1=	**480**	ns.MHz	Disp. D1=	#####	ps/(nm.km)																		
Worst"ave.TxPwr		**-1.0**	dBm	MPN k(OMA)	**0.3**		Reflection Noise factor	**0**	no units				RMS Baseline wander SD	**0.025**	fraction of 1/2 eye															
Ext. ratio penalty		4.01	dBo	Tx eye height	40.8%		Effective Rate	29840	MBd	(not in use)	**10**					V.E.C.P.	3.59	dBo											
Tx mask X1=		**0.3**	UI	Refl Tx	**-12**	dB	Tb_eff=	34	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	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	######	30	34	2.26	0.25	0.02	0.18		-1E-02	0.00	0.00		0.06	2.64	3.05	2.6	4.0	-5.9
0.002	**0.01**	**1.51**	**-0.2**	**0.00**	#####	######	**30**	**34**	**2.26**	**0.25**	**0.02**	**0.18**	**0**	**-0.01**	**0.00**	**0.00**	**0.21**	**0.08**	**2.9**	**3.3**	**2.9**	**3.8**	**-6.1**
0.012	0.04	1.54	-1.3	0.00	#####	######	30	34	2.27	0.25	0.02	0.18	0	-0.07	0.00	0.00	0.21	0.08	2.9	3.3	2.9	3.7	-6.1
0.022	0.08	1.58	-2.3	0.00	#####	######	31	34	2.31	0.25	0.02	0.18	0	-0.13	0.00	0.00	0.20	0.08	3.0	3.4	2.9	3.7	-6.2
0.031	0.11	1.61	-3.4	0.00	91,555	######	31	34	2.37	0.25	0.02	0.18	0	-0.19	0.01	0.00	0.20	0.09	3.1	3.5	3.0	3.6	-6.2
0.041	0.15	1.65	-4.5	0.00	69,778	######	31	35	2.45	0.25	0.02	0.18	0	-0.25	0.01	0.01	0.20	0.09	3.2	3.6	3.1	3.5	-6.2
0.051	**0.18**	**1.68**	**-5.5**	**0.00**	**56,369**	**86,275**	**32**	**35**	**2.56**	**0.25**	**0.02**	**0.18**	**0**	**-0.31**	**0.02**	**0.01**	**0.20**	**0.10**	**3.4**	**3.8**	**3.2**	**3.3**	**-6.3**
0.061	0.22	1.72	-6.6	0.00	47,284	72,368	33	36	2.69	0.25	0.02	0.18	0	-0.37	0.03	0.02	0.19	0.10	3.5	4.0	3.3	3.1	-6.3
0.071	0.26	1.76	-7.7	0.00	40,720	62,323	33	37	2.84	0.25	0.02	0.18	0	-0.43	0.04	0.04	0.19	0.12	3.8	4.2	3.5	2.9	-6.4
0.08	0.29	1.79	-8.7	0.00	35,757	54,726	34	37	3.01	0.25	0.02	0.18	0	-0.49	0.05	0.06	0.20	0.13	4.0	4.4	3.7	2.7	-6.4
0.09	0.33	1.83	-9.8	0.00	31,872	48,780	35	38	3.21	0.25	0.02	0.18	0	-0.55	0.06	0.09	0.20	0.16	4.3	4.7	4.0	2.4	-6.5
0.10	**0.36**	**1.86**	**-10.8**	**0.00**	**28,748**	**44,000**	**36**	**39**	**3.43**	**0.25**	**0.02**	**0.18**	**0**	**-0.61**	**0.07**	**0.14**	**0.21**	**0.19**	**4.6**	**5.1**	**4.3**	**2.0**	**-6.6**

- Reach allowed by ~3.6 dB vertical eye closure is 100 m OM4

- Link models for 16ps rise/fall time

25.8 Gb/s no FEC (power budget limit)

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)	**16**	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)	24	ps	*Target*	Target reach	**0.100**	km	*Fiber*	at	850	nm	NomSens OMA	**-7.61**	dBm	Margin	0.13	dB at	
Base Rate=	**25781**	MBd	RIN(OMA)	**-130**	dB/Hz	*and*	L_start=	**0.002**	km		C_att=	1.00		*Receive*	Refl Rx	**-12**	dB	*Answer!*		0.1 km
Transmitter			RIN at MinER	-138.0	dB/Hz	*graph*	L_inc=	**0.01**	km		Attenuation=	3.62	dB/km		Rec_BW=	**#####**	MHz	st Rx BW	**18750**	MHz
Wavelength Uc	**840**	nm	RIN_Coef=	**0.70**			Power Budget P=	5.61	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)	16.0	ps	Test Source ER=		
Tx pwr OMA=	**-2.00**	dBm	DCD_DJ=	**2.3273**	ps TP3		Pwr.Bud.-Conn.Loss	4.11	dB		Disp. So=	**0.103**	ps/nm^2*km		TP4 Eye	8	ps	*Test Tx*	**6.5**	dB
Min. Ext Ratio=	3.65	dB	Effect. DJ=	0.06	(UI) ex DCD		C1=	**480**	ns.MHz		Disp. D1=	#####	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	**0.025**	fraction of 1/2 eye			
Ext. ratio penalty	4.01	dBo	Tx eye height	58.4%			Effective Rate	27427	MBd		(not in use)	**10**						V.E.C.P.	2.16	dBo
Tx mask X1=	**0.3**	UI	Refl Tx	**-12**	dB		Tb_eff=	36	ps		BWm=	**4400**	MHz*km		P_BLW(no ISI)	0.07	dB			Stressed
X2=	**0.4**	UI	ModalNoisePen	**0.3**	dB		Effective Rec Eye	0.21	UI		Eff. BWm=	#####	MHz*km		P_BLW	0.07	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	######	24	29	1.06	0.23	0.02	0.17		-1E-02	0.00	0.00		0.09	1.47	1.85	1.5	2.6	-4.0
0.002	**0.01**	**1.51**	**-0.2**	**0.00**	**#####**	**######**	**24**	**29**	**1.06**	**0.23**	**0.02**	**0.17**	**0**	**-0.01**	**0.00**	**0.00**	**0.40**	**0.16**	**1.9**	**2.3**	**1.9**	**2.2**	**-4.4**
0.012	0.04	1.54	-1.3	0.00	#####	######	24	29	1.07	0.23	0.02	0.17	0	-0.07	0.00	0.00	0.40	0.16	2.0	2.4	2.0	2.1	-4.5
0.022	0.08	1.58	-2.3	0.00	#####	######	25	29	1.10	0.23	0.02	0.17	0	-0.12	0.00	0.00	0.40	0.16	2.1	2.4	2.0	2.1	-4.5
0.031	0.11	1.61	-3.4	0.00	91,555	######	25	30	1.15	0.24	0.02	0.17	0	-0.18	0.01	0.00	0.39	0.16	2.1	2.5	2.0	2.0	-4.5
0.041	0.15	1.65	-4.5	0.00	69,778	######	26	30	1.21	0.24	0.02	0.17	0	-0.23	0.01	0.01	0.39	0.17	2.3	2.6	2.1	1.9	-4.6
0.051	**0.18**	**1.68**	**-5.5**	**0.00**	**56,369**	**86,275**	**26**	**31**	**1.30**	**0.24**	**0.02**	**0.17**	**0**	**-0.29**	**0.02**	**0.03**	**0.38**	**0.19**	**2.4**	**2.8**	**2.2**	**1.7**	**-4.6**
0.061	0.22	1.72	-6.6	0.00	47,284	72,368	27	31	1.40	0.24	0.02	0.17	0	-0.34	0.02	0.06	0.38	0.21	2.6	3.0	2.4	1.5	-4.7
0.071	0.26	1.76	-7.7	0.00	40,720	62,323	28	32	1.52	0.24	0.02	0.17	0	-0.40	0.03	0.10	0.37	0.25	2.8	3.2	2.6	1.3	-4.8
0.08	0.29	1.79	-8.7	0.00	35,757	54,726	29	33	1.66	0.24	0.02	0.17	0	-0.45	0.04	0.17	0.38	0.31	3.1	3.5	2.8	1.0	-4.9
0.09	0.33	1.83	-9.8	0.00	31,872	48,780	30	34	1.83	0.24	0.02	0.17	0	-0.51	0.05	0.26	0.38	0.39	3.5	3.9	3.2	0.6	-5.1
0.10	**0.36**	**1.86**	**-10.8**	**0.00**	**28,748**	**44,000**	**31**	**35**	**2.01**	**0.25**	**0.02**	**0.18**	**0**	**-0.56**	**0.06**	**0.38**	**0.39**	**0.51**	**4.0**	**4.4**	**3.6**	**0.1**	**-5.3**

- Reach allowed by power budget is 100 m OM4
  - ~2.2 dB vertical eye closure penalty

25.8 Gb/s ‘high latency’ FEC (power budget limit)

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)	**16**	ps	Case: 850nm serial	**newMMF**		Attenuation=	**3.5**	dB/km	Model/format rev	3.1.16a		of	31-Oct-01	
Q=	**4.04**		Ts(10-90)	24	ps	*Target* Target reach	**0.170**	km	*Fiber* at	850	nm	NomSens OMA	**-10.02**	dBm	Margin	0.34	dB at
Base Rate=	**25781**	MBd	RIN(OMA)	**-130**	dB/Hz	*and* L_start=	**0.002**	km	C_att=	1.00		*Receive* Refl Rx	**-12**	dB	*Answer!*	0.17 km	
Transmitter			RIN at MinER	-138.0	dB/Hz	*graph* L_inc=	**0.017**	km	Attenuation=	3.62	dB/km	Rec_BW=	**#####**	MHz	st Rx BW	**18750**	MHz
Wavelength Uc	**840**	nm	RIN_Coef=	**0.70**		Power Budget P=	8.02	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)	16.0	ps	Test Source ER=		
Tx pwr OMA=	**-2.00**	dBm	DCD_DJ=	**2.3273**	ps TP3	Pwr.Bud.-Conn.Loss	6.524	dB	Disp. So=	**0.103**	ps/nm^2*km	TP4 Eye	8	ps	*Test Tx*	**6.5**	dB
Min. Ext Ratio=	3.65	dB	Effect. DJ=	0.06	(UI) ex DCD	C1=	**480**	ns.MHz	Disp. D1=	######	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	**0.025**	fraction	of 1/2 eye		
Ext. ratio penalty	4.01	dBo	Tx eye height	58.4%		Effective Rate	27427	MBd	(not in use)	**10**					V.E.C.P.	4.04	dBo
Tx mask X1=	**0.3**	UI	Refl Tx	**-12**	dB	Tb_eff=	36	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	######	24	29	1.06	0.23	0.02	0.17		-1E-02	0.00	0.00		0.03	1.41	1.79	1.4	5.1	-4.2
0.002	**0.01**	**1.51**	**-0.2**	**0.00**	**#####**	**######**	**24**	**29**	**1.06**	**0.23**	**0.02**	**0.17**	**0**	**-0.01**	**0.00**	**0.00**	**0.12**	**0.04**	**1.5**	**1.9**	**1.5**	**5.0**	**-4.3**
0.019	0.07	1.57	-2.0	0.00	#####	######	25	29	1.09	0.23	0.02	0.17	0	-0.11	0.00	0.00	0.12	0.04	1.6	2.0	1.6	4.9	-4.4
0.036	0.13	1.63	-3.9	0.00	80,754	######	25	30	1.17	0.24	0.02	0.17	0	-0.20	0.01	0.00	0.12	0.04	1.8	2.2	1.7	4.7	-4.4
0.052	0.19	1.69	-5.7	0.00	54,863	83,969	26	31	1.31	0.24	0.02	0.17	0	-0.29	0.02	0.01	0.12	0.05	2.0	2.4	1.8	4.5	-4.5
0.069	0.25	1.75	-7.5	0.00	41,544	63,584	28	32	1.50	0.24	0.02	0.17	0	-0.39	0.03	0.03	0.12	0.06	2.3	2.7	2.0	4.2	-4.6
0.086	**0.31**	**1.81**	**-9.3**	**0.00**	**33,428**	**51,163**	**30**	**34**	**1.75**	**0.24**	**0.02**	**0.17**	**0**	**-0.48**	**0.04**	**0.07**	**0.12**	**0.08**	**2.6**	**3.0**	**2.3**	**3.9**	**-4.7**
0.103	0.37	1.87	-11.1	0.00	27,965	42,802	32	36	2.06	0.25	0.02	0.18	0	-0.58	0.06	0.13	0.12	0.10	3.1	3.5	2.7	3.4	-4.8
0.12	0.43	1.93	-13.0	0.01	24,037	36,789	34	38	2.42	0.25	0.02	0.18	0	-0.67	0.08	0.22	0.13	0.15	3.7	4.1	3.2	2.8	-5.0
0.136	0.49	1.99	-14.8	0.01	21,077	32,258	36	40	2.85	0.25	0.02	0.18	0	-0.76	0.09	0.34	0.15	0.22	4.4	4.8	3.9	2.2	-5.2
0.153	0.55	2.05	-16.6	0.01	18,765	28,721	39	42	3.33	0.25	0.02	0.18	0	-0.86	0.11	0.48	0.17	0.33	5.2	5.6	4.6	1.3	-5.5
0.17	**0.62**	**2.12**	**-18.4**	**0.01**	**16,911**	**25,882**	**42**	**45**	**3.88**	**0.26**	**0.02**	**0.19**	**0**	**-0.95**	**0.13**	**0.66**	**0.20**	**0.50**	**6.2**	**6.6**	**5.6**	**0.3**	**-5.9**

- Reach allowed by power budget is 170 m OM4
  - ~4.0 dB VECP (too high)

25.8 Gb/s ‘high latency’ FEC (ISI limit)

Spreadsheet by Del Hanson, David Cunningham, Piers Dawe, David Dolfi Agilent Technologies														Rev. 3.2/3								10GEPBud3_1_16a.xls		of 17-Oct-01		
Basics Input= **Bold**				Ts(20-80) **16** ps			Case: 850nm serial **newMMF**							Attenuation= **3.5** dB/km								Model/format rev 3.1.16a		of 31-Oct-01		
Q= **4.04**				Ts(10-90) 24 ps			*Target* Target reach **0.155** km							*Fiber* at 850 nm								NomSens OMA **-10.02** dBm		Margin 1.24 dB at		
Base Rate= **25781** MBd				RIN(OMA) **-130** dB/Hz			*and* L_start= **0.002** km							C_att= 1.00								*Receive* Refl Rx **-12** dB		*Answer!* 0.155 km		
Transmitter				RIN at MinER -138.0 dB/Hz			*graph* L_inc= **0.015** km							Attenuation= 3.62 dB/km								Rec_BW= ##### MHz		st Rx BW **18750** MHz		
Wavelength Uc **840** nm				RIN_Coef= **0.70**			Power Budget P= 8.02 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) 16.0 ps		Test Source ER=		
Tx pwr OMA= **-2.00** dBm				DCD_DJ= **2.3273** ps TP3			Pwr.Bud.-Conn.Loss 6.524 dB							Disp. So= **0.103** ps/nm^2*km								TP4 Eye 8 ps		*Test Tx* **6.5** dB		
Min. Ext Ratio= 3.65 dB				Effect. DJ= 0.06 (UI) ex DCD			C1= **480** ns.MHz							Disp. D1= ##### 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 **0.025** fraction of 1/2 eye				
Ext. ratio penalty 4.01 dBo				Tx eye height 58.4%			Effective Rate 27427 MBd							(not in use) **10**										V.E.C.P. 3.54 dBo		
Tx mask X1= **0.3** UI				Refl Tx **-12** dB			Tb_eff= 36 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
				Tx mask top 0.2 UI					Pisi	P Eye	P_DJ	P_DJ		Preflection						Pcross	Ptotal	<Ptotal	LP Pen		OMA
L	Patt	Ch IL	D1.L	D2.L	BWcd	effBWm	Te	Tc	central	corners	central	corners		central	Beta	SDmpn	Pmpn	Prin		central	central	corners	central	Margin	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	######	24	29	1.06	0.23	0.02	0.17			-1E-02	0.00	0.00			0.03	1.41	1.79	1.4	5.1	-5.1
0.002	**0.01**	**1.51**	**-0.2**	**0.00**	#####	######	**24**	**29**	**1.06**	**0.23**	**0.02**	**0.17**		**0**	**-0.01**	**0.00**	**0.00**	**0.12**		**0.04**	**1.5**	**1.9**	**1.5**	**5.0**	**-5.2**
0.017	0.06	1.56	-1.9	0.00	#####	######	25	29	1.08	0.23	0.02	0.17		0	-0.10	0.00	0.00	0.12		0.04	1.6	2.0	1.6	4.9	-5.2
0.033	0.12	1.62	-3.5	0.00	88,185	######	25	30	1.15	0.24	0.02	0.17		0	-0.18	0.01	0.00	0.12		0.04	1.8	2.1	1.6	4.8	-5.3
0.048	0.17	1.67	-5.2	0.00	60,018	91,858	26	31	1.27	0.24	0.02	0.17		0	-0.27	0.01	0.01	0.12		0.05	1.9	2.3	1.8	4.6	-5.4
0.063	0.23	1.73	-6.9	0.00	45,488	69,620	27	32	1.43	0.24	0.02	0.17		0	-0.35	0.02	0.02	0.12		0.05	2.2	2.6	1.9	4.4	-5.4
0.079	**0.28**	**1.78**	**-8.5**	**0.00**	**36,622**	**56,051**	**29**	**33**	**1.64**	**0.24**	**0.02**	**0.17**		**0**	**-0.44**	**0.04**	**0.05**	**0.12**		**0.07**	**2.5**	**2.9**	**2.2**	**4.0**	**-5.5**
0.094	0.34	1.84	-10.2	0.00	30,649	46,908	31	35	1.89	0.24	0.02	0.17		0	-0.53	0.05	0.09	0.12		0.09	2.9	3.2	2.5	3.7	-5.6
0.109	0.40	1.90	-11.8	0.00	26,351	40,330	33	36	2.19	0.25	0.02	0.18		0	-0.61	0.07	0.16	0.13		0.12	3.3	3.7	2.9	3.2	-5.8
0.124	0.45	1.95	-13.5	0.01	23,110	35,370	35	38	2.54	0.25	0.02	0.18		0	-0.70	0.08	0.25	0.13		0.17	3.9	4.3	3.4	2.7	-6.0
0.14	0.51	2.01	-15.1	0.01	20,579	31,496	37	40	2.94	0.25	0.02	0.18		0	-0.78	0.10	0.36	0.15		0.24	4.5	4.9	4.0	2.0	-6.2
0.155	**0.56**	**2.06**	**-16.8**	**0.01**	**18,547**	**28,387**	**39**	**42**	**3.39**	**0.25**	**0.02**	**0.18**		**0**	**-0.87**	**0.11**	**0.50**	**0.17**		**0.34**	**5.3**	**5.7**	**4.7**	**1.2**	**-6.4**

- Reach allowed by 3.6 dB vertical eye closure is 155 m OM4

25.8 Gb/s ‘high latency’ FEC (ISI limit)

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)	**16**	ps	Case: 850nm serial		**newMMF**			Attenuation=	**3.5**	dB/km			Model/format rev	3.1.16a	of	31-Oct-01							
	Q=	**4.04**			Ts(10-90)	24	ps	*Target* Target reach		**0.135**	km		*Fiber* at	850	nm		NomSens OMA		**-10.02**	dBm		Margin	2.22	dB at				
	Base Rate=	**25781**	MBd		RIN(OMA)	**-130**	dB/Hz	*and* L_start=		**0.002**	km		C_att=	1.00			*Receive* Refl Rx		**-12**	dB		*Answer!*	0.135	km				
Transmitter					RIN at MinER	-138.0	dB/Hz	*graph* L_inc=		**0.013**	km		Attenuation=	3.62	dB/km		Rec_BW=		**#####**	MHz		st Rx BW	**18750**	MHz				
Wavelength Uc		**840**	nm		RIN_Coef=	**0.70**		Power Budget P=		8.02	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)		16.0	ps		Test Source ER=						
Tx pwr OMA=		**-2.00**	dBm		DCD_DJ=	**2.3273**	ps TP3	Pwr.Bud.-Conn.Loss		6.524	dB		Disp. So=	**0.103**	ps/nm^2*km		TP4 Eye		8	ps		*Test Tx*	**6.5**	dB				
Min. Ext Ratio=		3.65	dB		Effect. DJ=	0.06	(UI) ex DCD	C1=		**480**	ns.MHz		Disp. D1=	#####	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		**0.025**	fraction		of 1/2 eye						
Ext. ratio penalty		4.01	dBo		Tx eye height	58.4%		Effective Rate		27427	MBd		(not in use)	**10**								V.E.C.P.	2.97	dBo			
Tx mask X1=		**0.3**	UI		Refl Tx	**-12**	dB	Tb_eff=		36	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																				OMA	
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	######	24	29	1.06	0.23	0.02	0.17		-1E-02	0.00	0.00		0.03	1.41	1.79	1.4	5.1	-6.0					
0.002	**0.01**	**1.51**	**-0.2**	**0.00**	**#####**	**######**	**24**	**29**	**1.06**	**0.23**	**0.02**	**0.17**	**0**	**-0.01**	**0.00**	**0.00**	**0.12**	**0.04**	**1.5**	**1.9**	**1.5**	**5.0**	**-6.2**					
0.015	0.06	1.56	-1.7	0.00	#####	######	24	29	1.08	0.23	0.02	0.17	0	-0.09	0.00	0.00	0.12	0.04	1.6	2.0	1.6	4.9	-6.2					
0.029	0.10	1.60	-3.1	0.00	#####	######	25	30	1.13	0.24	0.02	0.17	0	-0.16	0.01	0.00	0.12	0.04	1.7	2.1	1.6	4.8	-6.3					
0.042	0.15	1.65	-4.5	0.00	68,612	######	26	30	1.22	0.24	0.02	0.17	0	-0.23	0.01	0.00	0.12	0.04	1.9	2.2	1.7	4.7	-6.3					
0.055	0.20	1.70	-6.0	0.00	52,080	79,710	27	31	1.34	0.24	0.02	0.17	0	-0.31	0.02	0.01	0.12	0.05	2.0	2.4	1.8	4.5	-6.4					
0.069	**0.25**	**1.75**	**-7.4**	**0.00**	**41,968**	**64,234**	**28**	**32**	**1.50**	**0.24**	**0.02**	**0.17**	**0**	**-0.38**	**0.03**	**0.03**	**0.12**	**0.06**	**2.3**	**2.7**	**2.0**	**4.3**	**-6.4**					
0.082	0.30	1.80	-8.9	0.00	35,145	53,790	29	33	1.69	0.24	0.02	0.17	0	-0.46	0.04	0.06	0.12	0.07	2.5	2.9	2.3	4.0	-6.5					
0.095	0.34	1.84	-10.3	0.00	30,230	46,267	31	35	1.91	0.25	0.02	0.18	0	-0.53	0.05	0.10	0.12	0.09	2.9	3.3	2.5	3.6	-6.6					
0.108	0.39	1.89	-11.8	0.00	26,521	40,590	33	36	2.18	0.25	0.02	0.18	0	-0.61	0.07	0.16	0.12	0.12	3.3	3.7	2.9	3.2	-6.8					
0.122	0.44	1.94	-13.2	0.01	23,622	36,154	34	38	2.47	0.25	0.02	0.18	0	-0.68	0.08	0.23	0.13	0.16	3.8	4.2	3.3	2.8	-6.9					
0.135	**0.49**	**1.99**	**-14.6**	**0.01**	**21,295**	**32,593**	**36**	**40**	**2.81**	**0.25**	**0.02**	**0.18**	**0**	**-0.76**	**0.09**	**0.33**	**0.14**	**0.21**	**4.3**	**4.7**	**3.8**	**2.2**	**-7.1**					

- Reach allowed by 3.0 dB vertical eye closure is 135 m OM4

28 Gb/s ‘low latency’ FEC (power budget limit)

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 | Model/format rev 3.1.16a | of 31-Oct-01

Basics	Input=	**Bold**		Ts(20-80)	**16**	ps	Case: 850nm serial	**newMMF**	Attenuation=	**3.5**	dB/km	NomSens OMA	**-10.18**	dBm	Margin	0.16	dB at	
	Q=	**3.74**		Ts(10-90)	24	ps	*Target* Target reach	**0.160**	km	*Fiber* at	850	nm	*Receive* Refl Rx	**-12**	dB	*Answer!*		0.16 km	
Base Rate=	**28050**	MBd		RIN(OMA)	**-130**	dB/Hz	*and* L_start=	**0.002**	km	C_att=	1.00		Rec_BW=	#####	MHz	st Rx BW	**20400**	MHz	
Transmitter				RIN at MinER	-138.0	dB/Hz	*graph* L_inc=	**0.016**	km	Attenuation=	3.62	dB/km	c_rx	**329**	ns.MHz				
Wavelength Uc	**840**	nm		RIN_Coef=	**0.70**		Power Budget P=	8.18	dB	at	840	nm				Test Source ER=			
Uw (see notes)	**0.60**	nm		Det.Jitter	**4.3**	ps inc. DCD	Connections C	**1.5**	dB	Disp. min. Uo=	**1316**	nm	T_rx(10-90)	14.7	ps	*Test Tx*	**6.5**	dB	
Tx pwr OMA=	**-2.00**	dBm		DCD_DJ=	**2.139**	ps TP3	Pwr.Bud.-Conn.Loss	6.676	dB	Disp. So=	**0.103**	ps/nm^2*km	TP4 Eye	7	ps	TestERpe	1.98	dBo	
Min. Ext Ratio=	3.65	dB		Effect. DJ=	0.06	(UI) ex DCD	C1=	**480**	ns.MHz	Disp. D1=	#####	ps/(nm.km)	Opening		(=Tx ey	V.E.C.P.	4.47	dBo	
Worst"ave.TxPwr	**-1.0**	dBm		MPN k(OMA)	**0.3**		Reflection Noise factor	**0**	no units				RMS Baseline wander SD	**0.025**	fraction of 1/2 eye			Stressed	
Ext. ratio penalty	4.01	dBo		Tx eye height	53.9%		Effective Rate	29840	MBd	(not in use)	**10**							Rx sens	
Tx mask X1=	**0.3**	UI		Refl Tx	**-12**	dB	Tb_eff=	34	ps	BWm=	**4400**	MHz*km	P_BLW(no ISI)	0.02	dB				
X2=	**0.4**	UI		ModalNoisePen	**0.3**	dB	Effective Rec Eye	0.21	UI	Eff. BWm=	#####	MHz*km	P_BLW	0.02	dB				
Y1=	**0.25**			Tx mask top	0.2	UI													

L	Patt	Ch IL	D1.L	D2.L	BWcd	effBWm	Te	Tc	Pisi	P Eye	P_DJ	P_DJ	Preflection					Pcross	Ptotal	<Ptotal	LP Pen		OMA
									central	corners	central	corners	central	Beta	SDmpn	Pmpn	Prin	central	central	corners	central	Margin	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	######	24	28	1.31	0.24	0.02	0.17		-1E-02	0.00	0.00		0.03	1.67	2.05	1.7	5.0	-4.0
0.002	**0.01**	**1.51**	**-0.2**	**0.00**	#####	######	**24**	**28**	**1.31**	**0.24**	**0.02**	**0.17**	**0**	**-0.01**	**0.00**	**0.00**	**0.13**	**0.04**	**1.8**	**2.2**	**1.8**	**4.9**	**-4.1**
0.018	0.06	1.56	-1.9	0.00	#####	######	25	29	1.34	0.24	0.02	0.17	0	-0.11	0.00	0.00	0.13	0.04	1.9	2.3	1.8	4.8	-4.2
0.034	0.12	1.62	-3.6	0.00	85,561	######	25	29	1.44	0.24	0.02	0.17	0	-0.20	0.01	0.00	0.13	0.05	2.1	2.4	1.9	4.6	-4.2
0.049	0.18	1.68	-5.4	0.00	58,195	89,069	26	30	1.58	0.24	0.02	0.17	0	-0.30	0.02	0.01	0.12	0.05	2.3	2.7	2.1	4.4	-4.3
0.065	0.24	1.74	-7.1	0.00	44,093	67,485	28	31	1.79	0.24	0.02	0.17	0	-0.40	0.03	0.03	0.12	0.06	2.6	3.0	2.3	4.1	-4.4
0.081	**0.29**	**1.79**	**-8.8**	**0.00**	**35,492**	**54,321**	**29**	**33**	**2.05**	**0.25**	**0.02**	**0.18**	**0**	**-0.49**	**0.05**	**0.06**	**0.12**	**0.08**	**2.9**	**3.3**	**2.6**	**3.7**	**-4.5**
0.097	0.35	1.85	-10.5	0.00	29,699	45,455	31	34	2.38	0.25	0.02	0.18	0	-0.59	0.06	0.12	0.13	0.11	3.4	3.8	3.1	3.3	-4.6
0.113	0.41	1.91	-12.2	0.00	25,531	39,076	33	36	2.76	0.25	0.02	0.18	0	-0.69	0.08	0.20	0.14	0.15	4.0	4.4	3.6	2.7	-4.8
0.128	0.47	1.97	-13.9	0.01	22,390	34,268	35	38	3.21	0.25	0.02	0.18	0	-0.78	0.10	0.31	0.16	0.22	4.7	5.1	4.2	2.0	-5.0
0.144	0.52	2.02	-15.6	0.01	19,936	30,513	38	40	3.72	0.26	0.02	0.18	0	-0.88	0.11	0.44	0.18	0.32	5.5	5.9	5.0	1.2	-5.3
0.16	**0.58**	**2.08**	**-17.3**	**0.01**	**17,968**	**27,500**	**40**	**43**	**4.31**	**0.27**	**0.02**	**0.19**	**0**	**-0.98**	**0.13**	**0.59**	**0.22**	**0.50**	**6.5**	**7.0**	**5.9**	**0.2**	**-5.6**

- Reach allowed by power budget is 160 m OM4
  - ~4.5dB VECP (too high)

28 Gb/s ‘low latency’ FEC (ISI limit)

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) 16 ps	Case: 850nm serial **newMMF**	Attenuation= 3.5 dB/km	Model/format rev 3.1.16a	of 31-Oct-01
Q= 3.74	Ts(10-90) 24 ps	*Target* Target reach 0.135 km	*Fiber* at 850 nm	NomSens OMA -10.18 dBm	Margin 1.67 dB at
Base Rate= 28050 MBd	RIN(OMA) -130 dB/Hz	*and* L_start= 0.002 km	C_att= 1.00	*Receive* Refl Rx -12 dB	*Answer!* 0.135 km
Transmitter	RIN at MinER -138.0 dB/Hz	*graph* L_inc= 0.013 km	Attenuation= 3.62 dB/km	Rec_BW= ##### MHz	st Rx BW 20400 MHz
Wavelength Uc 840 nm	RIN_Coef= 0.70	Power Budget P= 8.18 dB	at 840 nm	c_rx 329 ns.MHz	
Uw (see notes) 0.60 nm	Det.Jitter 4.3 ps inc. DCD	Connections C 1.5 dB	Disp. min. Uo= 1316 nm	T_rx(10-90) 14.7 ps	Test Source ER=
Tx pwr OMA= -2.00 dBm	DCD_DJ= 2.139 ps TP3	Pwr.Bud.-Conn.Loss 6.676 dB	Disp. So= 0.103 ps/nm^2*km	TP4 Eye 7 ps	*Test Tx* 6.5 dB
Min. Ext Ratio= 3.65 dB	Effect. DJ= 0.06 (UI) ex DCD	C1= 480 ns.MHz	Disp. D1= ##### 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 0.025 fraction	of 1/2 eye
Ext. ratio penalty 4.01 dBo	Tx eye height 53.9%	Effective Rate 29840 MBd	(not in use) 10		V.E.C.P. 3.57 dBo
Tx mask X1= 0.3 UI	Refl Tx -12 dB	Tb_eff= 34 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	######	24	28	1.31	0.24	0.02	0.17		-1E-02	0.00	0.00		0.03	1.67	2.05	1.7	5.0	-5.5
0.002	**0.01**	**1.51**	**-0.2**	**0.00**	**#####**	**######**	**24**	**28**	**1.31**	**0.24**	**0.02**	**0.17**	**0**	**-0.01**	**0.00**	**0.00**	**0.13**	**0.04**	**1.8**	**2.2**	**1.8**	**4.9**	**-5.6**
0.015	0.06	1.56	-1.7	0.00	#####	######	24	29	1.33	0.24	0.02	0.17	0	-0.09	0.00	0.00	0.13	0.04	1.9	2.3	1.8	4.8	-5.7
0.029	0.10	1.60	-3.1	0.00	#####	######	25	29	1.40	0.24	0.02	0.17	0	-0.17	0.01	0.00	0.13	0.05	2.0	2.4	1.9	4.7	-5.7
0.042	0.15	1.65	-4.5	0.00	68,612	######	26	30	1.51	0.24	0.02	0.17	0	-0.26	0.01	0.01	0.12	0.05	2.2	2.6	2.0	4.5	-5.8
0.055	0.20	1.70	-6.0	0.00	52,080	79,710	27	30	1.65	0.24	0.02	0.17	0	-0.34	0.02	0.02	0.12	0.05	2.4	2.8	2.2	4.3	-5.8
0.069	**0.25**	**1.75**	**-7.4**	**0.00**	**41,968**	**64,234**	**28**	**31**	**1.84**	**0.24**	**0.02**	**0.17**	**0**	**-0.42**	**0.03**	**0.04**	**0.12**	**0.06**	**2.6**	**3.0**	**2.4**	**4.0**	**-5.9**
0.082	0.30	1.80	-8.9	0.00	35,145	53,790	29	33	2.07	0.25	0.02	0.18	0	-0.50	0.05	0.07	0.12	0.08	3.0	3.4	2.7	3.7	-6.0
0.095	0.34	1.84	-10.3	0.00	30,230	46,267	31	34	2.34	0.25	0.02	0.18	0	-0.58	0.06	0.11	0.13	0.10	3.4	3.8	3.0	3.3	-6.1
0.108	0.39	1.89	-11.8	0.00	26,521	40,590	33	36	2.65	0.25	0.02	0.18	0	-0.66	0.08	0.18	0.14	0.14	3.8	4.2	3.4	2.9	-6.2
0.122	0.44	1.94	-13.2	0.01	23,622	36,154	34	37	3.01	0.25	0.02	0.18	0	-0.74	0.09	0.26	0.15	0.19	4.4	4.8	3.9	2.3	-6.4
0.135	**0.49**	**1.99**	**-14.6**	**0.01**	**21,295**	**32,593**	**36**	**39**	**3.41**	**0.25**	**0.02**	**0.18**	**0**	**-0.82**	**0.10**	**0.36**	**0.17**	**0.26**	**5.0**	**5.4**	**4.5**	**1.7**	**-6.6**

- Reach allowed by 3.6 dB vertical eye closure is 135 m OM4