Multilevel Modulation for 10GbE: Link and Component Specification Issues

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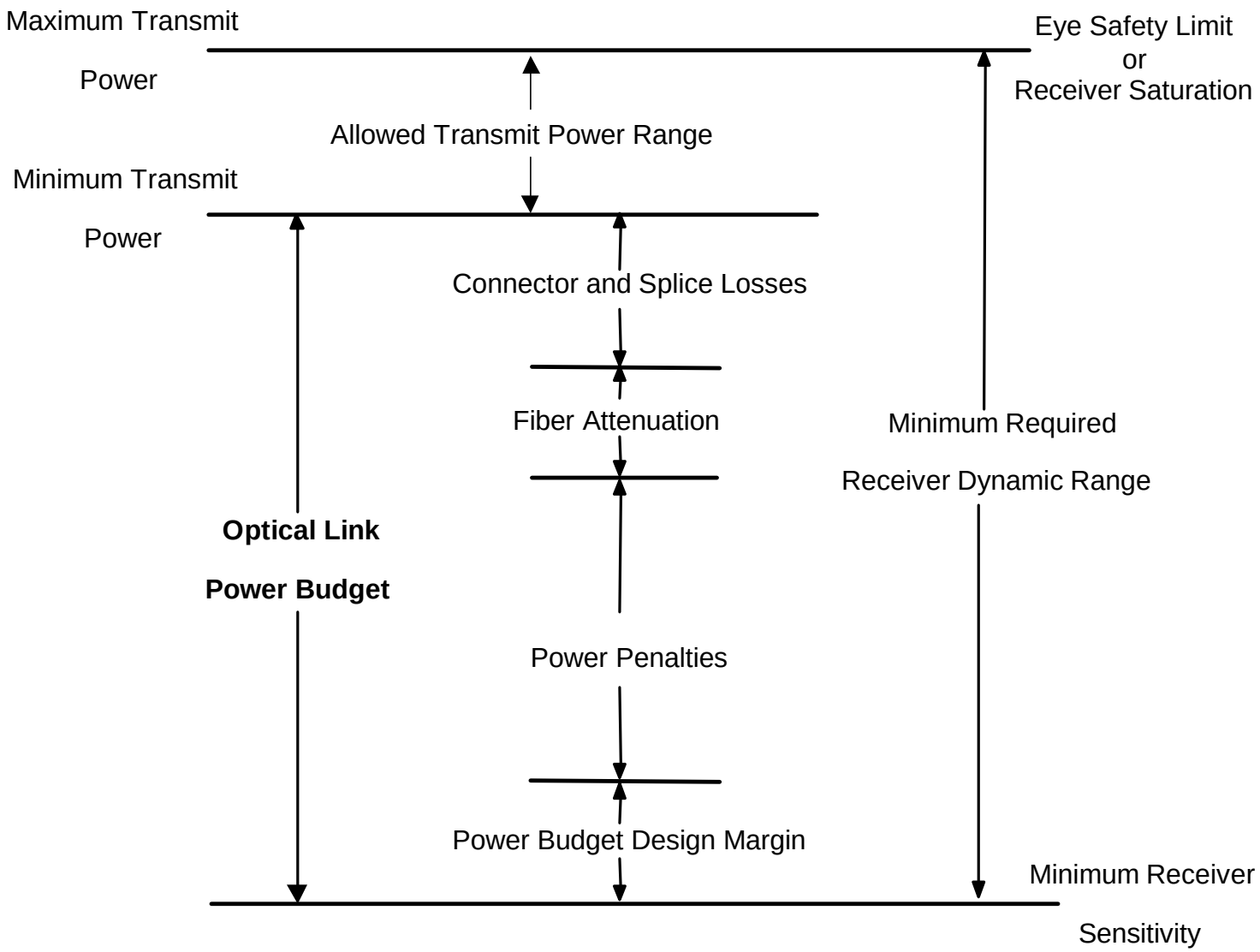
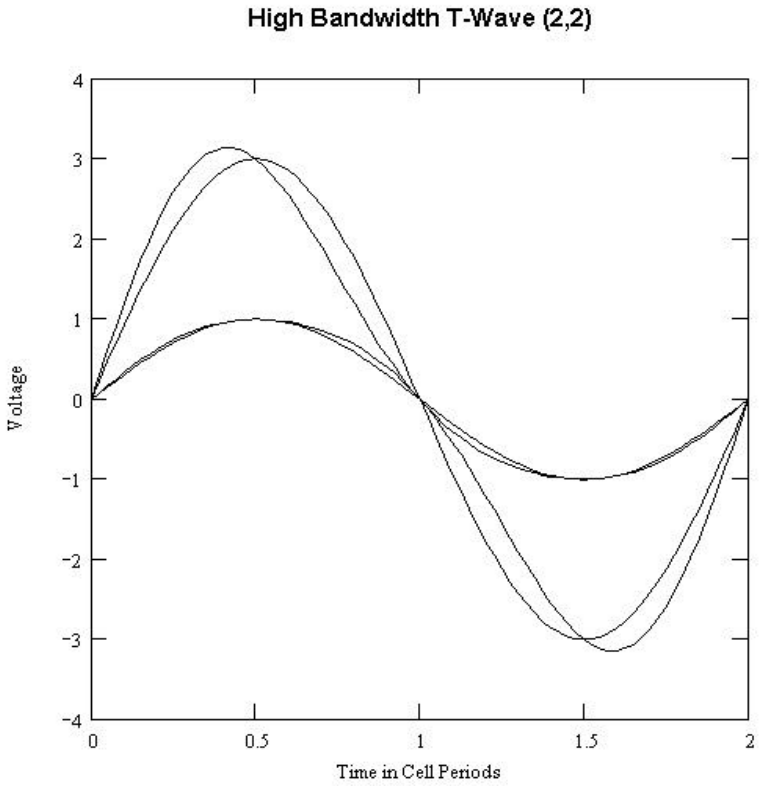
Conceptual Optical Power Budget

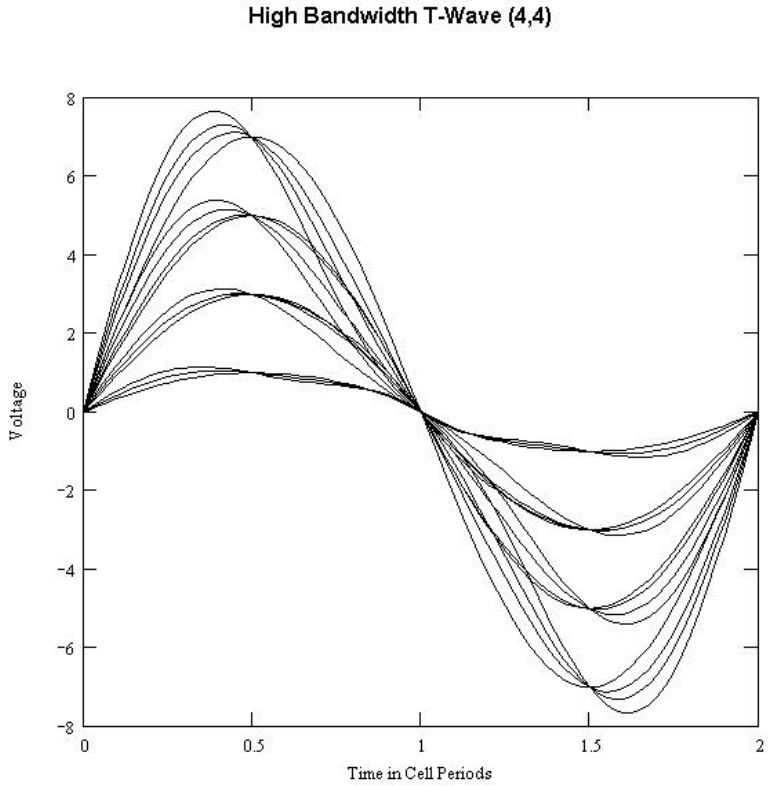


Multilevel Optical Link Issues

- Multilevel Power Penalty
- Relative Intensity Noise (RIN) Penalty
- Laser Linearity (Compression Ratio) Penalty
- ISI Penalty
- Cabled Fiber Attenuation
- Modal Noise
- Connection Insertion Loss
- Return Loss
- Minimum Received Eye Opening
- Mode Partition Noise (MPN)
- Jitter
- Coding Gain

Example Two Cell T-Waves





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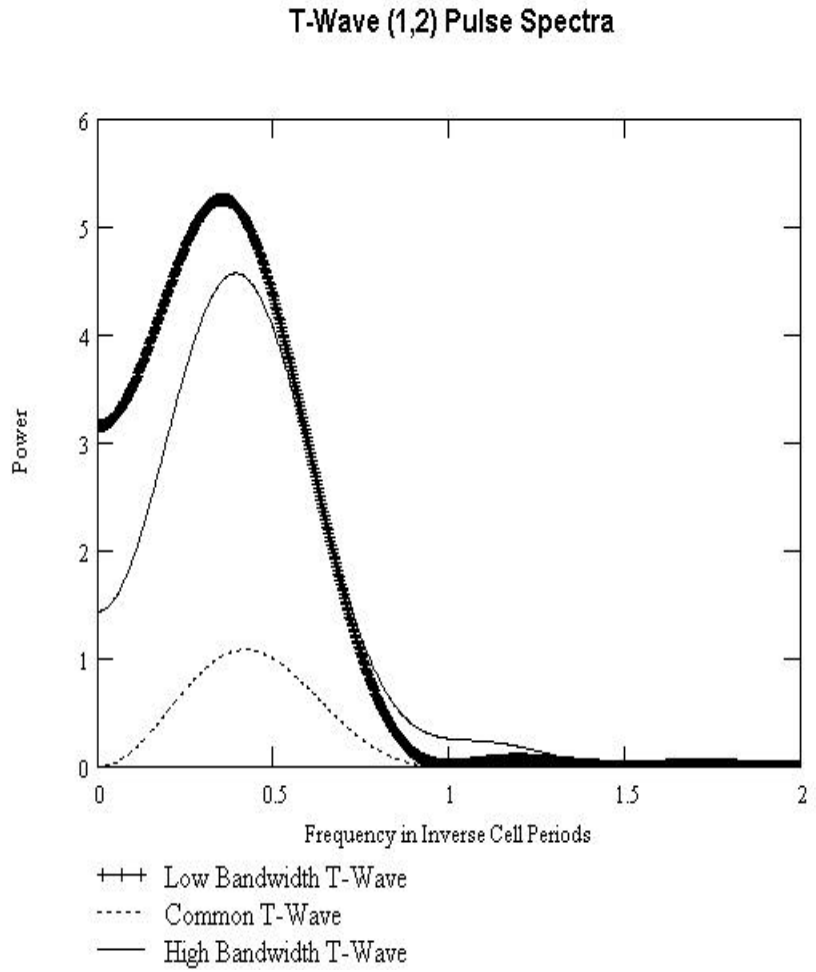
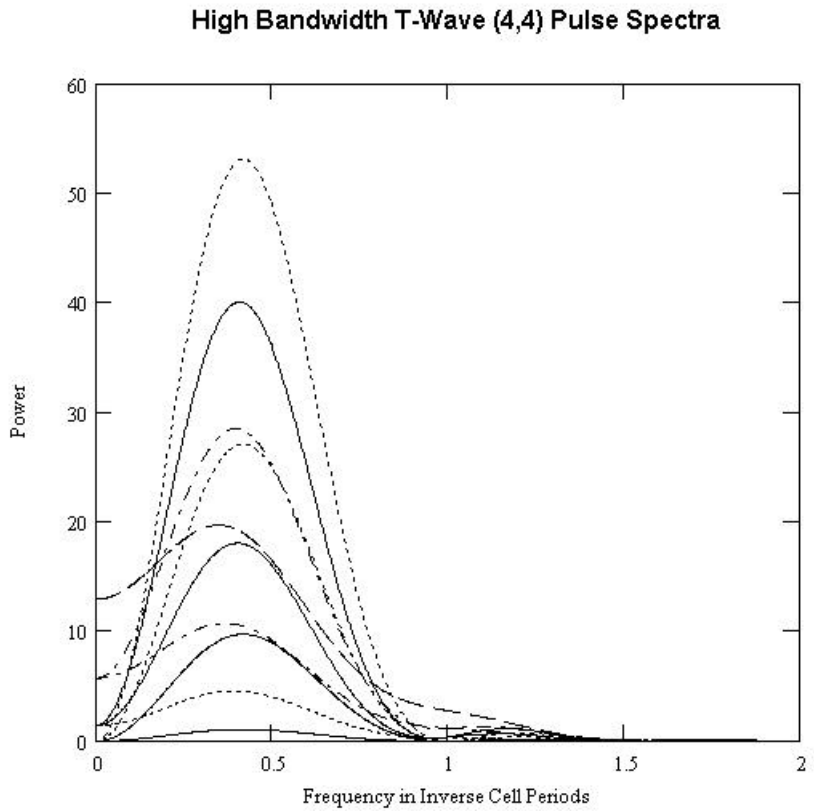
T-Wave Pulse Spectra





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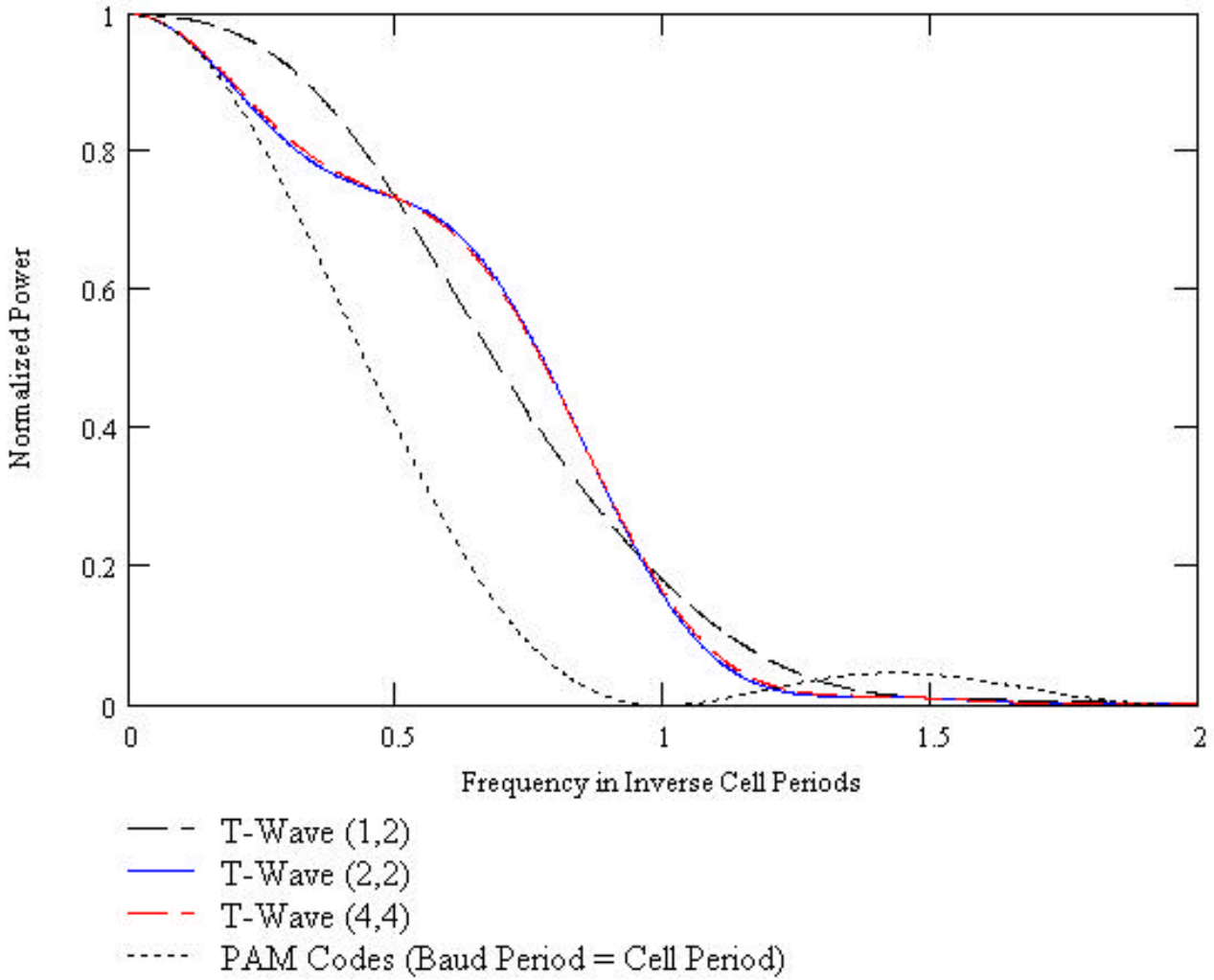
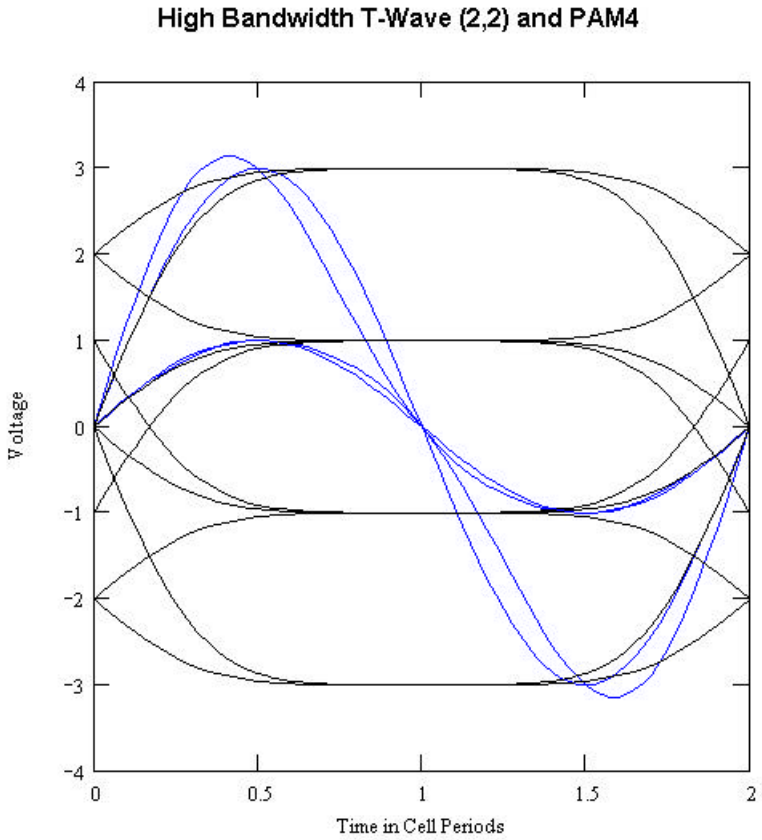
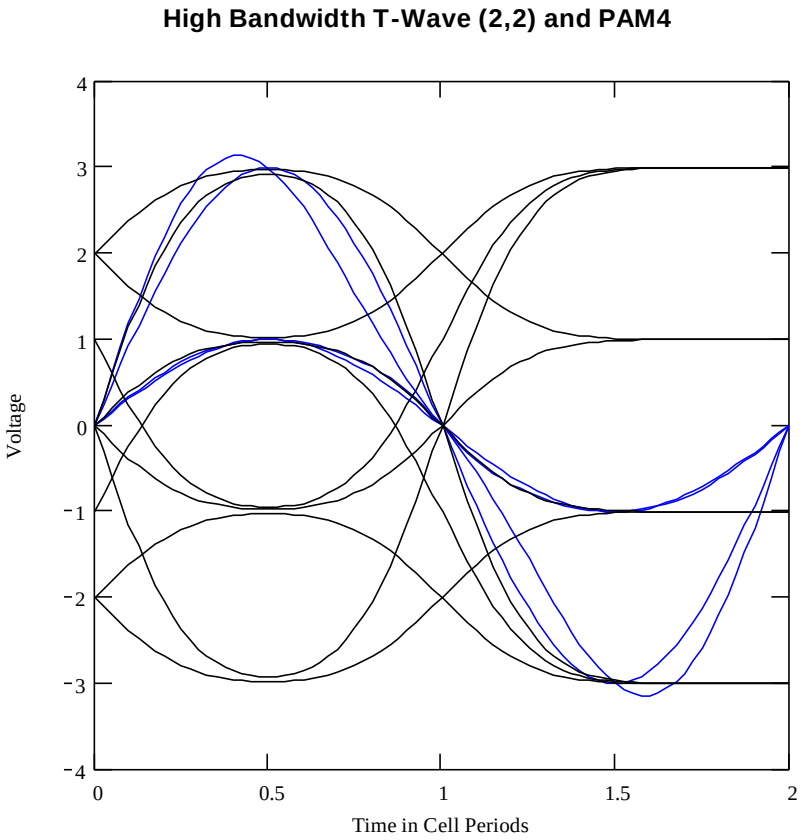
T-Wave Code Spectra



T-Wave and PAM Eye Diagrams





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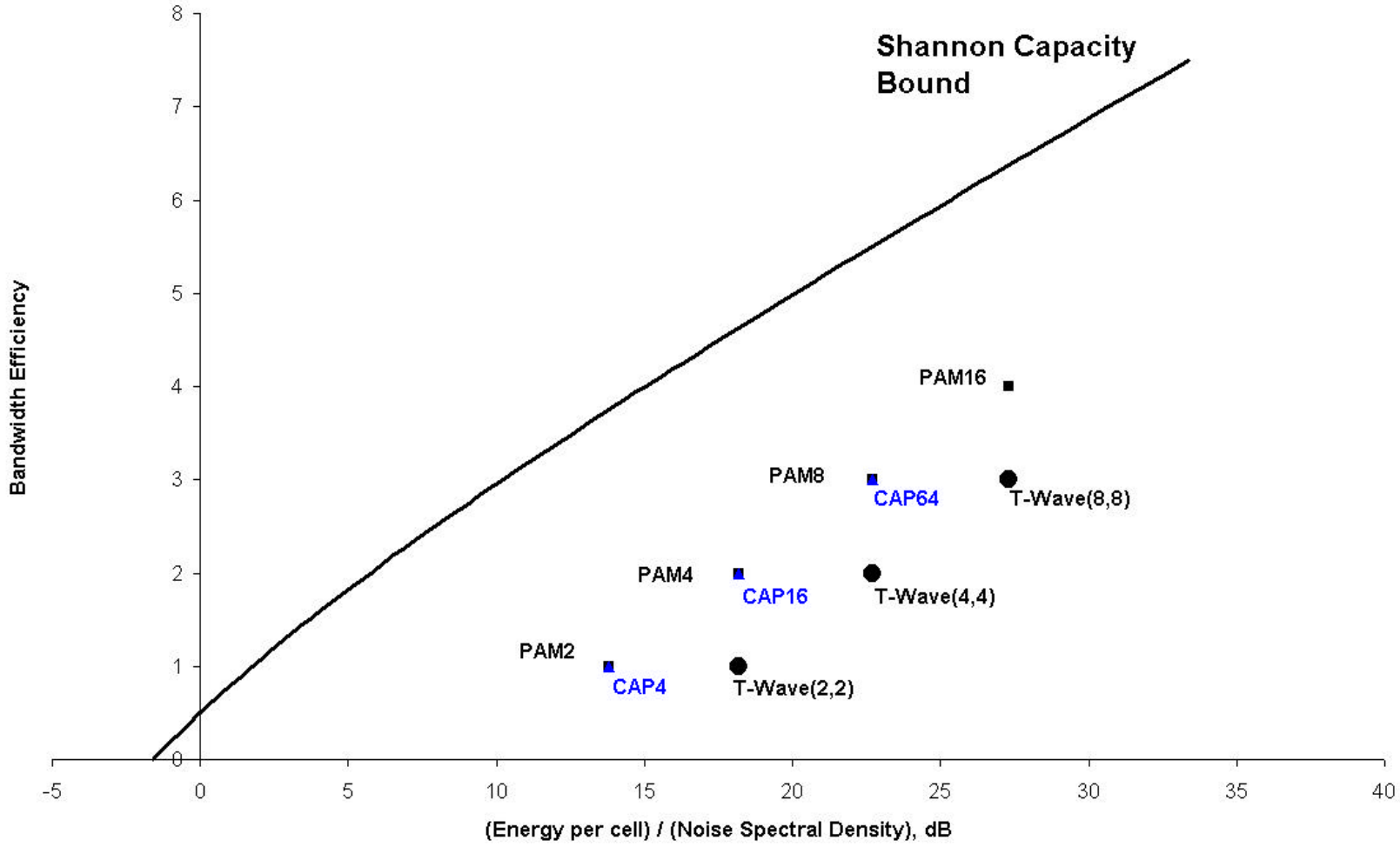
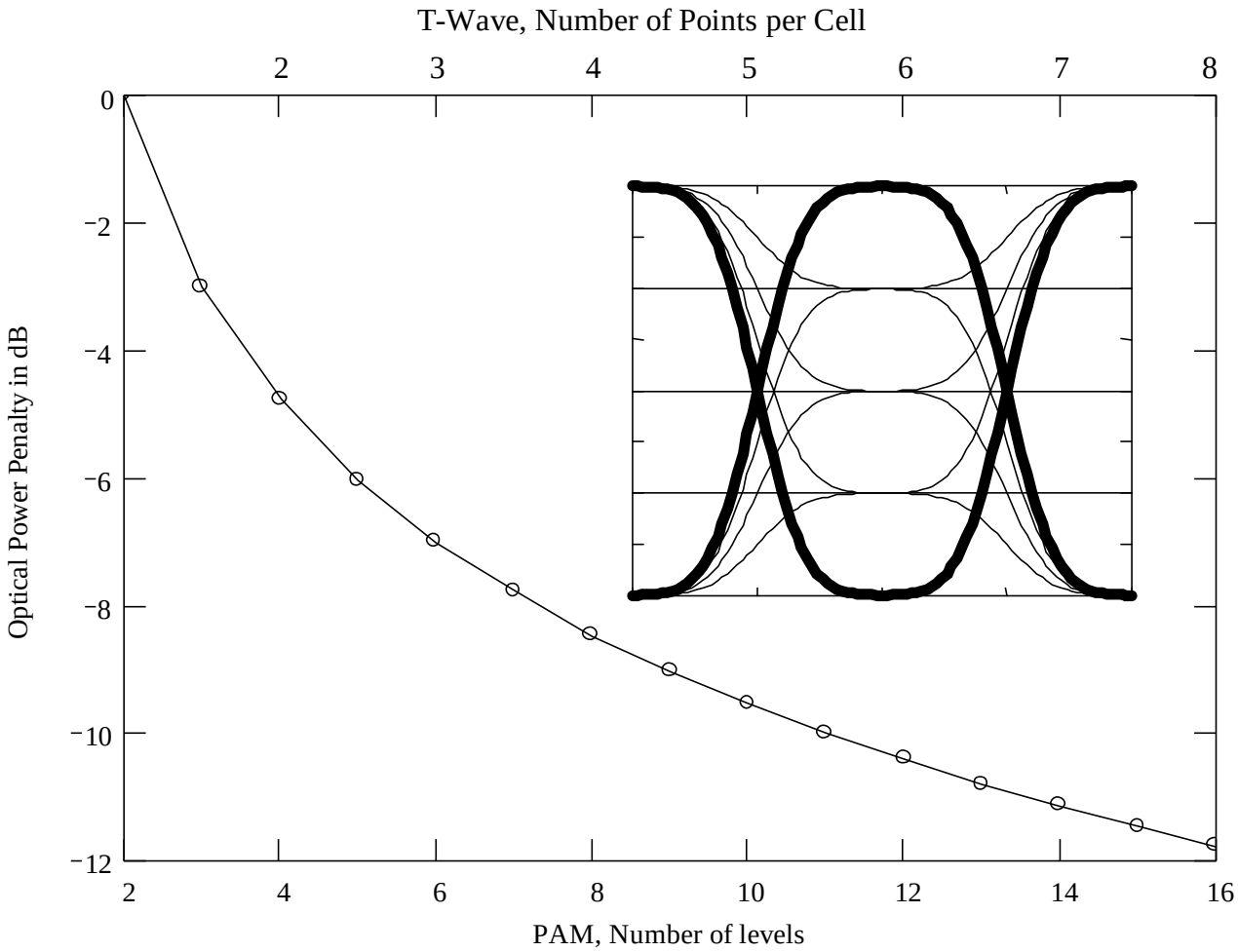
Bandwidth Efficiency Plane Graphs



Multilevel Optical Power Penalty For Multilevel Modulation



Note: Constant Symbol Rate Assumed

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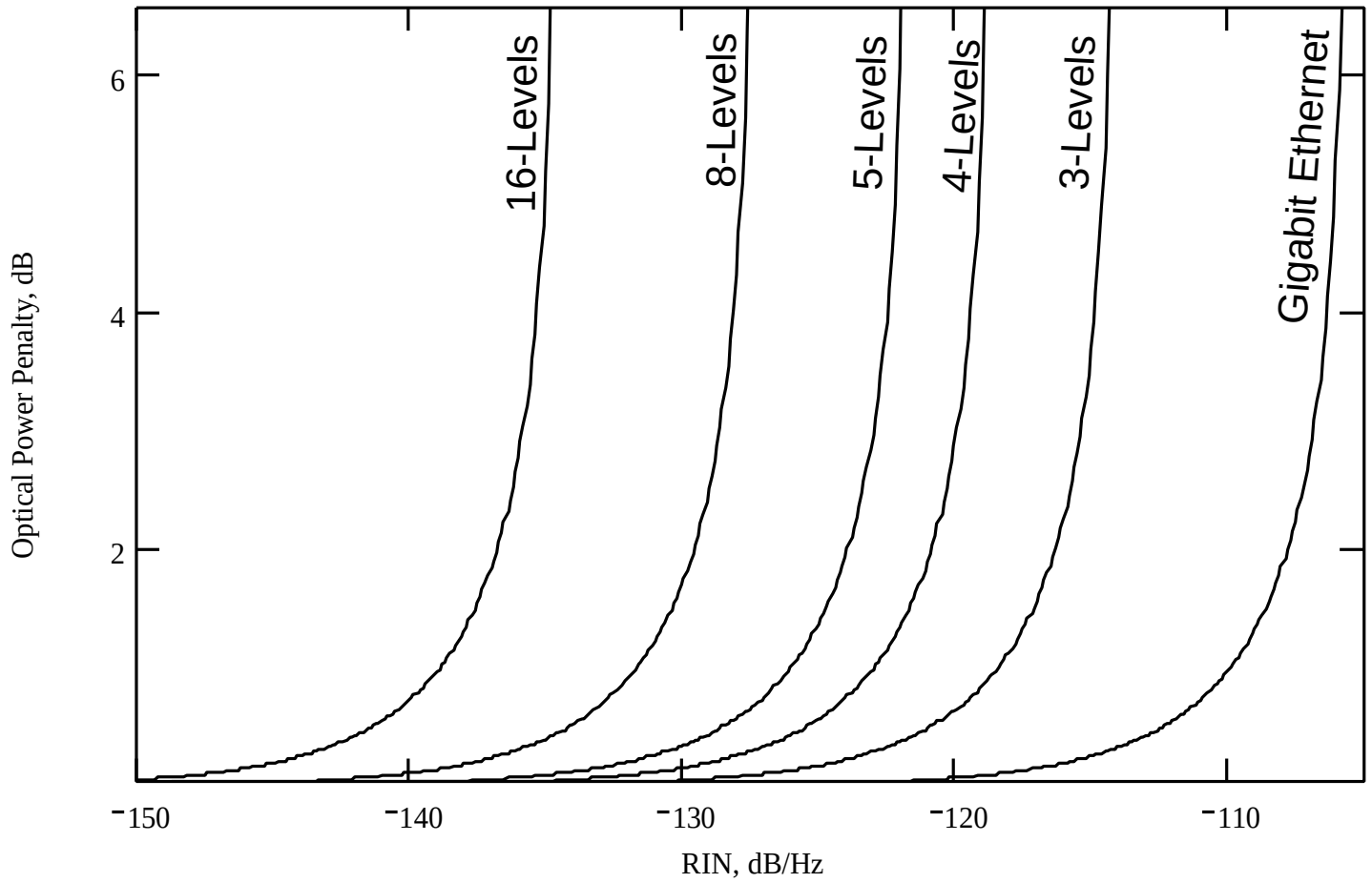
Optical Power Penalty Versus Relative Intensity Noise (RIN)



(Note: All Curves for 1.25 G Symbol per Second)

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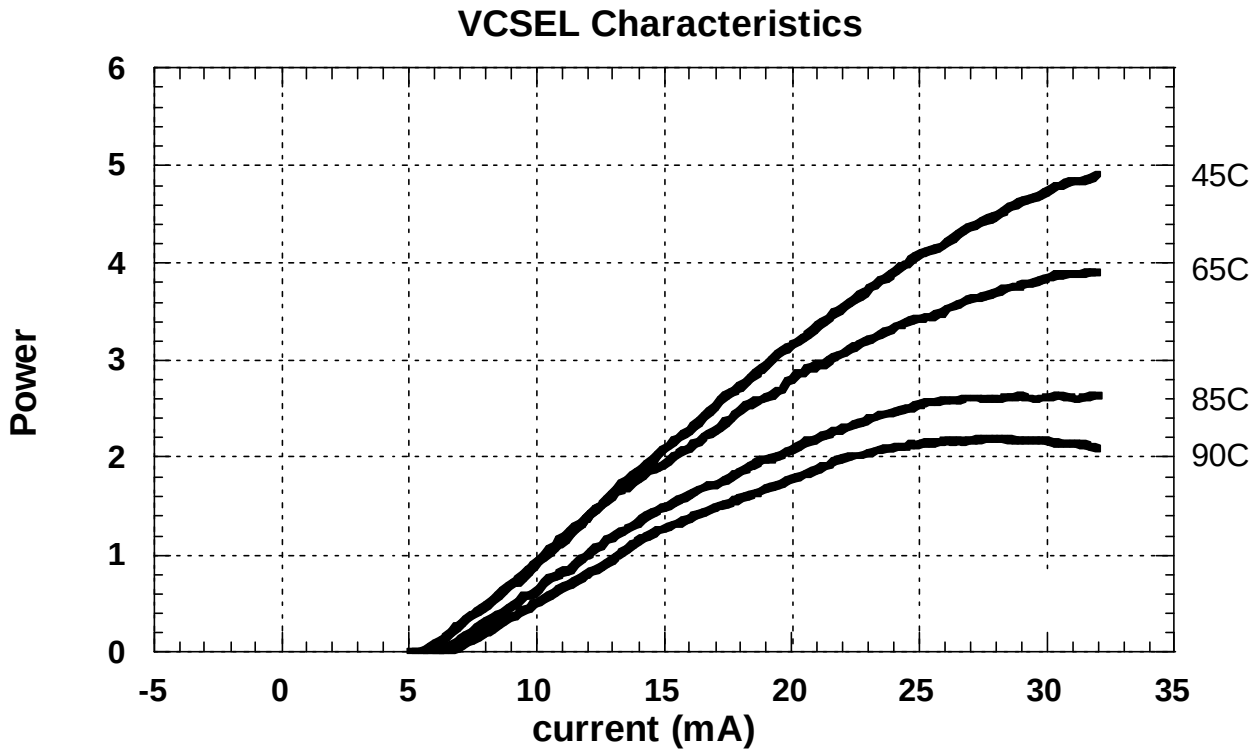
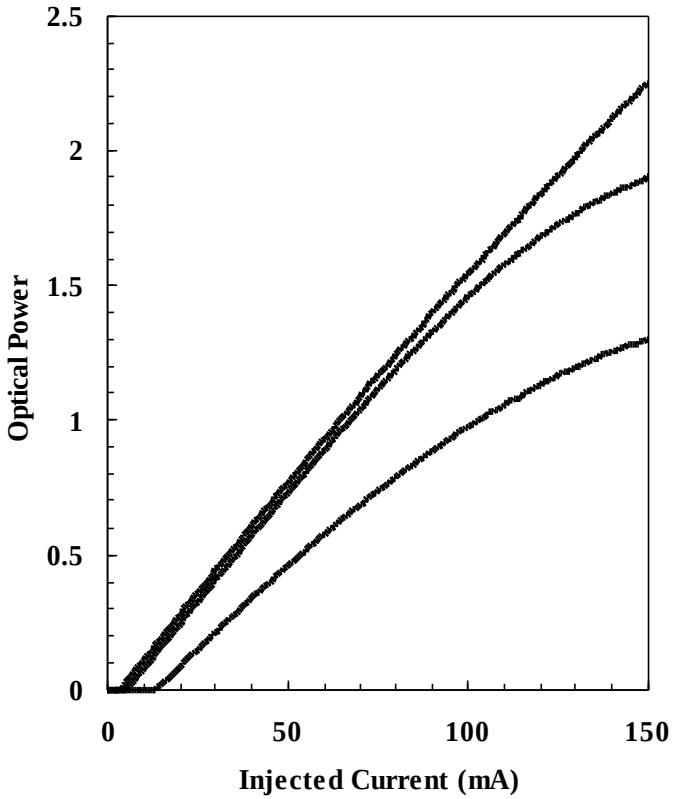
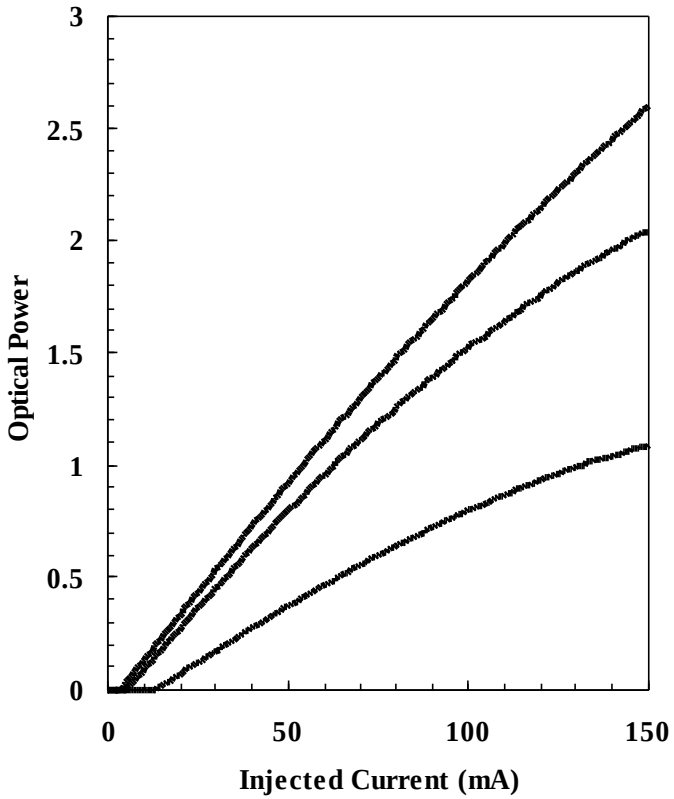

VCSEL Characteristics
Power
6
5
4
3
2
1
0
-5
0
5
10
15
20
25
30
35
current (mA)
45C
65C
85C
90C

Typical 1300nm Fabry Perot Laser
(Device A)



Typical 1300nm Fabry Perot Laser
(Device B)



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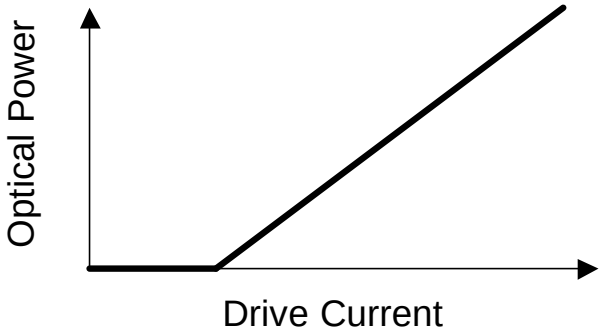
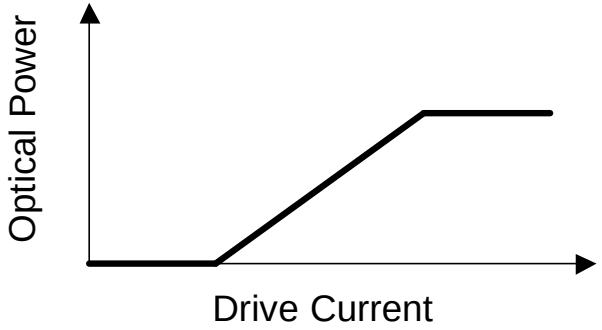
Linear Response

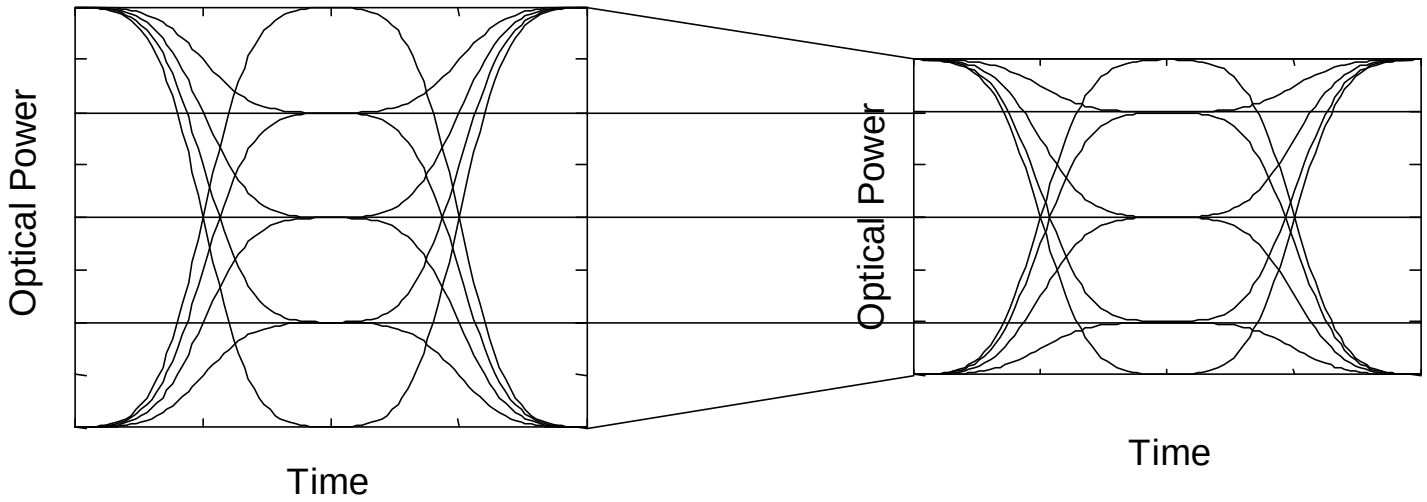


Non-linear Response



Linear Eye Diagram

Non-linear Eye Diagram



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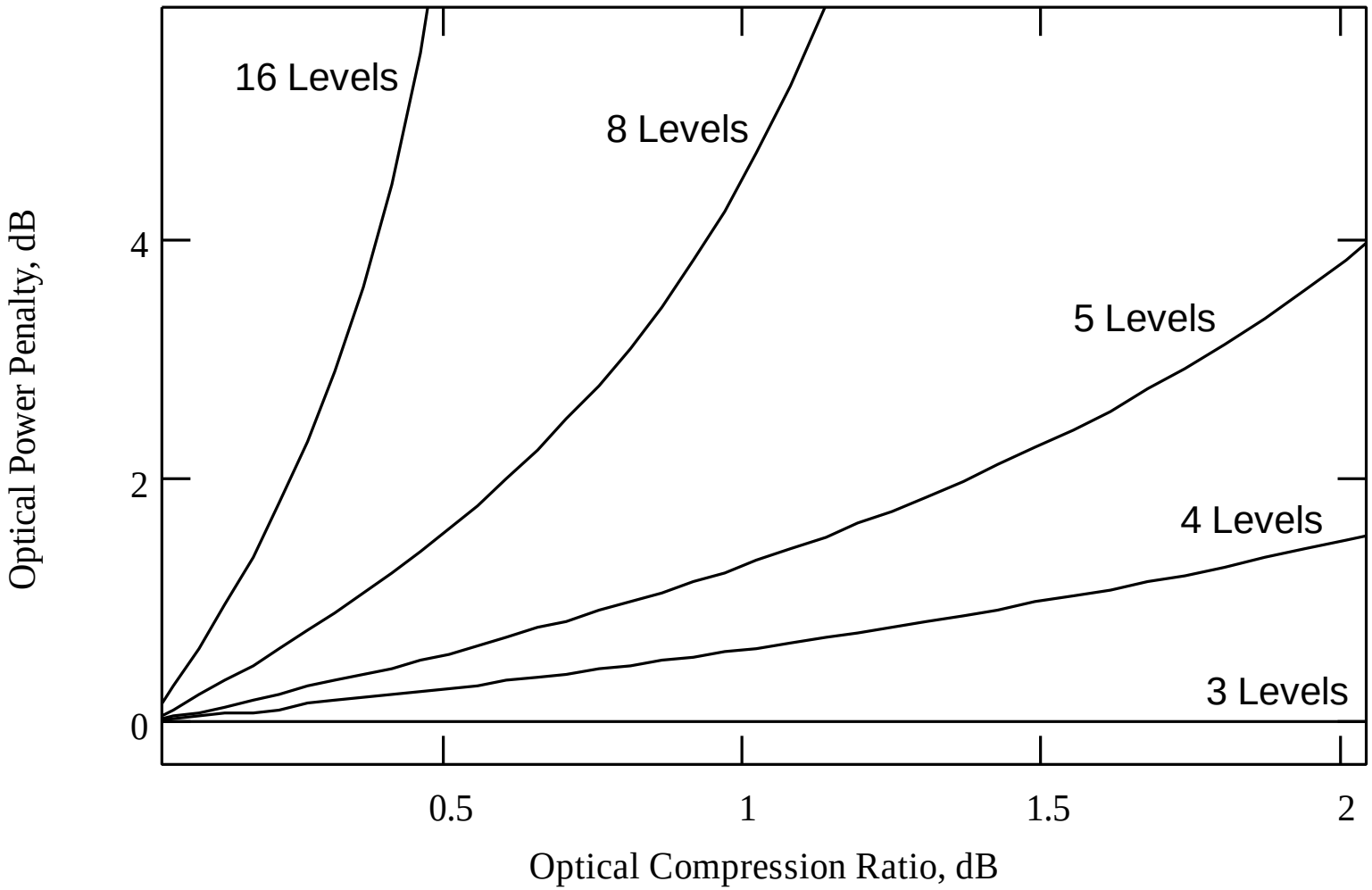
Power Penalty Relative to NRZ Due to Non-Linear Response



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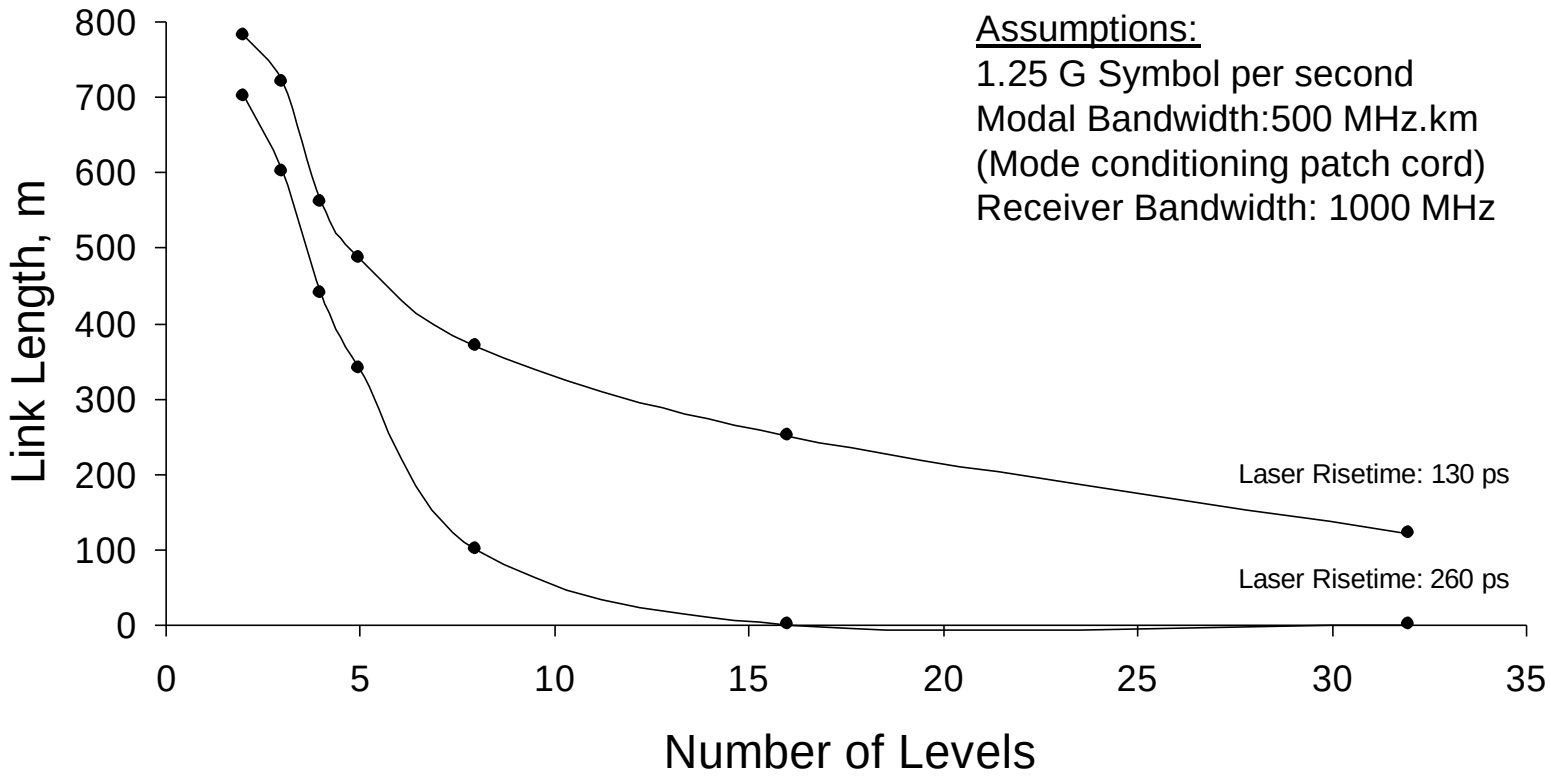
Non-Equalized Worst Case Link Length Versus Number of Levels (Gigabit Ethernet ISI Model)



Modal Noise Optical Power Penalty

- **The modal noise power penalty for multilevel systems requires careful theoretical and experimental investigation.**
- **For the same connector specifications, as an NRZ link, the worst case modal noise variance will remain constant. But in a power limited, multilevel system, the optical signal will decrease due to the multilevel power penalty.**
- **Therefore, modal noise power penalties are likely to be much larger compared to those of GbE and error rate floors may be encountered.**

Coding Gain and Link Specifications

- **Multilevel optical links suffer increased or new penalties compared to NRZ optical links:**
  - New Multilevel Power Penalty
  - Increased RIN Penalty
  - New Non-Linearity Penalty
  - Restricted ISI Penalty Range
  - Increased Modal Noise Penalty
  - Increased Return Loss Requirements
- **Codes that provide coding gain will be essential but coding gain cannot correct for all of the increased component/link penalties.**

10GbE Architecture Versus Electrical SNR

Architecture	Relative Electrical SNR, dB	Comment
GbE	0	
4 WDM + 8B10B	- 4	
PAM5	< - 18	Error Rate Floor?
PAM5 + EVEN	< - 15	Error Rate Floor?
PAM5 + Trellis	< -12	Error Rate Floor?

Note: Allocated a minimum penalty of 6 dB electrical for combined effect of RIN, MN, NLD penalties. Assumed coding gain of 3dB electrical for PAM5 + EVEN and 6 dB for PAM5 + Trellis.

Conclusions

- Multilevel component specifications will not be the same as for NRZ based links at the same symbol rate - they will be much more restrictive

- Many very challenging technical issues need to be addressed