300 meters on installed MMF

Part I: Architectures

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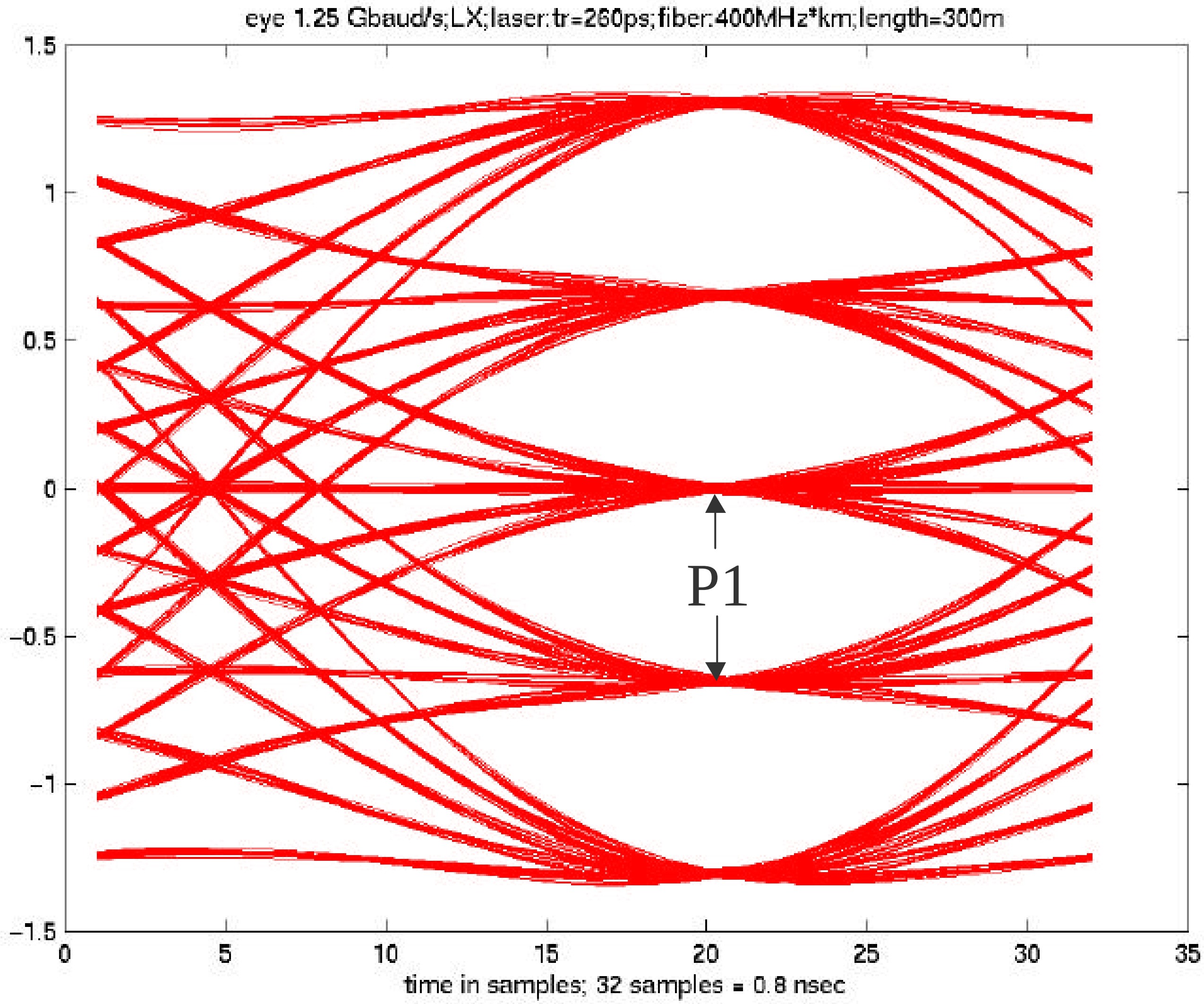
Objectives

- 300 meters provides an optimum coverage of installed multimode fiber
- compare proposed architectures that could support up to 300 meter link lengths on 50 um and 62.5 um MMF

Eye Patterns at fiber exit (1300 nm)

- Simulations use 1 GbE link model (see Ref 1) including laser rise-time, fiber modal and chromatic bandwidth, connector loss and cable attenuation at 1300 nm
- Simulated architectures:
  - PAM-5 + scrambling + 4-WDM @ 1.25 Gbaud/s
  - PAM-2 + 8b/10b + 4-WDM @ 3.125 Gbaud/s
  - PAM-5 + scrambling + serial @ 5 Gbaud/s

1.25 Gbaud/s - 300 meters



ISI loss = 0 dB

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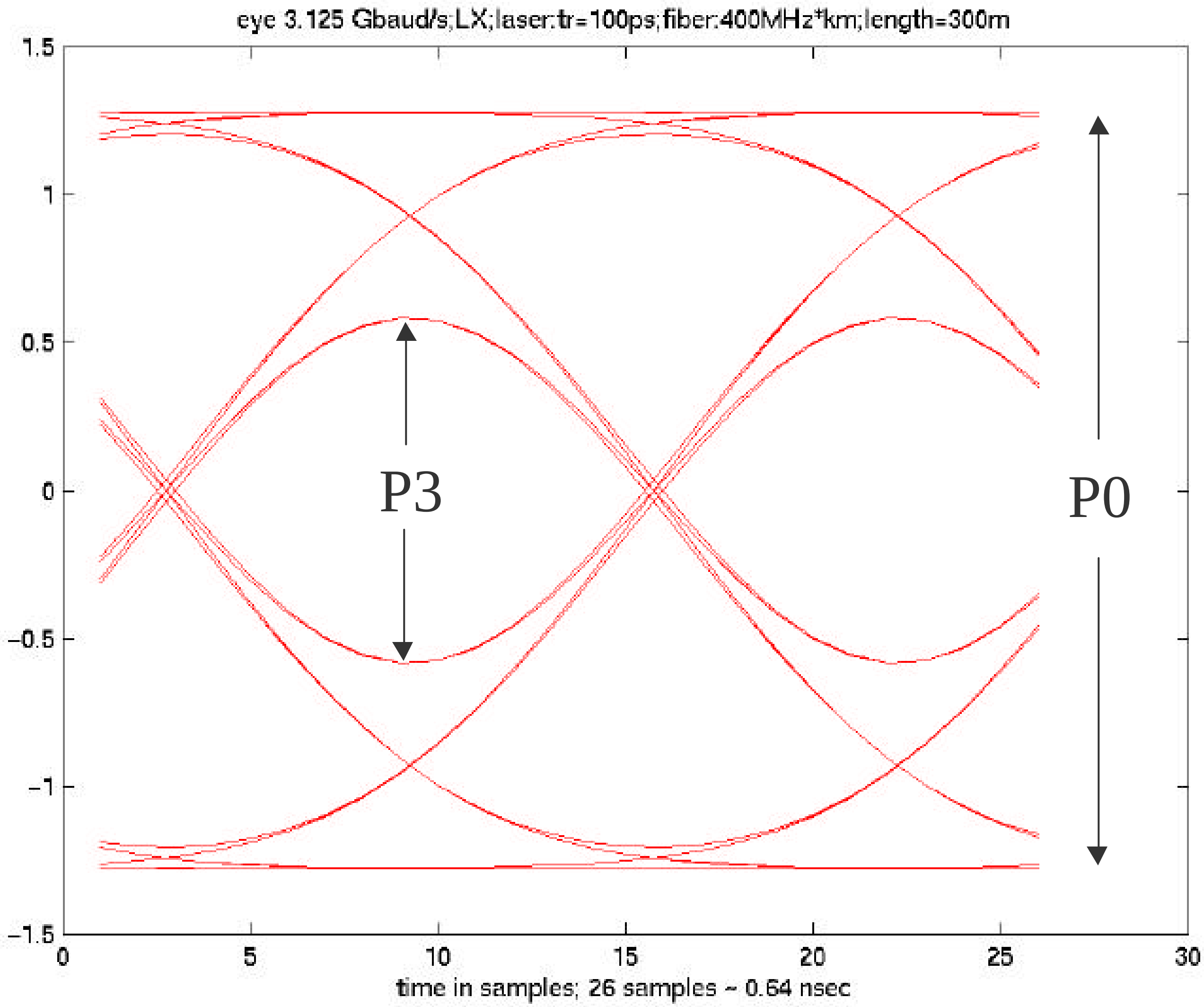
3.125 Gbaud/s - 300 meters



ISI loss = 10*log(P0/P3) ~ 3.5 dB

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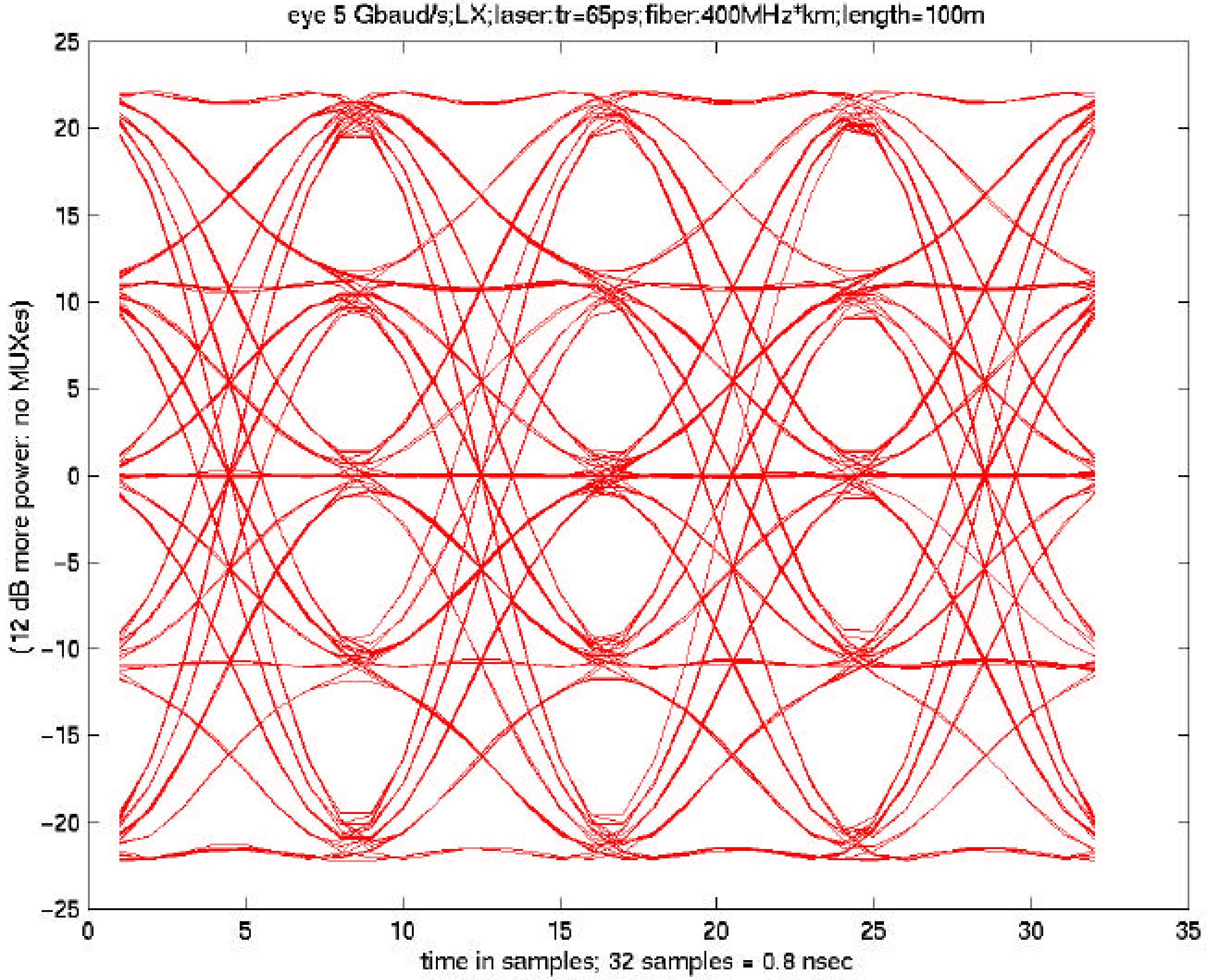
5 Gbaud/s - 100 meters (*)



(*) eye closed at 200 meters, even with 500 MHz*km fiber

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Eye patterns - 300m: Summary

- ISI is negligible at 1.25 Gbaud/sec
- The system running at 3.125 Gbaud/sec has a large ISI penalty loss.
- The architecture at 5 Gbaud/s can not be used with 300 meters fiber (the eye is already closed at 200 meters)

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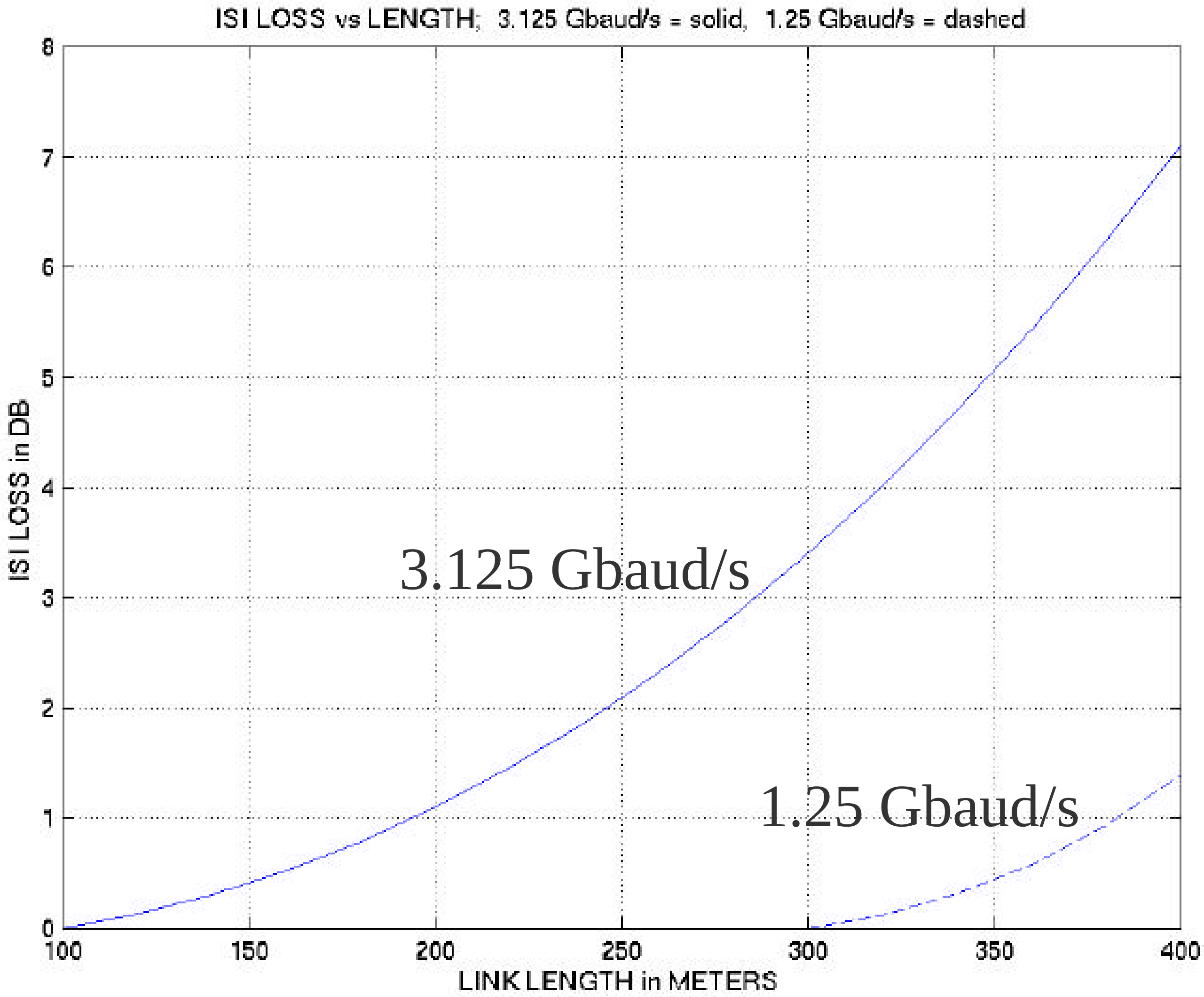
ISI LOSS vs LINK LENGTH



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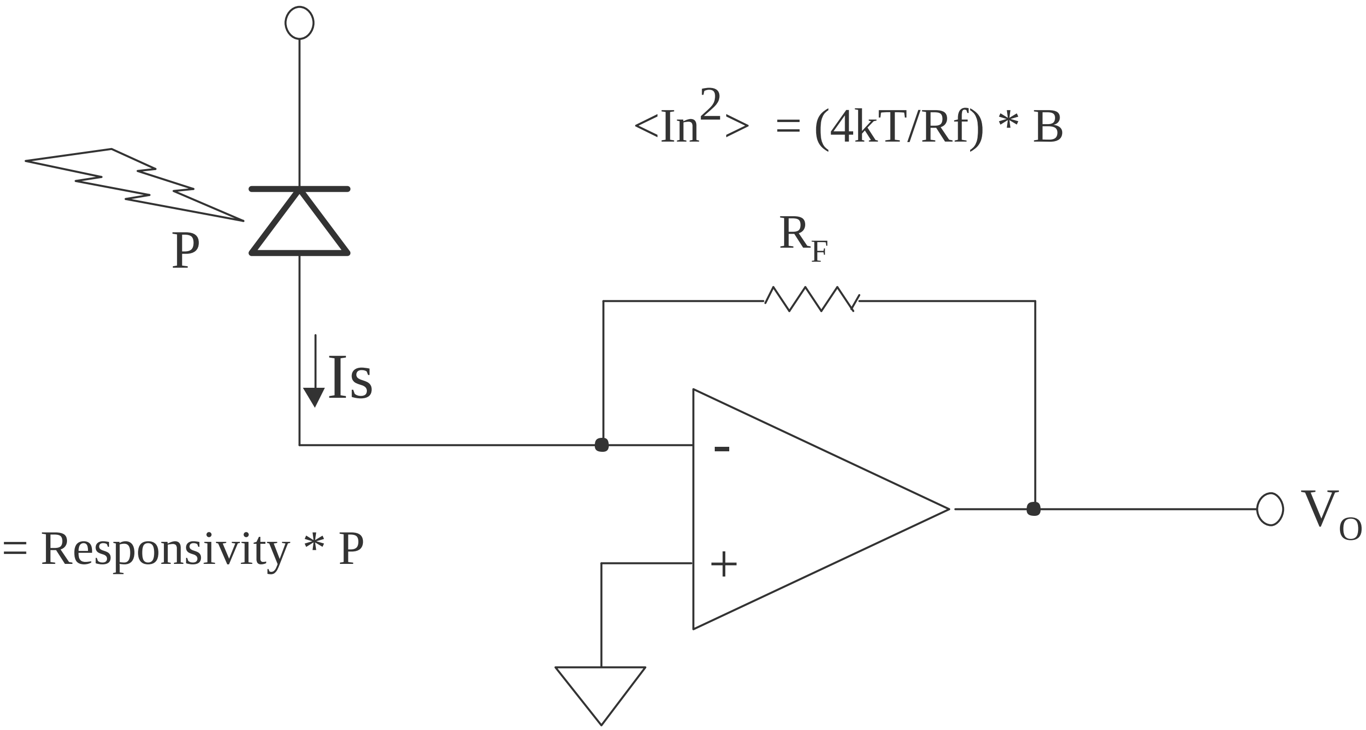
Receiver Front End

Assume PIN Photo Diode + Trans-Impedance Amplifier

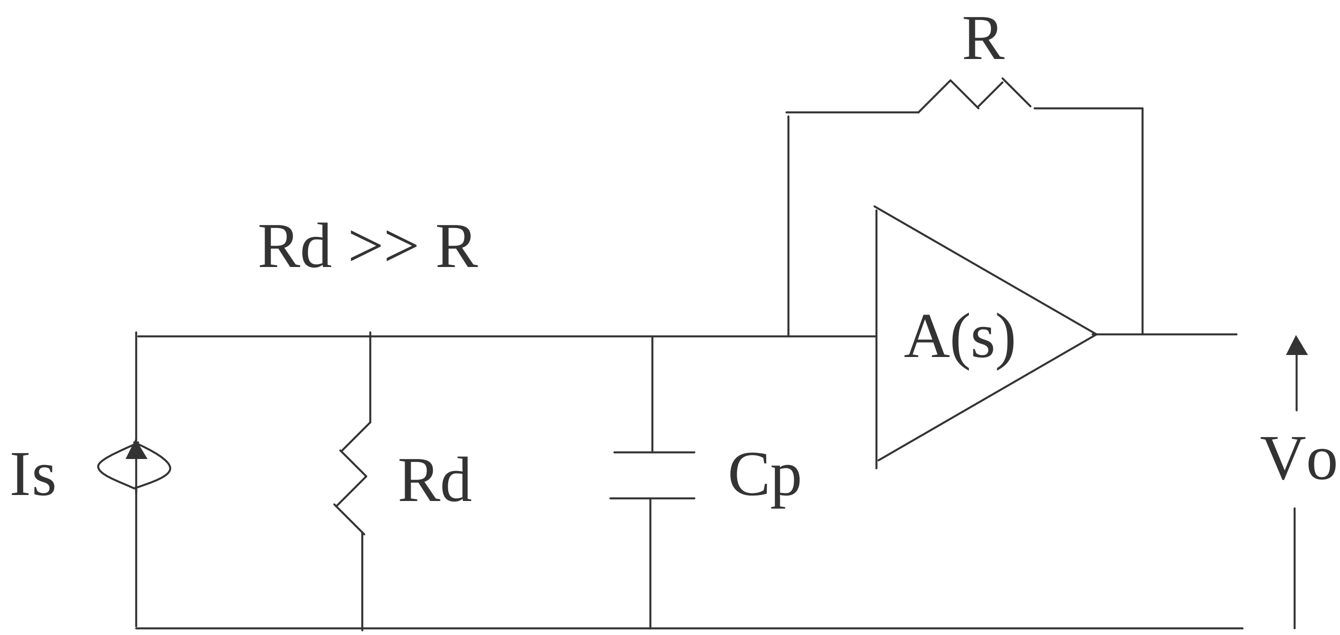


$\langle In^2 \rangle = (4kT/Rf) * B$

Is = Responsivity * P

Electrical SNR = $10 * \log (Is^2 / In^2)$

Small Signal Receiver Front End



$$A(s) = \frac{Ao}{1 + s/wa} \qquad wp = \frac{1}{R*Cp}$$

Small Signal Transfer Function

$$Vo/Is = -R * \frac{1}{1 + j*(1/Q)*(w/wo) - (w/wo)^2}$$

This is a 2nd order lowpass. wo = 2*pi*B. Usually, we set Q = 1/sqrt(2) (Butterworth).

Assuming Ao >> 1 and wa << wo we obtain:

$$wp = wo/Q$$

or

$$R = \frac{1}{Cp} * \frac{Q}{wo} = \frac{Q}{2*pi*Cp} * \frac{1}{B}$$

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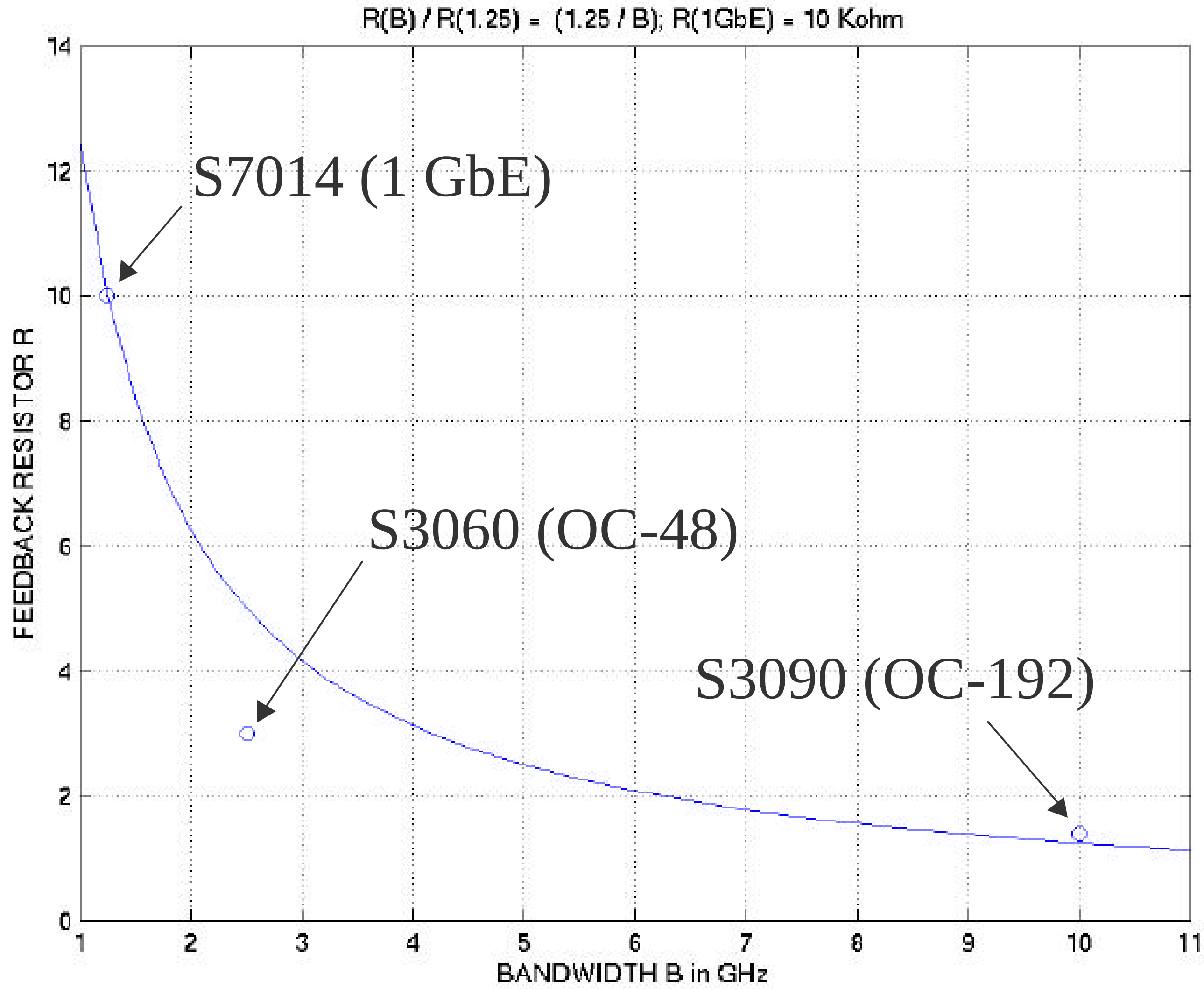
Feedback Resistor vs Bandwidth



AMCC's Transimpedance Amplifiers

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Thermal noise current

Replacing R into the equation for the thermal noise current, we finally obtain:

$$<In^2> = \frac{8*pi*k*T*Cp}{Q} * B^2$$

The thermal noise power is proportional to the **square** of the bandwidth B.

(for an alternative derivation see: Paul E. Green, “Fiber Optic Networks”, Prentice Hall, 1993, page 297, Eq 8.32)

Electrical SNR @ 300 m

Neglecting any coding gain of the 1.25 Gbaud/s system, the relative SNRs @ 300 meters are:

SNR(1.25Gb/s) - SNR(3.125Gb/s) =

$$= 10*\log(P1/P3)^2 + 10*\log(B3/B1)^2$$

with B3 = 3.125, B1 = 1.25. Hence,

SNR(1.25Gb/s) - SNR(3.125Gb/s) ~ -5 + 8= +3 dB

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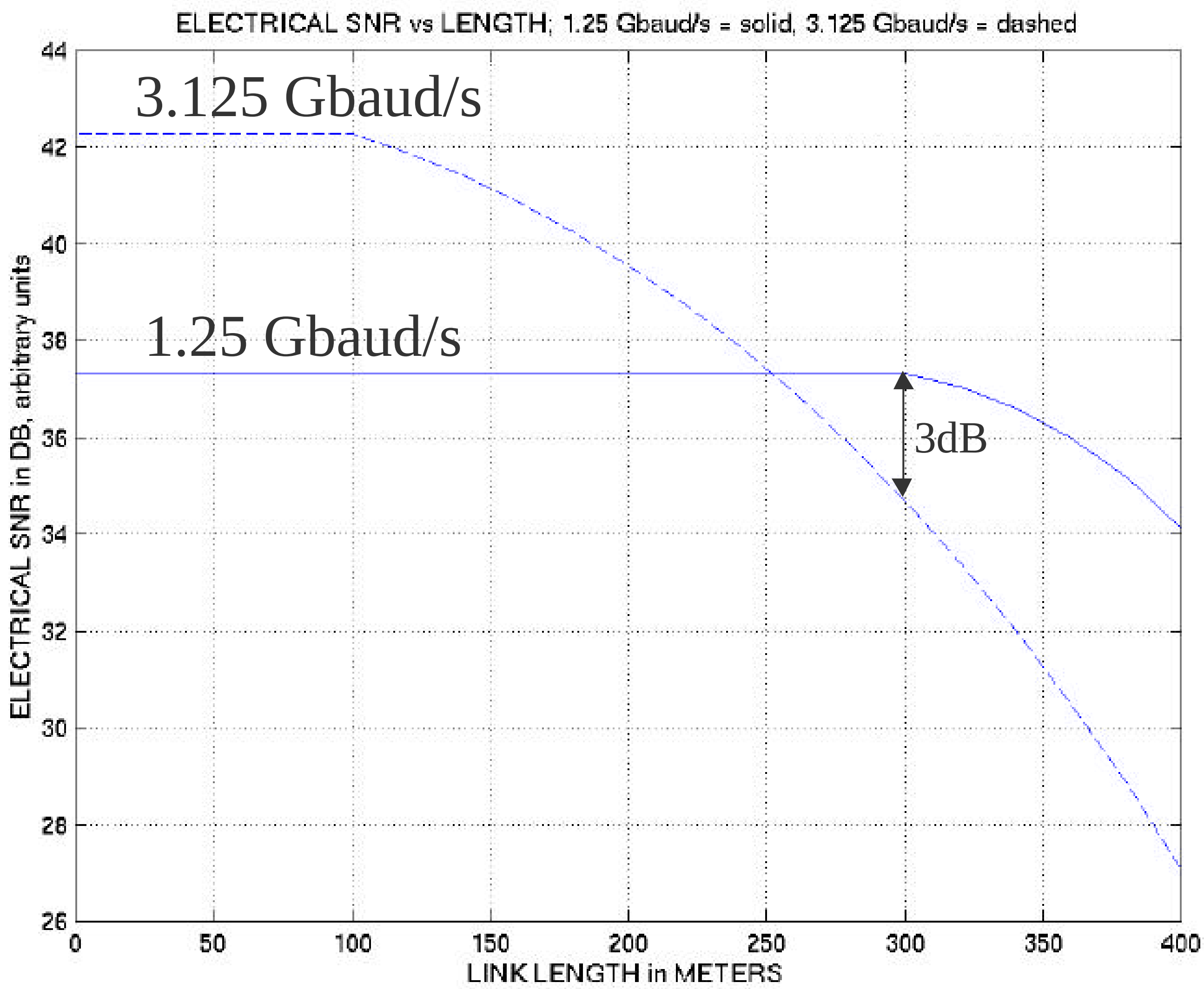
ELECTRICAL SNR vs LINK LENGTH



(coding gain @ 1.25 Gbaud/s not included. It would shift the curve up)

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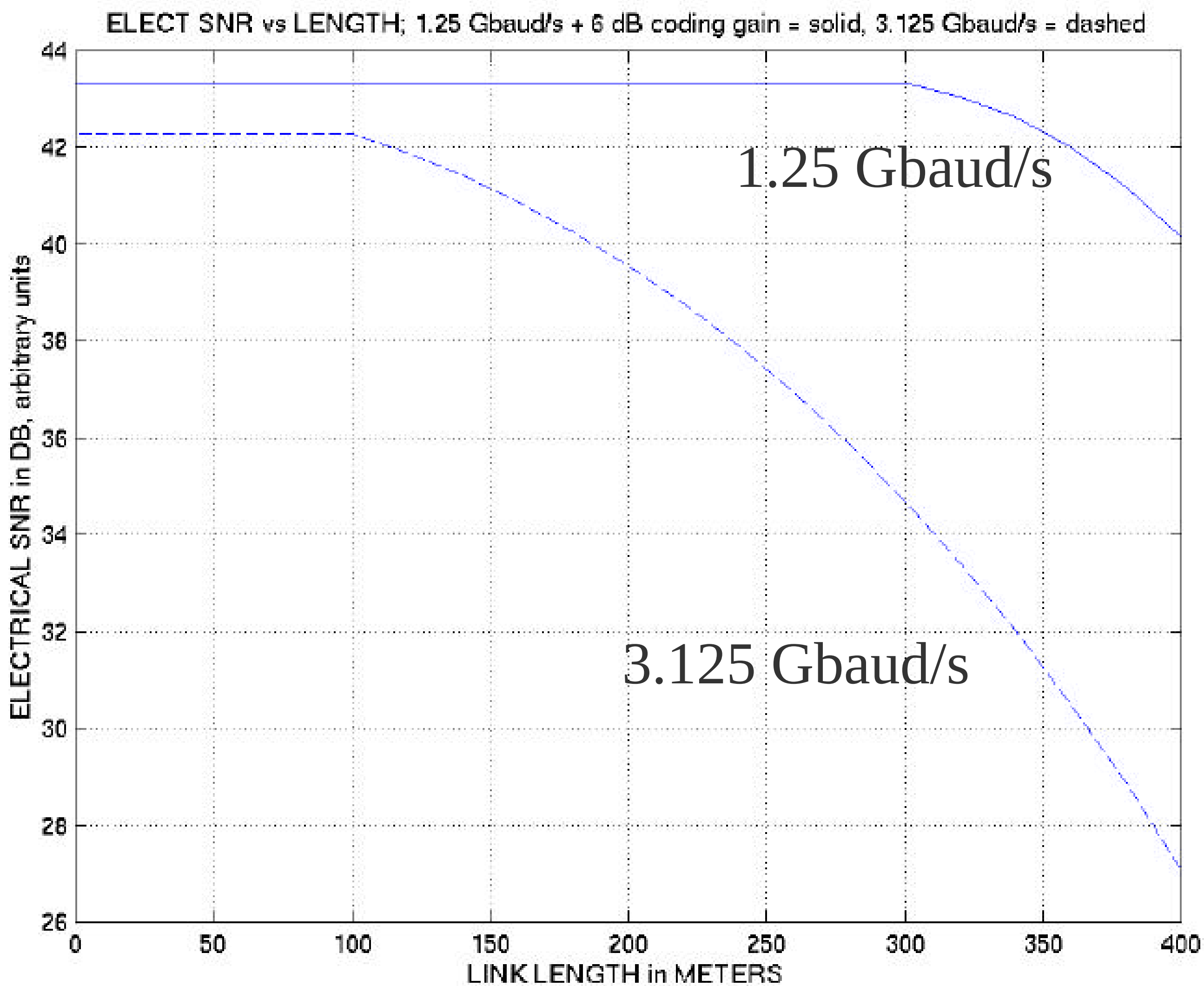
ELECTRICAL SNR vs LINK LENGTH



(coding gain of 6 dB @ 1.25 Gbaud/s included)

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Differential delay skew in 4-WDM

Use:

$$D = \frac{d}{d\lambda}\left(\frac{1}{Vg}\right)$$

(Vg = group velocity)

with D, a function of wavelength, given by Eq 9.10, Ref 1

Integrate:

$$D * d\lambda \quad = d\left(\frac{1}{Vg}\right)$$

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Differential delay skew

Differential delay between two wavelengths:

$$t2 - t1 = L^* \int_{\lambda_1}^{\lambda_2} D * d\lambda$$

where L is the fiber length

Differential Delay Skew

- Using wavelengths of 1280,1300,1320 and 1340 nm (see Ref 2), the differential delay skew between the extreme wavelengths is given by:
  - t4 - t1 ~ 0.33*L (L in meters, time in psec)
- @ 300 m the differential delay skew is 100 psec.
- Assuming one clock recovery per Rx (same sampling phase for the 4 channels), the 3.125 Gbaud/s system (with only 320 psec baud period) will be more sensitive to the delay skew penalty.

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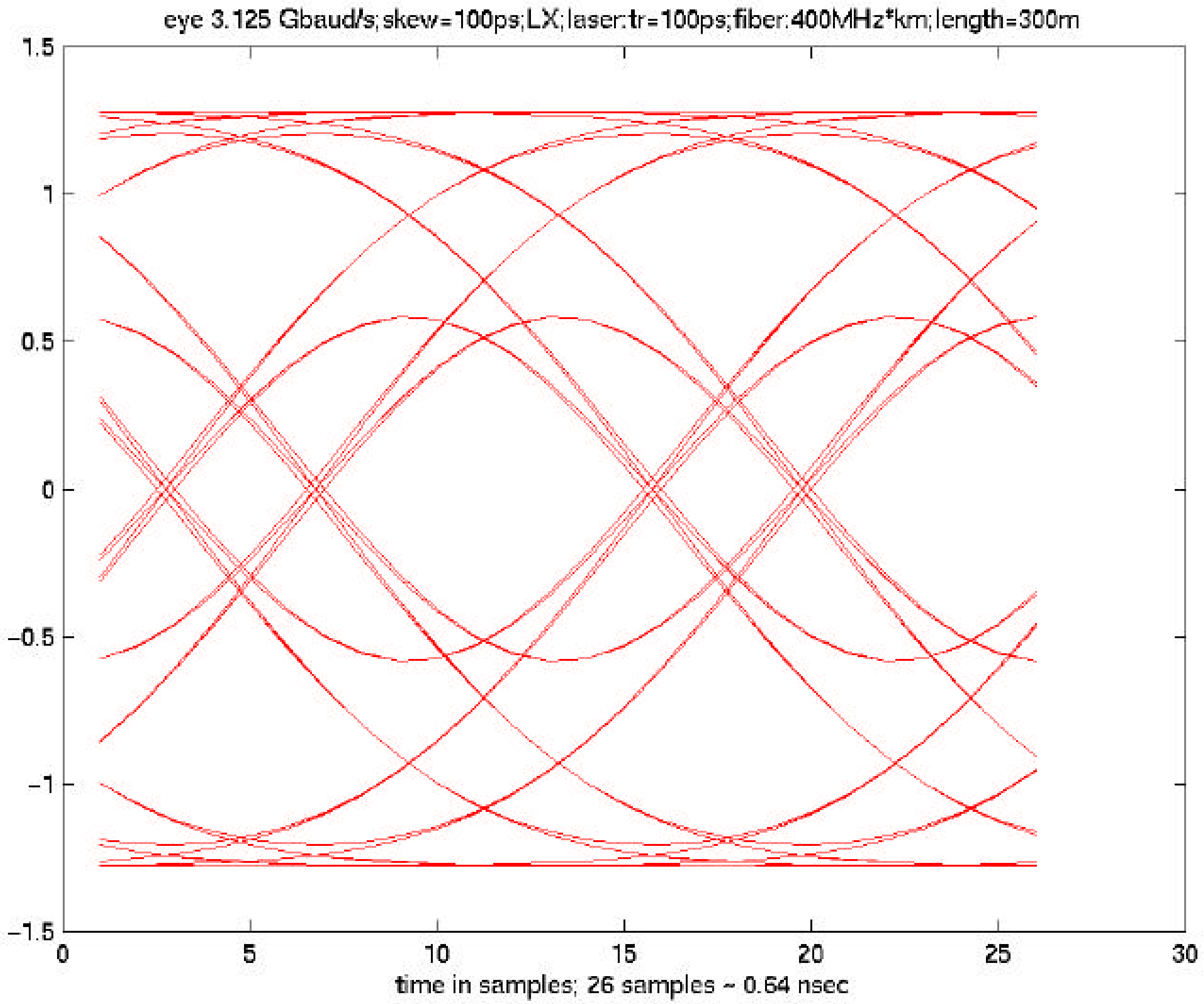
3.125 Gbaud/s -300 meters - delay skew effects



(superimposed extreme wavelengths' eye patterns)

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Summary of 3 architectures

PAM-5+ serial @ 5 Gbaud/s has a clear optical power advantage in shorter link lengths (no optical muxes), but ISI limits it to ~ 100 m link lengths.

8b/10b + 4-WDM@ 3.125 Gbaud/s provides a better coverage of the (0-200m) space, but at 300m ISI loss and delay skew penalty are large.

PAM-5 + 4-WDM @ 1.25 Gbaud/s becomes an attractive alternative, if used with coding gain, to provide the solution for the (0-300m) coverage space.

(continues in Part II)

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