



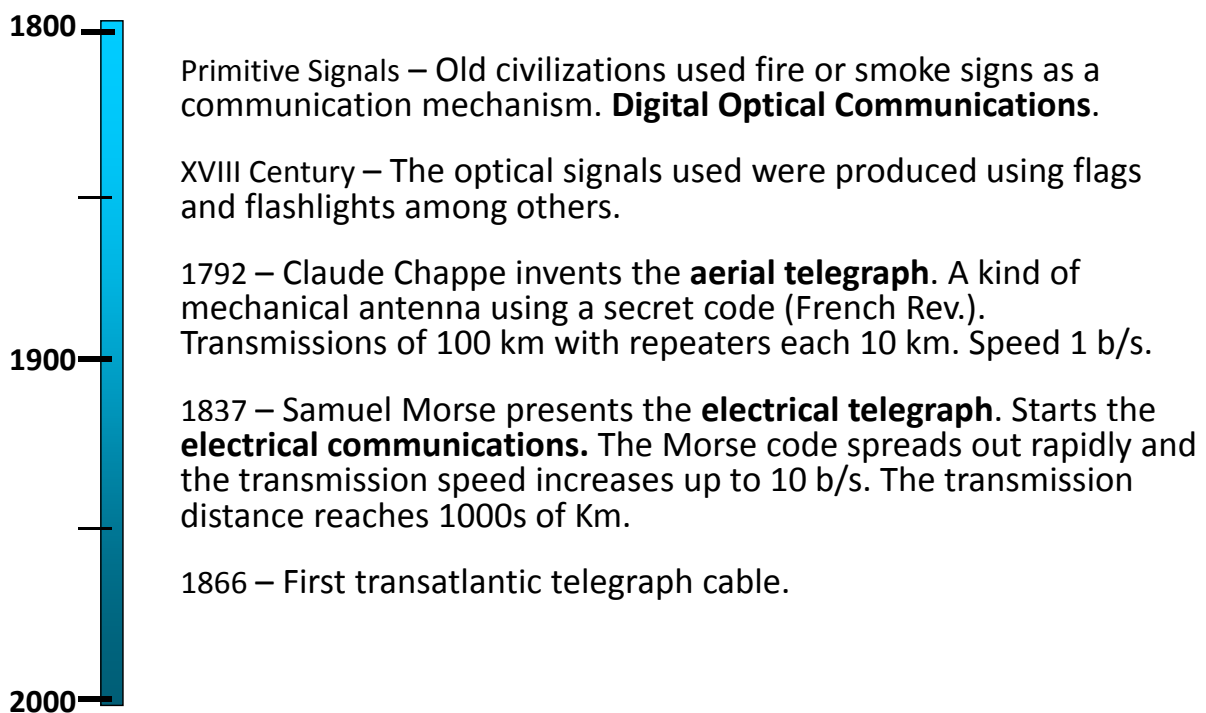
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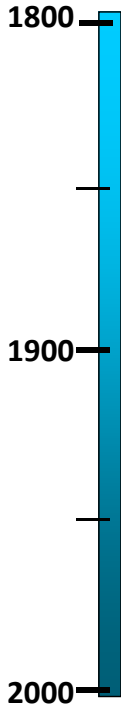
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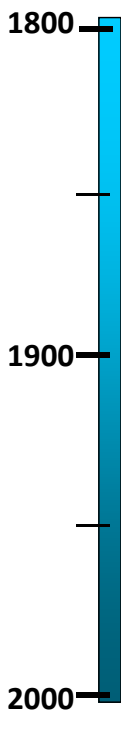
1. INTRODUCTION

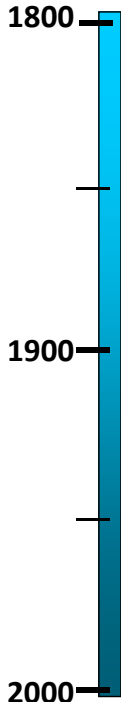
- HISTORICAL PERSPECTIVE
- BASIC FIBER-OPTIC SYSTEM
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- F.O. LOCALIZATION

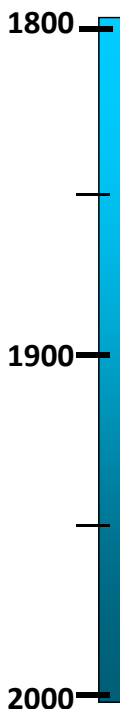
HISTORICAL PERSPECTIVE



- 
- 1800 – 1876 – Alexander **Graham Bell** patents **the telephone**, two hours before **Elisha Gray**. Recently the invention has been attributed to **Antonio Meucci**, 1871. Starts the **analog communications** era. The telephone experiences a worldwide extension until today.
- 1895 – First **radio communications** experiments by Guglielmo Marconi.
- 1931 – Transmission of first **TV**. images by René Barthélémy.
- 1900 – 1940 – First **coaxial cable** transmission system. Order of MHz.
- 1948 – First **microwave** transmission system over coaxial cable. Order of GHz. Transmission speed up to 100 Mb/s with repeater distance of just 1 Km due to cable losses (5-10 dB/km).
- 1956 – First transatlantic telephone cable.
- 2000

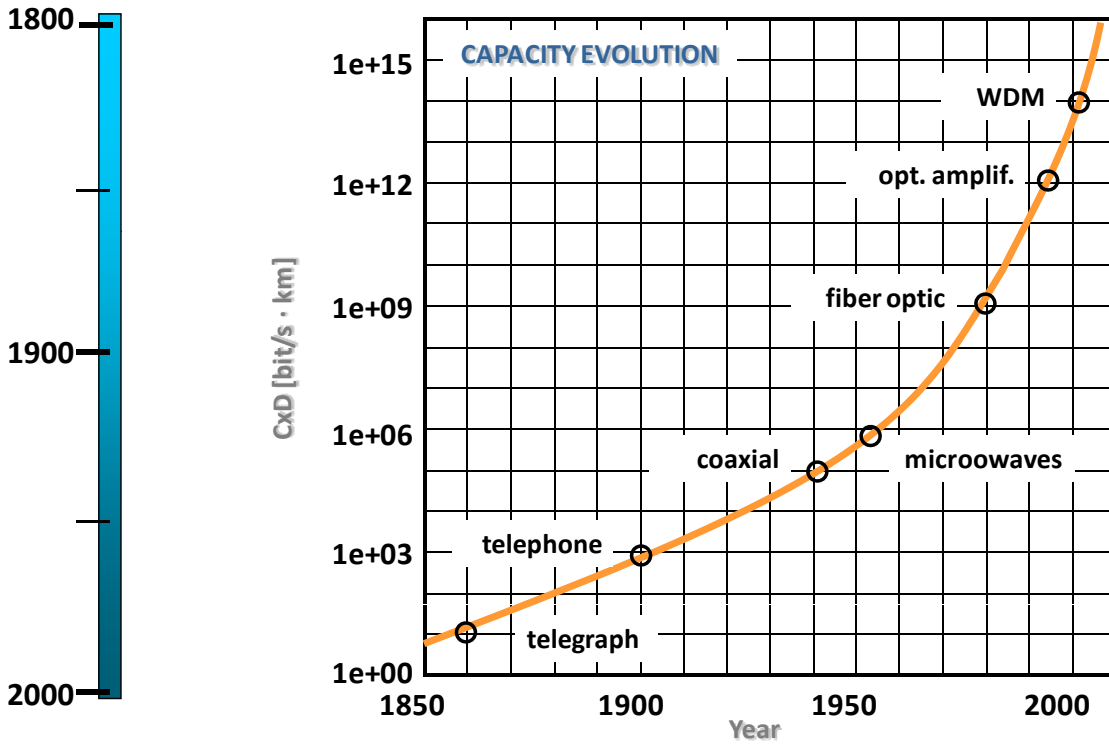
- 
- 1800 – 1952 – Physicist Narinder S. Kapany performed first light guiding experiments considered the invention of optical fiber. Kapany based his experiments on John Tyndall's theoretical work (Total Internal Reflection – 1850s) about light guiding in water fountains.
- 1953 – **Maser Theory** by Charles H. Townes (Columbia), and independently, Nikolai G. Basov and Aleksandr M. Prokhorov (Soviet Union). Nobel Prize 1964.
- 1900 – 1957 – **Laser Theory** by Charles H. Townes (Columbia) and Arthur Schawlow (Bell Labs). Patented on 1960 and conflict with Gordon Gould (graduate student at Columbia, recognized 1987).
- 1960 – First **Rubi Laser** (694 nm) by Theodore H. Maiman (Hugues Research Lab). This allows to think about an optical transmission system with a carrier on the order of 100 THz. D=1mm. We already have source. A little later Ali Javan (Iran) presents the first Gas Laser (He-Ne).
- 2000 – 1962 – First pulsed semiconductor GaAs (850 nm) laser by Robert N. Hall and red laser by Nick Holonyak, Jr. (General Electric).

- 
- 1800 – 1965 – Charles K. Kao (**Nobel Prize 2009**) and George A. Hockham (Standard Telephones and Cables) demonstrated that the main attenuation source of silica glass (1000 dB/km) was the presence of impurities. Their studies predicted an attenuation around 20 dB/km.
- 1900 – 1970 – Robert D. Maurer et al. (Corning) demonstrated an optical fiber (SiO_2) transmission with an attenuation of 17 dB/km in the region of $1\mu\text{m}$. We already have medium. Izo Hayashi and Morton Panish (Bell Labs), and independently, Zhores Alferov (Soviet Union) develop the first **semiconductor** (GaAs) laser diode working in continuous-wave at room temperature using the heterostructure. Dimensions similar to an optical fiber. Development of first LED diodes and photodetectors.
- 1973 – Development of optical fibers with lower attenuation than coaxial cables (4dB/km at 850 nm).
- 1977 – Development of third window by NTT (0.2dB/km at 1550 nm).
- 2000 – 1979 – First Single-Mode fiber (0.2dB/km at 1550 nm).

- 
- 1800 – 1980 – Development of first semiconductor **optical amplifiers**. First commercial fiber-optic transmission system. 45 Mb/s and a repeater distance of 10 km.
- 1986 – First **doped fiber** optical amplifiers David Payne (U. Southampton) and Emmanuel Desurvire (Bell Laboratories). Became commercial late 80's and increase the transmitter distance up to 100 km.
- 1900 – 1988 – First **transatlantic optical cable** (TAT-8)
- 1996 – First transpacific optical cable (TPC-5) including **WDM** technology 20x5 Gb/s.



back to digital optical
communications



What does 10 Gb/s mean ?

Encyclopedia Britannica



32 volumes
44 million words
24,000 photos



10 Gb

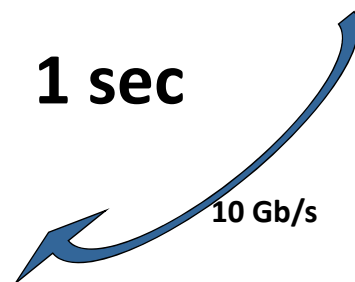
NYC



BCN

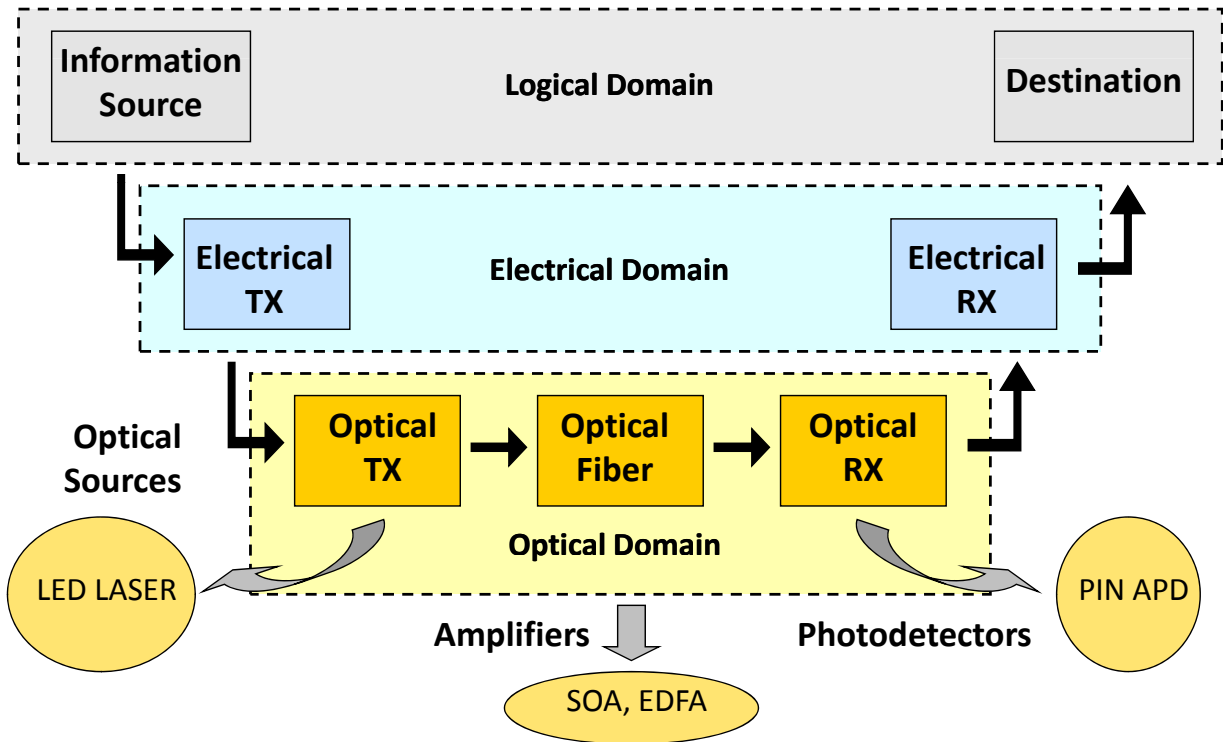


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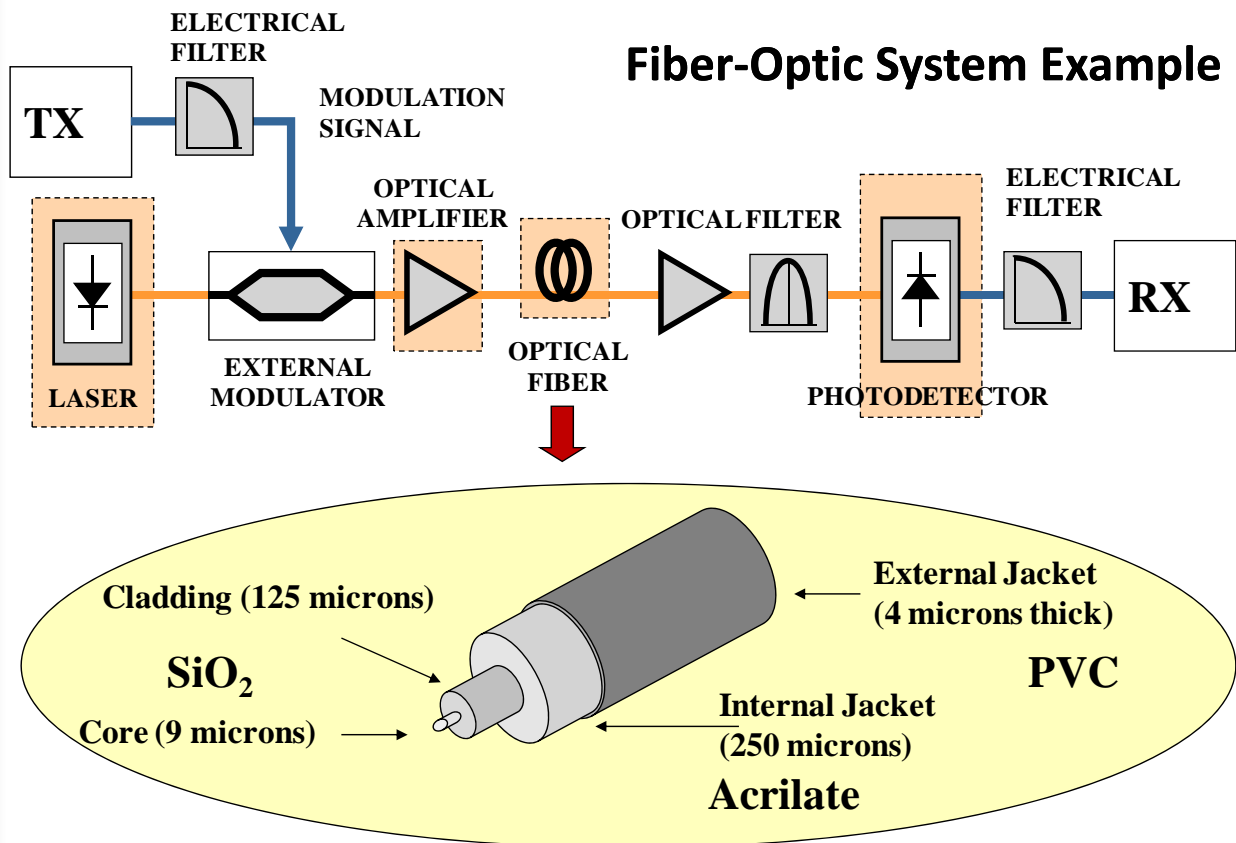


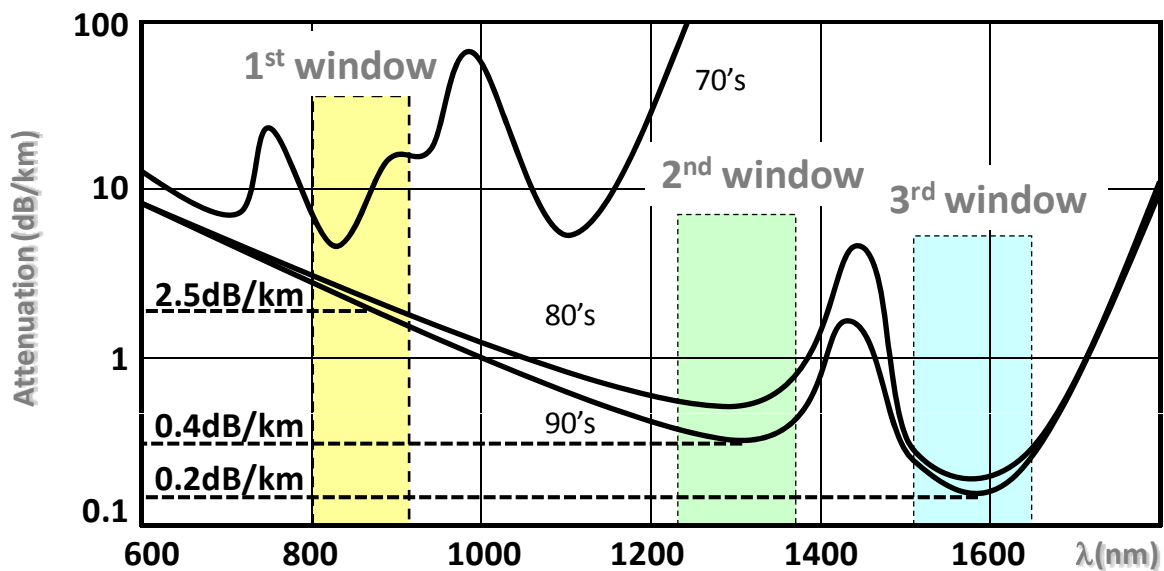
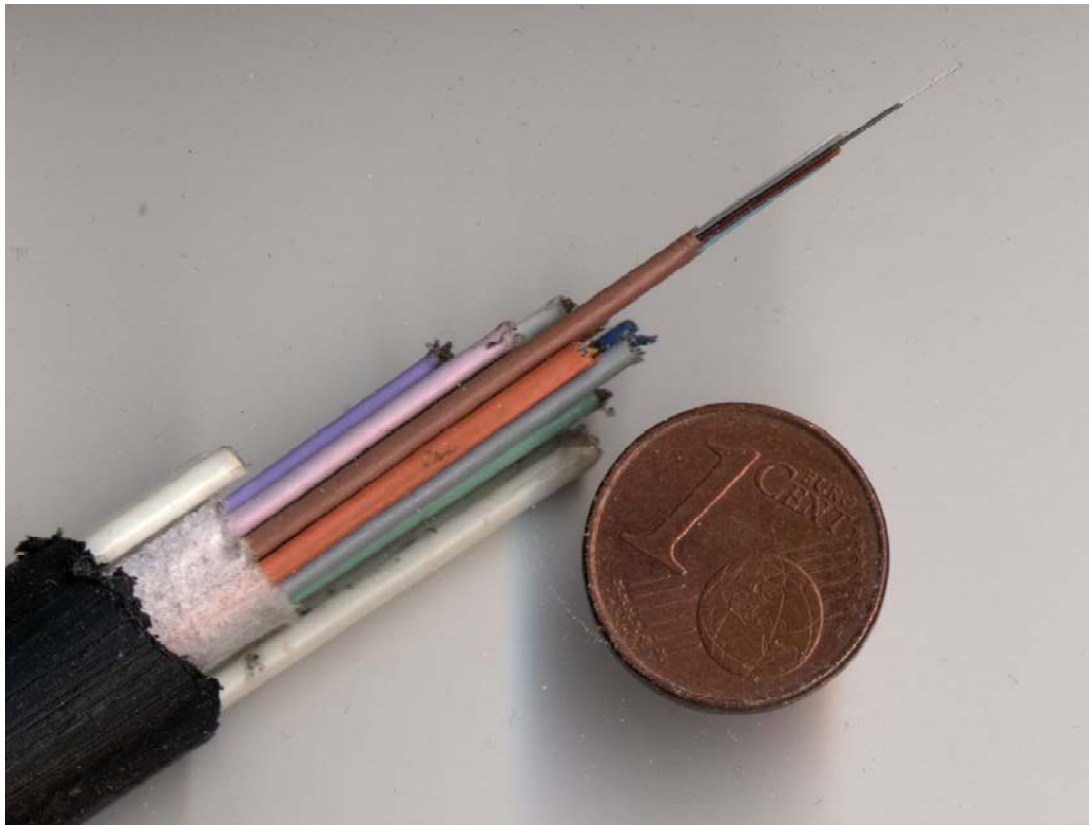
10 Gb/s

FIBER-OPTIC TRANSMISSION SYSTEM



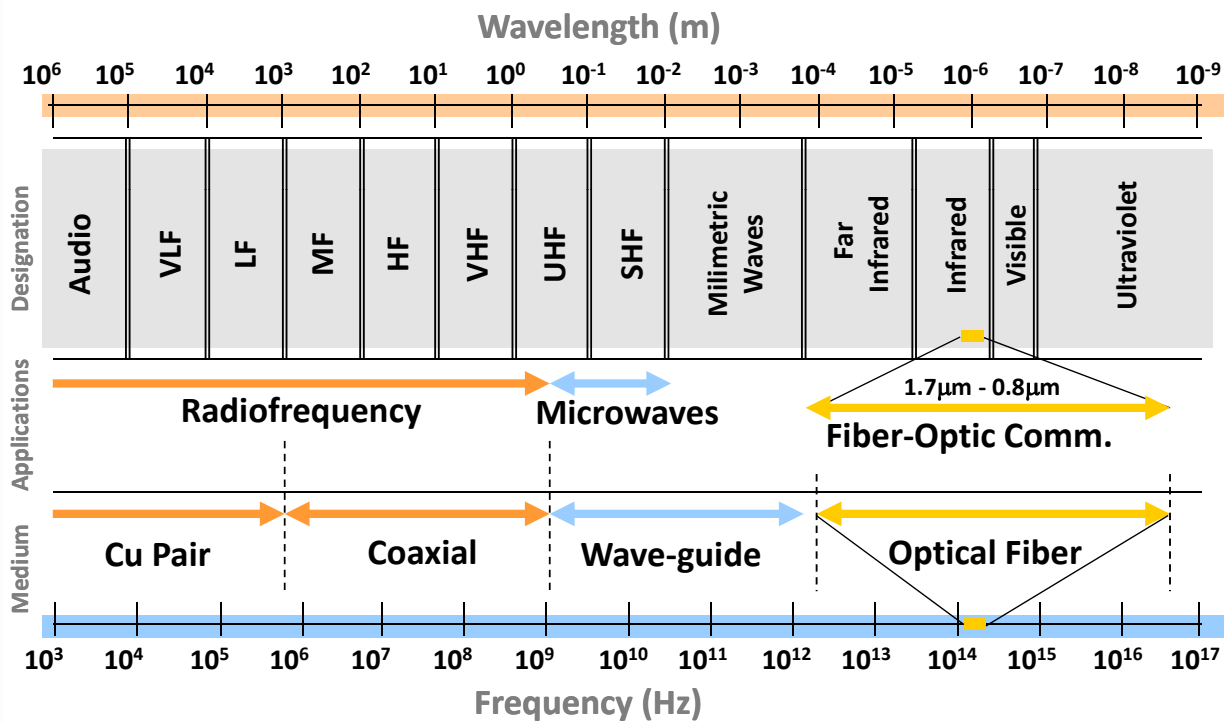
Fiber-Optic System Example





Lasers	AlGaAs	InGaAsP	InGaAsP
SC Amp.	AlGaAs	InGaAsP	
Fiber Amp		PDFA	EDFA
Photodet.	Si	InGaAsP	Ge

Electromagnetic Spectrum

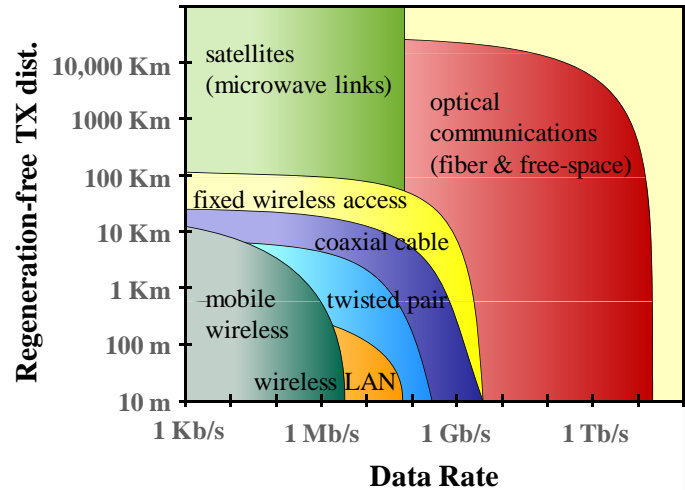


AVANTAGES OF F.O. COMMUNICATIONS

- ❑ 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 (SiO₂ abundance)

DRAWBACKS OF F.O. COMMUNICATIONS

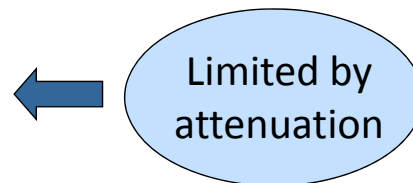
- ❑ Transducers necessity E/O-O/E
- ❑ Expensive devices (shared cost → Long-Haul)
- ❑ Fiber splices complexity
- ❑ Connectors complexity
- ❑ Tecnology unmaternity



5 FIBER-OPTIC GENERATIONS

First Generation 70s

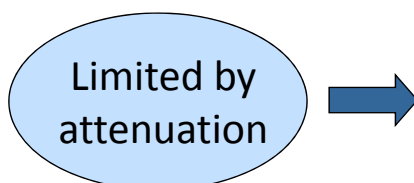
- Multi-Mode Fiber (5dB/km)
- Became commercial in 1980 (45 Mb/s)
- FP mm Laser AlGaAs at 850 nm, LED
- Bit rate 50-100 Mb/s
- Repeater distance 10 km



early 80s

Second Generation

- Single-Mode Fiber (0.5dB/km)
- Became commercial in 1987
- FP mm Laser InGaAsP at 1300 nm
- Bit rate 100 Mb/s - 1.7 Gb/s
- Repeater distance 50 km



Third Generation 80s

- Single-Mode Fiber (0.2dB/km) (DSF)
- Became commercial in 1990
- DFB sm Laser at 1310 nm & 1550 nm
- Bit rate 2.5 Gb/s
- Repeater distance 100 km
- Semiconductor optical amplif. (SOA)
- Coherent Systems

Limited by attenuation

Limited by dispersion

90s

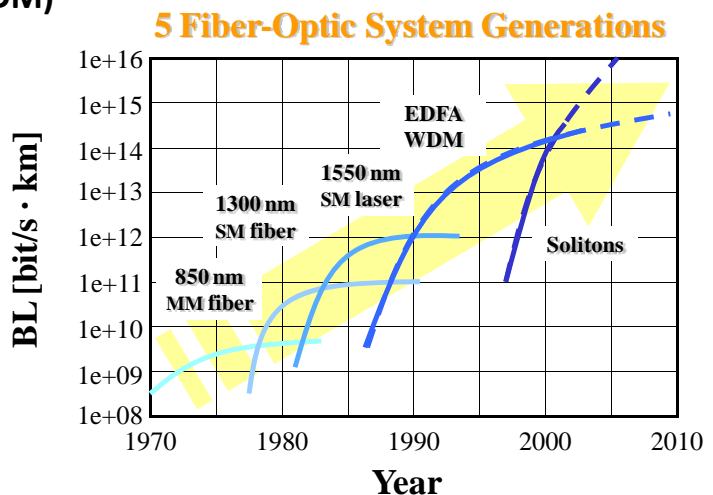
Fourth Generation

- Single-Mode Fiber (0.2dB/km) (DCF)
- Became commercial in 1996 (TPC-5)
- DBR sm Laser at 1550 nm
- Capacity 1-128 x 2.5-10 Gb/s (WDM)
- Repeater distance 100 km
- Erbium-doped fiber amplifier (EDFA)

Fifth Generation late 90s – early 2000

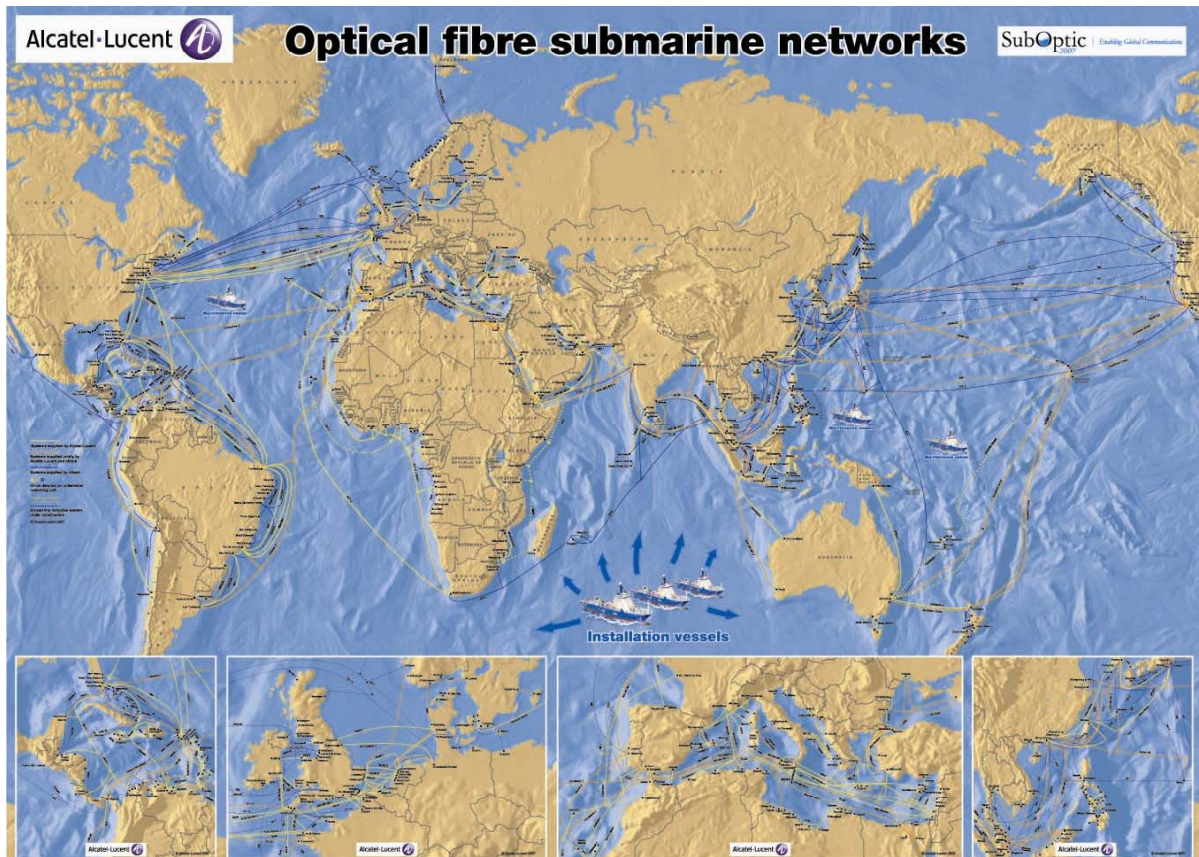
- Single-Mode Fiber (0.2dB/km) (LEAF)
- Became commercial in 2007
- EC sm Lasers at 1550 nm
- VCSELs cheap lasers
- Capacity 250 x 40 Gb/s (DWDM)
- Repeater distance 100 km
- Advanced Modulations
- Raman Amplifiers

Limited by NL & PMD



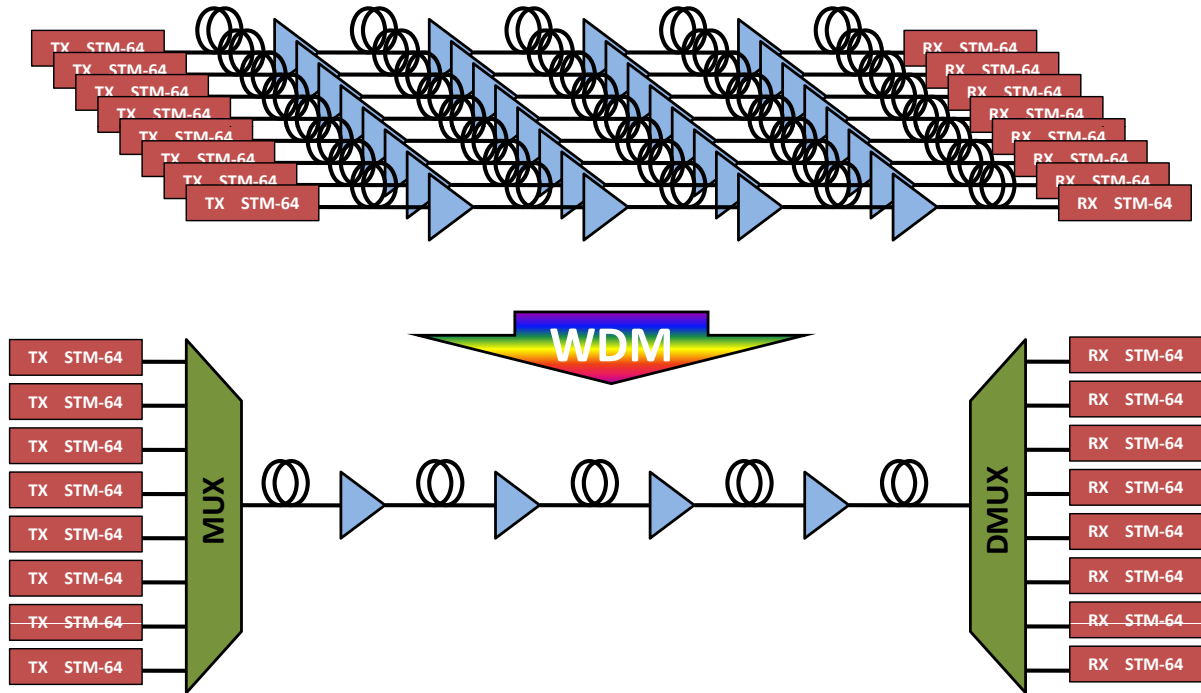
Next Generation 2010

- Single-Mode Fiber (0.2dB/km) (PCF)
- Will Become commercial in 2015 - 2020
- Broadband tunable Lasers
- Capacity N x 100 Gb/s (100G Ethernet)
- Fiber-to-the Home (FTTH)
- Repeater distance 100 km
- Advanced Modulations → Coherent Detection
- Broadband & distributed Amplification
- Digital Signal Processing (optical/electronic)

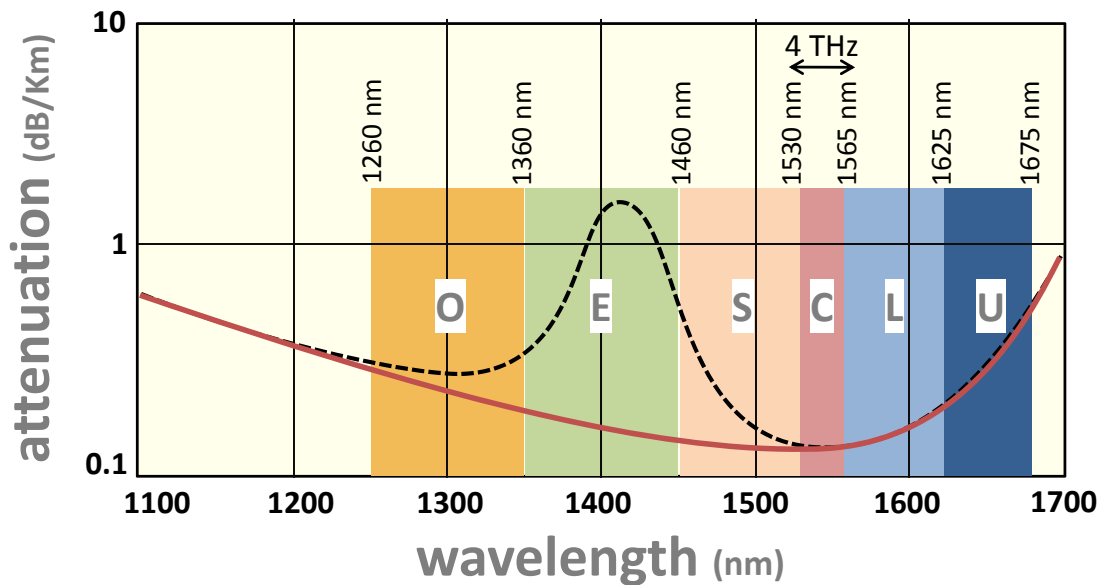


WDM WAVELENGTH DIVISION MULTIPLEXING

8 channels x 10 Gb/s = 80 Gb/s

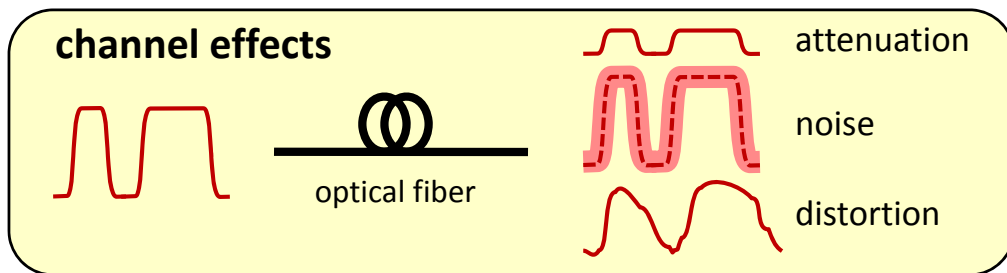
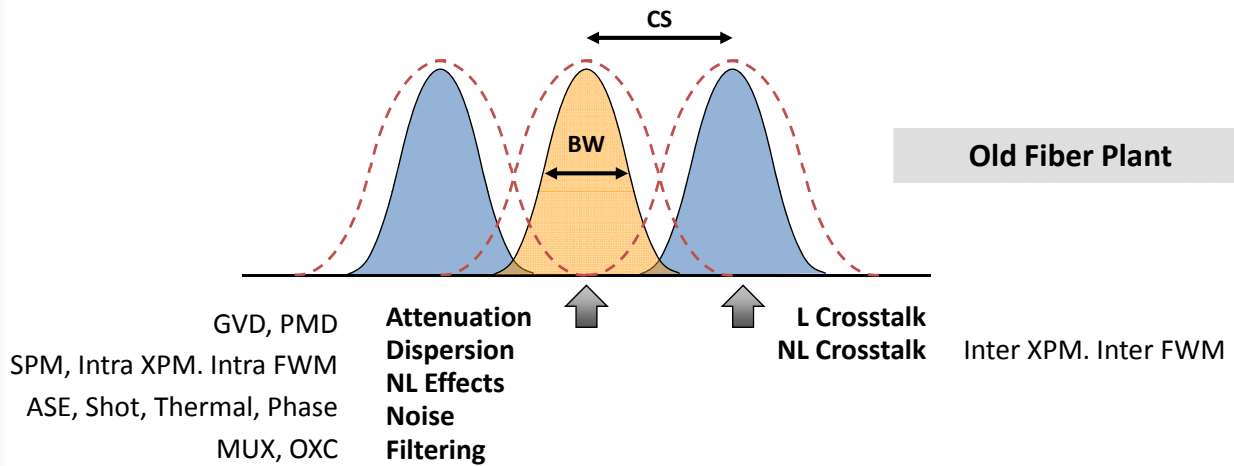


WDM transmission Bands

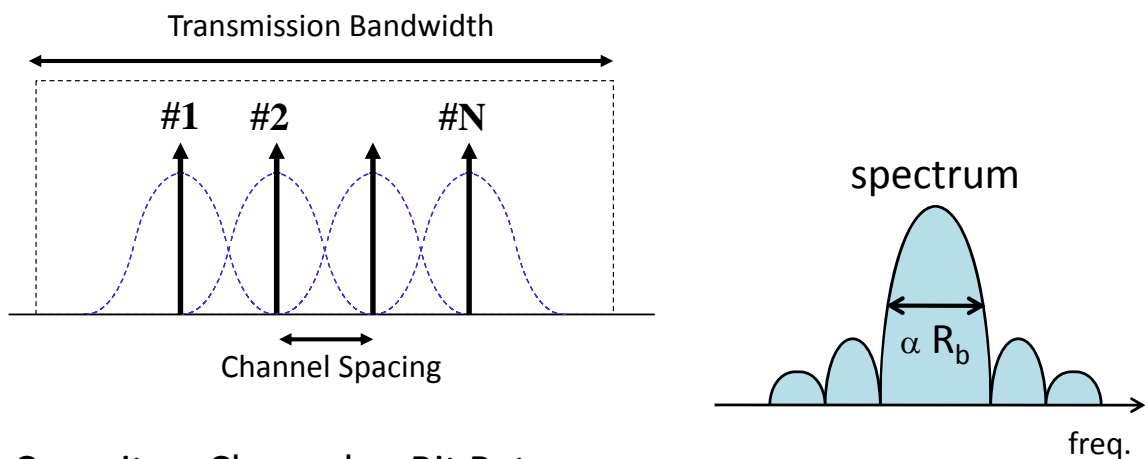


O – original C – conventional (erbium) L – long wavelength
 E – extended S – short wavelength U – ultralong wavelength

Main Impairments



System Capacity



Capacity = Channels x Bit Rate

Channels = Bandwidth / Spacing

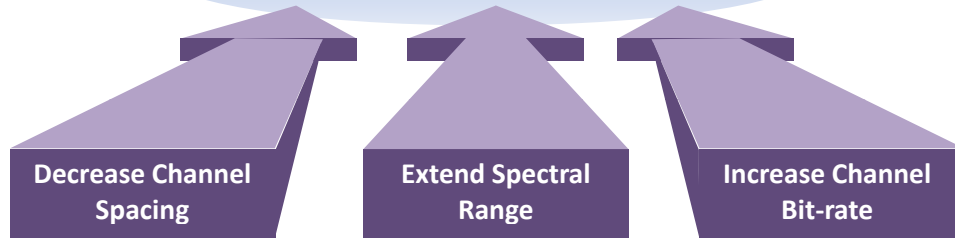
Capacity = Bandwidth x Bit Rate / Spacing

Spectral Efficiency

$$\eta \equiv \frac{R_B}{CS} \left[\frac{\text{b/s}}{\text{Hz}} \right]$$

System Capacity

Terabit Transmissions



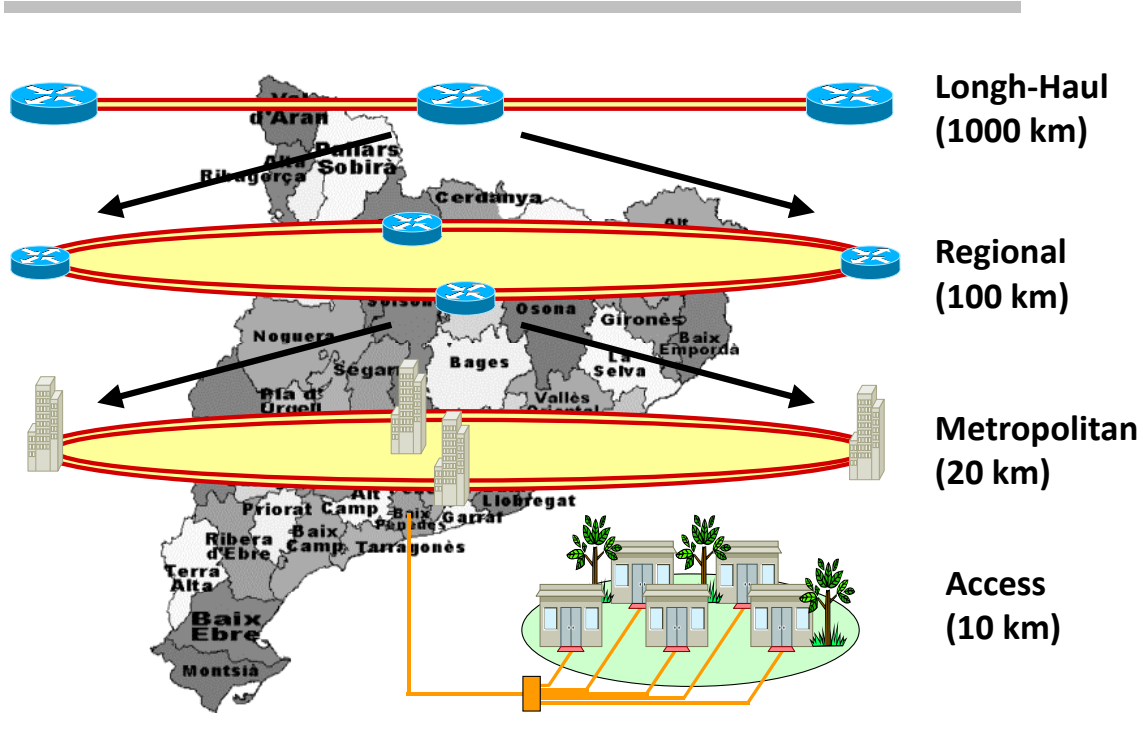
200 GHz
100 GHz
50 GHz
25 GHz

30 nm
80 nm
120 nm
150 nm

2.5 Gb/s
10 Gb/s
40 Gb/s
100 Gb/s

Status of commercial equipment (per fiber)	Year 1995	Year 2000	Year 2005	Year 2010
TDM line bit-rate	2.5 Gb/s	2.5-10 Gb/s	10-40 Gb/s	10-40-100 Gb/s
WDM channels	8	64-128	128-256	128-256
Channel Spacing	200 GHz	100-50 GHz	50-25 GHz	25 GHz
Overall Capacity	20 Gb/s	1 Tb/s	5 Tb/s	10 Tb/s

FIBER-OPTIC LOCALIZATION



SPANISH SITUATION (CMT2005)

32. KILÓMETROS DE RED DE TRANSPORTE POR TIPO DE TRANSMISIÓN

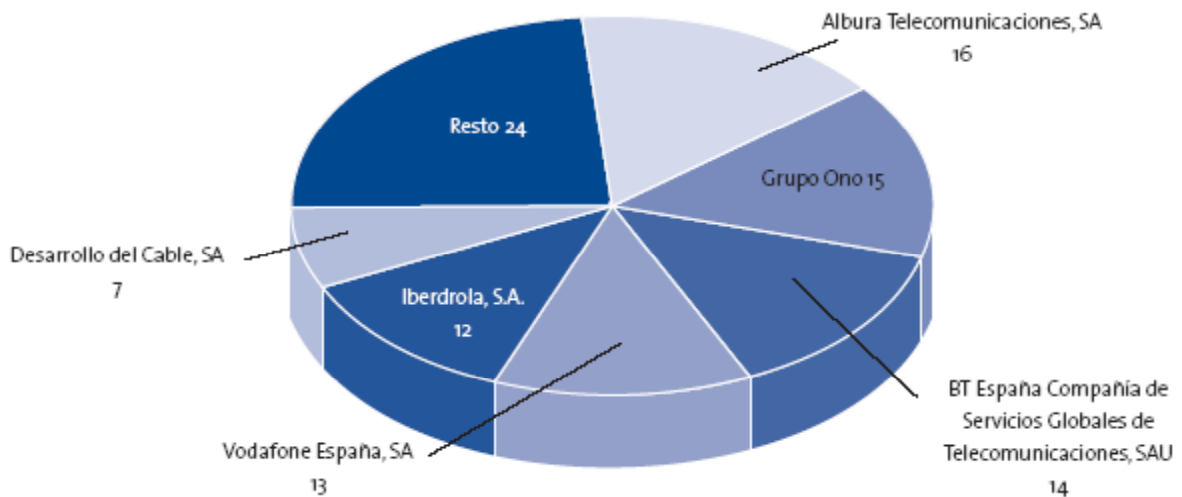
	2003	2004	2005
Cable óptico	908.401	1.155.868	1.330.249
Radioenlace	124.351	151.149	155.152
Cable coaxial	24.880	36.270	110.594
Otros	124.848	90.710	87.482
Total	1.182.480	1.433.997	1.683.477

Ownership ?

79 %
9.2 %
6.6 %
5.2 %

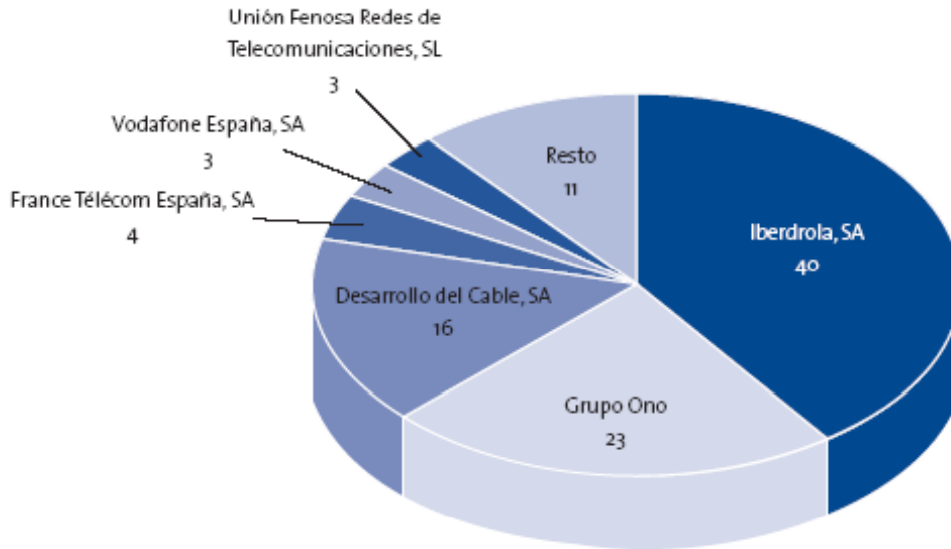
SPANISH SITUATION (CMT2005)

34. CAPACIDAD DE FIBRA OSCURA (TENDIDO) POR OPERADOR EN 2005 (PORCENTAJE)



SPANISH SITUATION (CMT2005)

35. CAPACIDAD DE FIBRA OSCURA (PARES DE FIBRA) POR OPERADOR EN 2005 (PORCENTAJE)



SPANISH SITUATION (CMT2005)

27. ACCESO POR TIPO DE SOPORTE EN 2005

Tipo de soporte	Instalados		En servicio
Cableados	24.122.061		20.067.195
Fibra óptica	252.110	1 %	171.734
Sólo par de cobre	16.838.793	68.6 %	15.427.262
Sólo HFC	884.890	3.6 %	703.402
HFC y par de cobre	6.143.939	25 %	3.762.468
Red eléctrica (PLC)	2.329		2.329
Vía radio	409.353		168.790
Radio	404.878	1.6 %	164.315
Satélite	4.475		4.475
Total	24.531.414		20.235.985

SPANISH SITUATION (CMT2005)

28. ACCESOS INSTALADOS POR TIPO DE SOPORTE Y GRUPOS DE OPERADORES EN 2005²²

Tipo de soporte	Telefónica de España	Operadores de cable	Resto	Total
Cableados	17.008.997	6.773.097	339.967	24.122.061
Fibra óptica	246.431	373	5.306	252.110
Sólo par de cobre	16.762.566	695	75.532	16.838.793
Sólo HFC	-	878.749	6.141	884.890
HFC y par de cobre	-	5.893.280	250.659	6.143.939
Red eléctrica (PLC)	-	0	2.329	2.329
Vía radio	398.292	3.083	7.978	409.353
Radio	394.269	3.083	7.526	404.878
Satélite	4.023	-	452	4.475
Total	17.407.289	6.776.180	347.945	24.531.414

SPANISH SITUATION (CMT2005)

30. ACCESOS POR TIPO DE SERVICIO Y GRUPO DE OPERADORES EN 2005²³

	Grupo Telefónica	Operadores de cable	Resto	Total
RDSI básico	1.023.257	19.047	17.859	1.060.163
RDSI primario	28.867	16.499	8.452	53.818
Telefonía básica	15.468.639	1.937.362	1.431.056	18.837.057
Televisión por cable	0	1.193.990	533.940	1.727.930
TV-IP	56.445	0	0	56.445
Banda ancha XDSL	2.708.636	78.460	434.760	3.221.856
Banda ancha cablemódem	-	969.212	155.893	1.125.105
Banda ancha PLC	-	0	2.329	2.329
Banda ancha LMDS	0	0	2.676	2.676
Banda ancha wifi	0	-	555	555
Otros servicios	0	1.501	2.720	4.221
Total	19.285.844	4.216.071	2.590.240	26.092.155

Residential Service Requirements

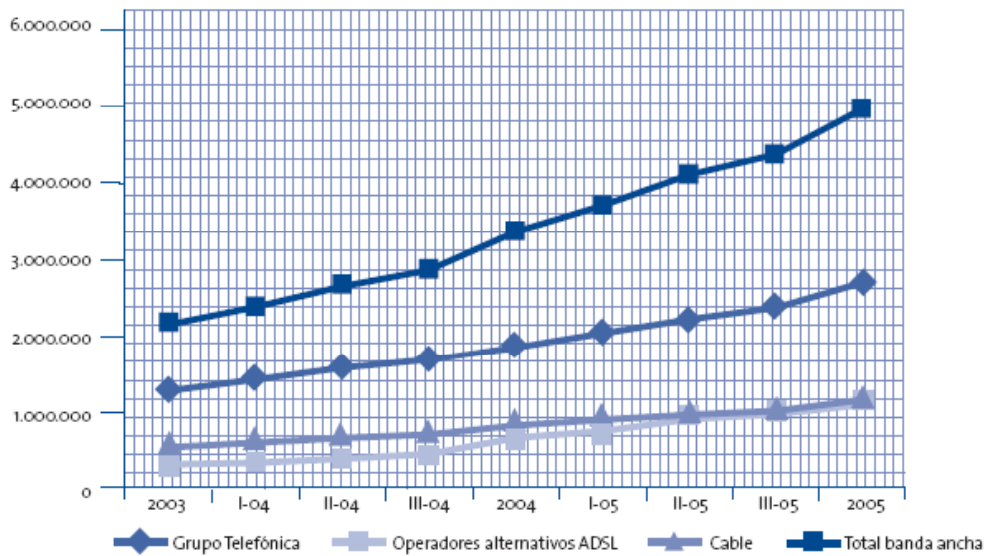
Application	Downstream	Upstream
HDTV (3 per home at 20 Mb/s) standard TV → 4.5 Mb/s	60 Mb/s	< 1 Mb/s
Online Gaming	2-20 Mb/s	2-20 Mb/s
VoIP Telephone (3 per home at 100 Kb/s)	0.3 Mb/s	0.3 Mb/s
Data / email ...	10 Mb/s	10 Mb/s
DVD rental (download time < 10 minutes)	14 Mb/s	< 1 Mb/s
TOTAL	~ 100 Mb/s	~ 30 Mb/s

APPENDIX

CMT 2005 data

SPANISH SITUATION (CMT2005)

85. EVOLUCIÓN DE LA BANDA ANCHA EN ESPAÑA (LINEAS)

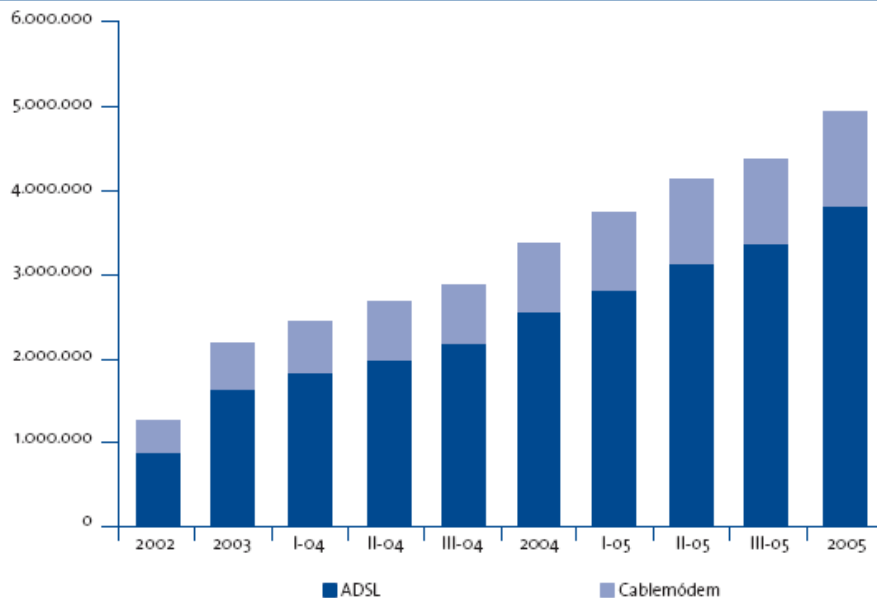


Fuente: CMT

Penetració 12%

SPANISH SITUATION (CMT2005)

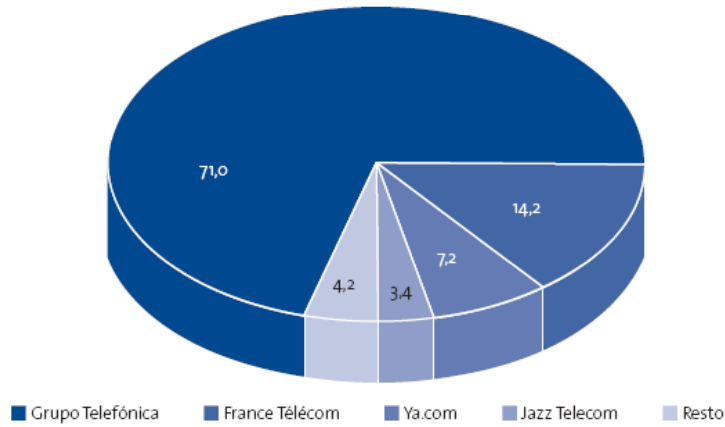
87. EVOLUCIÓN DE LAS LINEAS ADSL Y CABLEMÓDEM (LINEAS)



Fuente: CMT

SPANISH SITUATION (CMT2005)

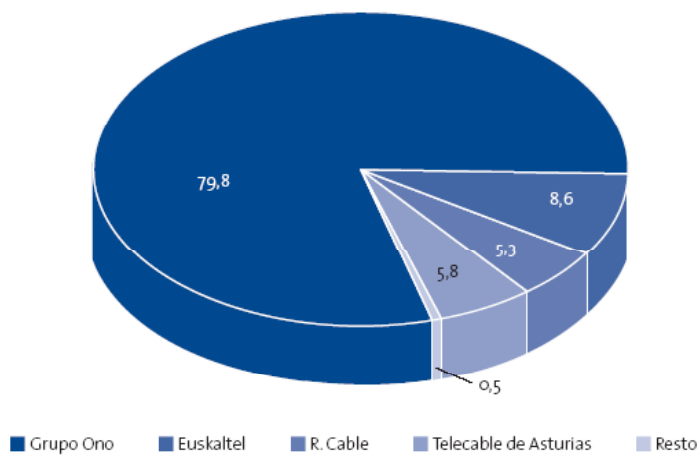
97. CUOTAS DE MERCADO LINEAS ADSL (PORCENTAJE)



Fuente: CMT

SPANISH SITUATION (CMT2005)

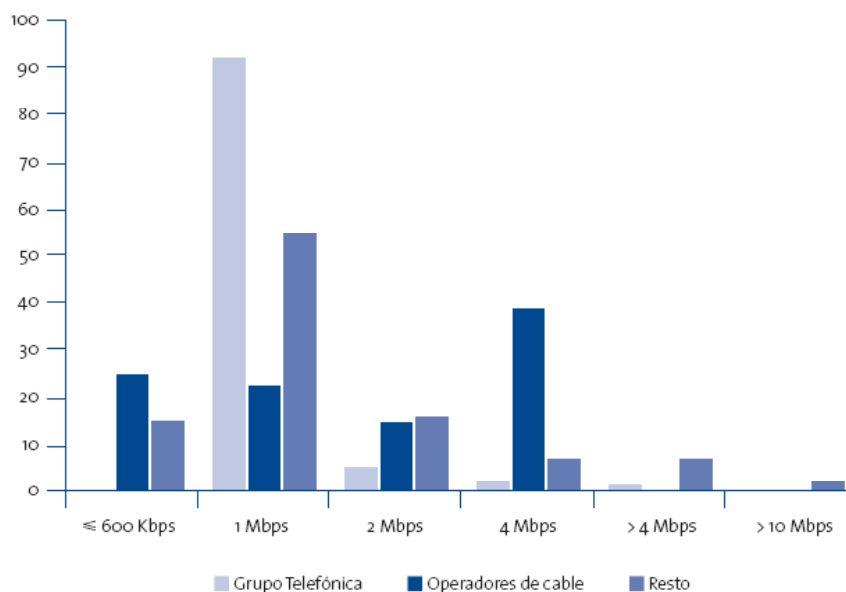
98. CUOTAS DE MERCADO POR LINEAS CABLEMÓDEM (PORCENTAJE)



Fuente: CMT

SPANISH SITUATION (CMT2005)

102. DISTRIBUCIÓN DE VELOCIDADES POR OPERADORES (PORCENTAJE DE LÍNEAS)



Fuente: CMT

SPANISH SITUATION (CMT2005)

228. NÚMERO DE ABONADOS A LA TELEVISIÓN DE PAGO POR TECNOLOGÍA

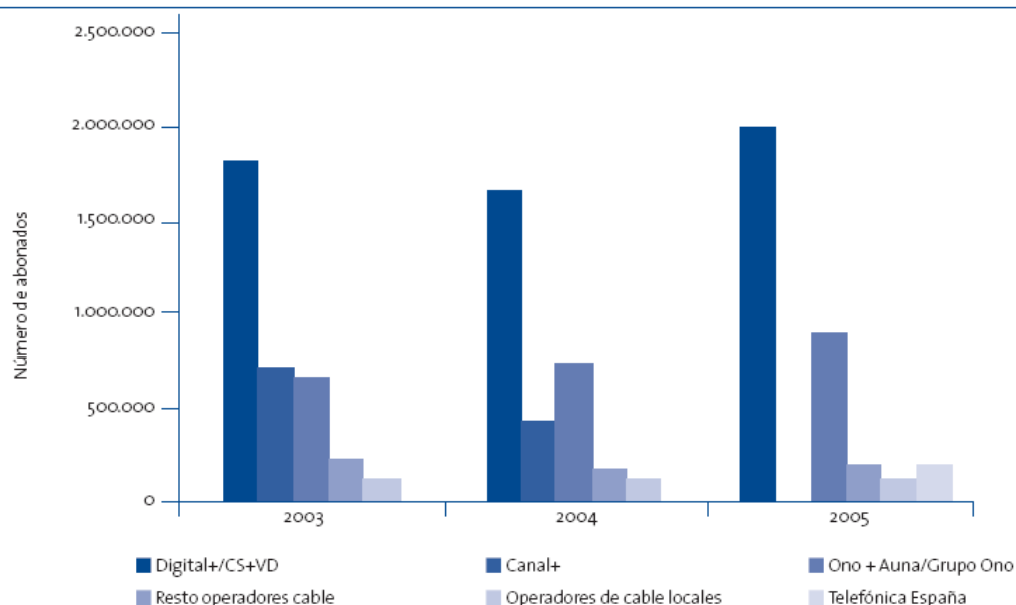
	2002	2003	2004	2005
Televisión satélite	1.995.669	1.795.686	1.652.573	1.960.030
Televisión terrestre	720.199	705.050	441.244	1.250
Televisión por cable	811.378	996.686	1.124.049	1.217.278
TV-IP	-	-	-	206.572
Total	3.527.246	3.497.422	3.217.866	3.385.130

233. NÚMERO DE ABONADOS Y CUOTA DE MERCADO DE LA TELEVISIÓN DE PAGO⁹¹

	2005 (abonados)	%
Sogecable	1.960.030	57,90
Grupo Ono	871.817	25,75
Resto de operadores de cable	201.885	5,96
Operadores de cable locales	144.826	4,28
Telefónica de España	206.572	6,10
Total	3.385.130	100,00

SPANISH SITUATION (CMT2005)

159. NÚMERO DE ABONADOS DE TELEVISIÓN DE PAGO



Fuente: CMT

SPANISH SITUATION (CMT2005)

104. CLIENTES RESIDENCIALES Y OFERTAS EMPAQUETADAS CON BANDA ANCHA (porcentaje)

	Internet	Internet +voz	Internet +TV	Triple
Grupo Telefónica	36	55	1	8
Operadores de cable	10	30	4	56
Resto	12	88	0	0

107. CLIENTES RESIDENCIALES CON DOBLES Y TRIPLES OFERTAS (miles)

	Triple	Doble	Banda ancha + voz	Banda ancha + TV	Voz + TV
Grupo Telefónica	130.111	992.062	934.526	18.512	39.024
Operadores de cable	598.829	889.239	320.172	44.257	524.810
Resto	-	873.007	873.007	-	-
Total	728.940	2.754.308	2.127.705	62.769	563.834