Cost Effective High Split Ratios for EPON

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The **Broadband** Company

Proposal for EPON

1. Define two EPON optical budgets:
   - 16 way split over 10km (current baseline)
   - 128 way split over 10km (proposed)
2. Define transmit power and sensitivity of two classes of OLTs (headend transceivers) that address these two budgets.
3. Include forward error correction in the specification, similar in performance to G.975, to reduce the burden on and the cost of the optics required to achieve the above goals.

NEXT SLIDES: JUSTIFICATION FOR PROPOSAL

Why consider high split ratios?

A 1:128 split? Are you crazy?

- A PON is by definition "power budget challenged" due to the splitter losses added to the fiber losses.
- However higher splitting ratios amplify the benefits of a PON such as:
  - Sharing the OLT optics and electronics costs.
  - Sharing feeder fiber costs and potential new install costs.
  - Efficient utilization of head end rack space, high density OLT.
  - Fiber management at headend is simpler.
  - Larger splits allow more flexibility.
  - Addresses MSO market as well as LEC market.

Disadvantages of High Split Ratios

- Reduced bandwidth per ONU.
- Increased optics cost either at OLT or ONU or both to achieve large optical power budgets.

Comparison to DOCSIS (Cable Modems)

- Why compare EPON requirements to DOCSIS?
  - DOCSIS is by far the largest deployed multipoint to point data delivery system for the access network, with millions of users. This is simply a reference point to a system with proven economics.
- A DOCSIS CMTS is the equivalent to a fiber OLT. The CMTS has a downstream bandwidth of typically 30 Mbps, and will be shared by 1,000 to 3,000 users. This amounts to 100kps to 300kps of dedicated bandwidth. Due to statistical multiplexing the perceived bandwidth to the user is much more.
- ONUs on a 128 way PON **will still have 100 times** the bandwidth of a typical cable modem.

Cost effective high split ratios - How?

- A PON is most sensitive to the ONU (CPE) costs because of the relatively high volume of ONUs.
- How can we increase the optical power budget and hence the possible splitting ratios without increasing the ONU cost?

ANSWER

1. **Make use of forward error correction (FEC) to increase the effective sensitivity of the OLT and ONU.**
2. **Increase the transmit power and the sensitivity of only the high power budget class of OLT (shared cost), *reduce* the requirements on the *standard* OLT.**

Forward Error Correction

- FEC can provide 2.7 to 5.4 dB of additional receiver sensitivity at a bandwidth cost of 7% depending on receiver type (more on this later).
- ITU G.975 Reed Solomon (255,239) FEC is well defined and has been implemented in ASICs at 10Gbps.
- Latency - G.975 FEC at 1Gbps is usually 3 times the block size. Latency = 3 x 255 x 8 x 1ns = 6.1us. *Compare this to the round trip delay of 100us from fiber.*
- Minimum Block Size - Blocks may be smaller than 255 bytes by using Shortened Last Codeword technique.

FEC Continued

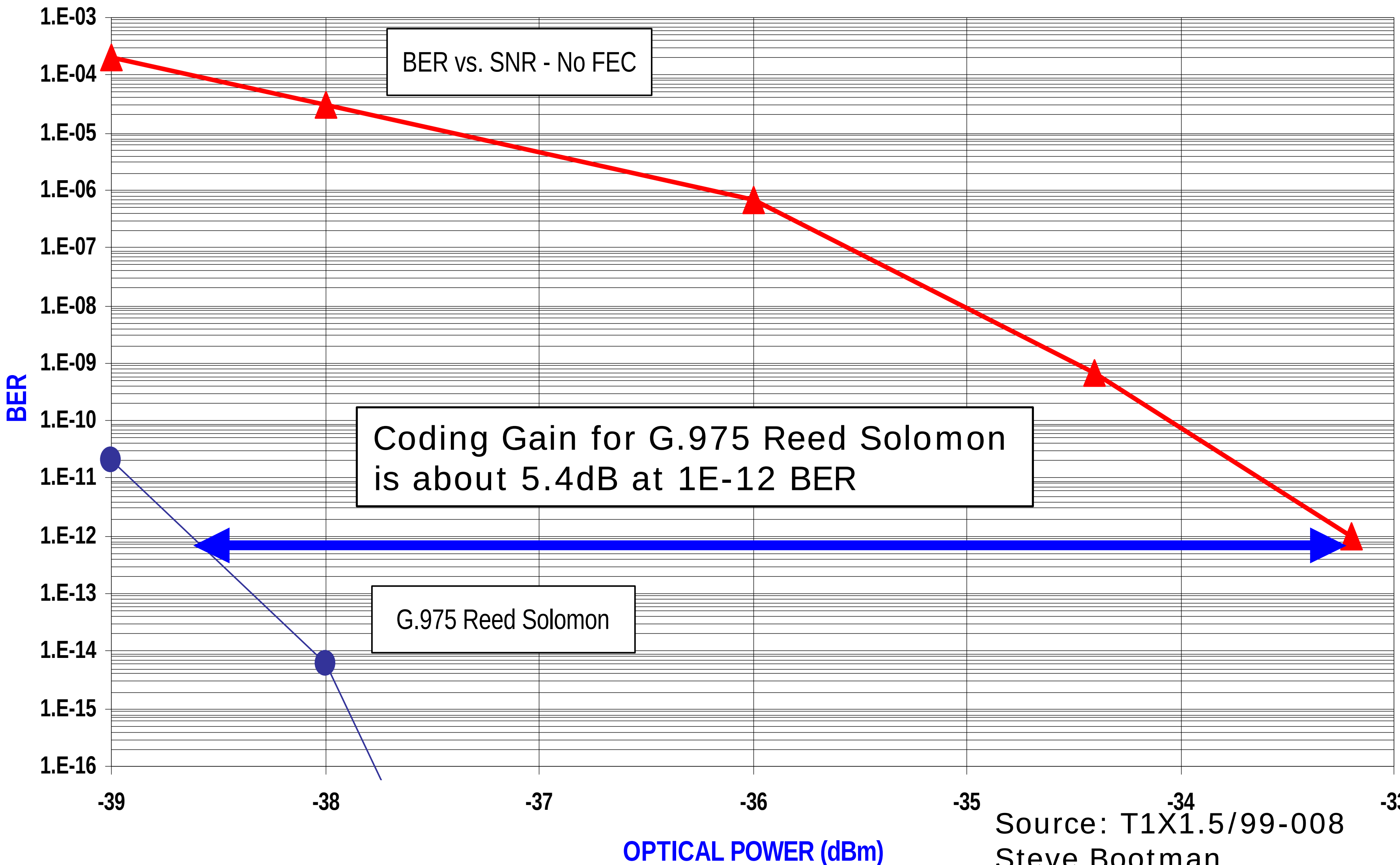
The main concerns expressed about FEC are:

- What is the added cost to the OLT and ONU?
  - The OLT cost (assuming the use of an FPGA instead of ASIC) increases by approximately 3%.
  - The ONU cost increase (*most important)*
    - Define the **BOT** (basic optical terminal) cost standard.
    - Addition of approximately 50k gates.
    - Increase ASIC by one size (adds an additional 200k gates)
    - Increases ASIC cost by 1% of a BOT (basic optical terminal), or a “centiBOT”.
- What is the added power consumption to the ONU?
  - Initial estimates are less than 200mW, more likely less than 100mW.

FEC Coding Gain - Optical vs. Electrical

- Most charts show the coding gain from FEC in terms of the electrical SNR rather than received optical power. In general, the gain is not the same.
- APDs and receivers that have optical amplification are in general *shot noise limited*. These will have BER vs. optical power curves similar to the electrical SNR curves and the coding gain will be close to the SNR curves.
- Receivers that use PIN detectors with no optical amplification are usually thermal noise limited, the coding gain will be closer to *1/2* the electrical coding gain (in decibels).

BER vs. Optical Power - Shot Noise Limited

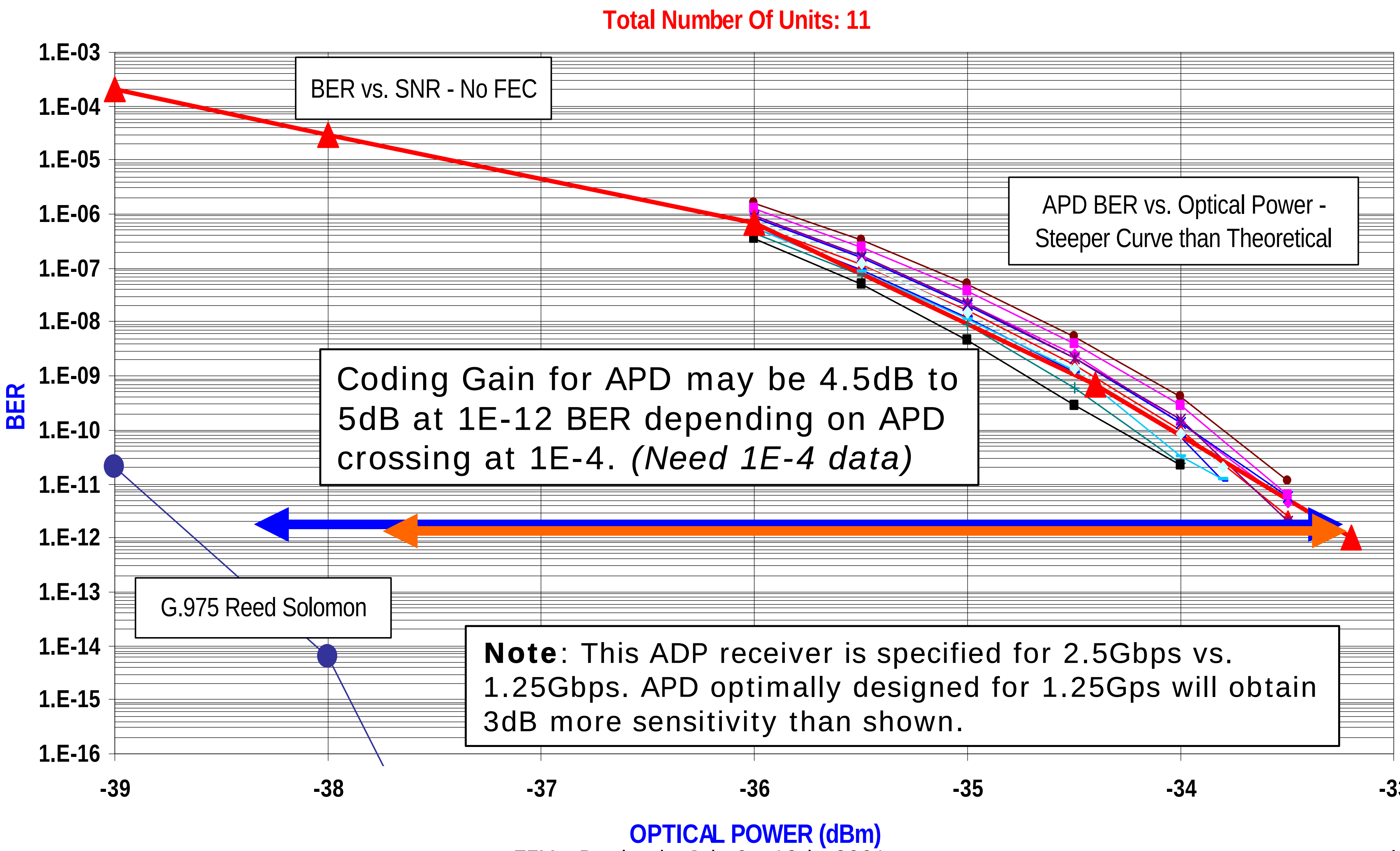


Source: T1X1.5/99-008
Steve Bootman

FEC Coding Gain - Optical vs. Electrical

- The APD coding gain is most important since upstream optical power budget for 128 splits is the most ‘challenged’.
- The next slide overlays data from 11 APD receivers on top of the previous BER curves, with and without FEC.
- The APD curve is slightly steeper so the full 5.4dB of coding gain will not be obtained.
- Accurate numbers on coding gain require data points at 1E-4 BER

BER vs. Optical Power for APD



Proposal - Two OLT classes

In a PON, cost should be shifted (if possible) from the ONU to the OLT, therefore:

- **Class A**: High Power - High Sensitivity
  - Receiver may need to be a pigtailed APD (avalanche photodiode)
  - Laser may need to be a pigtailed direct modulated MQW-DFB.
  - The WDM may need to be external, fused to the pigtails.
- **Class B**: Standard Power - Standard Sensitivity
  - This OLT transceiver will be *similar to the ONU* transceiver in terms of sensitivity and power.

Shared cost of Class A/B OLTs

- **Assumptions** (other assumptions may be used)
  - The service provider has up to 128 customers in a site (hub or CO) and 128 sharing provides adequate bandwidth.
  - Compare 1:16 split cost to 1:128 split cost but take into account that neither split is fully utilized. Assume 75% utilization over product life.
    - Note: A large split has a disadvantage in utilization at the start of deployment, but an advantage later due to smoothing effect of larger populations; therefore these two effects are assumed to cancel.
  - The unit of cost will be an EPON BOT (basic optical terminal).
  - Ignore the shared fiber savings since this is hard to quantify (although it may be the most important cost benefit in some cases).
  - The Class A OLT (and supporting cards) costs 14 BOTs. The Class B OLT costs 10 BOTs.
    - Note: Point of comparison; DOCSIS CMTS costs over >100 CMs

Shared cost of Class A/B OLTs (continued)

- Class A:
  - Shared cost of the OLT over 128 x 0.75 = 96 BOTs.
  - 14 BOTs/96 = **0.145 BOTs**
- Class B:
  - Shared cost of the OLT over 16 x 0.75 = 12 BOTs.
  - 10 BOTs/12 = **0.83 BOTs**
- Shared OLT cost is **5.7x** higher in the Class B vs. Class A, under these assumptions. (If a Class B: OLT is assumed to cost only 5 BOTs then the shared cost is still **4.5x** higher)
- *Note, this does not take into account fiber savings or headend shelf space savings.*

Proposed power budgets

- The next two power budget slides will use the presentation: “Power Budgets and Optics Considerations” from July 2001 EFM by Golob et. al. as the baseline and use the same table format.
- The next two slides will point out deviations from the referenced baseline in bold type.

16 way Single Fiber PtoM, 1550nm DFB, 1310 FP

Class B OLT with 16 way split ratio	
Downstream Wavelength/Laser Type	1550nm/DFB (Class B OLT)
Upstream Photodetector	PIN (Class B OLT)
Upstream Wavelength/Laser Type	1310nm/FP
Downstream Photodetector	PIN
Downstream Power Budget	21.9 dB
Upstream Power Budget	25.4 dB
Head End Tx	-2.8 to +2.2 dBm **(2.7dB relaxation)**
Head End Rx plus FEC	-26.3 dBm - 2.7dB = -29 dBm **(3.7dB relaxation)**
Tail End Tx	-3.6 to +1.4 dBm ***(1dB increase)***
Tail End Rx plus FEC	-22 dBm - 2.7 dB = -24.7 dBm

128 way Single Fiber PtoM, 1550nm DFB, 1310 FP

Class A OLT with 128 way split ratio	
Downstream Wavelength/Laser Type	1550nm/DFB (Class A OLT)
Upstream Photodetector	APD (Class A OLT)
Upstream Wavelength/Laser Type	1310nm/FP
Downstream Photodetector	PIN
Downstream Power Budget	21.9dB + 11dB = 32.9dB
Upstream Power Budget	25.4dB + 11dB = 36.4dB
Head End Tx	+8.2 to +13.2 dBm **(8dB increase)**
Head End Rx plus FEC	-35.5dBm - 4.5dB = -40dBm **(5.5dB increase)**
Tail End Tx	-3.6 to +1.4dBm ***(1dB increase*)**
Tail End Rx plus FEC	-22 dBm - 2.7dB = -24.7dBm

Laser Safety?

- IEC 60825-2 “Safety of optical fibre communication systems”, Second Edition defines requirements for laser diodes used in fiber optics. The FDA is now aligned with the IEC requirements.
- ONU (1285nm): Must be Class 1 since it is in an “unrestricted environment”. Otherwise it must have shuttered fiber optic connectors or automatic power reduction. Class 1 < +9.5dBm.
- OLT (1550nm): Proposed +13.2 dBm maximum is 3.2 dB above the Class 1 limit of +10dBm. It falls into the Class 3A category. However the OLT is used in a ‘restricted’ or ‘controlled’ environment. Labeling is required in these environments. LECs and MSOs commonly use lasers of this type.

Summary - Proposal for EPON

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Further Investigation

- Obtain more accurate values for APD and PIN coding gain.
- Is FEC decoder necessary in ONU or just OLT? Note that upstream is more power budget ‘challenged’ than the downstream.
- Is any power penalty needed for burst receiver vs. continuous? If so, how much?