Model Answer

Q1-1: The magnitude of the Fresnel reflection at the fiber–air interface is

$$r = (\frac{n_1 - n_2}{n_1 + n_2})^2 = (\frac{1.5 - 1}{1.5 + 1})^2 = 0.04$$

The optical loss in decibels at the single interface may

$$Loss_{Fres} = -10\ log_{10}(1 - r) = -10\ log_{10}(1 - 0.04) = 0.18\ dB$$

Hence the total loss due to Fresnel reflection at the fiber joint is approximately 0.36 dB.

Q1-2: State the main inherent connection problems when jointing fibers

(a) different core and/or cladding diameters;

(b) different numerical apertures and/or relative refractive index differences;

(c) different refractive index profiles;

(d) fiber faults (core ellipticity, core concentricity, etc.).

Q1-3: Assuming uniform illumination of guided modes only, the misalignment loss may be obtained using

$$L_t = 0.85\left(\frac{y}{a}\right) = 0.85\left(\frac{3}{25}\right) = 0.102$$

The coupling efficiency is

$$\eta_{lat} = 1 - L_t = 1 - 0.102 = 0.898$$

Hence the insertion loss due to the lateral misalignment is

$$Loss_{lat} = -10\ log_{10}0.898 = 0.47\ dB$$

(b) When assuming the uniform illumination of both guided and leaky modes Gloge's formula becomes:

$$L_t = 0.75\left(\frac{y}{a}\right) = 0.75\left(\frac{3}{25}\right) = 0.09$$

Therefore the coupling efficiency is:

$$\eta_{lat} = 1 - L_t = 1 - 0.09 = 0.91$$

and the insertion loss due to lateral misalignment is:

$$Loss_{lat} = -10\ log_{10}0.91 = 0.41\ dB$$

Q1-4: The angular coupling efficiency is

$$\eta_{ang} \approx \frac{16(n_1/n)^2}{(1 + n_1/n)^4}\ [1 - \frac{n\theta}{\pi n_1 (2\Delta)^{0.5}}]$$

$$\approx \frac{16(n_1/n)^2}{(1 + n_1/n)^4}\ [1 - \frac{n\theta}{\pi NA}]$$

For the NA = 0.2 fiber:

$$\approx \frac{16(1.48/1)^2}{(1 + 1.48)^4}\left[1 - \frac{\frac{5\pi}{180}}{\pi(0.2)}\right] = 0.797$$

The insertion loss due to the angular misalignment

$$Loss_{ang} = -10\ log_{10}0.797 = 0.98\ dB$$

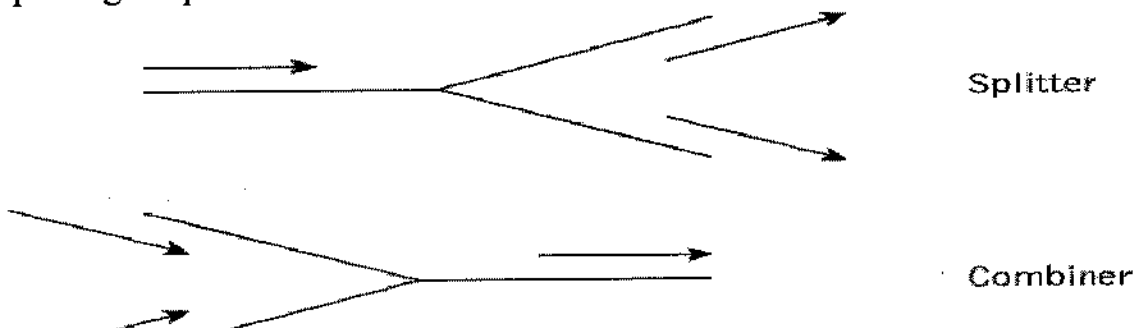
For the NA = 0.4 fiber:

$$\approx \frac{16(1.48/1)^2}{(1+1.48)^4}\left[1-\frac{\frac{5\pi}{180}}{\pi(0.4)}\right] = 0.862$$

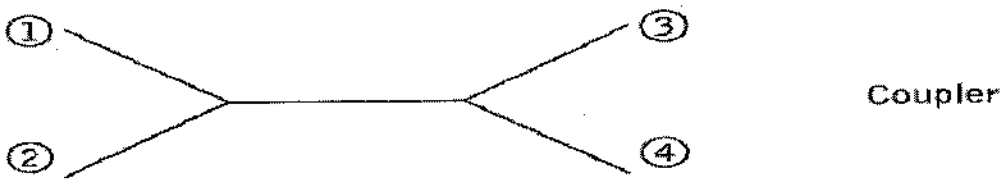
The insertion loss due to the angular misalignment

$$Loss_{ang} = -10\ log_{10}0.862 = 0.644\ dB$$

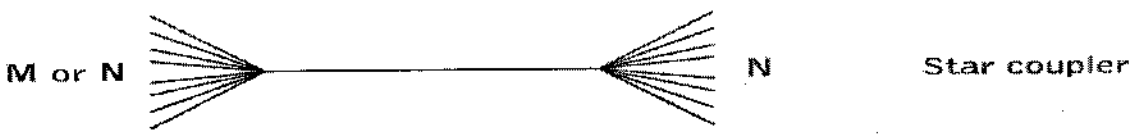
Q1-5: Optical fiber coupler types and functions: (a) three-port couplers; (b) four-port coupler; (c) star coupler; (d) wavelength division multiplexing and demultiplexing couplers



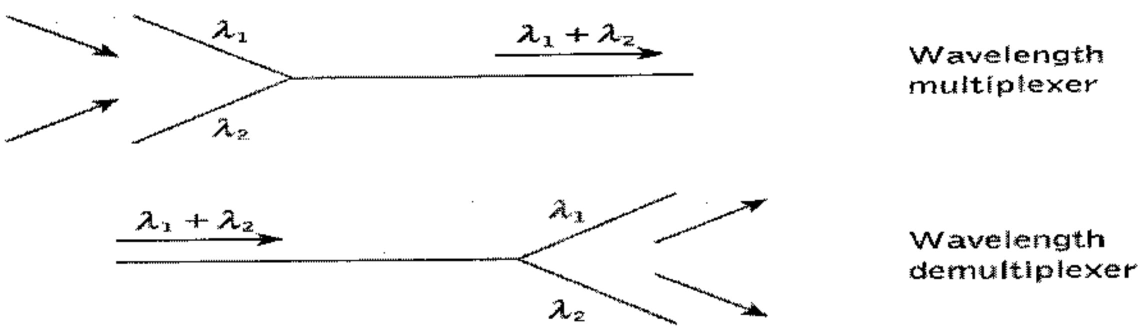
(a)



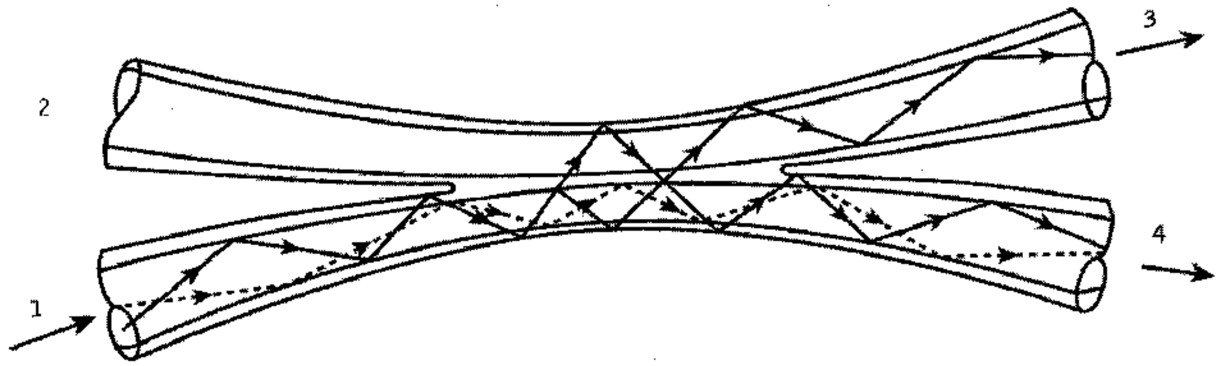
(b)



(c)



(d)



1- the excess loss is the ratio of power input to power output

$$\text{Excess loss (four-port coupler)} = 10\ log_{10}\frac{P_1}{P_3+P_4}\ dB$$

2-Insertion loss defined as the loss obtained for a particular port to-port optical path

$$\text{Insertion loss (ports 1 to 4)} = 10\ \log_{10}\frac{P_1}{P_4}\ \text{dB}$$

3- The crosstalk which provides a measure of the directional isolation† achieved by the device is the ratio of the backscattered power received at the second input port to the input power which may be written as:

$$\text{Crosstalk (four-port coupler)} = 10\ \log_{10}\frac{P_2}{P_1}\ \text{dB}$$

4- Finally, the splitting or coupling ratio indicates the percentage division of optical power between the output ports.

$$\text{split ratio} = \frac{P_3}{P_3+P_4} \times 100\ \% = [1 - \frac{P_4}{P_3+P_4}] \times 100\ \%$$

Q2-2:

The excess loss for the coupler

$$\text{Excess loss (four-port coupler)} = 10\ log_{10}\frac{P_1}{P_3+P_4}\ dB = 10\ log_{10}\frac{60}{53.5} = 0.5\ dB$$

$$\text{The insertion loss from 1 to 3} = 10\ \log_{10}\frac{P_1}{P_3} = 10\ \log_{10}\frac{60}{26} = 3.63\ \text{dB}$$

$$\text{The insertion loss from 1 to 4} = 10\ \log_{10}\frac{P_1}{P_4} = 10\ \log_{10}\frac{60}{27.5} = 3.39\ \text{dB}$$

$$\text{Crosstalk} = 10\ \log_{10}\frac{P_2}{P_1}\ \text{dB} = 10\ \log_{10}\frac{0.004}{60} = -41.8\ \text{dB}$$

$$\text{split ratio} = \frac{P_3}{P_3+P_4} \times 100\ \% = \frac{26}{53.5} \times 100 = 48.6\ \%$$

Q2-3

Splitting loss = 10 log10 N = 10 $\log_{10}$ 32=15.05 dB

$$\text{Excess loss} = 10\ \log_{10}\left(P_i \Big/ \sum_{1}^{N} P_j\right) = 10\ \log_{10}(10^3/32 \times 14) = 3.49\ \text{dB}$$

Hence the total loss for the star coupler:

Total loss = splitting loss + excess loss = 15.05 + 3.49=18.54 dB
The average insertion loss from the input port to an output port is

$$\text{insertion loss} = 10\log_{10}\frac{1000}{14} = 10\log_{10}\frac{60}{26} = 18.54 \text{ dB}$$

Q2-4:
There are three main types of noise due to spontaneous fluctuations in optical fiber communication systems: thermal noise, dark current noise and quantum noise.
The thermal noise current i_t in a resistor R may be expressed by its mean square value

$$i_t^2 = \frac{4KTB}{R}$$

Dark current noise: When there is no optical power incident on the photodetector a small reverse leakage current still flows from the device terminals.

$$i_d^2 = 2eBI_d$$

Quantum noise
The quantum behavior of electromagnetic radiation must be taken into account at optical frequencies since hf > KT and quantum fluctuations dominate over thermal fluctuations.
Q2-5: The probability of error:

$$P(e) = \exp(-z_m) = 10^{-9}$$

and thus $z_m = 20.7$.
z_m corresponds to an average number of photons detected in a time period τ for a BER of 10^{-9}.

$$z_m = \frac{\eta P_o \tau}{hf} = 20.7$$

Hence the minimum pulse energy or quantum limit:

$$E_{min} = P_o\tau = \frac{20.7hf}{\eta}$$

Thus the quantum limit at the receiver to maintain a maximum BER of 10^{-9} is:

$$\frac{20.7hf}{\eta}$$

(b) From part (a) the minimum pulse energy:

$$P_o\tau = \frac{20.7hf}{\eta}$$

Therefore the average received optical power required to provide the minimum pulse energy is:

$$P_o = \frac{20.7hf}{\tau\eta}$$

However, for ideal binary signaling there are an equal number of ones and zeros (50% in the on state and 50% in the off state). Thus the average received optical power may be considered to arrive over two bit periods, and:

$$P_o(\text{binary}) = \frac{20.7hf}{2\tau\eta} = \frac{20.7hfB_T}{2\eta}$$

where B_T is the bit rate. At a wavelength of 1 µm, $f = 2.998 \times 10^{14}$ Hz, and assuming an ideal detector, $\eta = 1$.

Hence:

$$P_o(\text{binary}) = \frac{20.7 \times 6.626 \times 10^{-34} \times 2.998 \times 10^{14} \times 10^{7}}{2}$$

$$= 20.6 \text{ pW}$$

In decibels (dB):

$$P_o \text{ in dB} = 10 \log_{10} \frac{P_o}{P_r}$$

where P_r is a reference power level.

When the reference power level is 1 watt:

$$\begin{aligned} P_o &= 10 \log_{10} P_o \quad \text{where } P_o \text{ is expressed in watts} \\ &= 10 \log_{10} 2.06 \times 10^{-11} \\ &= 3.14 - 110 \\ &= -106.9 \text{ dBW} \end{aligned}$$

When the reference power level is 1 milliwatt:

$$\begin{aligned} P_0 &= 10 \log_{10} 2.06 \times 10^{-8} \\ &= 3.14 - 80 \\ &= -76.9 \text{ dBm} \end{aligned}$$

Q3-1

Sys. rise [illegible]

[illegible] 0.7 [illegible] 0.7 [illegible] ps

[illegible] break [illegible]

[illegible] value is difficult [illegible] supplied

with [illegible] rise time = [illegible]

[illegible] because the [illegible] 6

$= 1.1 \sqrt{[illegible]^2 + [illegible] + (t_{ip})^2}$

[illegible] 35 [illegible]

[illegible] BW [illegible]

[illegible] 25 ps

So

[illegible] $1.1 \sqrt{(2)^2 [illegible]}$

= 2.4 ns

Get [illegible] actual system [illegible]

[illegible] = 3 [illegible]

[illegible] 1 ps

(35)

[illegible] sys [illegible]

[illegible] sum [illegible]

[illegible] but [illegible]

[illegible] = 2 [illegible]

10

$G(dBm) = 10\log_{10}\left(\frac{5\,nW}{1\,mW}\right) = -53.01$ dBm

→ total loss margin = $P_{source} - P_{min}$ (dB)

max power source P_{max} (source)

$P = G(dBm) = 10\log_{10}\frac{5000\times10^{-6}}{1\,mW} = 6.99$ dBm

≈ 7 dBm

Then total loss margin = 7 − (−53.01)

= 60.01 dBm

excess power = total loss margin − total attenuation

= 60.01 − 26.7 = 33.4 dBm

→ actual power at Rx = P_{min} + excess power dBm

= −53.01 + 33.4 = −19.61

→ determine actual SNR [illegible]

P_{in} [illegible] 10^{10} [illegible] 10^{-14}

σ_R = [illegible] (K^2) [illegible] 10^{-6} [illegible] 5

F Δ F [illegible] (0.1) [illegible]

10 [illegible]

[illegible] 53 dB

[illegible]

Q3-d

(4.) $R = \frac{\eta e}{hf} = \frac{0.8 * 1.602 * 10^{-19} * 1.3 * 10^{-6}}{6.626 * 10^{-34} * 3 * 10^{8}} = 0.8371 \ A W^{-1}$

$K^2 = 10^{SNR(dB)/10} = 10^{2.2} = 158.49$

$P_{min} = \frac{2eFK^2 \Delta F}{R} = \frac{2(1.6e-19)(1)(158.49)(25e9)}{0.8371}$

$= 1.515 \ \mu w$

In dBm $P_{min} = 10 \log_{10}\left(\frac{P_{min}}{1 mw}\right) = -28.1967$ dBm

* Fiber type : Single mode fiber

because long distance > 1 Km and high speed > 1 Gbps

* Power budget analysis :

[1] total fiber atten. = 15 * 0.2 = 3 dB

[2] No. of Splices = 29

Splices atten. = 29 * 0.1 = 2.9 dB

[3] Connector loss = 2 × 1 = 2 dB

[4] Source average power = 7 dBm

5 time degradation factor loss = 3 dB

6 environment degradation factor = 5 dB

7 total atten. = 3 + 2.9 + 2 + 3 + 5
= 15.9 dB

8 total loss margin = Source av. − Receiver sen.
= 7 dB − (−28.197)
= 35.197 dBm

9 Excess power = total loss margin − total atten.
= 35.197 − 15.9 = 19.297 dBm

10 Actual power at Receiver
= Receiver sensitivity + excess power
= −28.1967 + 19.297 = −8.9 dBm