Topic 9

9. System design (using WDM system as an example)

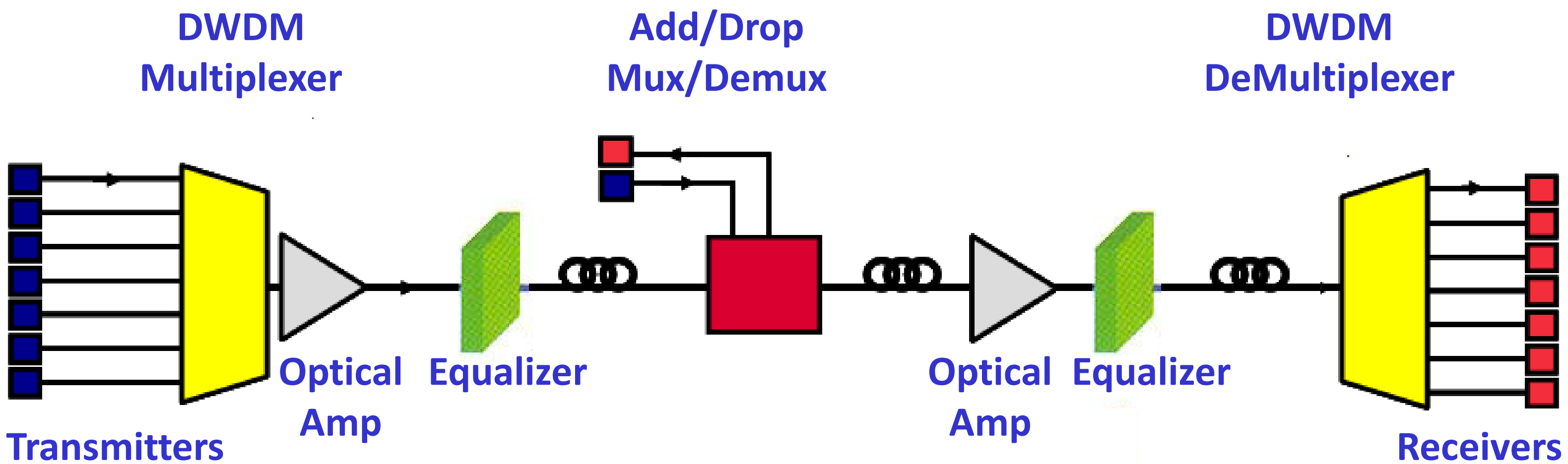
9.1 Communication system structure and components

9.2 Optical loss and optical dispersion

9.3 Optical Power Budgeting

9.4 Time Budgeting (discussed later)

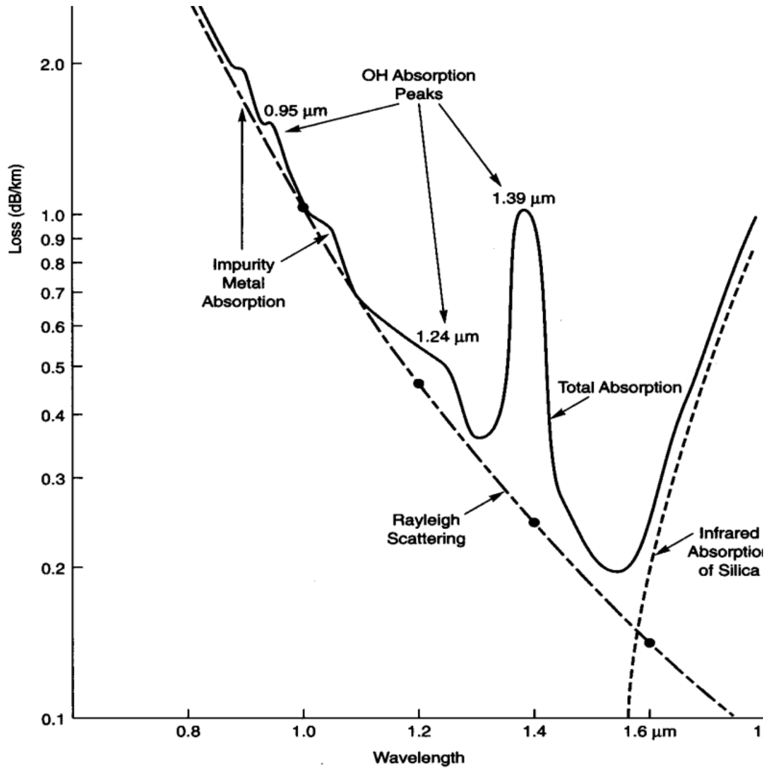
Wavelength Division Multiplex (WDM) Systems

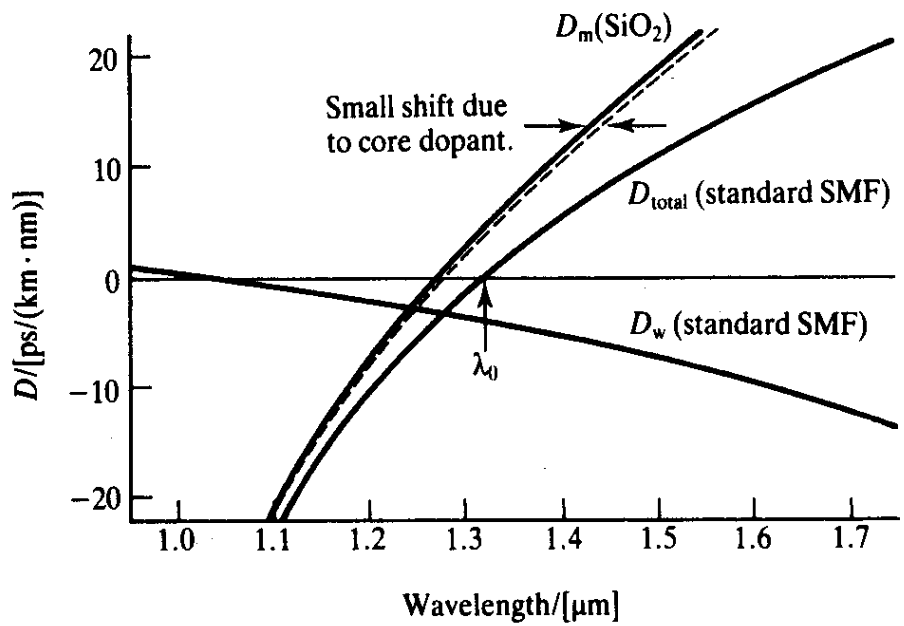


•A schematic of a **simple DWDM System, and it has contained all necessary components**

Multiple channel signals can be carried over a single optical fibre without interference, each using an individual wavelength

Optical Fibre





- Two key issues – **optical loss** and **optical dispersion**
- Single mode fibres are used in DWDM networks to achieve a high total capacity
- Minimal loss can be obtained at **~1.55 µm**, very important for long distance communication
- Minimal dispersion can be obtained at **~1.3 µm**

Optical Transmitter

- **Wavelength for optical source**
  The best wavelength is either 1.3 μ m or 1.55μm

- **Optical source:** a highly stabilized semiconductor emitter
  i) Semiconductor LED: ~100nm
  ii) Semiconductor LD:

  $$BL \propto \frac{L}{\Delta\tau} = \frac{L}{L\Delta\lambda D} = \frac{1}{\Delta\lambda D}$$

  $$\Delta\tau = L\Delta\lambda D$$

  Allow for modulation of light source at a very high bit rate
  Narrow line width: minimising dispersion,
  Fabry-Perot Laser: ~ 1nm
  DFB Laser: ~ 0.0001nm
  VCSEL laser: <1 nm

- **Modulation Characteristics**

LD – fast – if modulated above threshold

LED – slow –spontaneous recombination

$f \sim 1/\tau_{stim}$,	$\tau_{stim} \sim 10ps$,	$f \sim 100GHz$
$f \sim 1/\tau_{spon}$,	$\tau_{spon} \sim 10ns$,	$f \sim 100MHz$

Optical Receivers

- High Sensitivity – Low noise

$$L_{\max} = \frac{10}{\alpha}\log\left(\frac{p_i}{N_p Bhc/\lambda}\right)$$

$$BER = \tfrac{1}{2}\left[1 - erf\left(\frac{1}{2\sqrt{2}}\frac{S}{N}\right)\right]$$

- Speed – limited by depletion region width and area of photo-detector

- Optical receivers have to be operated at high frequencies.
(i) PIN photodiodes; or (ii) avalanche photo Diodes (APD) are typical optical receivers

Optical Amplifiers

•Introduction of optical amplifiers has led to the 4th generation of optical communication systems.

•By using an optical amplification scheme the total capacity of optical communication systems can be tremendously increased.

•Different optical amplification schemes are known. However, the most important optical amplifier is based on EDFA operating at a wavelength range of 1.55 um

• Optical Amplifiers can only amplify intensity, but cannot compensate for dispersion.

• Amplifiers can be used (i) prior to receivers to boost sensitivity (Receive Pre-amplification); (ii) after transmitter to boost power (Power amplification; (iii) in between instead of regenerators (In-line amplification)

Optical Dispersion(1)

Main mechanisms for optical dispersion:

1) Material dispersion
2) Wave guide dispersion
3) Modal dispersion: does not occur to single mode fibres

Optical Dispersion(2)

1) Material dispersion

   An optical pulse consisting of different wavelengths each travelling at different speeds.

The spreading of the pulse due to material dispersion: $\boxed{\Delta\delta = |D_m| \bullet \Delta\lambda \bullet L}$

(D_m: dispersion coefficient of material)

2) Wave guide dispersion

   Different refractive indices in the core and the cladding layers leads to a different propagation speed in the core and the cladding.

The spreading of the pulse due to waveguide dispersion: $\boxed{\Delta\delta = |D_w| \bullet \Delta\lambda \bullet L}$

(D_w: dispersion coefficient of waveguide)

In both cases, optical broadening is related to the **linewidth of optical source**

Dispersion Limits

For a Gaussian pulse,
B: Bit-rate; L: distance

$$BL \propto \frac{L}{\Delta\tau}$$

$$\Delta\tau = L\Delta\lambda D$$

- For a fibre link, a maximum pulse broadening of 50% of a bit slot is permitted. $D_{total}(\lambda)$= 15 ps/nm.km; A FP Laser $\Delta\lambda$=1nm is used

$$BL = \frac{0.5}{\Delta\tau} L$$

Therefore, (1) $\Delta\lambda\ D_{total}(\lambda)$ = 15 ps/km; (2) BL ~33.3x10^9 km/s

Want B in GBit (10^9) and L in km (10^3)
So BL≤33.3 (Gbit/s.km)

B (Gbit)	Distance (km)
0.01	3330
0.1	333
1	33.3
10	3.33
100	0.333
1000	0.0333

- **High bit-rate: sacrificing transmission distance**
- **Long transmission distance: sacrificing bit-rate**

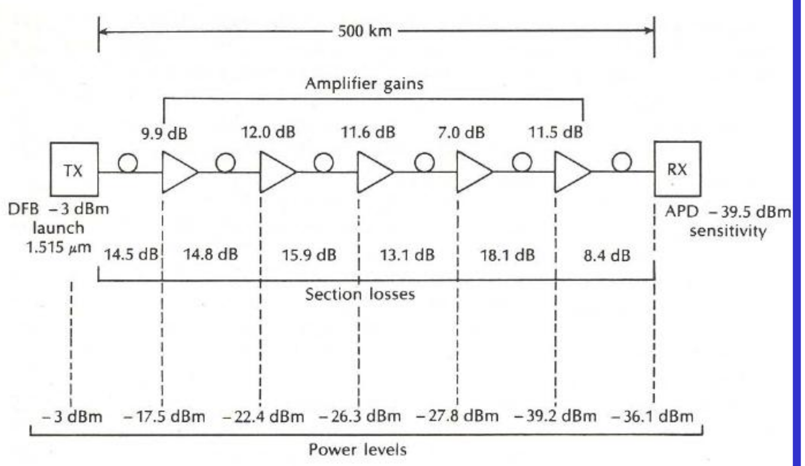
Optical Power budget-1

The overall attenuation: the sum of the actual fibre attenuation plus the attenuation due to fibre connectors and fibre splices

Optical gain: Due to optical amplifiers

Attenuation and gain: expressed in terms of per kilometer:

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



- **Optical power of the transmitter**: -3dBm (0.5mW)
- **Receiver sensitivity**: -39.5dBm (112nW).

The system has a power budget of 36.5dB.

Overall loss:

14.5 + 14.8 + 15.9 + 13.1 + 18.1 + 8.4 = 84.8 (dB)

Overall amplification due to OAs:

9.9 + 12 + 11.6 + 7.0 + 11.5 = 52(dB)

- This corresponds to a total loss of the system of 32.8dB which is smaller than the power budget

- we get a margin of 3.7dB.

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

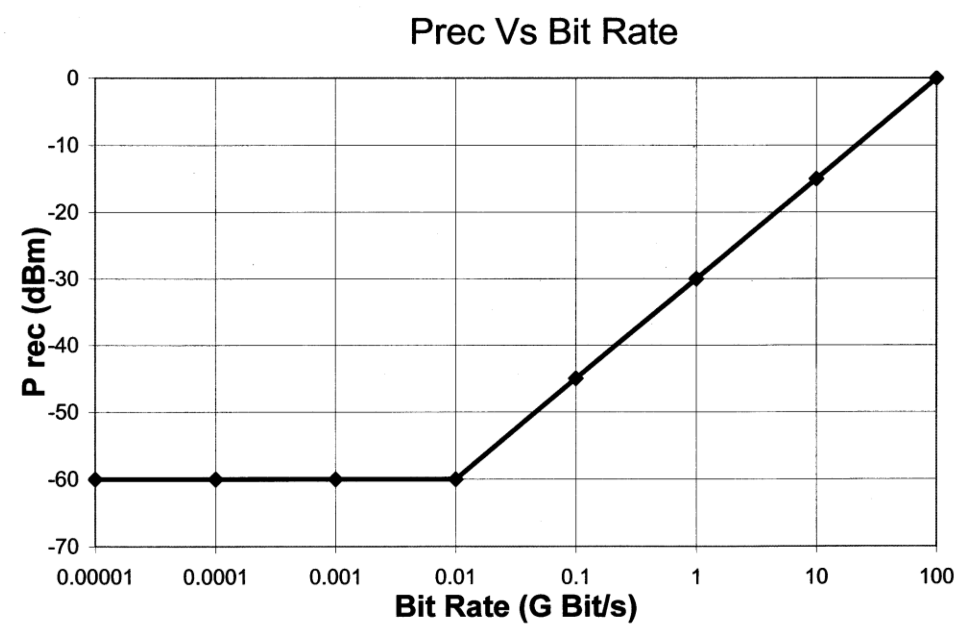
Launches 2dBm of power in fibre

$\Delta\lambda$=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

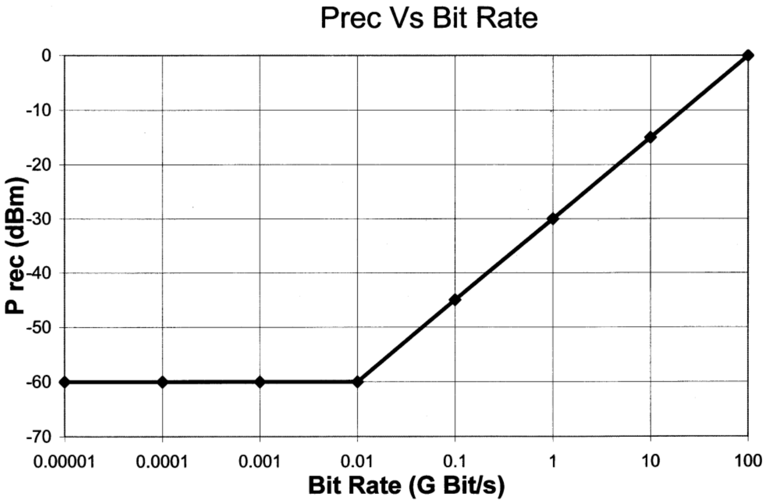


Loss Limits

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

@ < 0.01 Gbit/s Loss + Margin = 62dBm → 310km (zero margin), 280km (6 dB margin)
@ 0.1 Gbit/s Loss + Margin = 47dBm → 235 km (zero margin), 205km (6 dB margin)
@1 Gbit/s Loss + Margin = 32dBm → 160 km (zero margin), 130km (6 dB margin)
@10 Gbit/s Loss + Margin = 17dBm → 85 km (zero margin), 55 km (10 dB margin)
@100 Gbit/s Loss + Margin = 2dBm → 10 km (zero margin),

Transmitter launches 2dBm of power



T9 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.

T9 Tutorial Questions

T9.1 Sketch the loss and dispersion as a function of wavelength for a typical single mode fibre indicating key wavelengths

T9.2 Define limits for a loss limited system, and a dispersion limited system

T9 Tutorial Questions

T9.3 An optical fibre link consists of a transmitter, a single mode optical fibre and a photodetector. The transmitter operates at 1.55μm, has a linewidth $\Delta\lambda$ of 1nm, launches a power Pmax = 10mW into the fibre, and transmits digital pulses with a 1:1 mark:space ratio at a rate of 1 Gbits/s. The fibre has a total optical loss (fibre only) α of 0.2 dB/km and a dispersion coefficient D of 15 ps/(km.nm). The detector detects all light which reaches the end of the link and requires a minimum power of Pmin = 0.1mW at this bit rate. Calculate the maximum length of the link if no margin is required for the system. Describe any assumptions made. If a margin of 18 dB is required for the system, calculate the maximum transmission distance.

Terminology issues

Several examples:

Collimate
Momentum conservation
Phonon
Velocity and speed
Band offset
Relaxation oscillation
Threshold current
Multiplication factor

Suggestions:

Have a look at the index of reference book