VPI University Program

Photonics Curriculum Version 7.0

Lecture Series

Introduction to WDM Systems

Systems 1

Module Prerequisites

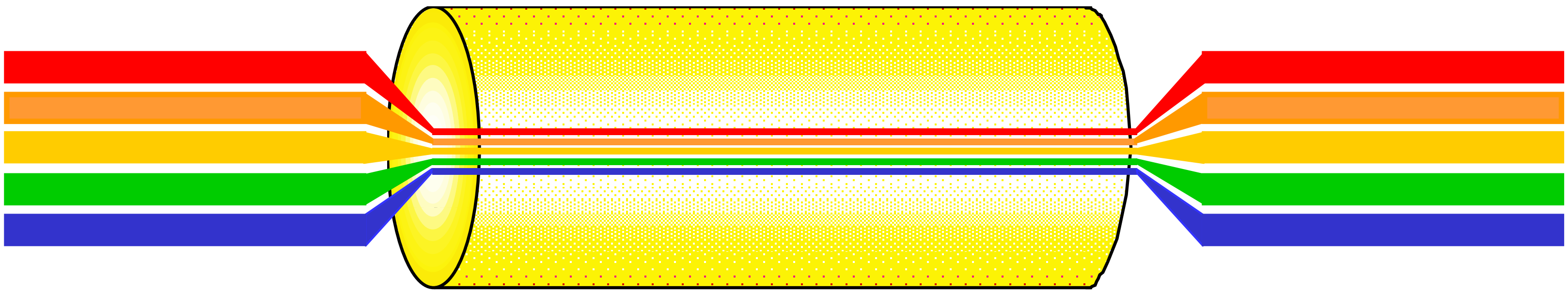
- Introduction to Fiber-Optic Communications I & II
- Recommended – Fibers I and Optical Amplifiers I

Module Objectives

- Wavelength Division Multiplexing (WDM) concepts
- WDM System components
- Key Issues in WDM System design

WDM Concepts

Optical Fiber – transmission of many λ's

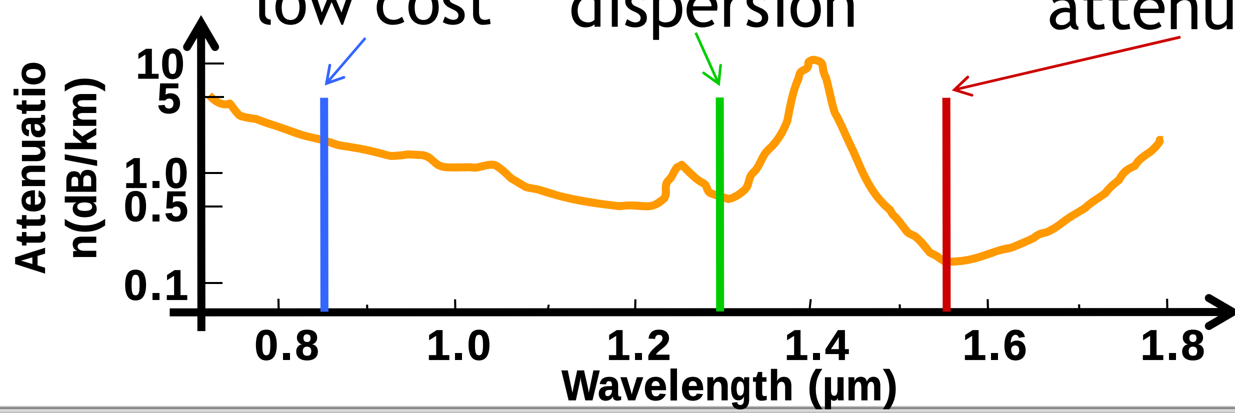


Which wavelengths?

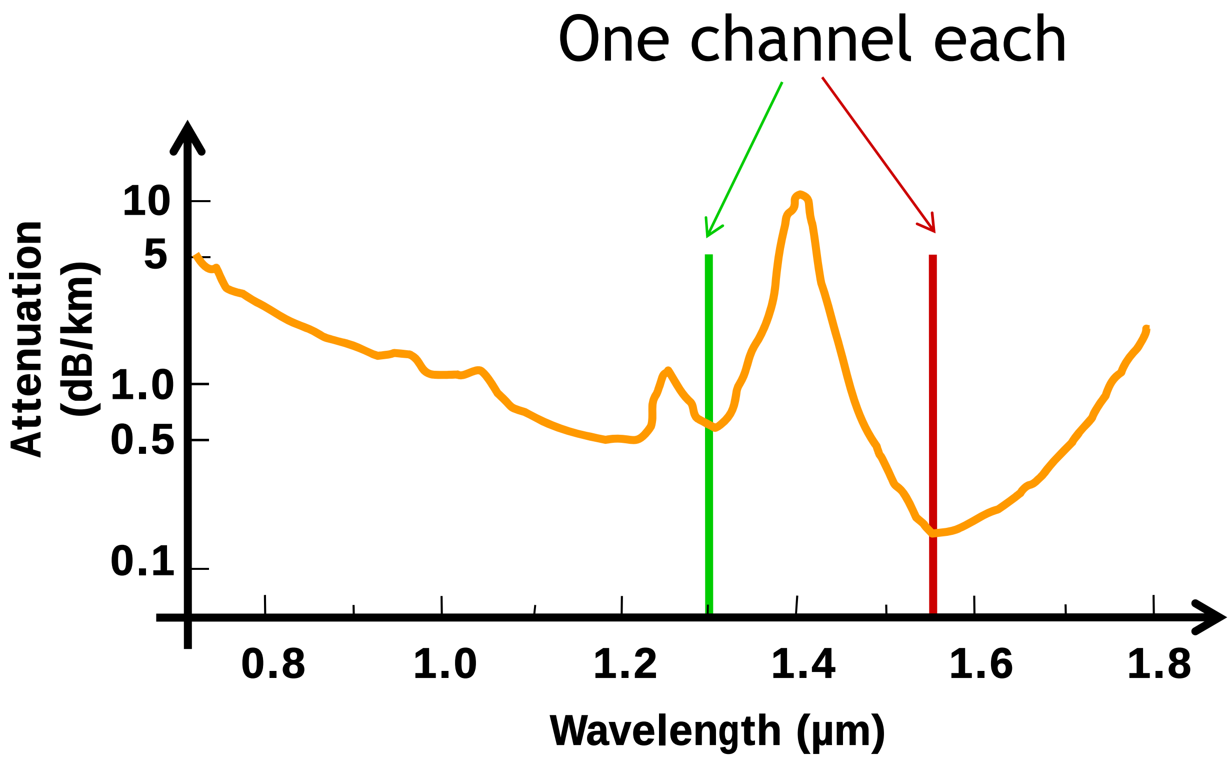
850 nm, low cost

1300 nm, zero dispersion

1550 nm, minimum attenuation



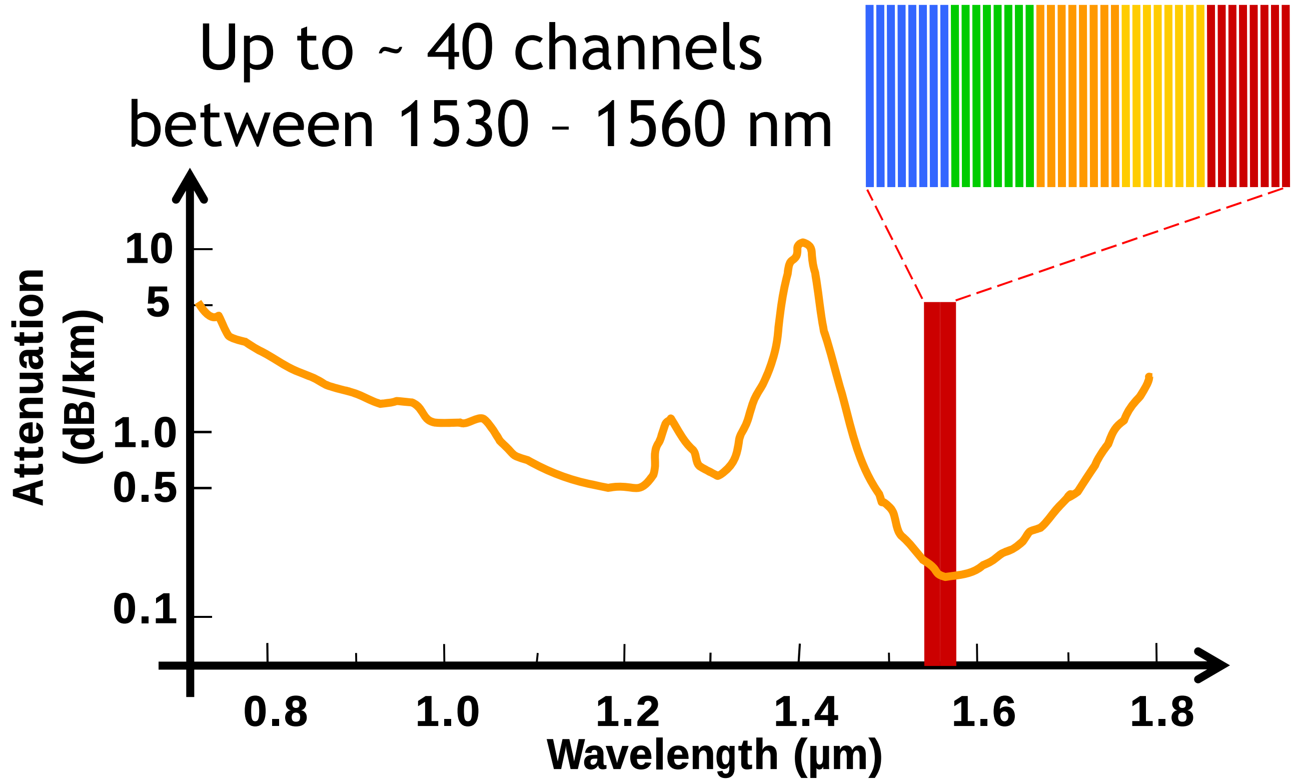
Coarse WDM



Simple, wide separation, independent

Dense WDM (DWDM)

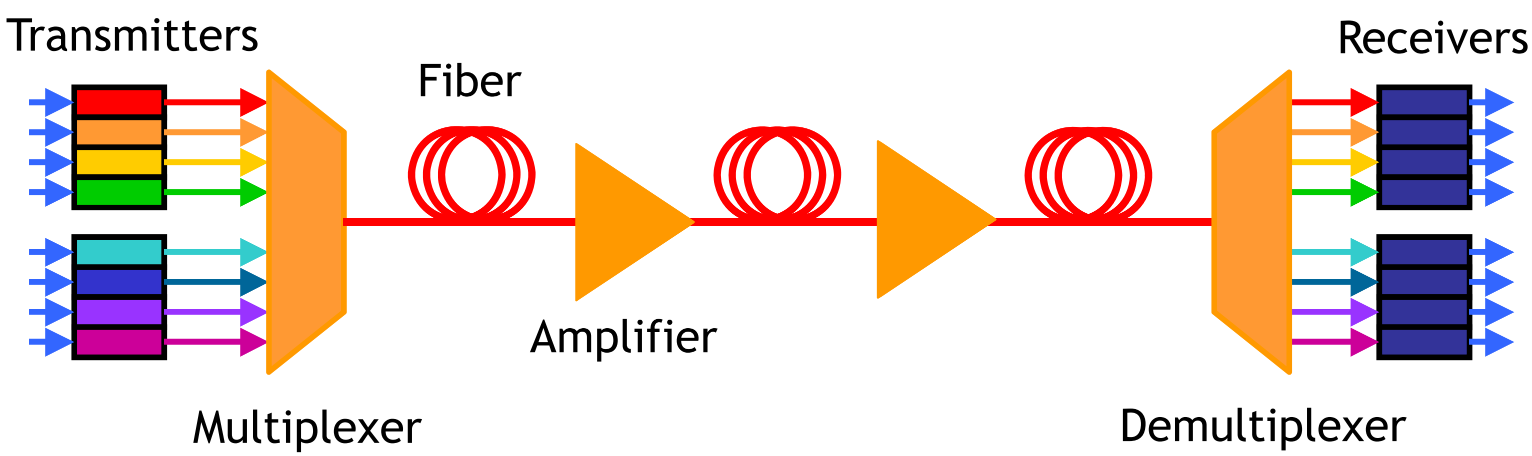
Up to ~ 40 channels
between 1530 – 1560 nm



Higher capacity, greater design challenges

DWDM System Components

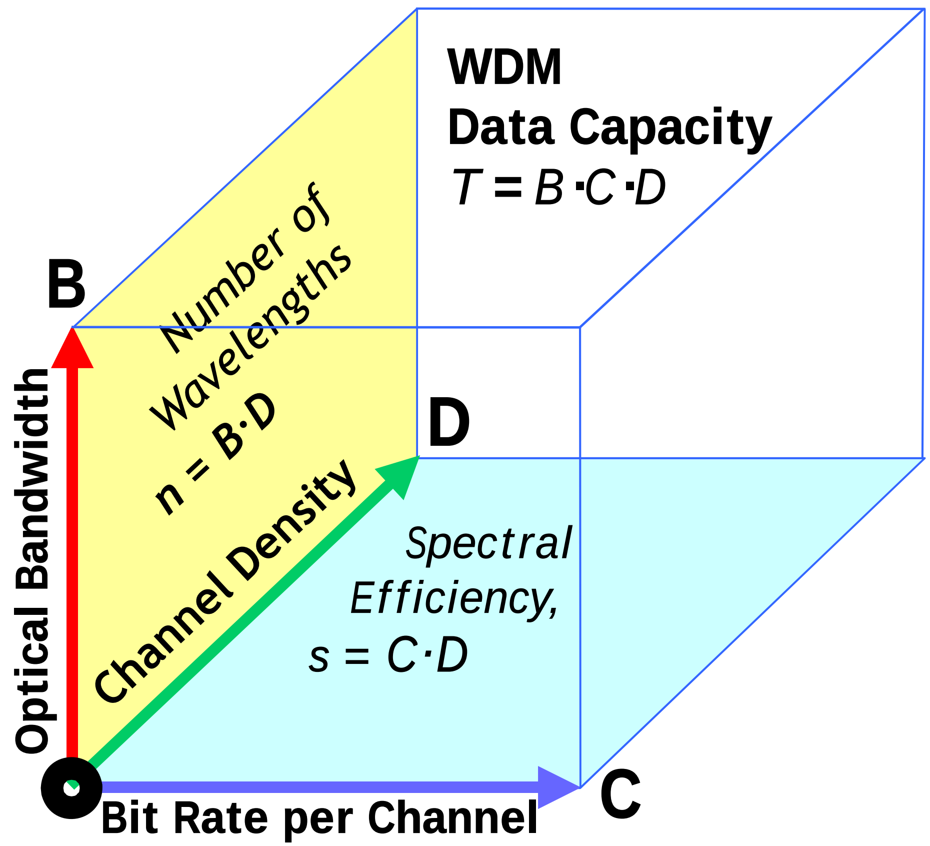
- Transmitters
- Multiplexer
- Optical Fiber
- Optical Amplifiers
- Demultiplexer
- Receivers



DWDM System Capacity

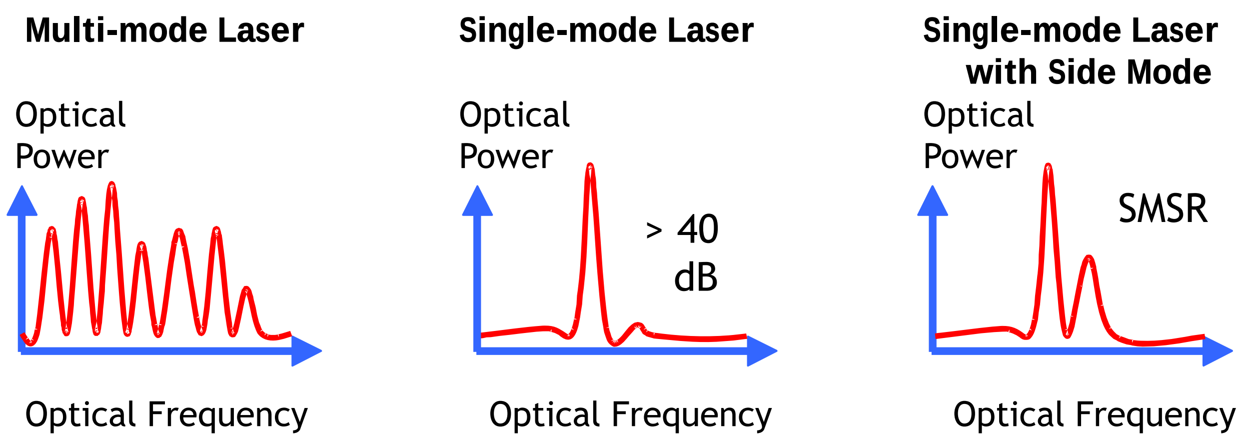
- Optical Bandwidth
- Bit rate per Channel
- Channel Density

WDM Capacity
is related to
Component
Performance



DWDM Component Performance

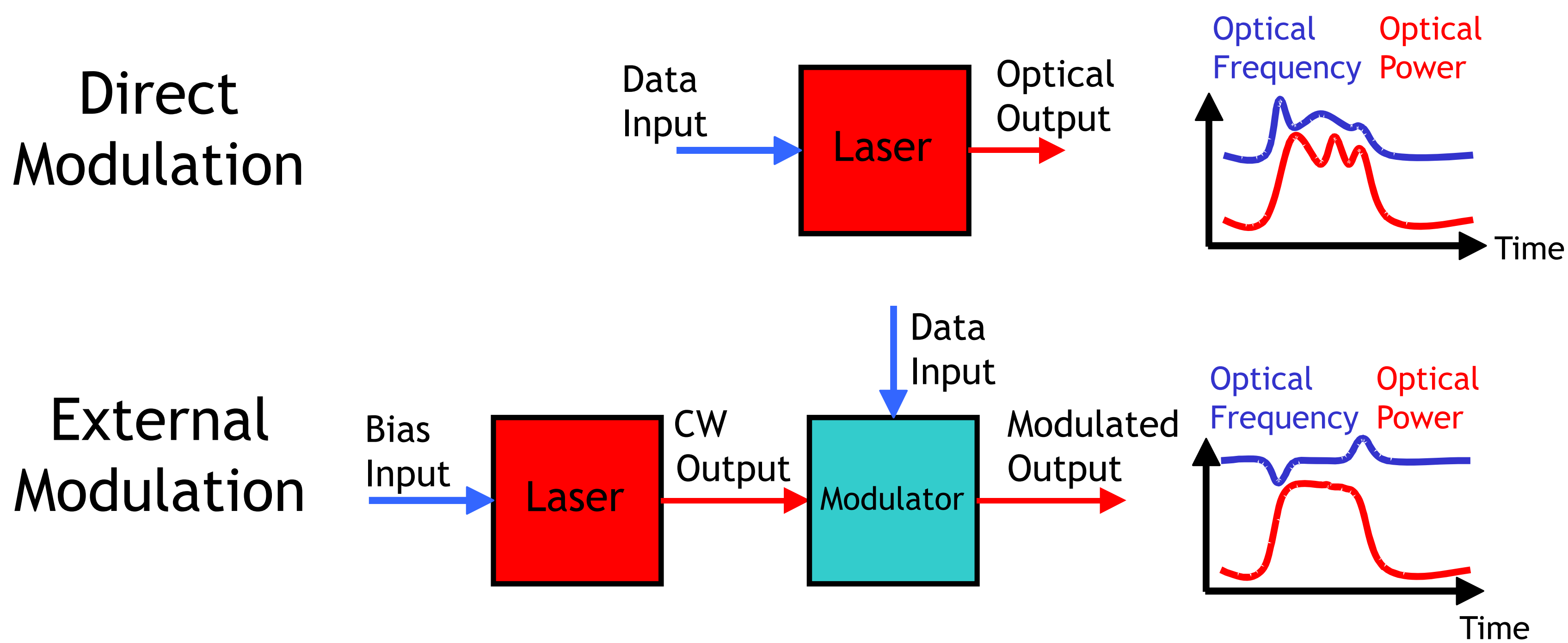
Laser



- Fluctuations in each mode
- Side Mode Suppression Ratio (SMSR)
- Side mode may interfere with other channels

DWDM Component Performance

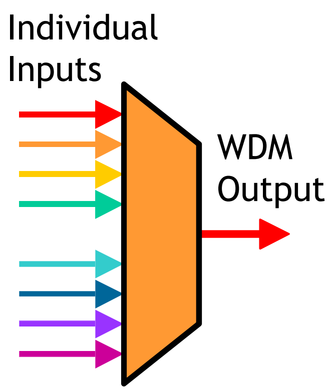
Directly or externally modulated Laser?

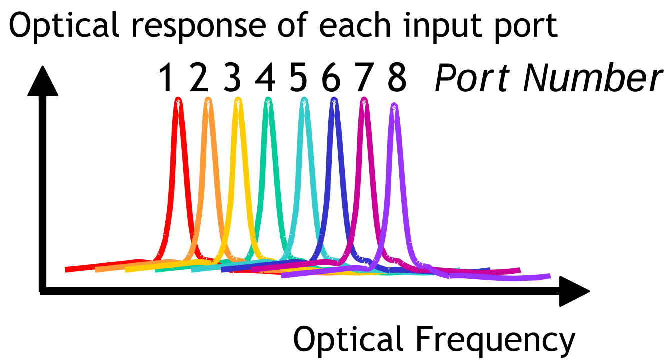


- Direct – simple, cheap but has lower bit rates and chirp
- External – expensive, higher bit rates and low chirp

DWDM Component Performance

Multiplexer

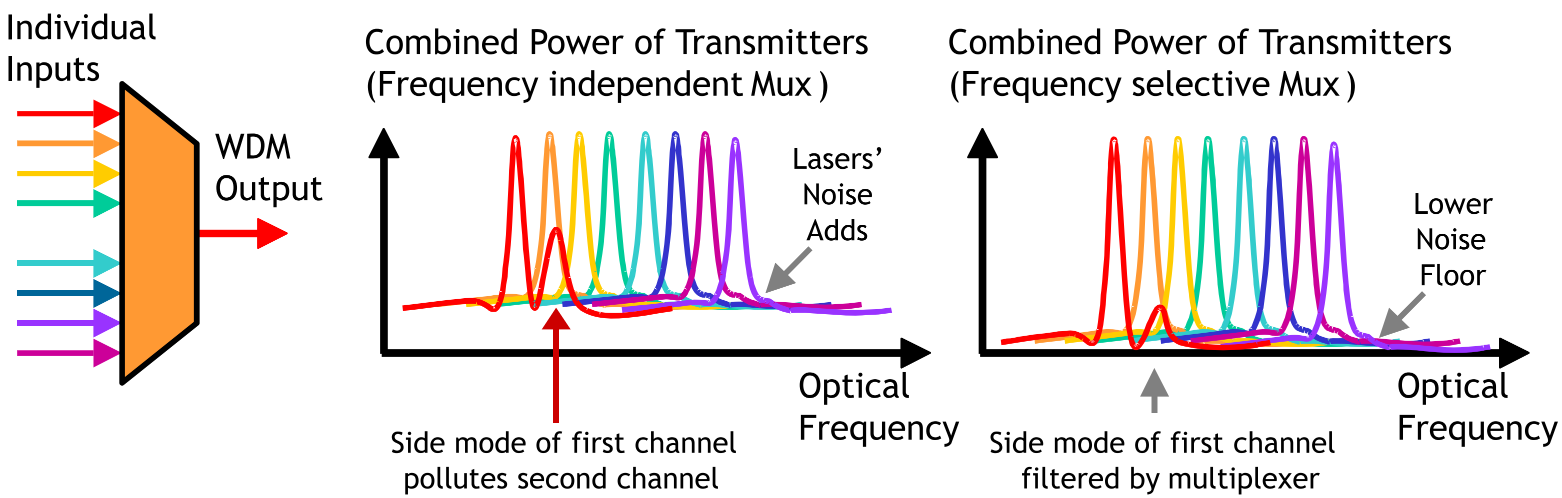




- loss per channel, temperature sensitivity
- rejection of adjacent channels
- passband width of each channel

DWDM Component Performance

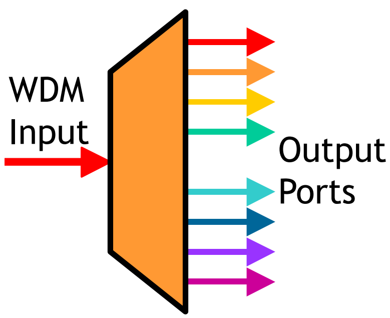
Multiplexer, Laser noise and side mode

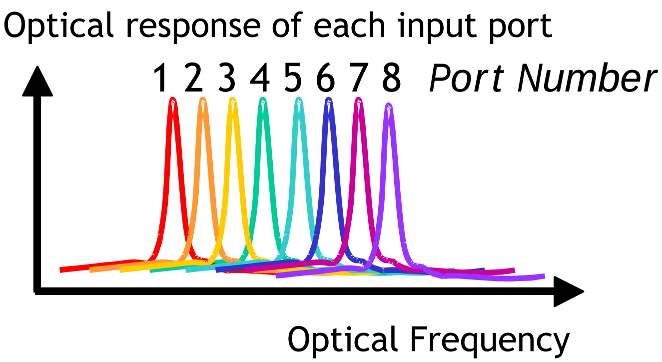


- Frequency independent or selective
- Laser noise higher or lower
- Laser side mode interference

DWDM Component Performance

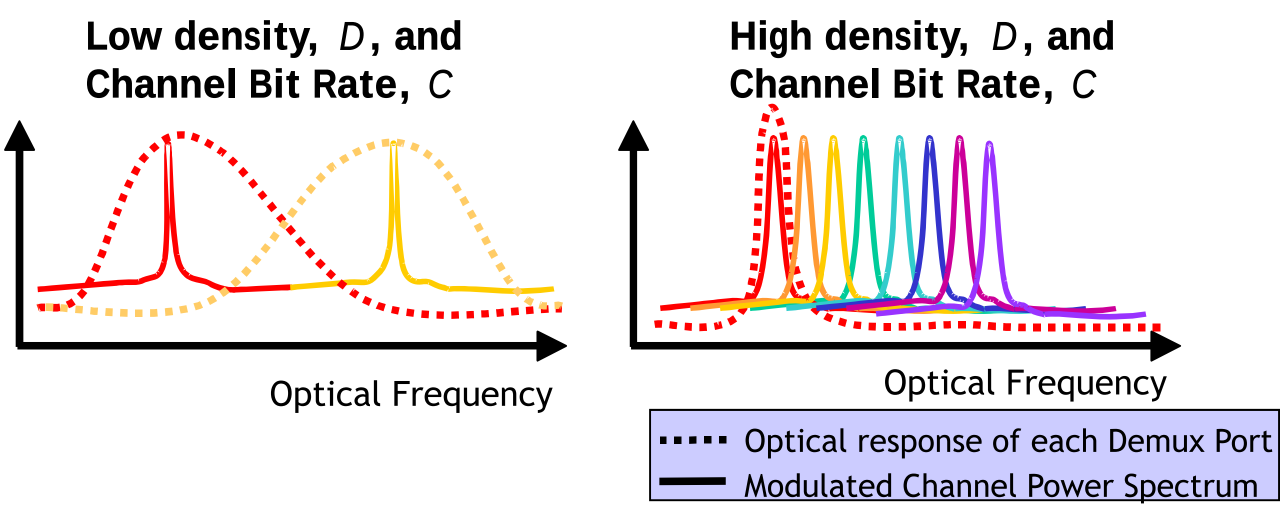
Demultiplexer





- flat passband, sharp transition to stopband
- low passband, high stopband attenuation
- linear phase response

Demultiplexer and channel density



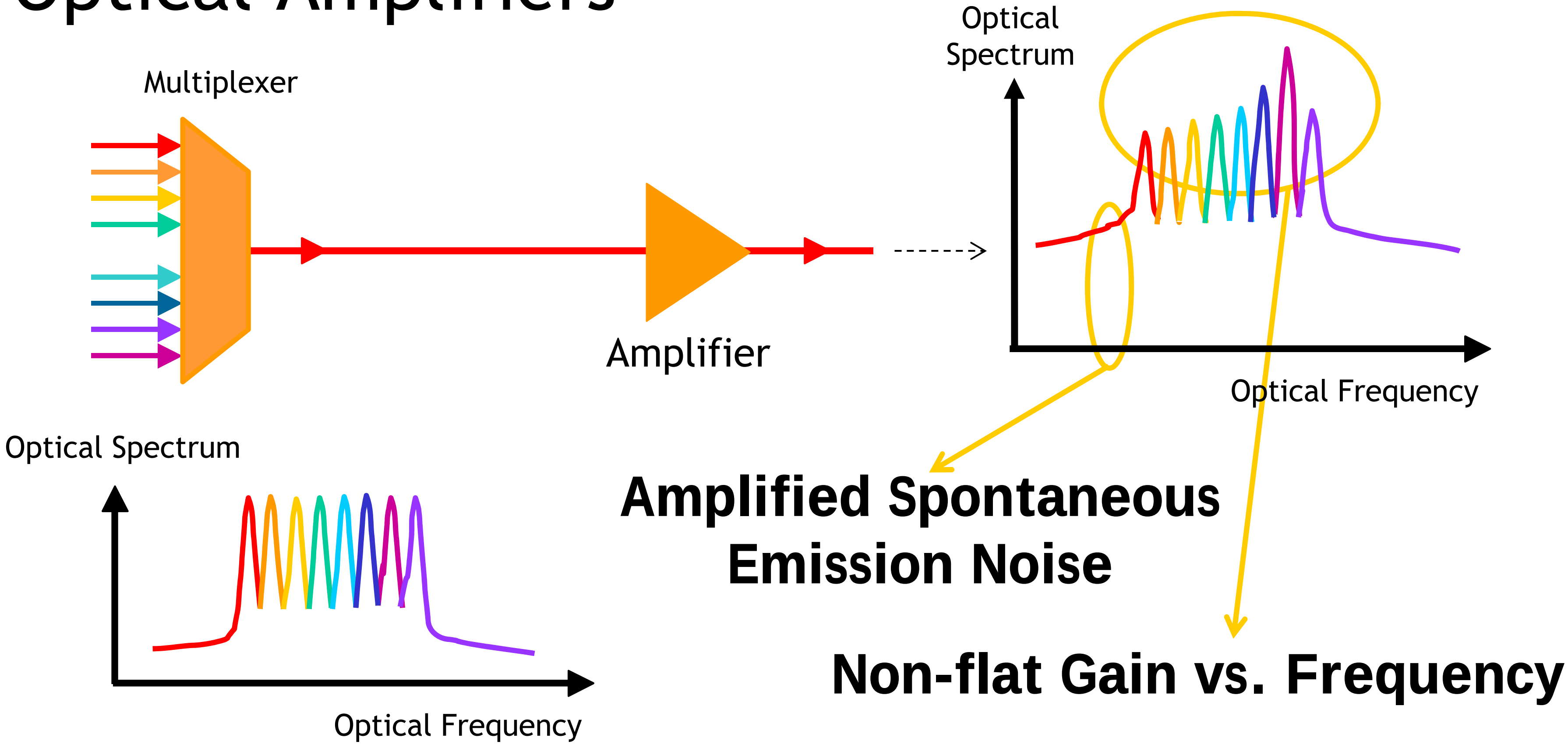
- High spectral efficiency:
    - sharp filters
    - good out-of-band rejection

Optical Fibers

- Attenuation
- Group Velocity Dispersion (GVD)
- Self Phase Modulation (SPM)
- Cross Phase Modulation (XPM)
- Four Wave Mixing (FWM)
- Stimulated Raman Scattering (SRS)
- Stimulated Brillouin Scattering (SBS)
- Polarization Mode Dispersion (PMD)

DWDM Component Performance

Optical Amplifiers



- Gain Flatness, Low Noise, Wide Bandwidth

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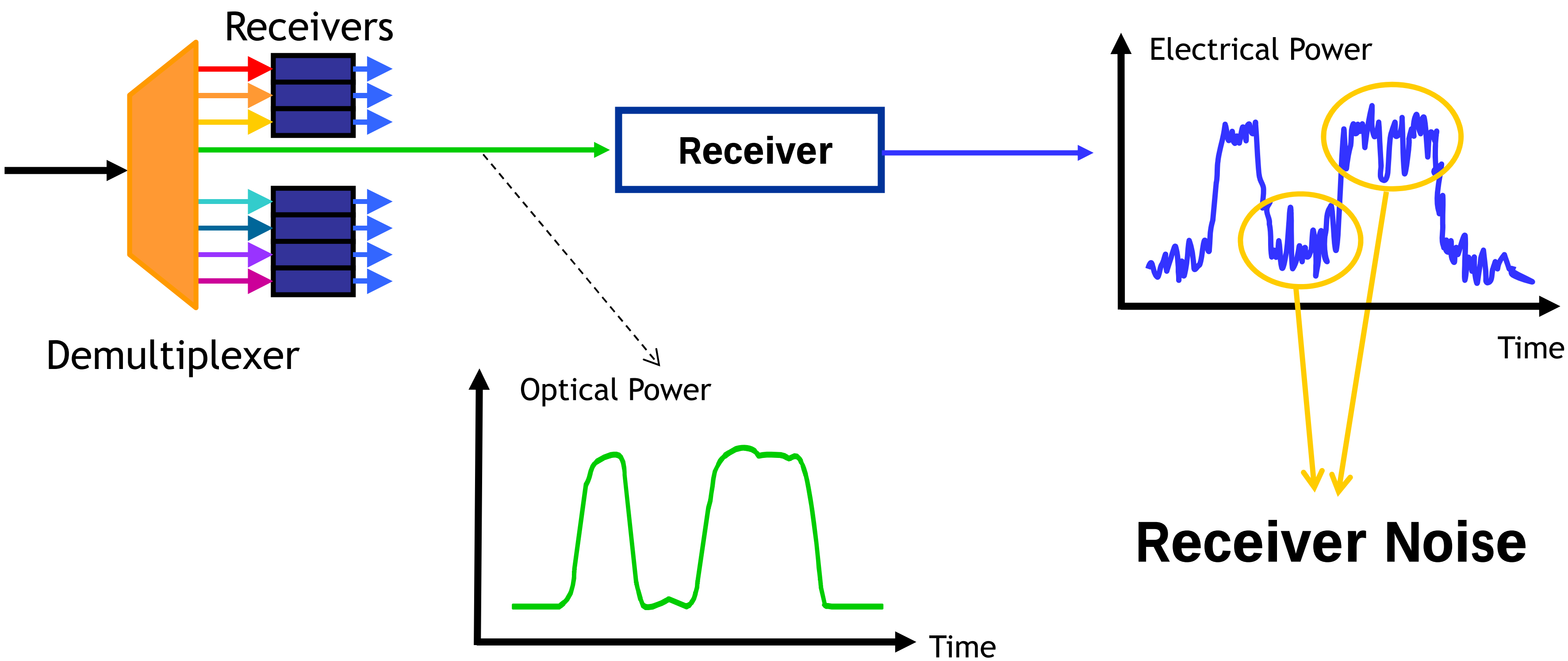
DWDM Component Performance

Receivers



- Receiver Noise, Receiver Sensitivity

DWDM Component Performance

Other components

- Add-Drop Multiplexers (ADM)
- Optical Cross Connects (OXC)

Performance Issues

- insertion Loss
- cross talk
- wavelength stability
- optical bandwidth per channel
- optical phase response per channel

Efficient Modulation Schemes

- Increase spectral efficiency

  Spectral Efficiency = (bits per second)/Bandwidth

- Example: NRZ modulation

  Needs 25 GHz bandwidth needed per 10 Gb/s channel

  $\Rightarrow$NRZ Spectral Efficiency = 10/25 = 0.4 bit/s/Hz

- Duobinary, *m*-ary and single-sideband schemes
  - Increase Spectral Efficiency to > 1 bit/s/Hz

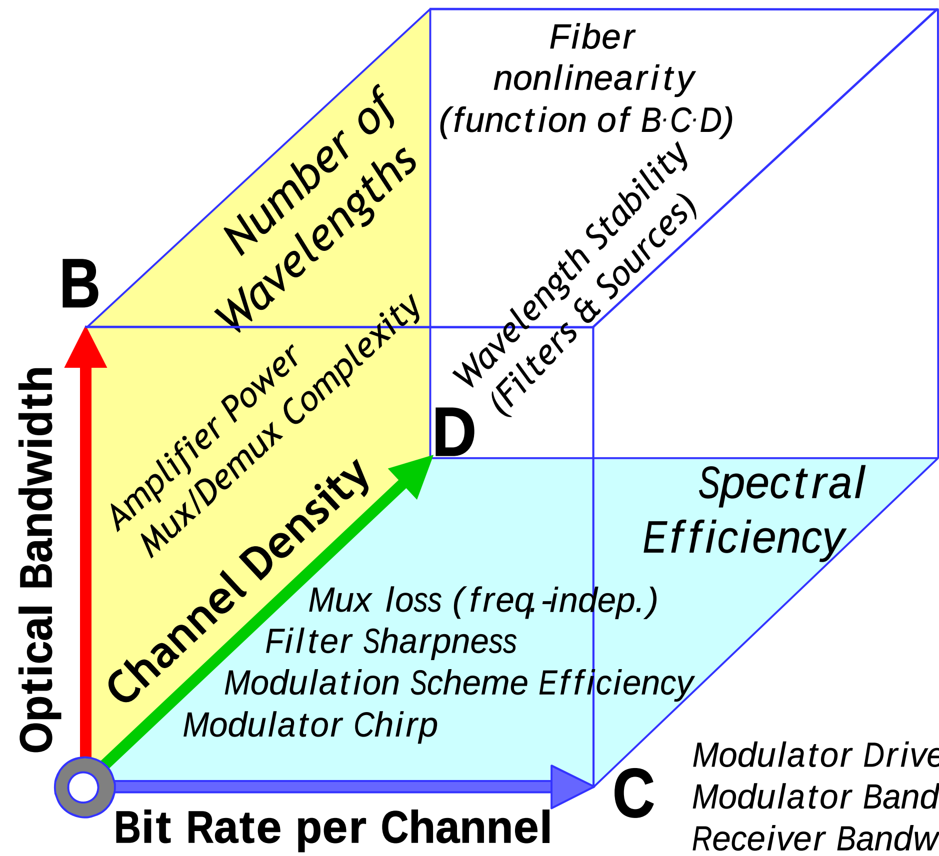
Other Performance Improvement Schemes

Forward Error Correction

- Coding to correct bit errors
- Disadvantage
  - Increases overhead (extra bits for error correction)
  - Reduces actual amount of transmitted data
- Advantage
  - improve BER ~ 10 orders of magnitude
  - Overhead typical a few percent of data rate

Summary of DWDM Component Limitations

Completing the Cube



Dispersion Flatness
Wideband Dispersion Compensation
Wide Low-Loss Window
Broadband Amplifiers

Modulator Driver Bandwidth
Modulator Bandwidth
Receiver Bandwidth
Fiber Dispersion (Pulse Spreading)
Polarization Dispersion
Optical Amplifier Noise

Summary

- WDM System concepts
- WDM System components
- How WDM capacity related to component performance
- Other WDM system performance schemes
  - Spectrally efficient modulation
  - Forward error correction

Proceed with the *Interactive Learning Module*