Statistical Study of NRZ, PAM-4, EDC, and Low-Cost Optics

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Supporters

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Objective

- Determine relative advantages of NRZ and PAM-4 when combined with EDC and low-speed optics under variety of conditions
- Vary channel length, channel model, EQ metric, laser rise time
- Overarching principle: simpler is better. NRZ should be used unless PAM-4 shows compelling advantage

Simulation Parameters

- 16 cases total
- Laser (2 cases)
  - Gaussian impulse response
  - 20-80% rise time
    - Case A: 47.1 ps (Nominal 10GBase-LR)
    - Case B: 80 ps (nominal 4G)
- Fiber Model (2 cases)
  - Case A: Cambridge data set (65 fibers), v2.0
    - 17, 20, 23u offset (195 sub-cases)
  - Case B: Gaussian

Simulation Parameters (cont'd)

- Fiber Length (2 cases)
  - Case A: 220m
  - Case B: 300m
- Receiver
  - 4th order Bessel Thompson
  - 3 dB Electrical BW: 7.5 GHz for 10G receiver
- Channel Metric (2 cases)
  - Case A: PIE-L
  - Case B: PIE-D

Calculation of Relative Margins

- Gaussian case
  - Relative margin is difference between PIE dispersion penalties for PAM-4 and NRZ
- Cambridge case
  - Relative penalty is difference between PIE dispersion penalties for PAM-4 and NRZ at 80% coverage
  - Each fiber/offset treated as a separate point in statistical population

Relative Margins

			Relative Margin (dB)	
PIE-D	Cambridge 2		220 m, 10G Rcv	300m, 10G Rcv
		Tx Speed 10G	N 1.5	N 1.1
		Tx Speed 4G	N 0.7	N 0.3
	Gaussian		220 m, 10G Rcv	300m, 10G Rcv
		Tx Speed 10G	P 0.8	P 1.5
		Tx Speed 4G	P 1.1	P 1.6

			Relative Margin (dB)	
PIE-L	Cambridge 2		220 m, 10G Rcv	300m, 10G Rcv
		Tx Speed 10G	N 0.6	P 0.3
		Tx Speed 4G	P 1.3	P 2.1
	Gaussian		220 m, 10G Rcv	300m, 10G Rcv
		Tx Speed 10G	P 4.5	P 4.1
		Tx Speed 4G	P 4.7	P 3.7

P n means PAM-4 is n dB optical better than NRZ

N n means NRZ is n dB optical better than PAM-4

NRZ better

PAM-4 better

Summary

- Gaussian channel model (more severe channel), PAM-4 is better in all cases
- Cambridge model, Linear Equalizer:
  - NRZ better at 220m with 10G Xmit
  - PAM-4 better at 300m or 220m with 4G Xmit
- Cambridge model, Decision Feedback Equalizer:
  - NRZ better in all cases (220 m or 300m, 10G or 4G xmit)

Conclusions

- With Cambridge model (current candidate for "official" model), NRZ better than PAM-4 in most cases of interest
  - Advantage could switch if:
    - Channel model gets worse (towards Gaussian), or
    - Limits are determined by linear equalizer capabilities (under certain conditions)
- Recommendation
  - NRZ should be baseline
  - PAM-4 should be employed if and only if needed as Task Force studies progress
- Area for further study: Low-speed receiver
  - Lower noise/greater distortion tradeoff