SVEUČILIŠTE U ZAGREBU
Fakultet elektrotehnike i računarstva

Master Programme Computing

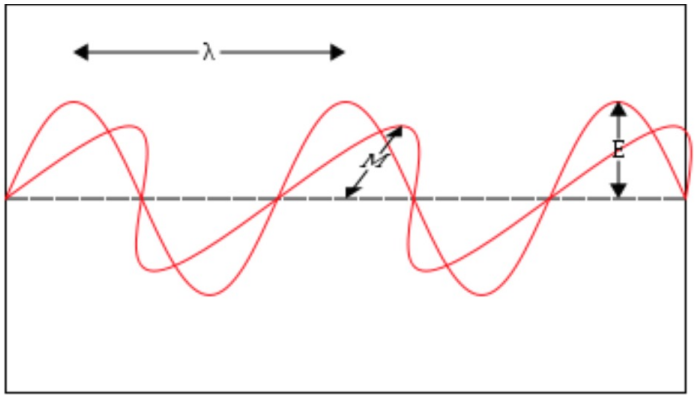
Advanced Architectures of Telecommunication Networks

Ac. year 2022/2023

High Speed Optical Networks - Introduction

Optical or photonic network?

- Processing, storage and transmission of information using basic light elements – photons
- λ – wavelength

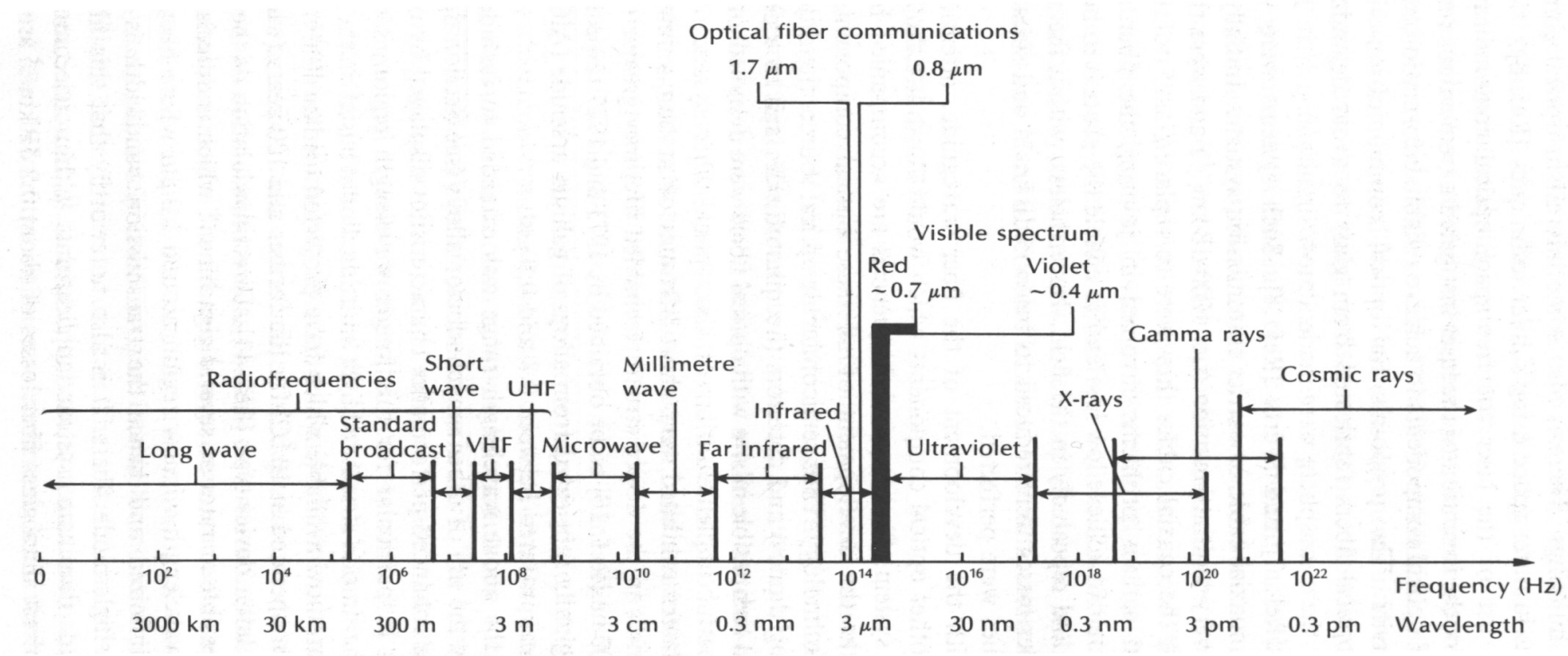


- Why optical networks?
  - Efficient (cheap) and fast way of communication that can meet the current and expected capacity requirements of telecommunication networks

Optical communication systems

- light as a medium for transmitting information
- light can travel over:
  - fibers (optical fibers)
  - free space optics
- the infrared spectrum is most commonly used
- the ability to transfer large amounts of data quickly and reliably over long distances
  - Eg. Youtube streaming?

Optical communications - wavelengths



" Optical Fiber Communications, Prentice Hall, 1992

- area 800 – 1700 nm GOF (Glass Optical Fiber)

Fibre characteristics

- little damping/attenuation
- Transparency in the visible and near infrared zone
- High frequency band
- Immunity to
  - Electromagnetic Interference (EMI)
  - Radio Frequency Interference (RFI)
  - Electro-Magnetic Pulse (EMP) - no shielding required
- Resistant to corrosion, high temperatures and thermal jumps
- Lightweight and small in size - easier to install
- planes, ships, satellites, cars…
- Electrical insulator (no sparks, no grounding)
- Ubiquitous source of material - sand

Maximum transmission speed (theoretical)

c = 300.000 km/s = $3x10^8$ m/s

λ = 1.300 nm = 1,3 10^{-6} m

f = c/λ = $3x10^8$ [m/s] / $1,3x10^{-6}$ [m] =

= 2,3 10^{14} [1/s]= 2,3 10^{14} Hz =

= 230 THz

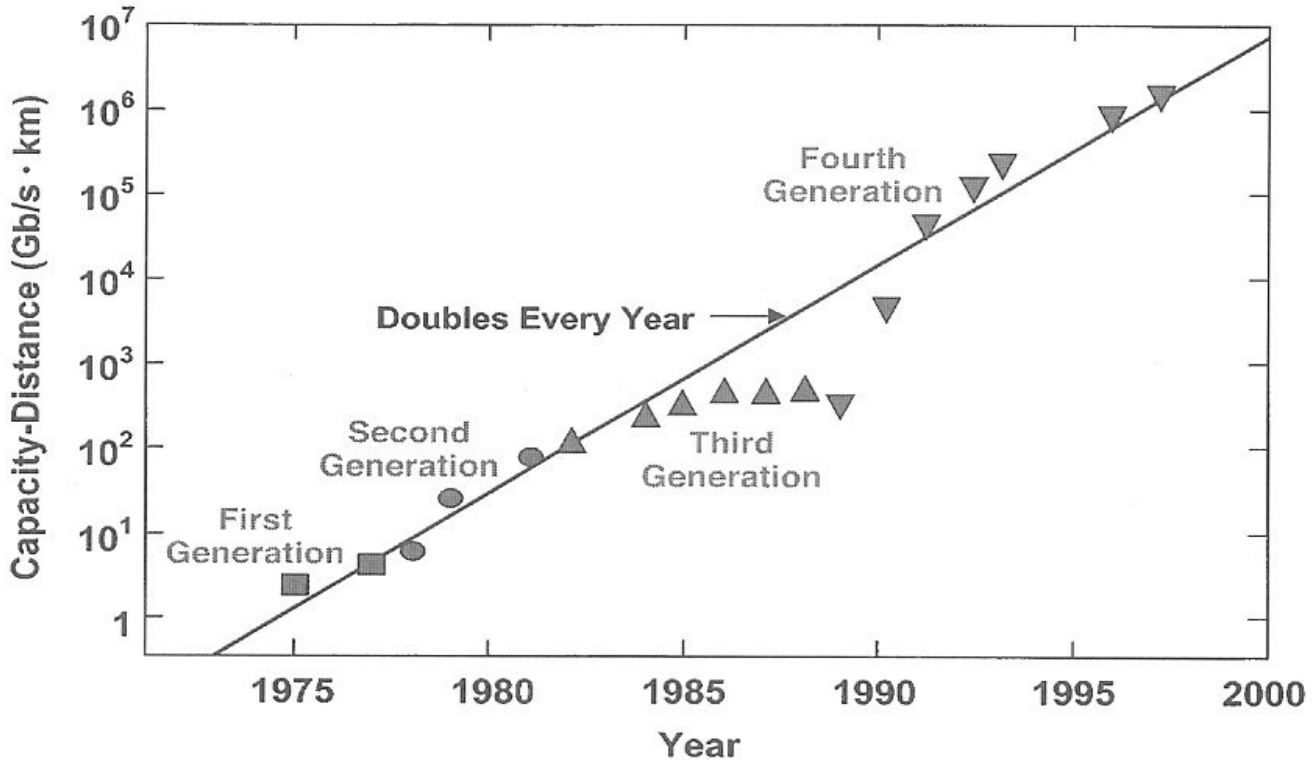
„carrier frequency"

Bandwith is the key (remember Information Theory)

B x ***L*** > 10 Pbit/s x km

(„old" coax. cable= 500 MHz)

Optical systems - generations



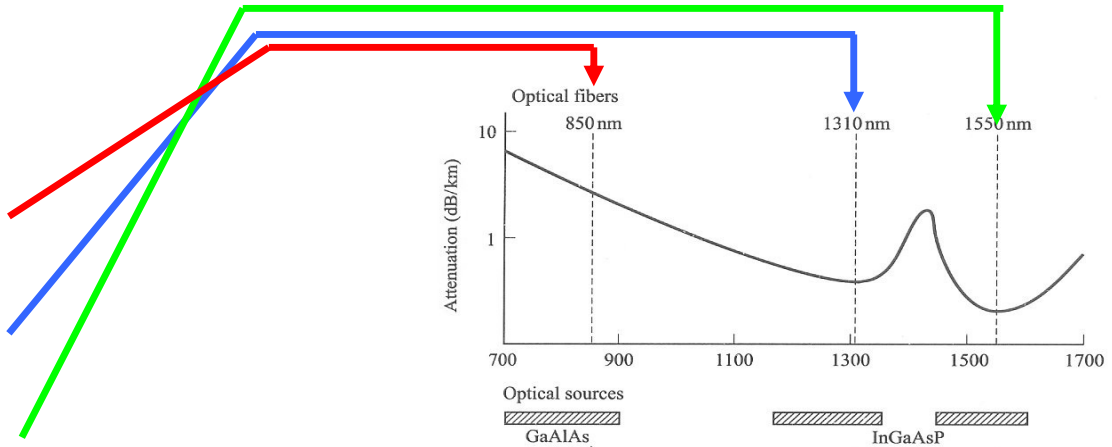
Agrawal, " Fiber-Optic Communication systems", Wiley Interscience, 2002

Generations - comparison

1st generation

2nd generation

3rd generation



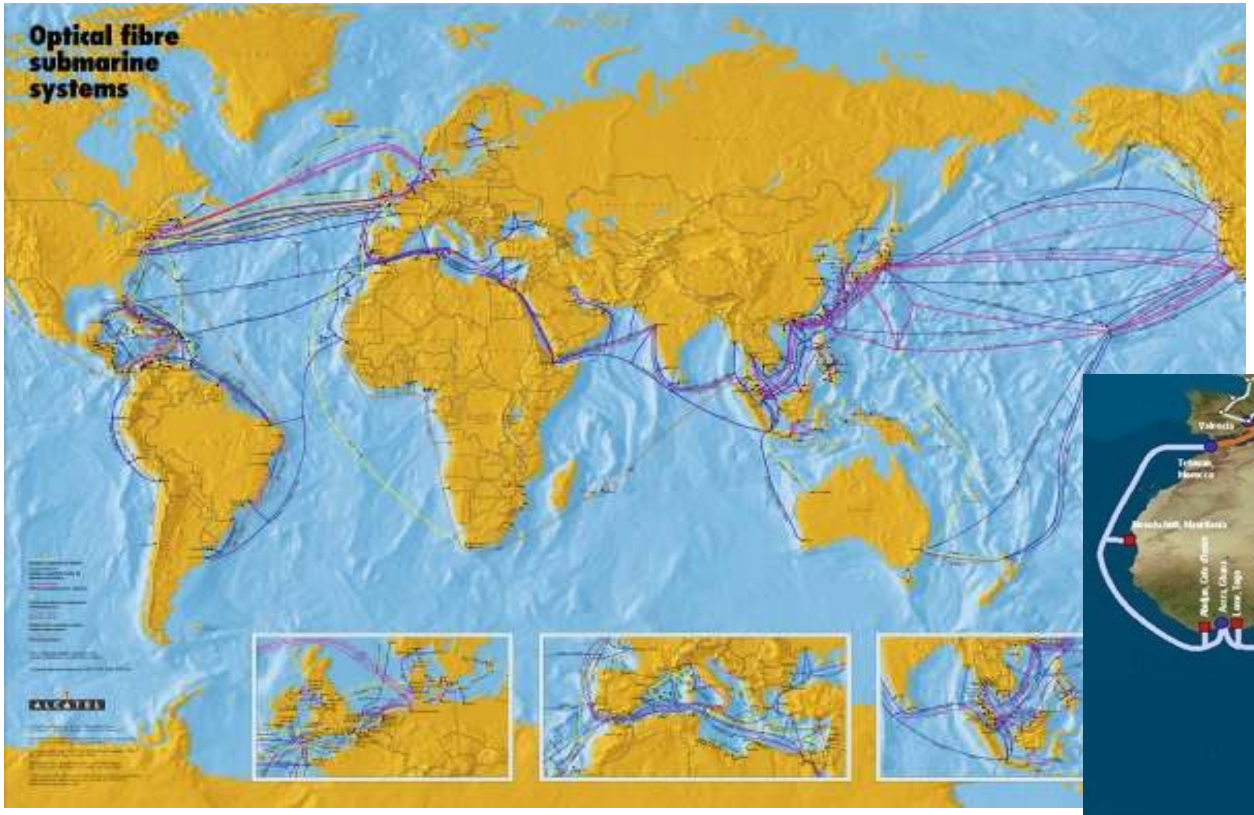
4th generation - EDFA

Keiser, "Optical Fiber Communications“,
Mc Graw Hill, 2000

4th Generation - OA & WDM (1990.)

- The use of optical amplifiers (OA) (EDFA - Erbium Doped Fiber Amplifier) allows to increase the distance between the regenerators. Fibre losses are compensated periodically by optical amplifiers on sections of 30 to 120 km.
- Wavelength Division Multiplexing (WDM) is applied: the transmission of multiple wavelengths over a single thread.
- Transmission at 2.5 Gbit/s over a distance of 21,000 km - possible undersea and international links.
- Transmission of 82 wave channels, each of 40 Gbit / s (equivalent to 51,250,000 voice channels) over 3000 km. B x D = 10 Pbit / s x km.
- SingleMode (SM) fibre (SMF / DSF)> 3rd window (EDFA)> B x D = 10 Pbit / s x km

International undersea network



•*http://www.cybergeography.org/atlas/cables.html*

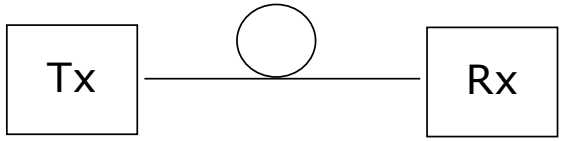
Trans-Atlantic Transmission (TAT-X)

TAT-8 (1988.) (*Trans-Atlantic Transmission*)
1.300 nm, **D=6.700 km**, **S=50 km**
Opto-electronic regenerators
2 pairs x 280 Mbit/s (redundancy)

TAT-9 (1990.)
1.550 nm, 565 Mbit/s
Opto-electronic regenerators

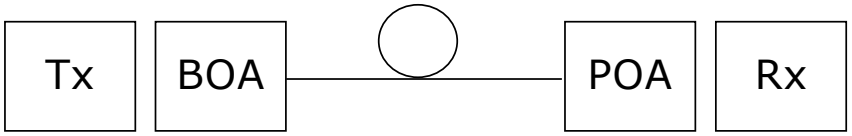
TAT-12 (1995.)
1.550 nm, S=45 km
All-optical transmission>> amplification - **EDFA**
5 Gbit/s

Transmission systems without regeneration



20-24 dB

50-60 km 1.300 nm



1550 nm

300 km at 2,5 Gbit/s

or

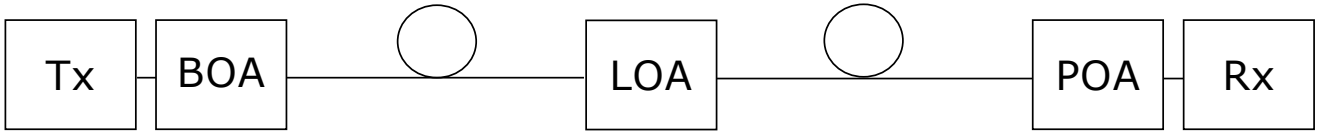
100-200 km at 10 Gbit/s

BOA – *Buster Optical Amplifier*

POA – *Pre-Optical Amplifier*

EDFA

Transmission systems with regeneration



BOA, LOA, POA – EDFA

LOA – *Line Optical Amplifier*

10.000 km

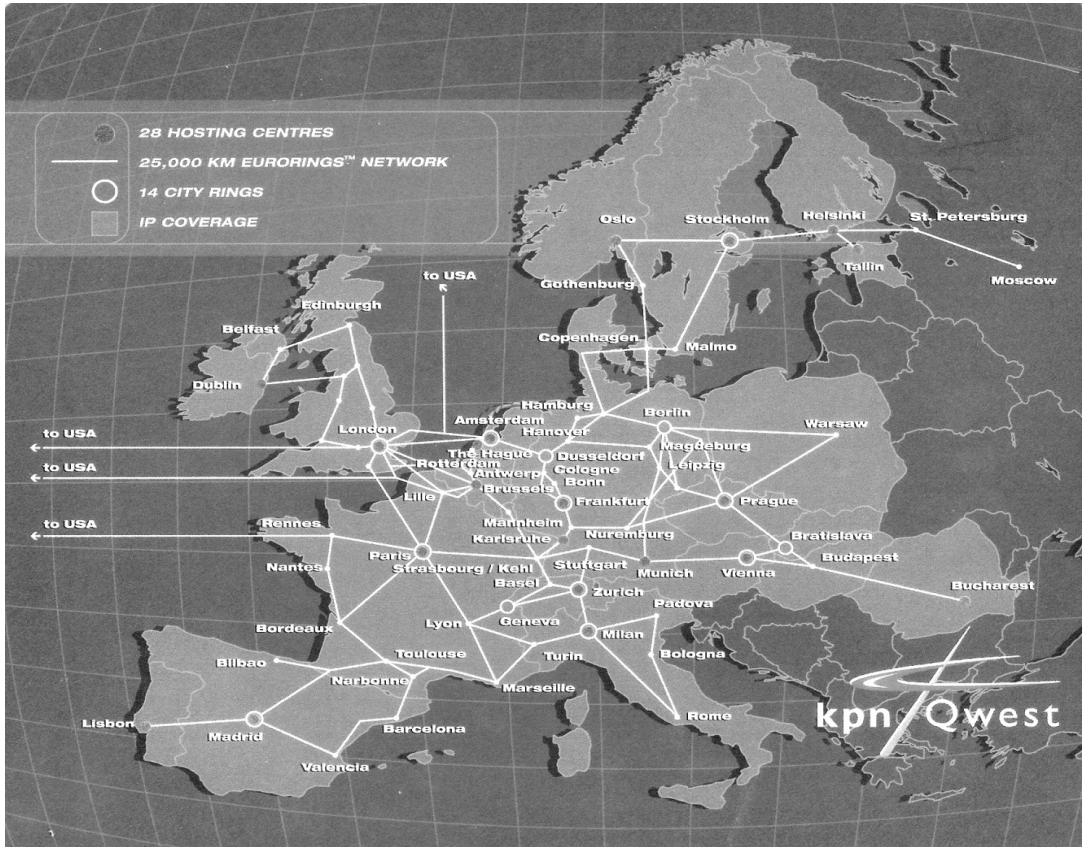
Problems:

Chromatic dispersion

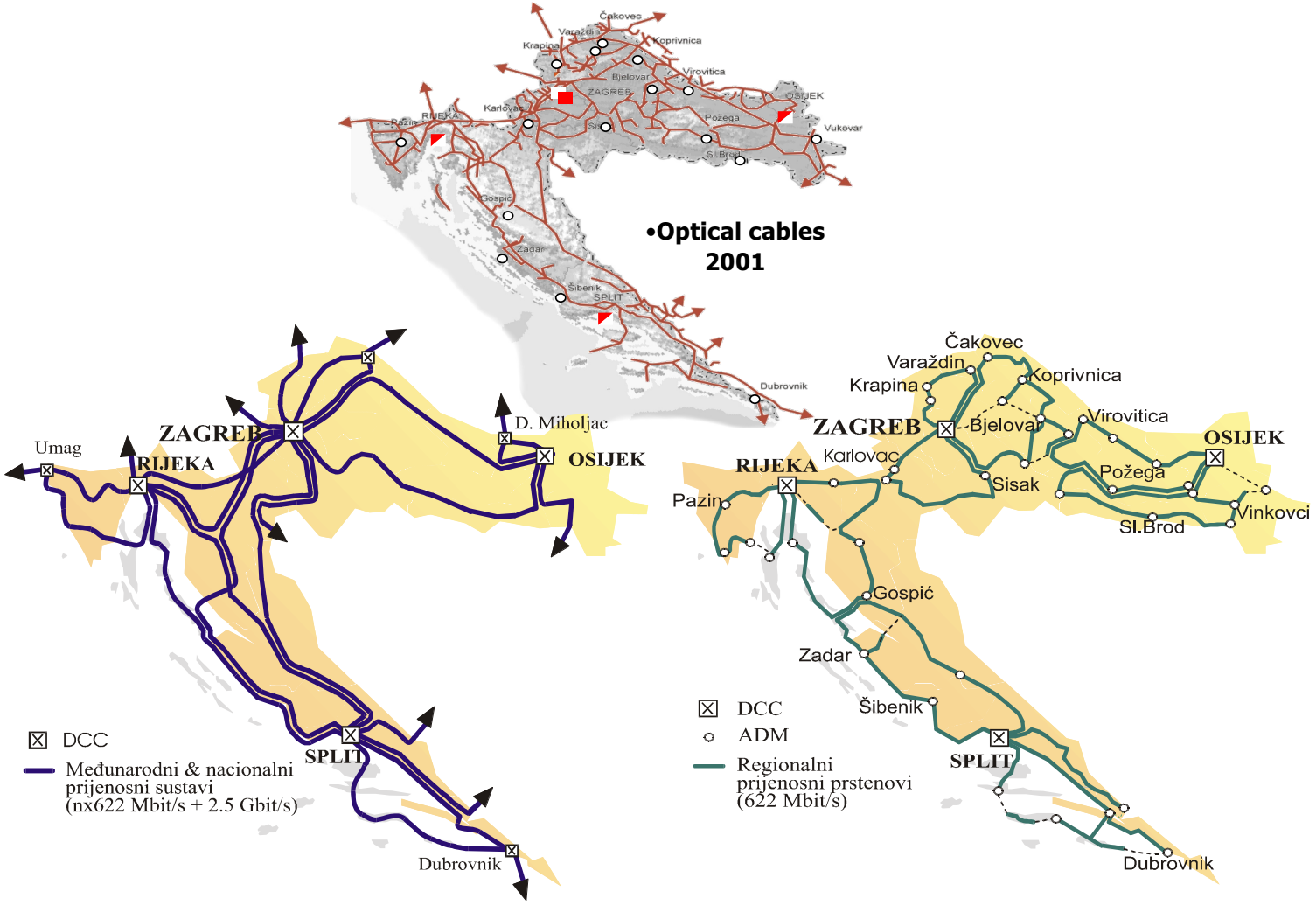
Amplified Spontaneous Emisson (ASE)

Results in lower bandwidth due to non-linear amplification!

Example of land network



Optical networks in Croatia



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High Speed Optical Networks – main components

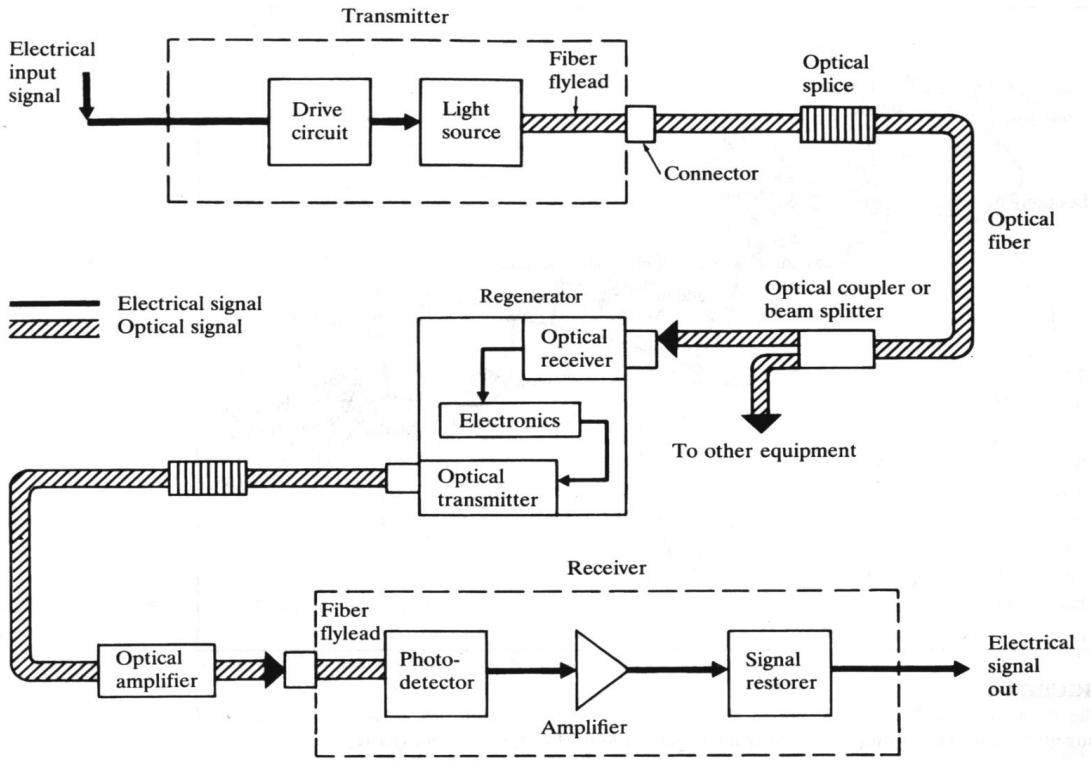
Optical communication link – key elements

1. Optical source
   - generates an optical signal at the desired wavelength
   - an optical signal is a mapped electrical signal with imprinted information
   - the most commonly used sources are:
   - laser diodes LD (laser diodes) - narrow spectrum
   - light emitting diodes (wide emitting diodes)

2. Optical cable
   - contains optical fibers and a protective sheath

3. Light detector
   - converts an optical signal into an electrically processable one
   - the most commonly used detectors are PIN diode and avalanche diode (APD - Avalanche Photodiode)

Basic optical link



Keiser, "Optical Fiber Communications“, Mc Graw Hill, 2000

Components of an all-optical network

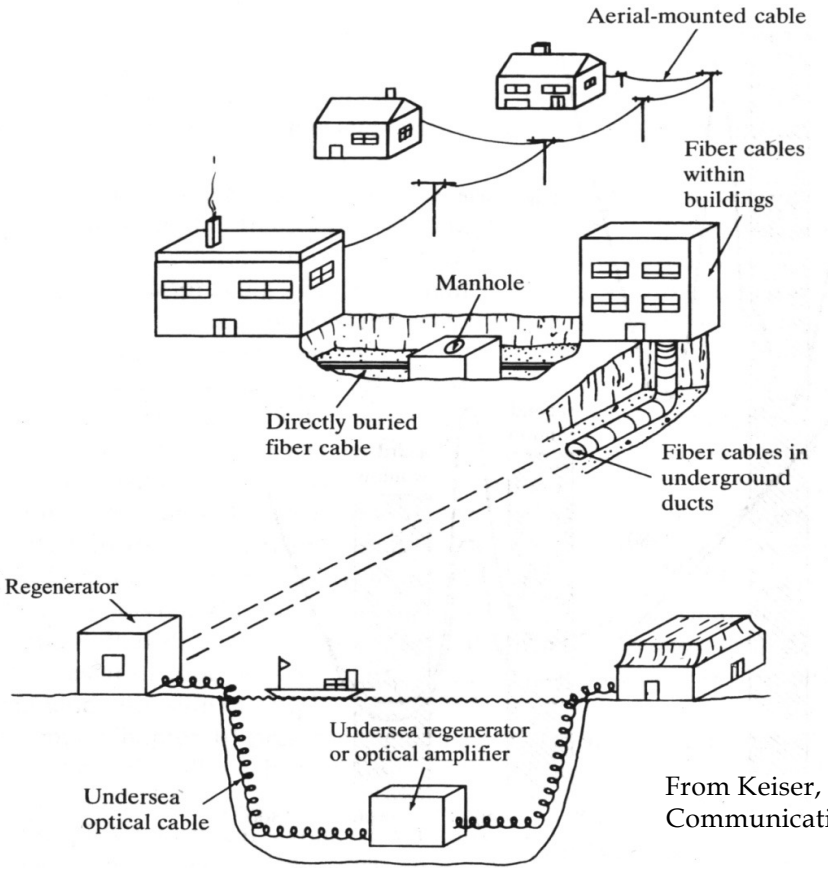
- transmitter - laser (direct, external modulation)
- receiver (PIN, AVD diodes)
- optical amplifier (EDFA, SOA, Raman)
- multiplexer, demultiplexer (WDM)
- switch (OXC) (optical cross-connect)
- add & drop multiplexer (ADM)
- integrated space switches (nxn)
- splitter, combiner
- filter (optical)
- wavelength converter
- thread connecting elements (with each other and with devices
- connectors (splices)

Additional elements

- If the optical signal is low in power, e.g. due to attenuation, optical amplifier (OA) (**1R regenerators**) can be used
- Three types of amplifiers
  - Semi-conductor optical amplifier (SOA) or laser optical amplifier - LOA
  - Erbium doped fiber amplifiers (EDFA)
  - Raman amplifier.
- If the signal distortions are too great (e.g. due to dispersion) signal re-shaping is required (**2R regenerators**)

- Elements for connecting threads to each other and to devices
  - connectors, splices
  - If the signals need to be split into several signals, a splitter is used.
  - If signals need to be combined into one signal, a coupler is used

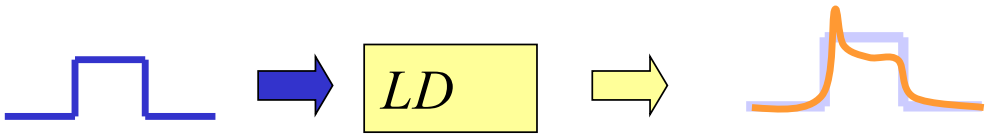
How fibres can be installed?



From Keiser, "Optical Fiber Communications", Mc Graw Hill, 2000

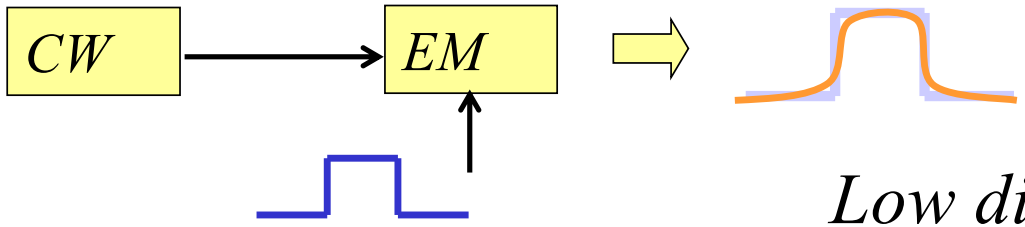
Laser transmitter

Direct modulation (DM)



"Chirp" → dispersion

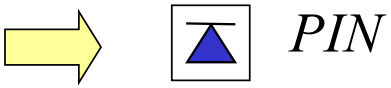
External modulation (EM)



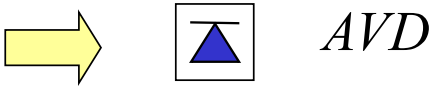
Low dispersion

Optical receiver

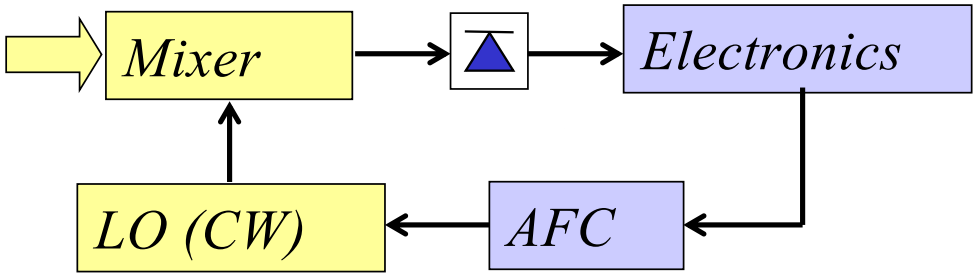
PIN diode



Avalanche diode

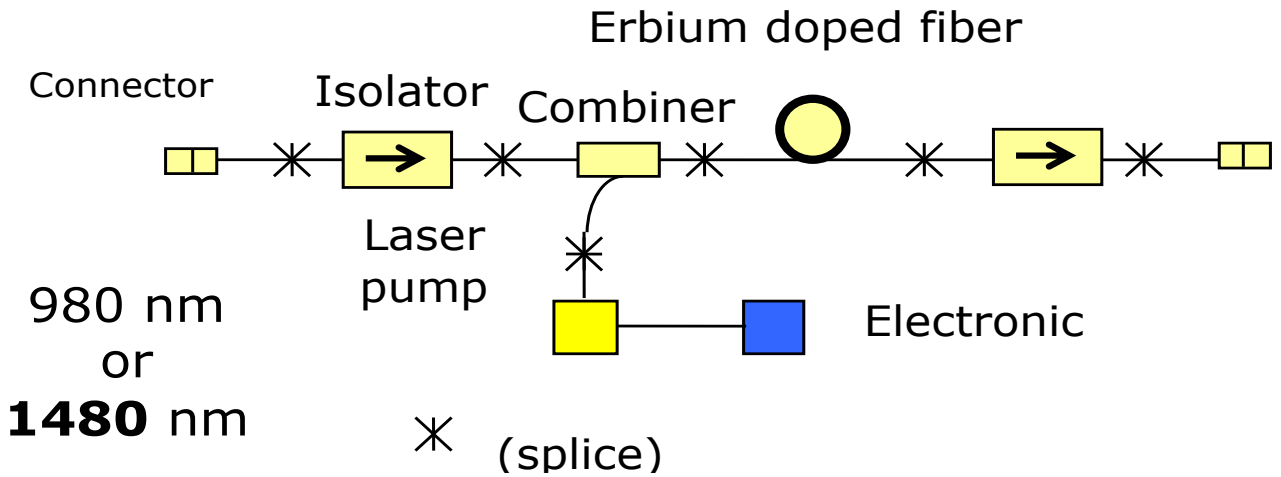


Coherent detection



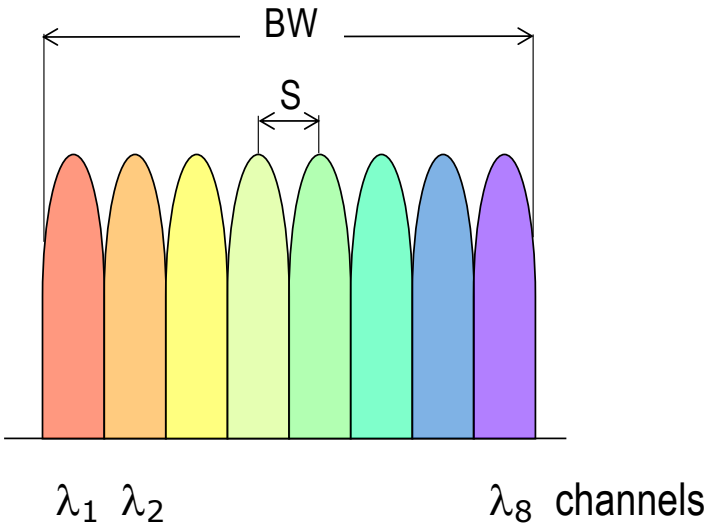
Erbium doped fiber amplifier (EDFA)

Works at: 1.530 -1.560 nm



Other possibilities, e.g.: PDFA 1300 nm (*Praseodimium Doped Fibre Amplifier*)

WDM – Wavelength Division Multiplexing



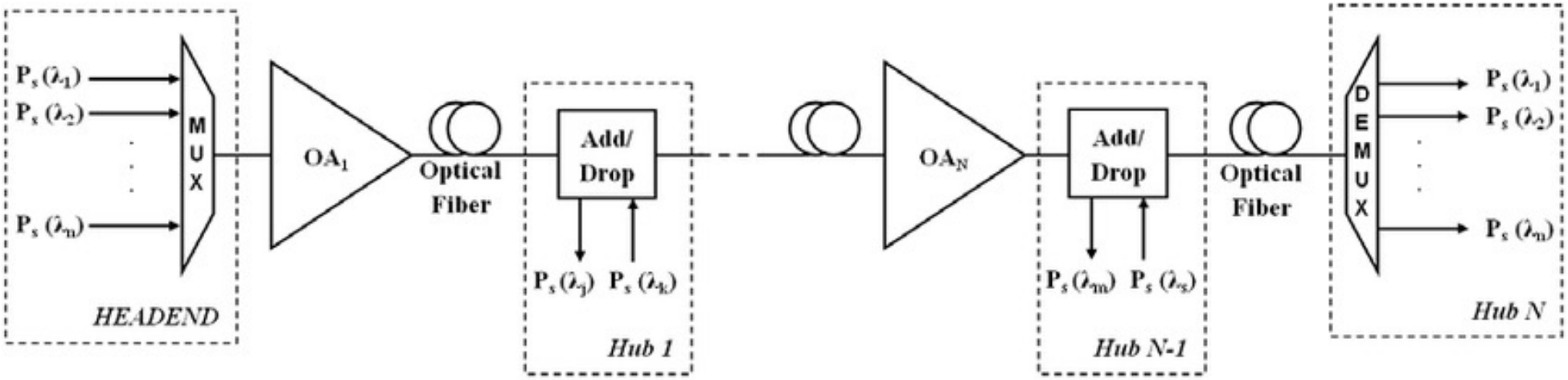
BW – frequency band, bandwidth

S – distance between wavelengths

1,2 Tbit/s
10 Gbit/s / λ
DWDM - 160 λ S < 1 nm
CWDM - 16 λ S = 20 nm

WDM – Wavelength Division Multiplexing
DWDM – Dense Wavelength Division Multiplexing
CWDM - Coarse Wavelength Division Multiplexing

WDM – Wavelength Division Multiplexing example architecture



https://www.researchgate.net/publication/311238350_Amplification_of_the_Multi-Wavelength_Signal_by_Using_EDFA_with_Constant_Gain/figures?lo=1&utm_source=google&utm_medium=organic

- Example: IP TV transmission
  - MUX (Multiplexor) combines inputs/channels/wavelengths
  - Optical Amplifiers amplify the signal along the way
  - ADM – can „take out” one channel and input another
  - DEMUX – splits channels onto receivers