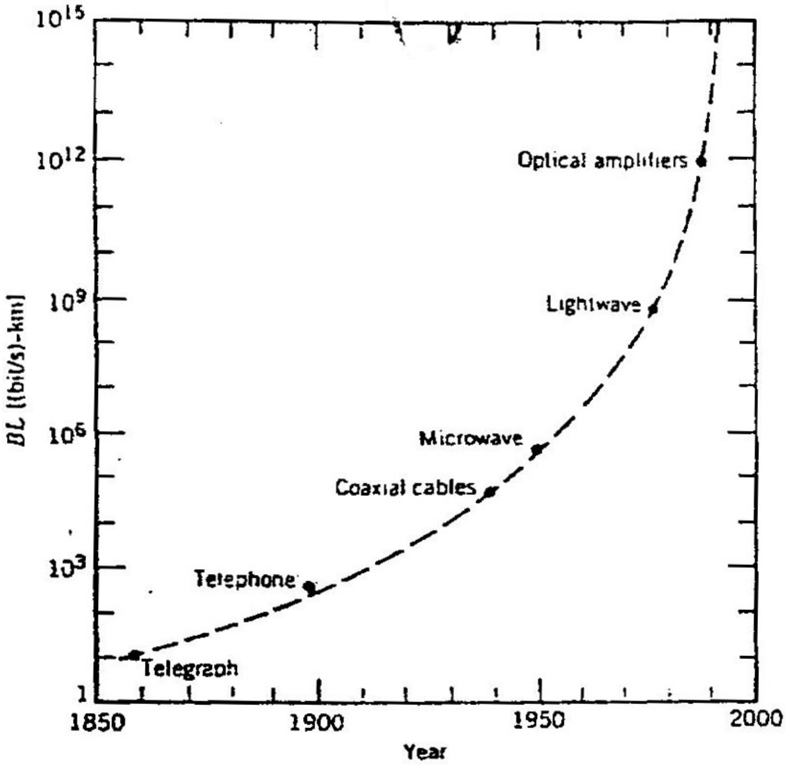


FIGURE 1.1 Increase in bit rate–distance product during 1850–2000. The emergence of new technologies is marked by a filled circle.

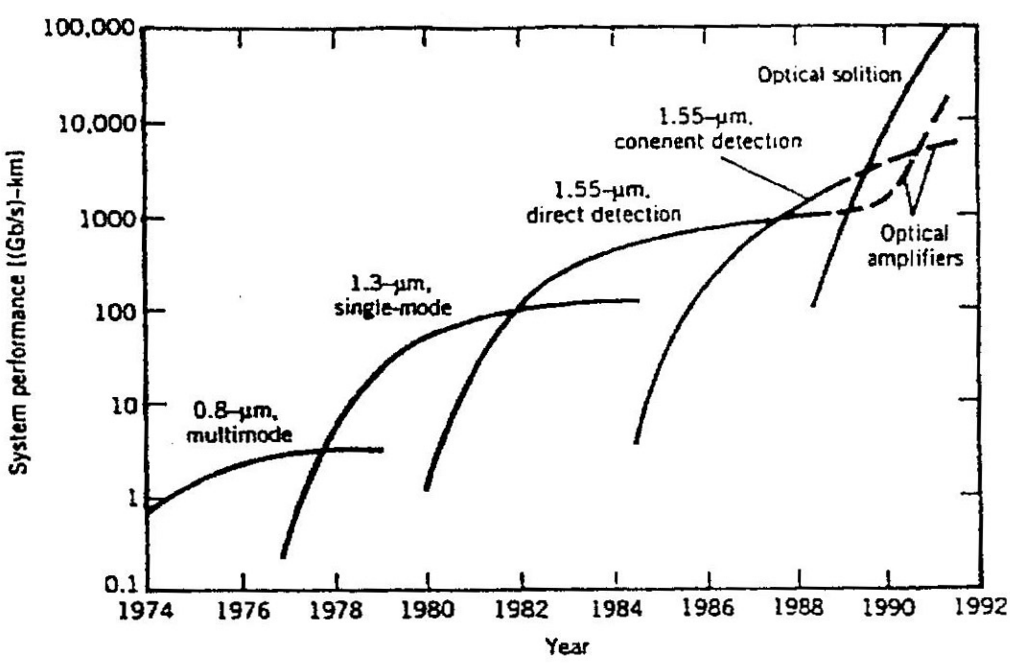


FIGURE 1.2 Progress in lightwave communication technology over the period 1974–1992. Different curves show the increase in the bit rate–distance product for five generations of fiber-optic communication systems.

Per-fiber capacity trends

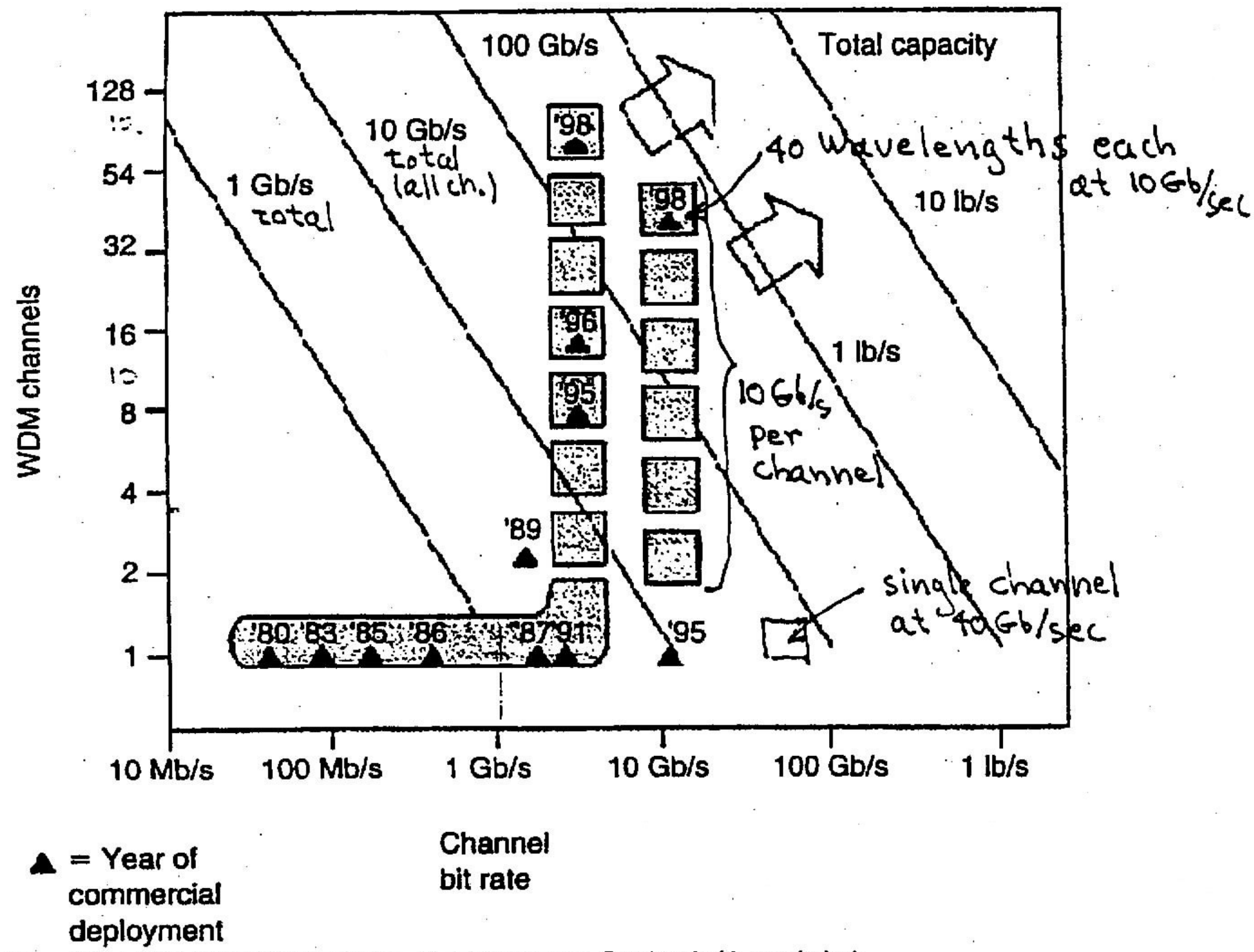


Figure I.1 Per-fiber capacity trends. (From Lucent Technologies, *Bell Labs Technology*, vol. 2 no. 2, Fall 1998, p. 3.)

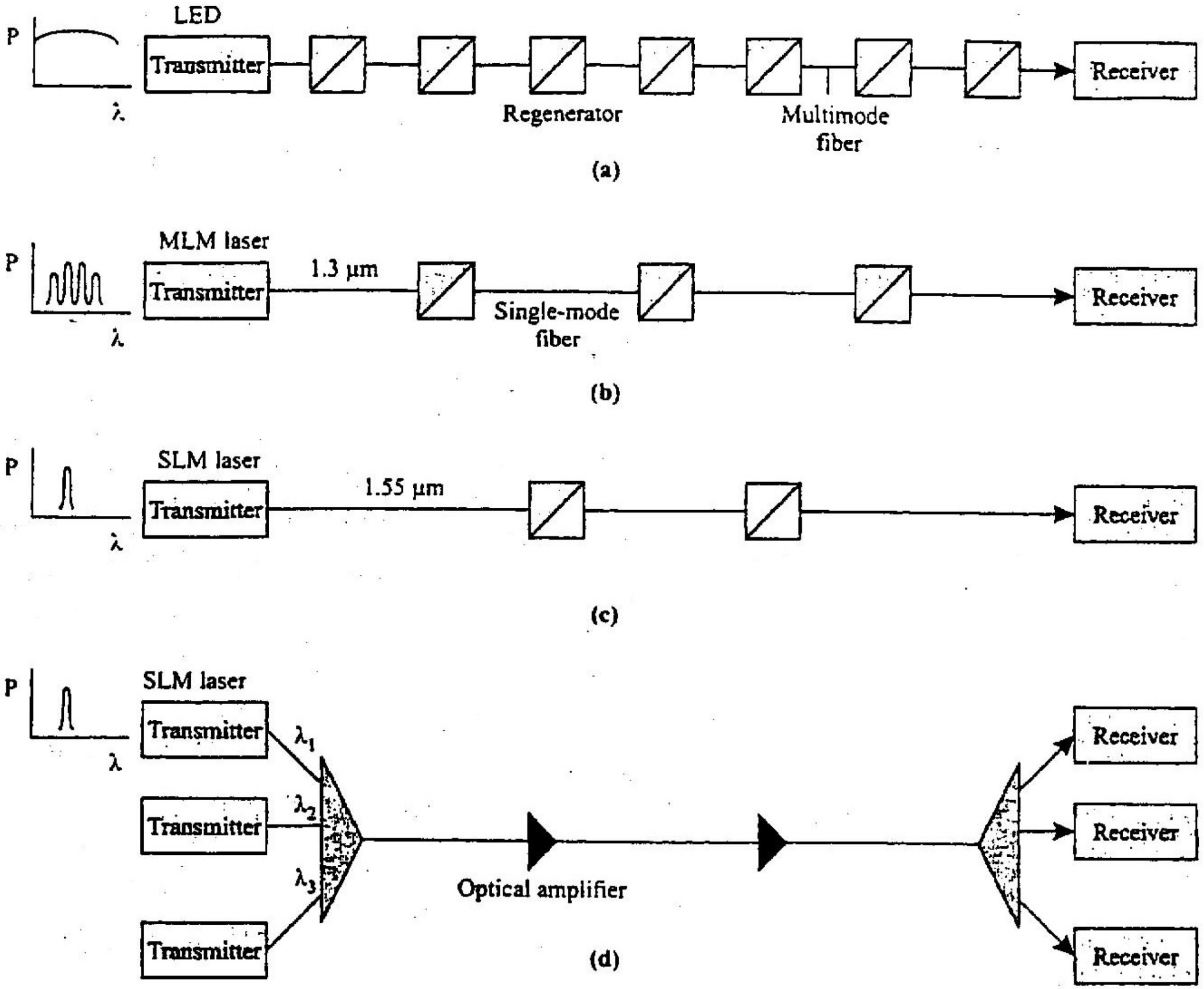
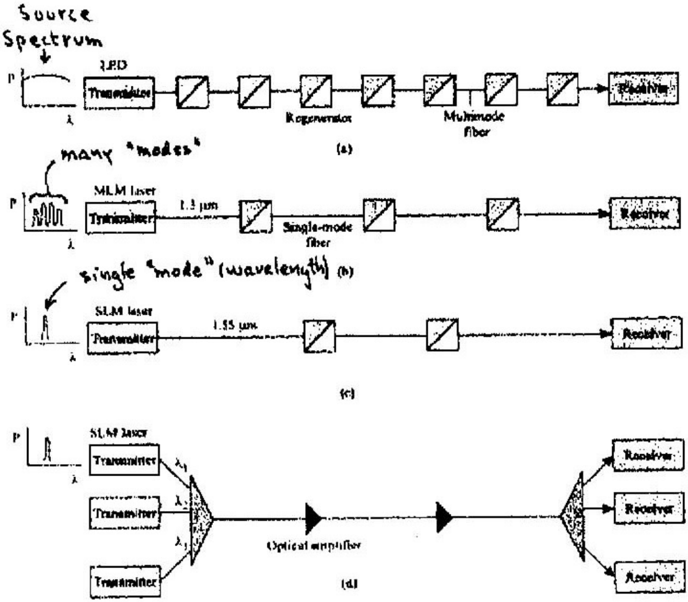


Figure 1.9 Evolution of optical fiber transmission systems. (a) An early system using LEDs over multimode fiber. (b) A system using MLM lasers over single-mode fiber in the 1.3 μm band to overcome modal dispersion in multimode fiber. (c) A later system using the 1.55 μm band for lower loss, and using SLM lasers to overcome chromatic dispersion limits. (d) A current-generation WDM system using multiple wavelengths at 1.55 μm and optical amplifiers instead of regenerators.

Basic Optical Communications Systems



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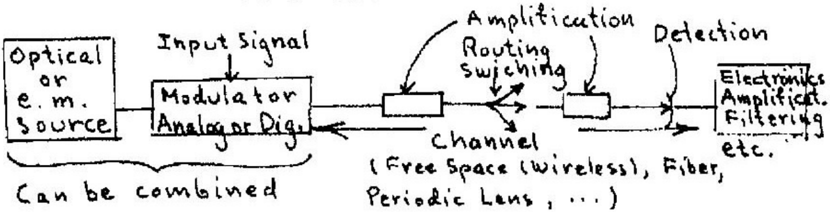
Basic Communication Link



Optical Fiber Characteristics

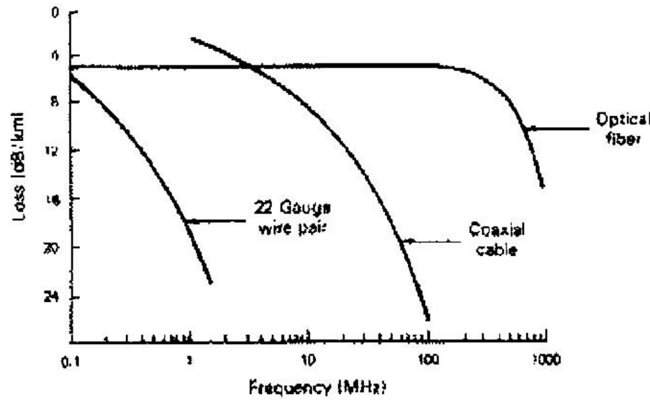


FIGURE 4-5. Comparison of Optical Fiber, Coaxial Cable, and Wire Pair [STAL83]

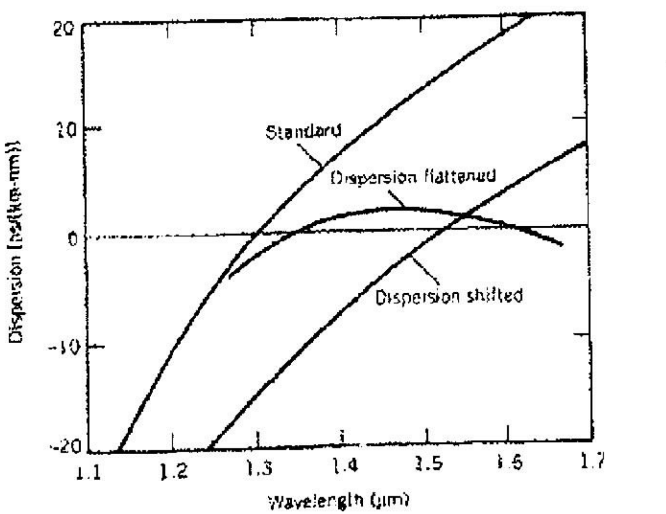


Figure 2.11 Typical wavelength dependence of the dispersion parameter D for standard, dispersion-shifted, and dispersion-flattened fibers.

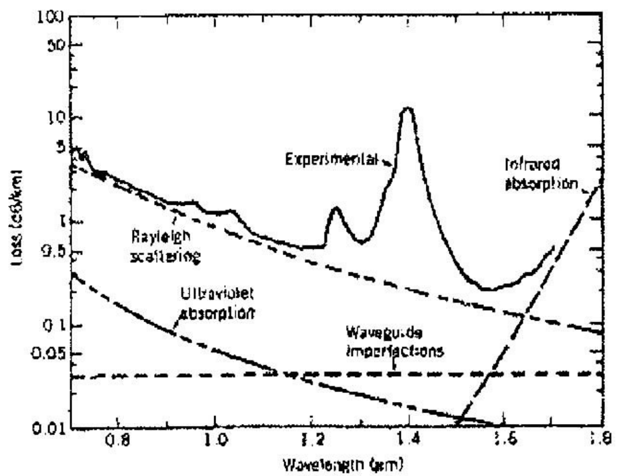


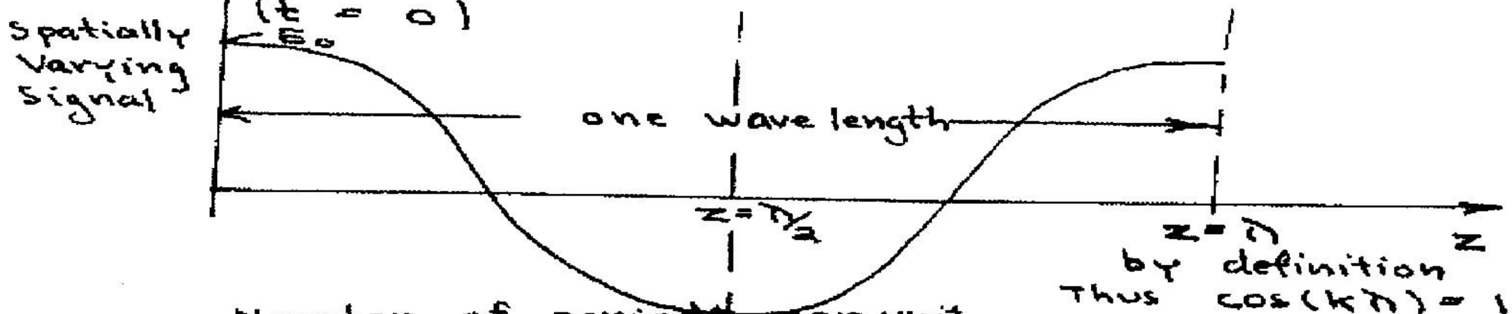
Figure 2.15 Spectral loss profile of a single-mode fiber. Wavelength dependence of fiber loss for several fundamental loss mechanisms is also shown. (After Ref. [11]. ©1979 IEE. Reprinted with permission.)

Basic Properties of Waves

Electric Field Component $= E_o \cos(\omega t - kz)$

$= \frac{E_o}{2} e^{i(\omega t - kz)} + \text{c.c.}$

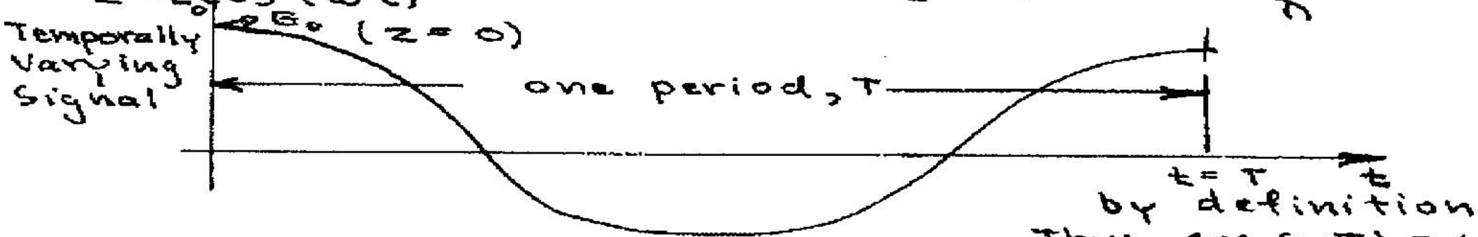
$E = E_o \cos(kz)$



by definition
Thus $\cos(k\lambda) = 1$
$k\lambda = 2\pi$ or
$k = \frac{2\pi}{\lambda}$

Number of periods per unit length $= \frac{1}{\lambda} = \frac{k}{2\pi} \triangleq$ Spatial frequency

$E = E_o \cos(\omega t)$



by definition
Thus $\cos(\omega T) = 1$
$\omega T = 2\pi$
$\omega = \frac{2\pi}{T}$

Number of periods per second $= \frac{1}{T} \triangleq f =$ "frequency"

<u>Observations</u>

1) $\frac{\omega}{k} = \frac{2\pi}{T} \cdot \frac{\lambda}{2\pi} = \lambda/T = \lambda f$

2) $f = \frac{1}{T} =$ no. of cycles per sec
$=$ frequency

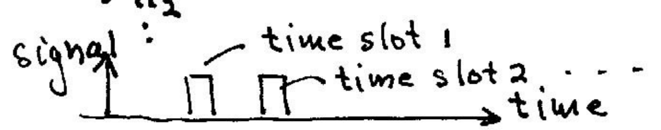
phase velocity → 3) To sit on the peak of the wave
$\omega t - kz = 0$ Thus $z/t = \omega/k = \boxed{\lambda f = c}$

4) c is the speed of light 299,792,458 m/s

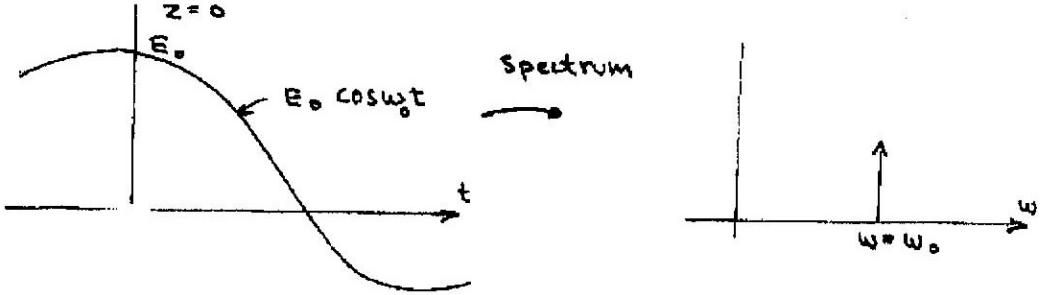
Leads to two fundamental types of modulation

1) wave division λ_1, λ_2, ⋮

2) time division



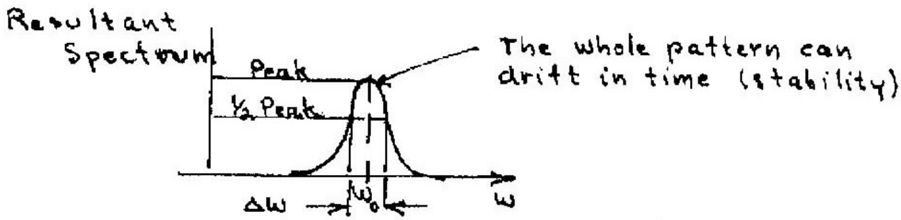
Spectral Content



a) Ideal Continuous Cosine at z = 0

b) Laser – Non-ideal and Thus Has

1) ω_0 varying in time (stability) (drift).
2) rapid variation due to "phase fluctuations" and amplitude fluctuations.
3) When modulated with a signal the electric field spectrum is further broadened.



$= 2\pi\,\Delta f$ (Spectral Width) or (Linewidth)

Example question!

If $\Delta f = 100\,\text{MHz}$ at $\lambda_0 = 1\,\mu\text{m}$, what is $\Delta\lambda$ in nanometers.

Ans. $\frac{1}{3000}$ nm

Sol^{n} $\lambda f = c \Rightarrow \Delta\lambda f + \lambda\Delta f = 0 \Rightarrow \Delta\lambda = -\frac{\lambda}{f}\Delta f$

Thus $\Delta\lambda = -(\lambda^2/c)\Delta f = -(1\times10^{-4})^2 \times \frac{1}{3\times10^{10}} \times (10^8) \times \frac{1}{100} \times 10^{9}$ nm.

Three Parameters For Optical Fibers

1) Loss

$$\text{Loss in dB} = -10 \lg_{10} \frac{P_o}{P_i}$$

Power decreases exponentially with distance

$$P_o = P_i e^{-\alpha L}$$ α is loss in nepers / m

Thus loss in dB $= -10 \lg_{10}(e^{-\alpha L})$

$= -10 \lg_e (e^{-\alpha L}) \lg_{10} e)$

$= .10 (\alpha) \times .4343$

$= 4.343 \alpha$

2) Dispersion $\approx$ 10 psec / nm / km = D

amount of broadening in picoseconds

bandwidth of the signal

fiber length

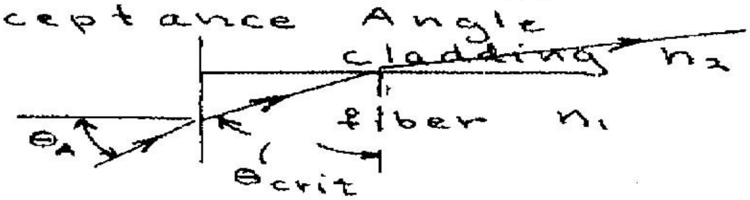
$\boxed{\Delta\tau = D \Delta\lambda L}$

Example: If Δf of the signal is 10 GHz what is the broadening per km

ans 10 psec × ($\Delta\lambda$) × 1 km

$= 10 \text{ psec} \times (\frac{1}{30} \text{ nm}) \times 1 \text{ km} = \frac{1}{3} \text{ psec}$

3) Acceptance Angle



Problem
Show that

$\boxed{\sin\theta_A = [n_1^2 - n_2^2]^{1/2}}$

(see next)

Fiber Loss

$\simeq 1.55\ \mu m$ - lowest loss

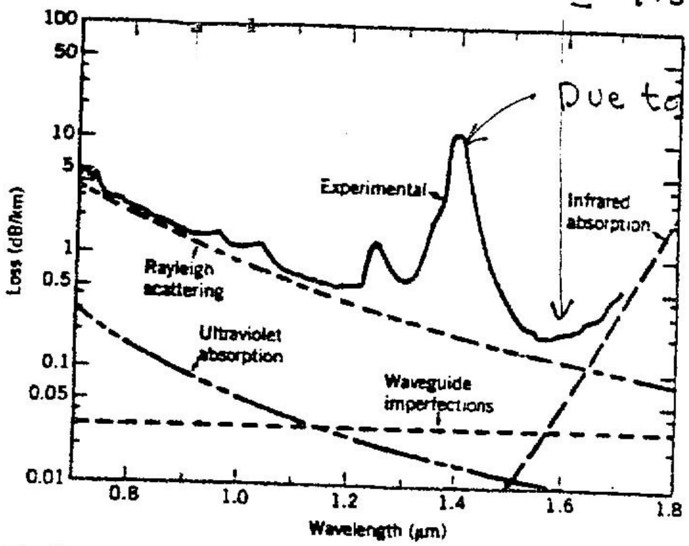
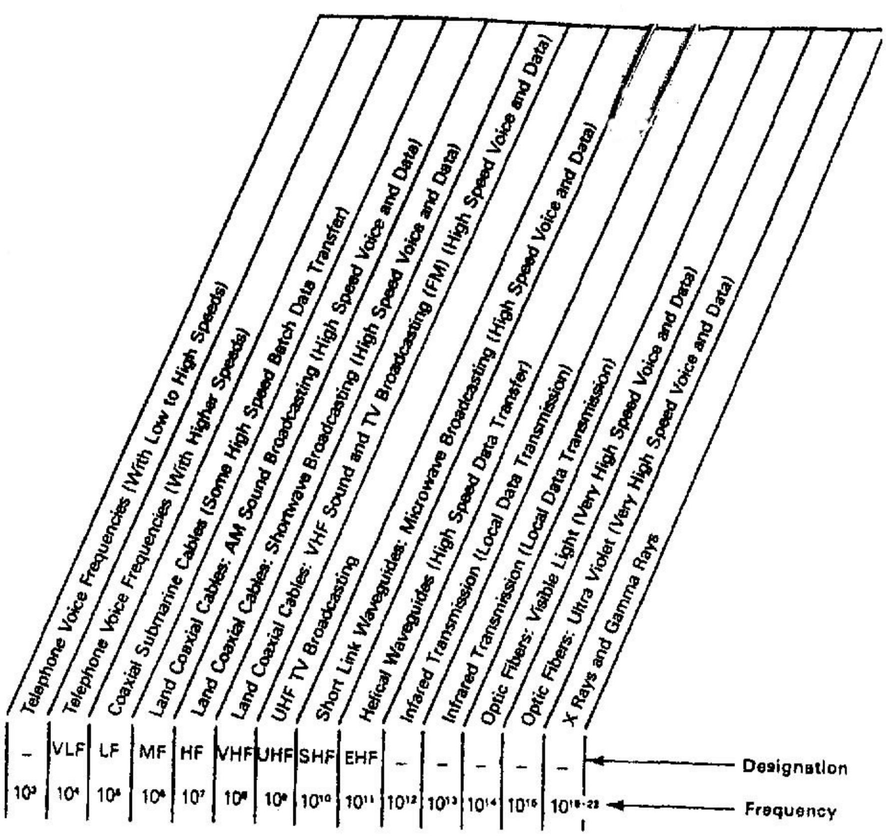
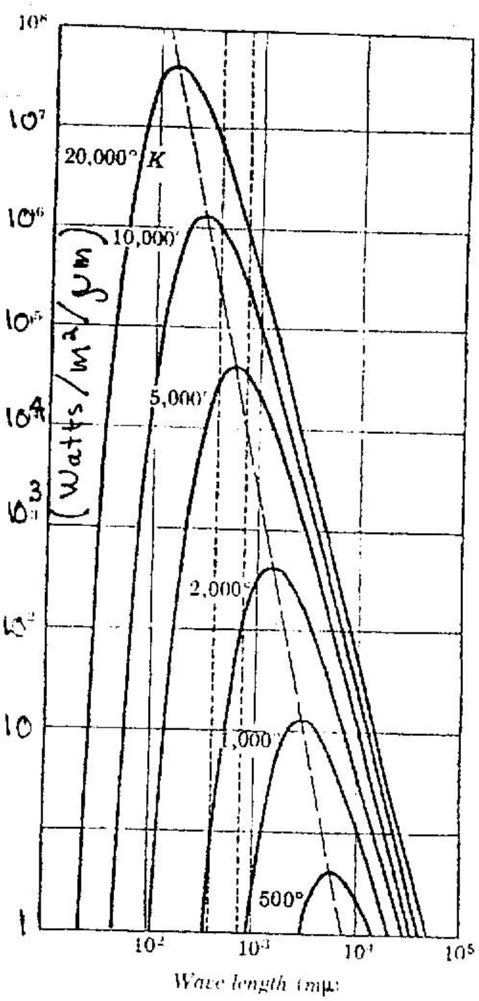


FIGURE 2.15 Spectral loss profile of a single-mode fiber. Wavelength dependence of fiber loss for several fundamental loss mechanisms is also shown. (After Ref. 11. Courtesy of IEE.)



Note: Applications may "overlap" the frequency designations or not use the entire frequency spectrum. For example, the highest UHF TV Channel (83) is 8.84 - 8.90 • 10^8 Hertz.

Frequency Designations



12-5. Spectral emittance of a blackbody at temperatures. The vertical dotted lines in- the boundaries of the visible spectrum.

Black Body Spectral ~~power~~ intensity

Phase velocity

signal = $A\cos(\omega t - kz)$ — one frequency

$\omega t - kz = \text{const.}$

$\therefore\ dz/dt = \omega/k$ = phase velocity = v_{ph},

$$= A\cos((\omega_1+\omega_2)t - (k_1+k_2)z) \quad - v_{ph} = \frac{\omega_1+\omega_2}{k_1+k_2}$$

$$\cos(\omega_1 t - k_1 z)\cos(\omega_2 t - k_2 z) - \sin(\omega_1 t - \cancel{k_1 z})\sin(\omega_2 t - k_2 z)$$

$$+ A\cos((\omega_1-\omega_2)t - (k_1-k_2)z) \quad - v_{ph} = \frac{\omega_1-\omega_2}{k_1-k_2}$$

$$\cos(\omega_1 t - k_1 z)\cos(\omega_2 t - k_2 z) + \sin(\omega_1 t - \cancel{k_1 z})\sin(\omega_2 t - k_2 z)$$

$$= 2A\cos(\omega_1 t - k_1 z)\cos(\omega_2 t - k_2 z)$$

$v = \omega_1/k_1 = v_{ph}$ $\qquad$ $v = \omega_2/k_2$

ω_2 small $= \Delta\omega$; $k_2 = \Delta k$ $\therefore\ v_g = \dfrac{\Delta\omega}{\Delta k} \rightarrow \dfrac{d\omega}{dk}$ = group velocity

Dispersion $\qquad T$ for a "group" $= \left(\dfrac{d\omega}{dk}\right)^{-1} L$

L = propagation length

This is speed of a pulse

Pulse spread $= \Delta T = \Delta\left(\dfrac{1}{\frac{d\omega}{dk}}\right) L = \Delta\left(\dfrac{dk}{d\omega}\right) L$

$$= \frac{d^2k}{d\omega^2} L\,\Delta\omega$$

$$\Delta T = L\,\Delta\omega \frac{d^2k}{d\omega^2} = \frac{d^2n}{d\lambda^2}\Delta\lambda\,\frac{\lambda}{c}\,L = \left(\frac{\lambda}{c}\frac{d^2n}{d\lambda^2}\right)(\Delta\lambda\, L)$$