Dr. Charles K. Kao premio Nobel de Fisica 2009: El nacimiento de las comunicaciones por fibra óptica.

José Luis Cruz.

Facultad de Física.

11 de Febrero de 2010

VNIVERSITAT DE VALÈNCIA

Nobelprize.org

The Nobel Prize in Physics 2009

"for groundbreaking achievements concerning the transmission of light in fibers for optical communication"

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

Photo: Richard Epworth

Charles K. Kao

1/2 of the prize

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

b. 1933
(in Shanghai, China)

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Willard S. Boyle

1/4 of the prize

Bell Laboratories
Murray Hill, NJ, USA

b. 1924
(in Amherst, NS, Canada)

Photo: National Inventors Hall of Fame Foundation/SCANPIX

George E. Smith

1/4 of the prize

Bell Laboratories
Murray Hill, NJ, USA

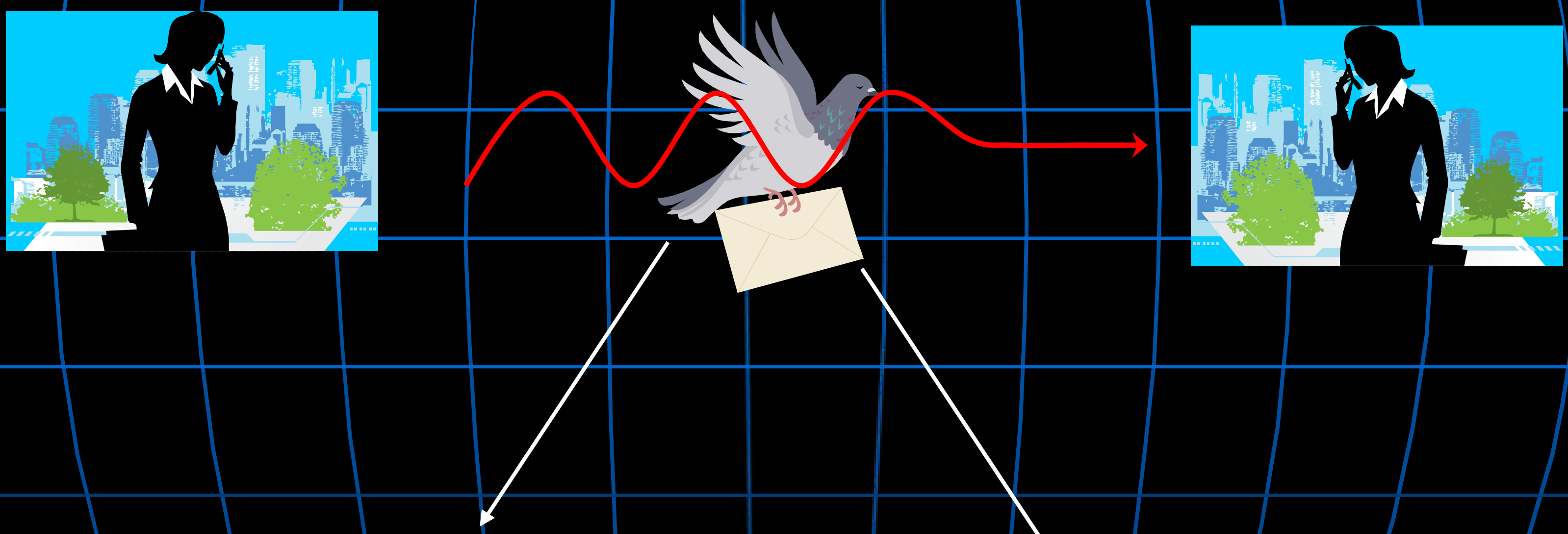
b. 1930

Titles, data and places given above refer to the time of the award.

Nobel

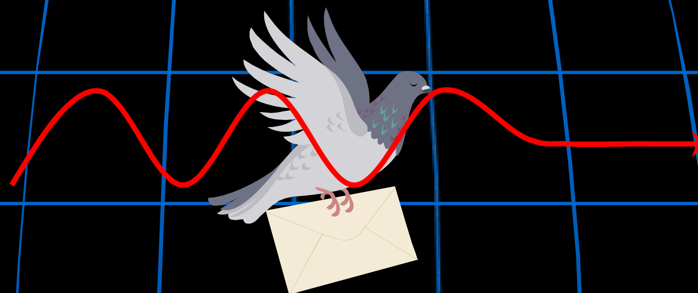
- Nacido en Shanghai en 1933.
- Doctorado en Ingeniería Eléctrica por el University College (Londres 1965) como estudiante externo de los laboratorios de la Standard Telephones and Cables Company (actual NORTEL).
- Profesor del Departamento de Electrónica de la Chinese University of Hong Kong en 1970.
- ITT Corporation en 1974.
- Vicechancellor of Chinese University of Hong Kong 1987 a 1996

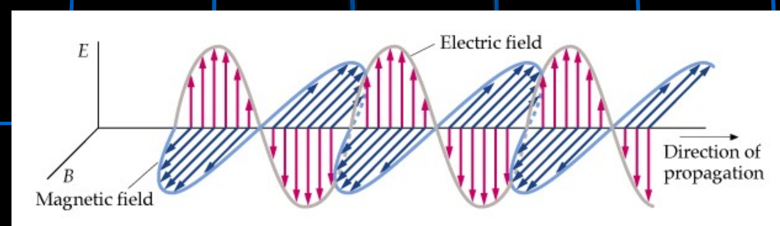
Las comunicaciones.



Medio de Transporte + Información

Medio de transporte: Ondas Electromagnéticas.



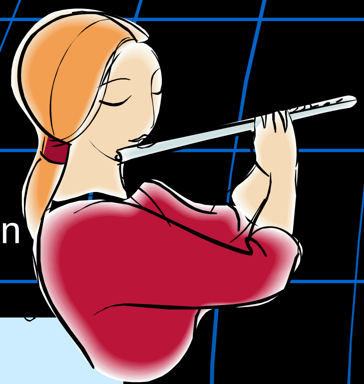


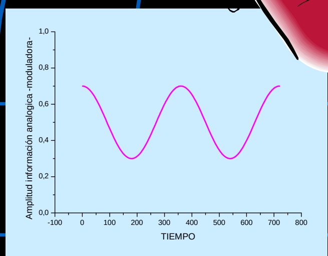
V= 300.000 Km/s

Una vuelta a la tierra por el ecuador en 0.13 segundos

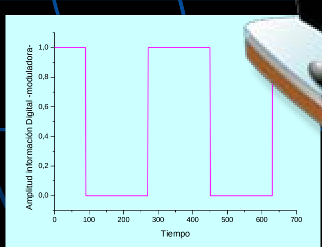
La Información

Información analógica

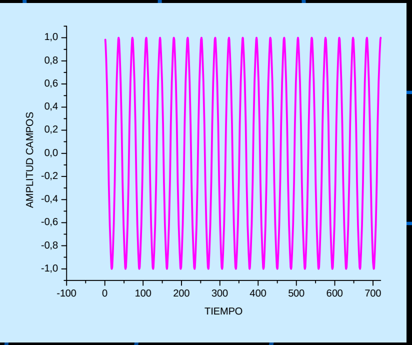




Información digital



Onda electromagnética

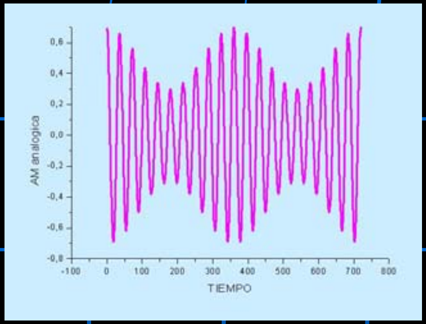


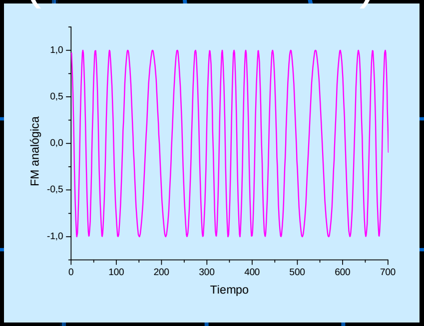
Modulación:

Amplitud modulada

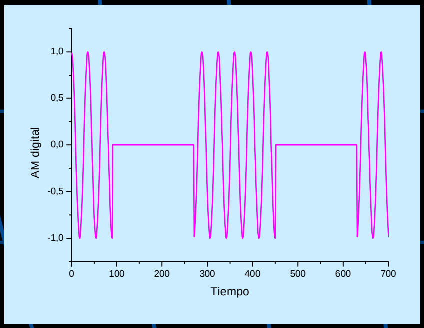
Frecuencia Modulada (también fase)

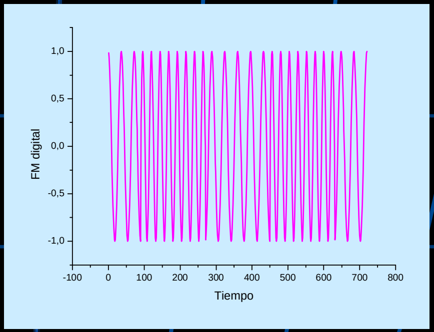
Analógica





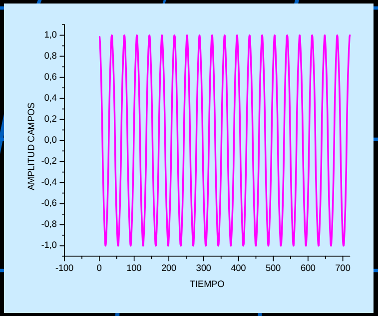
Digital



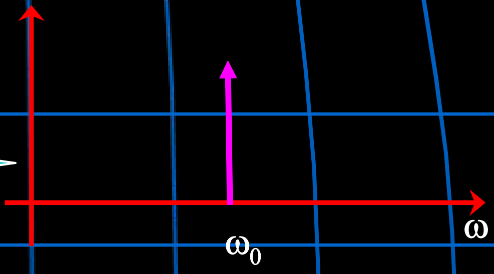


Espectro de frecuencias:

Onda sin modular:

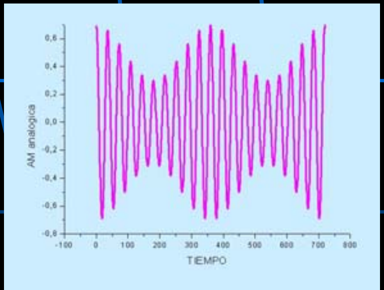


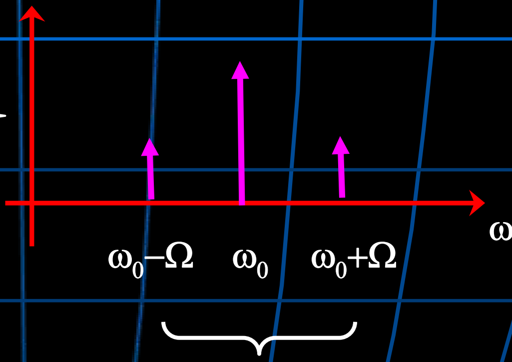
Transformada Fourrier



ω_0 **Frecuencia de la onda.**

Onda modulada:



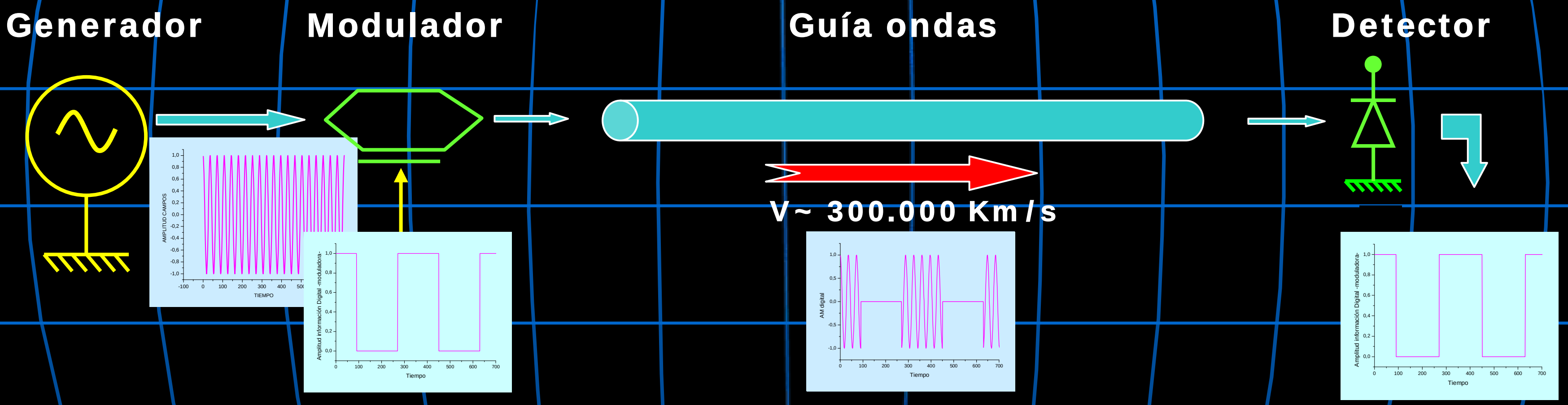


ω_0 **Frecuencia de la portadora.**

Ω **Frecuencia de la moduladora**

Ancho de banda

Bloques de un sistema de comunicación:



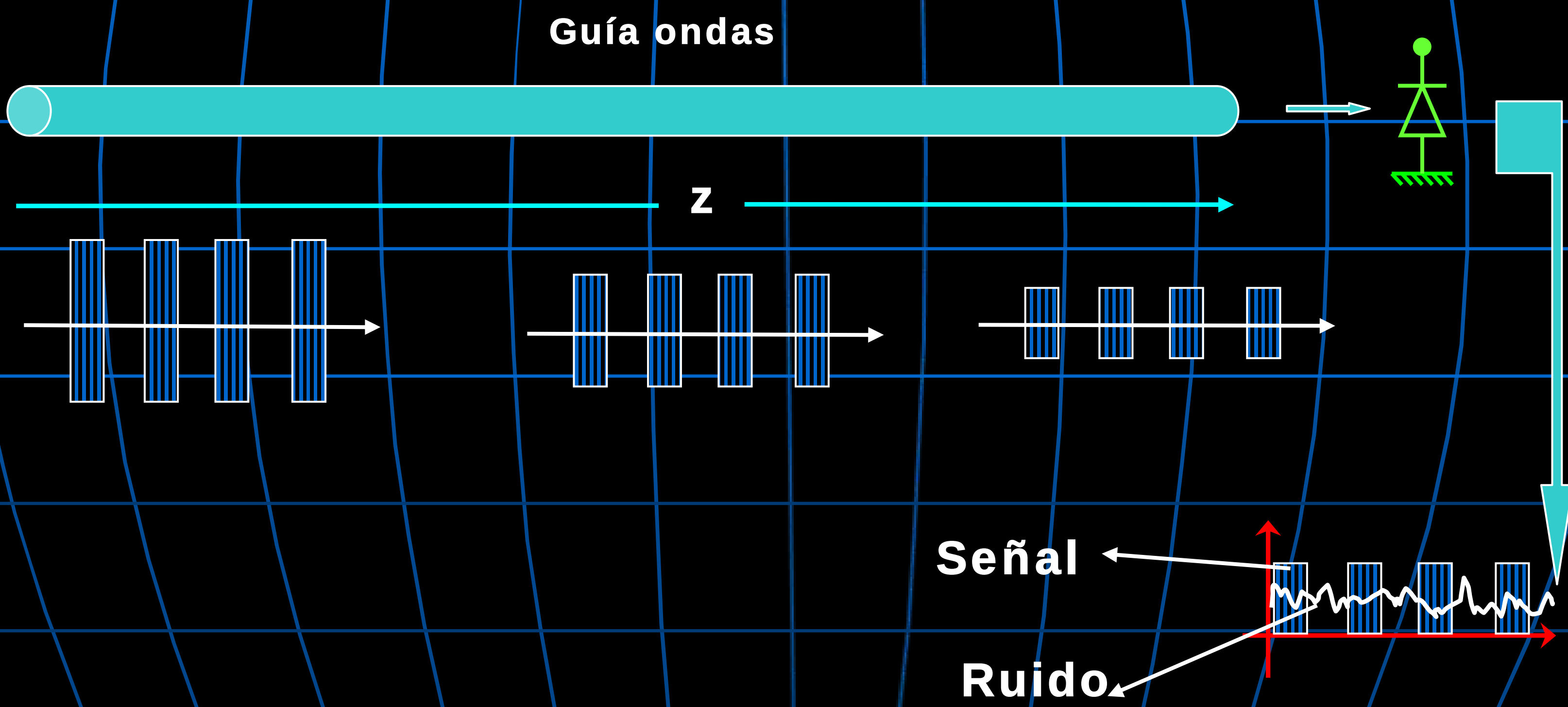
Retos un sistema de comunicación:

- Llevar la información lo más lejos posible.
- Transportar la mayor cantidad de información posible.

Limitaciones de las guías :

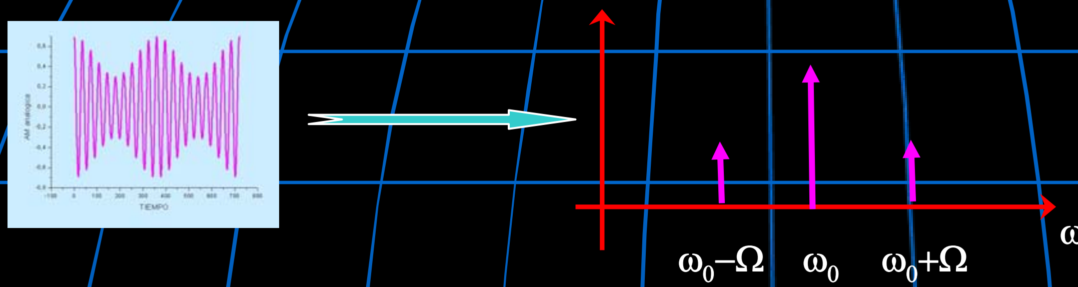
1º Atenuación: α

$$\vec{E}(z,t) = \vec{E}_o e^{-\alpha z} e^{j(\omega t - \beta(\omega) z)}$$



2º Dispersión: β(ω)

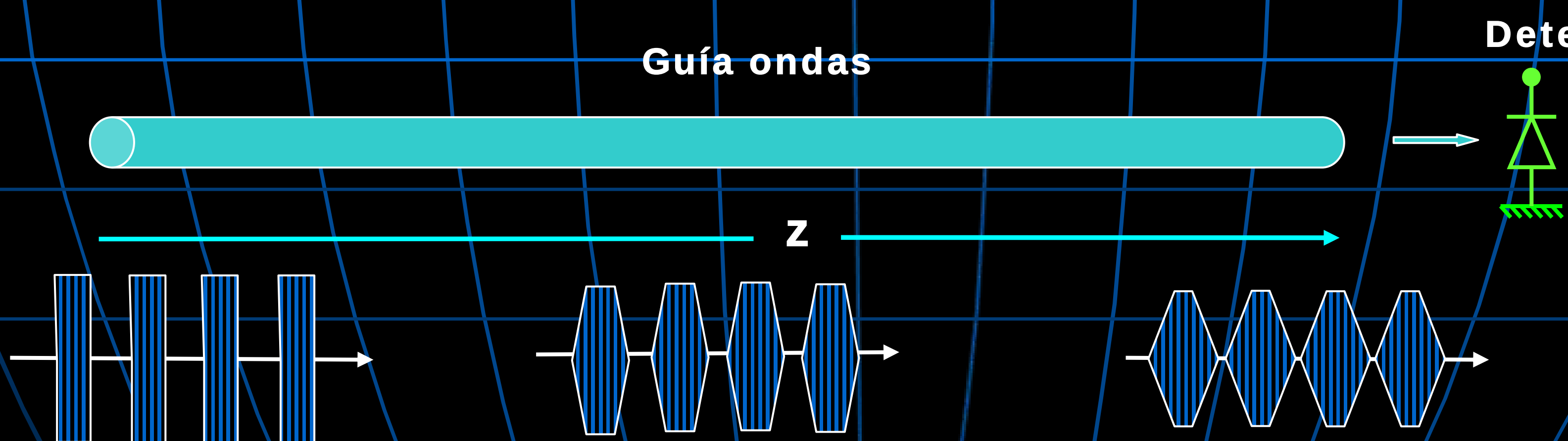
$$\vec{E}(z,t) = \vec{E}_o e^{-\alpha z} e^{j(\omega t - \beta(\omega) z)}$$



$$\begin{cases} \beta(\omega_0-\Omega) \\ \beta(\omega_0) \\ \beta(\omega_0+\Omega) \end{cases}$$

Diferentes frecuencias $\begin{cases} \omega_0-\Omega \\ \omega_0 \\ \omega_0+\Omega \end{cases}$

Diferentes retrasos de grupo (tiempo de transito) $\begin{cases} \tau(\omega_0-\Omega) \\ \tau(\omega_0) \\ \tau(\omega_0+\Omega) \end{cases}$



1966 Propuesta de Charles Kao:

1º Llevar la portadora a frecuencia ópticas del espectro.

124 J. Lytollis, C. K. Kao and G. I. Turner

Table 2. Channel Capacity of Various Systems

Communication type	Frequency (Hz)	Usable bandwidth (%)	Bandwidth (Hz)	Channel bandwidth (Hz)	Number of channels
Radio	$4{\cdot}2 \times 10^4$	10	$4{\cdot}2 \times 10^3$	$4{\cdot}2 \times 10^3$	1
Microwave	$4{\cdot}2 \times 10^9$	1	$4{\cdot}2 \times 10^8$	$4{\cdot}2 \times 10^3$	10000
Optical	$4{\cdot}2 \times 10^{14}$	0·1	$4{\cdot}2 \times 10^{11}$	$4{\cdot}2 \times 10^3$	100,000,000

J. Lytollis, K.O. Kao, G.I. Turner, "Infrared Optical Communication systems", Infrared Physics, 1968, 8, pp 123-129, 1968.

Standar telecocom laboratoies, UK

2º Usar como guía fibras ópticas de sílice fundida.

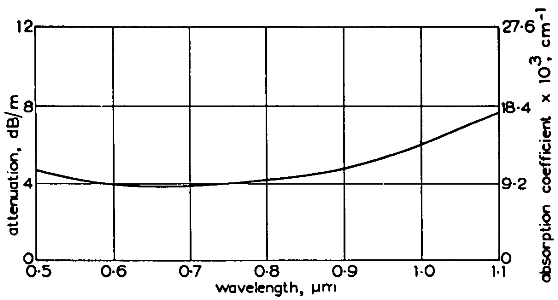


Fig. 1 *Attenuation in SW6 glass*

quartz and polymethyl methachrylate samples, respectively. Work is in progress towards obtaining lower-absorption glasses. Currently this is being given an additional boost, owing to laser-glass requirements. It is foreseeable that glasses with a bulk loss of about 20 dB/km at around 0.6 μm will be obtained, as the iron-impurity concentration may be reduced to 1 part per million.

4.4.2 Dispersion: The dispersion characteristics of dielectric-fibre waveguides have two regions of interest. One region corresponds to operating the waveguide far removed from cutoff. Thus, for a highly overmoded waveguide, extremely flat phase characteristics can be obtained, giving good dispersion characteristics. This, however, is not desirable, on account of mode instability. The other region occurs when the waveguide is operating very near to cutoff. The waveguide wavelength is then nearly equal to the free-space wavelength. The phase characteristics for the modes becomes flatter as the order of the mode decreases. This condition offers single-mode operations for the E_0, H_0 and HE_{11} modes. The HE_{11} mode dispersion characteristic is the best. The group-delay distortion for a 10 km route, using the HE_{11} mode under the operating condition when the $k_0 a = 0.6$, can be estimated as follows.

From the slope of the ω/β plot, the slope change over 1 Gc/s is taken to be approximately 10^{-6}. Assuming that the refractive-index change with frequency is negligible, the group delay is given approximately by

distance × velocity^{-1} × slope change

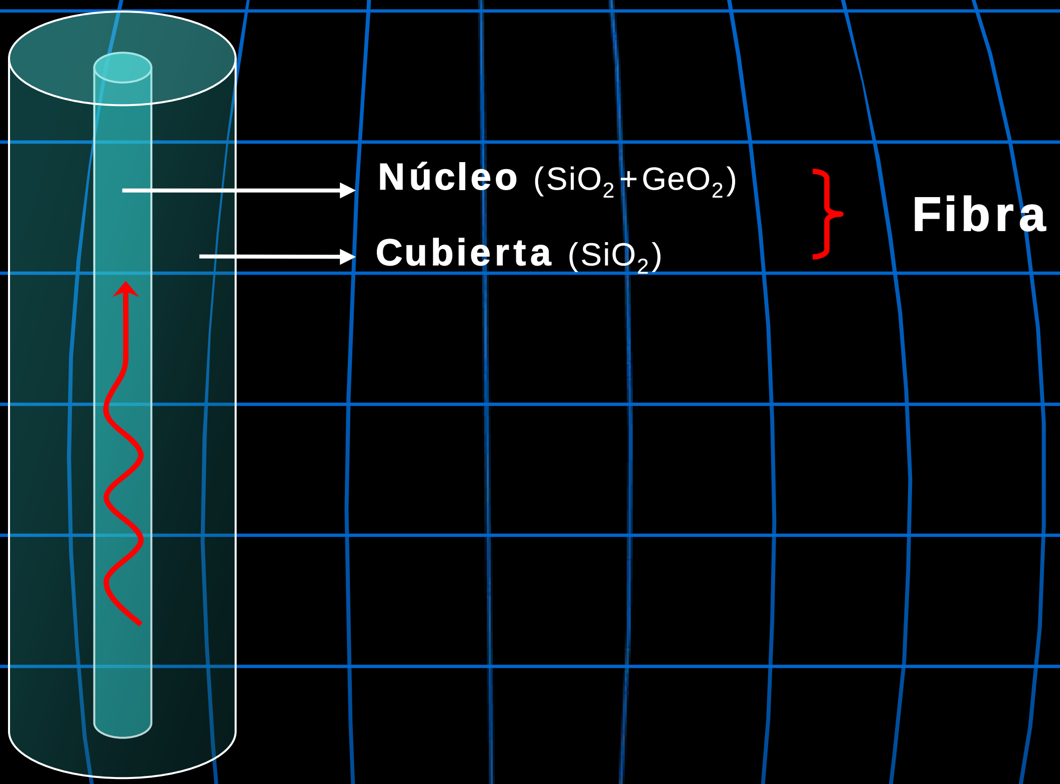
$$= 10 \times 10^9 \times \frac{1}{3 \times 10^{14}} \times 10^{-6} = \frac{1}{3} \times 10^{-10}\ \mathrm{s}$$

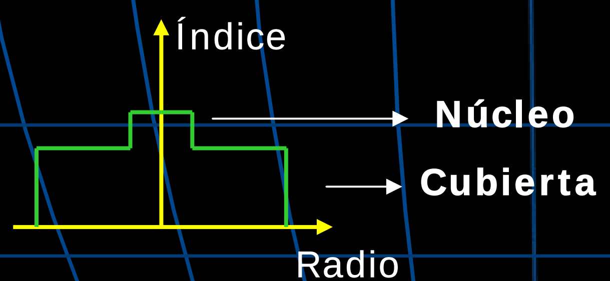
This represents a 24° phase shift for 1 GHz bandwidth.

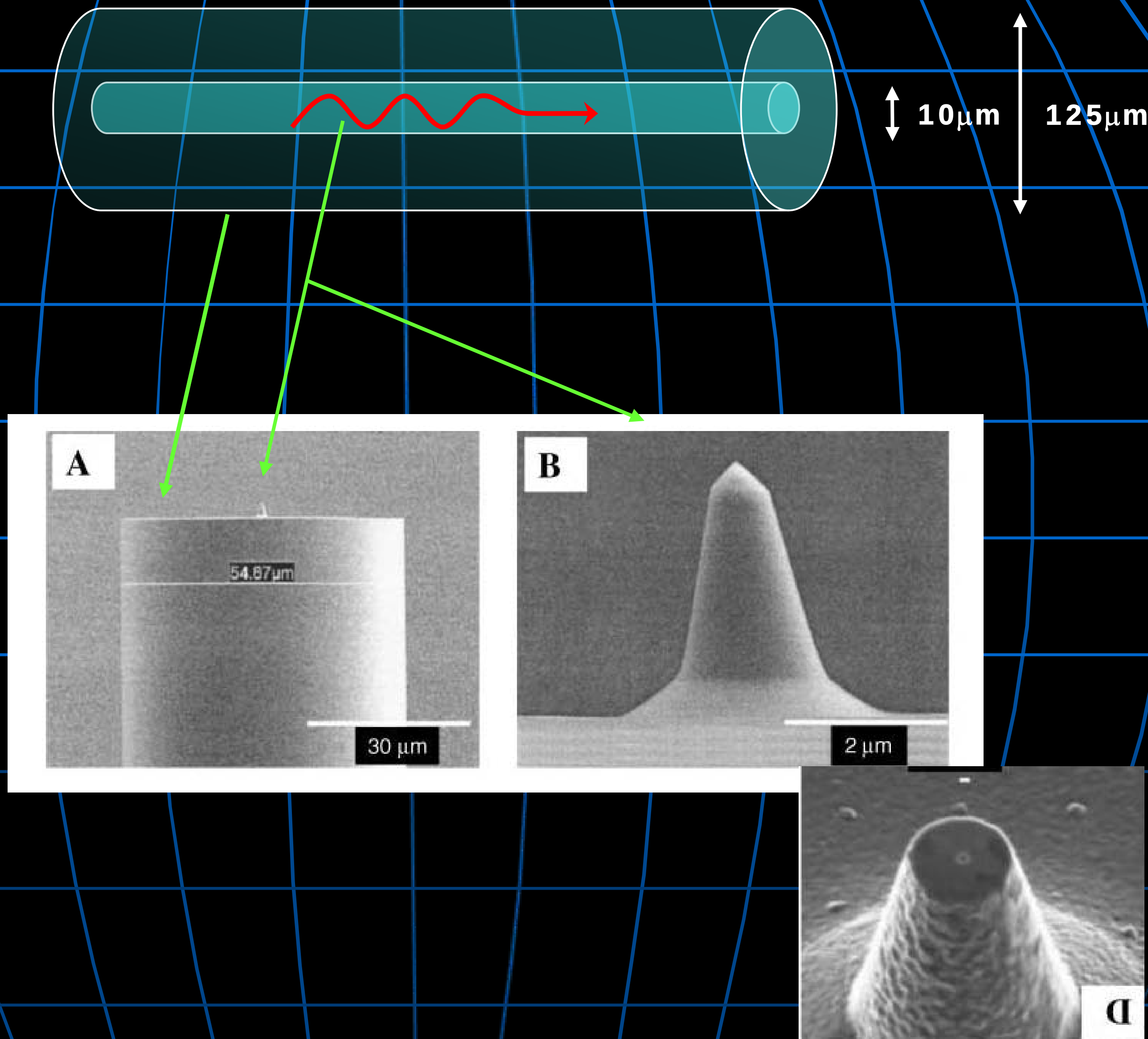
K.O. Kao, G.A. Hockman, "Dielectric fiber surface waveguides for optical frequencies", Proc. IEE, 1966, 133 (7), pp 1151-1158.

Standar telecocom laboratories, UK

Qué es la fibra óptica?







10µm
125µm
A
54.87µm
30 µm
B
2 µm
D

1979 Primeras fibras de características modernas:

Pequeñas pérdidas:

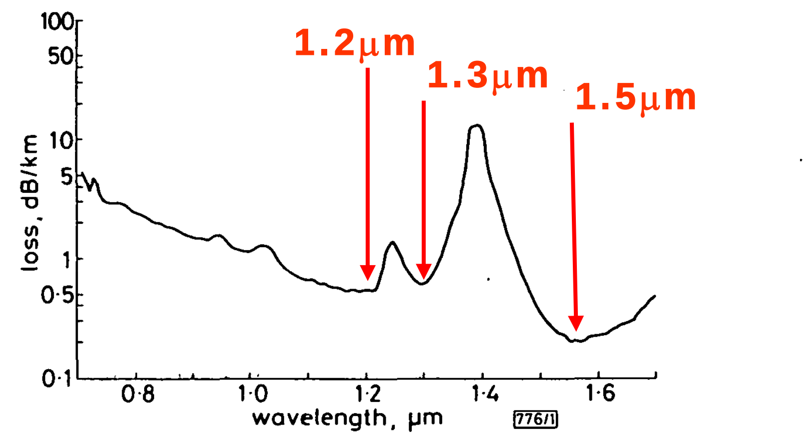


Fig. 1 *Spectral loss of 2·2 km single-mode fibre characterised by 9·4 µm core diameter, 0·0028 refractive-index difference between core and cladding and 1·1 µm cutoff wavelength*

T. Miya et al, "Ultimate low-loss single-mode fibre at 1.55µm", Electronics Letters, 1979, 15, pp 106.

(Nipon telegraph&telephone corporation, Tokay)

Pequeña dispersión:

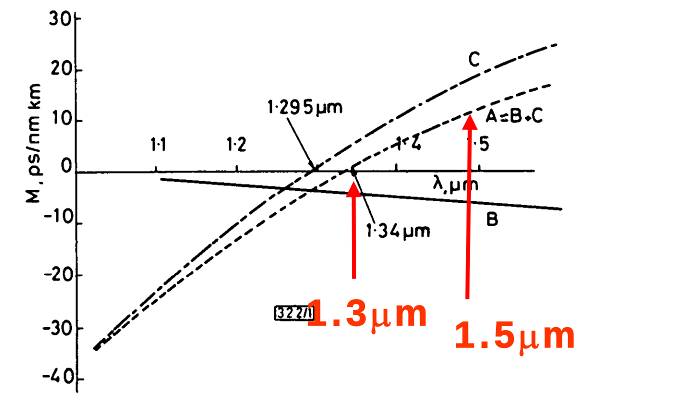


Fig. 1 *Chromatic dispersion measured from the wavelength variation of group delay time (broken line)*

Modal dispersion deduced from the spectral dependence of the mode spot size (full line), and material dispersion (dot-dashed line) determined from curves A and B

J.P. Pocholle et al, "Determination of modal dispersion in monomode fibers...", Electronics Letters, 1983, 19, pp 1093.

(Thomson-CSF, Orsay)

Pequeñas pérdidas: **Pequeña dispersión:**

Optical Specifications

Fiber Attenuation

Maximum Attenuation

Wavelength (nm)	Maximum Value* (dB/km)
1310	0.33 – 0.35
1383**	0.31 – 0.35
1550	0.19 – 0.20
1625	0.20 – 0.23

*Maximum specified attenuation value available within the stated ranges.
**Attenuation values at this wavelength represent post-hydrogen aging performance.
Alternate attenuation offerings available upon request.

Attenuation vs. Wavelength

Range (nm)	Ref. λ (nm)	Max. α Difference (dB/km)
1285 – 1330	1310	0.03
1525 – 1575	1550	0.02

The attenuation in a given wavelength range does not exceed the attenuation of the reference wavelength (λ) by more than the value α.

Cable Cutoff Wavelength (λ_{ccf})

$\lambda_{ccf} \leq 1260$ nm

Mode-Field Diameter

Wavelength (nm)	MFD (μm)
1310	9.2 ± 0.4
1550	10.4 ± 0.5

Dispersion

Wavelength (nm)	Dispersion Value [ps/(nm·km)]
1550	≤18.0
1625	≤22.0

Zero Dispersion Wavelength (λ_0): 1302 nm ≤ λ_0 ≤ 1322 nm
Zero Dispersion Slope (S_0): ≤ 0.089 ps/(nm²·km)

P_{in} = 1mW
L = 50Km

P_{out} = 0'1mW

Δt_{in} = 250ps
50Km

Δt_{out} = 280ps

1 Gb/s

Origen de las pérdidas:

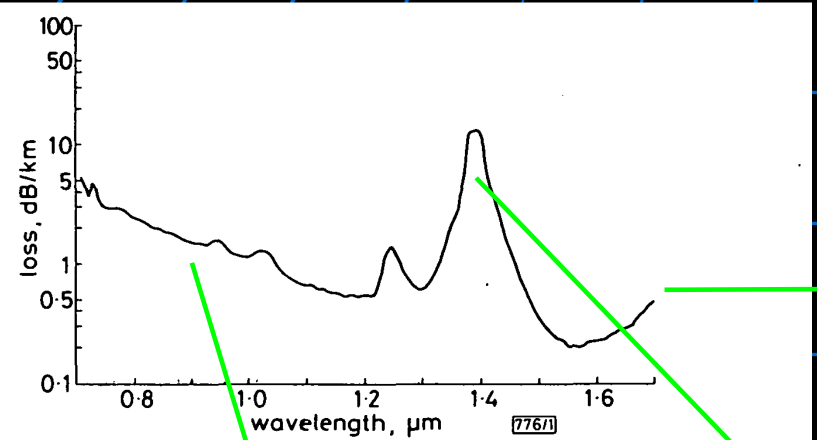
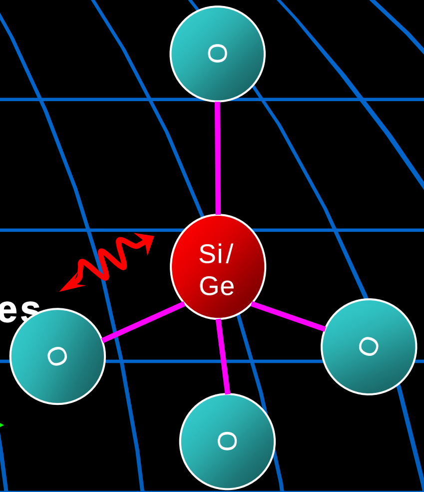
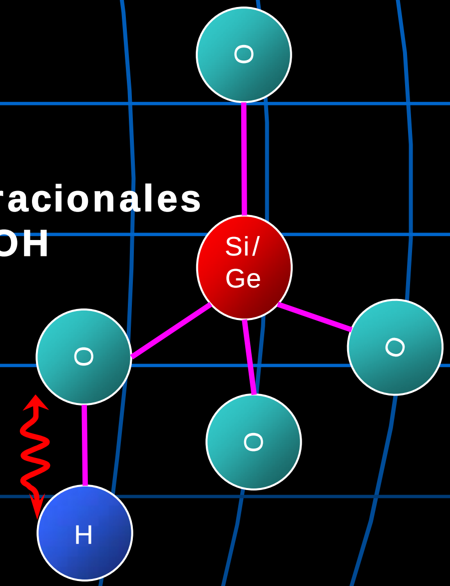


Fig. 1 *Spectral loss of 2·2 km single-mode fibre characterised by 9·4 μm core diameter, 0·0028 refractive-index difference between core and cladding and 1·1 μm cutoff wavelength*

Modos vibracionales del SiO_2 y del GeO_2

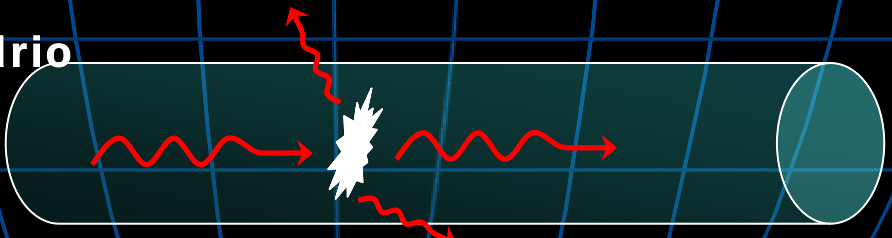


Modos vibracionales del grupo OH



Difusion Rayleigh:

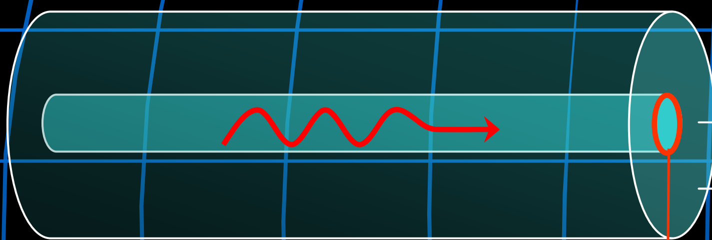
Variaciones locales de la constante dieléctrica en el vidrio amorfo ($1/\lambda^4$)

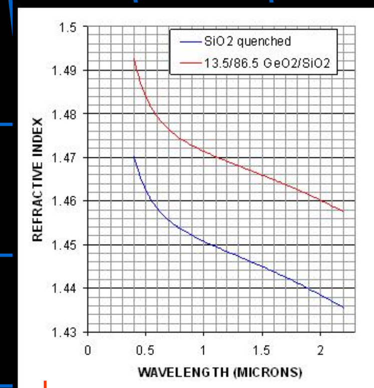


Origen de la dispersión:

Dispersión de la guía: las condiciones de contorno de los campos hacen β no sea lineal con ω.

Dispersión del material: El índice de refración del vidrio es función de la frecuencia.





$$\beta = \omega\sqrt{\mu_0\varepsilon_0}\, n_1\left(1 - 2\Delta u(\omega)/V(\omega)\right)^{1/2}$$

$$n_1 = f(\omega)$$

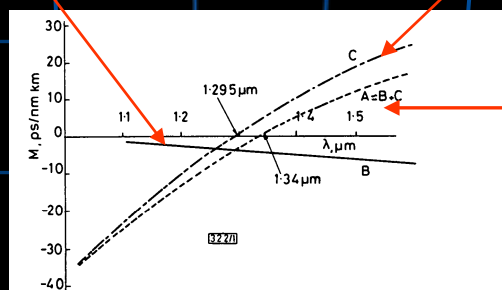
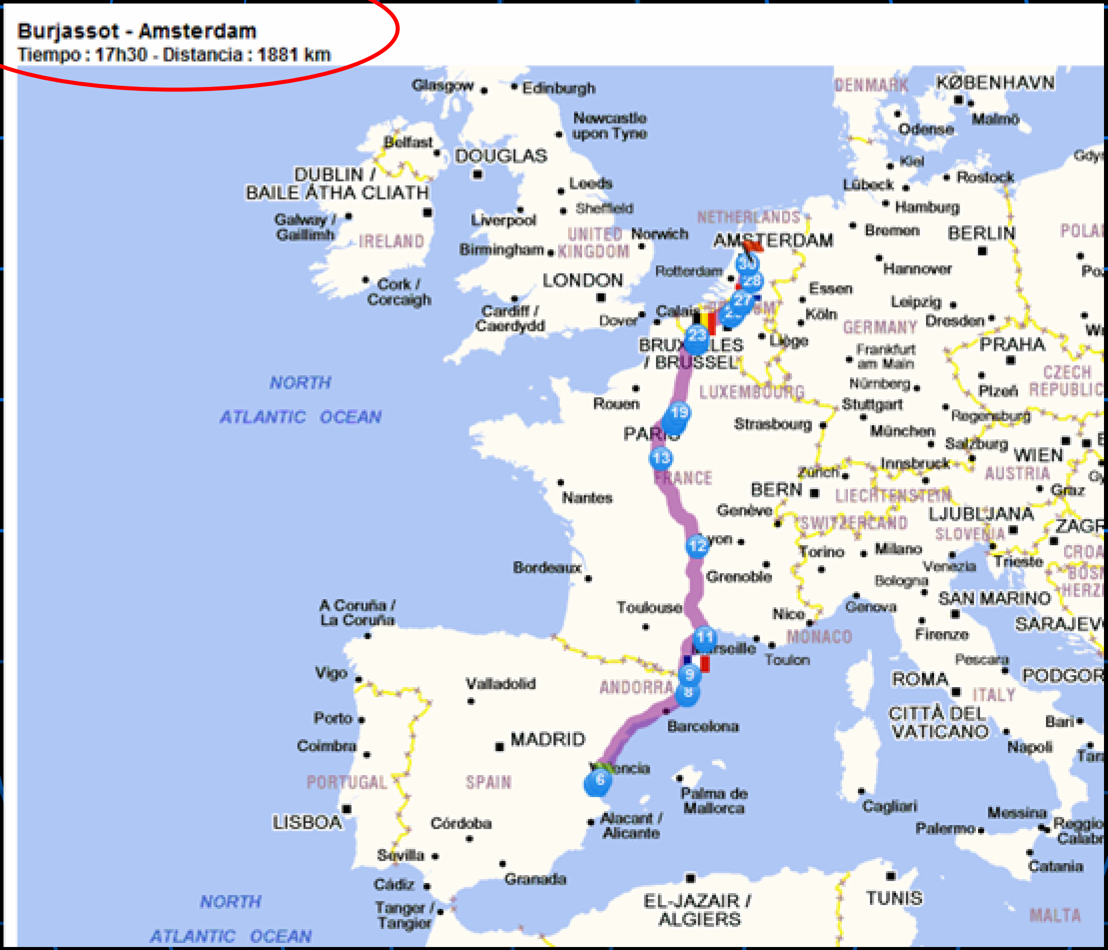


Fig. 1 *Chromatic dispersion measured from the wavelength variation of group delay time (broken line)*

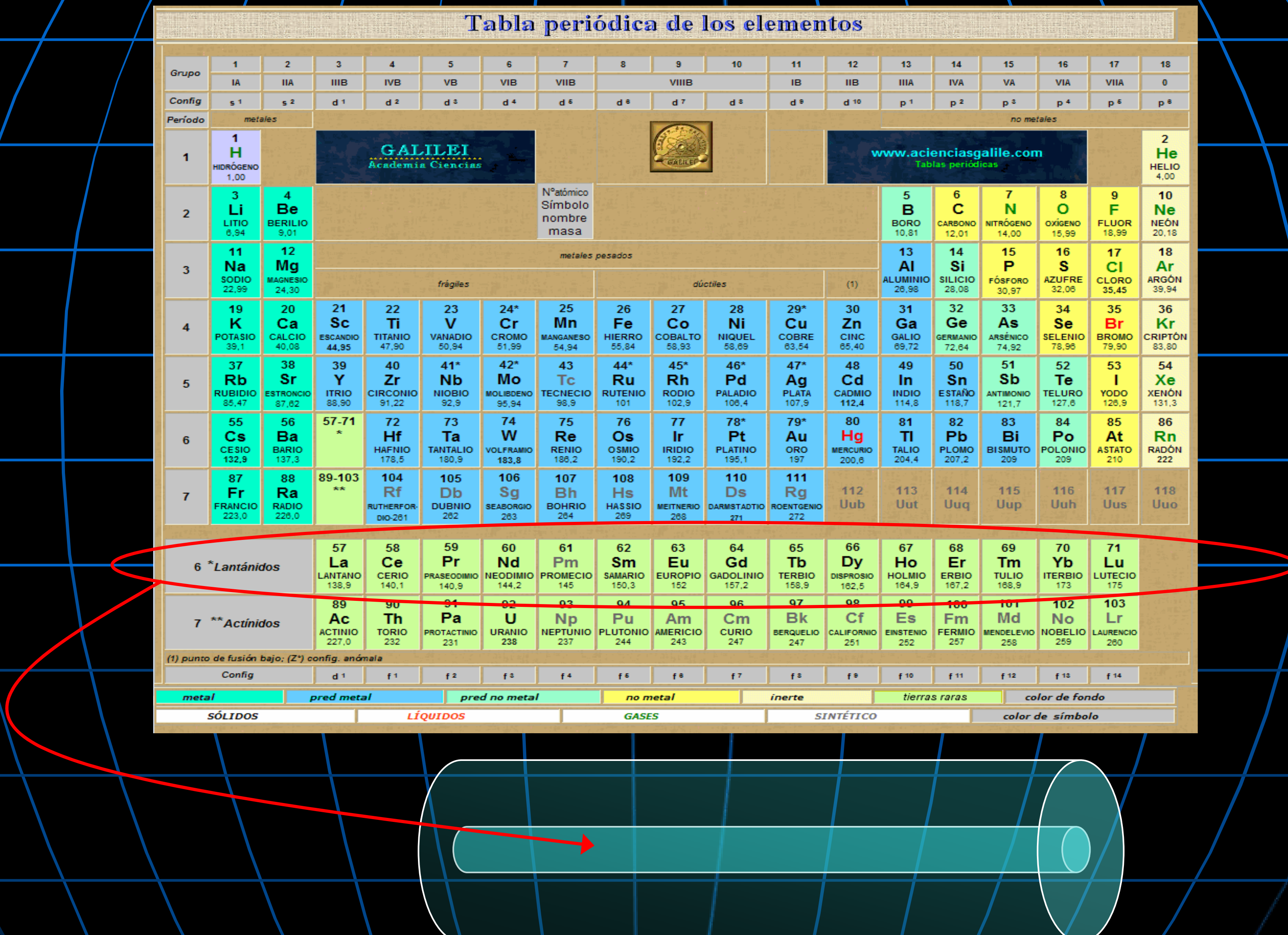
Modal dispersion deduced from the spectral dependence of the mode spot size (full line), and material dispersion (dot-dashed line) determined from curves A and B

Dispersión total

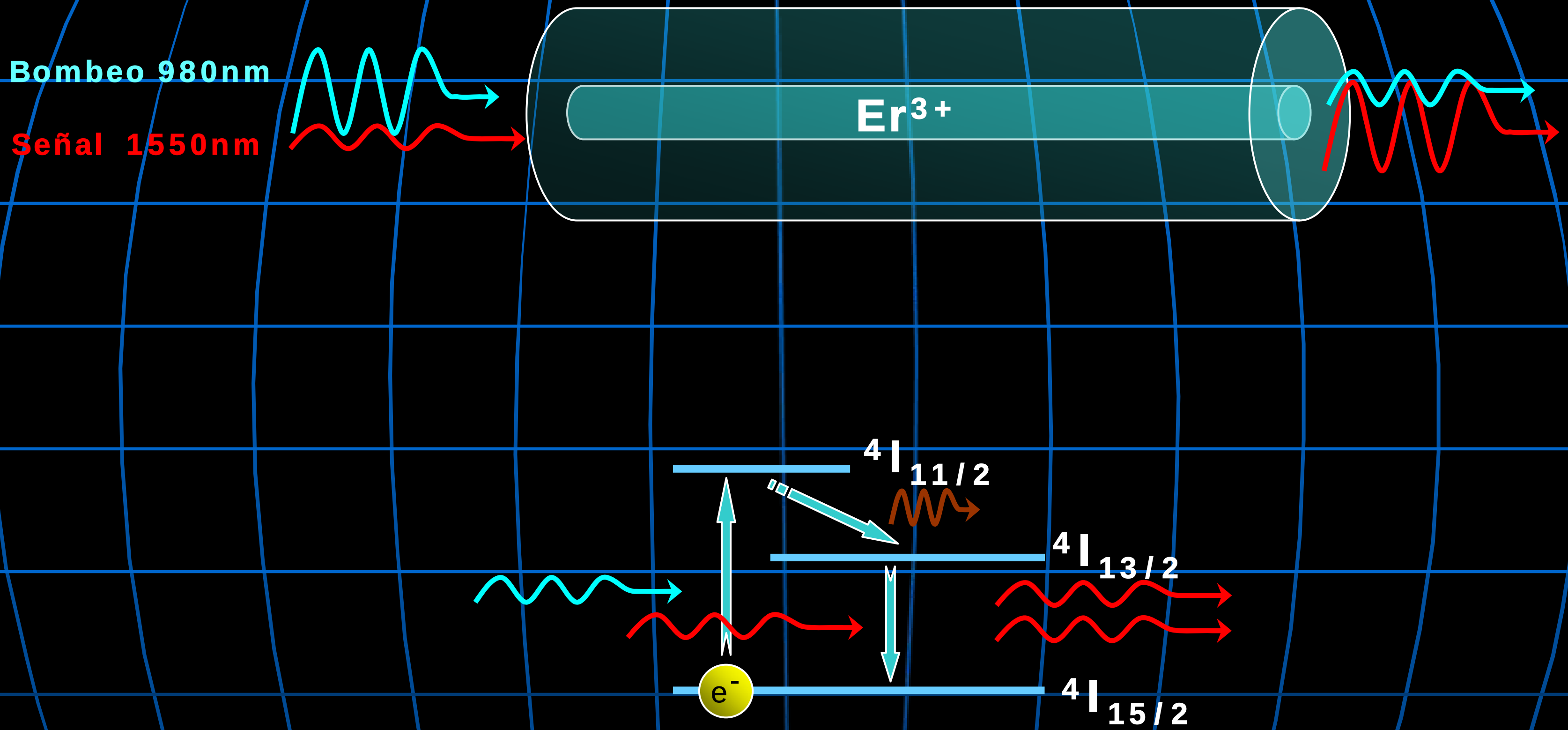
Largas Distancias: Necesidad de amplificar.



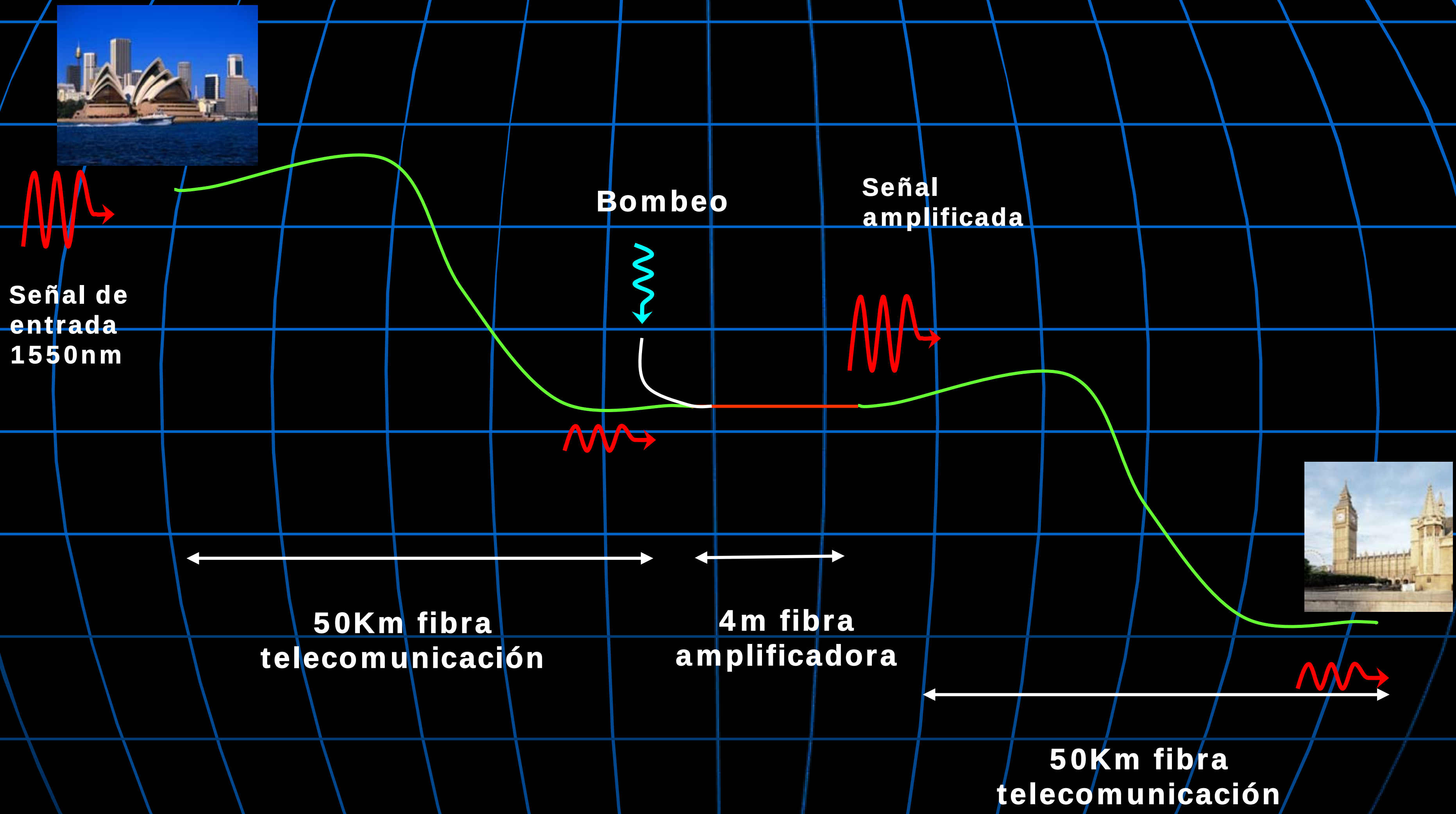
Amplificadores de Fibra óptica: Fibras dopadas con tierras raras



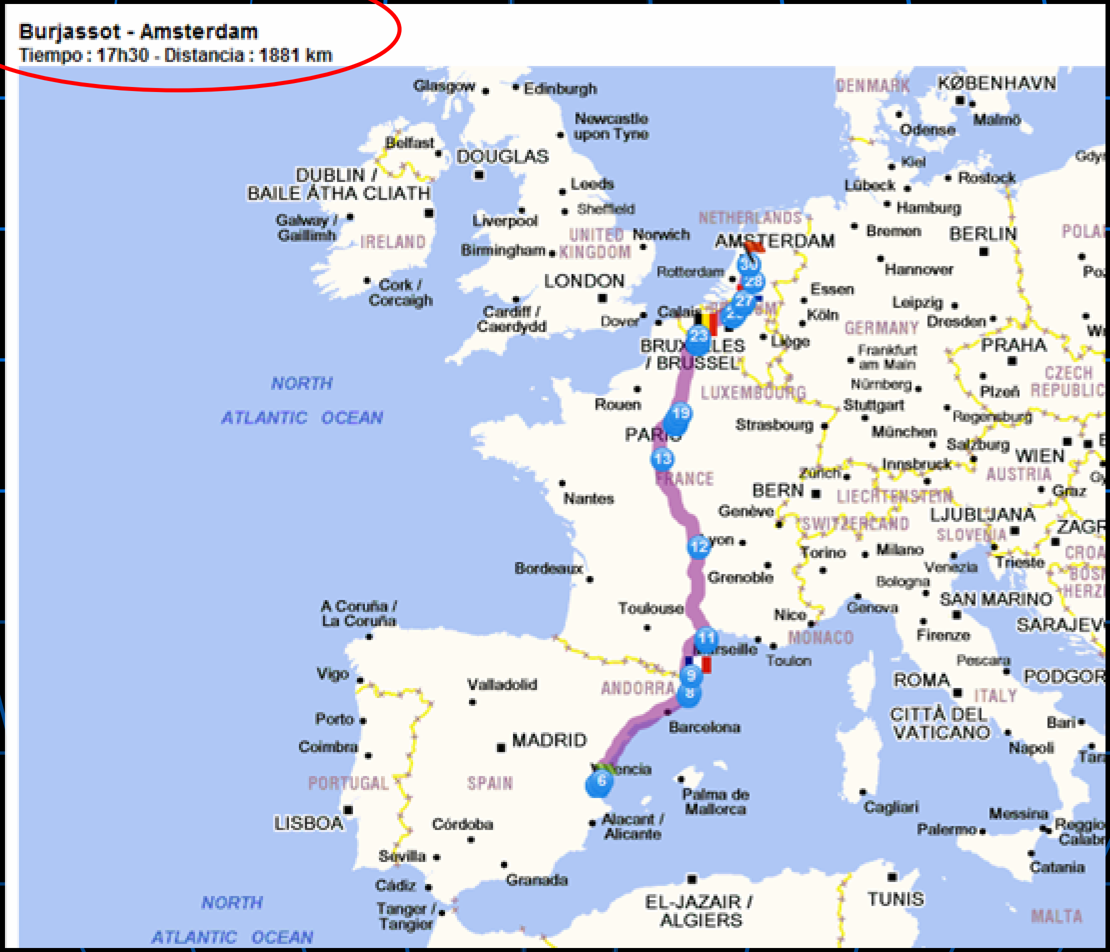
Amplificación en fibra monomodo (Erbio):



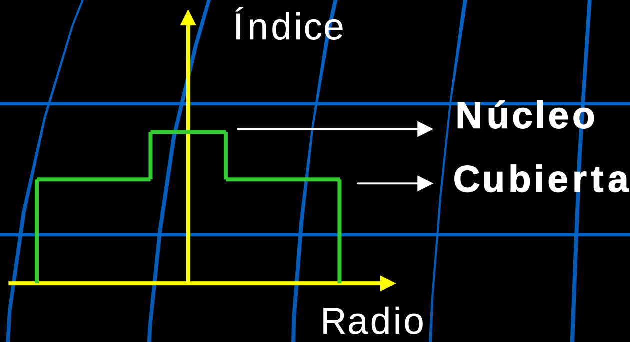
Amplificación en comunicaciones:

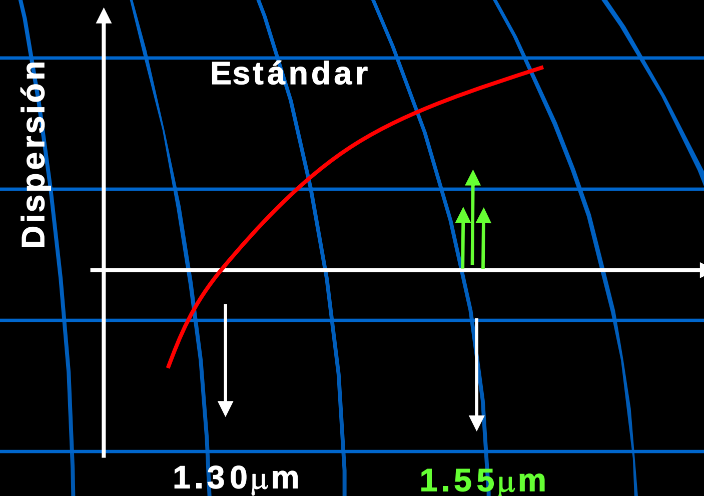


Largas Distancias: Necesidad de compensar dispersion.

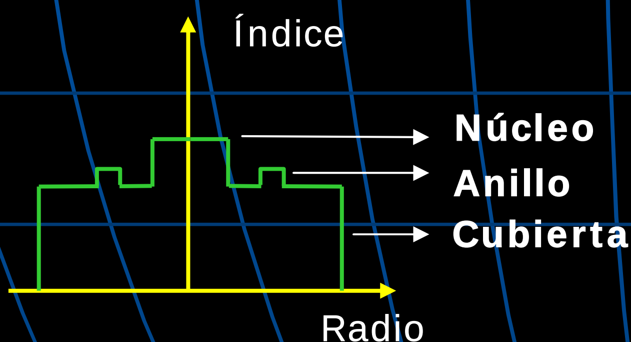


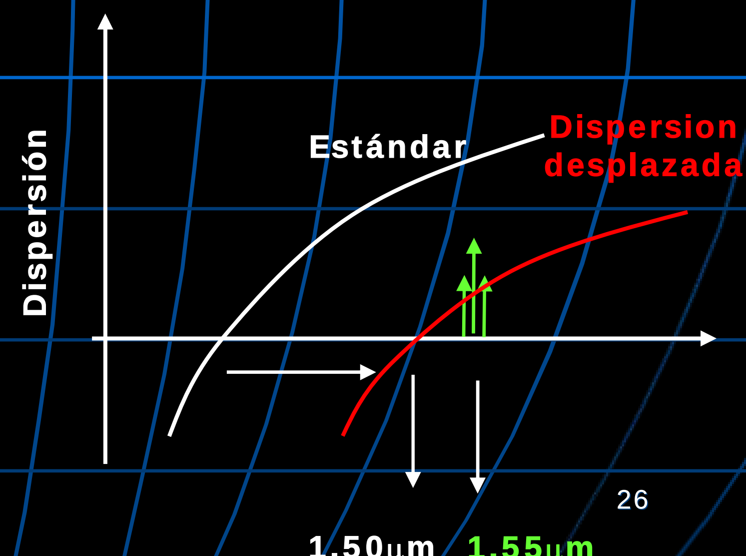
Fibra estándar de telecomunicación:



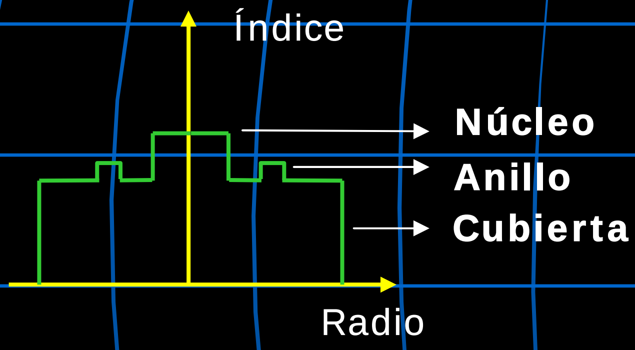


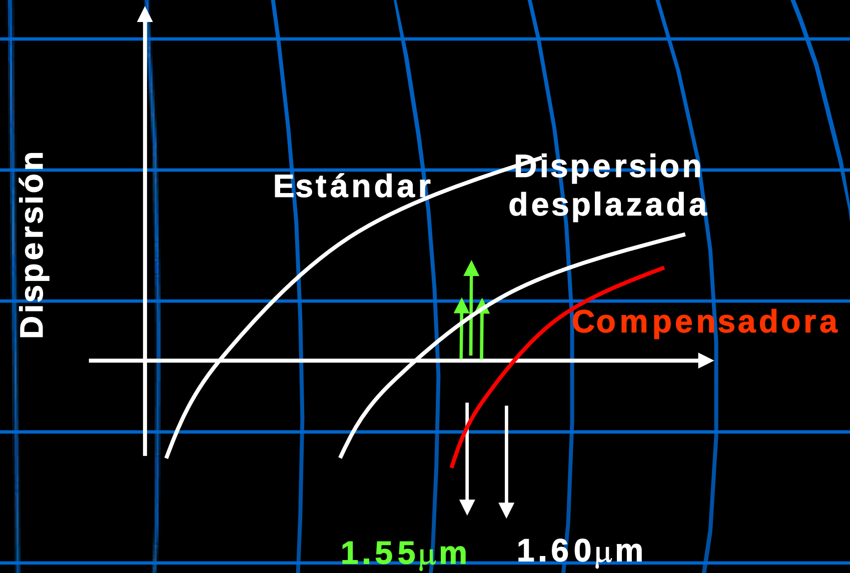
Fibra de dispersión desplazada:



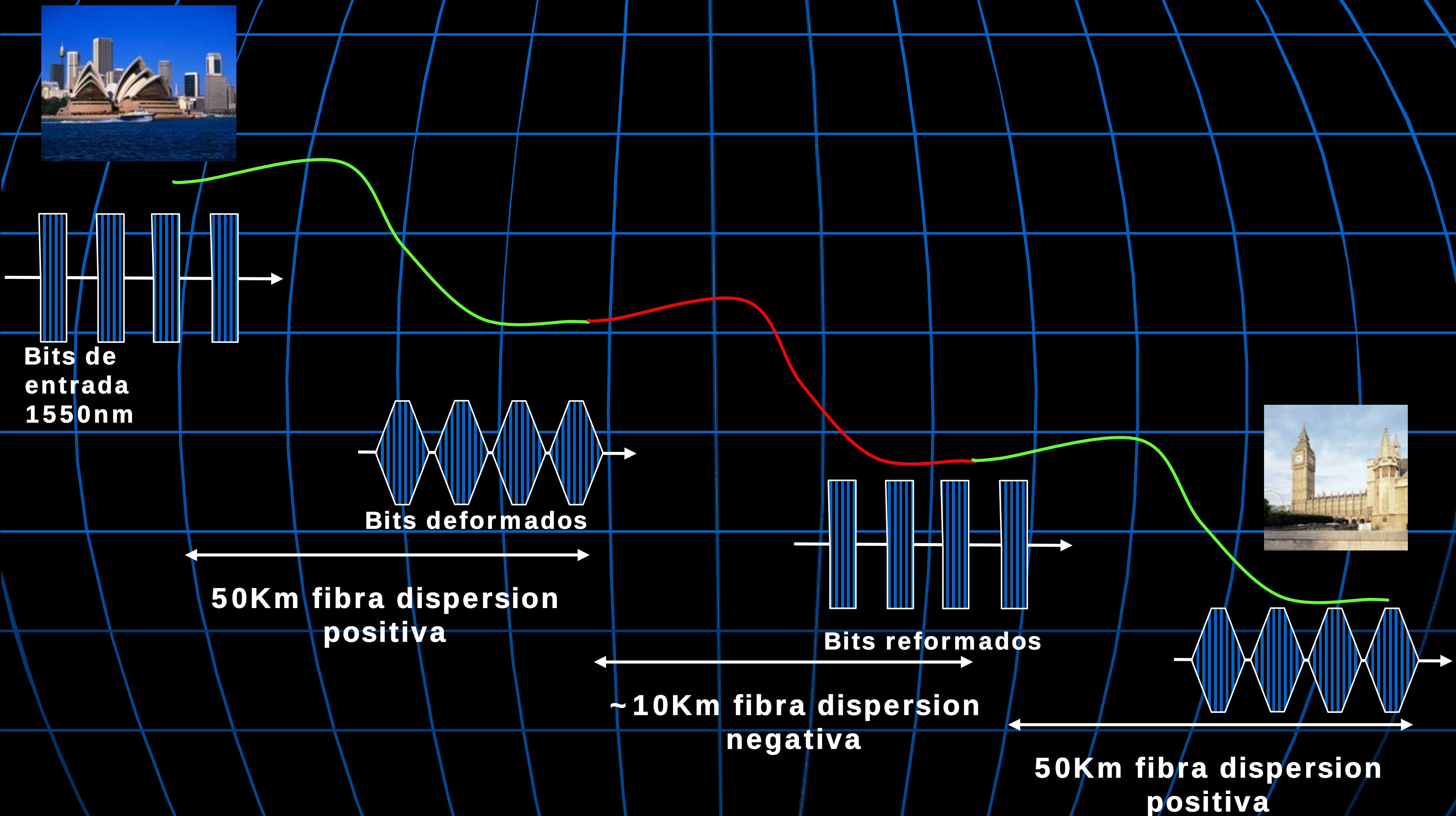


Fibra compensadora de dispersión:

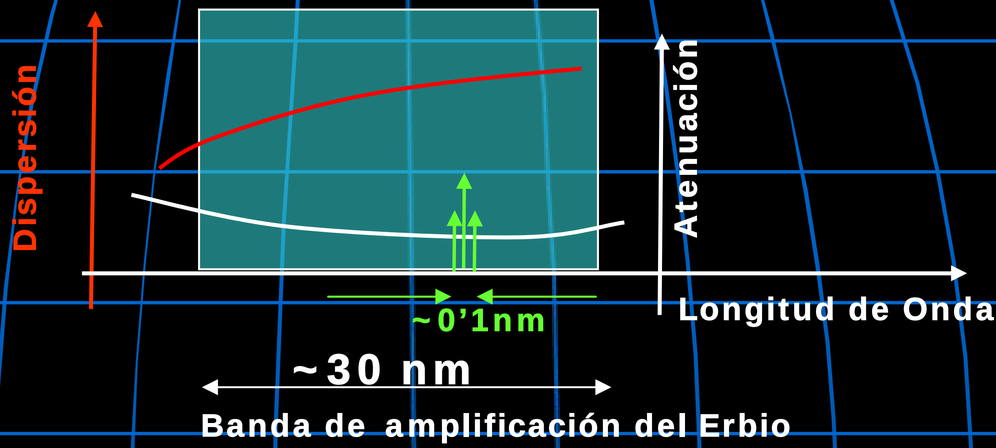




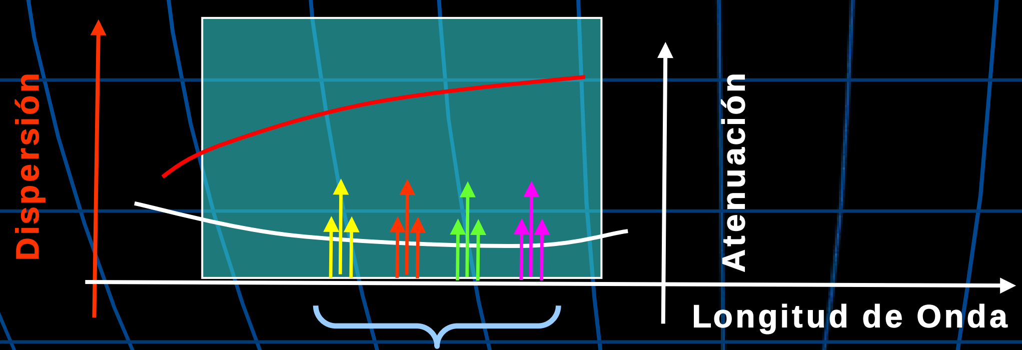
Compensación de dispersion en comunicaciones:



Incrementando la capacidad de datos:



Multiplexación en longitud de onda:

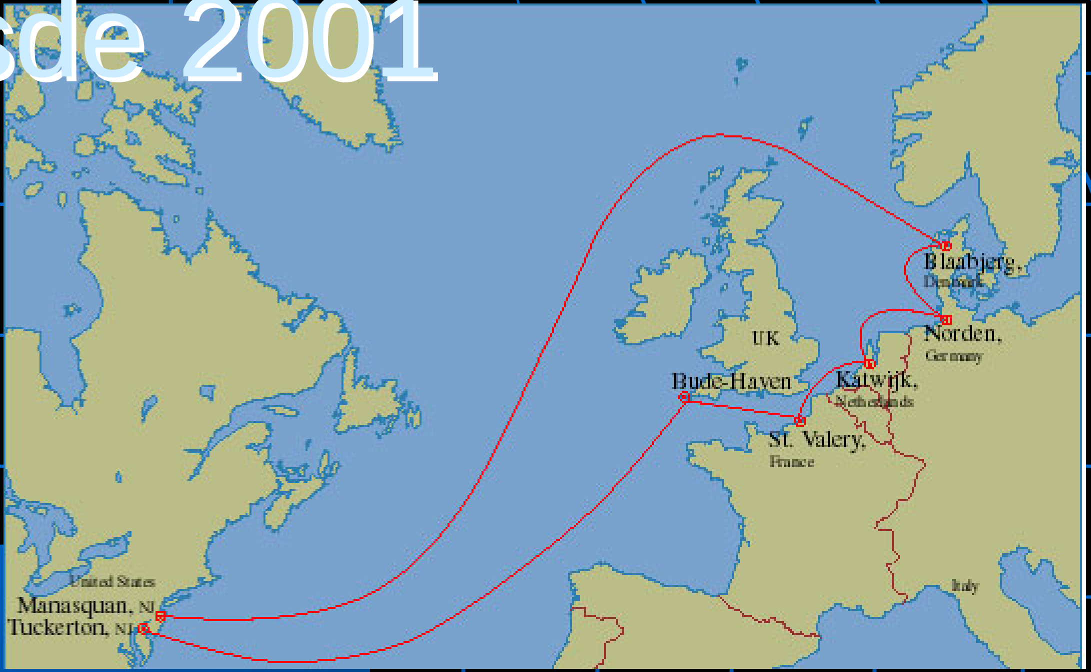


Múltiples canales → **Evitar dispersión cero**

Claves en la comunicación por fibra:

- Pocas pérdidas.
- Pequeña dispersión.
- Amplificación.
- Compensación de dispersión.
- Multiplexación en longitud de onda.

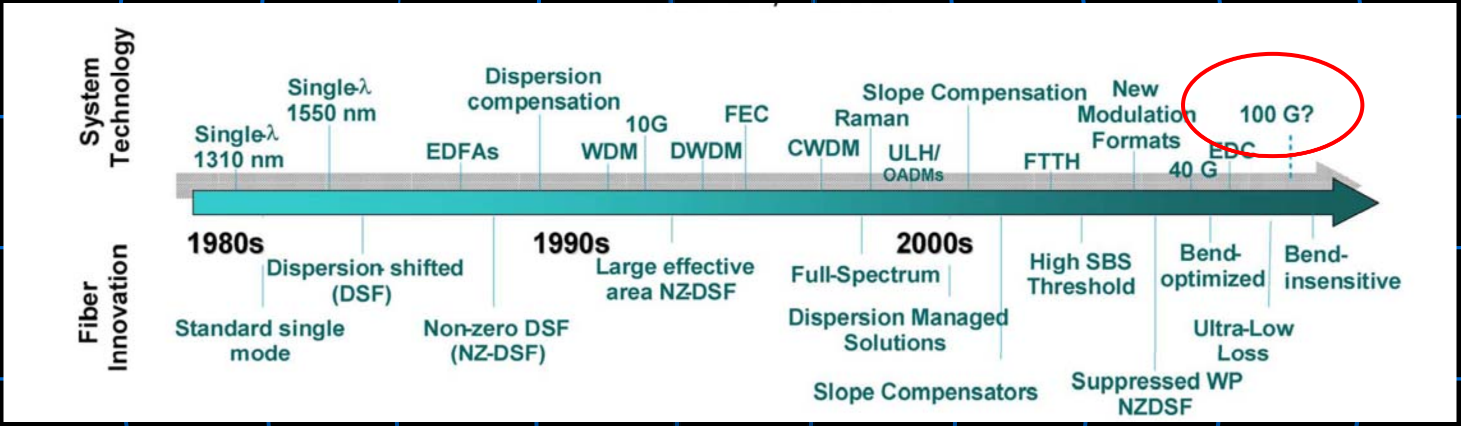
TAT-14 Cable System Operativo desde 2001



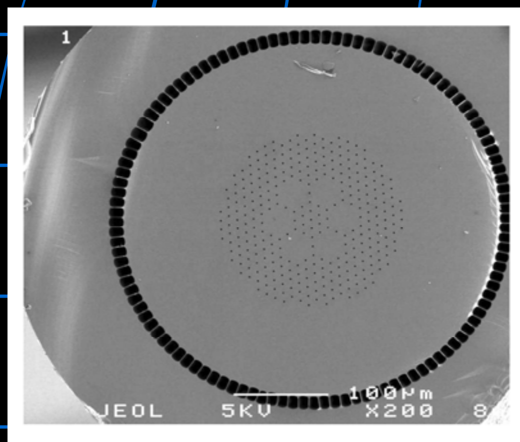
- Longitud 15476 Km.
- Dos rutas (Norte y Sur).
- Cuatro pares de fibra por ruta.
- 40 canales por fibra.
- 10=Gb/s por canal.

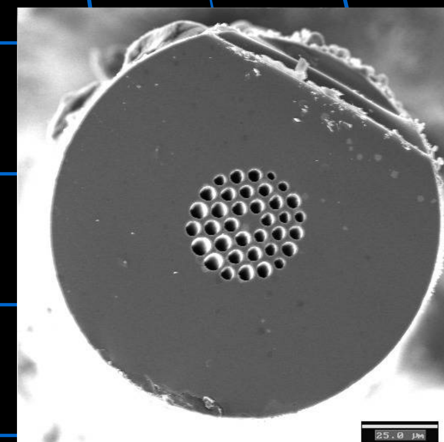
2×4×40×10G=3'2Tb/s

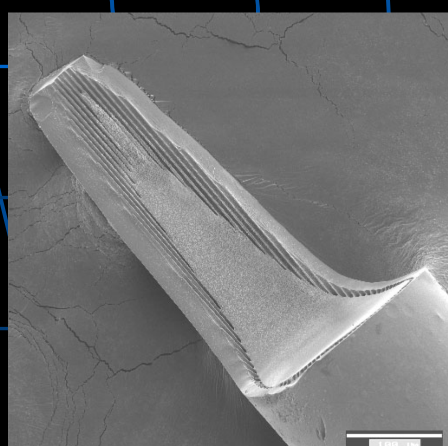
Cronología y Futuro:



Fibras para el futuro: Fibras micorestructuradas







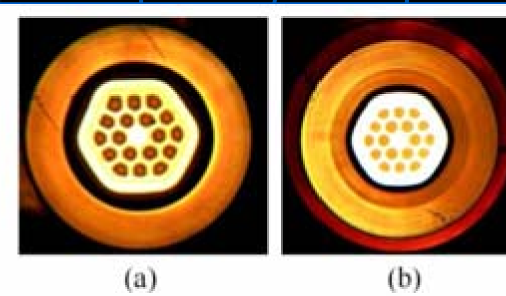
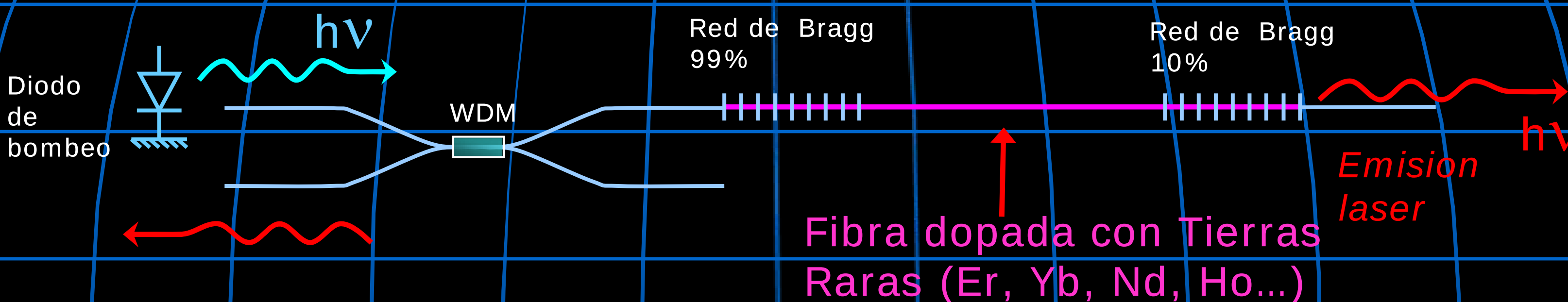
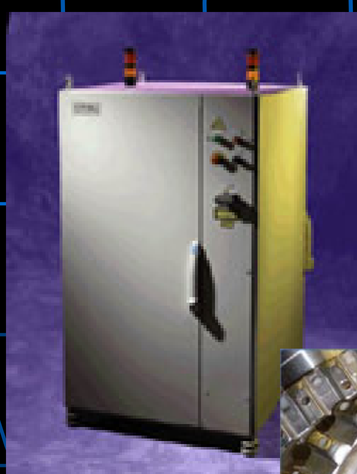


Fig. 1. Cross section of (a) LCF1 and (b) LCF2.

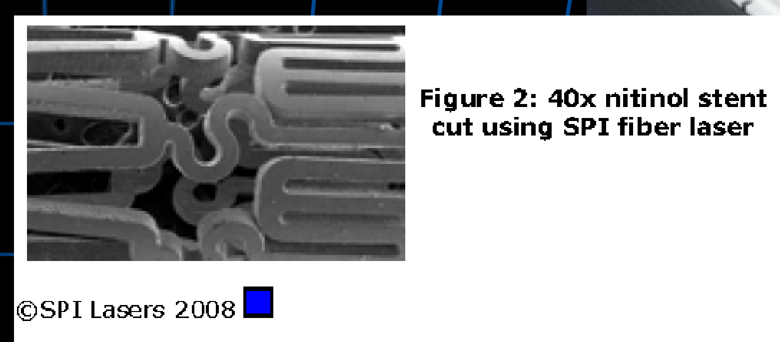
Otros desarrollos: Laseres de Fibra





Laseres de Potencia

Laseres de Pulsados



Gracias por su atención.