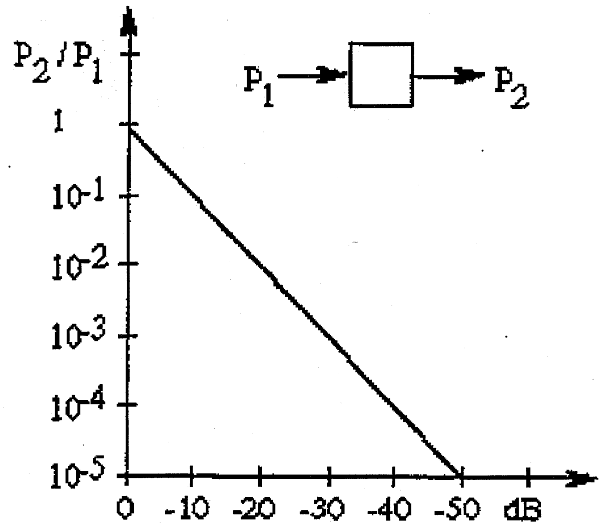
CHAPTER 1

FIBER OPTIC COMMUNICATIONS SYSTEMS

1-1 $dB = 10 \log_{10} (P_2/P_1)$

Loss (dB)	Fractional Power (P_2/P_1)
0	1
-1	0.8
-3	0.5
-6	0.25
-10	0.1
-20	0.01
-30	0.001
-40	0.0001
-50	0.00001



1-2 $dB = 10 \log_{10} (P_2/P_1)$

$dB/10 = \log_{10} (P_2/P_1)$

$P_2/P_1 = 10^{dB/10}$

$P_2 = P_1 \times 10^{dB/10} = 0.001 \times 10^{dB/10}$

1-3 $P_1 = 2$ mW

$P_2 = P_1 10^{dB/10} = 2 \times 10^{-3} \times 10^{-11/10} = 0.159$ mW

1-4 $P_2 = P_1 10^{dB/10} = 10 \times 10^{-9}$

$P_1 = P_2 10^{-dB/10} = 10 \times 10^{-9} \times 10^{-(-50)/10}$

$P_1 = 10 \times 10^{-9} \times 10^{5} = 10^{6} \times 10^{-9} = 10^{-3}$ W = 1 mW

1-5 From the text, we find that RG-19/U weighs 1110 kg/km.

1 mile of cable x 1110 kg/km x 1.609 km/mile x 2.2 lbs/kg = 3929 lbs.

1-6 From the text, we find that RG-19/U has an attenuation of 22.6 dB/km at 100 MHz.

Using RG-19/U, the allowed loss is:

$$\text{Loss} = 10 \log_{10} \frac{P_1}{P_2} = 10 \log_{10} \frac{10^{-6}}{10^{-2}} = -40 \text{ dB}$$

Maximum coaxial cable length = 40/22.6 = 1.8 km

Using a fiber with loss, the maximum length of fiber is:

Length = 40/5 = 8 km

1-7 44.7 x 10^6 bps x 1 message/64,000 bps = 698 messages

1-8 With manually operated blinker lights, I would guess about 2 or 3 bps.

1-9 Conducting Cable

900 (pairs/cable) x 24 (messages/pair) = 21,600 messages

Fiber

144 (fibers/cable) x 672 (messages /fiber) = 96,768 messages

96,768 (fiber cable)/21,600 (copper cable) = 4.48

About 4.5 copper cables are needed to carry the same amount information as the single fiber cable.

At the DS-4 rate, each fiber carries 4032 messages. The comparative message rates are then: 144 x 4032/21600 = 26.88 or about a factor of 27.

1-10

$$A_{fiber} = \pi \left(\frac{D_{fiber}}{2}\right)^2 = \pi\left(\frac{12.7}{2}\right)^2 = 126.67 \text{ mm}^2$$

$$A_{copper} = \pi \left(\frac{D_{copper}}{2}\right)^2 = \pi \left(\frac{70}{2}\right)^2 = 3{,}848.48 \text{ mm}^2$$

$$A_{copper} / A_{fiber} = 30$$

1-11

Frequency (Hz)	Wavelength (m) $\lambda = c/f = 3 \times 10^8/f$	Region of EM Spectrum
10	3×10^7	Power
60	5×10^6	Power
10^3	3×10^5	Radio
2×10^4	1.5×10^4	Radio
10^6	3×10^2	Radio
10^9	0.3	Radio
10^{10}	0.03	Microwave
10^{14}	3×10^{-6}	Infrared

1-12 Visible wavelengths range from 0.4 μm to 0.7 μm.

When $\lambda = 0.4$ μm, $f = \frac{c}{\lambda} = \frac{3 \times 10^8 \text{ m/s}}{0.4 \times 10^{-6} \text{ m}} = 7.5 \times 10^{14}$ Hz

When $\lambda = 0.7$ μm, $f = \frac{3 \times 10^8 \text{ m/s}}{0.7 \times 10^{-6} \text{ m}} = 4.3 \times 10^{14}$ Hz

Bandwidth $= \Delta f = (7.5 - 4.3) \times 10^{14} = 3.2 \times 10^{14}$ Hz

1-13

$$W = hf = \frac{hc}{\lambda} = \frac{(6.625 \text{ x } 10^{-34} \text{ J} \cdot \text{ S})(3 \text{ x } 10^{8} \text{ m/s})}{\lambda}$$

λ(μm)	W(J)
0.6	3.3×10^{-19}
0.82	2.4×10^{-19}
1.3	1.5×10^{-19}

A visible photon has more energy than an infrared photon.

1-14 $P = W/t = hfN = hNc/\lambda$, where N= number of photons/sec

$$P = 6.625x10^{-34}x10^{10}x3x10^{8} / 0.8x10^{-6} = 2.5x10^{-9}W$$

$$I = 2.5 \text{ x } 10^{-9} \text{ W } (0.65 \text{ A/W}) = 1.6 \text{ nA}$$

1-15

$$N = \frac{P\lambda}{hc} = \frac{(1 \text{ x } 10^{-9} \text{ W})(1.3 \text{ x } 10^{-6}\text{m})}{(6.625 \text{ x } 10^{-34} \text{ J} \cdot \text{ S})(3 \text{ x } 10^{8} \text{ m/s})} = 6.5 \text{ x } 10^{9} \text{ photons/second}$$

1-16

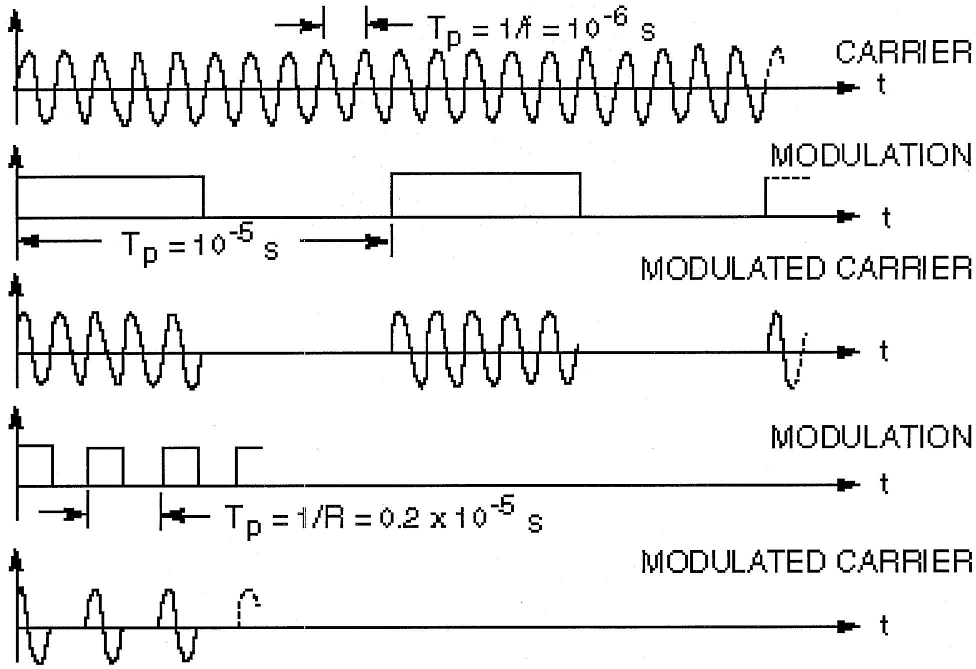
Carrier	Bit Rate (bps)
10 kHz	10^{2}
1 MHz	10^{4}
100 MHz	10^{6}
10 GHz	10^{8}
1 μm	3×10^{12}

For the $\lambda = 1$ μm carrier

$$f = \frac{c}{\lambda} = \frac{3 \text{ x } 10^{8} \text{ m/s}}{1 \text{ x } 10^{-6} \text{ m}}$$

$$= 3 \text{ x } 10^{14} \text{ Hz}$$

1-17



1-18

$$f = \frac{c}{\lambda} = \frac{3 \times 10^8 \text{ m/s}}{1.06 \times 10^{-6} \text{ m}} = 2.83 \times 10^{14} \text{ Hz, BW} = 0.01f = 2.83 \times 10^{12} \text{ Hz}$$

Assume $\Delta f = 4000$ Hz for one voice channel. Then

2.83×10^{12} Hz x 1 channel/4000 Hz = 7×10^8 channels

1-19 Open-ended solution.

1-20 Assume there are 10 billion (10^{10}) homes each having one 4000 Hz channel, then 10^{10} (homes) x 4000 (Hz/home) = 4×10^{13} Hz is the required bandwidth. Using an optical beam of frequency

$f = 3 \times 10^{14}$ Hz

$$\frac{\Delta f}{f} = \frac{4 \times 10^{13}}{3 \times 10^{14}} = 0.133$$

The bandwidth 13.3% of the carrier frequency. This might be possible.

1-21

$$10^{10} \text{ messages} \left(\frac{6.4 \times 10^4 \text{ bps}}{\text{message}}\right) = 6.4 \times 10^{14} \text{ bps}$$

A single optical carrier at $f \simeq 3 \times 10^{14}$ Hz could not be turned on and off this fast.

1-22 $P = 100$ nW $= 100 \times 10^{-9}$ W. Let N = number of photons

$W = Nhf = Pt$

$N/t = P/hf = (P/hc)\,\lambda$

(a) At 800 nm

$$N/t = \frac{10^{-7}\left(0.8 \times 10^{-6}\right)}{6.63 \times 10^{-34}\left(3 \times 10^{8}\right)} = 4 \times 10^{11} \text{ photons/second}$$

(b) At 1550 nm

$N/t = 4 \times 10^{11}\,(1.55/.8) = 7.8 \times 10^{11}$ photons/second

(c) The longer wavelength requires more photons because the energy per photon is smaller at the longer wavelength.

1-23 $P_R = -34$ dBm

P_T = Transmitted power in dBm

$L = -31$ dB, system losses

$P_R = P_T + L$

$-34 = P_T - 31$

$P_T = -34 + 31 = -3$ dBm

$P_T = 0.5$ mW

1-24 T3 rate is R = 45 Mbps

The number of errors each second is:

$N_e = 10^{-9} (45 \times 10^6) = 45 \times 10^{-3}$ errors/s

In one minute, then

$N_e = 60 (45 \times 10^{-3}) = 2.7$ errors/minutes

1-25 $R = 2.3$ Gbps $= 2.3 \times 10^9$ bps

Total capacity of the 144 fibers is

$144 (2.3 \times 10^9) = 3.312 \times 10^{11}$ bps

Allowing 64,000 bps per voice message, yields

$\frac{3.312 \times 10^{11}}{6.4 \times 10^4} = 0.5175 \times 10^7 = 5.175 \times 10^6$ messages = 5.175 million messages

1-26 $P_r = -38$ dBm, $P_T = 4$ dBm
$L = 4 - (-38) = 42$ dBm

1-27 $P_1 = -60$ dBm $= 10 \log P_1$(mW)
$P_1 = 10^{-6}$ mW $= 10^{-9}$ W
$P_2 = 60$ dBm $= 10 \log P_2$(mW)
$P_2 = 10^6$ mW $= 10^3$ W
$P_2 - P_1 = 1000$ watts (approximately)

1-28 $L = -5 -25 -15 +10 = 35$ dB

1-29 $f = c/\lambda = 3 \times 10^8/1.55 \times 10^{-6} = 1.93548 \times 10^{14}$
One hundredth of one percent is a data rate of:
$R = 10^{-4}(1.93548 \times 10^{14}) = 1.9354 \times 10^{10}$ bps = 19.4 Gbps
Use $R_{HDTV} = 20$ Mbps for each HDTV channel
$R/R_{HDTV} = 19.4 \times 10^9/20 \times 10^6 = 0.9677 \times 10^3 = 967$ video channels

1-30 Open-ended question.

1-31 OC-768 rate is 39,813.12 Mb/s

Number of voice channels is N:

$N = (39{,}813.12 \times 10^6)/(64 \times 10^3) = 622{,}080$

The actual number is less than this to accommodate overhead such as signaling and synchronization.

1-32 Photon energy W_p

$W_p = hf = hc/\lambda = 6.626 \times 10^{-34} \times 3 \times 10^8/\lambda$

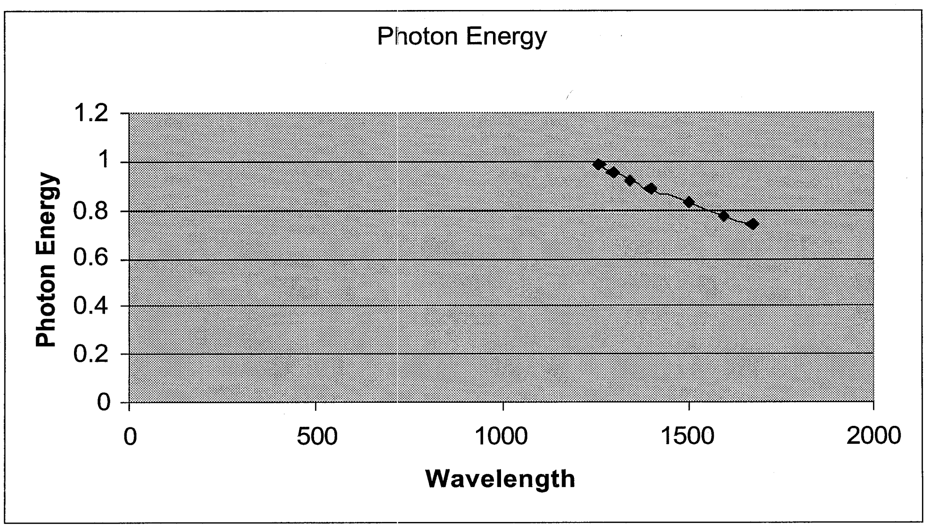
$W_p = 19.878 \times 10^{-26}/\lambda$ Joules

In eV

$W_p = 19.878 \times 10^{-26}/(1.6 \times 10^{-19}\,\lambda) = 1.2423 \times 10^{-6}/\lambda$

If the wavelength is in nm, the photon energy in eV becomes:

$W_p = 1242.3\,/\lambda$



1–33

Wavelength	Frequency	Energy
1.55 μm	1.935×10^{14} Hz	0.802 eV
1.55×10^{-3} mm	1.935×10^{11} kHz	1.282×10^{-19} J
1.55×10^{-6} m	1.935×10^{8} MHz	
1.55×10^{-9} km	1.935×10^{5} GHz	
	193.5 THz	

$$f = \frac{c}{\lambda} = \frac{3\times 10^{8}}{1.55\times 10^{-6}} = 1.935\times 10^{14}\ Hz$$

$$W_p = \frac{1242.3}{\lambda} = \frac{1242.3}{1550} = 0.802\ eV$$