40GBASE-ER4 optical budget

Pete Anslow, Ciena

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Introduction

The Next Generation 40 Gb/s and 100 Gb/s Optical Ethernet Study Group has an adopted objective:

Define a 40 Gb/s PHY for operation over at least 40 km of SMF

Which is expected to be satisfied via the definition of 40GBASE-ER4.

This contribution analyses the expected loss of a 40 km link and uses that together with the information in the consensus presentation anderson_01_0512_optx to propose some of the values for the 40GBASE-ER4 power budget.

40 km Channel loss

The channel loss budget for 100GBASE-ER4 was generated using the information used to create Annex I of ITU-T G.695 at the worst wavelength of 1294.53 nm.

The values for minimum and maximum loss for G.652.A&B are roughly equivalent to the 10% and 90% probability values for installed links. See G.Sup39 Figure 10-8.

Assuming the wavelength plan adopted for 40GBASE-ER4 is the same as that for 40GBASE-LR4, the worst case wavelength is 1264.5 nm, for which the minimum and maximum loss figures from Annex I of G.695 are 0.406 and 0.473 dB/km respectively.

Taking 40*0.406 + 2 dB for connectors gives 18.2 dB. Increasing this value to 19 dB channel loss would be equivalent to a fibre loss coefficient of 0.425 dB/km which is equivalent to roughly 40% of links from G.Sup39 Figure 10-8.

Starting with the 18 dB loss for the 100GBASE-ER4 channel and adding the difference between the minimum loss coefficients for the two wavelengths gives 19.3 dB, so 19 dB seems a reasonable starting point.

Connector loss

The previous slide used the usual 2 dB for connector loss in the 40 km “Engineered link”.

However, it may be that some statistical analysis of single mode connector losses along the lines of that conducted for multimode fibre in IEEE 802.3ba king_01_0508 is warranted to see if 2 dB is an appropriate value to use when it is acknowledged that not all 40 km links will be within the “Engineered link” loss limit.

Since single mode connectors seem to be available with a mean loss of 0.2 dB and a standard deviation of 0.1 dB, it may be that a total link loss of less than 19 dB is reasonable, but this analysis has not been performed within this presentation.

30 km Channel loss

Using the maximum loss figure from Annex I of G.695 of 0.473 dB/km gives 30*0.473 + 2 dB = 16.2 dB

Round this up to 16.5 dB for the 30 km loss gives 2.5 dB additional insertion loss allowed.

Alternatively, 35*0.473 + 2 dB = 18.6 dB.

Rounding this to 18.5 dB with 0.5 dB additional insertion loss allowed is something that could be considered.

Channel loss difference

The highest loss wavelength (for G.652.A&B fibre) in the range used by 40GBASE-LR4 is 1264.5 nm at 0.473 dB/km.

The lowest loss wavelength (from the max. loss curve) is 1317.5 nm at 0.415 dB/km.

Over a distance of 40 km, this difference could cause a difference in loss of 2.34 dB, so the *Difference in receive power between any two lanes (OMA) (max)* in Table 87-8 should be 2.3 dB greater than the *Difference in launch power between any two lanes (OMA) (max)* in Table 87-7.

PMD

For 40 km, a link PMD coefficient of 0.5 ps/sqrt(km) (assuming S = 3.75 or 2.6 sec/year above the “Max”) gives 11.86 ps DGD_max.

For a PIN based receiver, slide 4 from P802.3ba anslow_01_0308 shows an expected penalty of 0.17 dB for 12 ps of DGD.

While the expected penalty for an APD based receiver is expected to be slightly higher than that for a PIN, this seems to be acceptably small.

Table 87-9 changes

Table 87–9–40GBASE–LR4 and 40GBASE–ER4 illustrative link power budgets

Parameter	**40GBASE-LR4**	**40GBASE-ER4**		**Proposal for 40GBASE-ER4**		**Unit**
Power budget (for max TDP)	9.3	(= B+C)		21.6		dB
Operating distance	10	(D)	40 [a]	30	40	km
Channel insertion loss [b]	6.7	(A)	(B)	16.5	19	dB
Maximum discrete reflectance	-26			–26*		dB
Allocation for penalties [c] (for max TDP)	2.6	(C)		2.6*		dB
Additional insertion loss allowed	0	(= B–A)	0	2.5	0	dB

[a] Links longer than (D) km are considered engineered links. Attenuation for such links needs to be less than the worst case for B1.1, B1.3, or B6_a single-mode cabled optical fiber.

[b] The channel insertion loss is calculated using the maximum distance specified in Table 87–6 and cabled optical fiber attenuation of 0.47 dB/km at 1264.5 nm plus an allocation for connection and splice loss given in 87.11.2.1.

[c] Link penalties are used for link budget calculations. They are not requirements and are not meant to be tested.

* Value taken from consensus presentation anderson_01_0512_optx.pdf

Table 87-7 changes

Table 87–7–40GBASE–LR4 and 40GBASE–ER4 transmit characteristics

Parameter	40GBASE-LR4	40GBASE-ER4	Proposal for 40GBASE-ER4	Unit
Signaling rate, each lane (range)	10.3125 ± 100 ppm			GBd
Lane wavelengths (range)	1264.5 to 1277.5 1284.5 to 1297.5 1304.5 to 1317.5 1324.5 to 1337.5			nm
Side-mode suppression ratio (SMSR), (min)	30		30*	dB
Total average launch power (max)	8.3	(=F+6)		dBm
Average launch power, each lane (max)	2.3	(F ≤ f(G,L))		dBm
Average launch power, each lane [a] (min)	–7	(=H–3)	–1.7 (=1.3–3)	dBm
Optical Modulation Amplitude (OMA), each lane (max)	3.5	(G)		dBm
Optical Modulation Amplitude (OMA), each lane (min) [b]	–4	(H=J–TDPmin)	1.3 (=0.5+0.8)	dBm
Difference in launch power between any two lanes (OMA) (max)	6.5	(I)		dB
Launch power in OMA minus TDP, each lane (min)	–4.8	(J)	0.5 (=19–18.5)	dBm
Transmitter and dispersion penalty (TDP), each lane (max)	2.6	(K)	2.6*	dB
Average launch power of OFF transmitter, each lane (max)	–30		–30*	dBm
Extinction ratio (min)	3.5	(L)		dB
$RIN_{20}OMA$ (max)	–128		–128*	dB/Hz
Optical return loss tolerance (max)	20		20*	dB
Transmitter reflectance [c] (max)	–12		–12*	dB
Transmitter eye mask definition {X1, X2, X3, Y1, Y2, Y3}	{0.25, 0.4, 0.45, 0.25, 0.28, 0.4}			

* Value taken from consensus presentation anderson_01_0512_optx.pdf

Table 87-7 footnotes

[a] Average launch power, each lane (min) is informative and not the principal indicator of signal strength. A transmitter with launch power below this value cannot be compliant; however, a value above this does not ensure compliance.

[b] Even if the TDP < 0.8dB, the OMA (min) must exceed this value.

[c] Transmitter reflectance is defined looking into the transmitter.

Table 87-8 changes

Table 87–7–40GBASE–LR4 and 40GBASE–ER4 receive characteristics

Parameter	**40GBASE-LR4**	**40GBASE-ER4**	**Proposal for 40GBASE-ER4**	**Unit**
Signaling rate, each lane (range)	10.3125 ± 100 ppm			GBd
Lane wavelengths (range)	1264.5 to 1277.5 1284.5 to 1297.5 1304.5 to 1317.5 1324.5 to 1337.5			nm
Damage threshold [a] (min)	3.3	(>F–N+1)	3.8*	dBm
Average receive power, each lane (max)	2.3	(=F–N)		dBm
Average receive power, each lane [b] (min)	–13.7	(=H–3–B)	–20.7 (=–1.7–19)	dBm
Receive power, each lane (OMA) (max)	3.5	(=G–N)		dBm
Difference in receive power between any two lanes (OMA) (max)	7.5	(=I+Δ)	Δ = 2.3	dB
Receiver reflectance (max)	–26		–26*	dB
Receiver sensitivity (OMA), each lane [c] (max)	–11.5	(=J–B)	–18.5*	dBm
Receiver 3 dB electrical upper cutoff frequency, each lane (max)	12.3		12.3*	GHz
Stressed receiver sensitivity (OMA), each lane [d] (max)	–9.6	(=J–B+M)	–16.3*	dBm
Conditions of stressed receiver sensitivity test:				
Vertical eye closure penalty, [e] each lane	1.9	(M)	2.2*	dB
Stressed eye J2 Jitter, [e] each lane	0.3		0.3*	UI
Stressed eye J9 Jitter, [e] each lane	0.47		0.47*	UI

* Value taken from consensus presentation anderson_01_0512_optx.pdf

Table 87-8 footnotes

[a] The receiver shall be able to tolerate, without damage, continuous exposure to an optical input signal having this average power level

[b] Average receive power, each lane (min) is informative and not the principal indicator of signal strength. A received power below this value cannot be compliant; however, a value above this does not ensure compliance.

[c] Receiver sensitivity (OMA), each lane (max) is informative.

[d] Measured with conformance test signal at TP3 (see 87.8.11) for BER = 10^{-12}.

[e] Vertical eye closure penalty, stressed eye J2 Jitter, and stressed eye J9 Jitter are test conditions for measuring stressed receiver sensitivity. They are not characteristics of the receiver.

Table 87-14 changes

Table 87–14–Fiber optic cabling (channel) characteristics ~~for 40GBASE–LR4~~

Parameter	**40GBASE-LR4**	**<u>40GBASE-ER4</u>**		**Proposal for 40GBASE-ER4**		**Unit**
Operating distance (max)	10	(=D)	<u>40</u>	30	40	km
Channel insertion loss [a, b] (max)	6.7	(=B)		19		dB
Channel insertion loss (min)	0	(N)				dB
Positive dispersion [b] (max)	33.5		<u>134</u>	100.5	134	ps/nm
Negative dispersion [b] (min)	–59.5		<u>–238</u>	-178.5	-238	ps/nm
DGD_max [c]	10			12		ps
Optical return loss (min)	21			21		dB

[a] These channel insertion loss values include cable, connectors, and splices.

[b] Over the wavelength range 1264.5 nm to 1337.5 nm.

[c] Differential Group Delay (DGD) is the time difference at reception between the fractions of a pulse that were transmitted in the two principal states of polarization of an optical signal. DGD_max is the maximum differential group delay that the system must tolerate.

Conclusion

Setting the *Maximum channel insertion loss* to 19 dB as proposed on slide 3 together with taking the consensus values from anderson_01_0512_optx goes a long way towards defining the power budget for 40GBASE-ER4.

Analysis of connector loss distributions may allow a *Maximum channel insertion loss* of less than 19 dB

The remaining parameters needing values are:

G = Optical Modulation Amplitude (OMA), each lane (max)

L = Extinction ratio (min)

I = Difference in launch power between any two lanes (OMA) (max)

N = Channel insertion loss (min)

Thanks!