Optical PMD Considerations for 200G Lanes

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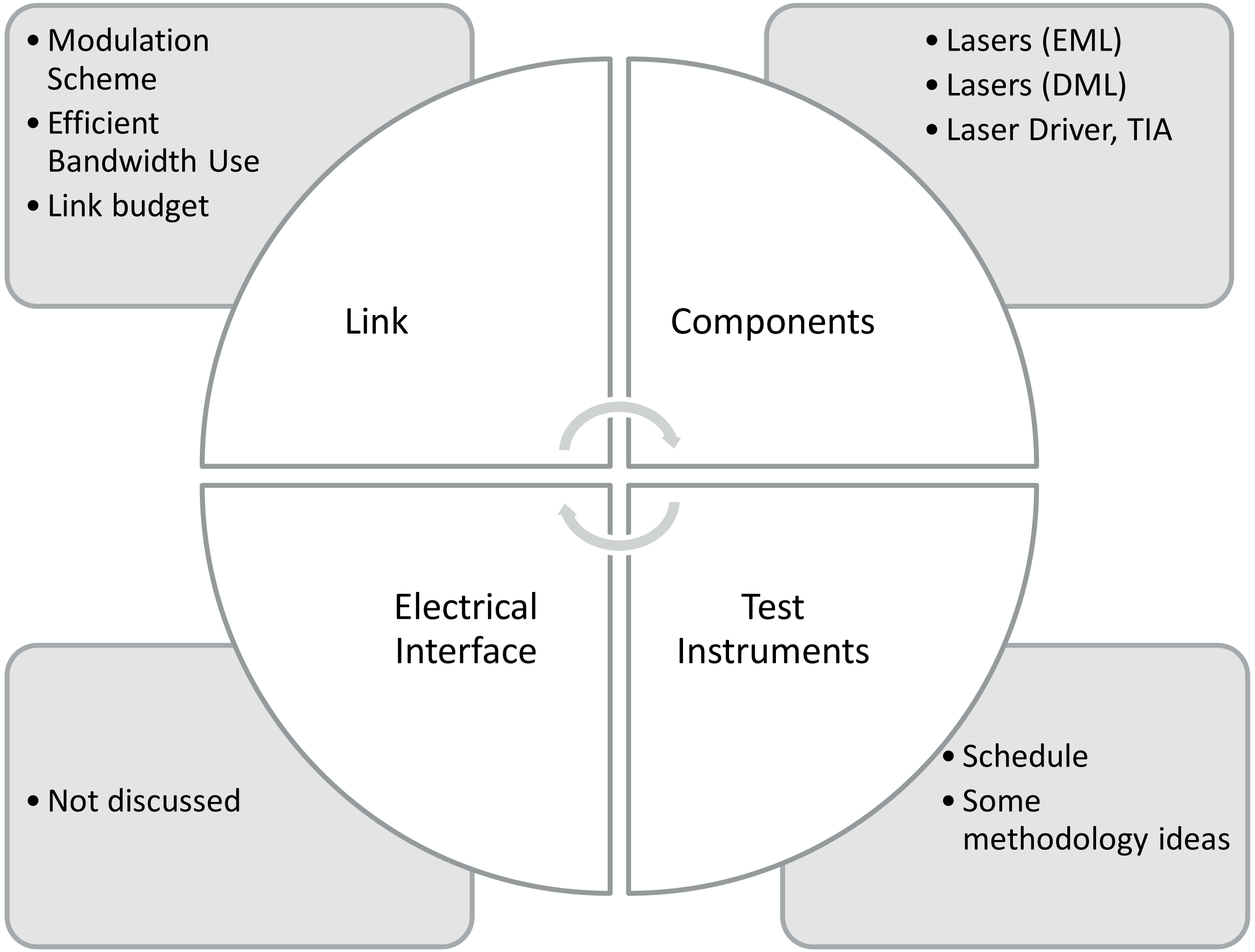
- Peter Szabo, II-VI

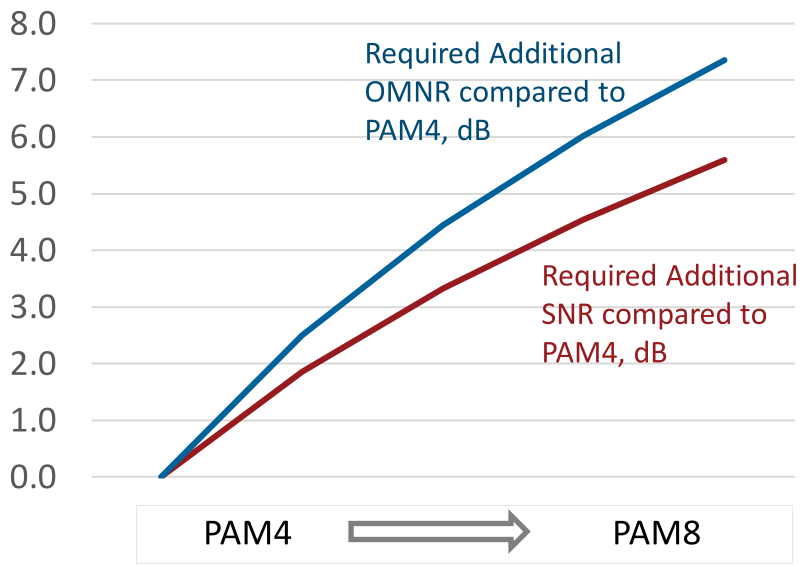
Optics Considerations for Beyond 400 Gb/s Ethernet

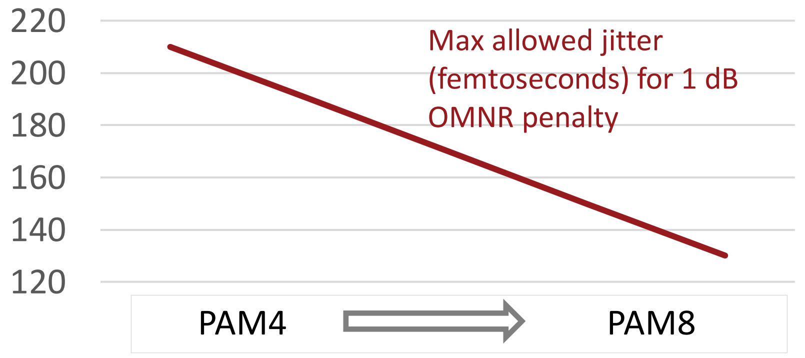
100G optical lanes are already defined in IEEE 802.3cu. Let’s focus on considerations for 200G optical lanes



Modulation Scheme

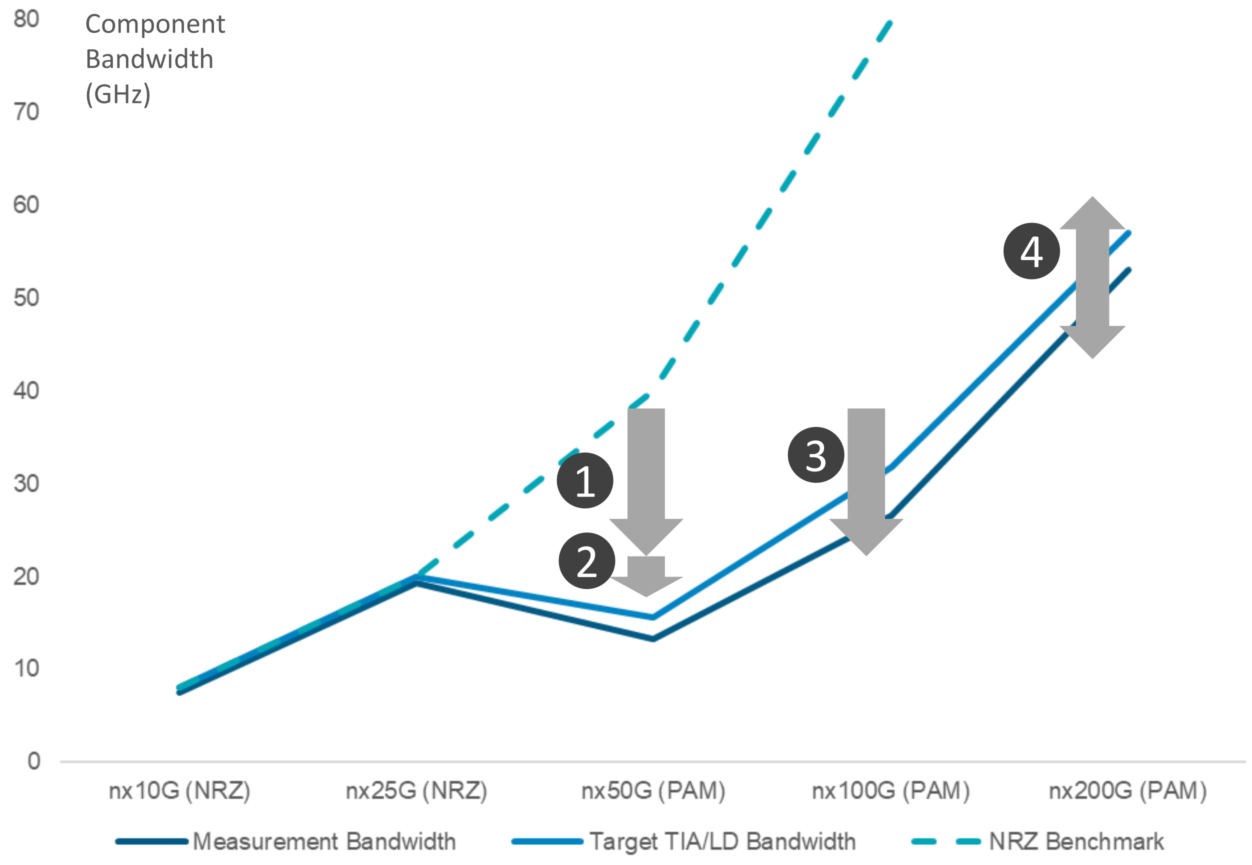
- PAM4 is the safest path forward
  - Backward compatibility is a key market requirement
- PAM6 and PAM8 require components that:
  - Maintain linearity over a larger amplitude range
  - Support a tighter jitter budget
- Intensity-proportional noises like RIN and MPI close the uppermost eye more rapidly for PAM8
- PAM4 over PAM8: 5.6 dB SNR advantage, 7.4 dB OMNR advantage, 80 fs jitter limit advantage
- Favors PAM4 if components with sufficient bandwidth will be available





OMNR: Outer Modulation to Noise Ratio

Progress in Using Component Bandwidth Efficiently



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1. With nx50G PAM4, IEEE specs reduced required bandwidth by half
2. And reduced bandwidth burden on components by adopting a 5-tap FFE reference receiver
3. Recognizing constraints on VCSEL bandwidth, the IEEE 802.3db is considering the use of 9-tap FFE reference receiver
4. For 200G lanes, thanks to advances in CMOS and DSP, more powerful pre-emphasis, equalization, detection, and FEC options are available for consideration

200G PAM4 Link Performance

- For 2 km reach, preliminary analysis suggests feasibility with appropriate scaling of component bandwidth
  - Further discounting is necessary to account for additional losses, impairments and manufacturing margin
- Implementations will leverage advances in clock recovery, jitter reduction and equalization
- Advanced equalization and detection schemes in DSP can offer higher performance at moderate incremental complexity
- Stronger link FEC can help further

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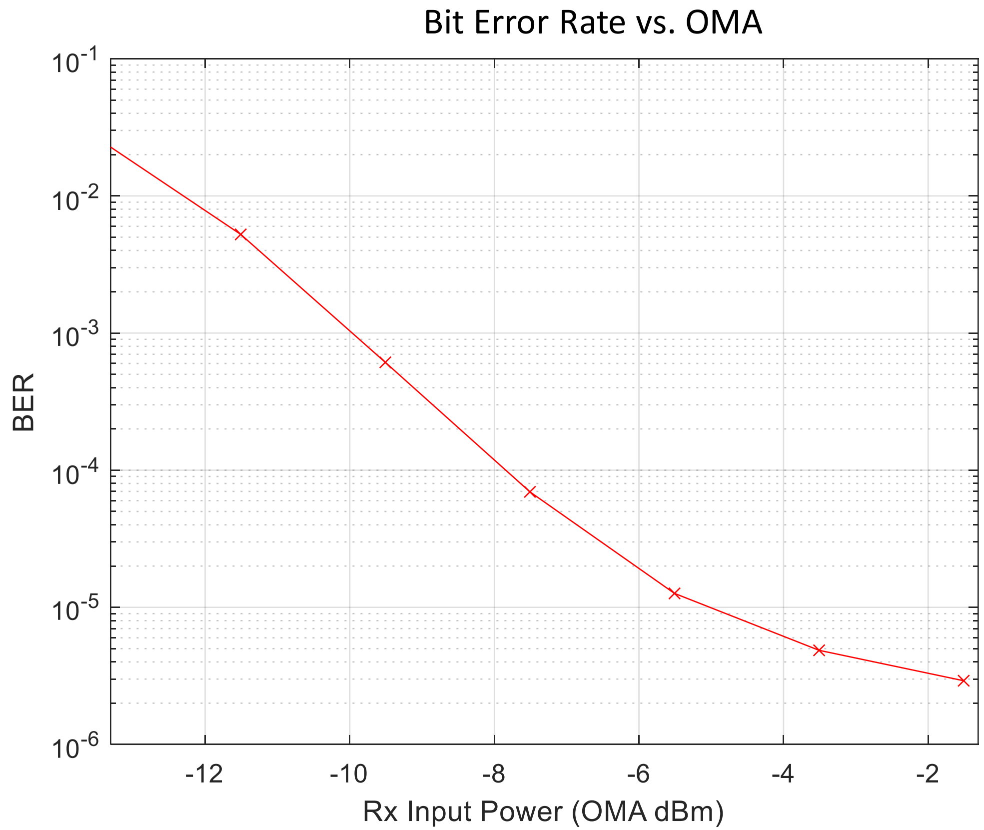
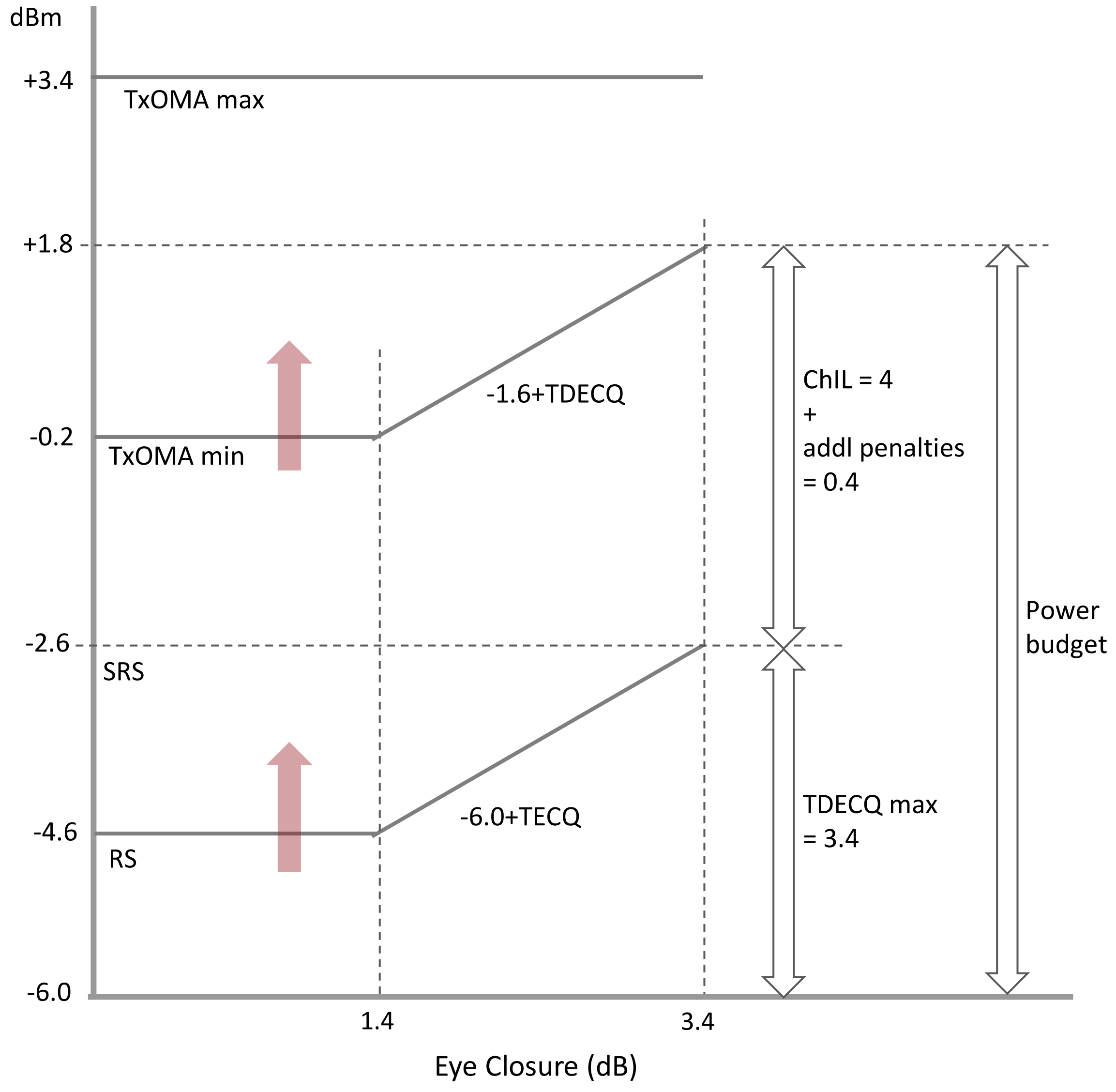


- Single channel optics link simulated
- Using **measured**, frequency scaled, 100Gb/s Rx and driver
  - Rx BW ~60 GHz, Tx BW ~70 GHz, Modulator BW ~ 60 GHz
  - Estimated interconnect impairments included
  - RIN, MPI, Optical Xtalk and TIA noise included
  - Simulated at 1337.5nm with λ_0 = 1300 nm
  - Tx ER ~ 4.5dB
- DSP Rx modelled as 21 T-spaced taps (5 pre-cursors)
- 10^6 symbols simulated → BER = 10^{-6} means no errors detected

OMA Budget



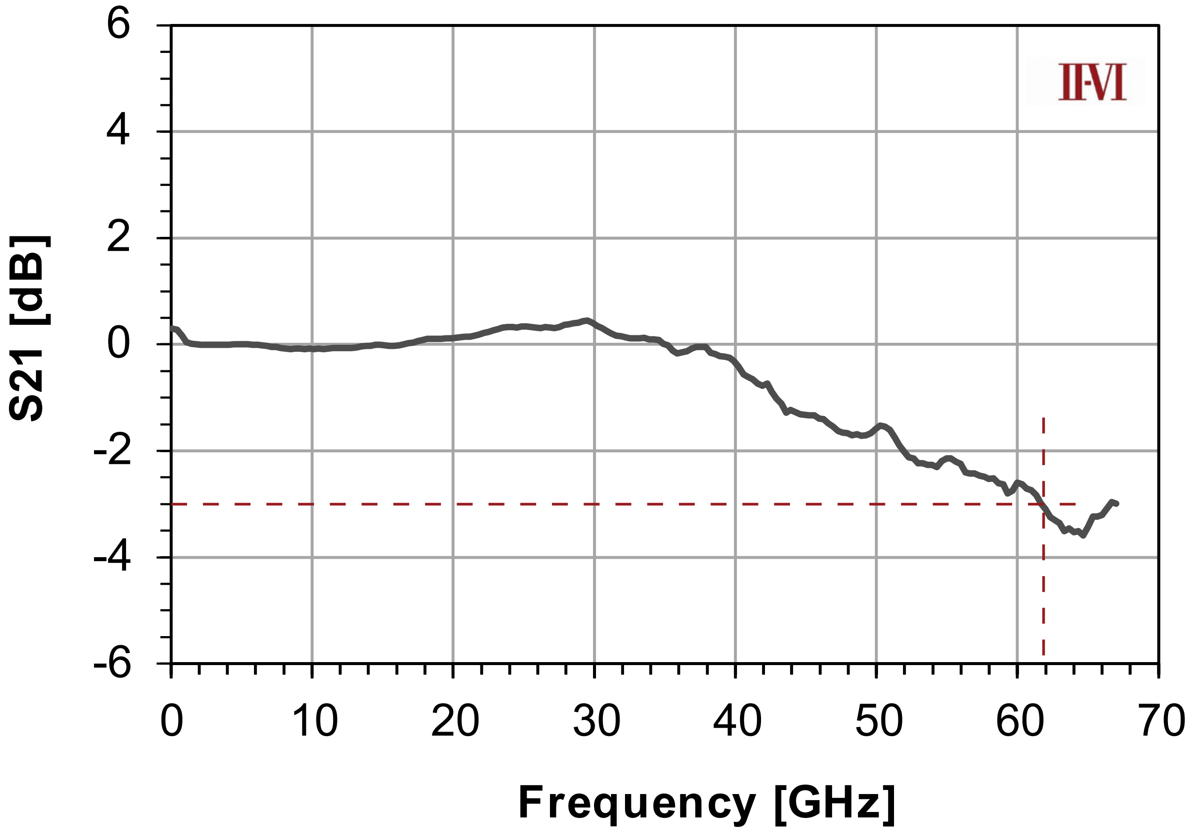
Example: Review 400G-FR4 Budget for Implications to Potential 800G-FR4 Budget

- For 200G lanes, we will need to raise RS by 2 to 2.5 dB
  - Therefore, Raise Tx OMA min as well
- Result: Pressure on Tx OMA max, impact on components
  - TIA linearity and fidelity
  - Indirectly, limit on TDECQ max as well
- What else can we tighten?
  - ChIL: Do we really need 4 dB Channel Insertion Loss?
  - MPI: Can we aim for a lower-reflectance cabling plant?

200G EML

- Recent advances in EML are encouraging
- Un-peaked 3 dB Bandwidth > 60 GHz; well-behaved frequency response. Can be significantly extended with suitable transmitter pre-emphasis.
- Low, controlled chirp, with only a weak dependence on modulator bias
- Suitable for potential 200G-FR1, 800G-FR4, 1600G-FR8

Representative chip-level S21 (Magnitude Response) of II-VI EML at 55°C



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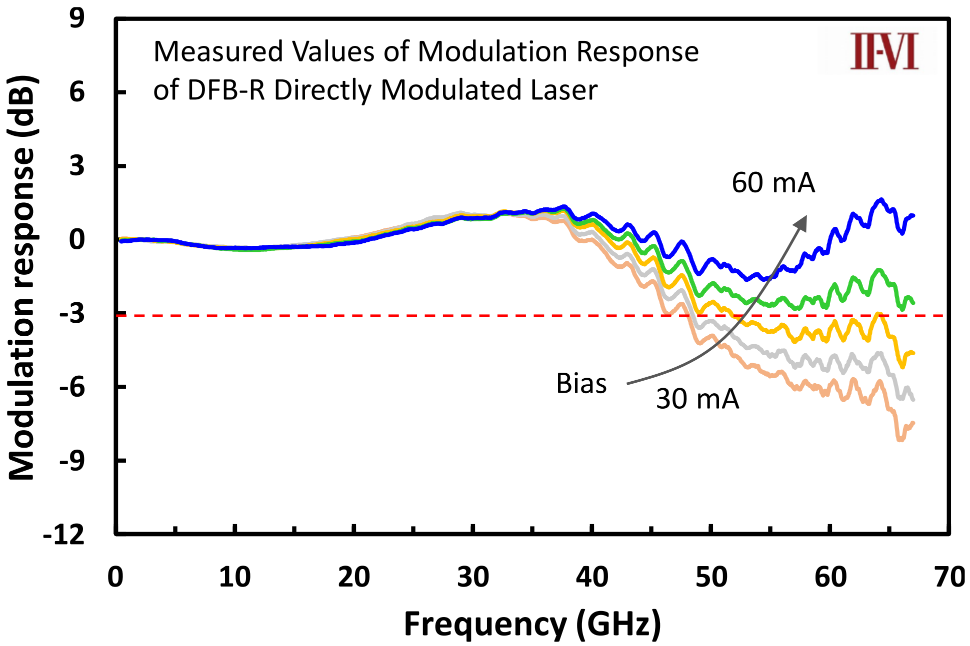
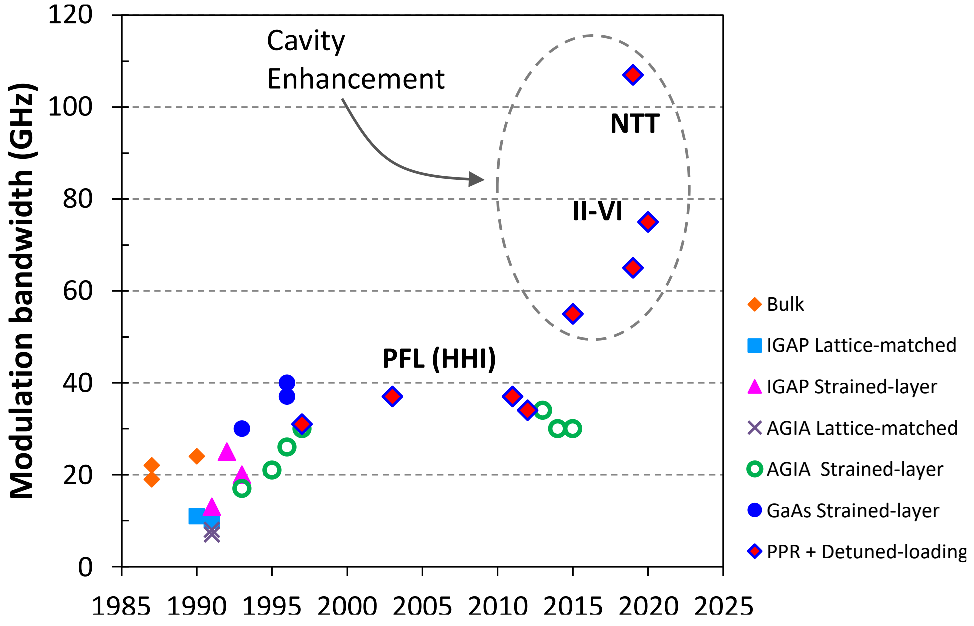
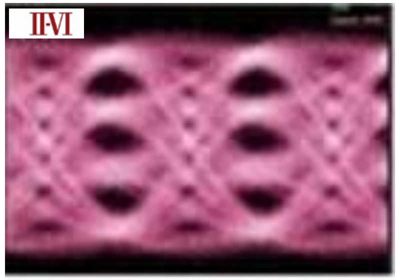
200G DML

- In recent years, a surge in DML (directly modulated laser) bandwidth has been reported
- A promising candidate is DFB-R laser, co-reported by II-VI
  - Uses detuned loading (leverages chirp to its advantage), photon-photon resonance, and in-cavity FM-AM conversion
  - 75 GHz bandwidth @60 mA, output power >20 mW, chirp param 0.6, Reflection tolerance >12%, RIN -150 dBc/Hz, 25 deg C.
- Further reading: Matsui, Y., Schatz, R., Che, D. et al. Low-chirp isolator-free 65-GHz-bandwidth directly modulated lasers. Nat. Photonics 15, 59–63 (2021). https://doi.org/10.1038/s41566-020-00742-2





106.2 Gb/s PAM4 eye diagram at 15 deg C for DR laser with a bandwidth of 65 GHz. The output of AWG (Keysight M8196A) was calibrated up to 40 GHz, including the frequency response of SHF RF amplifier, bias-T, and DR laser. Recorded in 2017.



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Photodiode, TIA and Laser Drivers

- Expected photodiode requirements
  - Bandwidth: ~70 GHz
  - Responsivity: ~0.8 A/W
- Expected TIA Requirements
  - Bandwidth: ~60 GHz
  - TIA transimpedance: ~3 kohms
  - TIA IRN: ~ 4 uA (rms)
- Expected Driver Requirements
  - Bandwidth: ~70 GHz
  - Output swing: ~1.5Vpp

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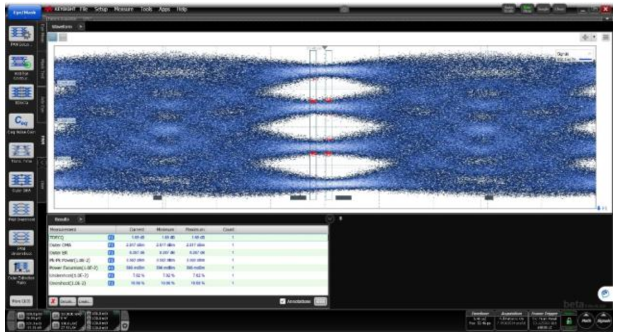
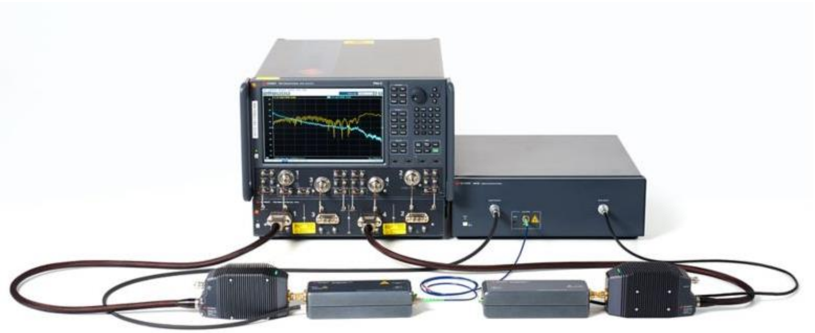
- Progress
  - Photodiodes are already becoming available
  - Thanks to coherent transmission products, TIA and Driver components are already feasible
    - 95 Gbaud components announced
    - Further work can focus on reducing power dissipation and optimizing for PAM
  - Newer processes with higher gain-bandwidth product are becoming available
  - Enable higher bandwidths and/or lower power
  - Expect new power-optimized devices for 100 Gbaud PAM4 to be announced by end of 2021
- Components can achieve the required bandwidths for 200 Gb/s PAM4
- System simulations indicate that PAM4 with KP4 FEC can give adequate BER performance using the expected requirements

Testing

- At 2x the signaling rate, key optical measurements methods will likely just scale
  - Through 802.3bs, 802.3cd, 802.3cu, TDECQ methodology has matured and proven itself
  - We still need to maintain interoperability: likely with more complex reference receiver
- Margins may be reduced, links may operate closer to FEC threshold
  - We will need to take greater care in characterizing mechanisms that produce error bursts (real-time scopes with FEC smarts)
  - PAM order higher than 4 is supportable, but SNR reduction likely degrades repeatability and sensitivity (12-edge analysis for PAM4 becomes 56-edge analysis for PAM8!)
- Time Frame
  - Expect a rollout similar to 100G/400G systems, evolving to keep pace with standards
  - Tools for early development exist today (very wide bandwidth oscilloscopes and optical network analyzers)





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Summary

- 200G PAM4 optical link up to 2 km appears feasible with direct detection
  - Can enable potential 800G-FR4, -DR4
- Components in the range of 55 to 70 GHz bandwidth are under development now
  - should be commercially available within the time frame of B400G project
- Continuing improvements in equalization techniques will help reduce burden on components
- Test instruments are expected to keep pace with the development of 200G lanes
- We have good reasons to be optimistic about the feasibility of 200G optical lanes