OPTICAL SYSTEMS

System analysis

Fibre

Transmitter

Detector

Amplifiers/Regenerators

Examples

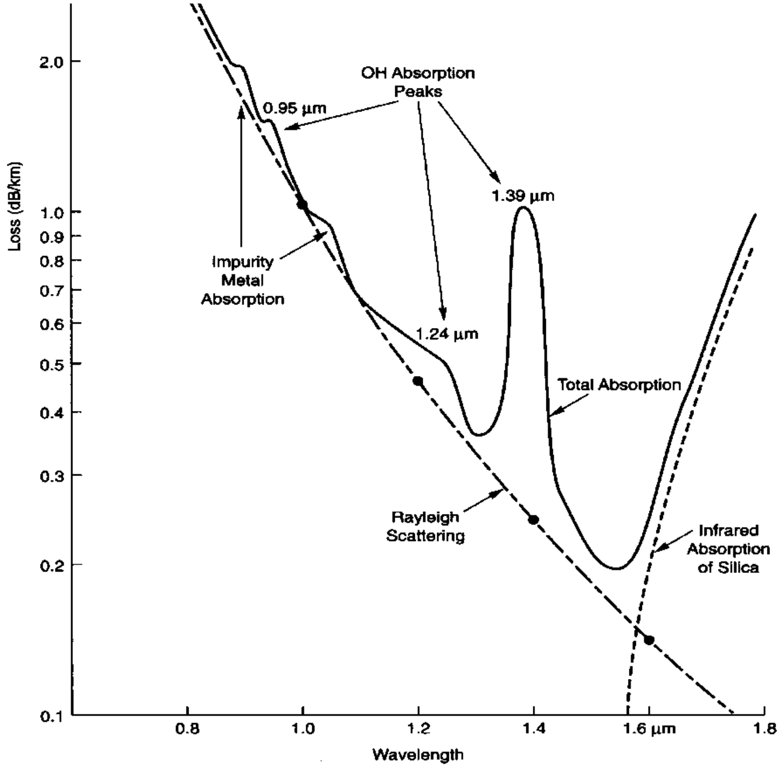
System Requirements

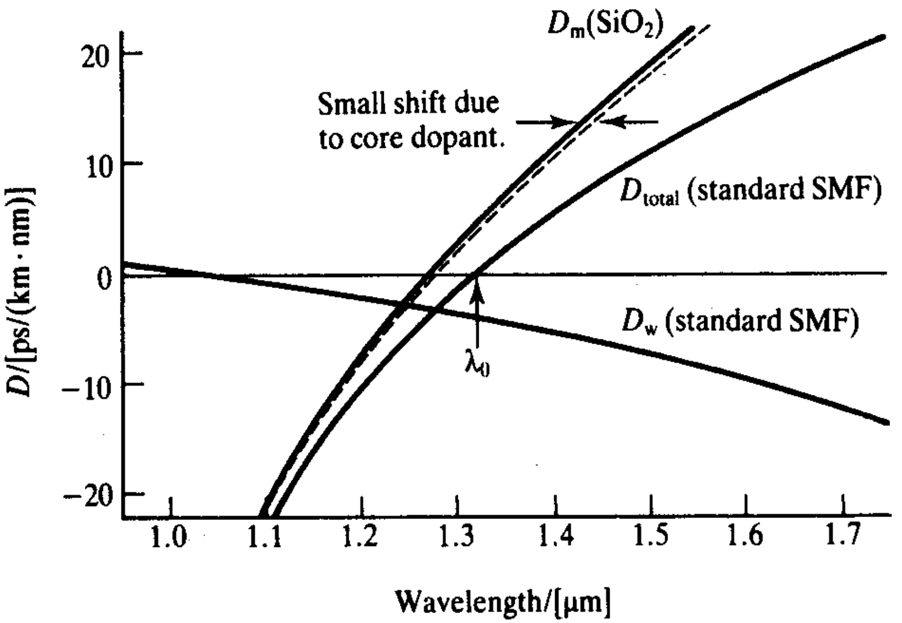
Require transmission at some data rate between points on a network with certain BER (10^{-9} – 10^{-12})

Build in options to increase data rate in future?

Fibre

Two key factors – Dispersion and loss





Affect system performance via making pulse less intense and broadening the optical pulse (n.b. polarization dispersion is ignored)

Transmitter

Wavelength
1.3 μ m, 1.55μm for Silica Fibre

Linewidth
LED ~100nm
Fabry-Perot Laser ~ 1nm
DFB Laser ~ 0.0001nm

Power
Need to couple light efficiently, robustly, cheaply, into fibre

Modulation Characteristics
LED – slow –spontaneous recombination
LD – fast – if modulated above threshold – but further implications
Broadening of linewidth with modulation (chirp)?

WDM?
Wavelength control, narrow linewidth

Detector

High Sensitivity – Low noise

-Internal Gain (APD)?

-external gain via boosting amplifier?

Fraction of incident light converted to current depends on depletion region width

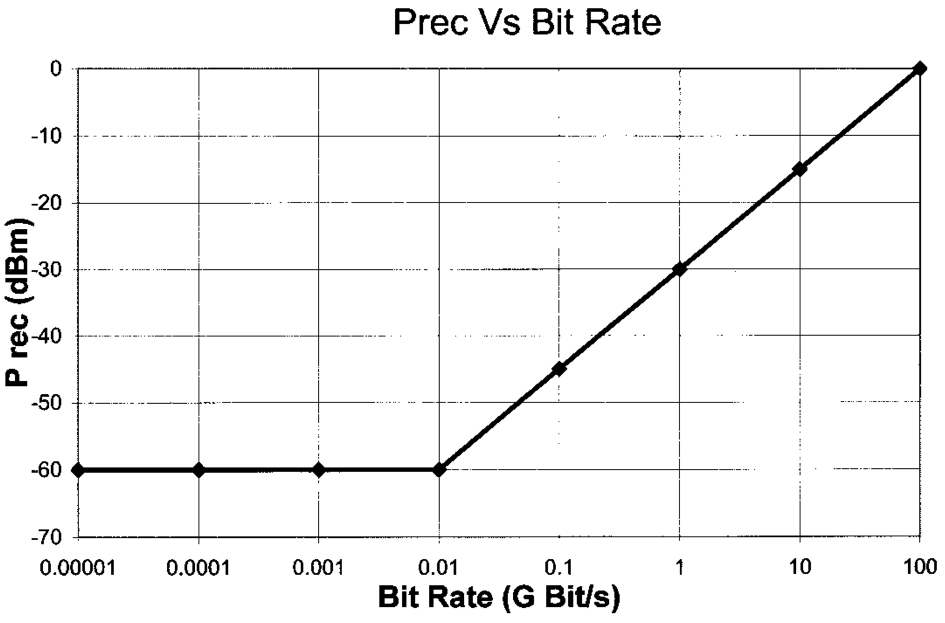
Speed – limited by depleted region width and area of diode

System Example

Single Mode Silica Fibre
Operating wavelength 1.55 μm at which wavelength D = 15 ps/nm.km
α=0.2dB/km

Transmitter Fabry Perot laser
AM with 50:50 mark:space ratio
Launches 2dBm of power in fibre
$\Delta\lambda$=1nm

Detector
p-i-n photodiode
Time averaged optical power
to measure a bit as a function of
bit rate is shown in the graph

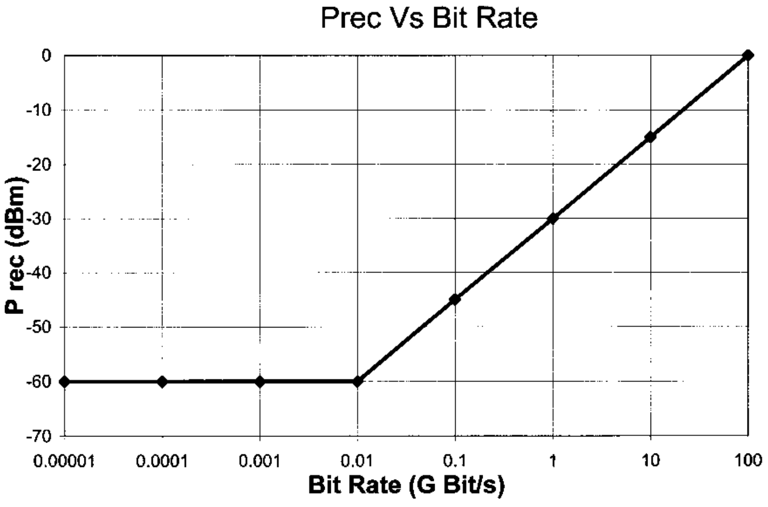


Loss Limits

Tx power - total loss+ amplification = margin + Rx sensitivity

@ < 0.01 Gbit/s: Loss + Margin = 62dBm   Loss = αL
$\rightarrow$ 310km Transmission Distance
@0.1 Gbit/s: Loss + Margin = 47dBm $\rightarrow$ 235 km Transmission Distance
@1 Gbit/s: Loss + Margin = 32dBm $\rightarrow$ 160 km Transmission Distance
@10 Gbit/s: Loss + Margin = 17dBm $\rightarrow$ 85 km Transmission Distance
@100 Gbit/s: Loss + Margin = 2dBm $\rightarrow$ 10 km Transmission Distance

Transmitter launches 2dBm of power



Dispersion Limits

Commonly used criterion is that broadening $\leq T_B/4$

$BL\Delta\lambda\ D(\lambda) \leq 1/4$

$D(\lambda) = 15$ ps/nm.km

For FP Laser $\Delta\lambda = 1$nm so

$\Delta\lambda\ D(\lambda) = 15$ ps/km $= 15\times10^{-15}$ s/m

$BL \leq 1/(60\times10^{-15})$ m/s

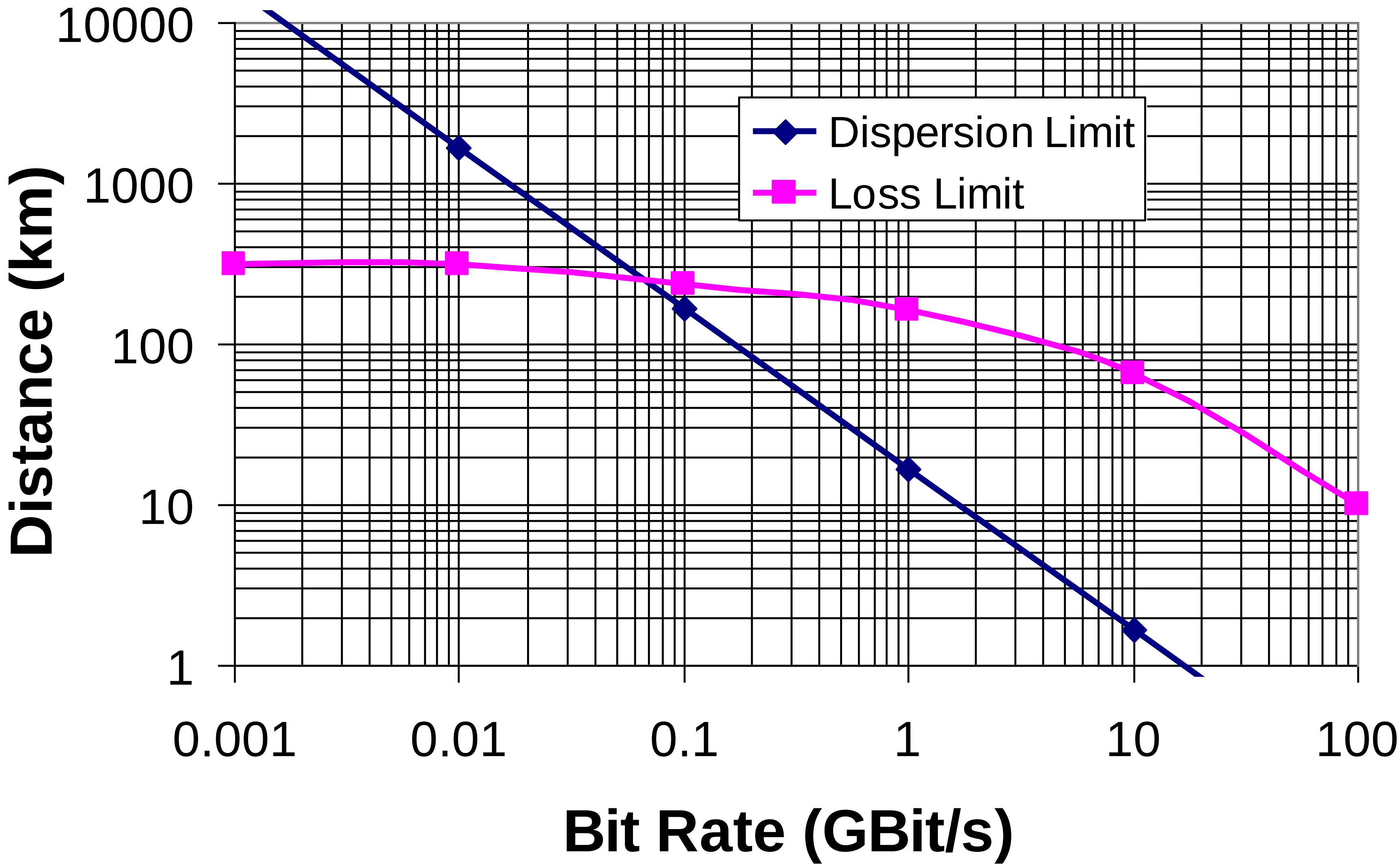
$BL \leq 1.67\times10^{13}$ m/s

Want B In GBit (10^9) and L in km (10^3)

So $BL \leq 16.7$ (Gbit/s.km)

B (Gbit)	Distance(km)
0.01	1670
0.1	167
1	16.7
10	1.67
100	0.167
1000	0.0167

Loss and Dispersion Limits - Silica Fibre



Plastic Optical Fibres

- Growing demand for delivering high speed services directly to work stations has led to development of high bandwidth graded-index polymer (plastic) fibres.

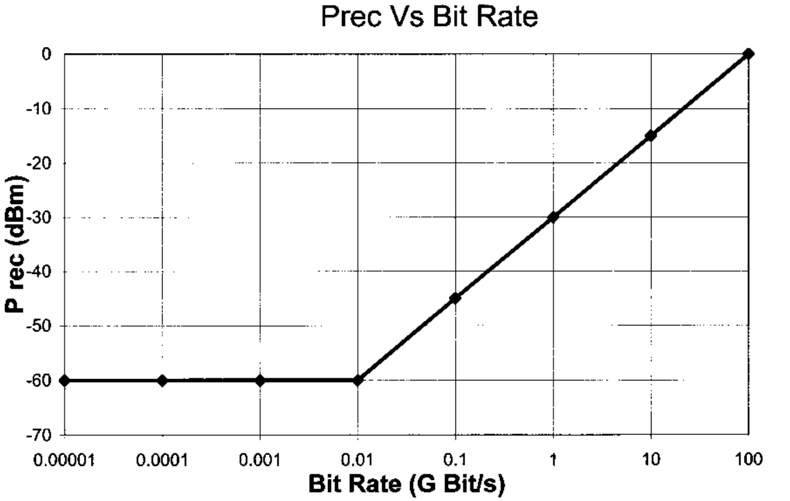
- Losses much greater than glass fibres but they are tough and durable. Core diameters 10x larger than glass and connector tolerances much larger.
- Cheap to manufacture.

Plastic Fibre Example

Multi Mode Plastic Fibre
Multimode plastic fibre operating at 650nm
Modal Dispersion = 300 ns/km, α=200dB/km

Two Transmitters
AM with 50:50 mark:space ratio
Both launch 2dBm of power in fibre
LED$\Delta\lambda$=100nm
FP $\Delta\lambda$=1nm

Detector
p-i-n photodiode
Time averaged optical power
to measure a bit as a function of
bit rate is shown in the graph



Loss Limits - Plastic

Tx power - total loss+ amplification = margin + Rx sensitivity

@ < 0.01 Gbit/s Loss + Margin = 62dBm   loss = αL

$\rightarrow$ 0.310 Km Transmission Distance

@0.1 Gbit/s Loss + Margin = 47dBm $\rightarrow$ 0.235 Km Transmission Distance

@1 Gbit/s Loss + Margin = 32dBm $\rightarrow$ 0.160 Km Transmission Distance

@10 Gbit/s Loss + Margin = 17dBm $\rightarrow$ 0.085 Km Transmission Distance

@100 Gbit/s Loss +Margin = 2dBm $\rightarrow$ 0.01 Km Transmission Distance

Dispersion Limits

Commonly used criterion is that broadening $\leq T_B/4$

BLD $\leq$1/4

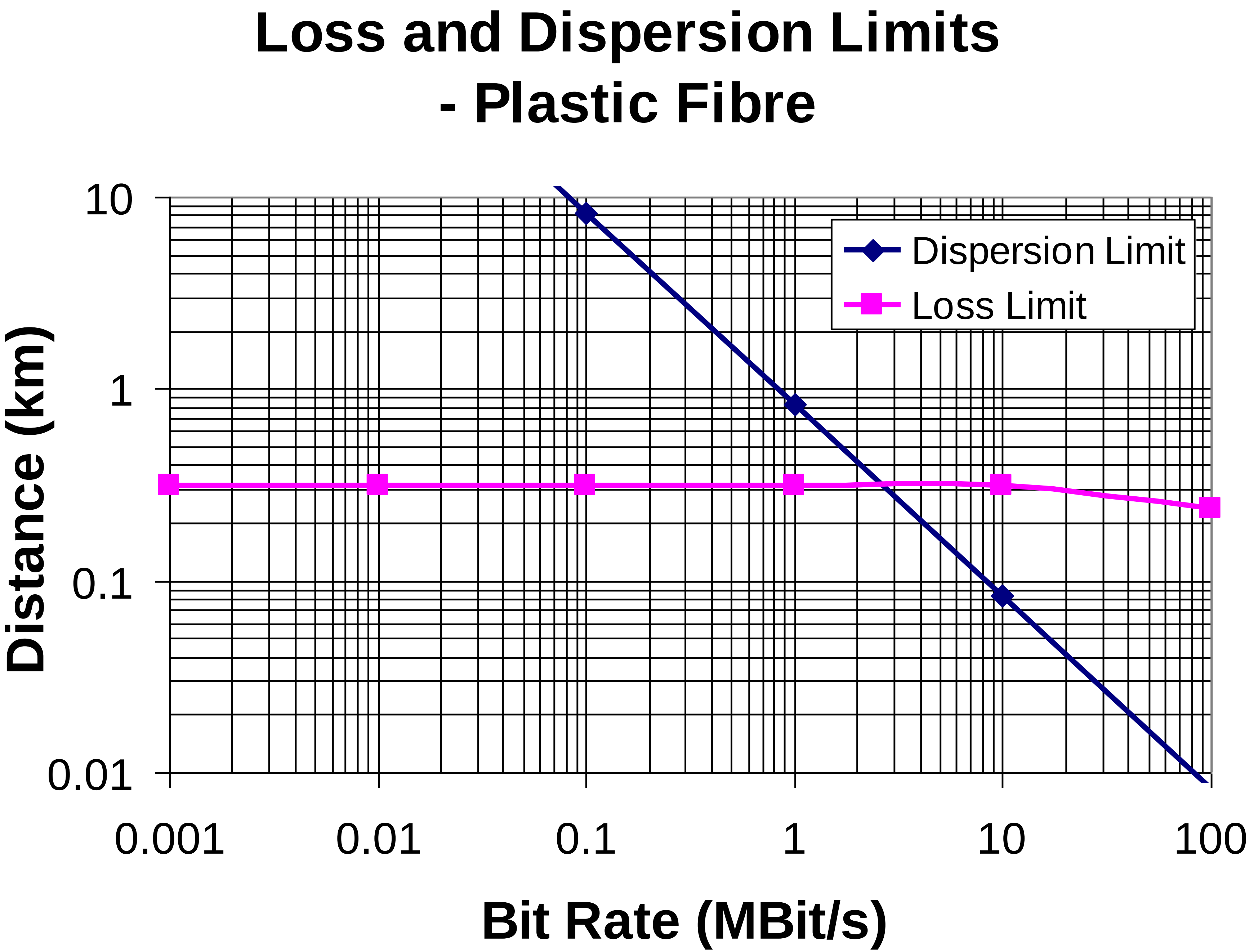
Modal Dispersion D = 300 ns/km

D = 300 ns/km = 300 x10^{-12} s/m = 3x10^{-10}

BL $\leq$1/ 1.2x10^{-9}
BL $\leq$8.3x10^{8} m/s

Want B in MBit (10^6) and L in km (10^3)
So BL$\leq$0.83 (Mbit/s.km)

B (Mbit)	Distance(km)
0.01	83
0.1	8.3
1	0.83
10	0.083
100	0.0083



Loss and Dispersion Limits
- Plastic Fibre
Distance (km)
10
1
0.1
0.01
0.001
0.01
0.1
1
10
100
Bit Rate (MBit/s)
Dispersion Limit
Loss Limit

Summary

Complex interplay between fibre dispersion and loss characteristics as a fn of wavelength and transmitter and receiver performance.

Required data rate, bit error rate, and link length will typically determine the wavelength of operation and result in either loss or dispersion being a limiting factor.

This in turn will determine the use of amplifiers or regenerators for long link lengths.

Example

In a certain optical fibre communication system the receiver needs a minimum power at the photo detector of -50 dBm. The transmitted power is 1 dBm and the link losses are:

Fibre loss 2dB/km Splice loss 0.2dB/km

Two connector losses at 4dB each Operating margin 10dB

(a) Calculate the maximum link length,

(b) If the fibre dispersion is 0.7 ns/km, for the length of fibre found in (a) determine the maximum transmission bit rate,

(c) Derive an expression for the bitrate-length product in relation to fibre dispersion for a NRZ pulse stream. Calculate the maximum bitrate for a length of 30 km.

(i) Power budget: $P_T = P_R + (\alpha_{fc} + \alpha_j)L + L_c + M$

$1 = -50 + (2 + 0.2)L + 2x4 + 10$

<u>hence L = 15 km</u>

(ii) Dispersion over length L, $\tau = 0.7 \times 15 = 10.5$ ns

Max bite rate $B_T = 1/2\tau$ = <u>47 Mb/s</u> OR $1/\tau$ = <u>94 Mb/s</u>

(iii)

Commonly used criterion is that broadening $\Delta t \leq T_B/4$

$\Delta t = L\Delta\lambda\, D(\lambda)$

$L\Delta\lambda\, D(\lambda) \leq T_B/4$

$BL\Delta\lambda\, D(\lambda) \leq 1/4$

<u>$BL=1/[4\, \Delta\lambda\, D(\lambda)]$</u>

Note: $\Delta\lambda\, D(\lambda)$ often quoted as dispersion in ns/km

So bitrate- length product is $B \times L = 1/(4\, \Delta\lambda\, D(\lambda))$ MHz.km

<u>For a length of 30 km, B = 1/(4x0.7x30) = 11.9 Mb/s.</u>