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1. INTRODUCTION

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- BASIC FIBER-OPTIC SYSTEM
- F.O. COM. ADVANTAGES
- 5 GENERATIONS OF OPTICAL COM.
- F.O. LOCALIZATION

HISTORICAL PERSPECTIVE

Primitive Signals – Old civilizations used fire or smoke signs as a communication mechanism. Digital Optical Communications.

XVIII Century – The optical signals used were produced using flags and flashlights among others.

1792 – Claude Chappe invents the aerial telegraph. A kind of mechanical antenna using a secret code (French Rev.). Transmissions of 100 km with repeaters each 10 km. Speed 1 b/s.

1837 – Samuel Morse presents the electrical telegraph. Starts the electrical communications. The Morse code spreads out rapidly and the transmission speed increases up to 10 b/s. The transmission distance reaches 1000s of Km.

1866 – First transatlantic telegraph cable.
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.

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.

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.


1960 – First Rubi Laser (694 nm) by Theodore H. Maiman (Hughes 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).

1962 – First pulsed semiconductor GaAs (850 nm) laser by Robert N. Hall and red laser by Nick Holonyak, Jr. (General Electric).
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.

1970 - Robert D. Maurer et al. (Corning) demonstrated an optical fiber (SiO₂) transmission with an attenuation of 17 dB/km in the region of 1900 nm. We already have medium.

Izuo Hayashy and Morton Panish (Bell Labs), and independently, Zhores Alferov (Soviet Union) developed 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 (4 dB/km at 850 nm).

1977 – Development of third window by NTT (0.2 dB/km at 1550 nm).

1979 – First Single-Mode fiber (0.2 dB/km at 1550 nm).

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.

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

1 sec

10 Gb/s
FIBER-OPTIC TRANSMISSION SYSTEM

Information Source  Logical Domain  Destination

Electrical TX  Electrical Domain  Electrical RX

Optical TX  Optical Fiber  Optical RX

Optical Sources  Amplifiers  Photodetectors

LED LASER  PIN APD

ELECTRICAL FILTER  MODULATION SIGNAL  OPTICAL AMPLIFIER  OPTICAL FILTER  ELECTRICAL FILTER

TX  RX

Fiber-Optic System Example

Cladding (125 microns)  External Jacket (4 microns thick)

SiO₂  PVC

Core (9 microns)  Internal Jacket (250 microns)

Acrilate

27 SEPTEMBER 2010  slide 11

1. INTRODUCTION - BASIC FIBER-OPTIC SYSTEM

27 SEPTEMBER 2010  slide 12
1. INTRODUCTION - BASIC FIBER-OPTIC SYSTEM

- **Basic Fiber-Optic System**

- **Optic Communications**

- **Lasers**: AlGaAs, InGaAsP

- **SC Amp.**: AlGaAs

- **Fiber Amp.**: InGaAsP, InGaAsP

- **Photodet.**: Si, InGaAsP, Ge

- **Attenuation** (dB/km):
  - 1st window: 0.4 dB/km, 2.5 dB/km
  - 2nd window: 0.2 dB/km, 80's, 70's
  - 3rd window: 0.1 dB/km, 90's

- **Wavelength (nm)**: 600, 800, 1000, 1200, 1400, 1600

- **1st Window**
  - 70's, 2.5 dB/km

- **2nd Window**
  - 80's, 0.2 dB/km

- **3rd Window**
  - 90's, 0.1 dB/km
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
- Technology unmaturity

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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

Limited by attenuation

Second Generation  80s
- 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

Limited by attenuation
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

Fourth Generation  90s

- 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

5 Fiber-Optic System Generations

- Limited by attenuation
- Limited by dispersion
- 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)

Limited by NL & PMD
**WDM WAVELENGTH DIVISION MULTIPLEXING**

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

![WDM Diagram](image)

**WDM transmission Bands**

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

![WDM Transmission Bands](image)
Main Impairments

- GVD, PMD
- SPM, Intra XPM, Intra FWM
- ASE, Shot, Thermal, Phase Modulation Dispersion
- NL Effects, Noise, Interference

Channel effects

- Optical fiber effects: attenuation, noise, distortion

System Capacity

Transmission Bandwidth

Capacity = Channels x Bit Rate

Channels = Bandwidth / Spacing

Capacity = Bandwidth x Bit Rate / Spacing

Spectral Efficiency

$$\eta = \frac{R_b}{CS} \quad \frac{b/s}{Hz}$$
**System Capacity**

Terabit Transmissions

- Decrease Channel Spacing: 200 GHz, 100 GHz, 50 GHz, 25 GHz
- Extend Spectral Range: 30 nm, 80 nm, 120 nm, 150 nm
- Increase Channel Bit-rate: 2.5 Gb/s, 10 Gb/s, 40 Gb/s, 100 Gb/s

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

**FIBER-OPTIC LOCALIZATION**

- Longh-Haul (1000 km)
- Regional (100 km)
- Metropolitan (20 km)
- Access (10 km)
### SPANISH SITUATION (CMT2005)

#### 32. KILÓMETROS DE RED DE TRANSPORTE POR TIPO DE TRANSMISIÓN

<table>
<thead>
<tr>
<th></th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cable óptico</td>
<td>908,401</td>
<td>1,155,868</td>
<td>1,330,249</td>
</tr>
<tr>
<td>Radioface</td>
<td>124,351</td>
<td>151,149</td>
<td>155,152</td>
</tr>
<tr>
<td>Cable coaxial</td>
<td>24,880</td>
<td>35,270</td>
<td>40,594</td>
</tr>
<tr>
<td>Otros</td>
<td>124,848</td>
<td>50,710</td>
<td>87,482</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>1,182,360</td>
<td>1,433,597</td>
<td>1,684,487</td>
</tr>
</tbody>
</table>

Ownership?

- 79%
- 9.2%
- 6.6%
- 5.2%

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

- Albarra Telecomunicaciones, SA: 16
- Grupo Ono: 15
- Vodafone España, SA: 13
- Iberdrola, SA: 12
- BT España Compañía de Servicios Globales de Telecomunicaciones, SAU: 14
- Desarrollo del Cable, SA: 7
- Resto: 24
SPANISH SITUATION (CMT2005)

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

<table>
<thead>
<tr>
<th>Operador</th>
<th>Instalados</th>
<th>En servicio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iberdrola, SA</td>
<td>352,110</td>
<td>173,359</td>
</tr>
<tr>
<td>Grupo Ono</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>Desarrollo del Cable, SA</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>Resto</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>France Telecom España, SA</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Vodafone España, SA</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Unión Frontera Redes de Telecomunicaciones, SL</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

1. INTRODUCTION - F.O. LOCALIZATION

27. ACCESO POR TIPO DE SOPORTE EN 2005

<table>
<thead>
<tr>
<th>Tipo de soporte</th>
<th>Instalados</th>
<th>En servicio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cableado</td>
<td>44,122,061</td>
<td>20,061,735</td>
</tr>
<tr>
<td>Fibra óptica</td>
<td>252,110</td>
<td>173,359</td>
</tr>
<tr>
<td>Solo par de cobre</td>
<td>16,898,791</td>
<td>15,427,262</td>
</tr>
<tr>
<td>Solo HFC</td>
<td>884,890</td>
<td>703,402</td>
</tr>
<tr>
<td>HFC y par de cobre</td>
<td>6,113,939</td>
<td>3,760,468</td>
</tr>
<tr>
<td>Red eléctrica (PLC)</td>
<td>2,329</td>
<td>2,329</td>
</tr>
<tr>
<td>Vía radio</td>
<td>4,779,533</td>
<td>1,687,930</td>
</tr>
<tr>
<td>Radio</td>
<td>404,878</td>
<td>164,376</td>
</tr>
<tr>
<td>Satellite</td>
<td>1,477</td>
<td>1,477</td>
</tr>
<tr>
<td>Total</td>
<td>24,537,414</td>
<td>20,235,985</td>
</tr>
</tbody>
</table>
### 28. ACCESOS INSTALADOS POR TIPO DE SOPORTE Y GRUPOS DE OPERADORES EN 2005^22

<table>
<thead>
<tr>
<th>Tipo de soporte</th>
<th>Telefónica de España</th>
<th>Operadores de cable</th>
<th>Resto</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cableados</td>
<td>17,068,997</td>
<td>6,775,097</td>
<td>339,967</td>
<td>24,123,061</td>
</tr>
<tr>
<td>FIBRA ÓPTICA</td>
<td>246,431</td>
<td>371</td>
<td>5,306</td>
<td>252,110</td>
</tr>
<tr>
<td>Solo par de cobre</td>
<td>16,765,566</td>
<td>6,95</td>
<td>75,532</td>
<td>16,843,293</td>
</tr>
<tr>
<td>Solo HFC</td>
<td>-</td>
<td>8,749</td>
<td>6,141</td>
<td>884,850</td>
</tr>
<tr>
<td>HFC y par de cobre</td>
<td>-</td>
<td>5,893,280</td>
<td>250,659</td>
<td>6,143,939</td>
</tr>
<tr>
<td>Red Digital (RDC)</td>
<td>-</td>
<td>0</td>
<td>729</td>
<td>729</td>
</tr>
<tr>
<td>Via radio</td>
<td>398,292</td>
<td>3,085</td>
<td>7,778</td>
<td>409,353</td>
</tr>
<tr>
<td>Radio</td>
<td>394,269</td>
<td>3,081</td>
<td>7,526</td>
<td>404,878</td>
</tr>
<tr>
<td>Satélite</td>
<td>4,463</td>
<td>404</td>
<td>404</td>
<td>4,463</td>
</tr>
<tr>
<td>Total</td>
<td>17,072,989</td>
<td>6,776,160</td>
<td>347,945</td>
<td>24,534,518</td>
</tr>
</tbody>
</table>

### 30. ACCESOS POR TIPO DE SERVICIO Y GRUPO DE OPERADORES EN 2005^23

<table>
<thead>
<tr>
<th>Grupo Telefónica</th>
<th>Operadores de cable</th>
<th>Resto</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADSL básico</td>
<td>10,234,577</td>
<td>19,042</td>
<td>17,859</td>
</tr>
<tr>
<td>ADSL primario</td>
<td>28,817</td>
<td>16,499</td>
<td>8,452</td>
</tr>
<tr>
<td>Telefonía básica</td>
<td>15,468,893</td>
<td>1,037,762</td>
<td>1,431,056</td>
</tr>
<tr>
<td>Televisión por cable</td>
<td>0</td>
<td>1,933,960</td>
<td>533,940</td>
</tr>
<tr>
<td>TV-IP</td>
<td>59,445</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Banda ancha XDSL</td>
<td>2,708,638</td>
<td>78,460</td>
<td>434,760</td>
</tr>
<tr>
<td>Banda ancha cablemodem</td>
<td>-</td>
<td>562,242</td>
<td>85,893</td>
</tr>
<tr>
<td>Banda ancha PLC</td>
<td>-</td>
<td>0</td>
<td>2,282</td>
</tr>
<tr>
<td>Banda ancha LMDS</td>
<td>0</td>
<td>0</td>
<td>2,696</td>
</tr>
<tr>
<td>Banda ancha wifi</td>
<td>0</td>
<td>-</td>
<td>555</td>
</tr>
<tr>
<td>Otros servicios</td>
<td>0</td>
<td>1,521</td>
<td>2,720</td>
</tr>
<tr>
<td>Total</td>
<td>19,284,844</td>
<td>4,216,571</td>
<td>2,890,240</td>
</tr>
</tbody>
</table>
## Residential Service Requirements

<table>
<thead>
<tr>
<th>Application</th>
<th>Downstream</th>
<th>Upstream</th>
</tr>
</thead>
<tbody>
<tr>
<td>HDTV (3 per home at 20 Mb/s)</td>
<td>60 Mb/s</td>
<td>&lt; 1 Mb/s</td>
</tr>
<tr>
<td>standard TV → 4.5 Mb/s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Online Gaming</td>
<td>2-20 Mb/s</td>
<td>2-20 Mb/s</td>
</tr>
<tr>
<td>VoIP Telephone</td>
<td>0.3 Mb/s</td>
<td>0.3 Mb/s</td>
</tr>
<tr>
<td>(3 per home at 100 Kb/s)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Data / email ...</td>
<td>10 Mb/s</td>
<td>10 Mb/s</td>
</tr>
<tr>
<td>DVD rental (download time &lt; 10 minutes)</td>
<td>14 Mb/s</td>
<td>&lt; 1 Mb/s</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>~ 100 Mb/s</td>
<td>~ 30 Mb/s</td>
</tr>
</tbody>
</table>

**APPENDIX**

CMT 2005 data
SPANISH SITUATION (CMT2005)

Evolución de la banda ancha en España (líneas)

Fuente: CMT

Penetración 12%

SPANISH SITUATION (CMT2005)

Evolución de las líneas ADSL y Cablemodem (líneas)

Fuente: CMT
SPANISH SITUATION (CMT2005)

97. CUSTAS DE MERCADO LÍNEAS ADSL (PORCENTAJE)

Fuente: CMT

98. CUSTAS DE MERCADO POR LÍNEAS CABLEMODEM (PORCENTAJE)

Fuente: CMT
SPANISH SITUATION (CMT2005)

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

Fuente: CMT

27 SEPTEMBER 2010
1. INTRODUCTION - APPENDIX
SPANISH SITUATION (CMT2005)

159. NÚMERO DE ABONADOS DE TELEVISIÓN DE PAGO

<table>
<thead>
<tr>
<th>Año</th>
<th>Digital+CS+VD</th>
<th>Canal+</th>
<th>Ono + Auna/Grupo Ono</th>
<th>Resto operadores cable</th>
<th>Operadores de cable locales</th>
<th>Telefónica España</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003</td>
<td>1500000</td>
<td>700000</td>
<td>800000</td>
<td>1000000</td>
<td>2000000</td>
<td>3000000</td>
</tr>
<tr>
<td>2004</td>
<td>1600000</td>
<td>800000</td>
<td>900000</td>
<td>200000</td>
<td>3000000</td>
<td>4000000</td>
</tr>
<tr>
<td>2005</td>
<td>1700000</td>
<td>900000</td>
<td>1000000</td>
<td>300000</td>
<td>4000000</td>
<td>5000000</td>
</tr>
</tbody>
</table>

Fuente: CMT

1. INTRODUCTION - APPENDIX

SPANISH SITUATION (CMT2005)

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

<table>
<thead>
<tr>
<th>Servicio</th>
<th>Internet</th>
<th>Internet +voz</th>
<th>Internet +TV</th>
<th>Triple</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grupo Telefónica</td>
<td>36</td>
<td>55</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>Operadores de cable</td>
<td>10</td>
<td>30</td>
<td>4</td>
<td>56</td>
</tr>
<tr>
<td>Resto</td>
<td>12</td>
<td>88</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Servicio</th>
<th>Triple</th>
<th>Doble</th>
<th>Banda ancha + voz</th>
<th>Banda ancha + TV</th>
<th>Voz + TV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grupo Telefónica</td>
<td>150000</td>
<td>990000</td>
<td>988986</td>
<td>148532</td>
<td>390324</td>
</tr>
<tr>
<td>Operadores de cable</td>
<td>598829</td>
<td>889239</td>
<td>812012</td>
<td>44257</td>
<td>514810</td>
</tr>
<tr>
<td>Resto</td>
<td>0</td>
<td>873007</td>
<td>873007</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Total</td>
<td>2183490</td>
<td>4275465</td>
<td>4228575</td>
<td>586509</td>
<td>595396</td>
</tr>
</tbody>
</table>