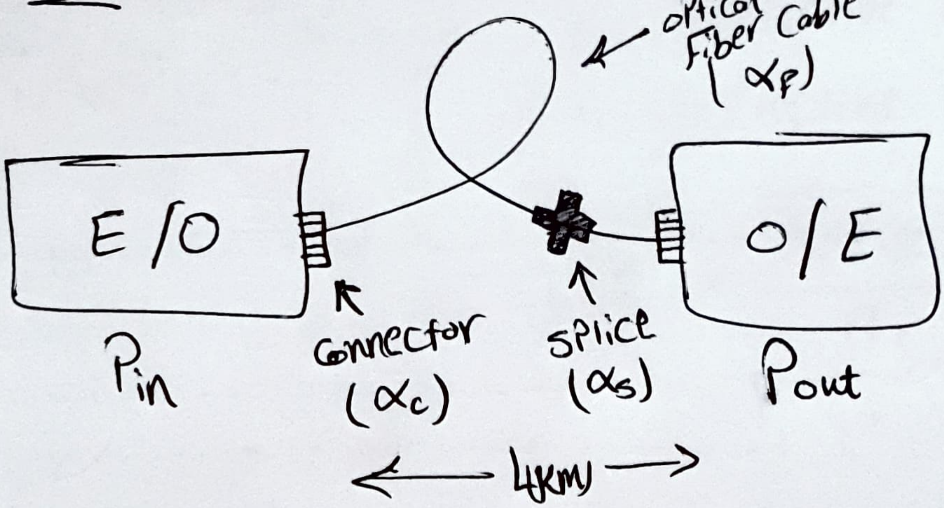
EL DOFD3
ORGANIZATION

Sheet 01 (Laws Zatoona) & Answers

References
Mokhtar Sections

Electromagnetic Waves 2

No Excellence
Just Pass



attenuation in optical fiber communication

$$\alpha_t \Big|_{dB} = 10 \log\left(\frac{P_{in}}{P_{out}}\right) = P_{in}\Big|_{dB} - P_{out}\Big|_{dB}$$

α_f : optical fiber attenuation cofficient (dB/Km)

α_s : splice attenuation cofficient (dB/splice)

α_c : connector attenuation cofficient (dB/connector)

n : no. of sections

$$n = \frac{\text{total fiber length}}{\text{reel length}}$$

$(n-1)$: no. of splices

α_{ICL} : input coupling loss

α_{OCL} : output coupling loss

$$\alpha_t \Big|_{dB} = \alpha_f L + (n-1)\alpha_s + 2\alpha_c + \alpha_{ICL} + \alpha_{OCL}$$

waves sec 2

Numerical aperture

n_1: reflective index of core

n_2: reflective index of cladding

$$\boxed{N_A = \sqrt{n_1^2 - n_2^2}}$$

$$\boxed{N_A = n_1\sqrt{2\Delta}}$$

$$\Delta = \frac{n_1 - n_2}{n_1}$$

$$n = \frac{C}{V}$$

Δ; Fractional difference index

C: velocity of Light ($3 * 10^8$)

V: velocity in the meduim

$$\boxed{\theta_{max} = \sin^{-1}(N_A)}$$

θ_{max}: the acceptance angle

The normalized Frequency

$$\boxed{V = \frac{\pi d}{\lambda} N_A}$$

d → Core diameter

$$\boxed{V = \frac{2\pi a}{\lambda} N_A}$$

a → Core radius

note

For single mode optical Fiber (SM)

$$\boxed{V = 2.405}$$

The no. of modes (M)

note assume (α) = 2 if not given

$$\boxed{M\big|_{SI} = \frac{V^2}{2}}$$

$$\boxed{M\big|_{GI} = \left(\frac{\alpha}{\alpha+2}\right) M\big|_{SI}}$$

$$\boxed{M\big|_{GI} = \left(\frac{\alpha}{\alpha+2}\right) a^2 K^2 n_1^2 \Delta}$$

$$\boxed{K = \frac{2\pi}{\lambda}}$$

The Fractional Power wasted in Cladding

$$\boxed{\frac{P_{cladding}}{P_{Total}} = \frac{4}{3\sqrt{M}}}$$

Sheet (1) <u>Waves</u>

(1) $\alpha_F = 1.5\ dB/Km$ $\quad P_{in} = 0.5\ mW$ $\quad P_{out} = ??$

$L = 8\ Km$ $\quad$ max reel length $= 2\ Km$

$\alpha_s = 0.1\ dB/splice$ $\quad \alpha_{ICL} = 1\ dB$ $\quad \alpha_{OCL} = 2\ dB$

$$n = \frac{\text{total Fiber length}}{\text{reel length}} = \frac{8}{2} = 4$$

must be intger

$$\alpha_t|_{dB} = \alpha_F L + (n-1)\alpha_s + \underbrace{2\alpha_c}_{0} + \alpha_{ICL} + \alpha_{OCL}$$

$$\alpha_t|_{dB} = (1.5 * 8) + (3 * 0.1) + 1 + 2 = 15.3\ dB$$

$$\alpha_t|_{dB} = P_{in}|_{dB} - P_{out}|_{dB} \Rightarrow P_{out}|_{dB} = P_{in}|_{dB} - \alpha_t$$

$$P_{out}|_{dB} = 10 \log(0.5) - 15.3 = -18.3\ dB$$

$$P_{out} = 10^{-1.83} = \boxed{0.0148\ mW}$$

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(2) $L = 3.5\ Km$ $\quad$ max reel length $= 3\ Km$ $\quad \alpha_s = 0.2$

$\alpha_{ICL} = 1\ dB$ $\quad \alpha_{ocl} = 0.8\ dB$ $\quad P_{out} = 0.45\ P_{in}$

$$\alpha_t = 10 \log\left(\frac{P_{in}}{P_{out}}\right) = 10 \log\left(\frac{\cancel{P_{in}}}{0.45\cancel{P_{in}}}\right) = 3.47\ dB$$

$$n = \frac{\text{total Fiber length}}{\text{reel Length}} = \frac{3.5}{3} = 2$$

$$\alpha_t = \alpha_F L + (n-1)\alpha_s + \underbrace{2\alpha_c}_{0} + \alpha_{Icl} + \alpha_{OCL}$$

$$3.47 = 3.5\,\alpha_F + (1*0.2) + 1 + 0.8$$

$$\alpha_F = \frac{(3.47-0.2-1-0.8)}{3.5} = \boxed{0.42\ dB/Km}$$

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(3) $\alpha_F = 0.5\ dB/Km$ $\quad P_{in} = 1\ mW \quad P_{out} = 0.1\ mW$

$L = ??$ $\quad \alpha_s, \alpha_c, \alpha_{ICL}, \alpha_{OCL} \Rightarrow$ ignored

$$\alpha_t = 10\ \text{Log}\left(\frac{P_{in}}{P_{out}}\right) = 10\ \text{Log}\left(\frac{1}{0.1}\right) = 10\,dB$$

$$\alpha_t = \alpha_F L \Longrightarrow L = \frac{\alpha_t}{\alpha_F} = \frac{10}{0.5} = \boxed{20\ Km}$$

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(4) $L = 12\,Km$ $\quad \alpha_F = 1.5\ dB/Km \quad P_{in} = ?? \quad P_{out} = 0.3\,\mu W$

max reel length $= 3\,Km$ $\quad \alpha_s = 0.1$

the Coupling Losses are (2dB) at each transmit and recieve end. $\Longrightarrow \alpha_{ICL} = 2\,dB$, $\alpha_{OCL} = 2\,dB$

$$n = \frac{12}{3} = 4$$

$$\alpha_t = \alpha_F L + (n-1)\alpha_s + \cancel{2\alpha_c}^{\,0} + \alpha_{ICL} + \alpha_{OCL}$$

$$\alpha_t = (1.5*12) + (3*0.1) + 2 + 2 = 22.3\ dB$$

$$\alpha_t\big|_{dB} = P_{in}\big|_{dB} - P_{out}\big|_{dB} \Longrightarrow P_{in}\big|_{dB} = P_{out}\big|_{dB} + \alpha_t\big|_{dB}$$

$$P_{in}\big|_{dB} = 10\ \text{Log}(0.3) + 22.3 = 17.071\,dB$$

$$P_{in} = 10^{1.7071} = \boxed{51\ \mu W}$$

(5) 50/125 step index $n_1 = 1.48$ $n_2 = 1.465$

50 → Core diameter (μm)

125 → cladding diameter (μm)

$\lambda = 1320\, nm$

$$NA = \sqrt{n_1^2 - n_2^2} = \sqrt{(1.48)^2 - (1.465)^2} = \boxed{0.21}$$

$$\theta_{max} = \sin^{-1}(NA) = \sin^{-1}(0.21) = \boxed{12.13^\circ}$$

$$V = \frac{\pi d}{\lambda} NA = \frac{\pi * 50*10^{-6}}{1320*10^{-9}} * 0.21 = 25$$

$$M|_{SI} = \frac{V^2}{2} = \frac{(25)^2}{2} = \boxed{312.5}$$

$$\frac{P_{cladding}}{P_{Total}} = \frac{4}{3\sqrt{M}} = \frac{4}{3\sqrt{312.5}} = \boxed{7.5\%}$$

For single mode fiber $\Longrightarrow V = 2.405$

$$d = \frac{V\lambda}{\pi NA} = \frac{2.405 * 1320*10^{-9}}{\pi * 0.21} = \boxed{4.812\, \mu m}$$

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(6) $a = 25\, \mu m$ $n_1 = 1.48$ $\Delta = 0.01$ $\lambda = 0.84\, \mu m$

$$NA = n_1 \sqrt{2\Delta} = 1.48\sqrt{2*0.01} = \boxed{0.21}$$

$$V = \frac{2\pi a}{\lambda} NA = \frac{2\pi * 25*10^{-6}}{0.84*10^{-6}} * 0.21 = \boxed{39.27}$$

$$M|_{SI} = \frac{V^2}{2} = \frac{(39.27)^2}{2} = \boxed{771}$$

$$\frac{P_{cladding}}{P_{Total}} = \frac{4}{3\sqrt{M}} = \frac{4}{3\sqrt{771}} = \boxed{4.8\%}$$

(7) single mode $\Rightarrow V = 2.405$ $d = 10\,\mu m$

$\lambda = 1.3\,\mu m$ $n_1 = 1.55$

$$V = \frac{\pi d}{\lambda} NA \Longrightarrow NA = \frac{V\lambda}{\pi d}$$

$$NA = \frac{2.405 * 1.3 * 10^{-6}}{\pi * 10 * 10^{-6}} = \boxed{0.0995}$$

$$NA = \sqrt{n_1^2 - n_2^2} \Longrightarrow (NA)^2 = n_1^2 - n_2^2$$

$$n_2 = \sqrt{n_1^2 \;\; NA^2} = \sqrt{(1.55)^2 - (0.0995)^2} = \boxed{1.5468}$$

$$\Delta = \frac{n_1 - n_2}{n_1} = \frac{1.55 - 1.549}{1.55} = \boxed{0.206\,\%}$$

$$\theta_{max} = \sin^{-1}(NA) = \sin^{-1}(0.09957) = \boxed{5.712^\circ}$$

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(8) $n_1 = 1.55$ $n_2 = 1.51$ $d = 50\,\mu m$ $\lambda = 0.8\,\mu m$

$$NA = \sqrt{n_1^2 - n_2^2} = \sqrt{(1.55)^2 - (1.51)^2} = \boxed{0.35}$$

$$\theta_{max} = \sin^{-1}(NA) = \sin^{-1}(0.35) = \boxed{20.487^\circ}$$

$$V = \frac{\pi d}{\lambda} NA = \frac{\pi * 50 * 10^{-6}}{0.8 * 10^{-6}} * 0.35 = \boxed{68.72}$$

$$M|_{SI} = \frac{V^2}{2} = \frac{(68.72)^2}{2} = \boxed{2361}$$

note
assume $\alpha = 2$ if not given

$$M|_{GI} = \left(\frac{\alpha}{\alpha+2}\right) M|_{SI} = \left(\frac{2}{2+2}\right) * 2361 = \boxed{1180}$$

9 $\lambda = 1300\text{ nm}$ Graded Index $(\alpha = 1)$

$n_1 = 1.48$ $n_2 = 1.46$ $d = 50\ \mu m$

$$NA = \sqrt{n_1^2 - n_2^2} = \sqrt{(1.48)^2 - (1.46)^2} = 0.24$$

$$V = \frac{\pi d}{\lambda} NA = \frac{\pi * 50 * 10^{-6}}{1300 * 10^{-9}} * 0.24 = 29$$

Step Index (SI)

$$M|_{SI} = \frac{V^2}{2} = \frac{(29)^2}{2} = \boxed{420}$$

$$\frac{P_{cladding}}{P_{Total}} = \frac{4}{3\sqrt{M}} = \frac{4}{3\sqrt{420}} = \boxed{6.5\ \%}$$

Graded Index (GI) $(\alpha = 1)$

$$M|_{GI} = \left(\frac{\alpha}{\alpha+2}\right) M|_{SI} = \left(\frac{1}{1+2}\right) * 420 = \boxed{140}$$

$$\frac{P_{cladding}}{P_{Total}} = \frac{4}{3\sqrt{M}} = \frac{4}{3\sqrt{140}} = \boxed{11.3\ \%}$$