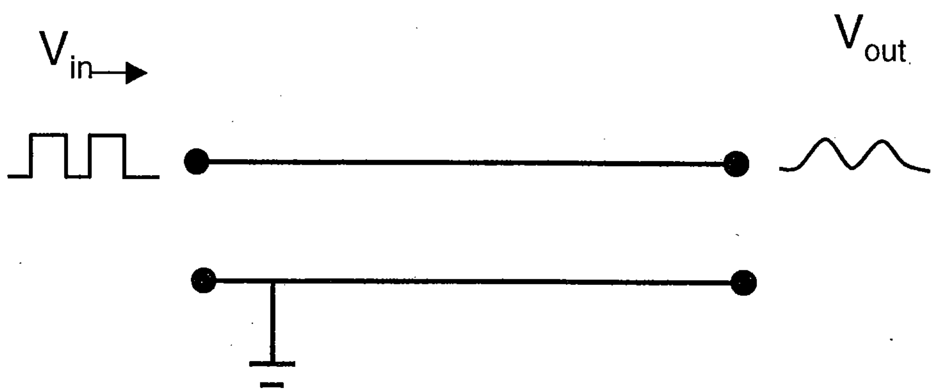
What's wrong with electrical transmission?

The maximum rate of information information transfer is limited by the number of bits per second that can be transmitted.

As the bit rate increases, the individual pulse representing a bit must be turned on and off faster.

The non-zero resistance of the metal and capacitance in a metal cable limit this transition time to τ > 10 nanoseconds (10×10^{-9} seconds).

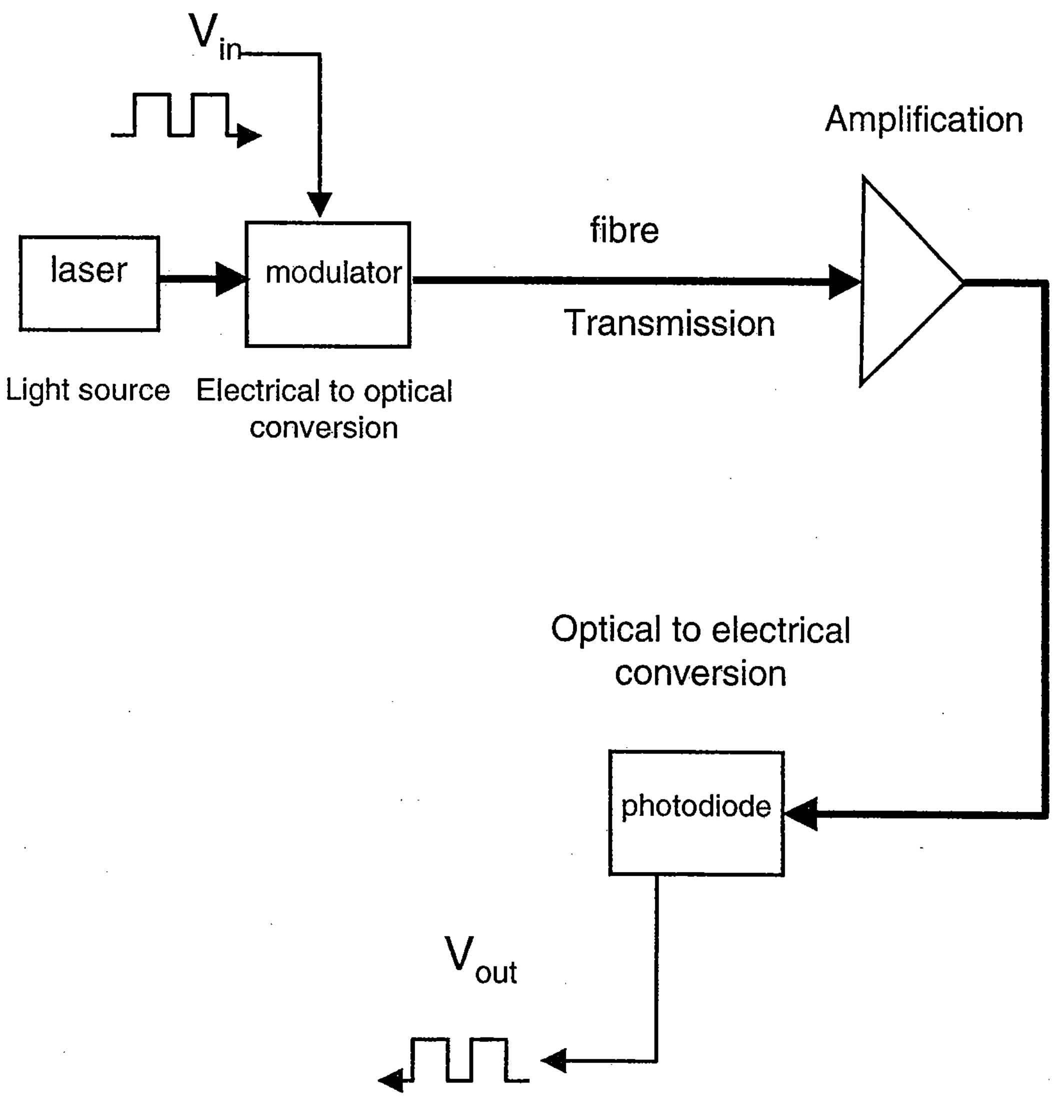
Maximum bit rate ~ 100's of megabits/second



Electrons vs. Photons

Electrical transmission	**Optical transmission**
? > 10 nanoseconds = 10^{-8} s *bandwidth limited*	? > 100 picoseconds = 10^{-11} s *dispersion and electronics limited*
Bandwidth ~ 100 MHz = 10^{8} Hz	Bandwidth ~ 100 THz = 10^{14} Hz
Electromagnetic interference	No EMI
Copper or Aluminum ($$, large and heavy)	Glass (cheaper, small, light, but more fragile)
Energy loss, signal attenuation > 20 dB/km	Attenuation ~ 0.2 dB/km
Signal remains electrical	Signal must be converted electrical ⇒ optical ⇒ electrical

An optical communication system



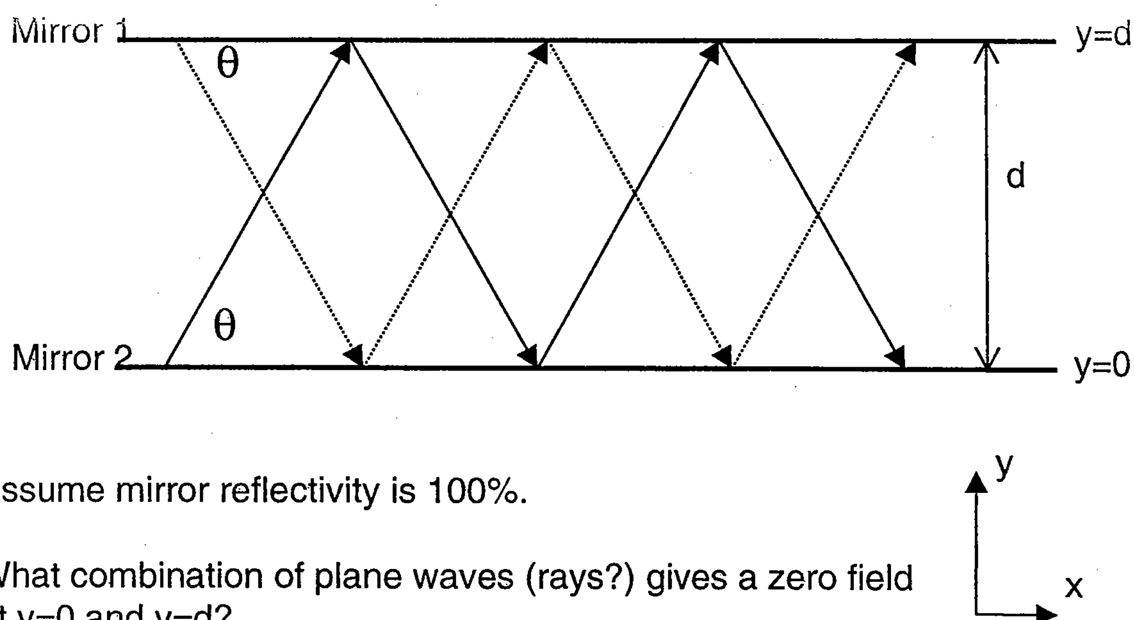
Lecture 21:optical systems

Transmission

Free space beam propagation is not practical due to rain, fog, line of sight problems, etc.

An optical equivalent of electrical wire is needed.

Optical waveguides - ray optic picture



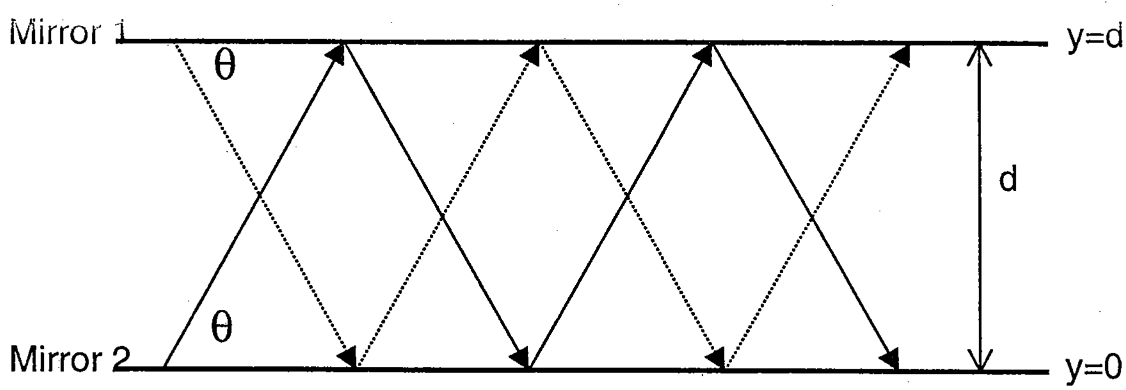
Assume mirror reflectivity is 100%.

What combination of plane waves (rays?) gives a zero field at y=0 and y=d?

$$E_+(x,y) = A\sin(k_x x + k_y y - \omega t + \phi)$$

$$E\_(x,y) = B\sin(k_x x - k_y y - \omega t + \phi)$$

Optical waveguides



$$E_{total} = E_{+} + E_{-} = 2A\sin(k_y y)\cos(k_x x - \omega t + \phi)$$

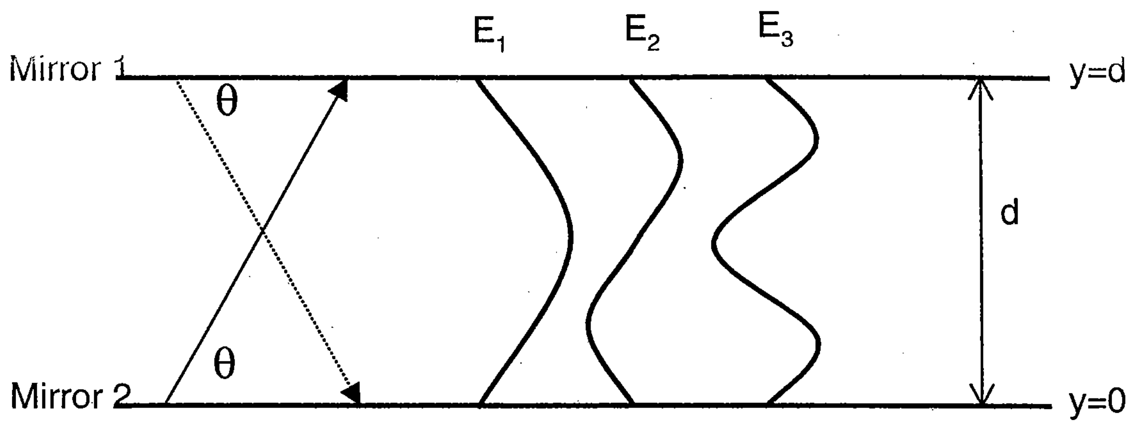
To satisfy boundary conditions, must have:

where integer ***m*** is the ***mode*** number.

$$k_y = \frac{m\pi}{d}$$

Lecture 21:optical systems

Waveguide modes



Mode field profile:

$$E_m = D\ \sin(\frac{\pi\ m}{d}\ y)\cos(\beta_m x - \omega\ t + \phi)$$

Mode propagation constant:

$$\beta_m = \frac{n\omega}{c} \cdot \cos\theta_m$$

- Light can only propagate in the form of these modes inside a waveguide!

Waveguide modes (continued)

$$\beta_m = \frac{n\omega}{c} \cdot \cos\theta_m$$ ⇒ the mode wavevector or propagation constant

$$\sin\theta_m = \frac{c}{n\omega} \cdot \frac{m\pi}{d}$$ ⇒ β_m can only have discrete values!

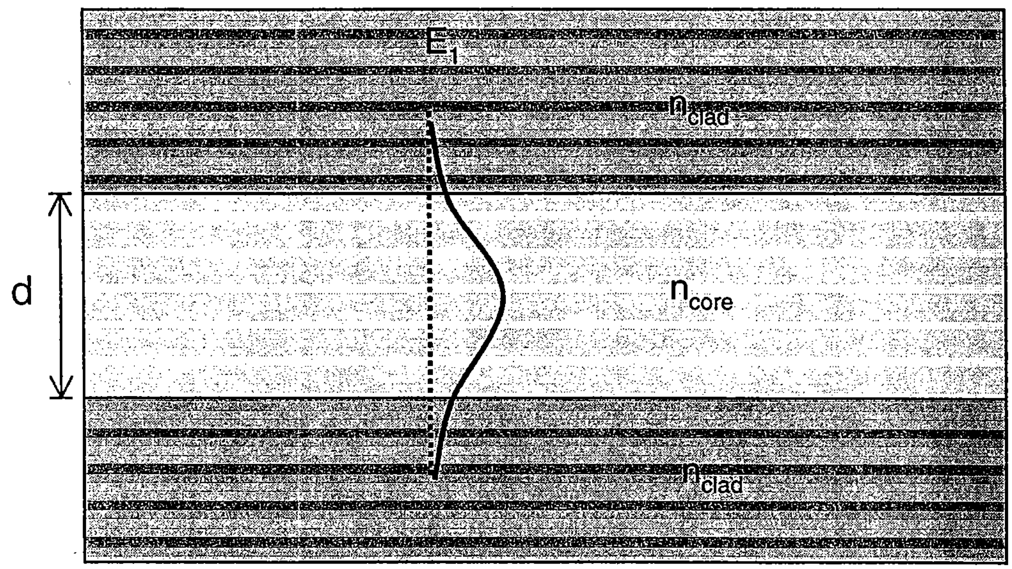
Mode effective index: $$N_{eff} = \beta_m \cdot \frac{c}{\omega}$$

Speed of light depends on the mode: $v_m = c/N_{eff}$

⇒ *Mode dispersion*

Real optical waveguides

Real waveguides for long distance propagation must use ***total internal reflection*** for confining light; otherwise losses are too high



Total internal reflection $\Rightarrow$ $n_{clad} < n_{core}$

- Choose (n_{core} - n_{clad}) and core diameter *d* small enough that only the fundamental E_1 mode is supported

Real waveguides

- Real waveguides must use total internal reflection, so that reflection induced losses are zero.

- $n_{core} > n_{clad}$

- θ_m must be less than the critical angle for total internal reflection, hence the number of modes is restricted.

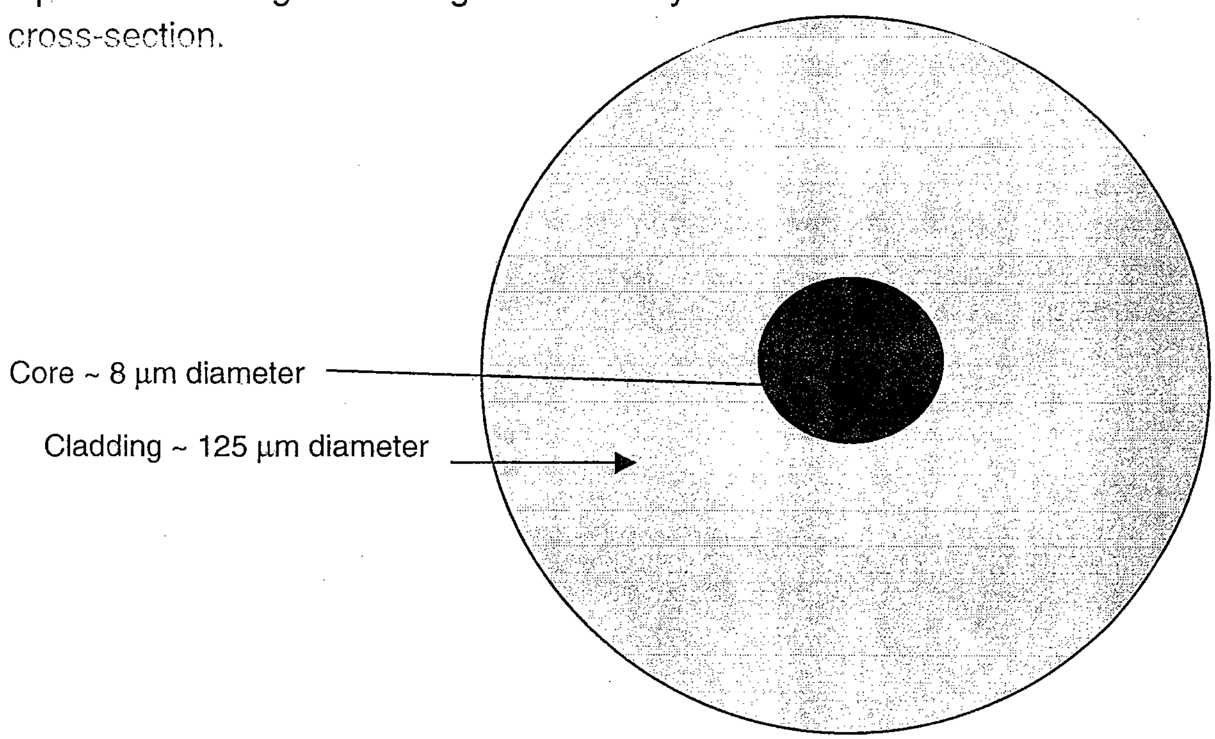
- It is possible to make single mode waveguides, for small index difference and/or small core thicknesses.

- Guided light spills over into evanescent tails in the cladding regions.

- The effective index N_{eff} always lies somewhere between the index of the core and the index of the cladding.

Optical Fibre

Optical fibre is a glass waveguide with a cylindrical cross-section.



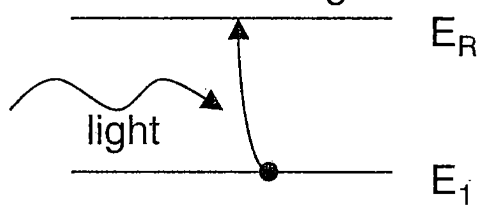
λ = 1300 nm   wavelength of **minimum index dispersion** (the variation of index n with wavelength- an intrinsic property of glass)

λ = 1550 nm   wavelength of **minimum loss** (due to impurities and molecular vibration absorption by O-H, Si-H).

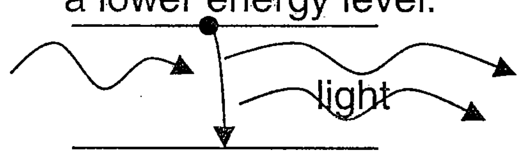
Signal regeneration - optical amplifiers

In any atom or solid, the state of the electrons can change by:

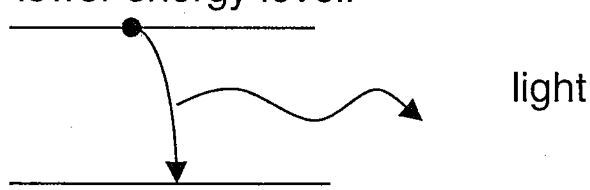
1) Stimulated absorption - in the presence of a light wave, a photon is absorbed, the electron is excited to a higher energy level.



2) Stimulated emission - in the presence of a light wave, a photon is emitted, the electron drops too a lower energy level.



3) Spontaneous emission - in the absence of light, a photon is emitted and the electron drops to a lower energy level.



NOTE: For stimulated processes , the absorbed or emitted photon has exactly the same phase ϕ and frequency ω (or wavelength λ) as the stimulating light.