EDC based 10GBASE-LRM link budget

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Statement of problem (the channel) 1/5

- This budget is for 220 m at 500 MHz.km rating
  - Assume 300 m of OM3 would be similar – for study by channel ad hoc
- All values to be kept under review as channel definition and link budgeting evolve
- Fiber attenuation
  - 1.5 dB/km at 1300 nm * 220 m, adjusted for 1270 nm
  - 0.35 dB A fair estimate as it's small anyway
    - Would be 0.45 dB for 300 m
- Loss from up to 4 connectors
  - 2 dB Pessimistic considering that a controlled launch should avoid the outside of the fiber core
- Total loss: 2.4 dB

Statement of problem (the channel) 2/5 Distortion

- Distortion
  - Difficult to define in a general way
    Cannot (yet) assume one specific shape such as Gaussian
  - Definition used here: distortion would cost 5 dBo (optical dB) sensitivity penalty with a perfect linear equaliser
    (e.g. feedforward equaliser with infinity of taps available)
  - Work of channel ad hoc will validate or revise this number. Maybe slightly pessimistic?
  - Real equalisers can perform better or worse than this definition of channel. For the worked example, 4 dB actual penalty is used.
- Also some distortion from transmitter
  - Some of which is equalised – included in above
  - Some is not: called “uncorrected distortion” here
  - Could constrain by “transmitter penalty” metric and/or eye mask
  - “For further study”:
    - Is the ratio of uncorrected to corrected distortion appropriate?
    - To what extent if any is it a spec item?

Statement of problem (the channel) 3/5 Distortion cont.

- Bandwidth of receiver
  - For further study, although not a spec item
- Speed of transmitter
  - For further study

Statement of problem (the channel) 4/5

- Modal noise penalty
  - 0.5 dB Value used by Gigabit Ethernet where exact value did not matter much. Pessimistic as controlled launch avoids outside of core
- Channel temporal variability
  - Not well understood
  - Some may be tracked by equaliser
  - Remainder addressed here within an “uncorrected ISI” term
- RIN
  - Keep balance between cost and error ratio
  - Keep RINxOMA < -128 dB/Hz like 10GBASE-L
  - “x” (back reflection criterion) probably easier than for SMF
    - Much of light reflected back towards transmitter will not couple into a laser with a single spatial mode
  - Allow 0.4 dB RIN penalty per tougher-than textbook equations in 10GE model with -128 dB/Hz and high (3.6 dB uncorrected) ISI
    - RIN in equalised link is not intuitive – subject to further investigation

Statement of problem (the channel) 5/5

- Mode partition noise
  - In some laser types the power fluctuates between modes of different wavelength (mode partitioning). This causes noise after chromatic dispersion
  - Dispersion at 1270 nm as bad as –9.9 ps/nm/km
  - -9.9 * 220m => -2.2 ps/nm
  - MPN penalty assumed 0 per standard equations – for FP, DFB or VCSEL laser.
- Reflection noise
  - Assumed negligible
    - With multimode fiber, hard to see that much light would be congruent and coherent with its echo, as so many paths through the fiber
    - And may be multi longitudinal mode laser (e.g. Fabry Perot)
- Uncorrected distortion (see earlier)
  - Allow 1 dB? A little more?
  - Contributions from transmitter and real (not infinite) equaliser

What's the budget?

- Budget (for 4 connectors and 220 m FDDI MMF)
- To achieve 10^-12 BER over implementer's rated life, temperature, and so on
  - Corrected distortion — 5 dB *
  - Uncorrected distortion (ISI) — 1 dB? A little more?
  - Loss — 2.4 dB
  - Modal noise — 0.5 dB
  - RIN — 0.4 dB
  - Consequent penalty † — 0.2 dB

  - Total — 9.5 dB
  - Is this the budget? (definition A)

* Everything in optical dB. Note that actual equaliser may have different penalty: 4 dB for example

† This term ("Pcross") allows for the way the effect of two penalties is more than their sum in dB. Argument for including it: it's true. Argument against: assumes "worst of everything" and that's too pessimistic: should allow for "diversity"

Definitions of budget

- Gigabit Ethernet definition
  - Transmitter minimum power – receiver sensitivity to clean signal
  - Includes all losses and impairments
- SONET definition
  - Transmitter minimum power – receiver sensitivity to worst Tx signal without channel's distortion
  - Includes channel's losses and impairments ("dispersion penalty" or "path penalty") but not transmitter's dynamic signal quality ("transmitter penalty")
- New? definition (A) used here
  - Includes all losses and impairments
  - Define a channel distortion penalty wrt perfect linear equaliser
  - But real equaliser can beat the perfect linear equaliser
  - So "budget A" as previous slide is sum of all impairments and any intended margin, NOT as Gigabit Ethernet
  - Alternative definition (B) as Gigabit Ethernet:
    Tx min power – Rx sensitivity to clean signal

Comparison with 10GBASE-L low TDP transmitter

Item	10GBASE-L low TDP	10GBASE-LRM
Corrected distortion	0	5 dB
(actual cost: for example		4 dB)
Uncorrected distortion	1*	1 dB? A little more?
Loss	6.2	2.4 dB
Modal noise	0	0.5 dB
RIN	0.1*	0.4 dB
Reflection noise	0.3*	
Consequent penalty	0.1	0.2 dB
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Total (method A)	7.7	9.5 dB
(Alternative definition (B)	7.7	8.5 dB)

Note higher dB budget than 10 km 10GBASE-L. This is OK.

*These items are contributors to TDP which is about 1.4 dB in this example. See 802.3ae 52.9.10 or 802.3ah clause 58 for detail of TDP

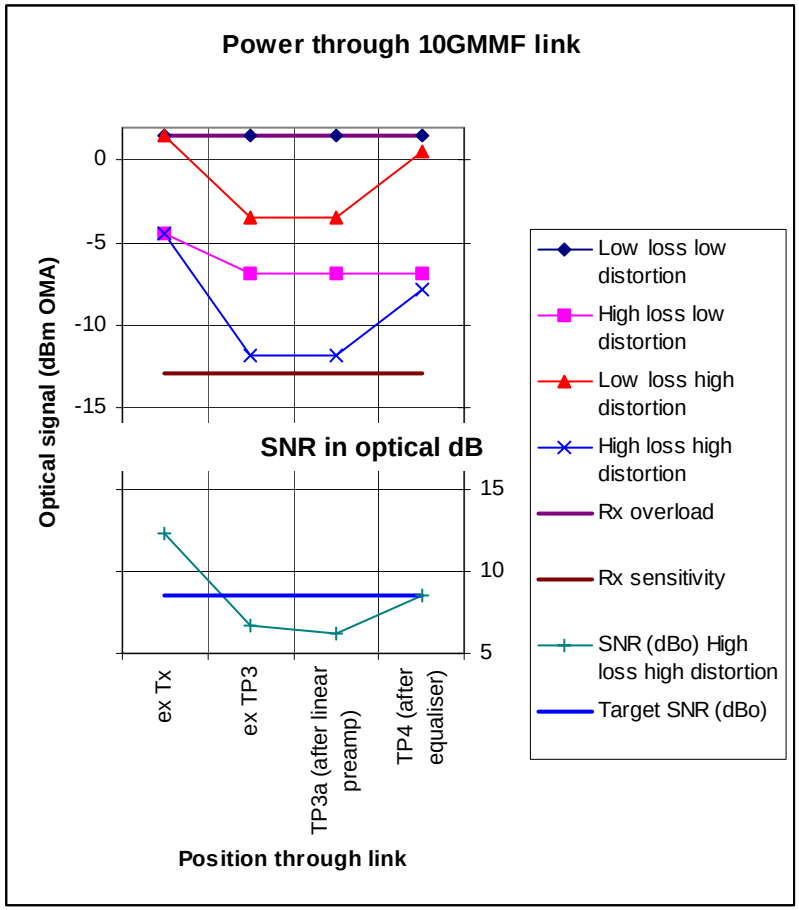
Economic viability is essential

- Avoid sand-bagging the budget
- Seek economies of scale by commonality with other fiber optic products
- Avoid exotic electro-optic technology
- Provide adequate transmitter power tolerance for high yield with reasonable test costs
- Avoid excessive dynamic range requirements on receiver
- Last two items lead us to an OMA oriented specification

Transmitter and receiver

- Transmitter should not cost more than 10GBASE-L
  - RIN spec no tighter
  - Use RINxOMA definition to allow flexibility in implementation
  - Transmit power in same range as 10GBASE-L
    - Opportunity for optimisation here
    - Use OMA definition to get most out of tolerances
  - Spectral limits much easier
    - Opportunity to use cheaper laser types – for study
    - Budget is agnostic to laser type
- Receiver should not cost more than 10GBASE-L
  - Can’t ask for much better sensitivity than 10GBASE-L’s –12.6 dB OMA
    - Note that receiver never sees a signal of this strength so it’s not a spec item – mentioned here to guide our understanding

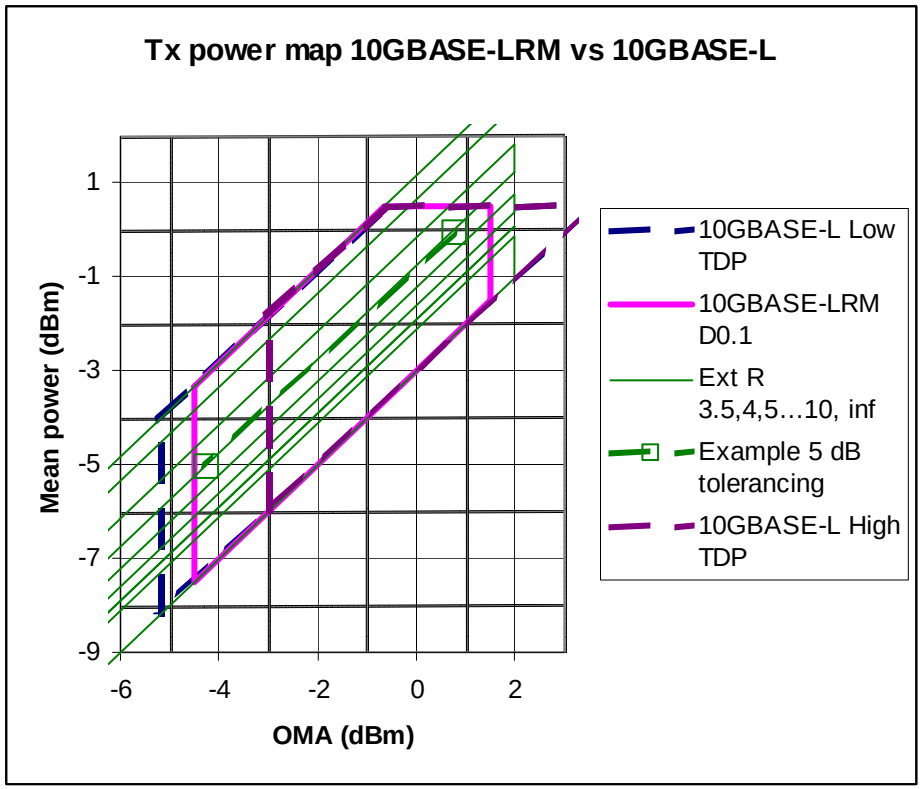
Power and SNR through link



Note the two distortion items may not be spec items, even together. Receiver to be specified by power and distortion of TP3 compliance test signal

Tx OMA max	+1.5 dBm
" OMA min	-4.5 dBm
" RINxOMA	-128 dB/Hz
Tx mean power max	+0.5 dBm
same as 10GBASE-L – see next slide	
Distortion (defined by noise enhancement for an ideal linear equaliser)	5 dBo
Distortion (defined by penalty for actual equaliser)	4 dBo
Uncorrected ISI	1 dBo
Rx overload	1.5 dBm
Indicative Rx sensitivity	-13 dBm OMA
Headline Rx dynamic range	14.5 dBo
Actual range of mean powers at TP3	10.4 dBo
"Budget"	9.5 or 8.5 dBo

Transmitter power map



- Dynamic range is important in equalised link
- OMA style spec minimises receiver dynamic range for given transmitter tolerance

Comparison with earlier proposals

	bhoja_2_0104	bottacchi0403	This proposal
Budget	9.4	9	9.5 or 8.5
Loss	2.3	3	2.4
Allowance for penalties	7.1	6	7.1 or 6.1
Tx min OMA		-4.2	-4.5
Sensitivity		-13.2	-13

Good agreement among proposals

Conclusion

- This budget is achievable and well constrained
  - Clear consensus on what's needed – good for schedule!
  - Few areas of uncertainty, each thought to be <1 dB
- Need to review:
  1. Relation of defined noise enhancement for an ideal linear equaliser, penalty for actual equaliser, residual ISI (if high probability) or patterning noise (if low enough probability), channel model, and other metrics of channel distortion
  2. Impact of transmitter and receiver speed with equalisation
  3. Effect of RIN
- Budget is feasible and cost effective