Wavelength-Division Multiplexing (WDM)

CME 451

WDM Technology

- WDM combines multiple wavelengths on a single fiber
  - using transmitters of different wavelengths
  - each wavelength requires separate laser source and light detector
- Wavelengths and grid spacings specified by ITU standards
- CWDM: coarse, with fewer than 8 wavelengths
- DWDM: dense, with more than 8 wavelengths

WDM Principle

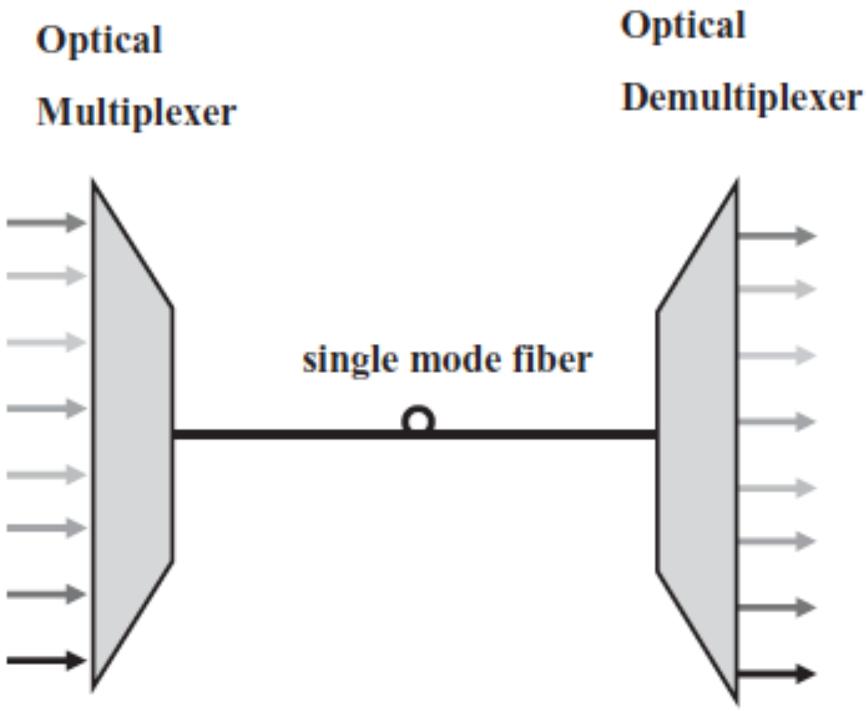

FIGURE 3.1 WDM principle of operation.

WDM channels

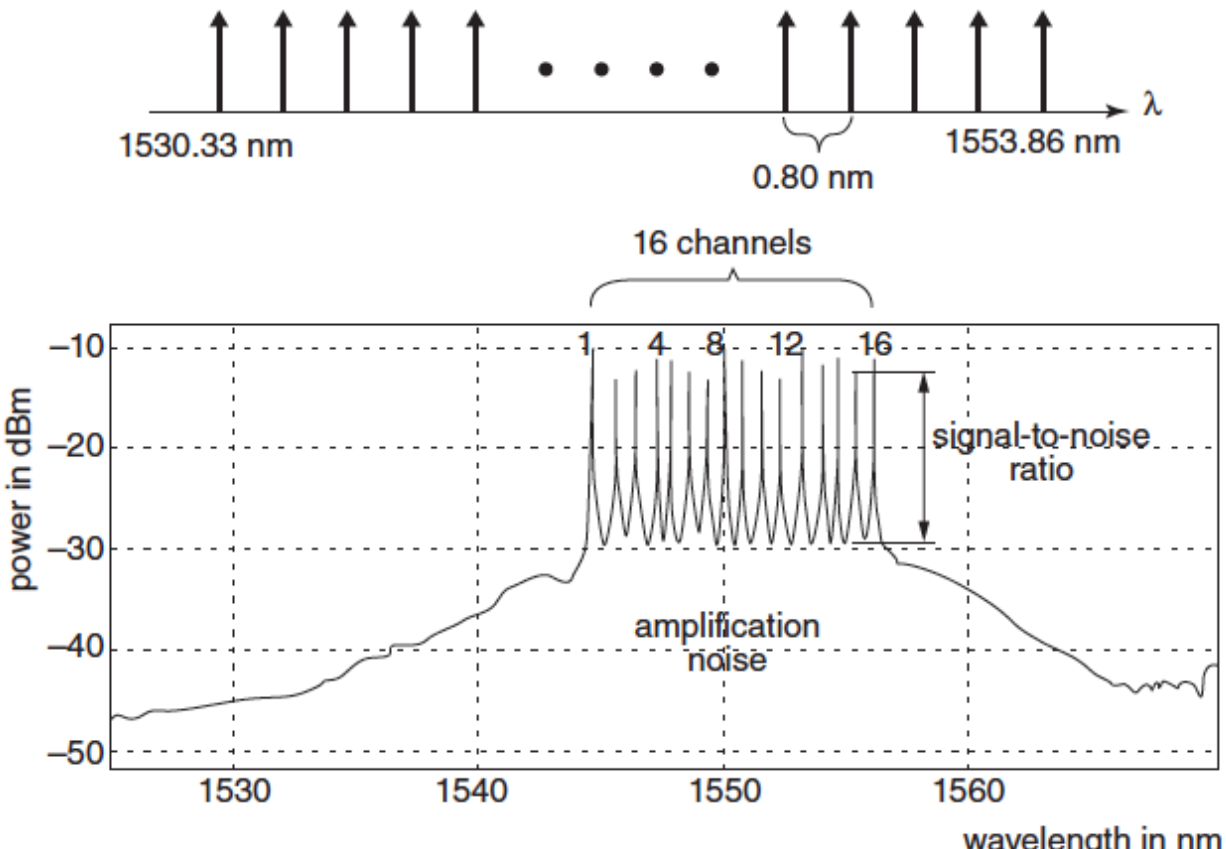

FIGURE 3.2 Sixteen-channel WDH signal.

Impairments and WDM

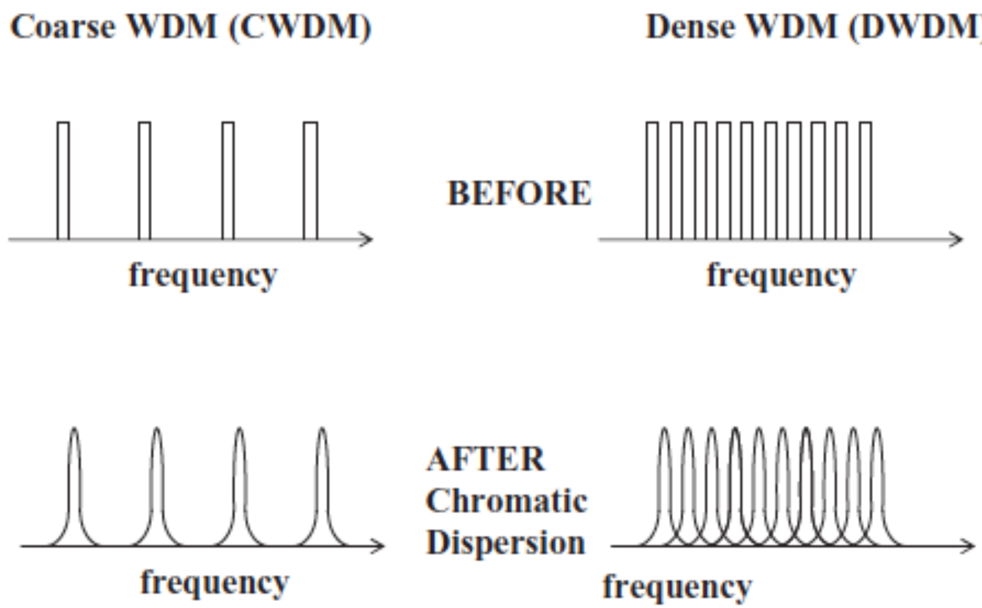

FIGURE 3.3 Chromatic dispersion effect in DWDM and CWDM systems.

WDM Capacity

- Optical transmission range 1280 – 1650 nm (recall chapter 2)
  - Bandwidth of 50 THz
  - Single electrical stream cannot fully exploit such capacity
  - Need multiple transmitters

WDM Expansion

- Possible approaches
  - More fiber
    - Cost.
  - More bandwidth:
    - Larger wavelength range for transmission;
    - Need new optical fiber with wider optical bw.
  - More wavelengths:
    - Smaller channel spacing: 50, 25, 12.5 GHz;
    - Components with higher stability and performance.
  - More bits:
    - Increasing transmission rate: 10 Gb/s ⇨ 40 Gb/s;
    - Expensive electronics & dispersion problems.

WDM Expansion

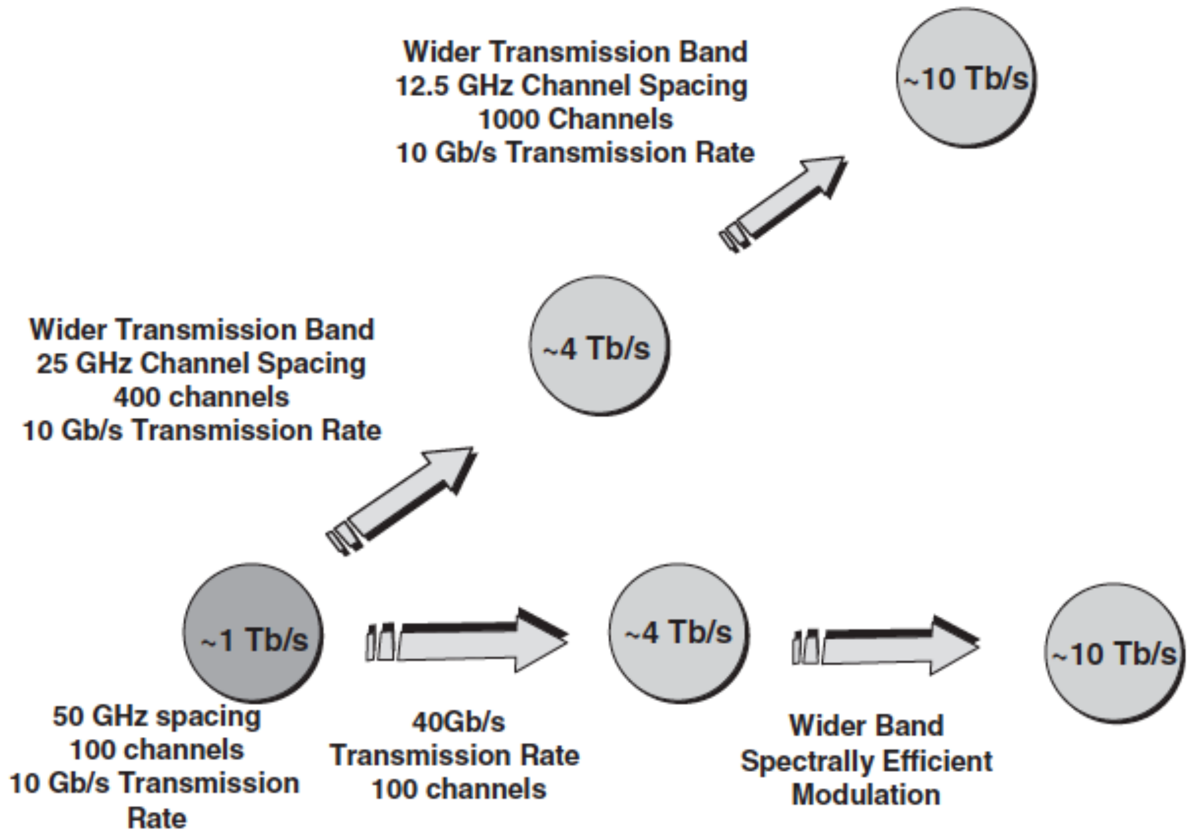

FIGURE 3.4 Hypothetical paths to increase WDM capacity.

Networking Equipment

- Recall two main types of distortions:
  - Signal attenuation
    - Equipment: Amplification
  - Dispersion (leading to smearing and ISI)
    - Equipment: Dispersion compensation (optical or electrical)
- Optical amplifier vs. O-E-O regeneration
  - cost vs. performance

Network Equipment

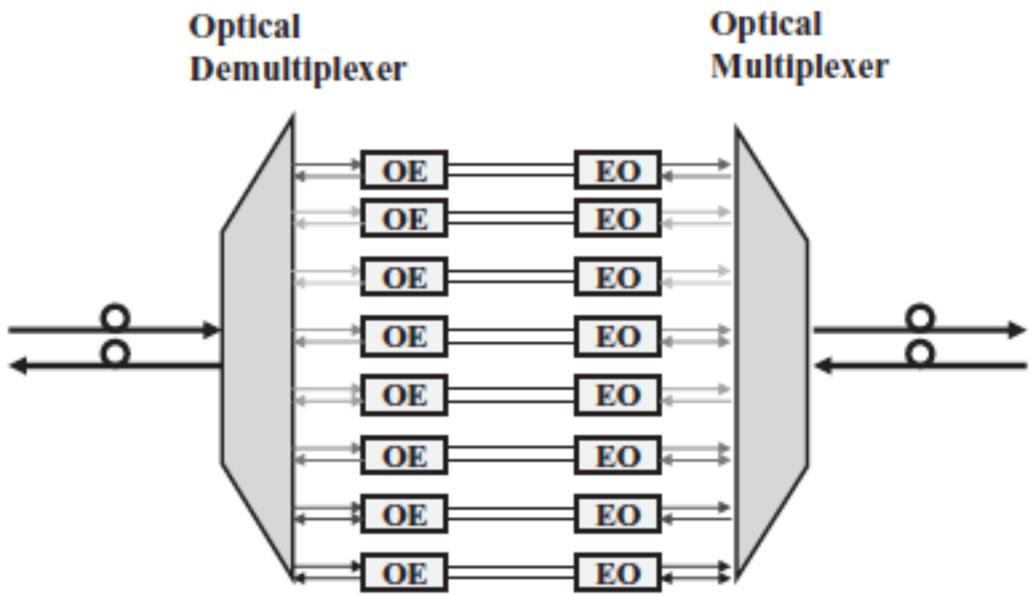

FIGURE 3.5 WDM regenerator with O-E-O conversion.

Network Equipment

- Simple optical cross-connect (switch)
  - n inputs, n outputs, n x n switching

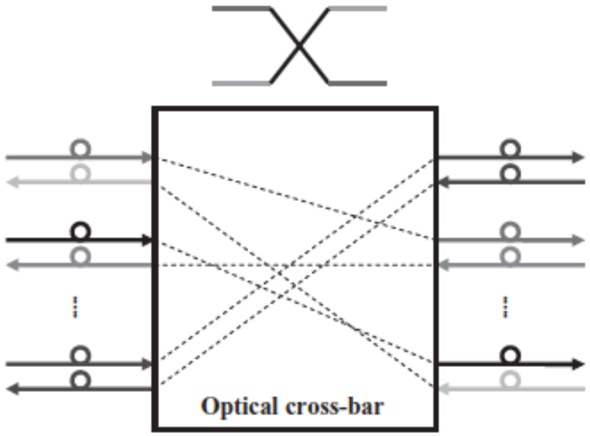

FIGURE 3.6 Optical $n \times n$ cross-connect with optical core.

MEMS for Optical Switching

- Microelectronic mechanical systems (MEMS)
  - simple mirrors (two positions): nxn array
  - 3-D architecture (n states): 2n mirrors

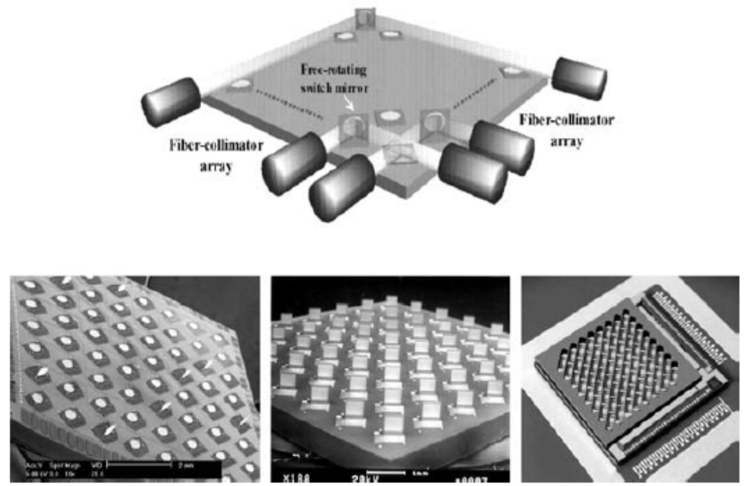

FIGURE 3.7 Two-dimensional switching architecture using an $n \times n$ mirror array. (From Chu et al., 2001.)

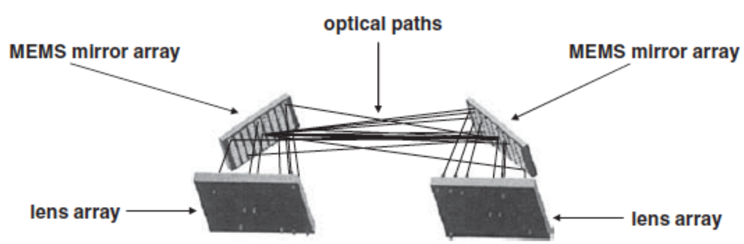

FIGURE 3.8 Three-dimensional switching architecture.

Switching & wavelength conversion

- Wavelength conversion useful to solve wavelength blocking problem (described later)

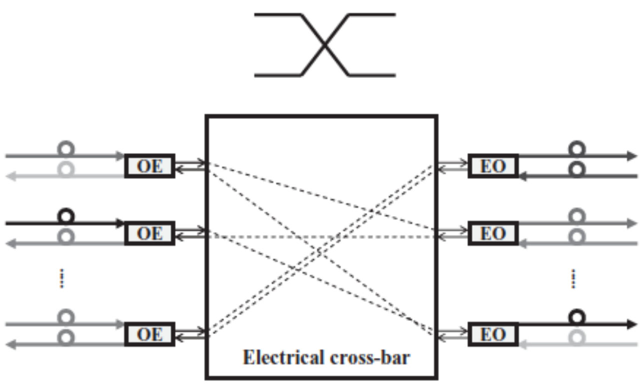

FIGURE 3.11 Optical $n \times n$ cross-connect with electrical core and wavelength-conversion capability.

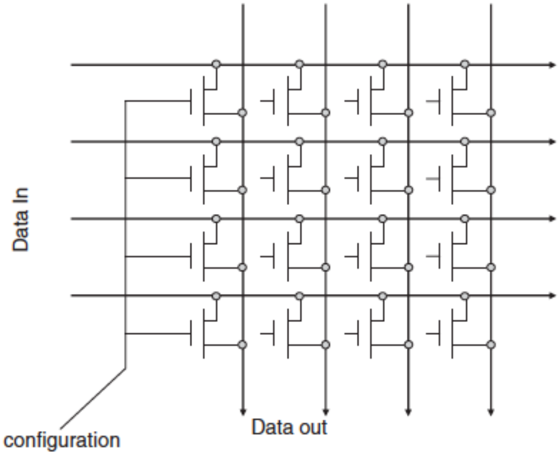

FIGURE 3.12 Electronic $n \times n$ cross-connect.

OADM & ROADM

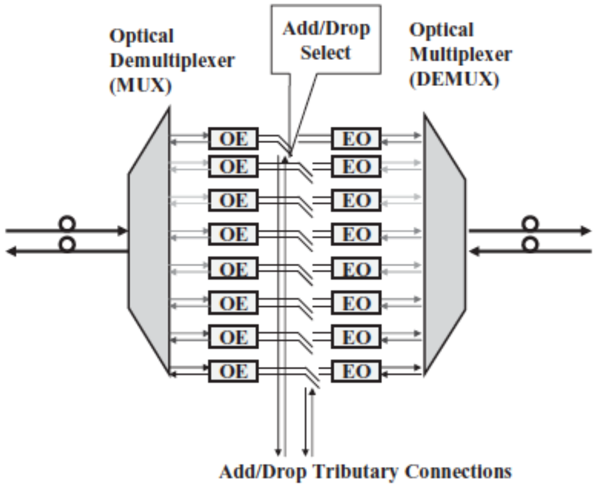

FIGURE 3.13 Optical add–drop multiplexer or WDM terminal with add–drop capability.

- Used to launch and terminate WDM signals.
- Add and drop electrical signals as required.
- Grooming: convert low-bandwidth signals into one larger BW signal.
- Remotely reconfigurable to avoid manual reconfiguration tasks.

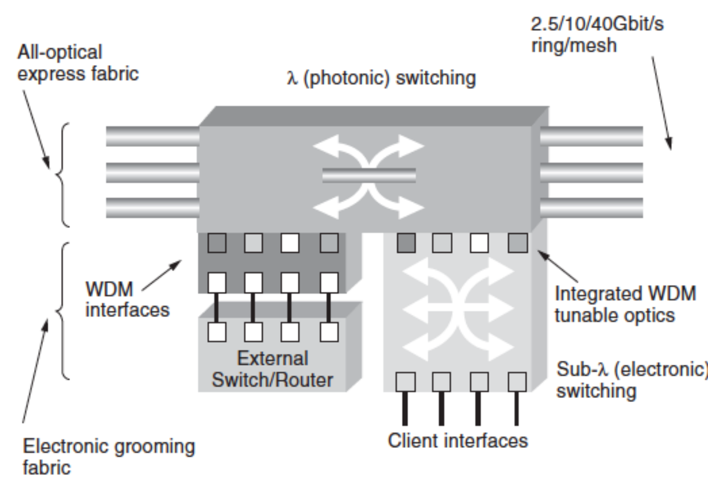

FIGURE 3.14 Reconfigurable optical add–drop multiplexer. (Courtesy of Ciena Inc.)

WDM Networks

- WDM Network provisioning
  - Fixed-wavelength lasers vs. tunable lasers (R&D)
  - Tunable lasers: potential for all optical bypasses.
- Wavelength blocking: network node is blocked at a particular wavelength.
  - Wavelength conversion and O-E-O solution.
  - O-E-O as practical solutions
    - also for attenuation and dispersion problems.

Wavelength Blocking

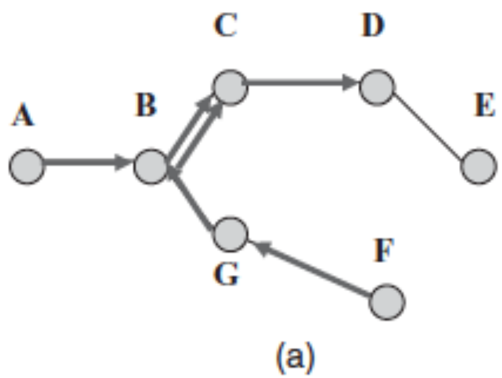

FIGURE 3.15 (a) Wavelength blocking problem between B and C; (b) solution by converting wavelength at point B (dashed lines).

WDM Network Protection

- Physically separated designs for redundancy.
- Not easy to implement in practice.

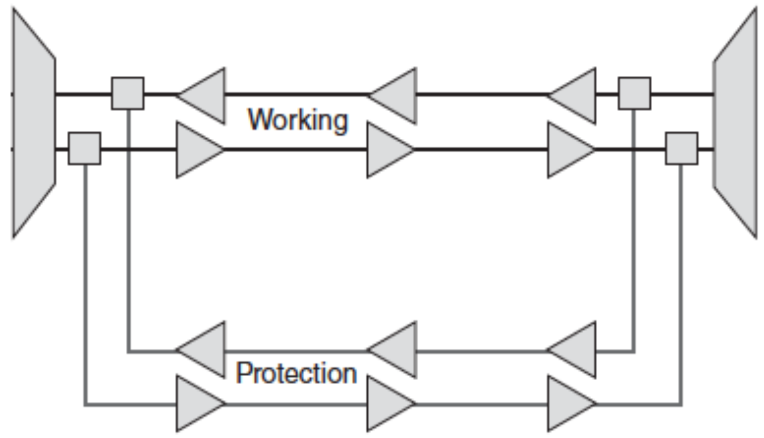

FIGURE 3.16 Working and protection two-fiber-pair configuration.

WDM Design Case Study

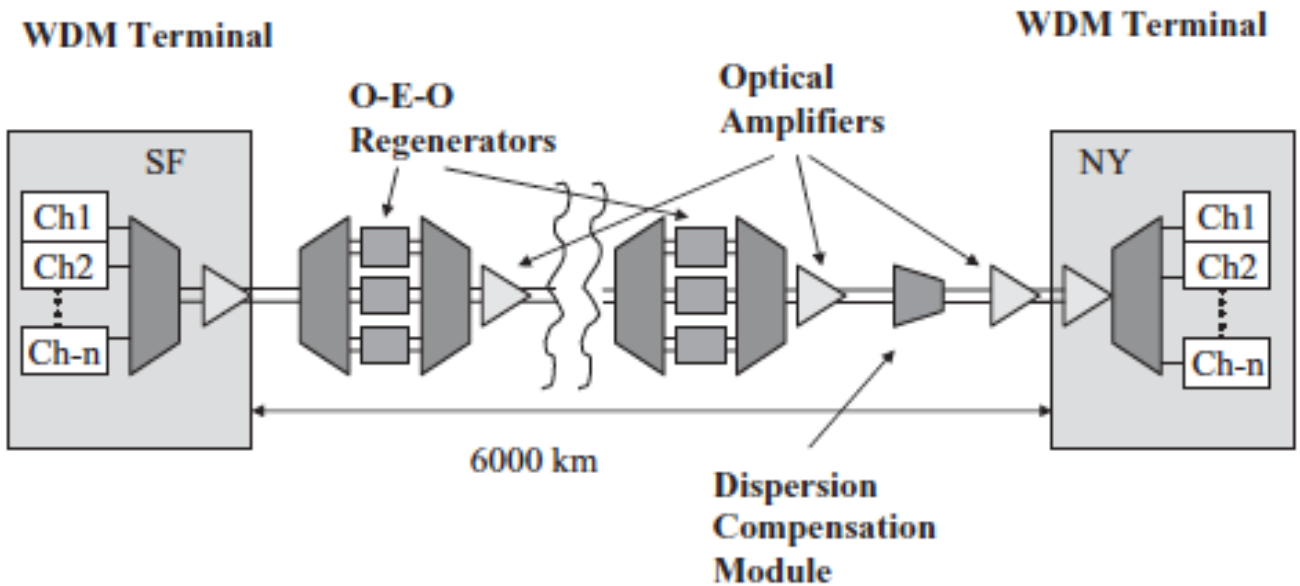

FIGURE 3.17 San Francisco-to-New York WDM point-to-point link.