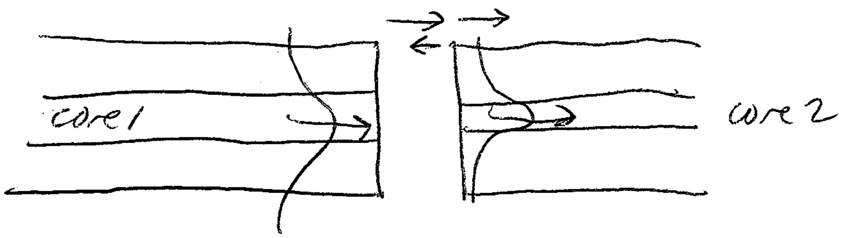
Waveguide coupling



Coupling efficiency between two w.g.'s, apply continuity of transverse electric + magnetic fields

$\mathcal{E}$ and $\mathcal{H}$ are spatial mode profiles (not polarization)

$$\mathcal{E}_i(x) + r\,\mathcal{E}_i(x) + \int r(\beta)\,\mathcal{E}_\beta(x)\,d\beta = t\,\mathcal{E}_t(x) + \int t(\beta)\,\mathcal{E}_\beta(x)\,d\beta$$

$$\mathcal{H}_i(x) - r\,\mathcal{H}_i(x) - \int r(\beta)\,\mathcal{H}_\beta(x)\,d\beta = t\,\mathcal{H}_t(x) + \int t(\beta)\,\mathcal{H}_\beta(x)\,d\beta$$

r, t are amplitude reflection + transmission coef.

$\mathcal{E}_\beta$ and $\mathcal{H}_\beta$ are radiation modes, assume negligible

→ mult. by $\mathcal{E}_t^*$ and integrate

$$\frac{1}{2}\int \mathcal{E}_n \mathcal{E}_m^* = \frac{\omega\mu}{\beta_n}\,\delta_{nm}$$

$$t = \frac{\beta_t}{2\omega\mu}(1+r)\int \mathcal{E}_i(x)\,\mathcal{E}_t^*(x)\,dx$$

$$\left[\ \mathcal{H}_x = -\frac{\beta}{\omega\mu}\,\mathcal{E}_y \quad \leftarrow \text{prop const.}\right.$$

$$\left.\Rightarrow \frac{1}{2}\int \mathcal{E}_n(x)\,\mathcal{E}_m(x)\,dx = \frac{\omega\mu}{\beta_n}\,\delta_{nm}\ \right]$$

doing the same for $\mathcal{H}$

$$t = \frac{\beta_i}{2\omega\mu}(1-r)\int \mathcal{E}_i(x)\,\mathcal{E}_t^*(x)\,dx$$

$$t = \frac{2\beta_t}{\beta_i+\beta_t}\cdot\frac{\beta_i}{2\omega\mu}\int \mathcal{E}_i \mathcal{E}_t^* \, dx$$

? ←

$$r = \beta_i - \beta_t / \beta_i + \beta_t$$

look's like fresnel coefficients

for non-normalized modes

$$\eta = |t|^2 = \left[\frac{4\beta_i\beta_t}{(\beta_i+\beta_t)^2}\right] \frac{\left[\int E_t E_i^* \, dx\right]^2}{\int |E_t|^2 dx \int |E_i|^2 dx}$$

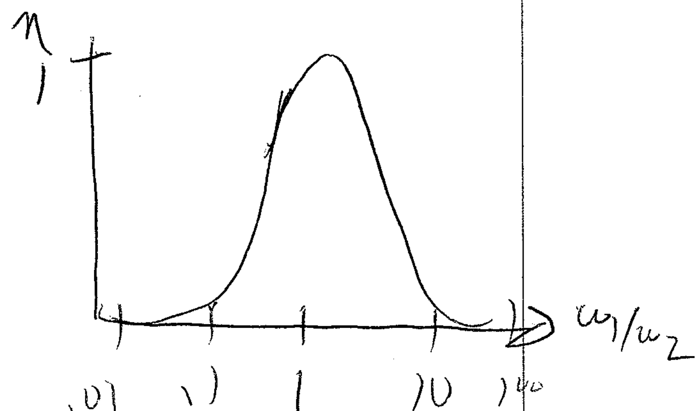
ex. 11.1 Fiber to fiber coupling

HE_{11} modes ~ Gaussian radii w_1 and w_2 (MFD)

assume $\beta_1 \approx \beta_2$

$$\eta = \frac{\left[\int_0^\infty\int_0^{2\pi} A_1 e^{-r^2/w_1^2} A_2 e^{-r^2/w_2^2} \, r\,dr\,d\phi\right]^2}{\int_0^\infty\int_0^{2\pi} A_1^2 e^{-2r^2/w_1^2} \, r\,dr\,d\phi \int_0^\infty\int_0^{2\pi} A_2^2 e^{-2r^2/w_2^2} \, r\,dr\,d\phi}$$

$$= 4\frac{w_1^2 w_2^2}{(w_1^2+w_2^2)^2}$$



ex. 11.2 - Gaussian beam to fiber

$\lambda = 1.52\,\mu m$ from laser $w_0 = 1\,mm$

Fiber has MFD of $10\,\mu m$

spot size @ fiber $w_1 = \frac{2\pi}{\lambda}\frac{f}{w_0} = 2\times 6.9\times10^{-4} f$

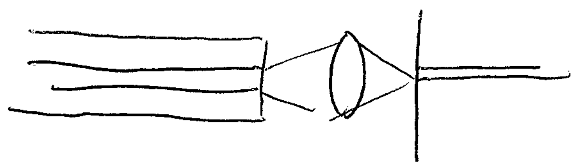
w_1 needs to match $w_2 = 10\,\mu m/2 = 5\,\mu m \Rightarrow f = .723\,cm$

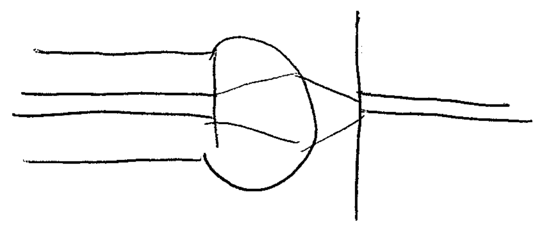
Fresnel losses $R = \left(\frac{\beta_1-\beta_2}{\beta_1+\beta_2}\right)^2 = \left(\frac{n_{eff}-1}{n_{eff}+1}\right)^2$

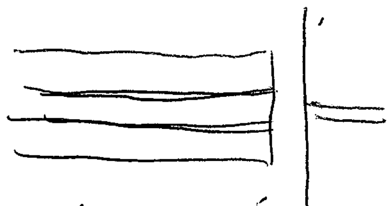
$n_{eff} \approx 1$, so that $R \sim 4\%$

max coupling ~ 96%, good ~ 80%

Coupling fiber to integrated waveguide

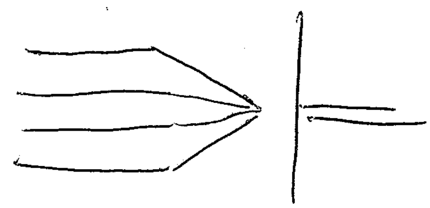




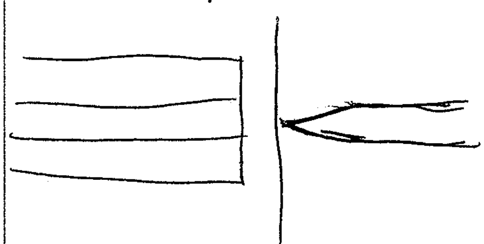


edge coupling

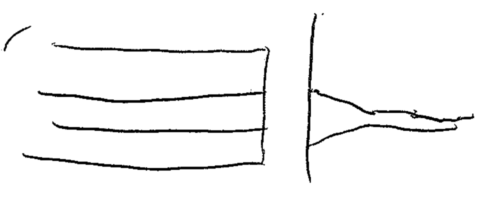
horn taper



inverse taper



or



For edge coupling $\eta = 4\left(\frac{n^i_{eff}\, n^t_{eff}}{(n^i_{eff}+n^t_{eff})^2}\right) \frac{4w_1^2 w_2^2}{(w_1^2+w_2^2)^2}$

(verify by BPM)

to a Si/SiO_2 wg. of .5μm MFD from 10μm MFD fiber

$\eta \sim 1\%$

taper purpose is to convert mode size w/o generating radiation modes

inverse taper - same, but reduce confinement by making core small