Escola Tècnica Superior d'Enginyeria de Telecomunicació de Barcelona

UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH

FIBER-OPTIC COMMUNICATIONS

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OPTICAL COMMUNICATIONS GROUP

www.tsc.upc.edu/gco

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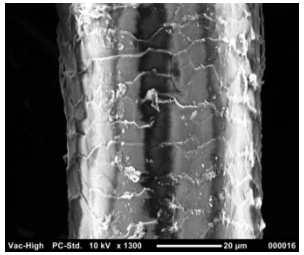
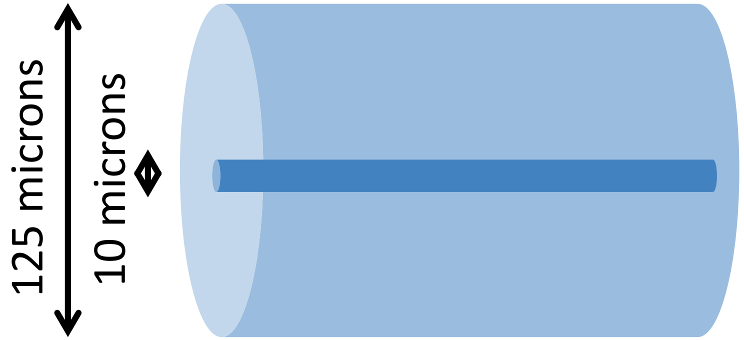
FIBER-OPTIC COMM.
OVERVIEW

What's an optical fiber ?

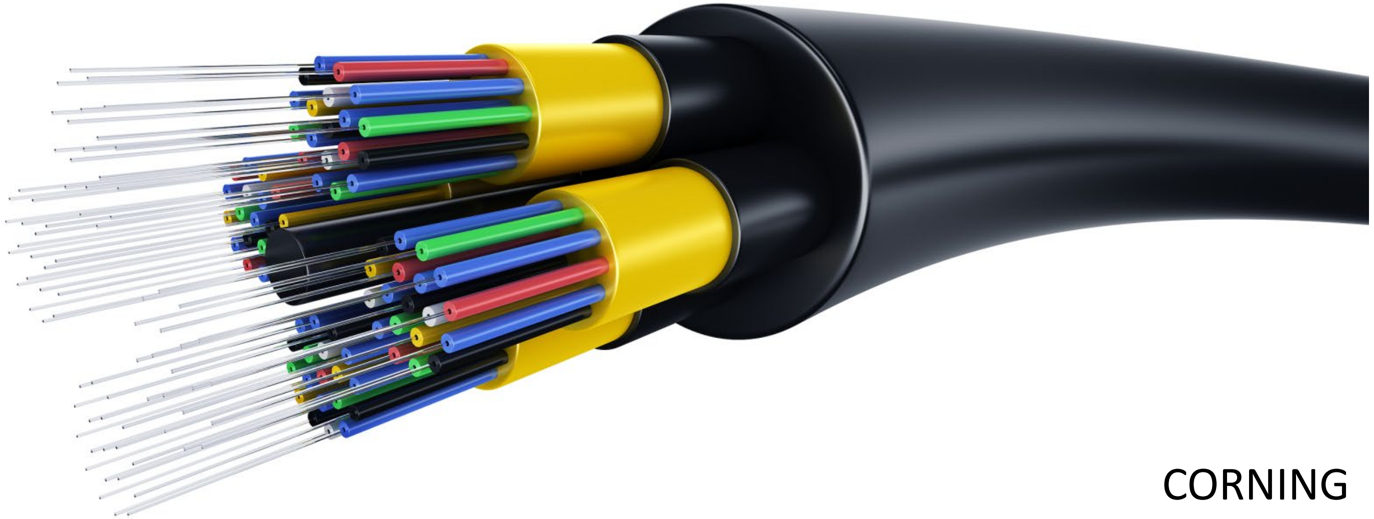
70-90 microns

HUMAN HAIR





OPTICAL FIBER



CORNING

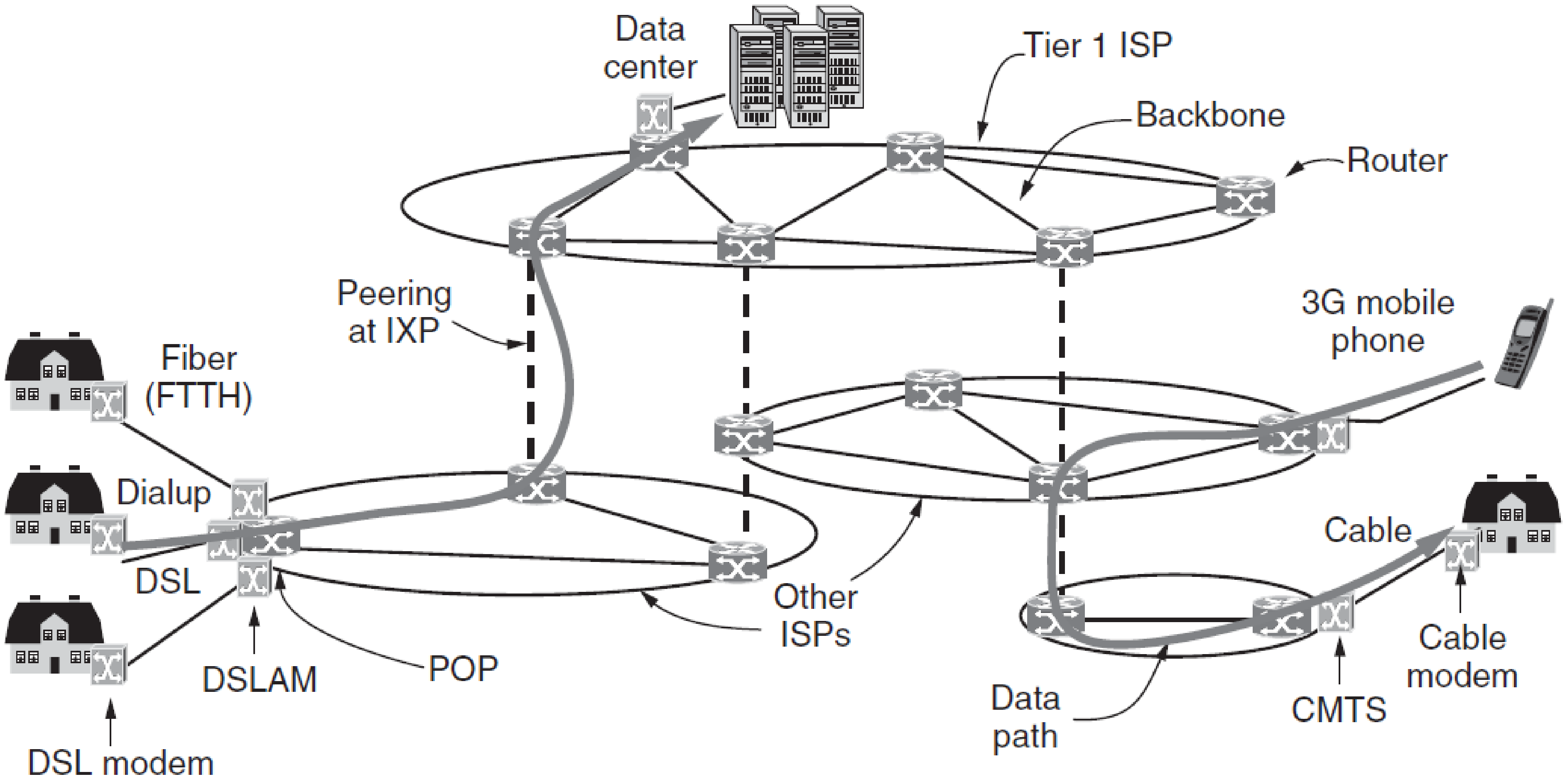
Optical Fiber Capacity

What’s the capacity of an optical fiber ?

1 Tb/s = 10^{12} b/s

Optical Fiber in the Internet

Overview of the Internet architecture



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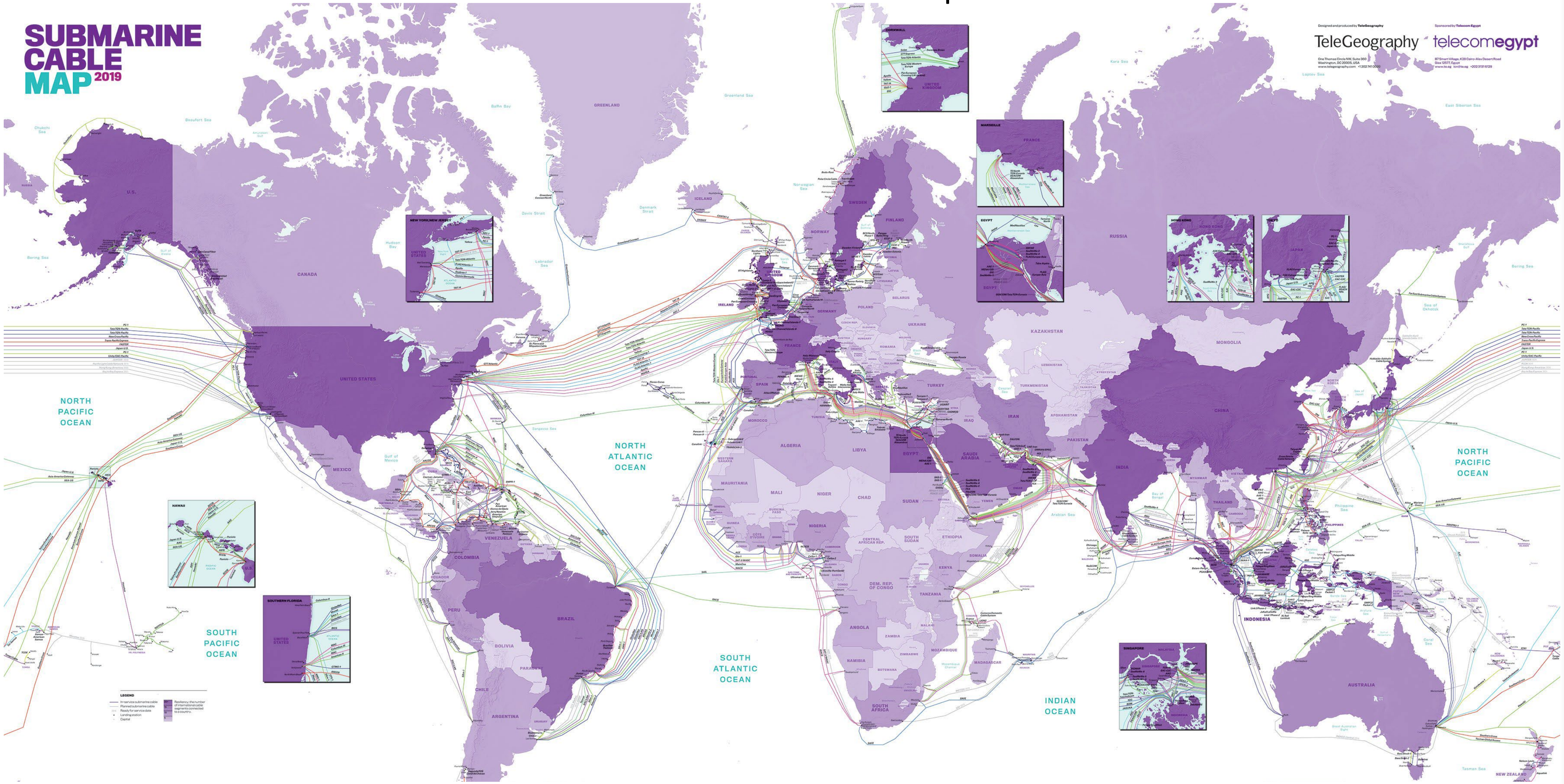
Submarine F.O. Networks

Animated Map of the World's Undersea Internet Cables

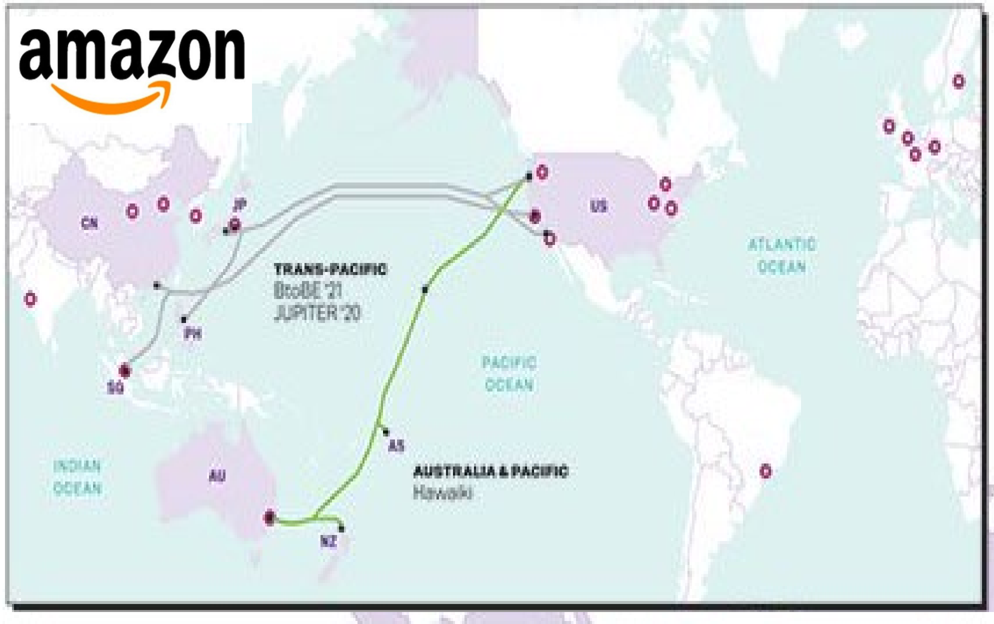
TE SubCom Repeatered Undersea Cable Networks

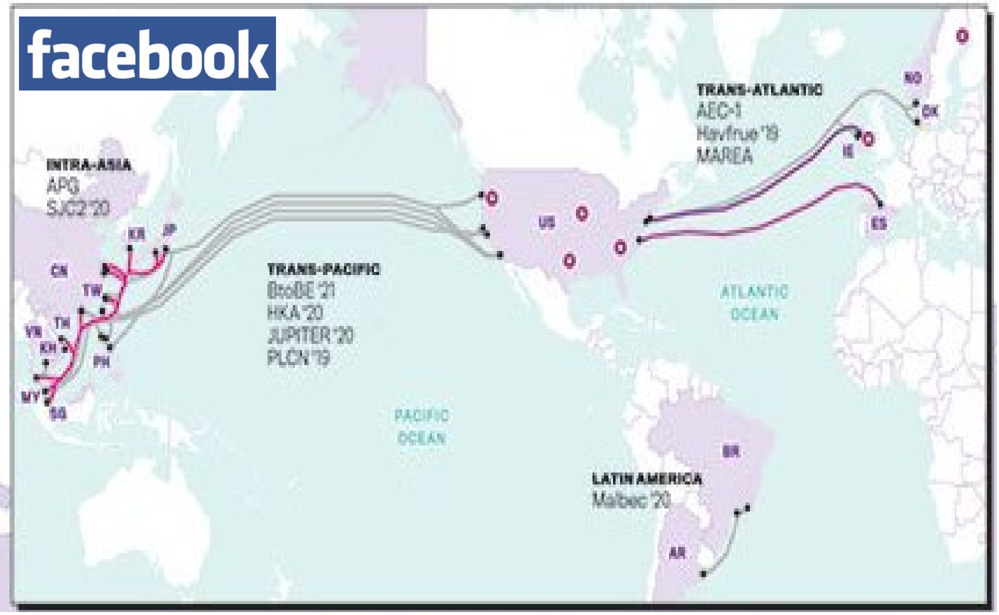


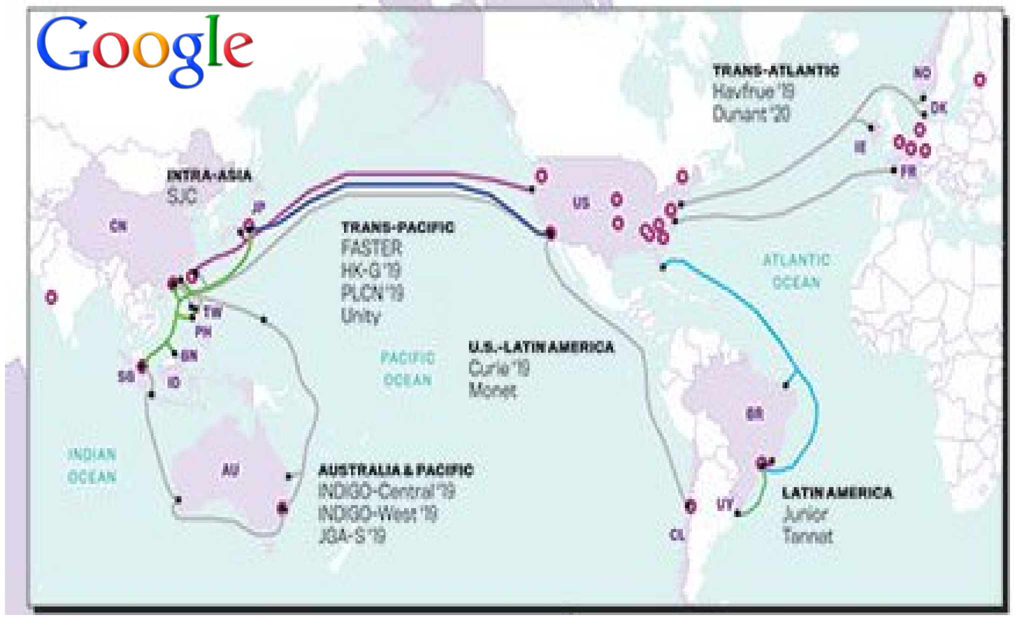
How Undersea Internet Fiber Optic Cables Are Laid On The Ocean Floor

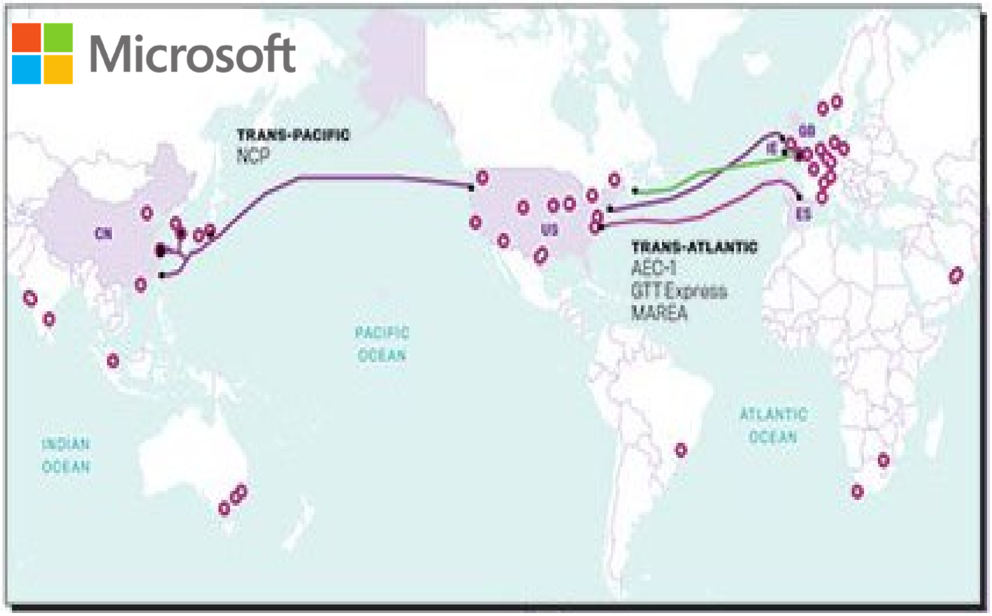
Repair Animation - Undersea Fiber Optic Cable System

Submarine F.O. Networks









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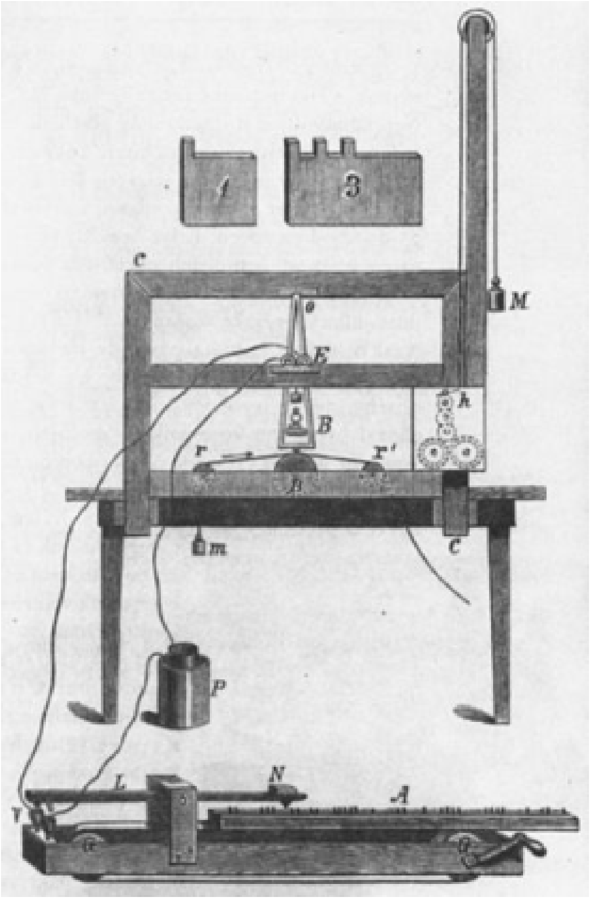
HISTORICAL PERSPECTIVE

The telegraph was the first (digital) transmission (electrical) system using a metallic line. It was developed by Samuel Morse in year 1837.

Samuel Finley Breese Morse
April 27, 1791, Charlestown, Massachusetts
April 2, 1872 , New York City, New York



Early Days
The Telegraph Era

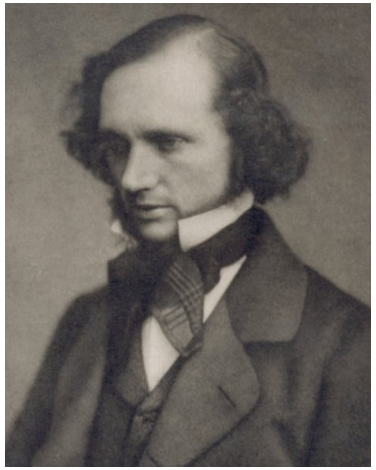
In year 1855, William Thomson (Lord Kelvin) studied the viability of installing a submarine cable to send telegraphic signals across the Atlantic Ocean. This was the firs analysis based on the distributed circuit model of a transmission line. For the first time the line was modeled using 4 uniformly distributed parameters:

- Longitudinal: Resistance (R) & Inductance (L).
- Transversal: Conductance (G) & Capacitance (C).

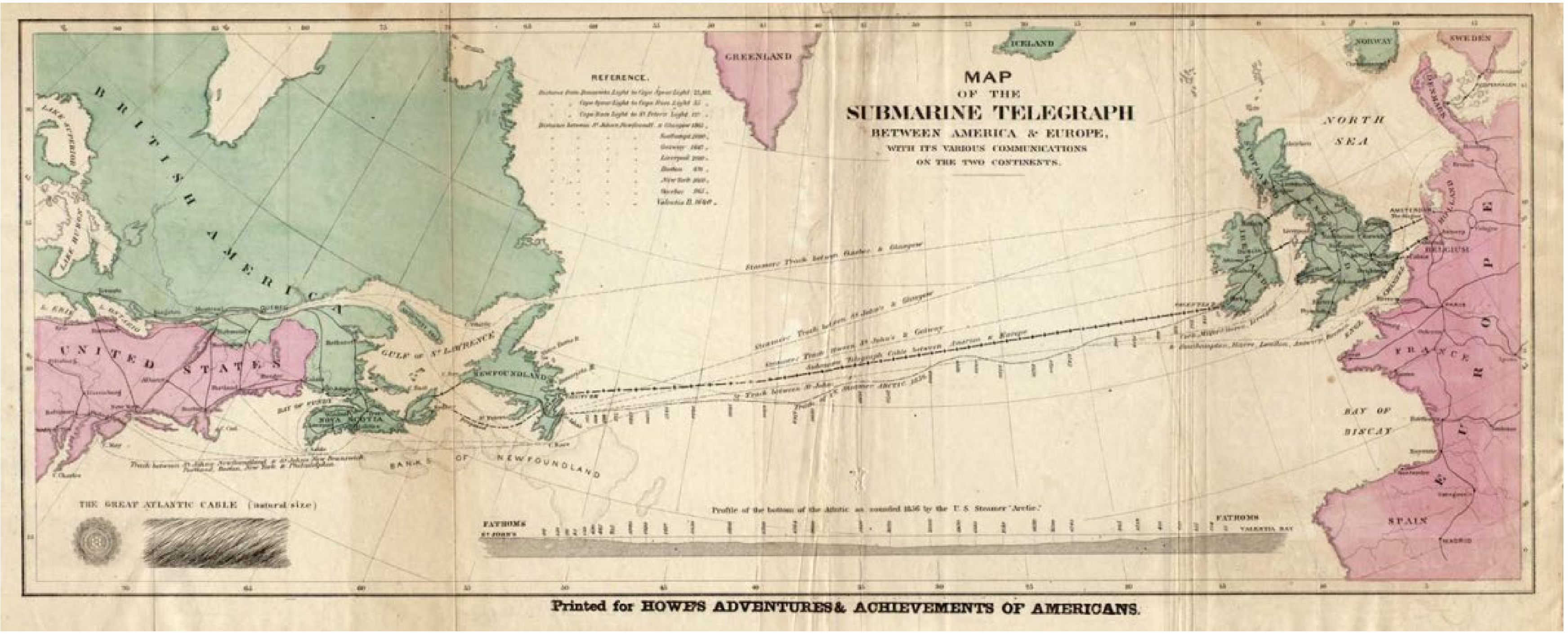
The first transatlantic telegraph cable was installed in 1866 by The Atlantic Telegraph Company lead by Lord Kelvin.

Edward Orange Wildman Whitehouse
1 October 1816, Liverpool
26 January 1890, Brighton

William Thomson
(Lord Kelvin)
26 juny de 1824, Belfast, UK
17 desembre de 1907, Largs, UK



Early Days
The Telegraph Era



1858 , 1865 , 1866

980 kg/km

SS Great Eastern

Early Days
The Telephone Era

With the invention of the telephone by Alexander Graham Bell in year 1875, it started the analog transmission era which lasted approximately one century. The transmission of voice signals, with several hundred times higher bandwidth than the telegraphic signals, put into evidence the need of reliable cables. The contemporary telegraphic lines were used first (iron wires with ground return). Those circuits became impracticable due to the high noise level.

Alexander Graham Bell
March 3, 1847 Edinburgh, Scotland, UK
August 2, 1922 Beinn Bhreagh, Nova Scotia, Canada

Alexander Graham Bell telephone prototype, 1876

Early Days
The Telephone Era

As electrical power distribution became more commonplace, the telephone wires shared the route with electrical power lines. Within a few years, the growing use of electricity brought an increase of interference. Twisted pair cables were invented by Alexander Graham Bell in 1881 to cancel out the interference.

As a consequence of the great success of the telephone, a huge increment on the circuit demand, or telephone channels, was experienced. This fact forced the infeasibility of handling all the traffic with aerial lines in big cities.

Telephone Pole Line Construction in New York, about 1903

Early Days
The Telephone Era

A bigger capacity and protection (meteorological phenomena) lead to the development of multi-pair subterranean cables designed to be buried. For an unamplified telephone line, a twisted pair cable could only manage a maximum distance of 30 km. Open wires, on the other hand, with their lower capacitance had been used for enormous distances - the longest was the 1500 km from New York to Chicago built in 1892.

Bell placing the first New York to Chicago telephone call in 1892

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Early Days
The Telephone Era

The first subterranean cable experiences, using oil impregnated silk as insulator, were conducted in 1883. In 1885 the lead-based jacket was developed which was a big step in cable evolution:

- Dry paper Insulator to reduce the capacity and the losses introduced by the insulation.
- Twisted pair to reduce the diaphony among circuits.

The first interurban twisted pair cable experiences were conducted in 1898. They had relatively big gauges and small capacities to reduce attenuation.

Telephone Cable Being Pulled into Underground Conduit - Lead Covered Cable, Washington, D.C., 1953.

Early Days
The Telephone Era

High capacity coaxial line appears in 1935. It solved the limitation on the number of multiplex channels of the symmetric lines (in practice, limitation to transmit frequencies higher than 1 MHz).

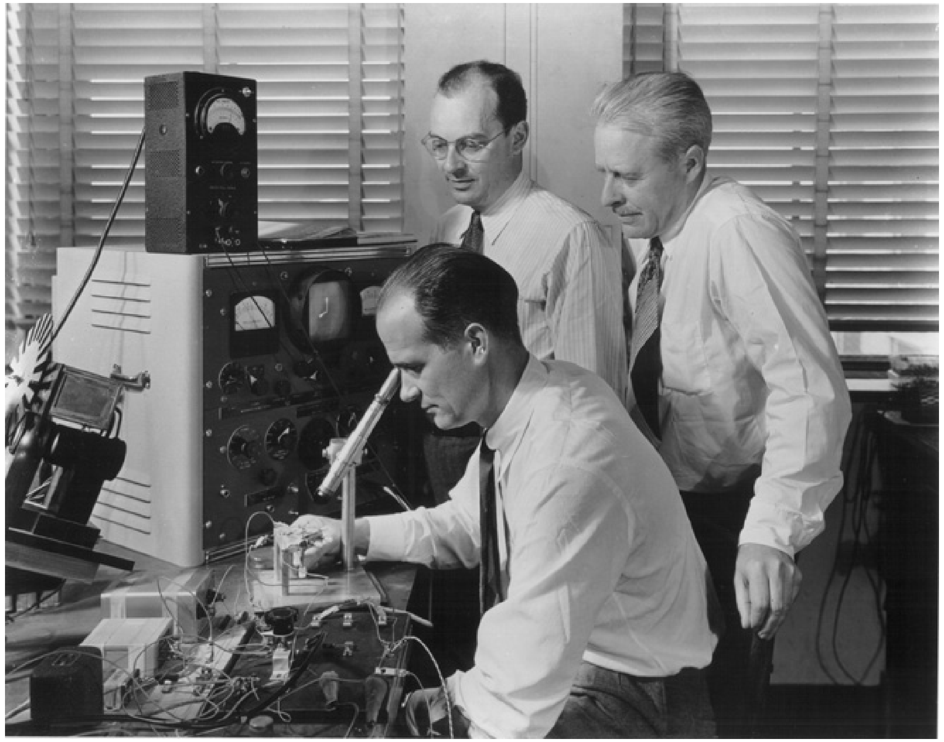
First modern coaxial cable patented (1929) by Lloyd Espenschied and Herman Affel of AT&T's Bell Telephone Laboratories.

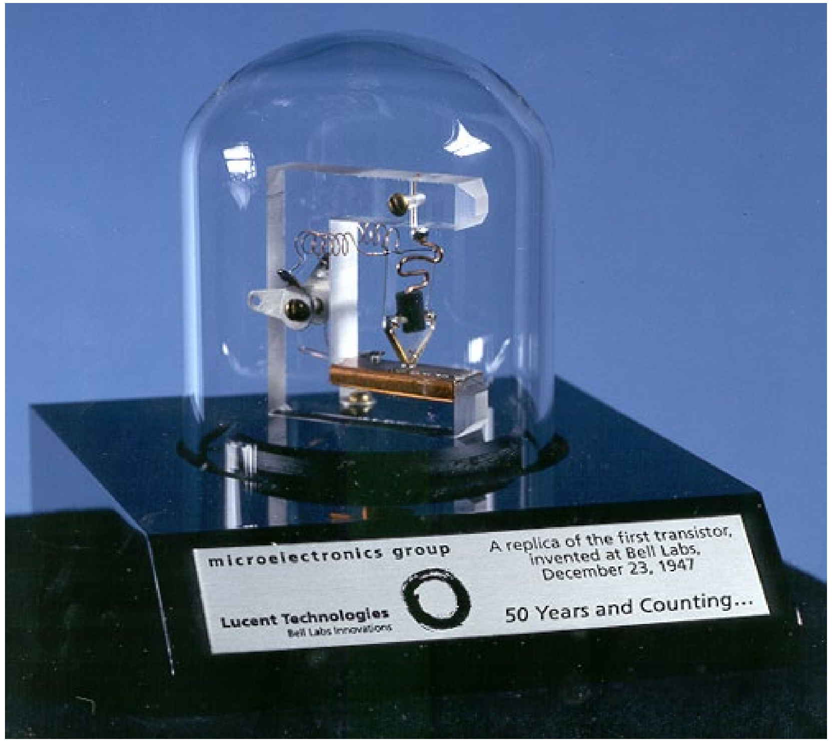
In 1936, AT&T put in service the first coaxial cable for television use in New York City.

Lloyd Espenschied (left) and Herman A. Affel (right), 1949.

Early Days
The Telephone Era

The invention of the transistor in 1948 caused a revolution in the telecommunications field. It allowed to design compact repeaters with high gain at low consumption. This was key to build long distance systems and to dramatically increase the number of channels. The first submarine coaxial cables were developed.



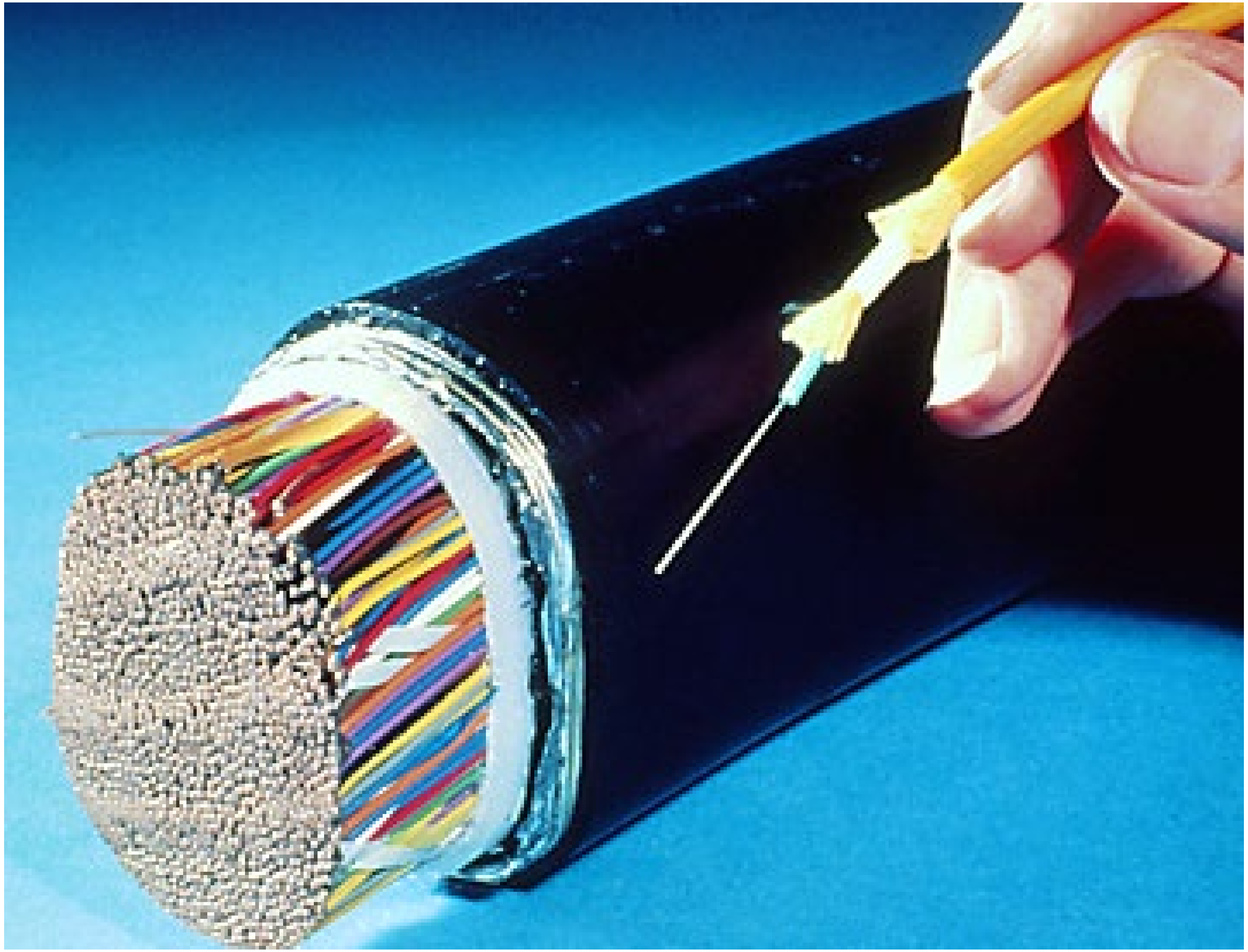


1947: John Bardeen and Walter Brattain, with support from colleague William Shockley, demonstrate the transistor at Bell Laboratories in Murray Hill

Early Days
The Telephone Era

Transatlantic Cable (TAT-1) Under Construction, 1955. When AT&T opened TAT-1 in 1956, the first trans-Atlantic telephone cable, the initial capacity was 36 calls at a time.

The Optical Communications Era



The Optical Communications Era

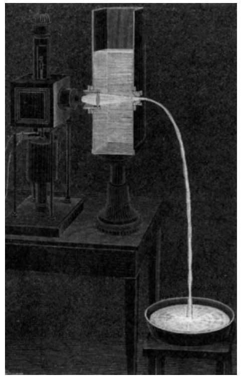
Claude Chappe
December 25, 1763 Brûlon, Sarthe
January 23, 1805 Paris

An optical telegraph is a system of conveying information by means of visual signals, using towers with pivoting shutters, also known as blades or paddles. Information is encoded by the position of the mechanical elements; it is read when the shutter is in a fixed position. The system was invented in 1792 in France by Claude Chappe, and was popular in the late 18th to early 19th century.

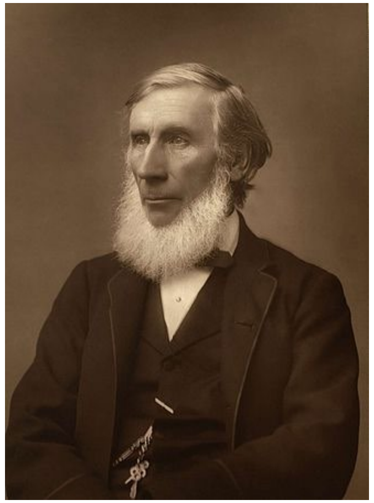
The Optical Communications Era

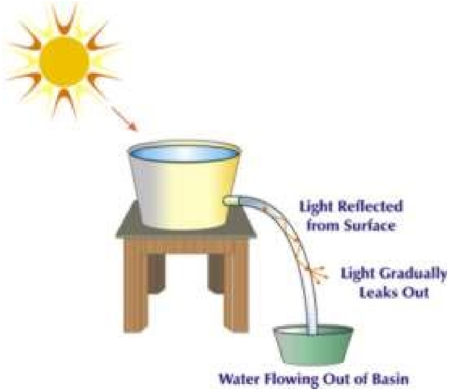
Guiding of light by refraction, the principle that makes fiber optics possible, was first demonstrated by Daniel Colladon and Jacques Babinet in Paris in the early 1840s. John Tyndall included a demonstration of it in his public lectures in London, 12 years later. Tyndall also wrote about the property of total internal reflection in an introductory book about the nature of light in 1870.

Jean-Daniel Colladon
(15 December 1802, Geneva - 30 June 1893)



John Tyndall
2 August 1820 Leighlinbridge, Ireland
4 December 1893 (aged 73) Haslemere, England





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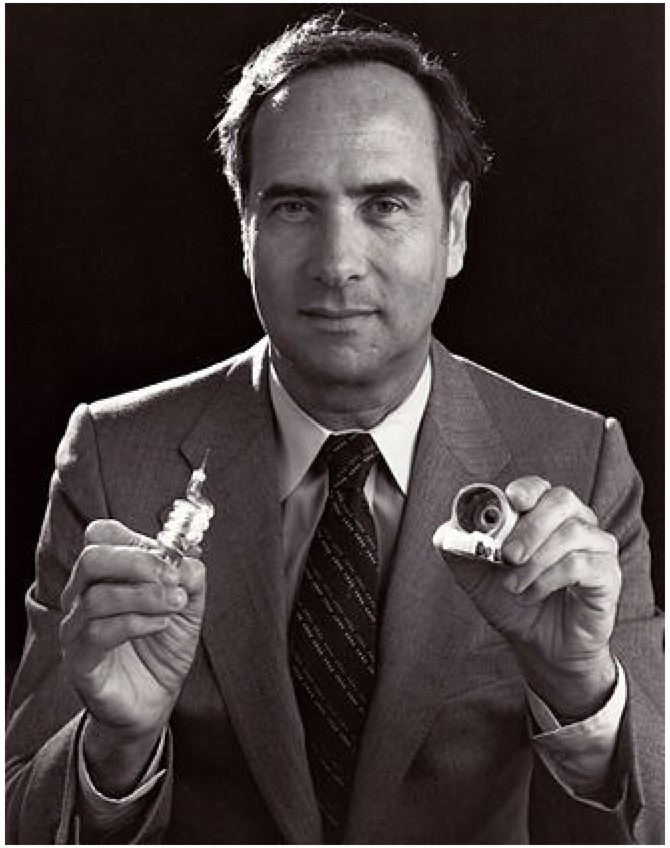
The Optical Communications Era



Theodore Harold Maiman
July 11, 1927 Los Angeles
May 5, 2007 Vancouver
First Laser 1960
(Hugues Research Lab).

Aleksandr Prokhorov (left) and **Nikolai Basov** (right) show their laboratory to **Charles Townes** (center). The three shared the Nobel Prize in physics in 1964 for their work on masers and lasers.

The Optical Communications Era

Charles Kuen Kao
4 November 1933 Shanghai, China

Charles K. Kao and George A. Hockham of the British company Standard Telephones and Cables (STC) were the first to promote the idea that the attenuation in optical fibers could be reduced below 20 decibels per kilometer (dB/km) in 1966. They proposed that the attenuation in fibers available at the time was caused by impurities that could be removed, rather than by fundamental physical effects such as scattering. **Nobel Prize 2009**.

Robert D. Maurer (center), Donald Keck (left), Peter C. Schultz (right)

The crucial attenuation limit of 20 dB/km was first achieved in 1970, by researchers Robert D. Maurer, Donald Keck, Peter C. Schultz, and Frank Zimar working for American glass maker Corning Glass Works, now Corning Incorporated. They demonstrated a fiber with 17 dB/km attenuation by doping silica glass with titanium. A few years later they produced a fiber with only 4 dB/km attenuation using germanium dioxide as the core dopant.

The Optical Communications Era

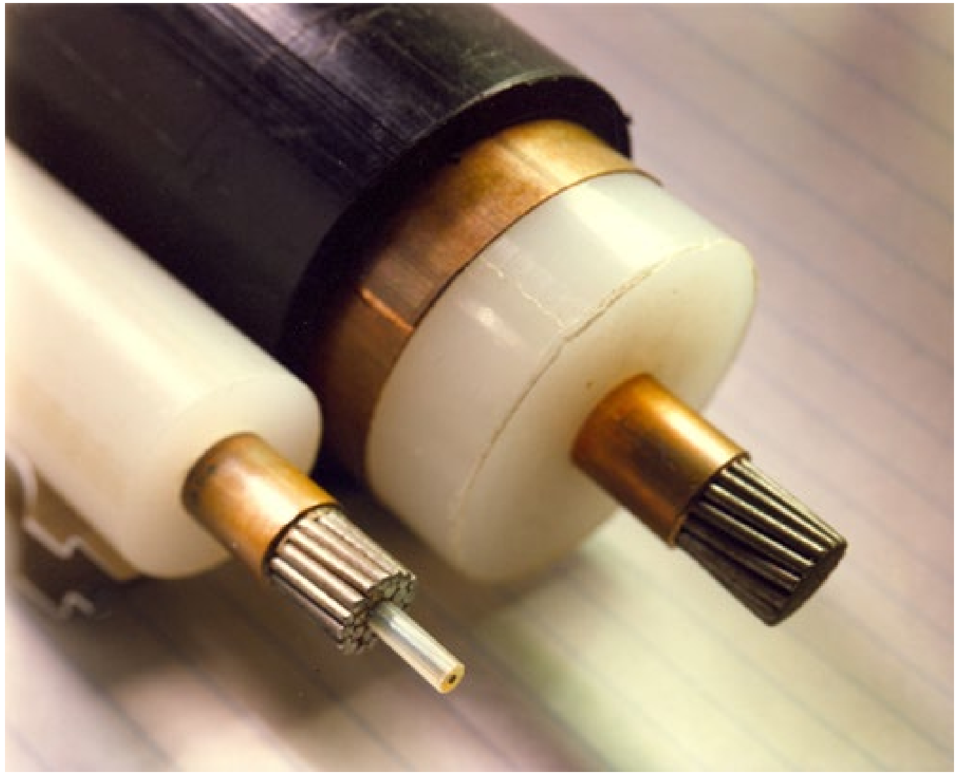
1986 – First **doped fiber** optical amplifiers David Payne (U. Southampton) and Emmanuel Desurvire (Bell Labs). Important development contribution by Randy Giles (Bell Labs).

Optical amplifiers are key for the development of long distance fiber-optic communications. **Erbium-doped fiber amplifiers (EDFA)** have been the most widely used due to their high gain (40 dB) and low noise figure (5 dB) over a wide range (4 THz).

Emmanuel Desurvire (left), Randy Giles (center), and David Payne (rigth) awarded with the Millennium Technology Prize 2008.

The Optical Communications Era

Photo of laying cable for TAT-8. Laying cable and a repeater for TAT-8 from the deck of the CS Long Lines, 1987.



A sample of TAT-8 fiber optic submarine cable (l) next to a sample of TAT-7 copper submarine cable (r). The former had 10 times the capacity of the latter.

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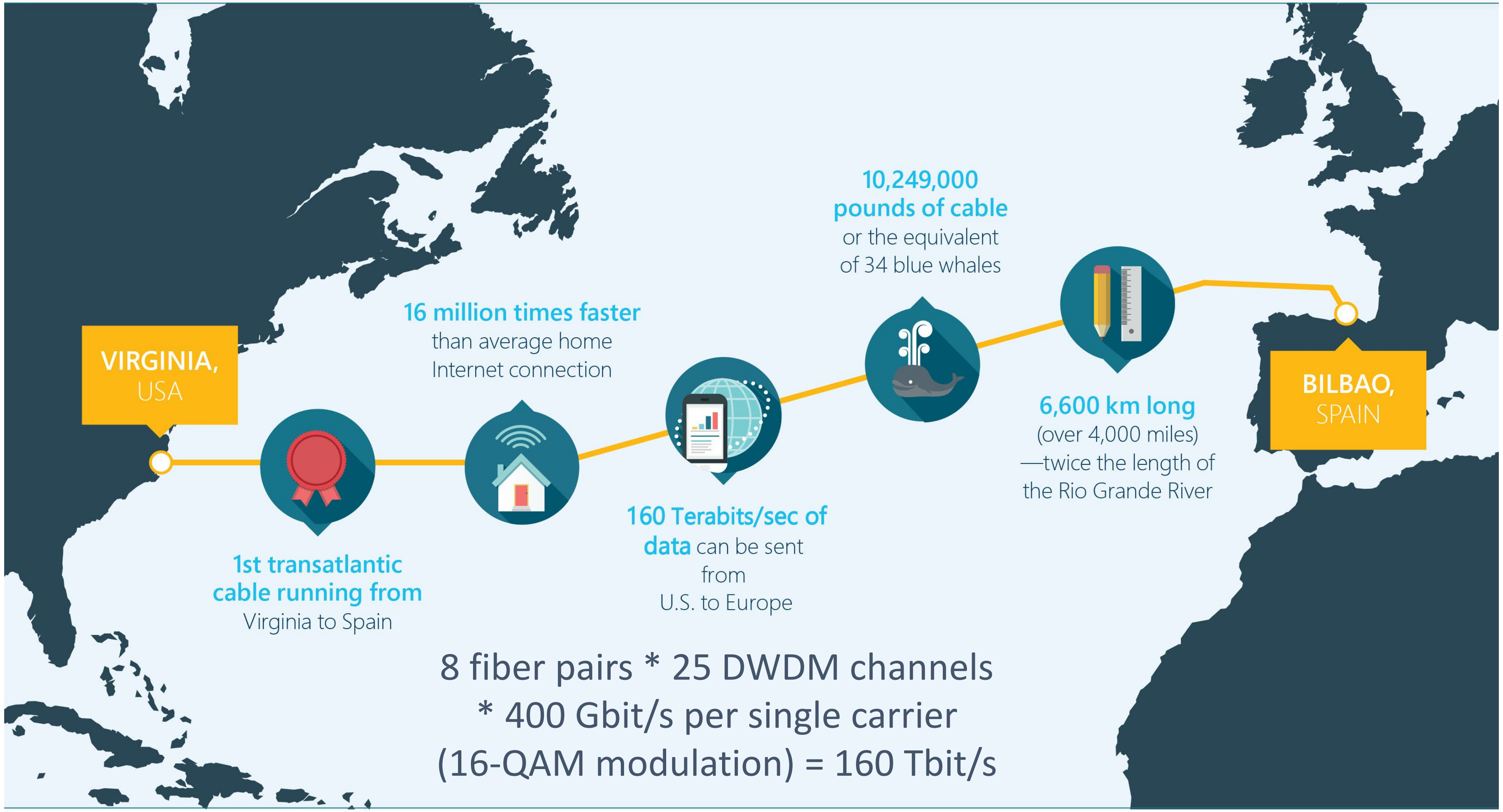
The Optical Communications Era

MAREA TRANSATLANTIC SUBSEA CABLE

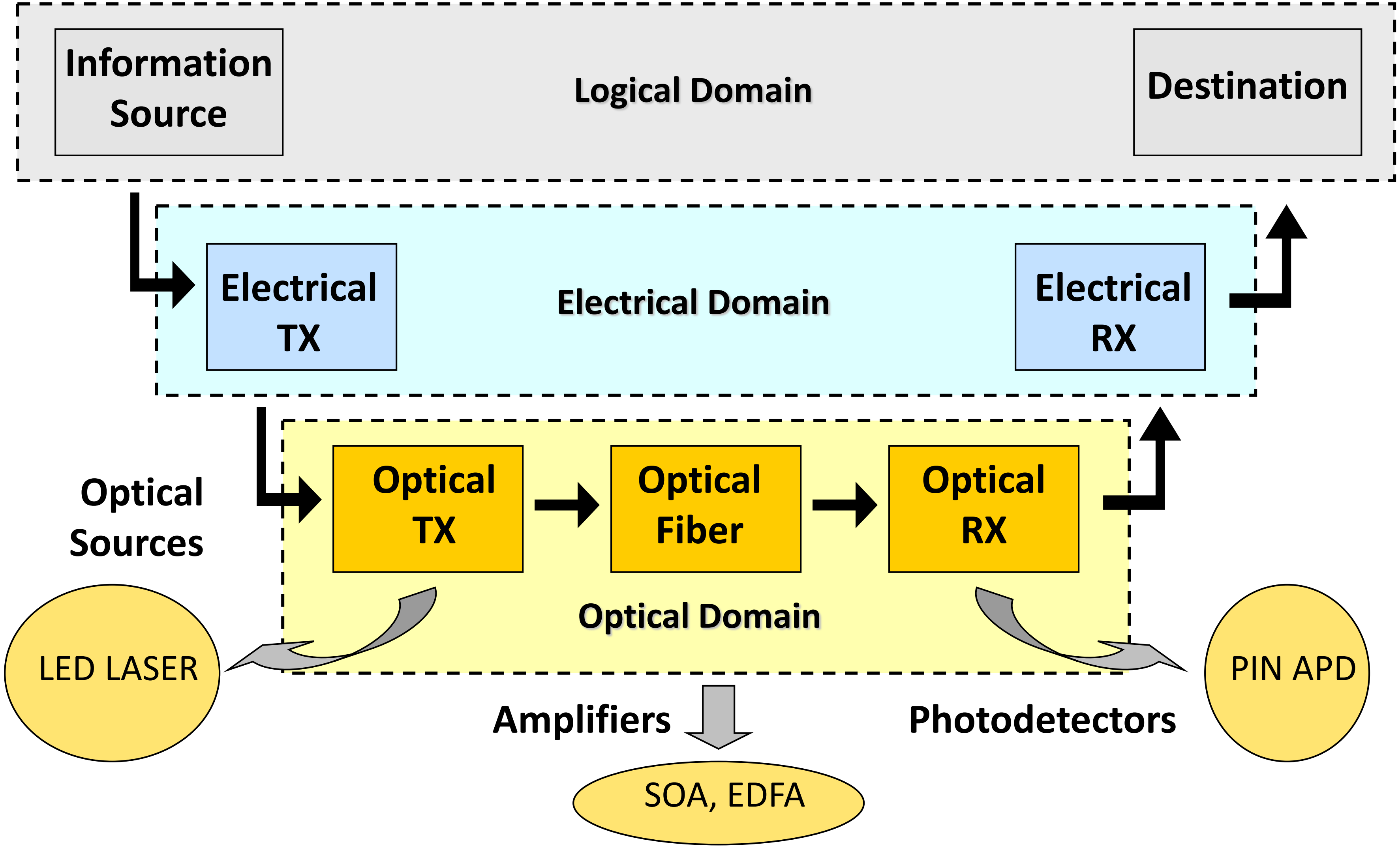
Faster. Stronger. More Resilient.

February 2018

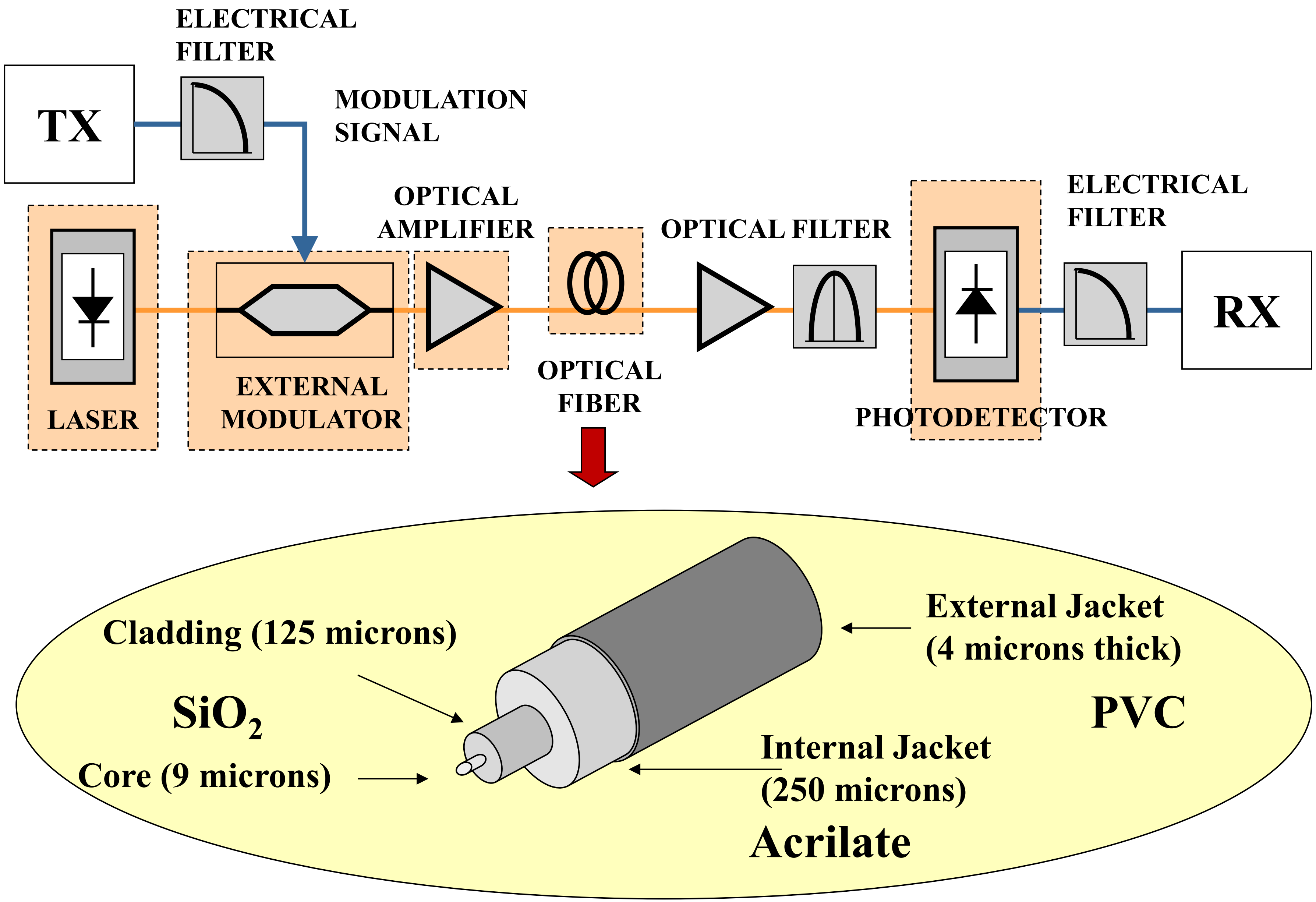


Microsoft TELXIUS facebook

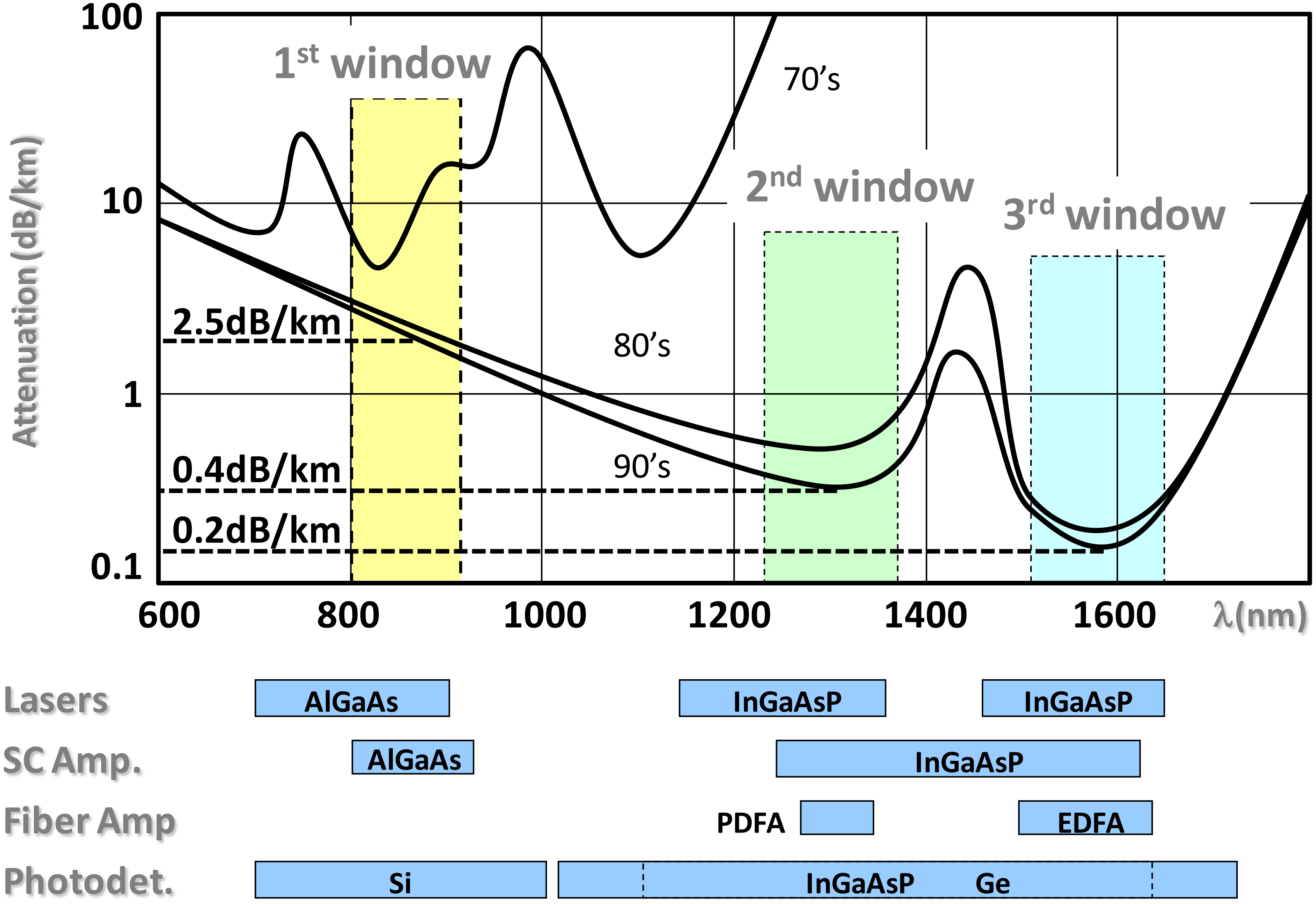
F.O. COMMUNIC. SYSTEM



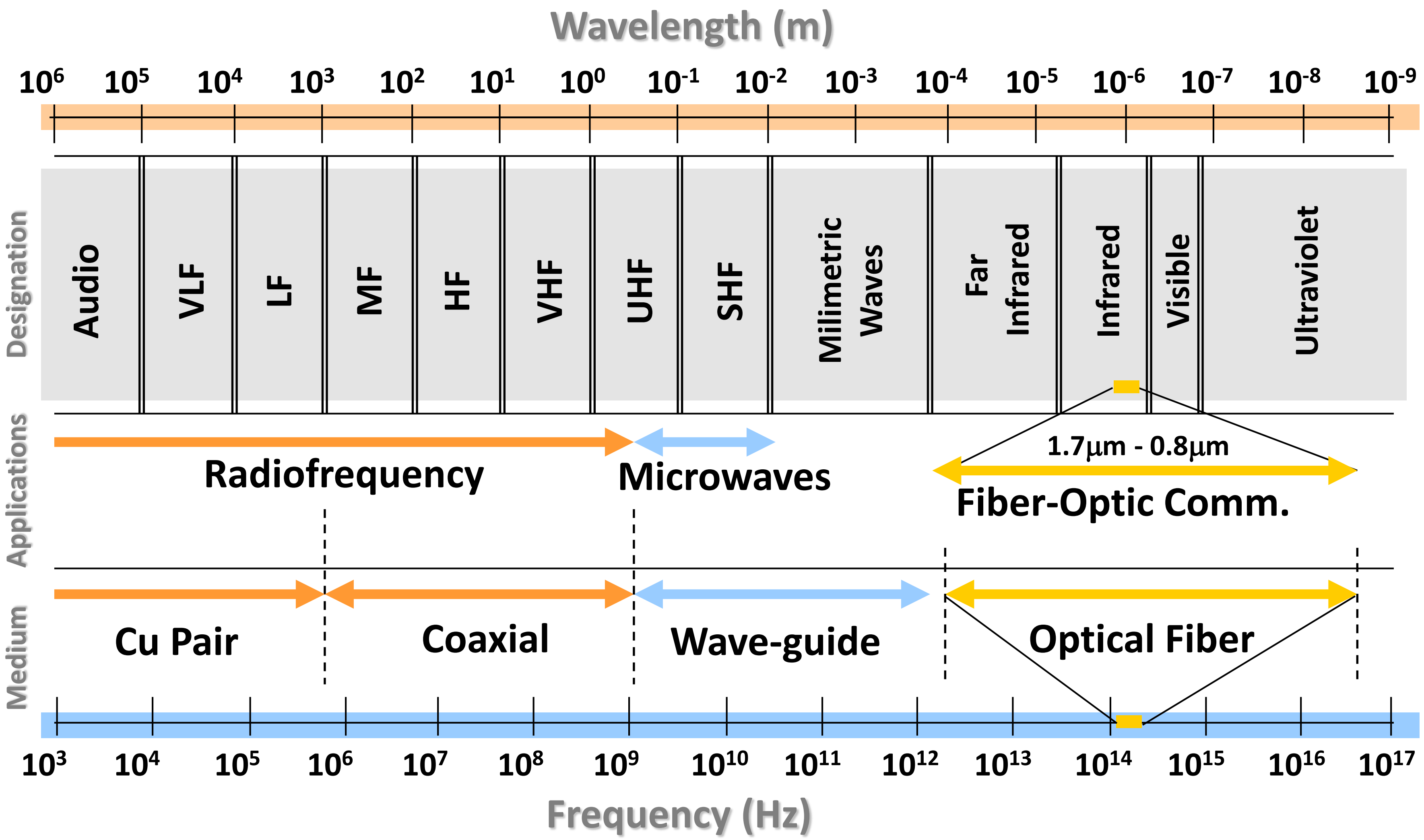
F.O. Communications System Example



F.O. Communication Windows



Electromagnetic Spectrum

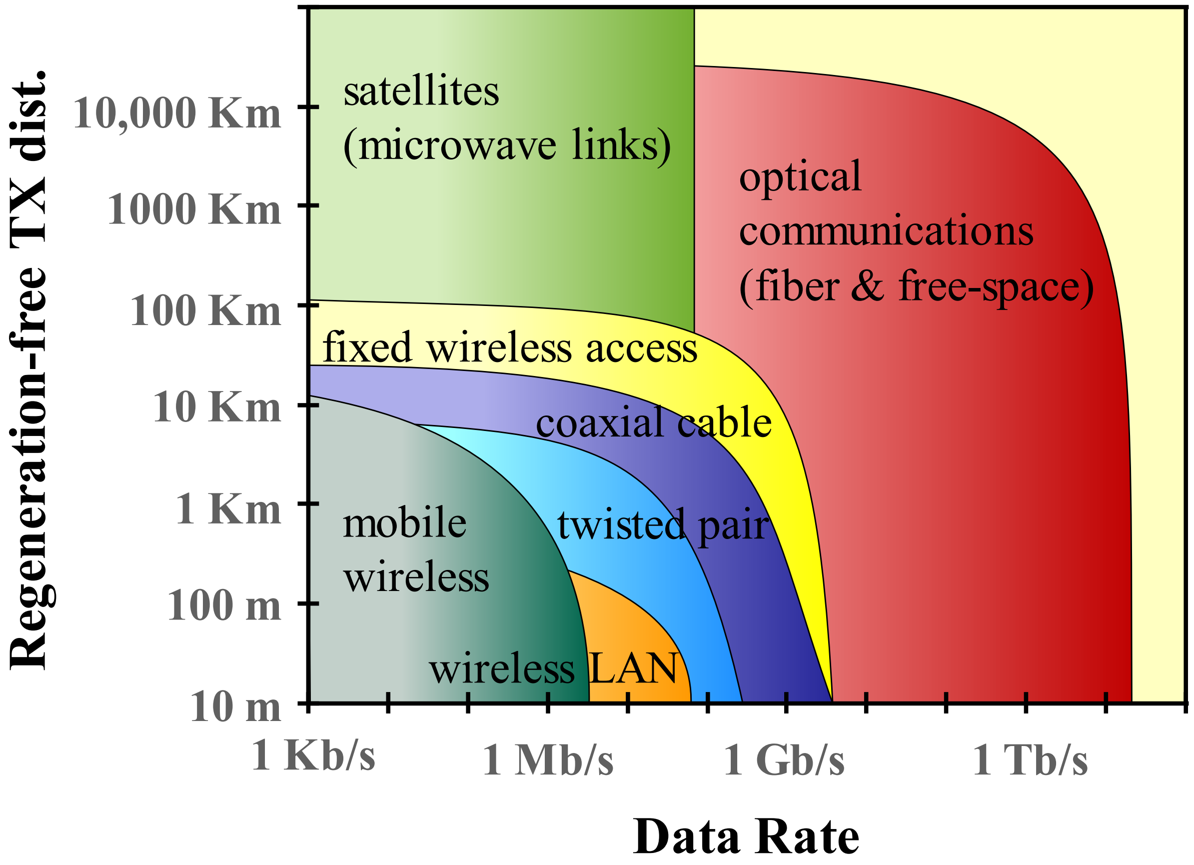


FIBER OPTICS ADVANTAGES

- Huge Capacity (Tb/s → 1% of the carrier 100 THz)
- Low attenuation (0.2 dB/km) in a wide freq. range (30 nm – 4 THz)
- Reduced weight and dimensions.
- Isolator (dielectric medium) – electromagnetic interferences immunity
- No diaphony (reduced radiation)
- Temperature stability (-55°C to 125 °C)
- Flexible and robust (mechanically)
- Intrusions security (reduced radiation)
- Potential reduced cost (SiO_2 abundance)

Fiber Optic Drawbacks

- E/O-O/E transductors required
- Expensive devices (shared cost → Long-Haul)
- Fiber splices complexity
- Connectors complexity
- Tecnology unmaturity



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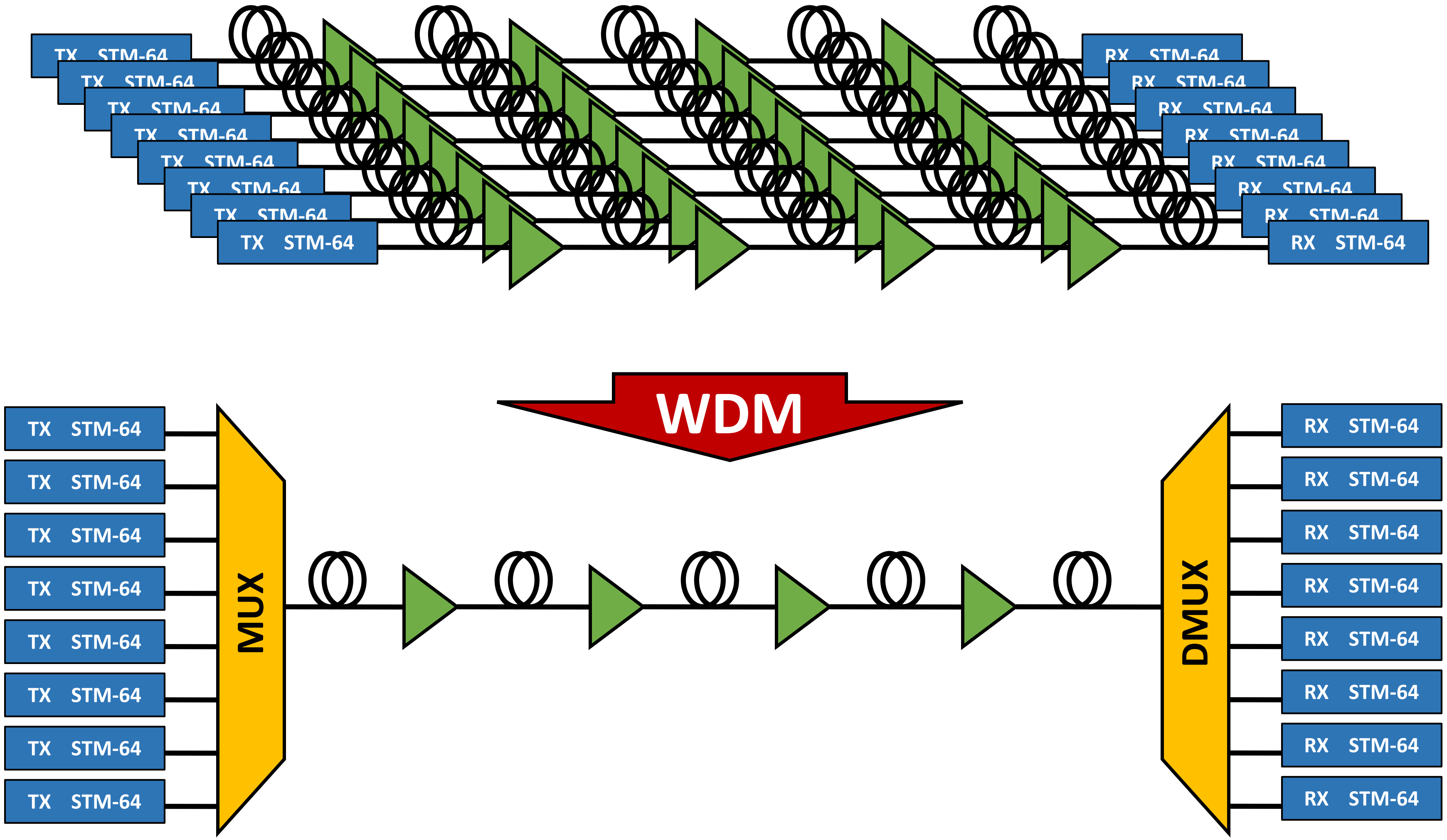
Wavelength Division Multiplexing (WDM)

10 channels x 100 Gb/s = 1 Tb/s



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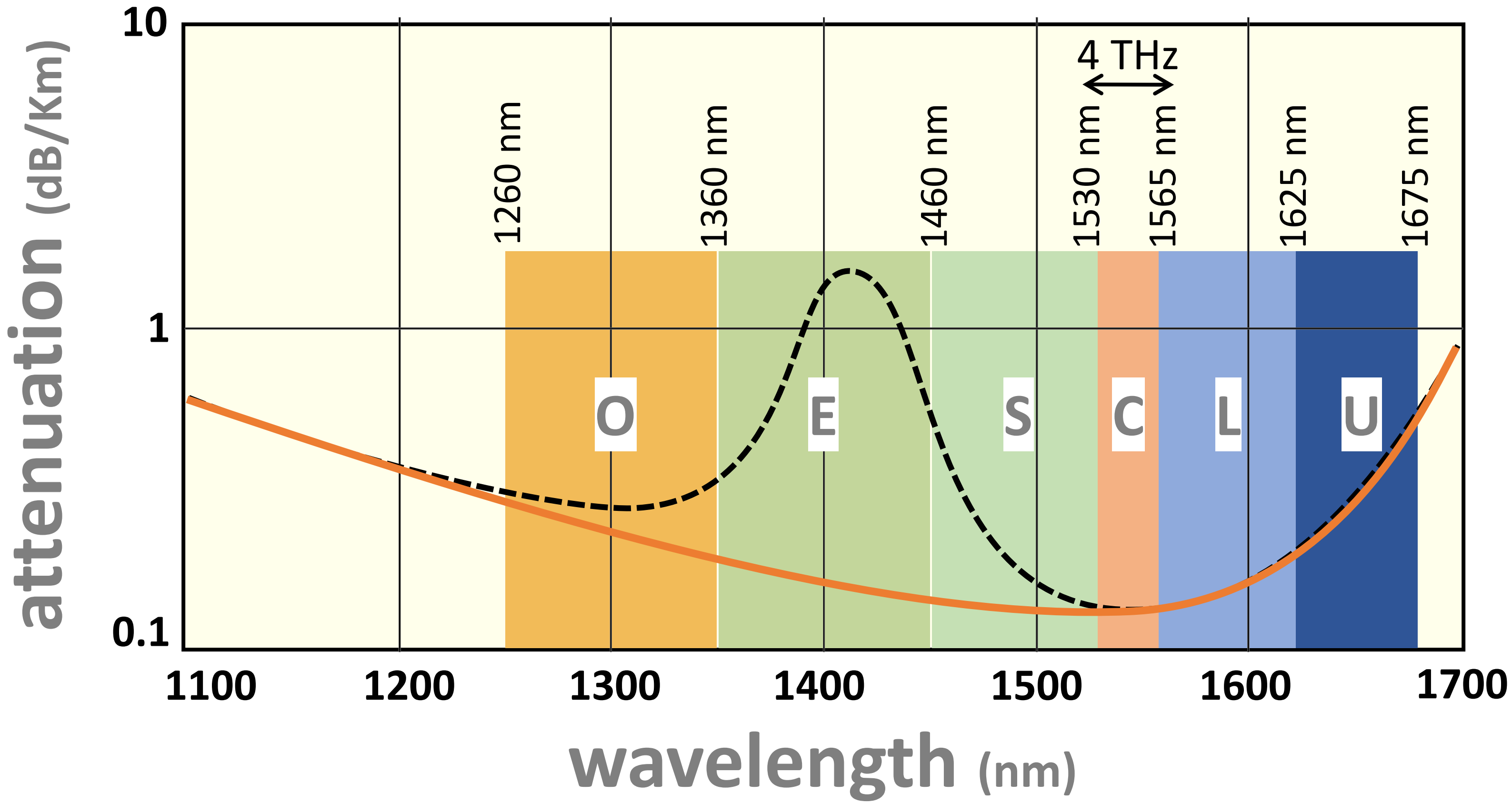
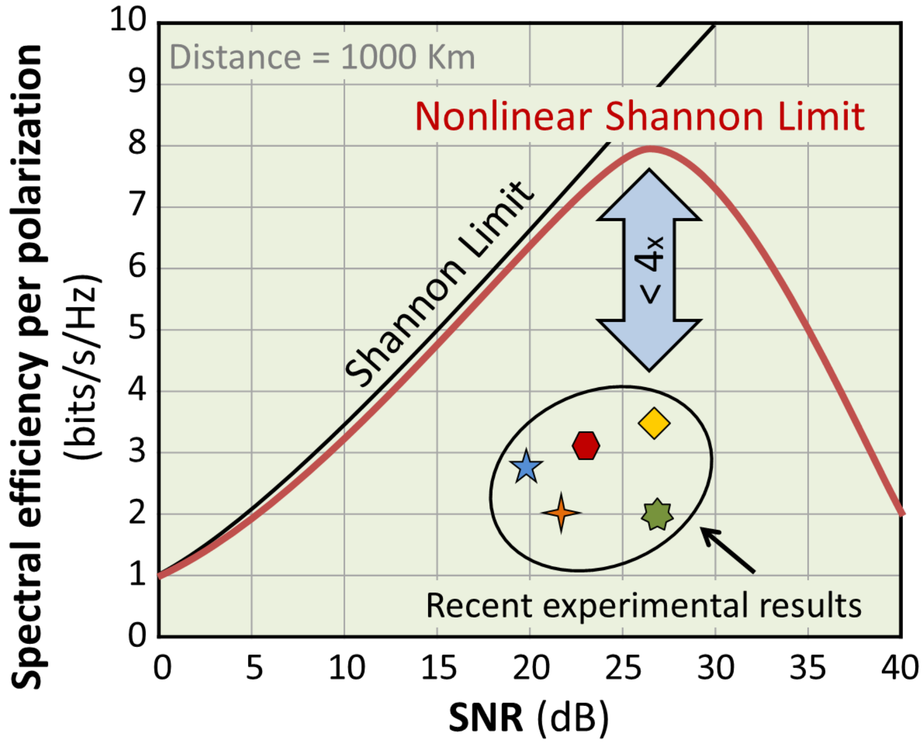
Wavelength Division Multiplexing (WDM)

WDM transmission Bands



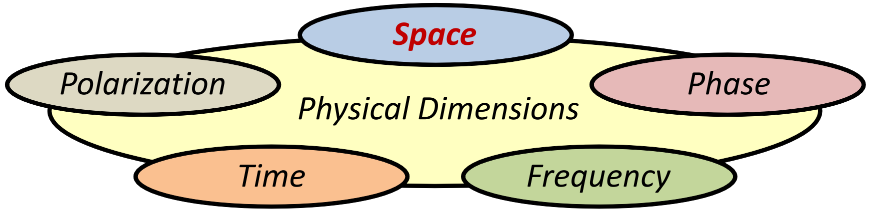
O – original	C – conventional (erbium)	L – long wavelength
E – extended	S – short wavelength	U – ultralong wavelength

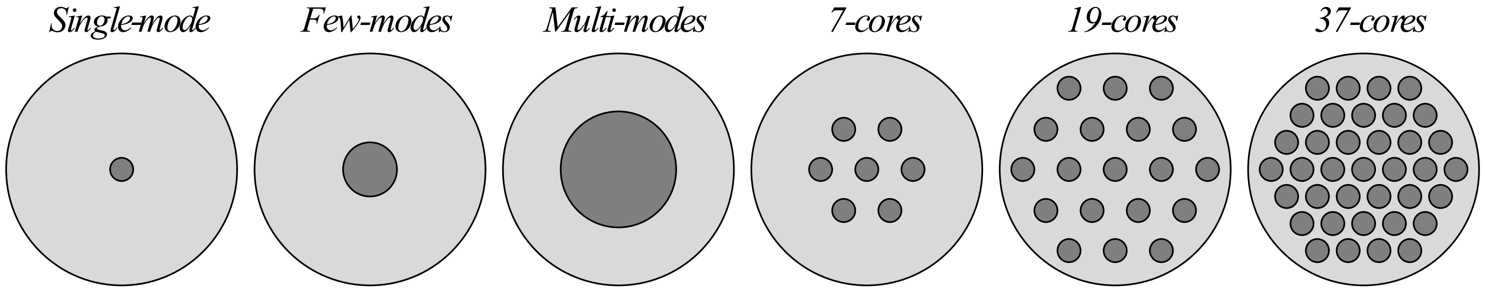
Spatial Division Multiplexing (SDM)



Fiber-Optic Capacity Crunch

Recent experimental records are within a factor <4 of the nonlinear Shannon limit.

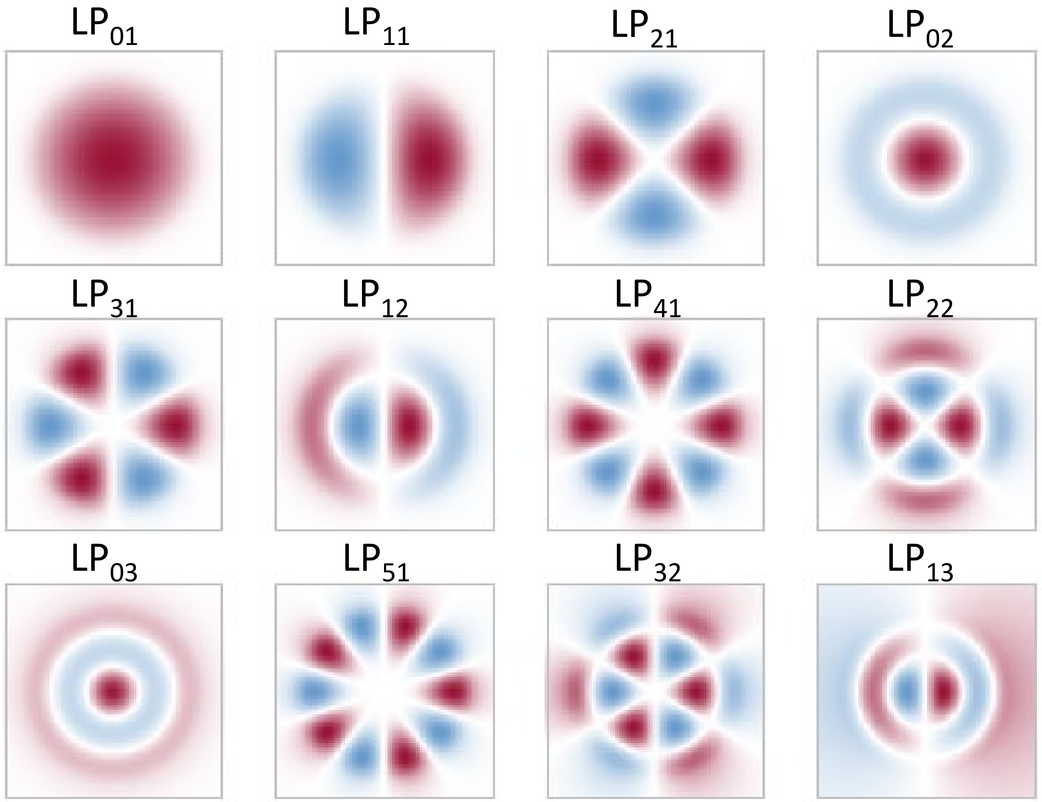




Spatial Division Multiplexing (SDM)

Mode Division Multiplexing (MDM)

Multi-mode fibers can support hundreds of propagation modes which are orthogonal



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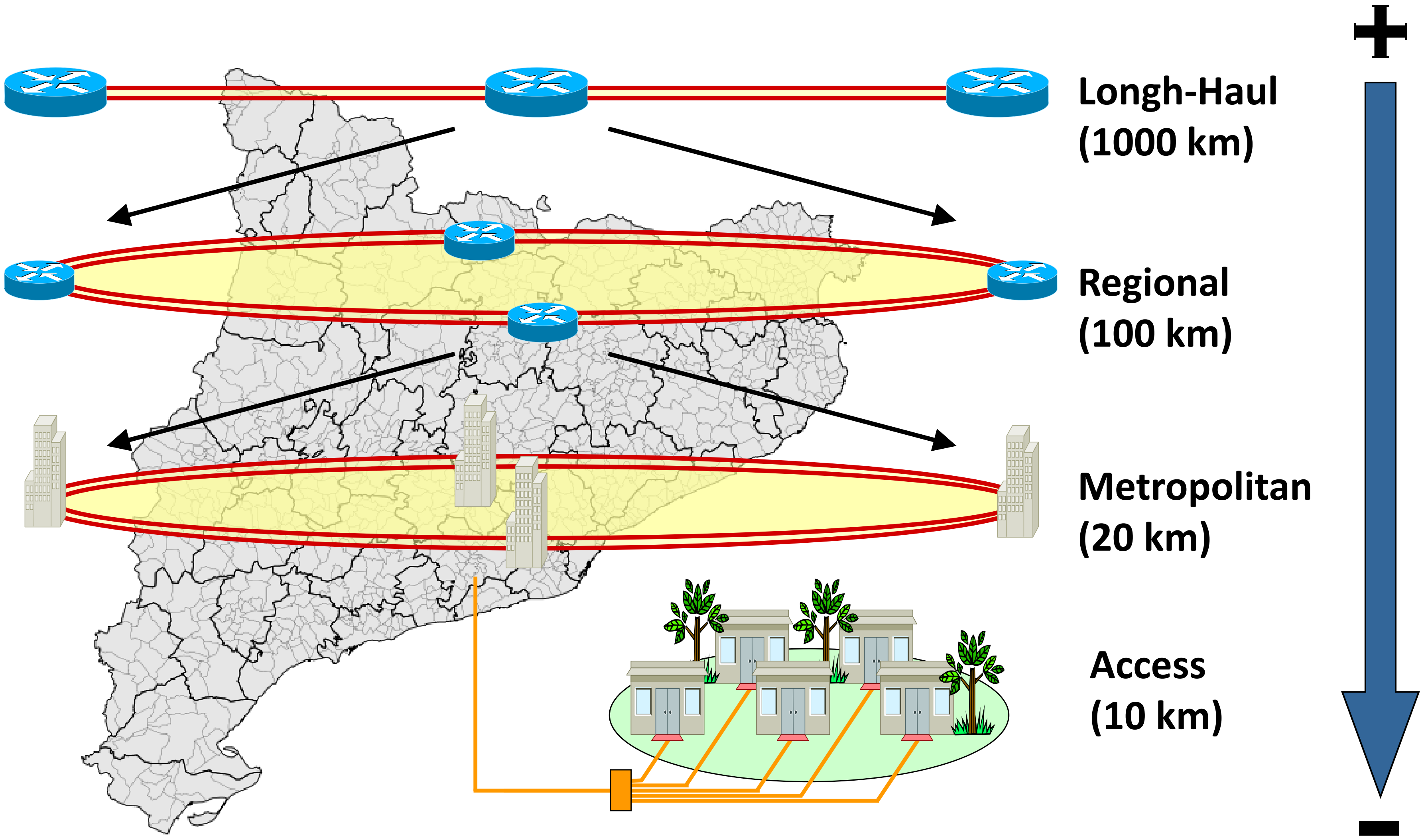
OPTICAL FIBER LOCALIZATION



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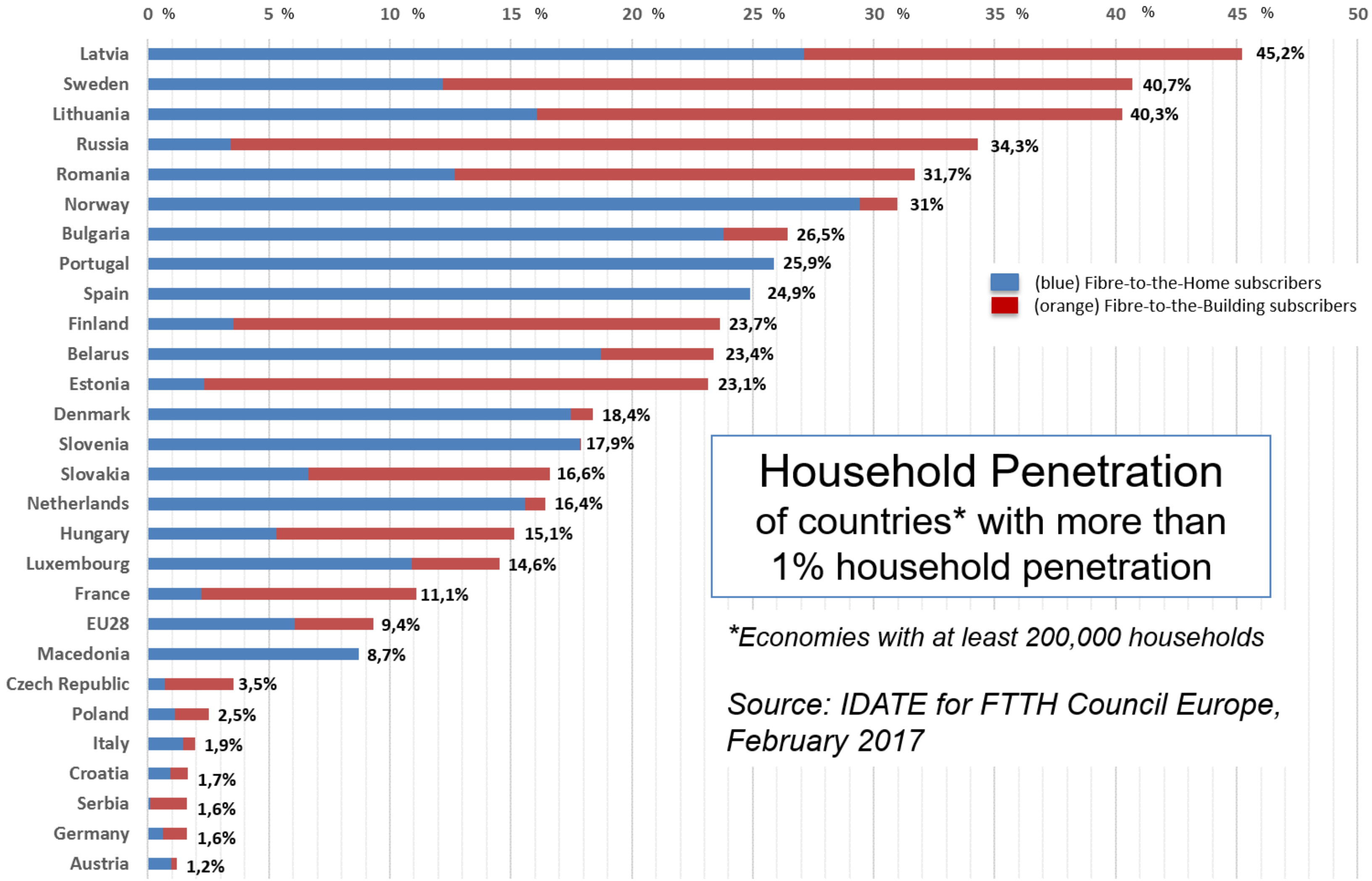
Optical Access Networks

Optical Access Penetration in the EU



Household Penetration
of countries* with more than 1% household penetration

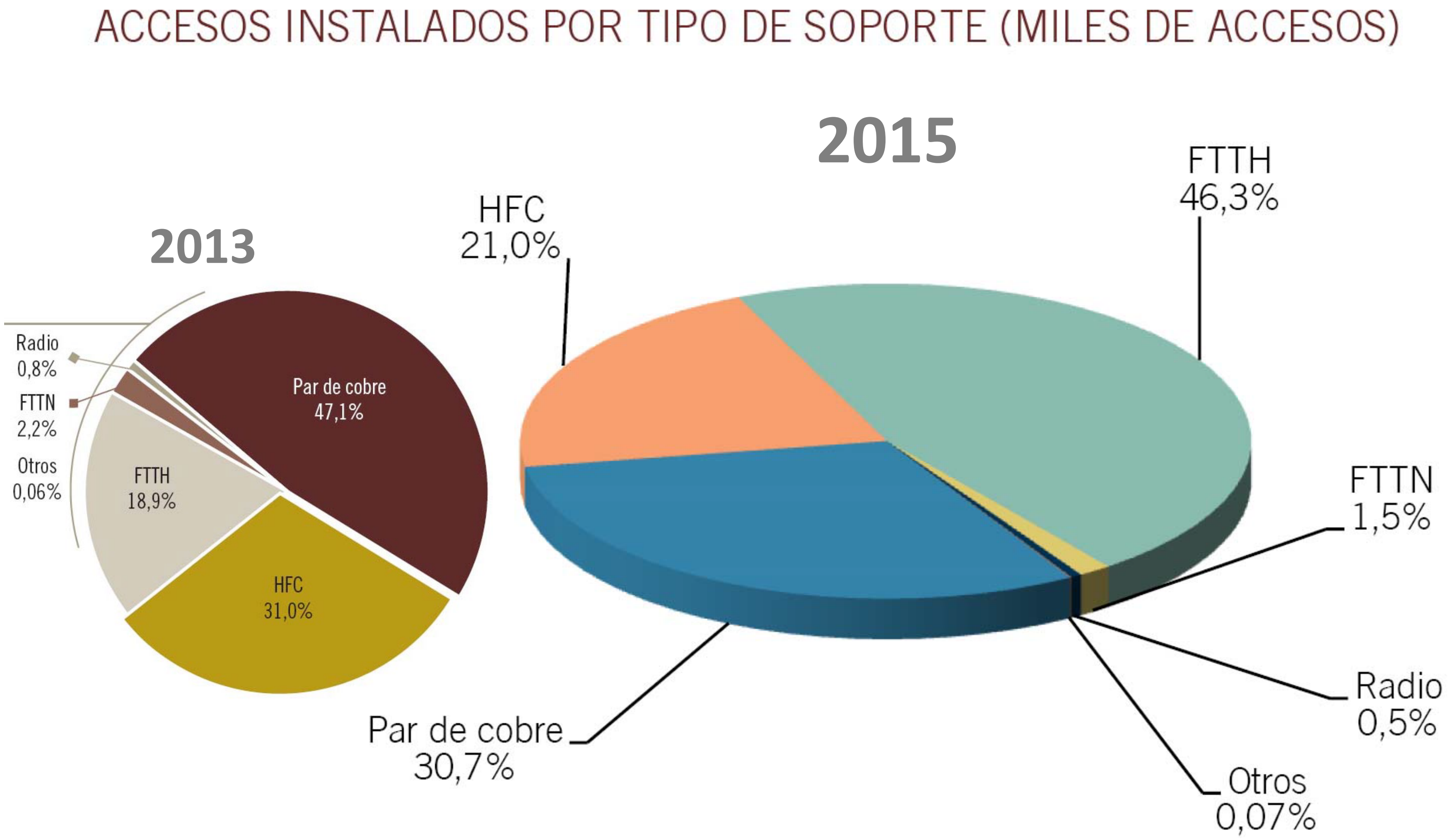
**Economies with at least 200,000 households*

Source: IDATE for FTTH Council Europe, February 2017

Optical Access Networks

Spanish Situation

Comisión Nacional de los Mercados y la Competencia (CNMC) www.cnmc.es



Optical Access Networks

Spanish Situation

Comisión Nacional de los Mercados y la Competencia (CNMC) www.cnmc.es

EVOLUCIÓN DE ACCESOS INSTALADOS

	2011	2012	2013	2014	2015
Par de cobre	16.065.690	15.740.106	15.539.052	15.435.440	15.154.659
HFC	9.497.692	9.773.825	9.943.515	10.258.742	10.363.432
FTTH	1.607.108	3.250.556	6.244.313	15.134.930	22.861.673
FTTN	691.435	700.495	709.946	716.744	717.539
Radio	236.807	219.532	262.030	234.445	243.825
Otros	14.207	19.322	19.167	40.467	34.790