LE 426

Optical Communications

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Chapter 1

Overview of Optical Communications

Optics

- Optics is an old subject involving the generation, propagation & detection of light.
- Three major developments are responsible for rejuvenation of optics & its application in modern technology:

1- Invention of Laser

2- Fabrication of low-loss optical Fiber

3- Development of Semiconductor Optical Device

As a result, new disciplines have emerged & new terms describing them have come into use, such as:

- **Electro-Optics**: is generally reserved for optical devices in which electrical effects play a role, such as lasers, electro-optic modulators & switches.

Photonics

- **Optoelectronics**: refers to devices & systems that are essentially electronics but involve lights, such as LED, liquid crystal displays & array photodetectors.
- **Quantum Electronics**: is used in connection with devices & systems that rely on the interaction of light with matter, such as lasers & nonlinear optical devices.
- **Quantum Optics**: Studies quantum & coherence properties of light.
- **Lightwave Technology**: describes systems & devices that are used in optical communication & signal processing.
- **Photonics**: in analogy with electronics, involves the control of photons in free space and matter.

Optical (or Photonic) Communications

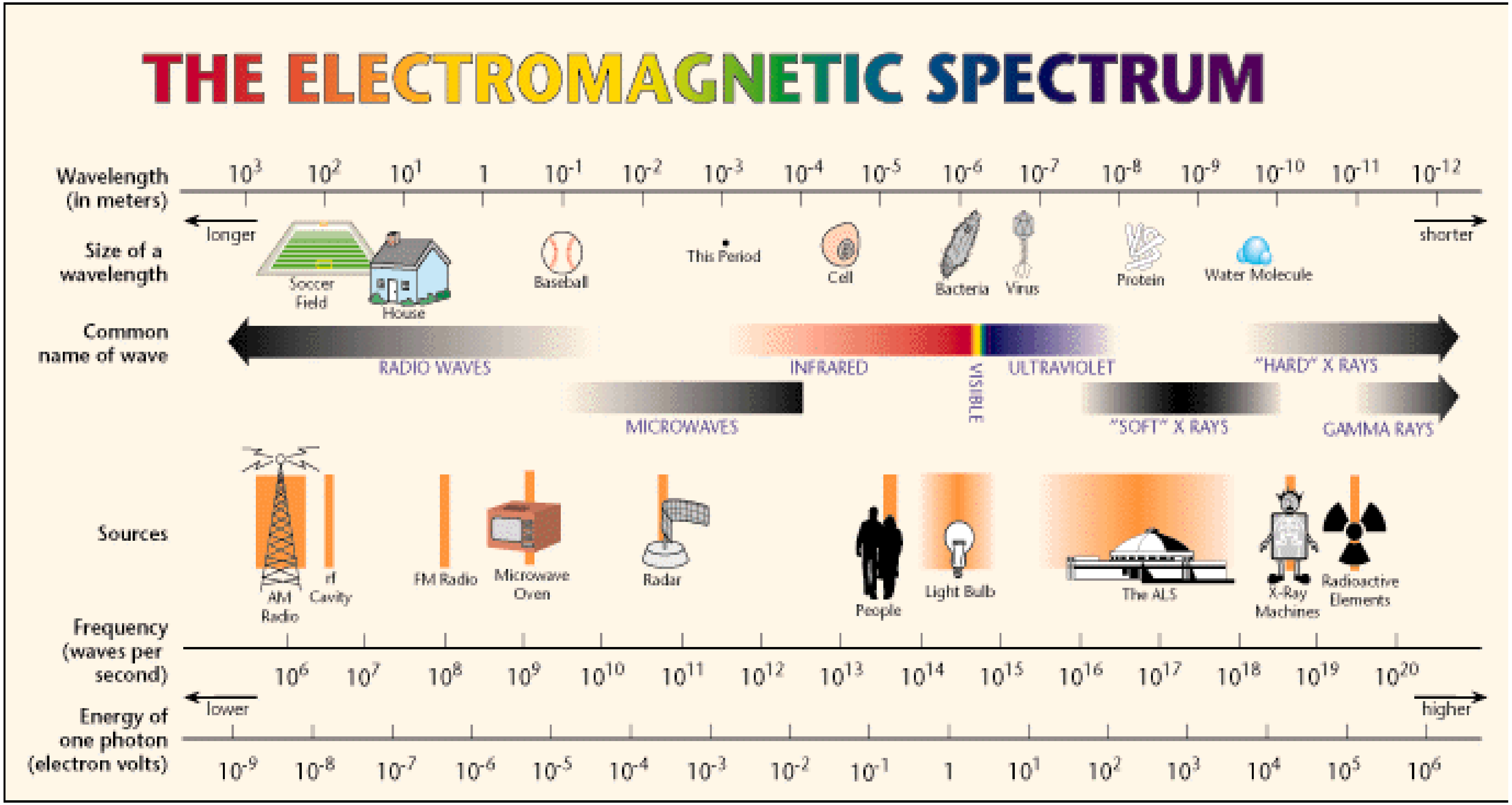
- Photonics reflects the importance of the photon nature of light. Photonics & electronics clearly overlap since electrons often control the flow of photons & conversely, photons control the flow of electrons.
- The scope of Photonics:

  1- Generation of Light (coherent & incoherent)

  2- Transmission of Light (through free space, fibers, imaging systems, waveguides, …)

  3- Processing of Light Signals (modulation, switching, amplification, frequency conversion, …)

  4- Detection of Light (coherent & incoherent)
- **Optical Communications**: describes the applications of photonic technology in communication devices & systems, such as transmitters, transmission media, receivers & signal processors.



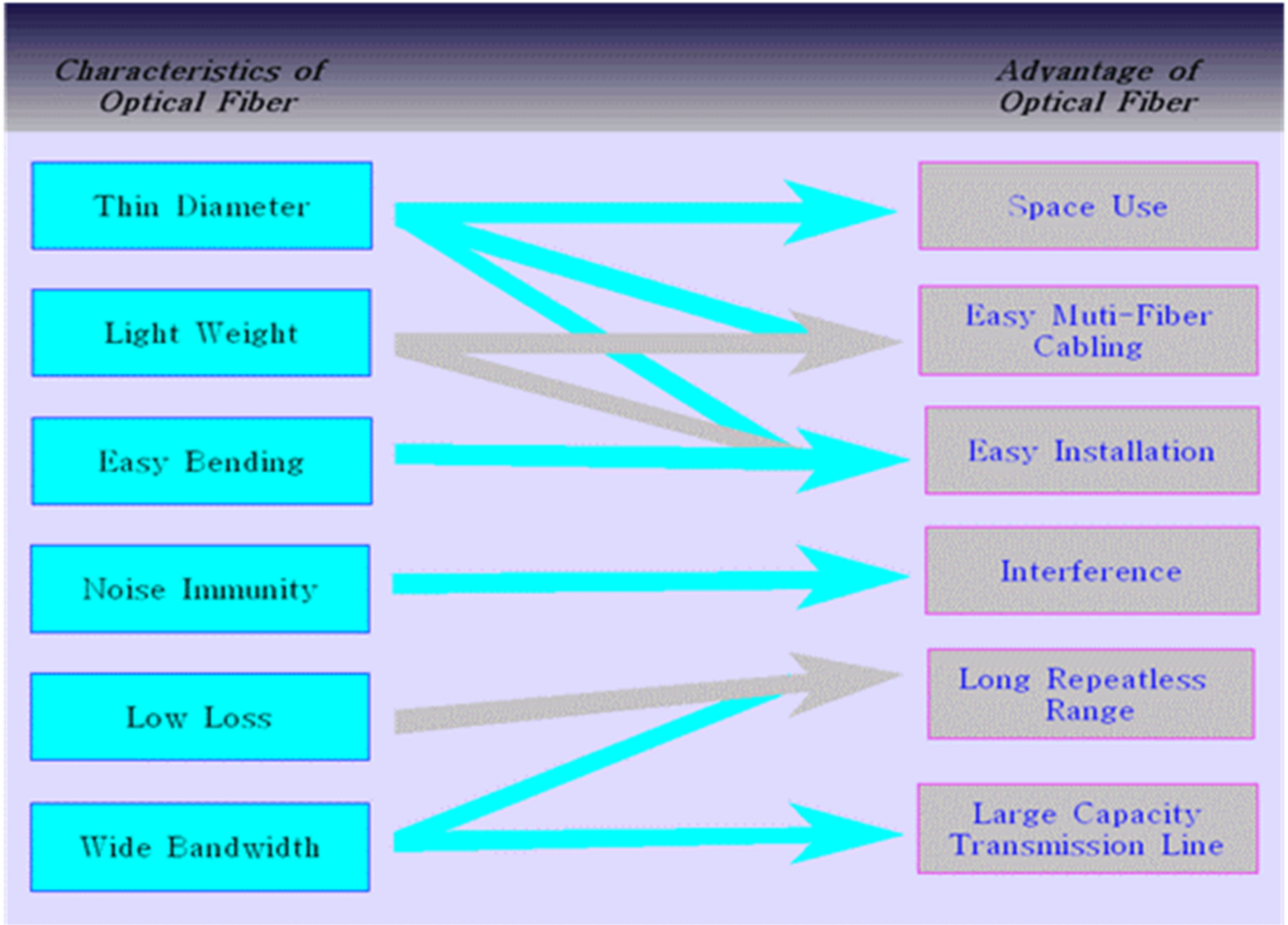
THE ELECTROMAGNETIC SPECTRUM
Wavelength (in meters)
10^3 10^2 10^1 1 10^-1 10^-2 10^-3 10^-4 10^-5 10^-6 10^-7 10^-8 10^-9 10^-10 10^-11 10^-12
longer
shorter
Size of a wavelength
Soccer Field
House
Baseball
This Period
Cell
Bacteria
Virus
Protein
Water Molecule
Common name of wave
RADIO WAVES
INFRARED
VISIBLE
ULTRAVIOLET
"HARD" X RAYS
MICROWAVES
"SOFT" X RAYS
GAMMA RAYS
Sources
AM Radio
rf Cavity
FM Radio
Microwave Oven
Radar
People
Light Bulb
The ALS
X-Ray Machines
Radioactive Elements
Frequency (waves per second)
10^6 10^7 10^8 10^9 10^10 10^11 10^12 10^13 10^14 10^15 10^16 10^17 10^18 10^19 10^20
lower
higher
Energy of one photon (electron volts)
10^-9 10^-8 10^-7 10^-6 10^-5 10^-4 10^-3 10^-2 10^-1 1 10^1 10^2 10^3 10^4 10^5 10^6

Why Optical Communications?

- Extremely wide bandwidth: high carrier frequency (a wavelength of 1552.5 nm corresponds to a center frequency of 193.1 THz!) & consequently orders of magnitude increase in available transmission bandwidth & larger information capacity.
- Availability of very low loss Fibers (0.25 to 0.3 dB/km), high performance active & passive optical components such as tunable lasers, very sensitive photodetectors, couplers, filters.
- Low cost systems for data rates in excess of Gbit/s.
- Optical Fibers have small size & light weight.
- Immunity to electromagnetic interference (high voltage transmission lines, radar systems, power electronic systems, airborne systems, …)
- Electrical Isolation -> Lack of EMI cross talk between channels
- Signal security
- Abundant raw materials.

ADVANTAGES OF OPTICAL FIBERS

1. VERY HIGH INFORMATION CARRING CAPACITY.
2. LESS ATTENUATION (order of 0.2 db/km)
3. SMALL IN DIAMETER AND SIZE & LIGHT WEIGHT
4. LOW COST AS COMPARED TO COPPER (as glass is made from sand..the raw material used to make OF is free….)
5. GREATER SAFETY AND IMMUNE TO EMI & RFI, MOISTURE & CORROSION
6. FLEXIBLE AND EASY TO INSTALL IN TIGHT CONDUITS
7. ZERO RESALE VALUE (so theft is less)
8. IS DIELECTRIC IN NATURE SO CAN BE LAID IN ELECTICALLY SENSITIVE SURROUNDINGS
9. DIFFICULT TO TAP FIBERS, SO SECURE
10. NO CROSS TALK AND DISTURBANCES


Characteristics of Optical Fiber
Advantage of Optical Fiber
Thin Diameter
Light Weight
Easy Bending
Noise Immunity
Low Loss
Wide Bandwidth
Space Use
Easy Muti-Fiber Cabling
Easy Installation
Interference
Long Repeatless Range
Large Capacity Transmission Line

DISADVANTAGES OF OPTICAL FIBERS…

1. The terminating equipment is still costly as compared to copper equipment.
2. Optical fiber is delicate so has to be handled carefully.
3. Last mile is still not totally “fiberized” due to costly subscriber premises equipment.
4. Communication is not totally in optical domain, so repeated electric – optical – electrical conversion is needed.
5. Optical amplifiers, splitters, MUX-DEMUX are still in development stages.
6. Tapping is not possible. Specialized equipment is needed to tap a fiber.
7. Optical fiber splicing is a specialized technique and needs expertly trained manpower.
8. The splicing and testing equipments are very expensive as compared to copper equipments.

APPLICATIONS OF OPTICAL FIBERS…

1. LONG DISTANCE COMMUNICATION BACKBONES
2. INTER-EXCHANGE JUNCTIONS
3. VIDEO TRANSMISSION
4. BROADBAND SERVICES
5. COMPUTER DATA COMMUNICATION (LAN, WAN etc..)
6. HIGH EMI AREAS
7. MILITARY APPLICATION
8. NON-COMMUNICATION APPLICATIONS (sensors etc…)

Comparison with Other Media

Area	Coax	Microwave	Satellite	Optical Fiber
Engineering of system	simpler, straight	Detail Engg. required	Detail Engg. required	simpler
Reliability	highly reliable	Increased maintenance requirement	require stringent maintenance	Most reliable
Capacity	Up to 10800 channels (60MHz) per cable	Max 1800,1920 channels (analog,digital) per RF link	1332 channels/ transponder	20k channel of 1Gbps
Cost	Very costly	Cheaper	Costlier than coax	Cheapest for higher # of channels

Comparison with Other Media (cont'd)

Area	Coax	Microwave	Satellite	Optical Fiber
Implementation time	More time consuming especially in difficult terrain	Lesser	Least	Easier than that of coax. cables
Effects of EM and electrostatic induction	Max. protection required	Not required	Not required	Not required
Repeater spacing for wide band system	2-4 km	About 40 km	1/3rd globe	40-45 km

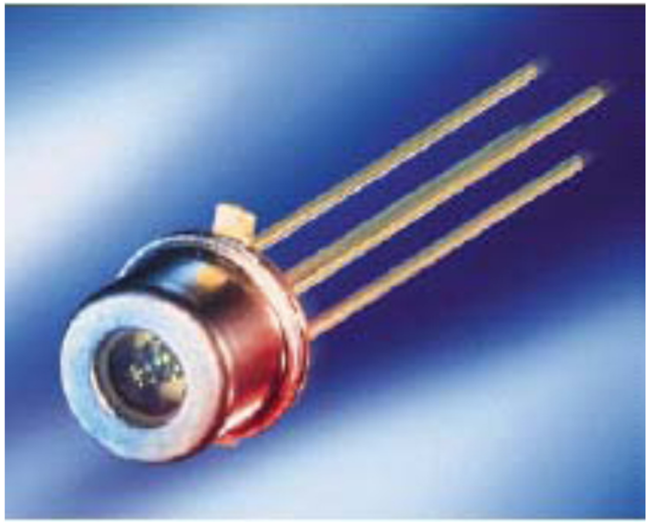
BW demands in communication systems

Type & applications	**Format**	**Uncompressed**	**Compressed**
Voice, digital telegraphy	4 kHz voice	64 kbps	16-32 kbps
Audio	16-24 kHz	512-748 kbps	32-384 kbps (MPEG, MP3)
Video conferencing	176×144 or 352 × 288 frames @ 10-30 frames/s	2-35.6 Mbps	64 kbps-1.544 Mbps (H.261 coding)
Data transfer, E-commerce, Video entertainment			1-10 Mbps
Full-motion broadcast video	720×480frames @ 30 frames/s	249 Mbps	2-6Mbps (MPEG-2)
HDTV	1920 × 1080 (~2.1MP) frames@ 30 frames /s	1.6 Gbps	19-38 Mbps (MPEG-2)

Evolution of Light wave systems

1st Generation: The development of low-loss fibers and semiconductor lasers (GaAs) in the 1970's.

A Gallium Arsenide (GaAs) laser operates at a wavelength of 0.8 μm. The optical communication systems allowed a bit rate of 45Mbit/s and repeater spacing of 10km.

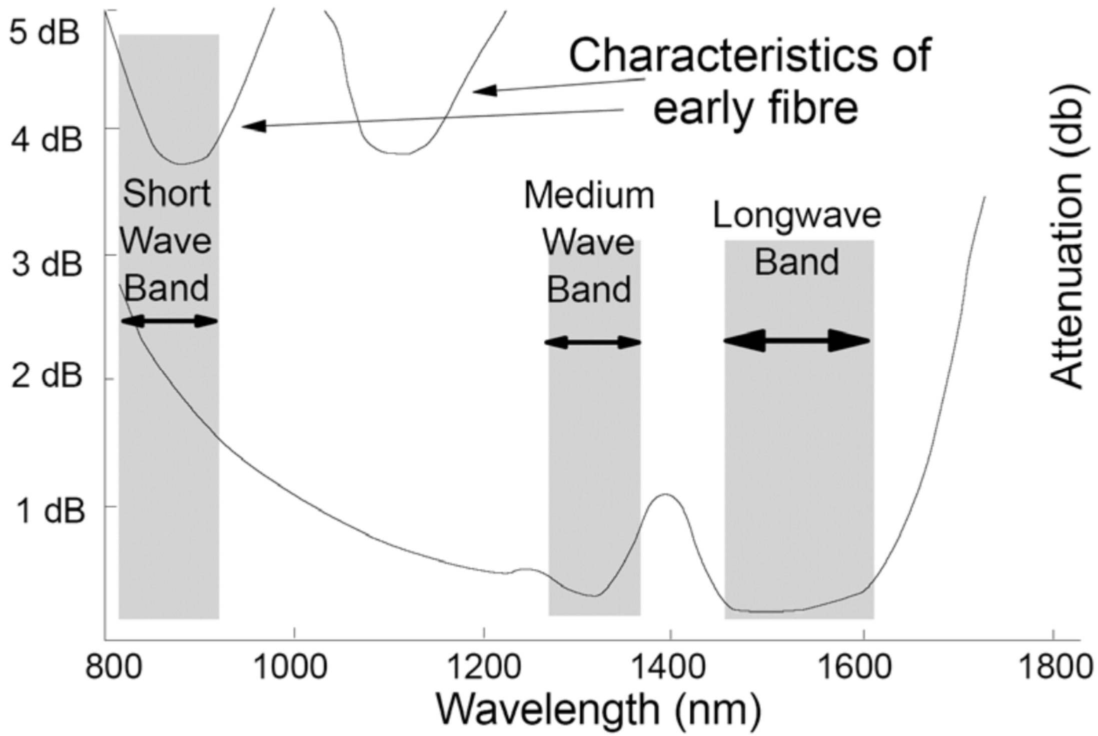


Example of a laser diode.

(Ref.: Infineon)

Evolution of Lightwave systems

2nd Generation: The repeater spacing could be increased by operating the lightwave system at 1.3 μ m. The attenuation of the optical fiber drops from 2-3dB/km at 0.8 μ m down to 0.4dB/km at 1.3 μ m. Silica fibers have a local minima at 1.3 μ m.

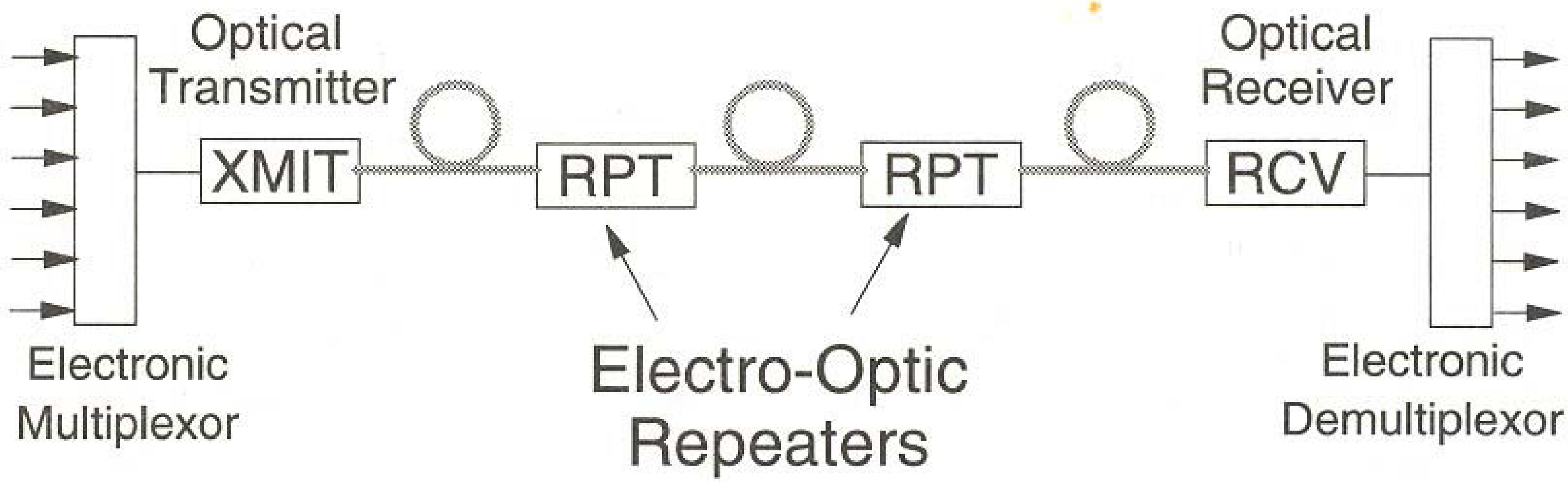


2^{nd} Generation: The transition from 0.8 μm to 1.3 μm lead to the 2^{nd} Generation of lightwave systems. The bit rate-distance product can be further increased by using single mode fibers instead of multi-mode fibers.

Single mode fibers have a distinctly lower dispersion than multi mode fibers.

Lasers are needed which emit light at 1.3 μm.

3rd Generation: Silica fibers have an absolute minima at 1.55 μ m. The attenuation of a fiber is reduced to 0.2dB/km. Dispersion at a wavelength of 1.55 μ m complicates the realization of lightwave systems. The dispersion could be overcome by a dispersion-shifted fibers and by the use of lasers, which operate only at single longitudinal modes. A bit rate of 4Gbit/s over a distance of 100km was transmitted in the mid 1980's.

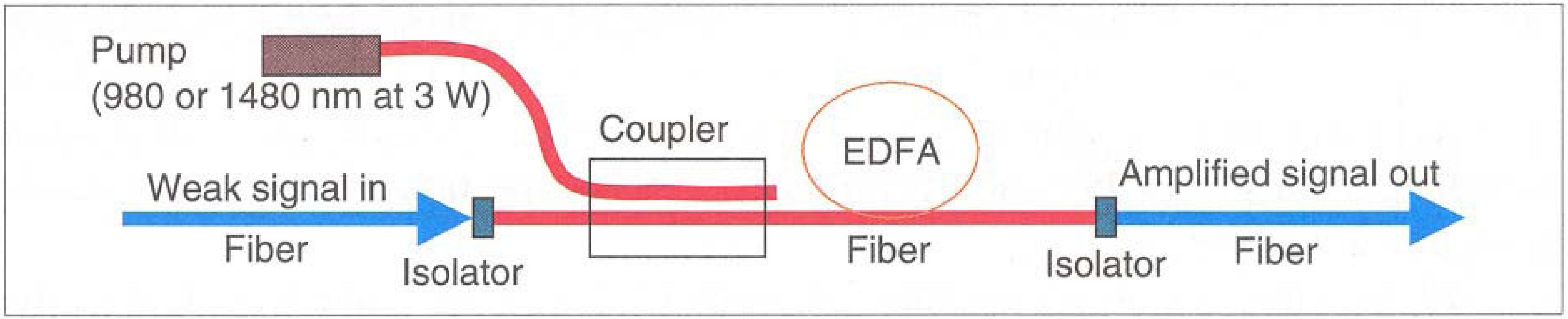


Traditional long distance single channel fiber transmission system.

Ref.: H. J.R. Dutton, Understanding optical communications

3rd Generation: The major disadvantage of the 3rd Generation optical communication system is the fact that the signals are regenerated by electrical means. The optical signal is transferred to an electrical signal, the signal is regenerated and amplified before the signal is again transferred to an optical fiber.

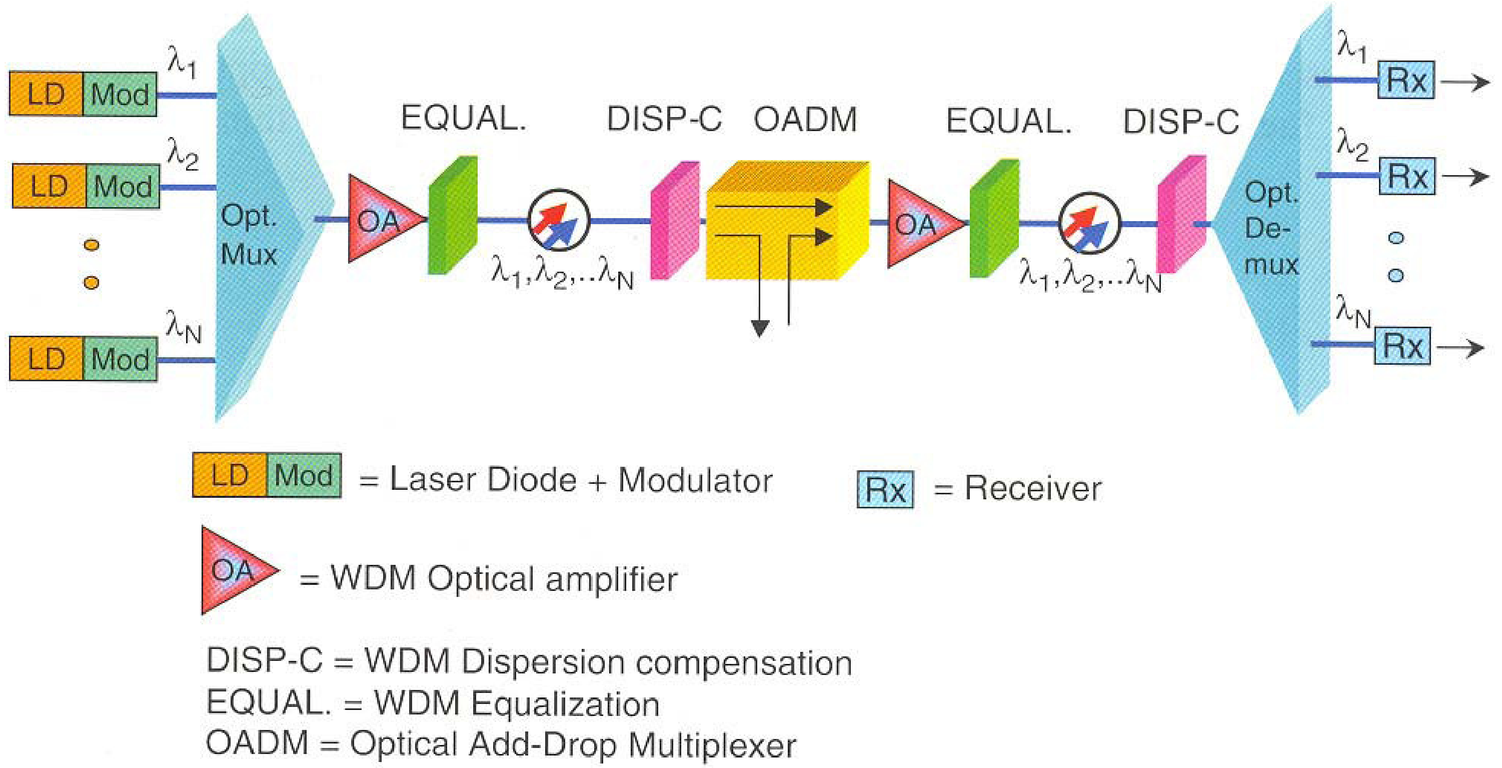
4th **Generation:** The development of the optical amplifier lead to the 4th Generation of optical communication systems.



Schematic sketch of an erbium-doped fiber amplifier (EDFA).

Ref.: S.V. Kartalopoulos, Introduction to DWDM Technology

Evolution of Lightwave systems

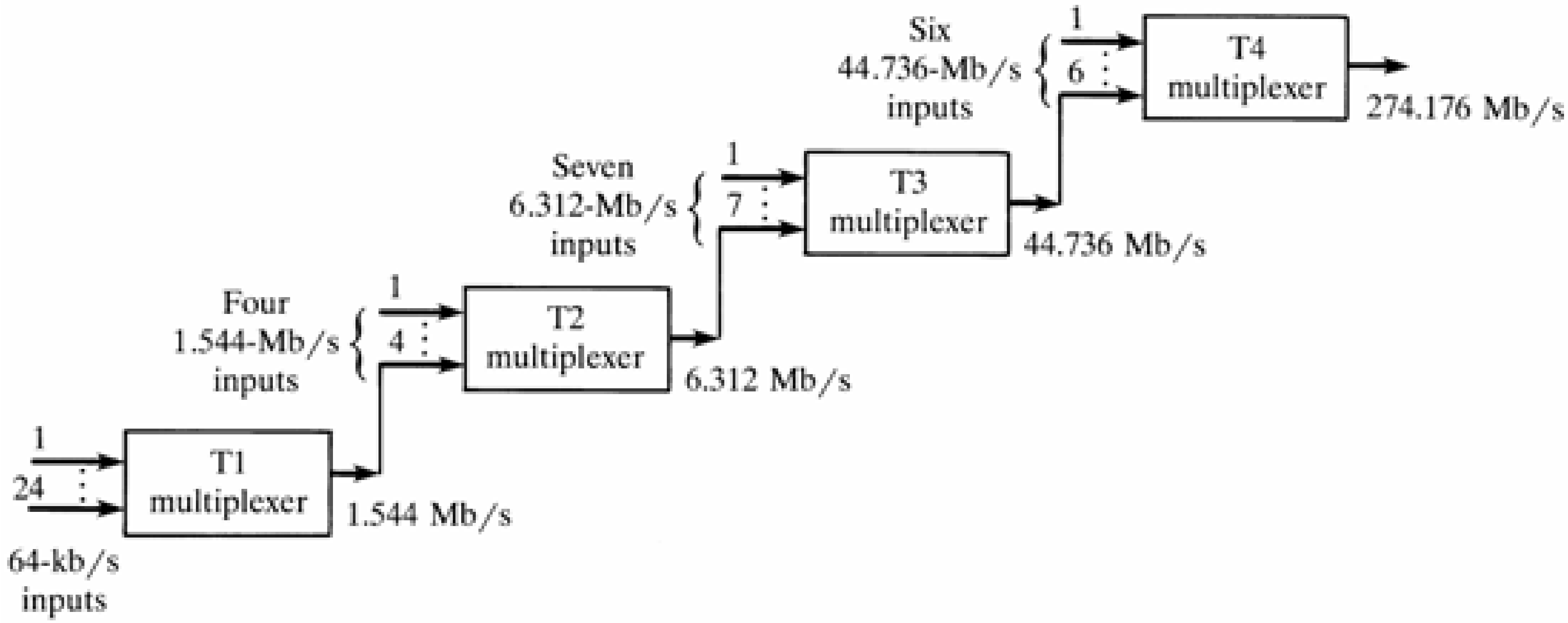


State of the Art optical communication system: Dense Wavelength Division Multiplex (DWDM) in combination of optical amplifiers. The capacity of optical communication systems doubles every 6 months. Bit rates of 10Tbit/s were realized by 2001.

Ref.: S. Kartalopoulos, WDWM Networks, Devices and Technology

Early application of fiber optic communication

- Digital link consisting of time-division-multiplexing (TDM) of 64 kbps voice channels (early 1980).



Optical Fiber communications, 3rd ed.,G.Keiser,McGrawHill, 2000

SONET & SDH Standards

- **SONET** (Synchronous Optical NETwork) is the network standard used in north America & **SDH** (Synchronous Digital Hierarchy) is used in other parts of the world. These define a synchronous frame structure for sending multiplexed digital traffic over fiber optic trunk lines.

- The basic building block of SONET is called **STS-1** (Synchronous Transport Signal) with 51.84 Mbps data rate. Higher-rate SONET signals are obtained by byte-interleaving *N* STS-1 frames, which are scramble & converted to an Optical Carrier Level *N* (**OC-N**) signal.

- The basic building block of SDH is called **STM-1** (Synchronous Transport Module) with 155.52 Mbps data rate. Higher-rate SDH signals are achieved by synchronously multiplexing *N* different STM-1 to form **STM-N** signal.

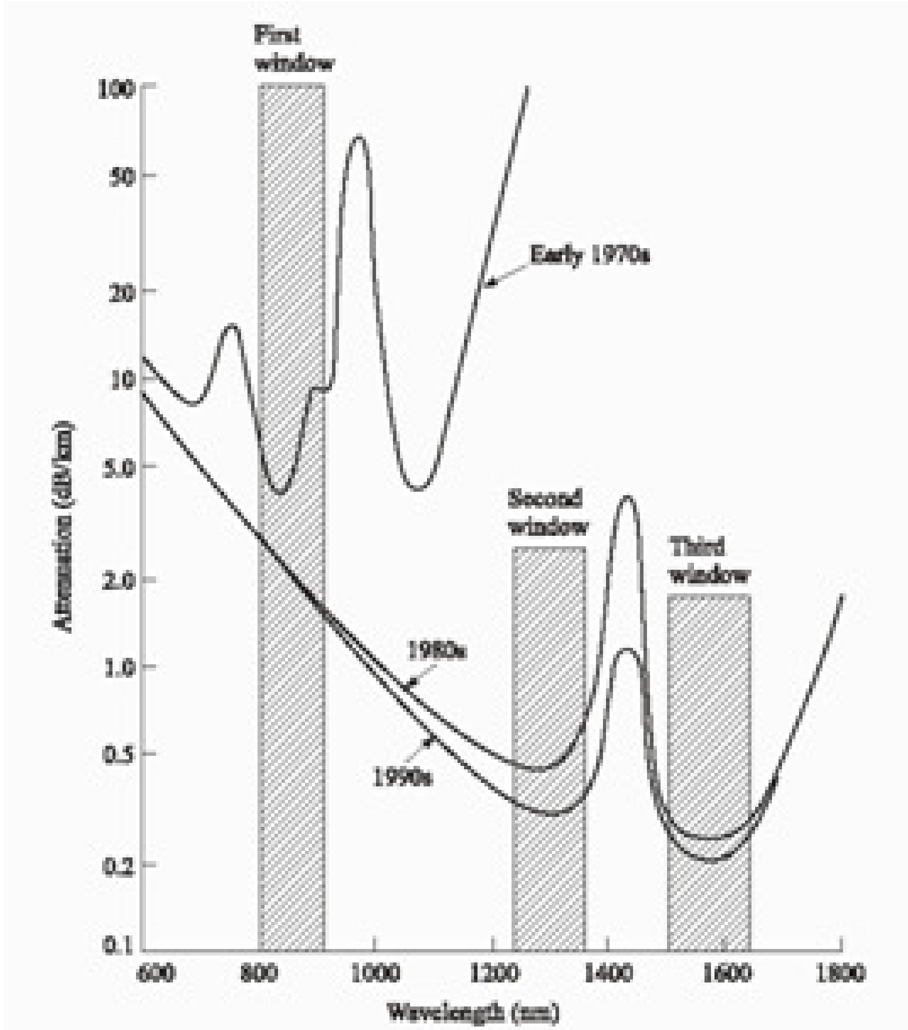
SONET & SDH transmission rates

SONET level	Electrical level	Line rate (Mb/s)	SDH equivalent
OC-1	STS-1	51.84	-
OC-3	STS-3	155.52	STM-1
OC-12	STS-12	622.08	STM-4
OC-24	STS-24	1244.16	STM-8
OC-48	STS-48	2488.32	STM-16
OC-96	STS-96	4976.64	STM-32
OC-192	STS-192	9953.28	STM-64

Optical Fiber communications, 3rd ed.,G.Keiser,McGrawHill, 2000

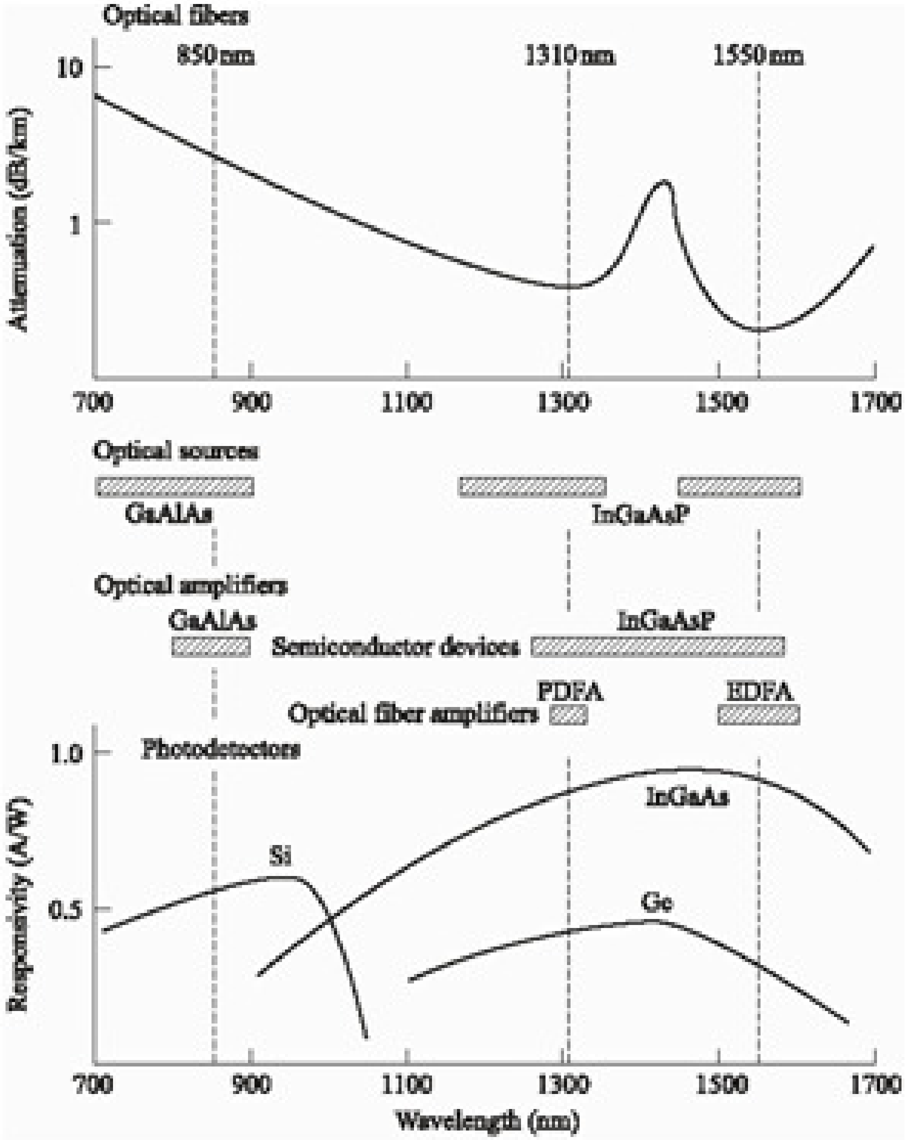
Evolution of fiber optic systems

- 1950s:Imaging applications in medicine & non-destructive testing, lighting
- 1960s:Research on lowering the fiber loss for telecom. applications.
- 1970s:Development of low loss fibers, semiconductor light sources & photodetectors
- 1980s:single mode fibers (OC-3 to OC-48) over repeater sapcings of 40 km.
- 1990s:Optical amplifiers (e.g. EDFA), WDM (wavelength division multiplexing) toward dense-WDM.



Optical Fiber communications, 3rd ed.,G.Keiser,McGrawHill, 2000

Operating range of 4 key components in the 3 different optical windows



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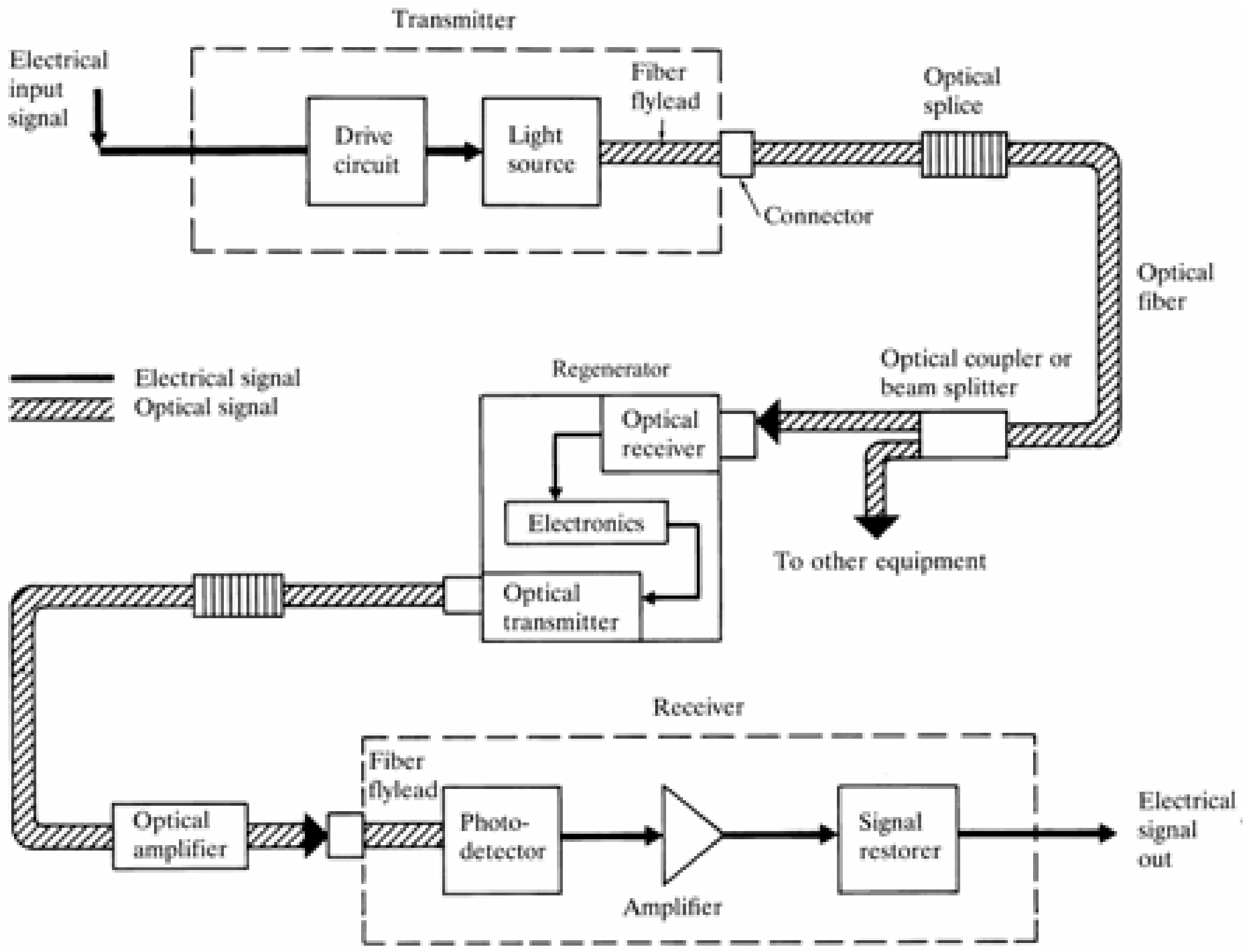
Major elements Of typical photonic comm link



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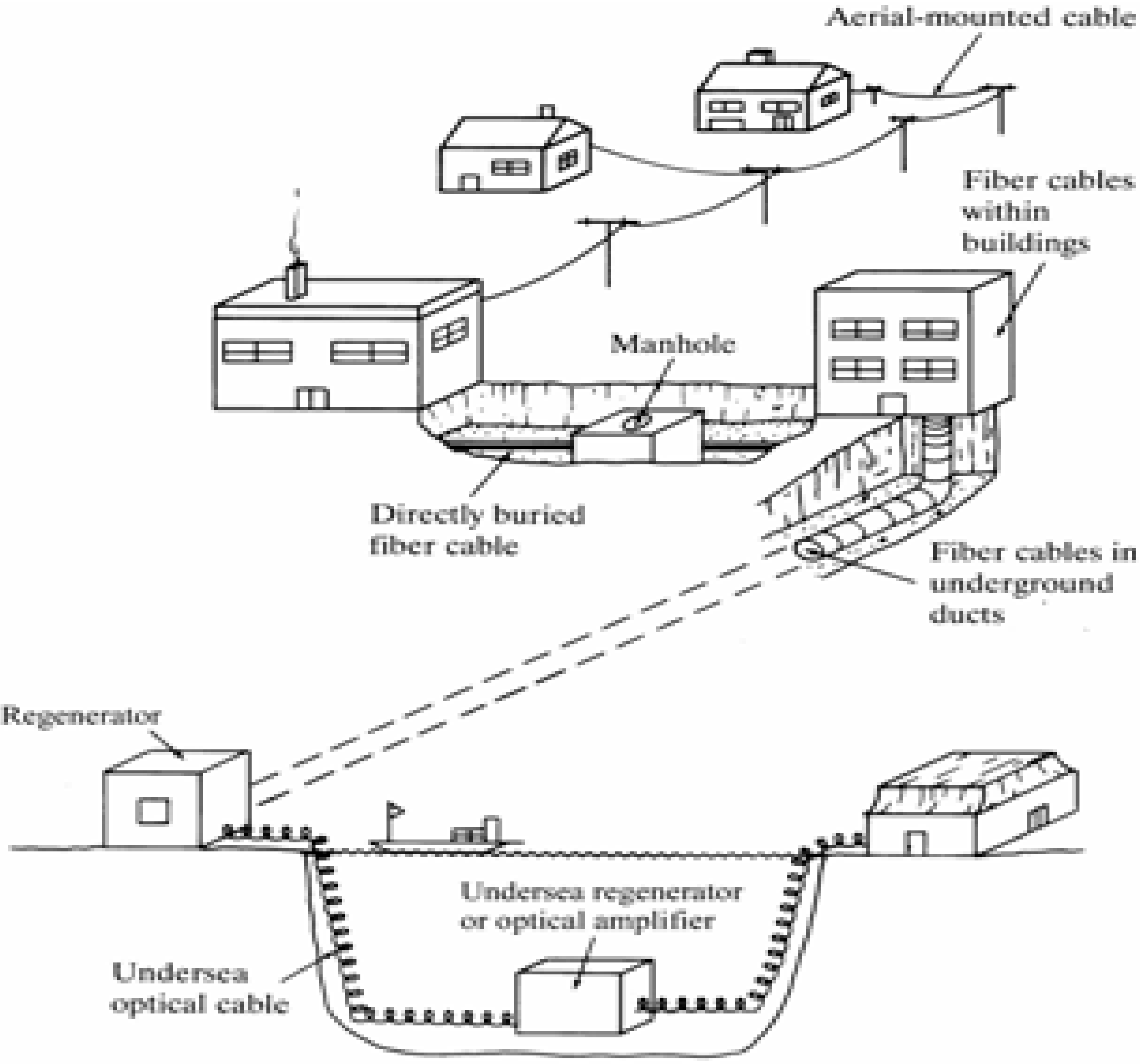
Installation of Fiber optics



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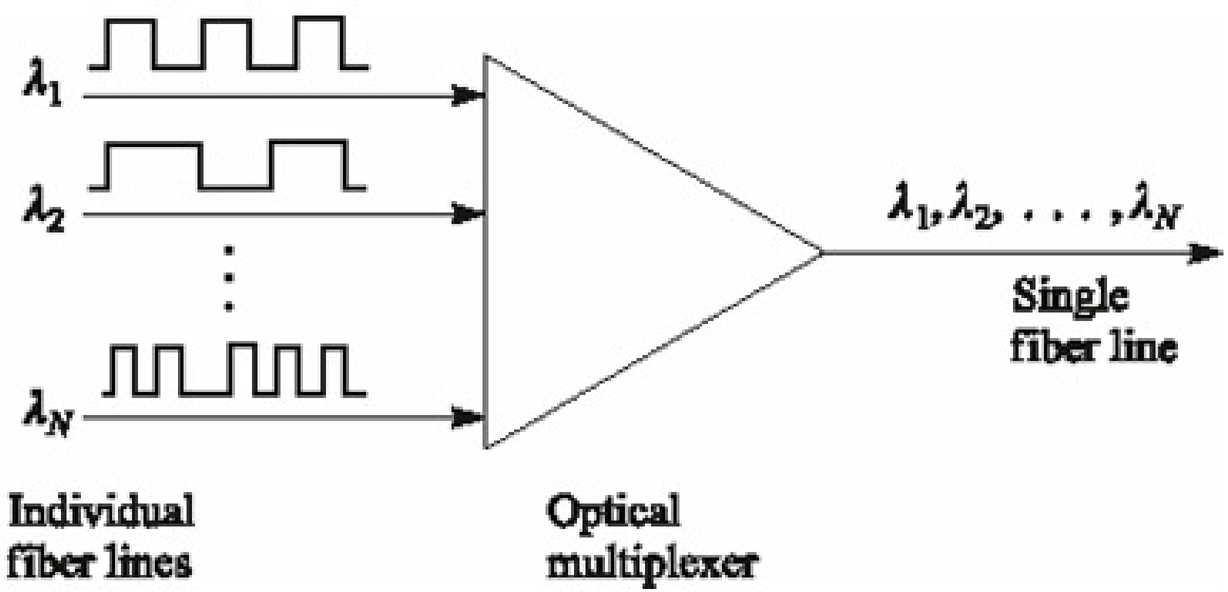
WDM Concept



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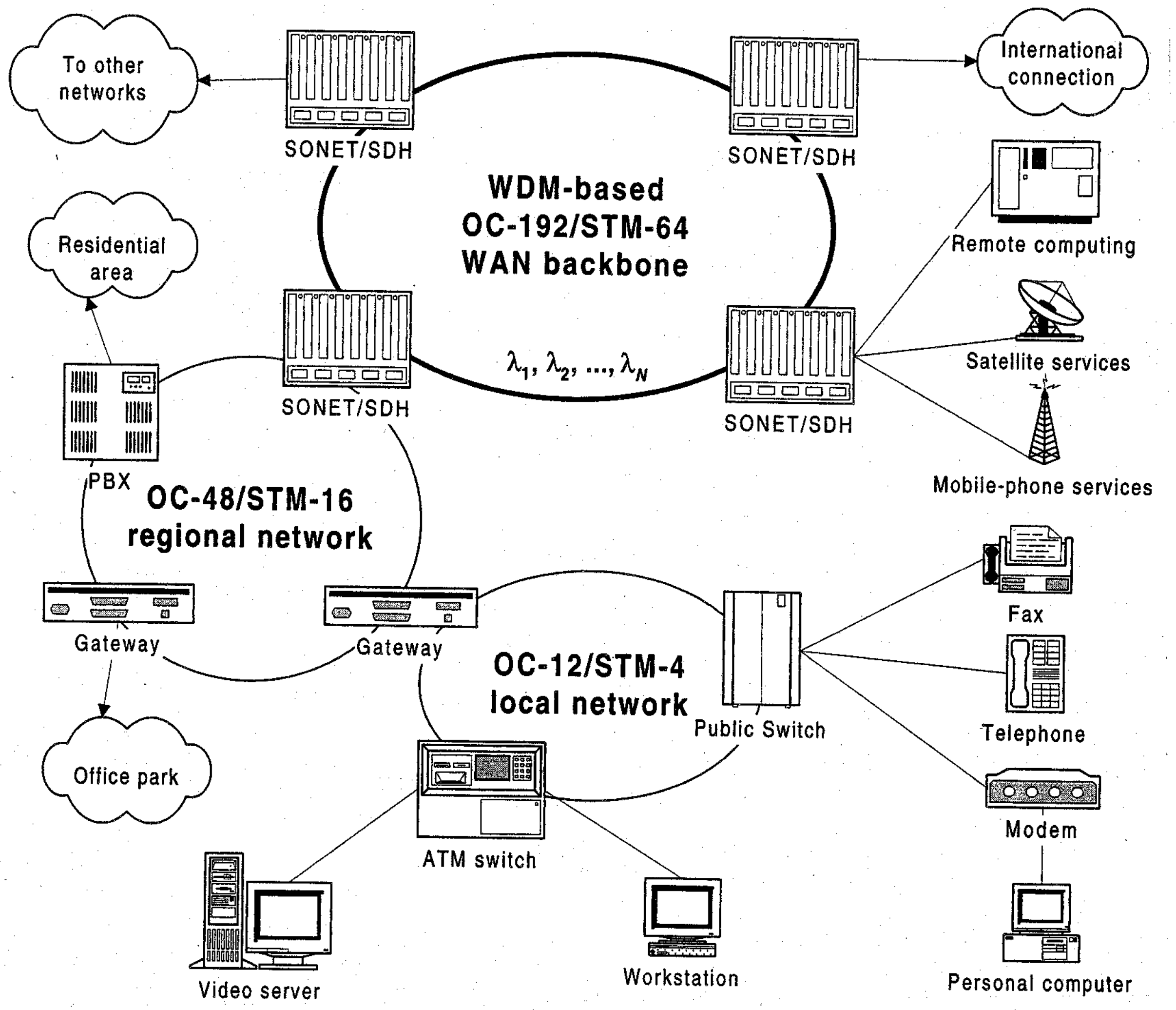

FIGURE 1-9
Conceptual SONET/SDH optical transport network connecting local, metropolitan, and wide-area communications elements.

Optical Fiber communications, 3rd ed.,G.Keiser,McGrawHill, 2000