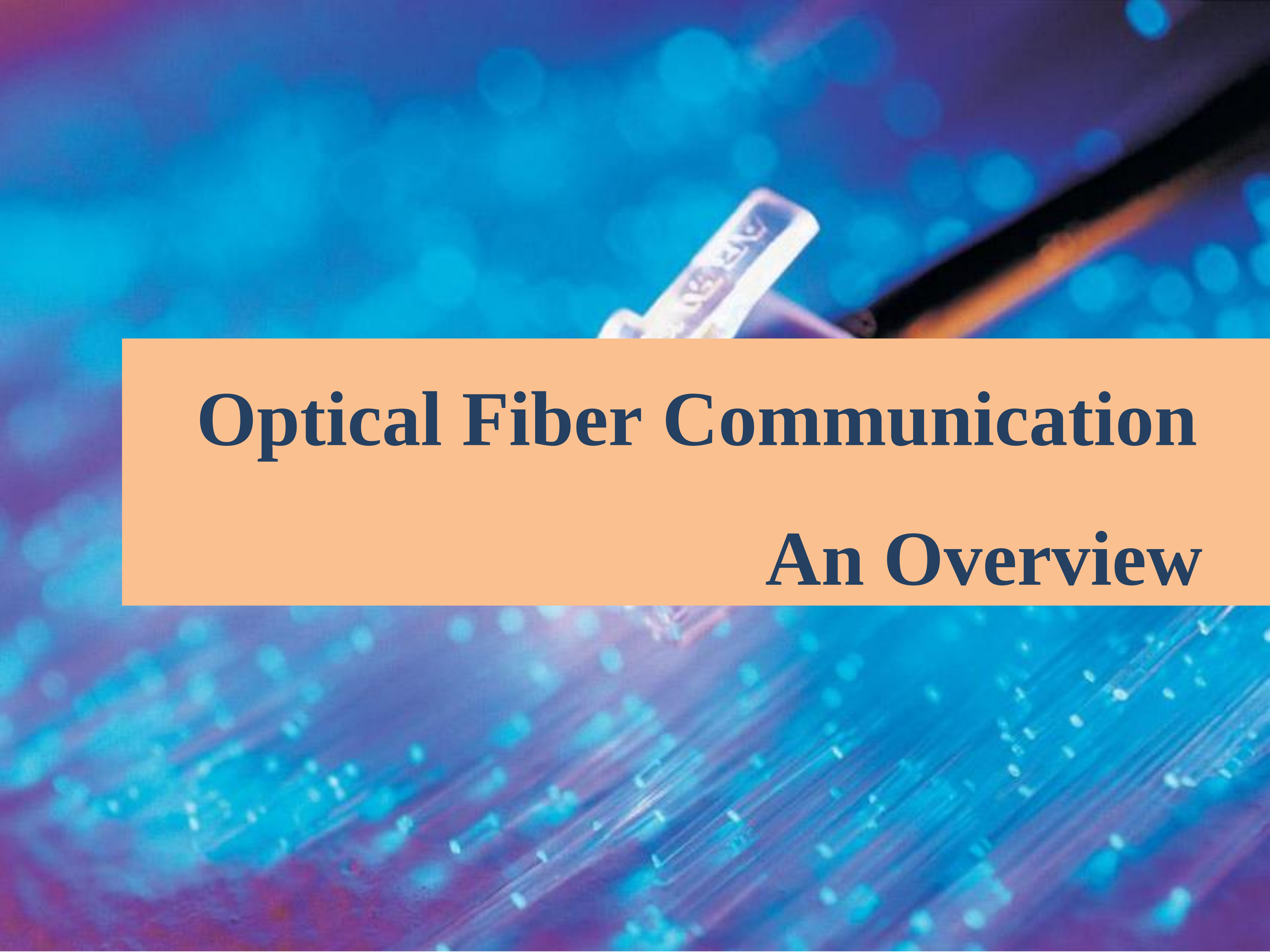


Optical Fiber Communication

An Overview

What is Optical Fiber Technology?

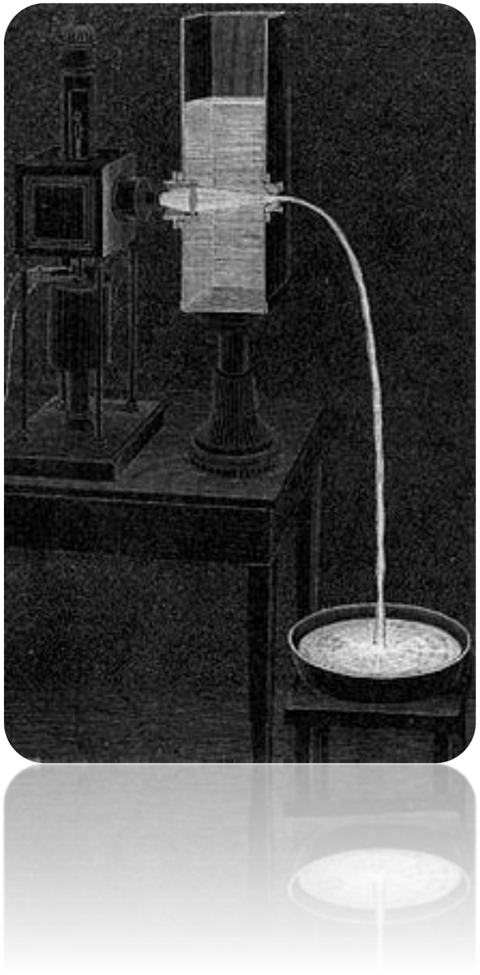
❑ Also called **Lightwave Technology**

- Optical Fiber Technology uses light as the primary medium to **carry information**.
- The light often is guided through **optical fibers**.
- Most applications use **invisible (infrared) light**: LEDs or LDs.

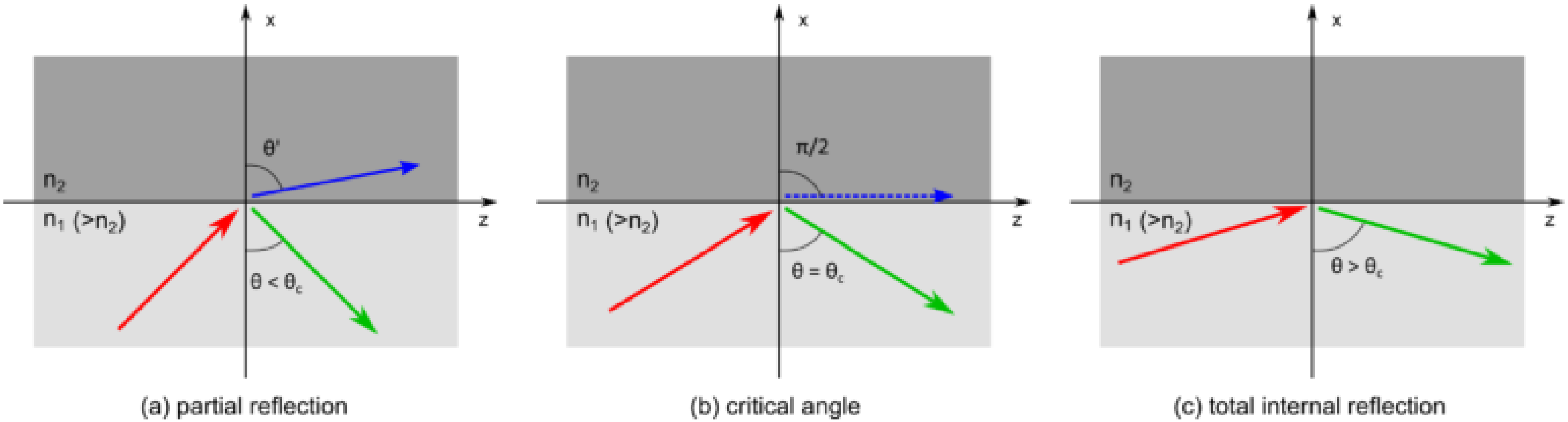
History for Optical Fiber

- Fiber optics is not really a new technology, it's fairly old.

- Guiding of light by refraction, the principle that makes fiber optics possible, was first demonstrated by Daniel Colladon and Jacques Babinet in Paris in the early 1840s.



How?→ Total Internal Reflection of light



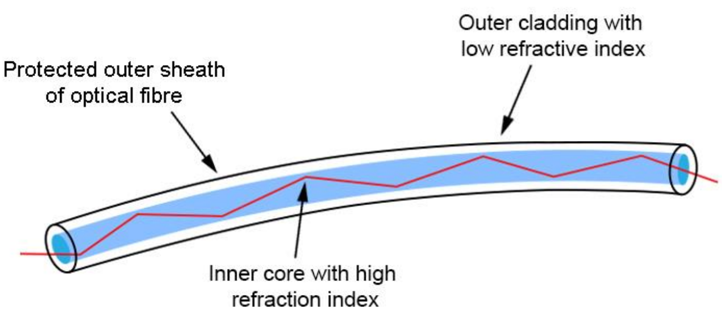
Snell's law:

$$n_1 \sin\theta = n_2 \sin\theta'$$

the critical angle:

$$\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$$

- The ray must be travelling from the optically denser medium (higher refractive index, **Core**) to the optically rarer medium (lower refractive index, **Cladding**).
- The ray must be incident at an angle greater than **the critical angle** of the medium pair.



Why Optical Fiber Technology?

- During past three decades, **remarkable** and **dramatic** changes took place in the electronic communication industry.

- A phenomenal increase in **voice**, **data** and **video** communication - demands for **larger capacity** and **more economical** communication systems.
- **Lightwave Technology : Technological route for achieving this goal.**

➢ **Most cost-effective way** to move **huge amounts of information quickly and reliably**.

Why Optical Fiber Communication ?

Capacity ! Capacity ! and More Capacity !

- A technical revolution in **Communication Industry** to explore for **large capacity, high quality** and **economical systems** for communication at **Global level.**

✓**Radio-waves** and **Terrestrial Microwave** systems have long since reached their capacity.

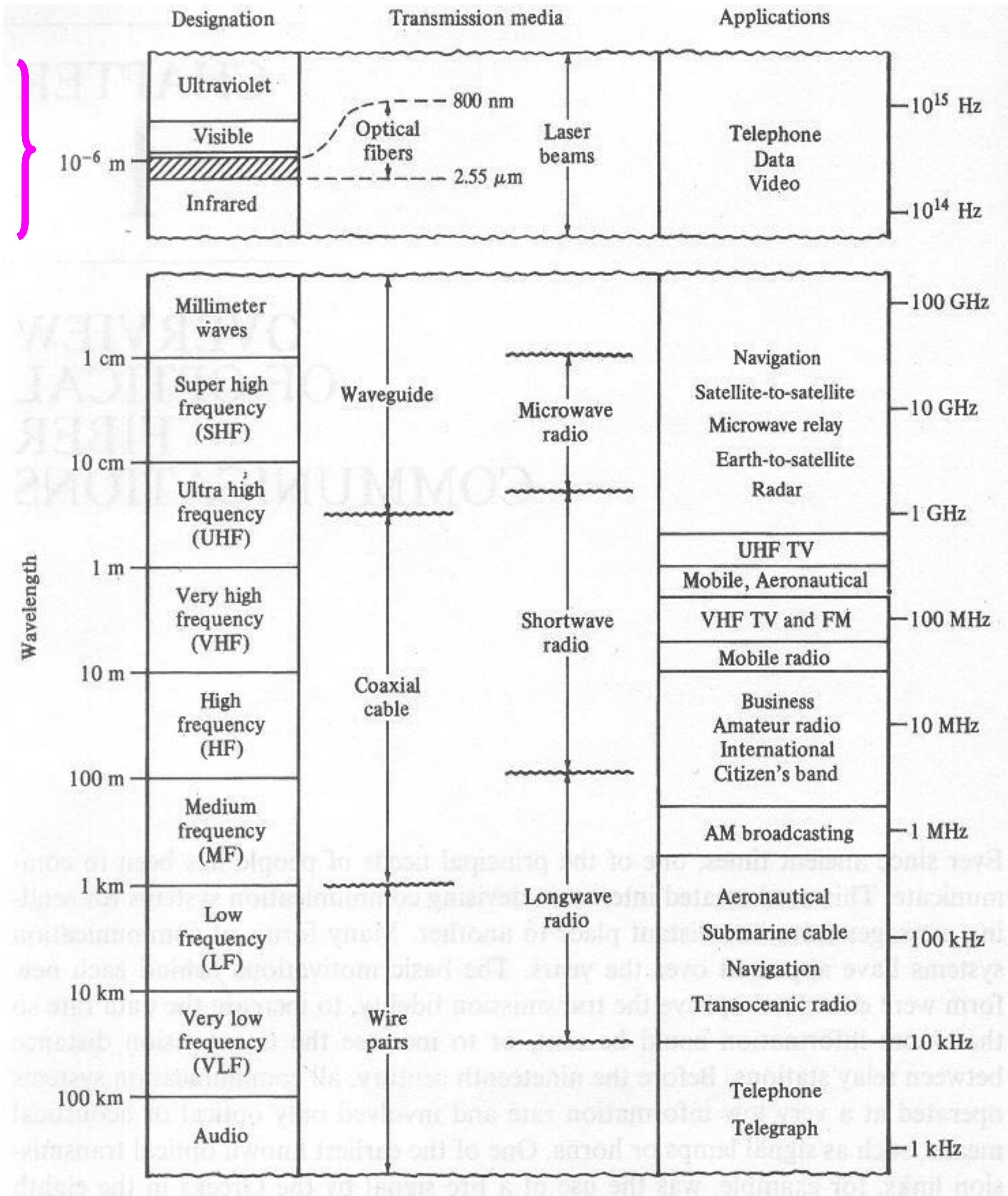
✓**Satellite Communication Systems** can provide, at best, only a temporary relief to the ever-increasing global demand.

- extremely high initial cost of launching;
- geometry of suitable orbits;
- available **microwave frequency** allocations and;
- if needed repair is nearly impossible.

Next option: **Optical Communication Systems !**

Optical Region

Frequency increase



The Electromagnetic Spectrum

Potential of Optical Fiber Communication?

- ❑ The information carrying capacity of a communications system is directly proportional to its bandwidth; $C = BW \times \log_2(1+SNR)$
  - ➢ **Wider the bandwidth, greater the information carrying capacity.**

- **Theoretically: BW is 10% of the carrier frequency.**

Signal Carrier	Bandwidth
VHF Radio system: 100 MHz.	10 MHz
Microwave system: 6 GHz	0.6 GHz.
Lightwave system: 10^6 GHz	10^5 GHz.

- A system with light as carriers has an **Excessive bandwidth** (more than 100,000 times than achieved with microwave frequencies**)**
  - ➢ meet the today's communication needs or that of the foreseeable future.

- ❑ Communication System with light as the carrier of information

  ⇒ **A great deal of attention.**

Communication Channel Capacity

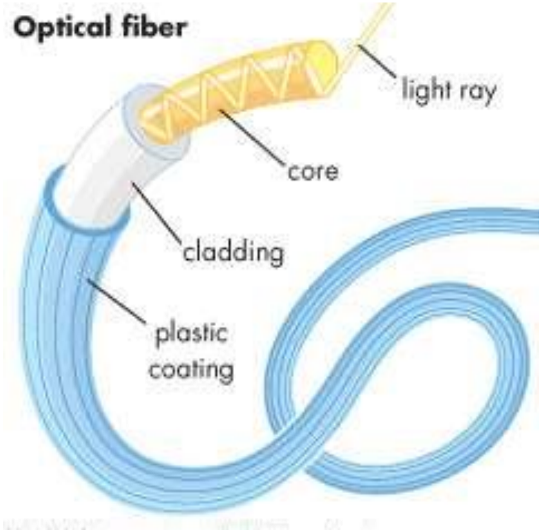
Communication Medium	Carrier Frequency	Bandwidth	2 way voice Channels
Copper Cable	1 MHz	100 kHz	< 2000
Coaxial Cable	100 MHz	10 MHz	13,000
Optical Fiber Cables	100 –1000 THz	40 THz	>3,00,000 or 90,000 Video signals

Major Difficulties ?

- **Transmission of light wave for any useful distance through earth's atmosphere ⇒ Impractical : Attenuation and Absorption of ultra high light frequencies by water vapors, oxygen and air particulate.**
  - **The only practical type of optical communication system that uses a fiber guide.**

Optical Fiber ?

A strand of glass or plastic material with special optical properties, which enable light to travel a large distance down its length.



- **Powerful & Intense Optical Sources**

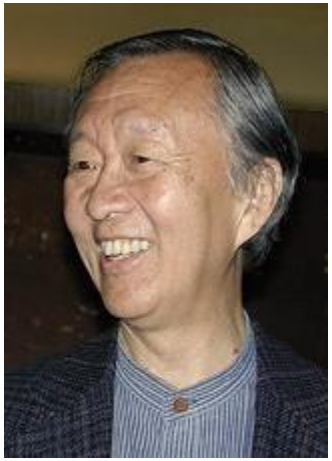
❖ **Invention of LASER (1960) and low loss Optical Fiber Wave guides (1970)** – An edge toward making the dream of carrying huge amount of information, a reality.

Optical Fiber Timeline

- **1951**: Light transmission through bundles of fibers- **flexible fiberscope** used in medical field.
- **1957** : First fiber-optic **endoscope** tested on a patient.
- **1960** : Invention of **Laser** (development, T Maiman).
- **1966**: Charles Kao et al: proposed **cladded fiber cables with lower losses** as a communication medium.
- **1970**: (Corning Glass, NY) developed fibers with losses **below 20 dB/km**.
- **1972:** First **Semiconductor diode laser** was developed.
- **1977**: GT&E in Los Angeles and AT&T in Chicago send live telephone signals through fiber optics (850nm, MMF, 6 Mbps, 9km) **-World's first FO link.**
- **1980s**: **2nd** generation systems: 1300nm, SM, 0.5 dB/km, O-E-O.
  3rd generation systems: 1550nm, SM, 0.2 dB/km, EDFA, 5Gb/s.
- **1990s** : Bell Labs sends 10 Billion bits through 20,000 km of fibers using a **Soliton system & WDM Techniques**.
- **2000s** : NTT, Bell Labs and Fujitsu are able to send **Trillion bits per second** through single optical fiber. $\Rightarrow$ **All optical networks.**

The Nobel Prize in Physics 2009

"For ground breaking achievements concerning the transmission of **light in fibers** for optical communication"

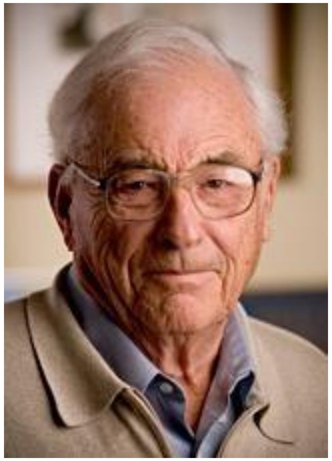


Charles K. Kao
(b. 1933 Shanghai, China)

1/2 of the prize

Standard Telecommunication Laboratories, Harlow, UK;
Chinese University of Hong Kong, Hong Kong, China

"For the invention of an imaging semiconductor circuit – the CCD sensor"

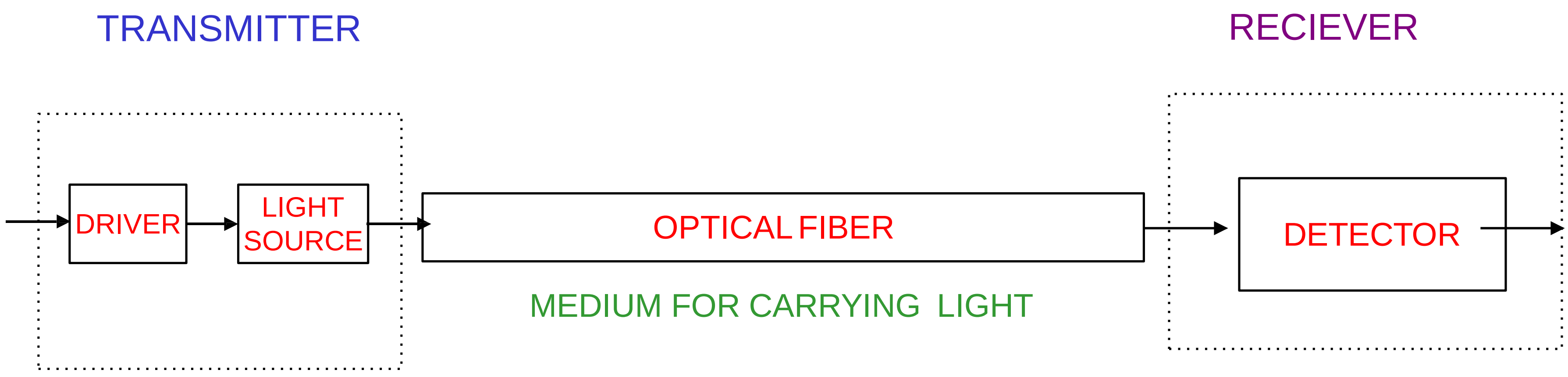


Willard S. Boyle
b. 1924
1/4 of the prize

George E. Smith
b. 1930
1/4 of the prize

Bell Laboratories, Murray Hill, NJ, USA

Basic Fiber Optic Link



- Converts **electrical signal to light.**
- Driver modifies the information into a suitable form for conversion into light.
- Source is LED or LD whose output is modulated.

- Detector accepts light, converts it back to electrical signal.
- Detector is PIN or APD.
- Elect. Signal is demodulated to separate out the information.

Two Major Communication Issues

❑ ATTENUATION

Attenuation is signal loss over distance ⇒ Light pulses lose their energy and amplitude falls as they travel down the cable.

➢ **Attenuation puts distance limitations on long- haul networks.**

❑ DISPERSION

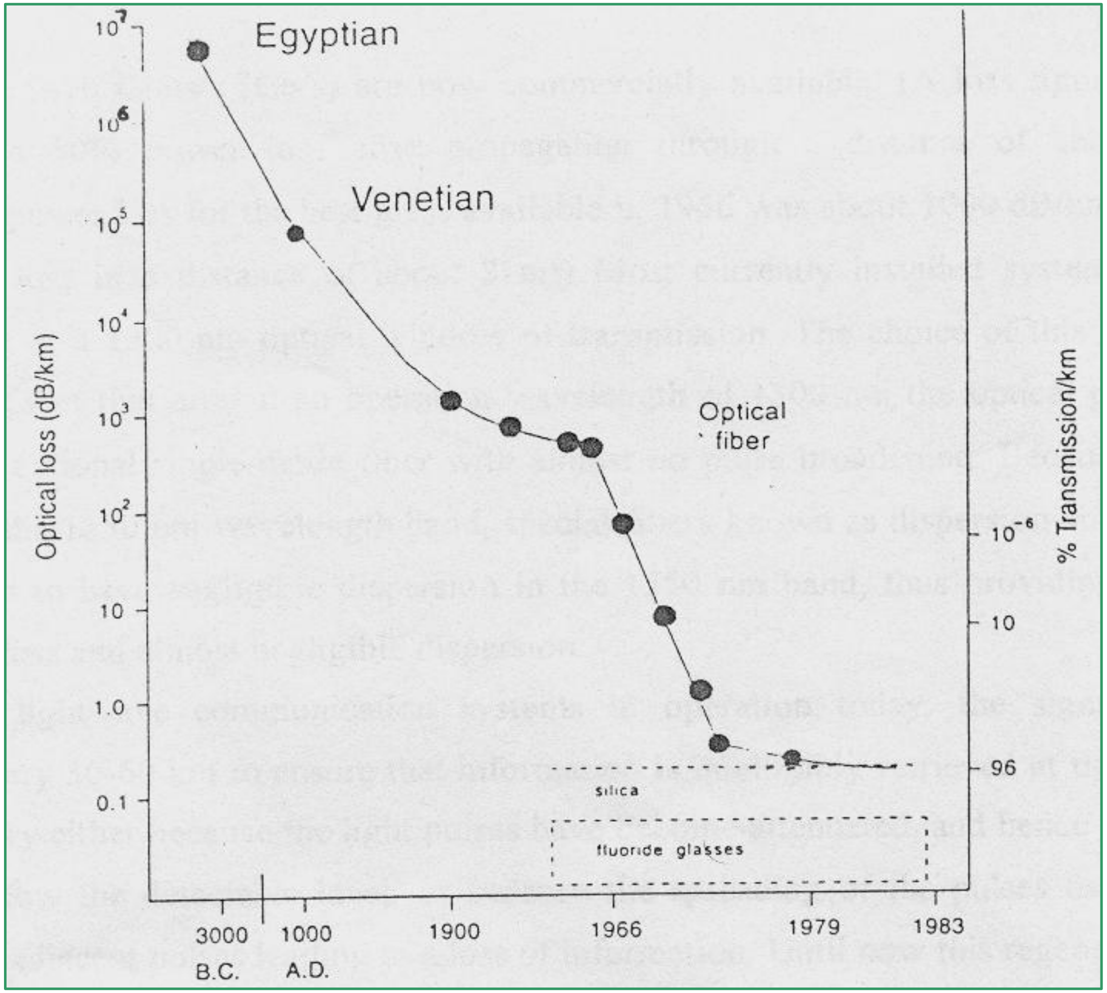
Dispersion is the broadening of a light pulse as it travels down the cable.

- Intermodal (Modal) dispersion
- Intramodal (Chromatic) dispersion : (Material & Waveguide)

➢ **Puts data rate limitation on networks.**

Transmission Loss in Optical Glass

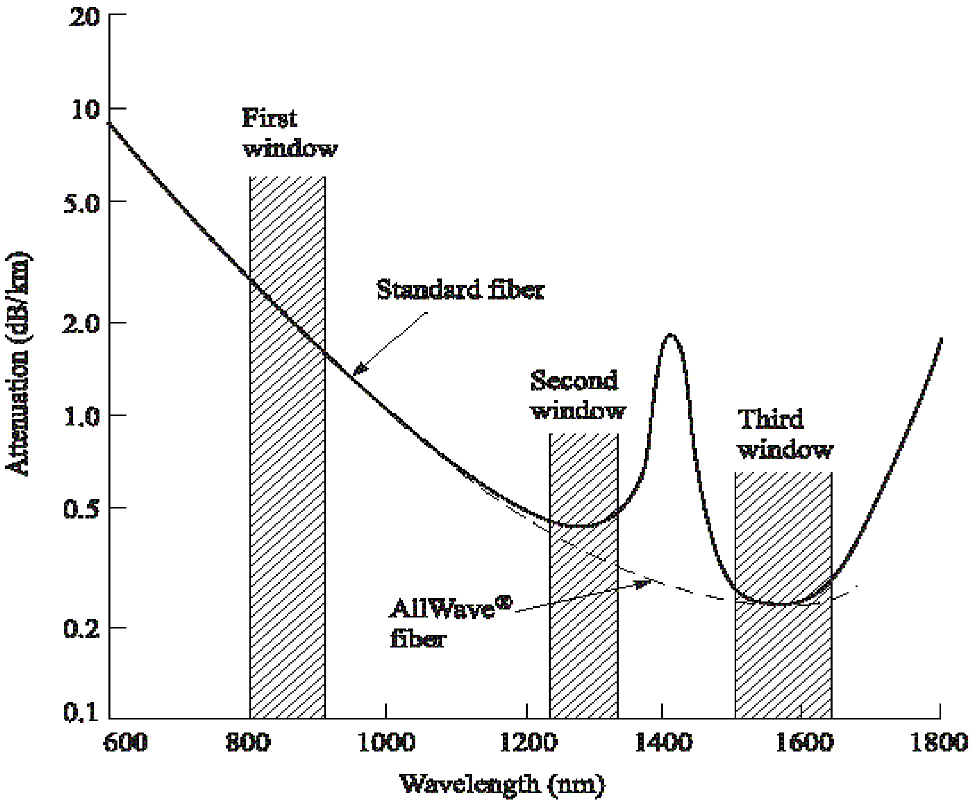
- **1970, First Optical Fiber**: Losses ≅ 20 dB/km at 633nm.
- **1977,** losses reduced to 5dB/km at 850nm.
- **1980s, Losses reduced to ≈ 0.2 dB/km at 1550 nm.**



Dramatic reduction in transmission loss in optical glass.

Fiber Attenuation

- 4dB/km at 850 nm
- 0.5 dB/km at 1310 nm
- 0.2 dB/km at 1550 nm



Attenuation in Silica Optical Fibers

Fiber Dispersion

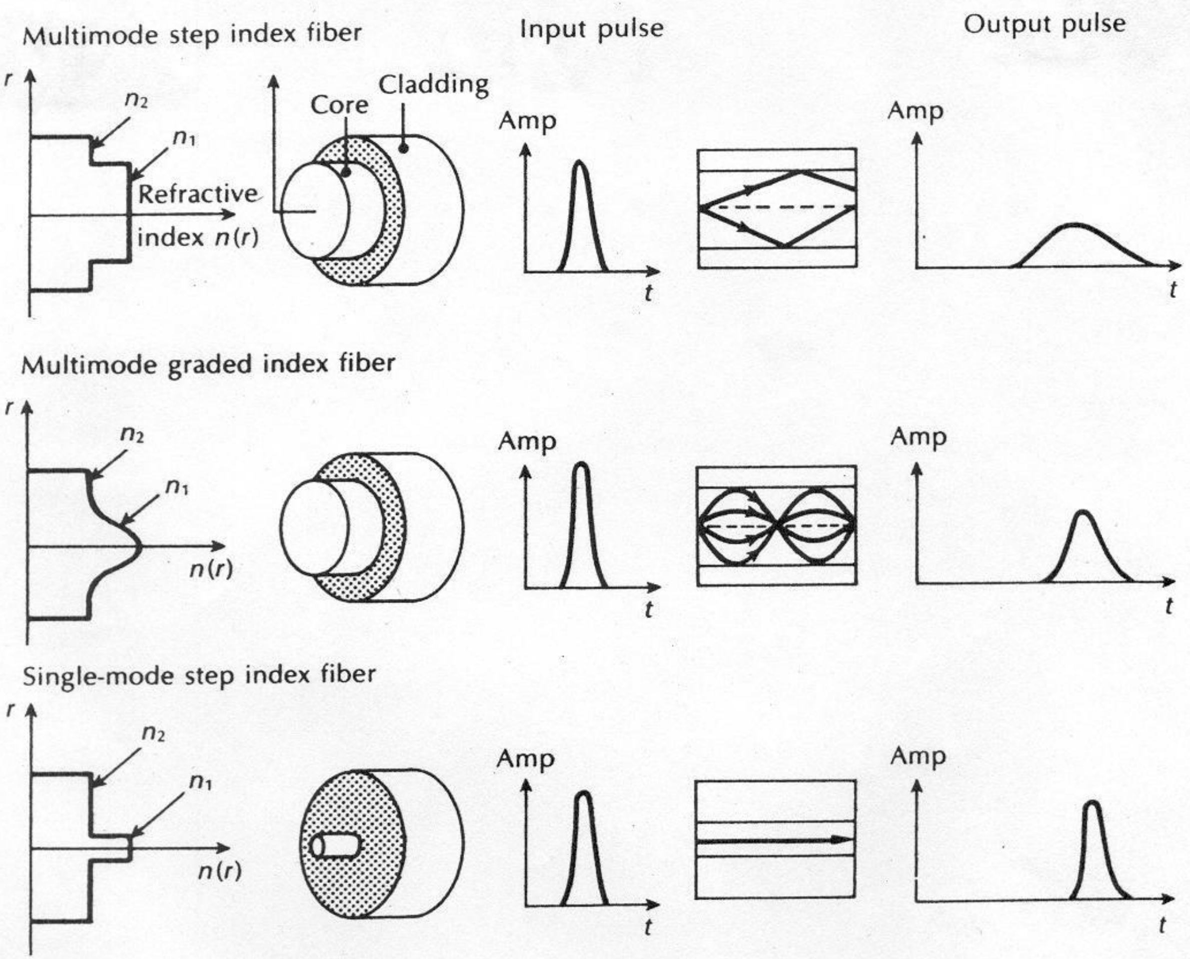


Figure 3.8 Schematic diagram showing a multimode step index fiber, multimode graded index fiber and single-mode step index fiber, and illustrating the pulse broadening due to intermodal dispersion in each fiber type.

- ☞ Dispersion is minimum in SMFs

Advantages of Optical Fiber

- **Wide Bandwidth: Extremely high** information carrying capacity (~GHz)
  - 3,00,000 voice channels on a pair of fiber.
  - Voice/Data/Video Integrated Service.
  - 2.5 Gb/s systems from NTT ,Japan; 5 Gb/s System Siemens.
- **Low loss** : Information can be sent over a **large distance**.
  - Losses ~ 0.2 dB/km
  - Repeater spacing >100 km with bit rates in Gb/s.
- **Interference Free** :
  - Immune to Electromagnetic interference: **No cross talk** between fibers.
  - Can be used in harsh or noisy environments.
- **Higher security** : No radiations, Difficult to tap.
  - Attractive for Defense, Intelligence and Banks Netwroks

❖ Compact & light weight

- Smaller size : Fiber thinner than human hair.
- Can easily replace 1000 pair copper cable of 10 cm dia.
- Fiber weighs 28gm/km; considerably lighter than copper.
- Light weight cable.

❖ Environmental Immunity/Greater safety

- **Dielectric**- No current, No short circuits –Extremely safe for hazardous environments; attractive for **oil & petrochemicals.**
- Not prone to lightning.
- Wide temperature range.
- Long life > 30 years.

❖ Abundant Raw Material : Optical fibers made from Silica (**Sand)**

- Not a scarce resource in comparison to copper.

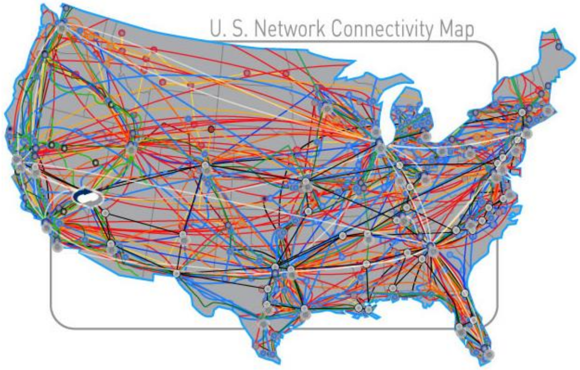
Some Practical Disadvantages

- Optical fibers are relatively **expensive**.
- **Connectors very expensive**: Due to high degree of precision involved
- Connector installation is **time consuming and highly skilled operation**
- Jointing (Splicing) of fibers requires **expensive equipment and skilled operators**
- Connector and joints are **relatively lossy**.
- Difficult to **tap in and out** (for bus architectures)
  - need expensive couplers.
- Relatively careful handling required

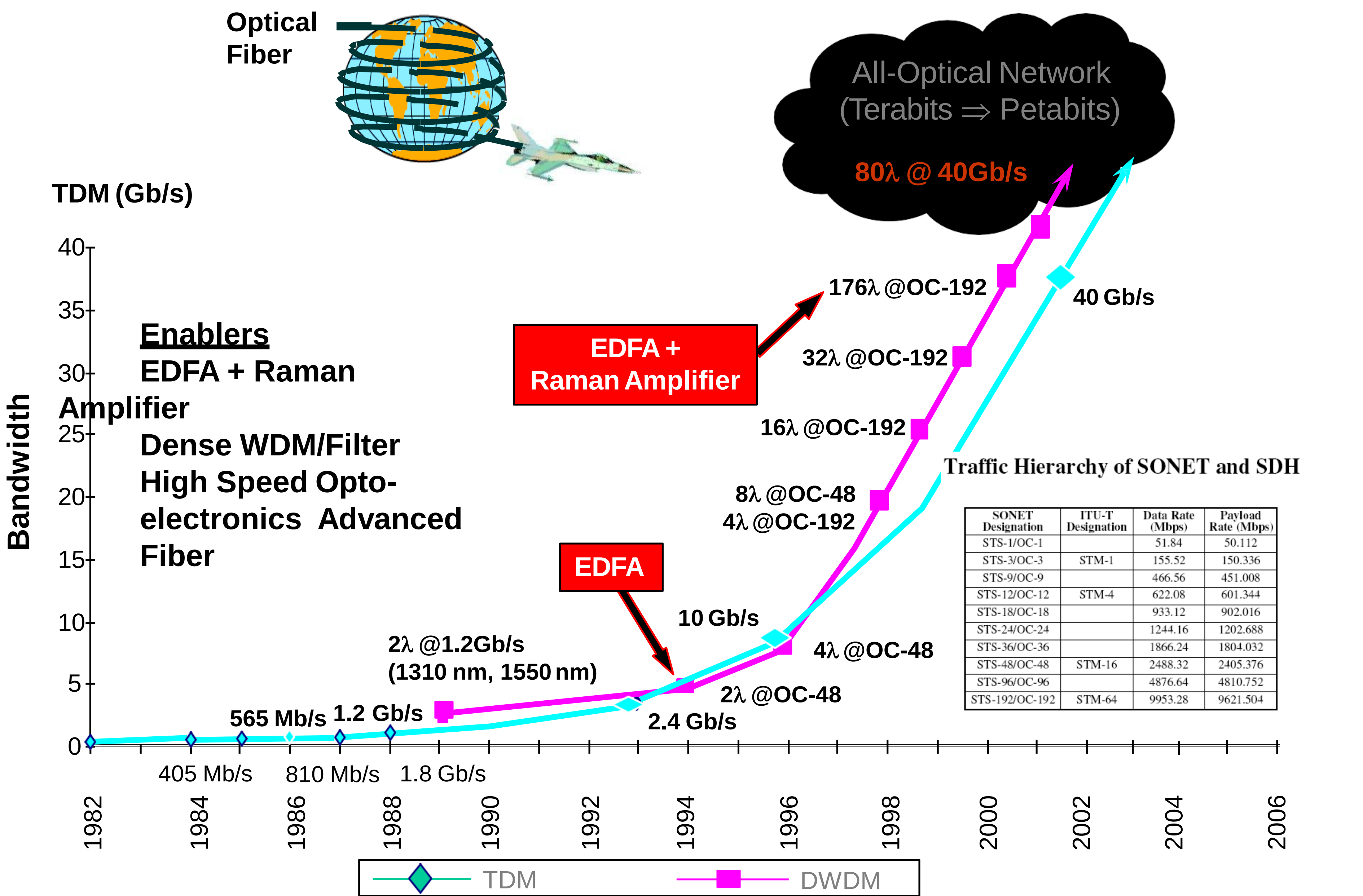
Application of Optical Fiber Communications

Optical fiber communication has wide range of application **in different fields**.

- Fibers can be used under sea communication.
- It is used in military application.
- Fibers are used in **LAN** system of offices, industrial plants and colleges etc.
- Fiber are used in telecommunication.
- Fiber are used in medical imaging like **endoscope**.



Bandwidth Evolutionary Landmarks

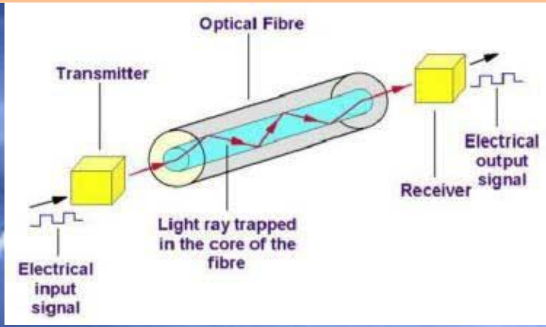


Traffic Hierarchy of SONET and SDH

SONET Designation	ITU-T Designation	Data Rate (Mbps)	Payload Rate (Mbps)
STS-1/OC-1		51.84	50.112
STS-3/OC-3	STM-1	155.52	150.336
STS-9/OC-9		466.56	451.008
STS-12/OC-12	STM-4	622.08	601.344
STS-18/OC-18		933.12	902.016
STS-24/OC-24		1244.16	1202.688
STS-36/OC-36		1866.24	1804.032
STS-48/OC-48	STM-16	2488.32	2405.376
STS-96/OC-96		4876.64	4810.752
STS-192/OC-192	STM-64	9953.28	9621.504

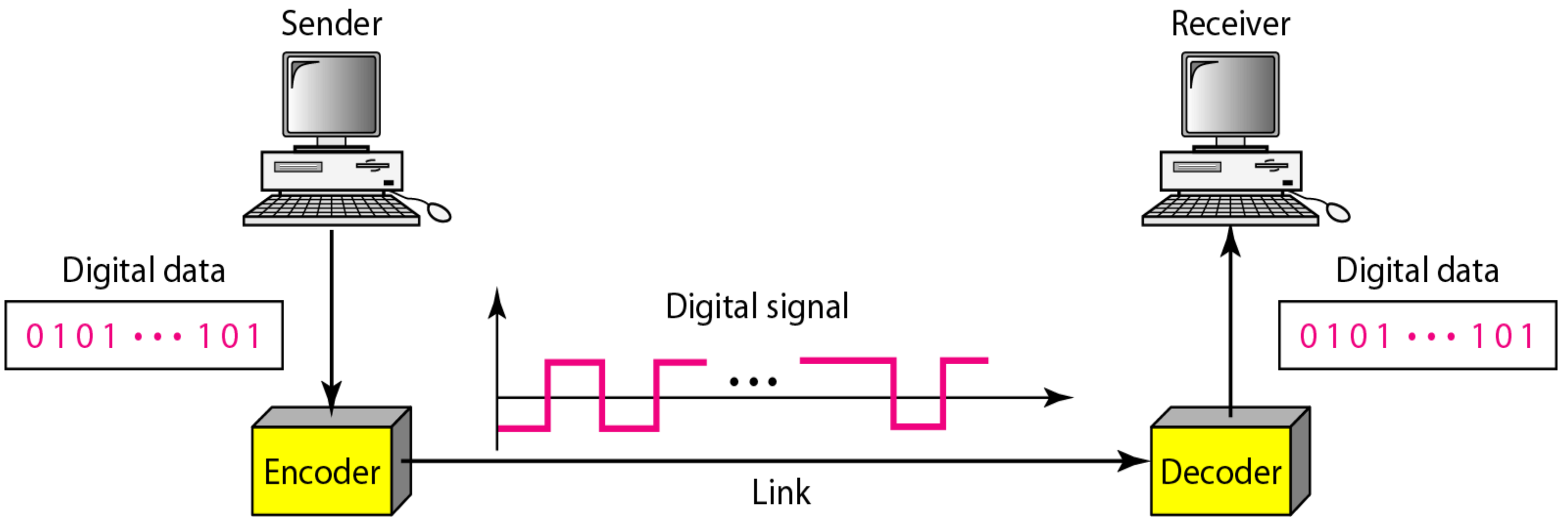
Coding

An Overview



Line Coding

- ❑ The process of converting digital data to digital signal is called **line coding**.
- ❑ To eliminate DC baseline drifting due to a long string of consecutive 0's and 1's.



Commonly used line codes :

- ➢ non-return-to-zero (**NRZ**)
- ➢ Return-to-zero (**RZ**)
- ➢ Manchester/ Differential Manchester
- ➢ AMI and pseudoternary

Manchester , Differential Manchester

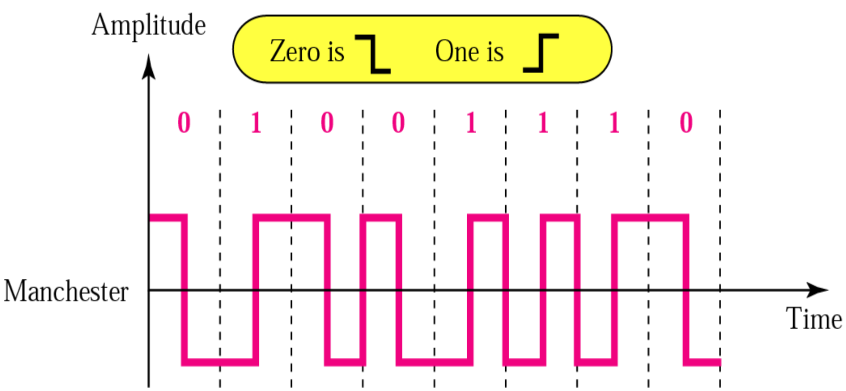
Combined idea of RZ and NRZ-L = Manchester
Combined idea of RZ and NRZ-I = Differential Manchester

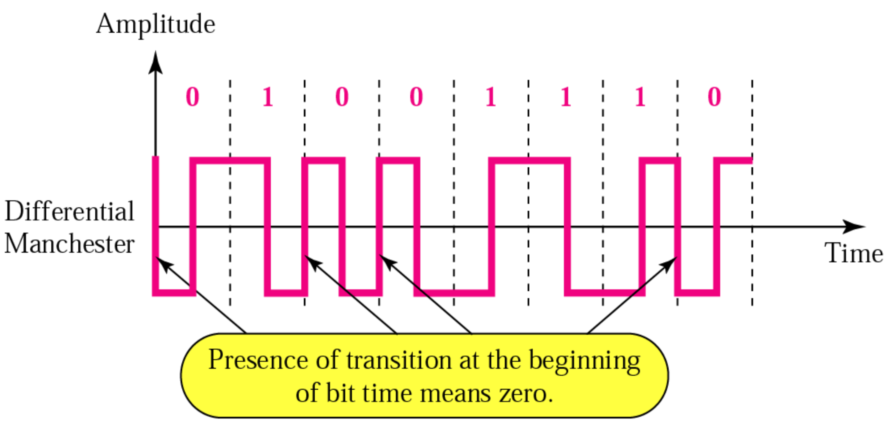
Advantage:

- No DC Component.

Disadvantage:

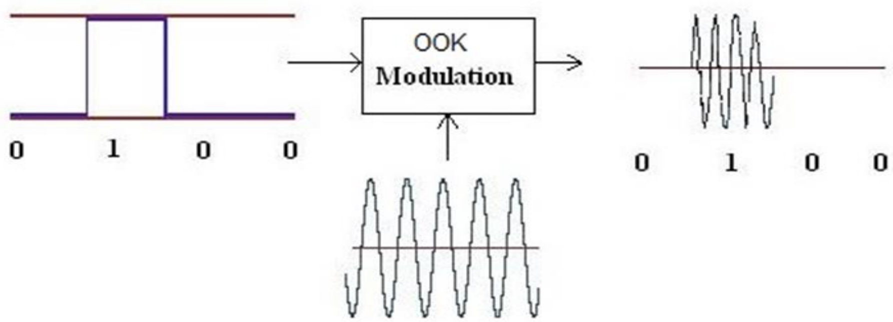
- Large bandwidth due to large number of transition.
- Does not have error detection Capability.





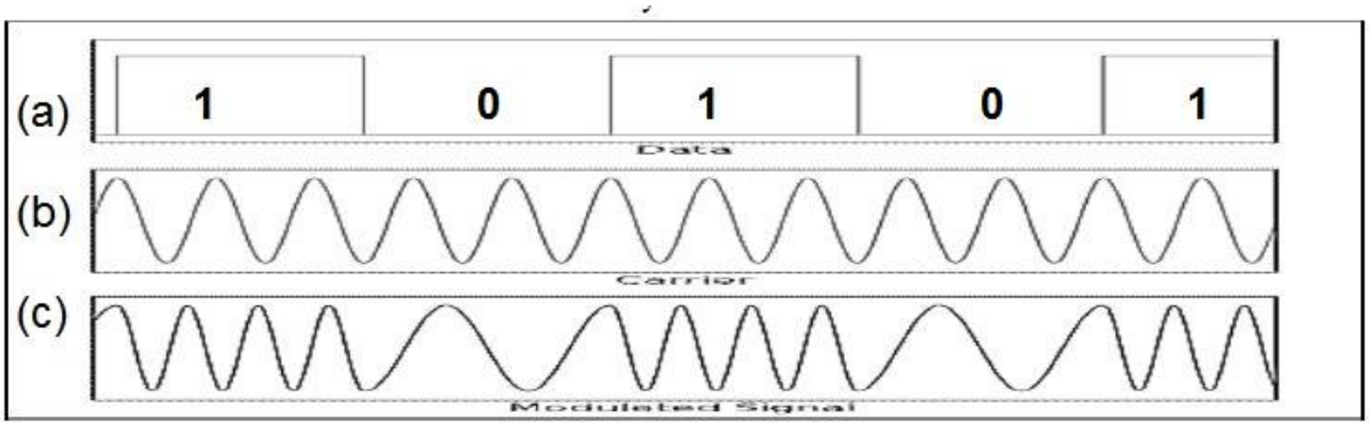
On/Off Keying (OOK) Modulation

- Power-efficiency
- Bandwidth efficiency
- Simple design
- Low cost



Frequency Shift Modulation

- ➢ Frequency of the **carrier** is varied to represent digital data (binary 0/1).
- ➢ Peak amplitude and phase remain constant.

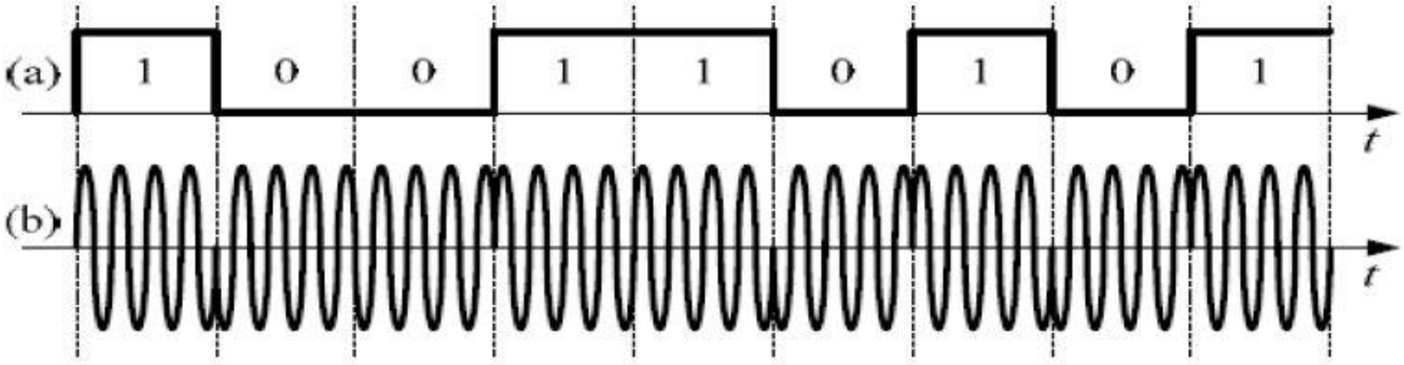


(a) Binary signal (b)carrier (c) **FSK** modulated signal.

Ref: Jawla, Shashi, and R. K. Singh. "Different Modulation Formats Used In Optical Communication System." IOSR Journal of Electronics and Communication Engineering (IOSR-JECE) 8.4 (2013).

Phase Shift Modulation

- Phase of the carrier is varied to represent digital data (binary 0 or 1).
- Amplitude and frequency remains **constant**.
- **PSK** modulation is widely used in wireless transmission.



(a) Binary signal, (b)PSK modulated signal

Ref: Jawla, Shashi, and R. K. Singh. "Different Modulation Formats Used In Optical Communication System." IOSR Journal of Electronics and Communication Engineering (IOSR-JECE) 8.4 (2013).

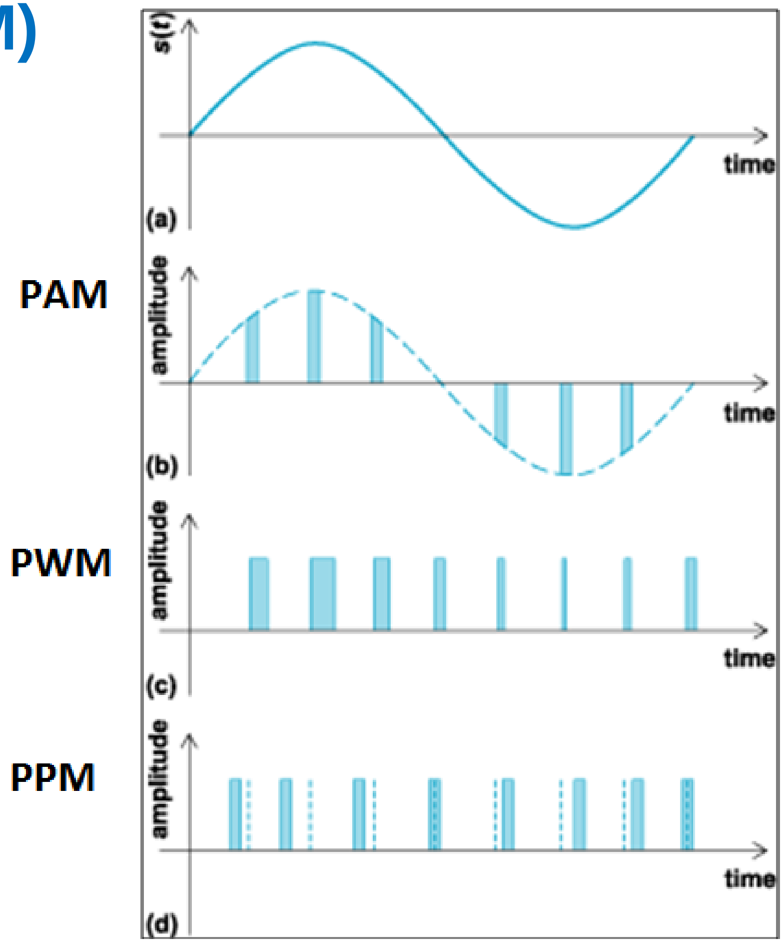
Pulse Position Modulation

Pulse Position Modulation (PPM)

- Position of pulse carrier is varied .
- Phase and Amplitude remain same

Advantage

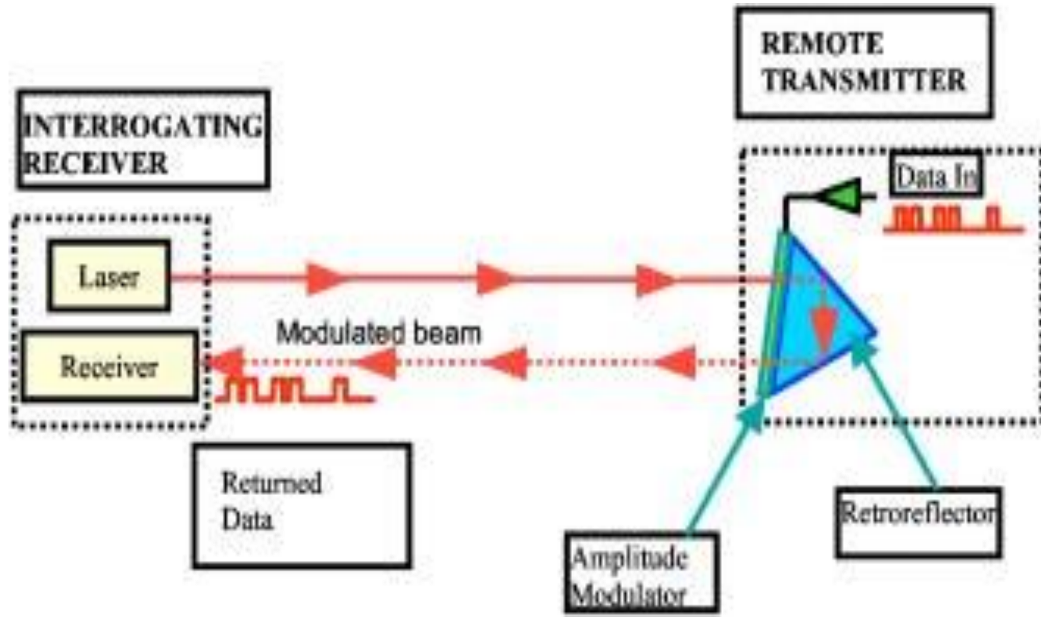
- Less Noise Interference
- Noise separation is easy
- Transmission power of each pulse is same



https://qph.ec.quoracdn.net/main-qimg-cf8bdc2c33ac7430c7474ff5909b6a1b

Modulating Retro Reflector (MRR)

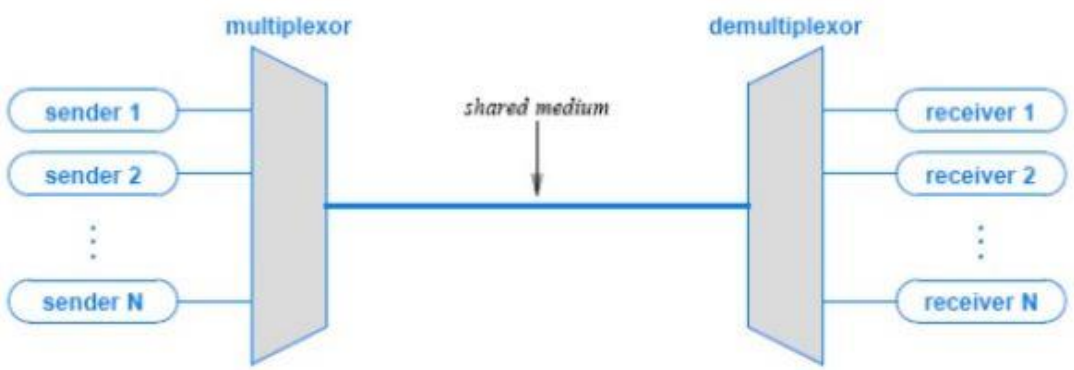
- **MRR** is used to reduce the burden on transmitter.
- Its function as an optical communications device without emitting its own optical power.
- It is use to save Light Source.



http://imagebank.osa.org/getImage.xqy?img=QC5sYXJnZSxvZS0yMi0yMy0yODU1My1nMDAx

Multiplexing

- Process of combining two or more input signals into a single transmission is called **multiplexing**.
- Multiplexing enhances efficiency use of bandwidth.
- Independent pair of sender and receiver share a transmission medium.
- cost saving can be gained by using single channel to send multiple information signal.

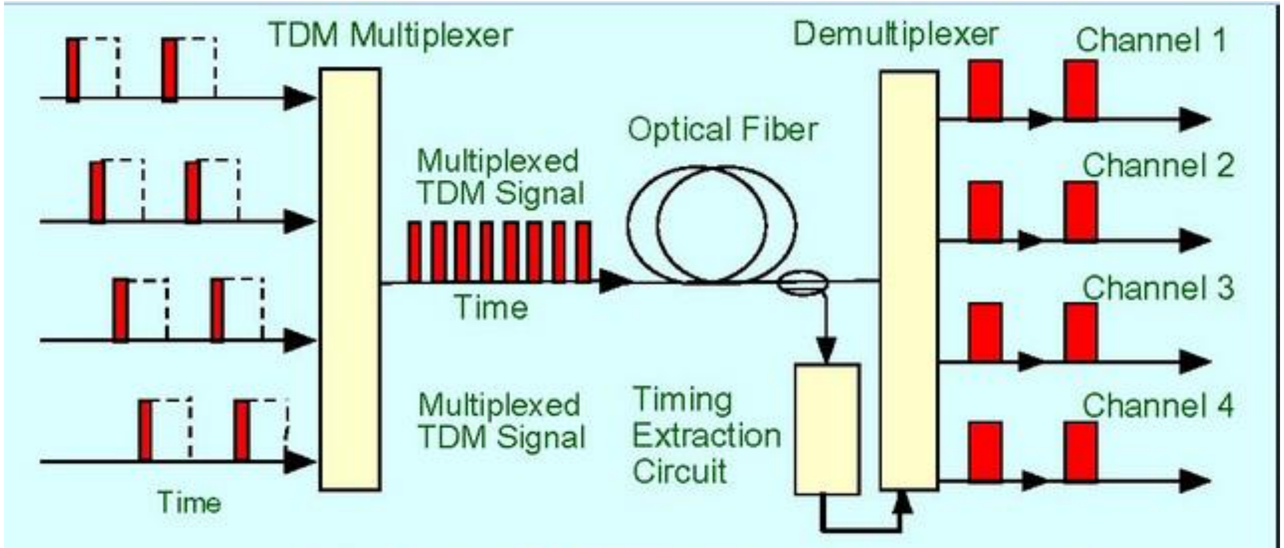


Concept of Multiplexing

Ref: https://image.slidesharecdn.com/multiplexingppt15sep-140928125221-phpapp01/95/multiplexing-ppt15-sep-5-638.jpg?cb=1413204797

Time division Multiplexing(TDM)

- **TDM** assign time slots to each channel repeatedly.
- Transmitting an item from one source, then transmitting an item from another source and so on.
- Deliveries very high capacity of data over optical fiber.

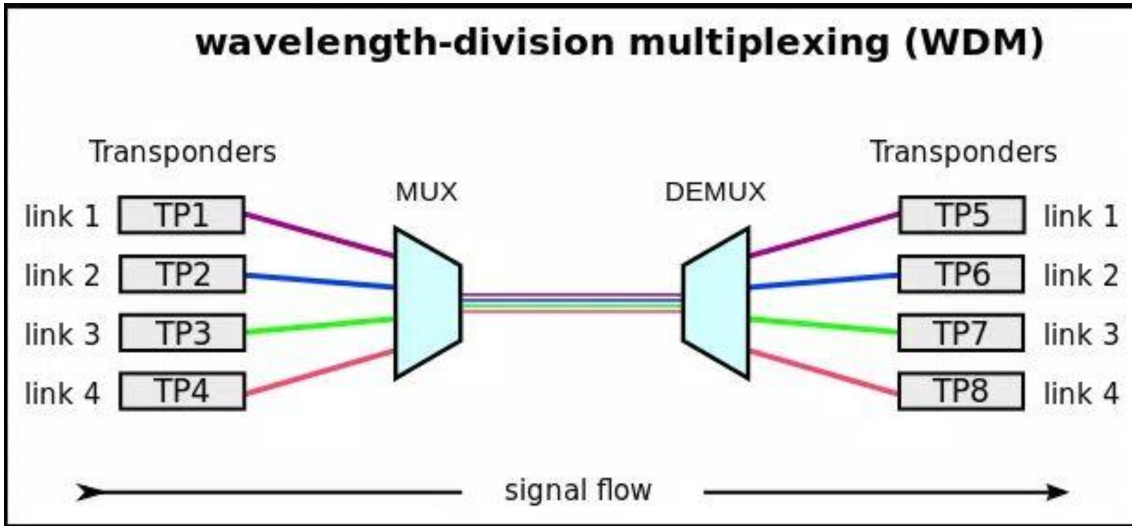


(a) Time Division Multiplexing (TDM) Transmission

Ref: http://www.pandacomdirekt.com/fileadmin/_processed_/csm_tdm_e_01_d589958b87.png

Wavelength division Multiplexing

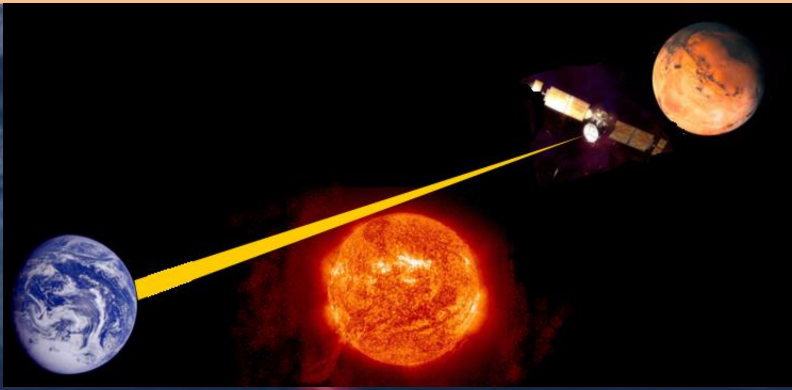
- In **WDM** different optical signals are combined together at one end of the optical fiber and separated into different channels at the other end.
- WDM increases the bandwidth.
- Lowers the networking cost by reducing the needed fibers.



http://www.fiber-optical-networking.com/wp-content/uploads/2015/04/20150417100422.png

Free Space Optical Communication

An Overview

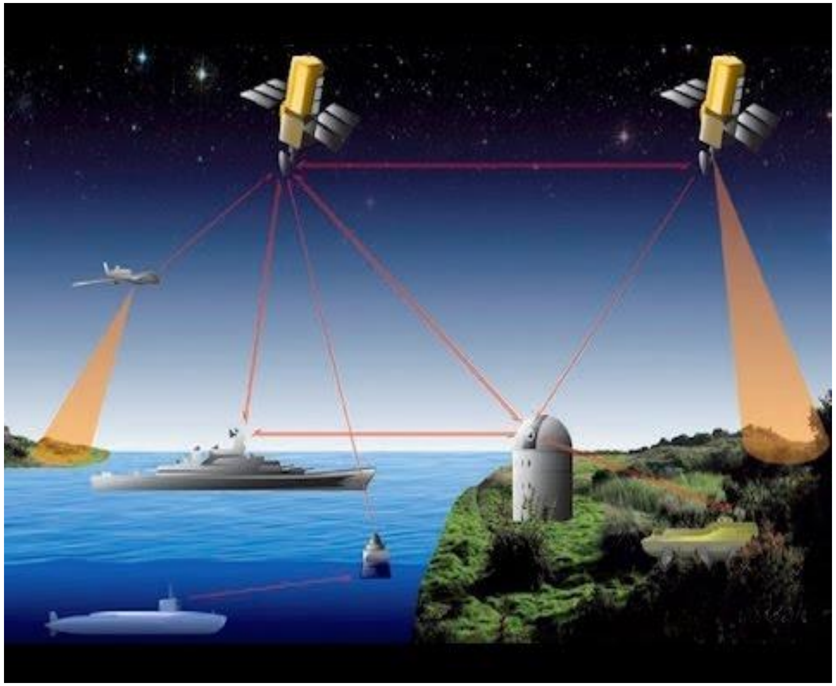


Free Space optical communication (FSO)

- FSO (free space optics) is an optical communication technology in which information is transmitted by propagation of light in free space.

- FSO system consists of an optical transceiver at both ends.

- Enables optical transmission data rate up to **10 Gbps.**



Characterization of Free Space Optical Channel

- To have an efficient FSO link, the obstacles related to atmospheric conditions should be overcome.

- The FSO link range is determined by light absorption and scattering.

- A large amount of information data can be transferred over FSO links

Challenges in Free Space Optics

- **Misalignment error :**

  Wind, Earthquake

- **Geometric losses:**

  Propagation, divergence angle

- **Background noise:**

  Direct or indirect sunlight or artificial light

- **Weather attenuation losses**:

  Haze, Dust, Fog , Rain, Snow

- **Atmospheric turbulence:**

  Inhomogeneity in Temperature and Pressure

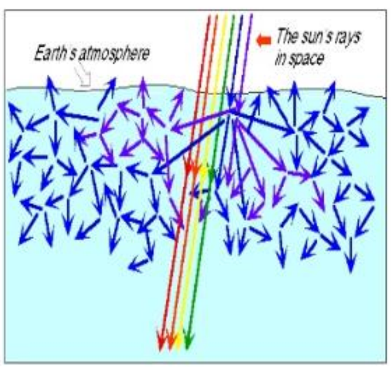
Challenges in Free Space Optics

Effect of Atmosphere on the Propagation of optical field

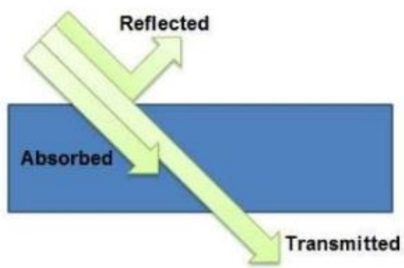
Attenuation Effect

Index refractive Effect

- Scattering



- Absorption



Local Random Phase Disturbances Due to (random) changes in the index of refraction (depending on the Link scenario)

Beam divergence loss- Differaction near the reciever some Transmitted beam will not be collected by the receiver and that will cause.

Possible Solution

1:Buffering

- Store data and transmit it later when obstacle pass.
- Need huge volumes of storage for even brief outages.

2: Retransmission

- Helpful when there is strong turbulence in the atmosphere.
- It may increase the probability of correct detection.

3: Rerouting Transit Paths

- Enabling alternative routes from sender to recipient.
- Rerouting requires point-to-multipoint transceivers.
- High redundancy and short link ranges increase the rerouting capabilities

Applications of FSO

Outdoor wireless access:

used as a wireless service provider for communication.

Enterprise connectivity:

FSO systems are easily installable therefor used in interconnecting LAN segments to connect two buildings or other property

Fiber backup:

used as a back uplink in case of failure of transmission through fiber link.

Military access:

It is secure and undetectable system therefor it is suitable for military application.

Bridging WAN Access:

Support high speed data rate and act as a backbone for high speed trunking network.

Point to Point link:

Used to communicate between point-to-point links e.g two buildings, two ships,

Advantages of FSO

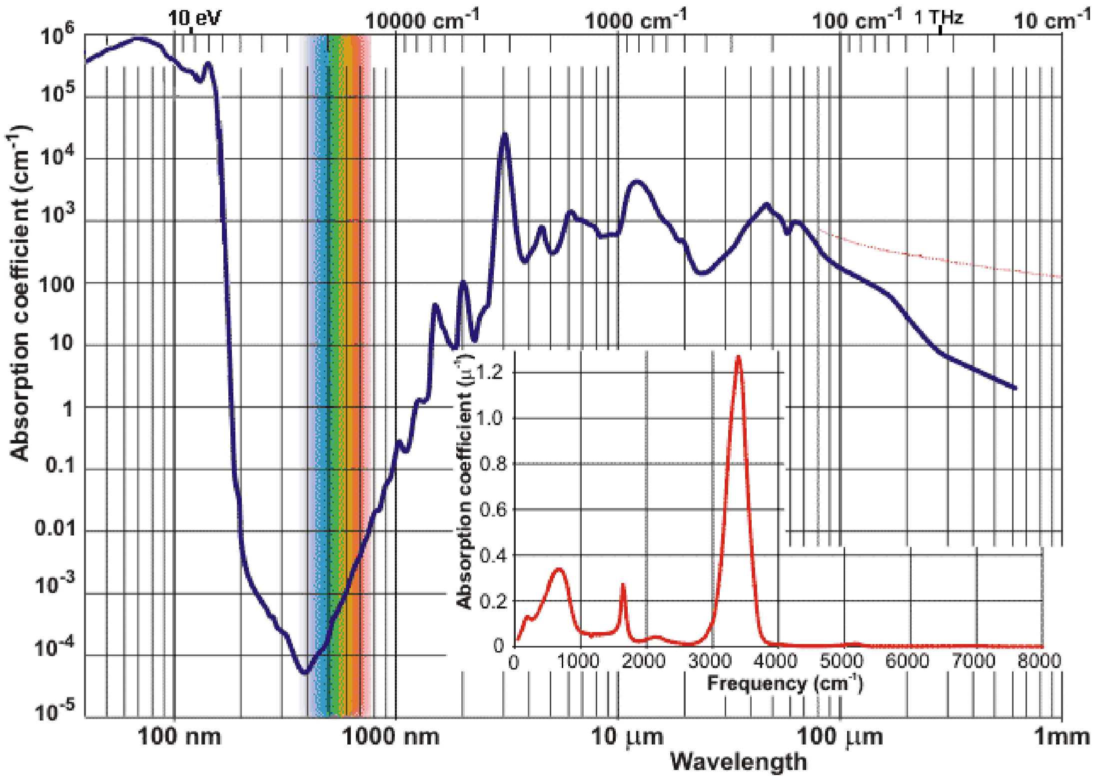
- FSO deliver better speed than broadband.
- Installation is very easy.
- Low Cost.
- High data rate can be obtained.
- There is immunity to radio frequency interference.
- There is relatively high bandwidth.
- Low power.
- Straight forward deployment- no licenses required.
- Transmission of optical beam is done in air. Hence, transmission is having speed of light.

Underwater Wireless Optical Communications

An Overview

Underwater Wireless Optical Communications

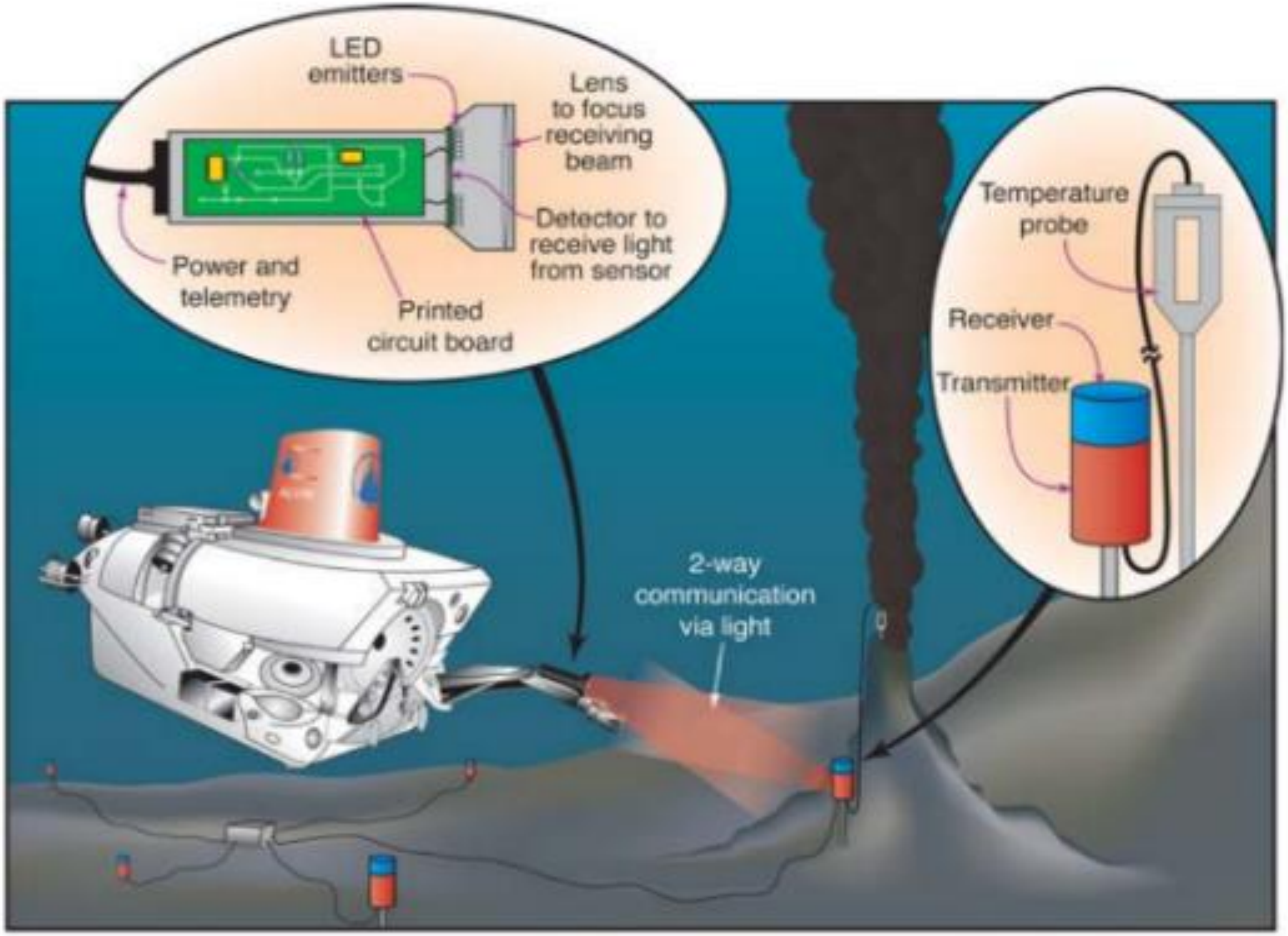
Interest towards **optical wireless communication** has increased for terrestrial, space and underwater links as it is capable of providing high data rates with low power and mass requirement.



Comparison of different wireless underwater technologies

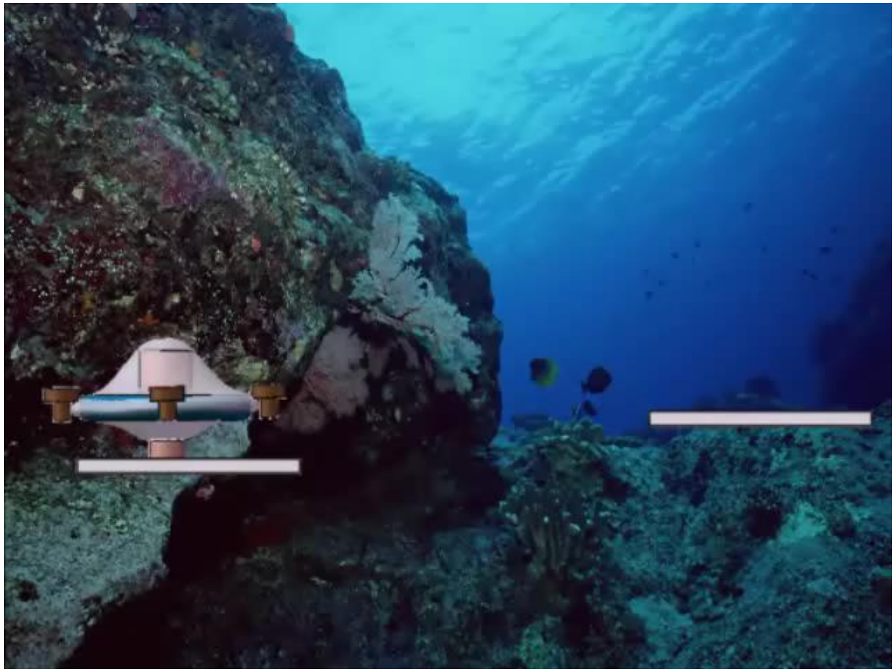
Parameters	Acoustic	RF	Optical
Attenuation	Distance and frequency dependent (0.1 - 4 dB/km) [12]	Frequency and conductivity dependent (3.5 - 5 dB/m) [13]	0.39 dB/m (ocean) - 11 dB/m (turbid) [14]
Speed (m/s)	1500 m/s	$\approx 2.255 \times 10^8$	$\approx 2.255 \times 10^8$
Data rate	~ kbps	~ Mbps	~ Gbps
Latency	High	Moderate	Low
Distance	up to kms	up to $\approx$ 10 meters	$\approx$ 10 - 100 meters
Bandwidth	Distance dependent [8]: 1000 km < 1kHz 1 - 10 km $\approx$10 kHz < 100 m $\approx$ 100 kHz	$\approx$ MHz	10 - 150 MHz
Frequency band	10 - 15 kHz	30 - 300 Hz (ELF) (for direct underwater communication system) or MHz (for buoyant communication system)	10^{12} - 10^{15} Hz
Transmission power	tens of Watts (typical value)	few mW to hundreds of Watts (distance dependent)	Few Watts
Antenna size	0.1 m	0.5 m	0.1 m
Efficiency	$\approx$ 100 bits/Joules		$\approx$ 30, 000 bits/Joules
Performance parameters	Temperature, salinity and pressure	Conductivity and permittivity	Absorption, scattering/turbidity, organic matter

Short-range high-speed underwater transmission



Two related projects in China

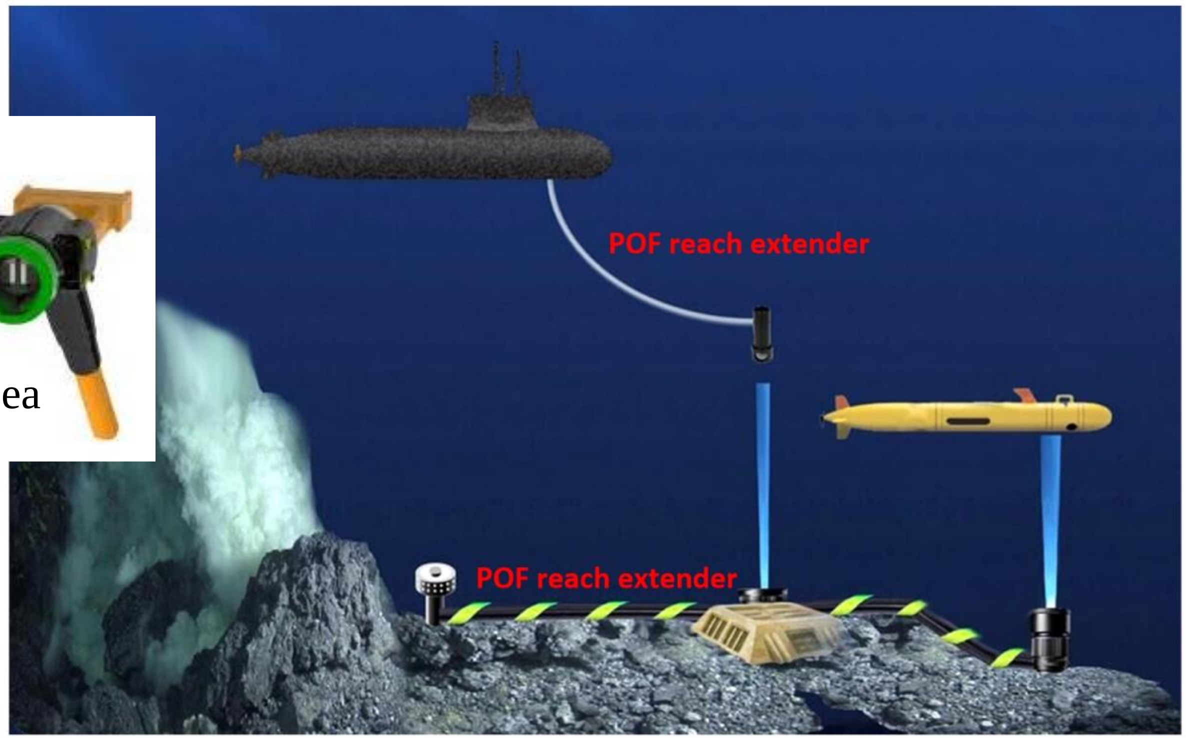
Supported by **The National Key Research and Development Program of China.**
2017-2020



OFDM-based high-speed UWOC

Extend the transmission distance and coverage-underwater Fi–Wi with a passive front end.

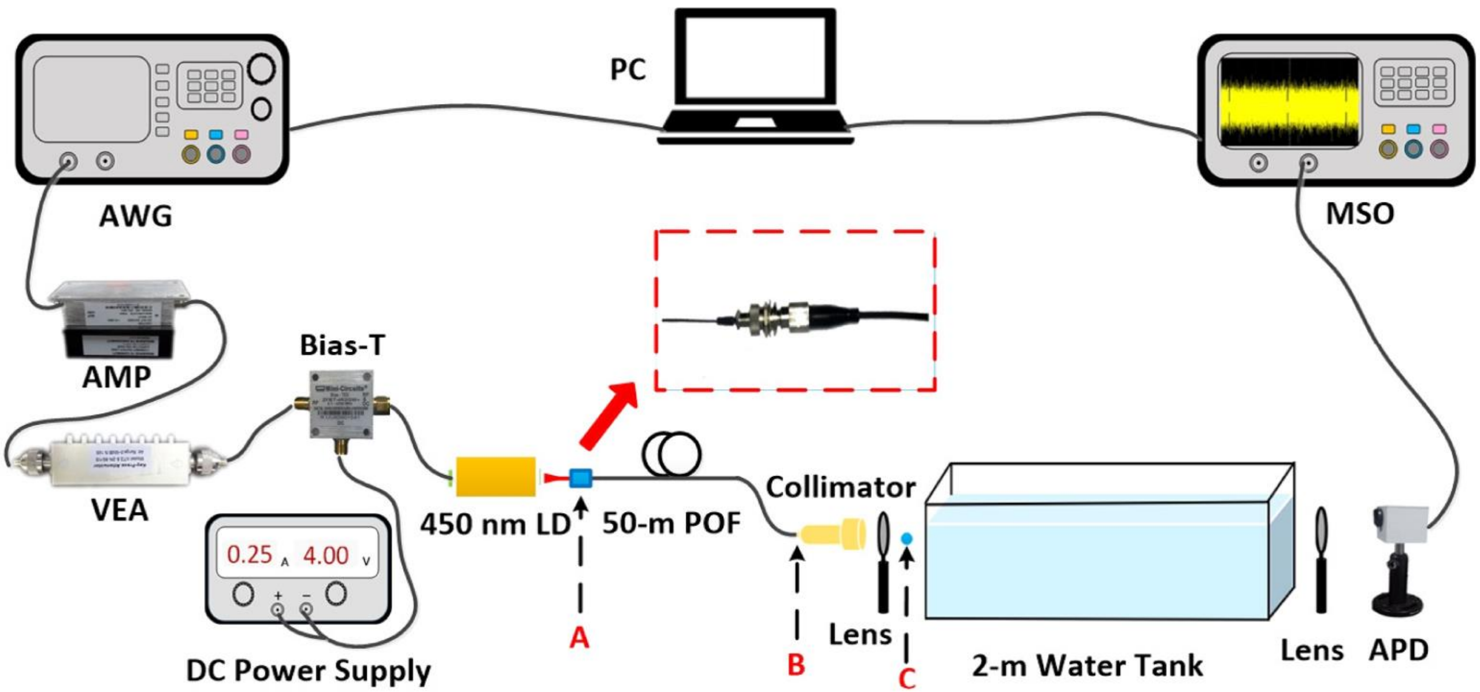
wet-mate subsea connector



J. Xu, B. Sun, W.C. Lyu, M.W. Kong, R. Sarwara, J. Han, W. Zhang and N. Deng, "Underwater fiber-wireless communication with a passive front end," **Optics Communications**, Oct 2017. (
highlighted article with a news story by Elsevier)

OFDM-based high-speed UWOC

Extend the transmission distance and coverage-underwater **Fi–Wi.**



Demonstration: 50-m SI-POF and 2-m underwater wireless channel , 1.7 Gb/s (32-QAM) .

OFDM-based high-speed UWOC

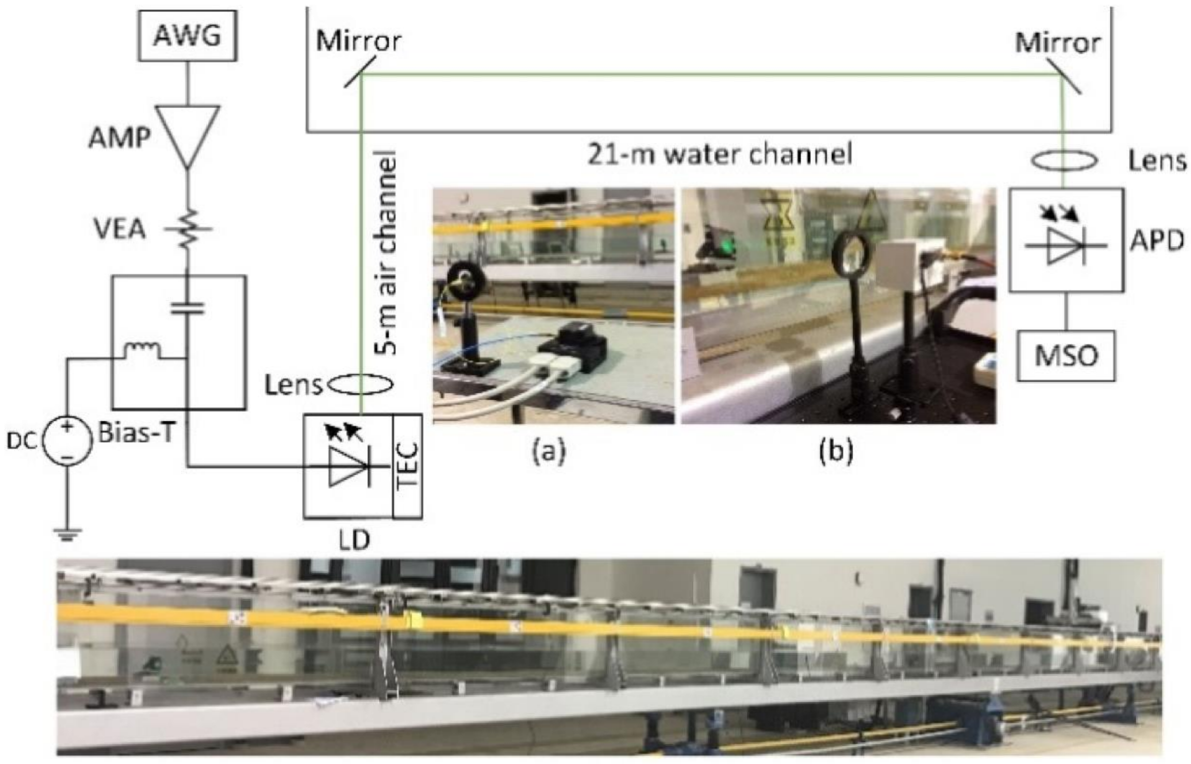
Transmission through air-water interface.

Y. F. Chen, M.W. Kong, T. Ali, J.L. Wang, R. Sarwar, J. Han, C. Y. Guo. B. Sun, N. Deng and J. Xu*, “26 m/5.5 Gbps Air-water Optical Wireless Communication Based on an OFDM-modulated 520-nm Laser Diode,” ***Opt. Express,*** (2017).

浙江大学海洋学院
OCEAN COLLEGE, ZHEJIANG UNIVERSITY

OFDM-based high-speed UWOC

Transmission through air-water interface.

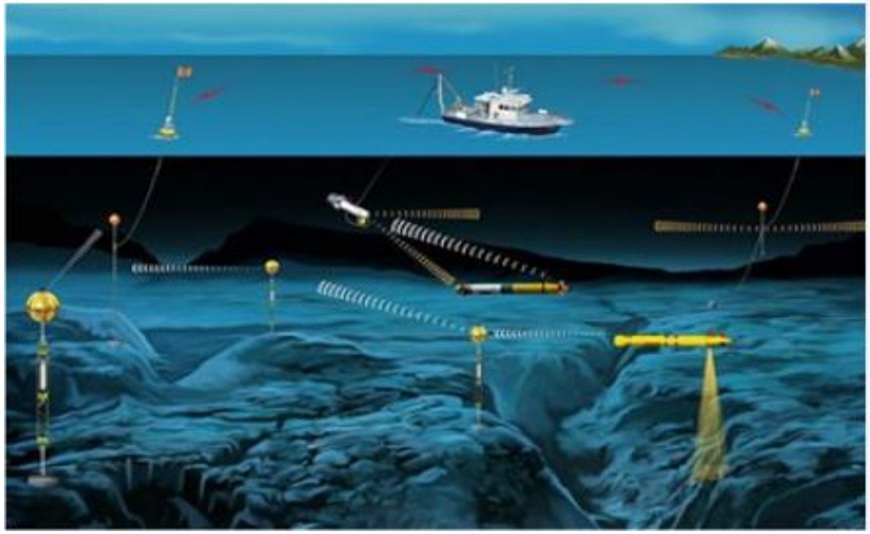


Demonstration: 5-m air and 21-m underwater , 5.5 Gb/s (32-QAM), bidirectional.

Underwater Link Geometry

UW link can be implemented in different forms.

- ➢ Line-of-sight (LOS).
- ➢ Non-line-of-sight (NLOS).
- ➢ Retro reflector-based LOS (R-LOS).



- ➢ **LOS:**

The transmitter direct the light of beam in direction of receiver.

- ➢ **NLOS**:

The power is received via scattering from the particles inside the water.

- ➢ **R-LOS**:

Its function as an optical communications device without emitting its own optical power.

THANKS