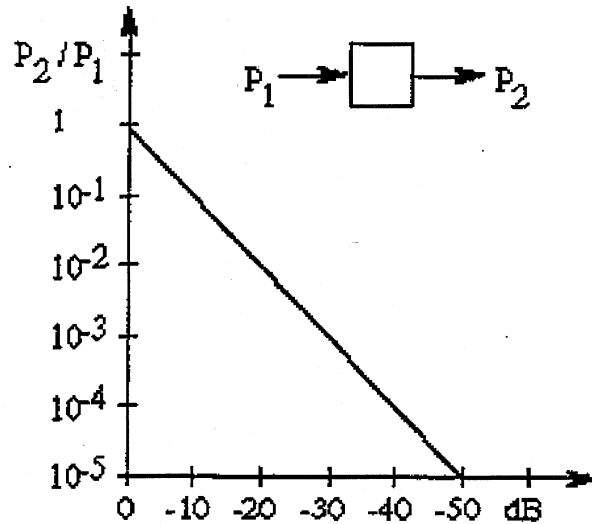


CHAPTER 1

FIBER OPTIC COMMUNICATIONS SYSTEMS

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

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

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

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

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

1-3 $P_1 = 2 \text{ mW}$

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

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

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

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

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

$$1 \text{ mile of cable} \times 1110 \text{ kg/km} \times 1.609 \text{ km/mile} \times 2.2 \text{ lbs/kg} = 3929 \text{ lbs.}$$

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:

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

$$\text{Maximum coaxial cable length} = 40/22.6 = 1.8 \text{ km}$$

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

$$\text{Length} = 40/5 = 8 \text{ km}$$

1-7 $44.7 \times 10^6 \text{ bps} \times 1 \text{ message}/64,000 \text{ bps} = 698 \text{ messages}$

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

1-9 Conducting Cable

$$900 \text{ (pairs/cable)} \times 24 \text{ (messages/pair)} = 21,600 \text{ messages}$$

Fiber

$$144 \text{ (fibers/cable)} \times 672 \text{ (messages /fiber)} = 96,768 \text{ messages}$$

$$96,768 \text{ (fiber cable)}/21,600 \text{ (copper cable)} = 4.48$$

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: $144 \times 4032/21600 = 26.88$ or about a factor of 27.

1-10

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

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

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

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 .

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

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

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

1-13

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

$\lambda(\mu\text{m})$	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

$$P = 6.625 \times 10^{-34} \times 10^{10} \times 3 \times 10^8 / 0.8 \times 10^{-6} = 2.5 \times 10^{-9} \text{ W}$$

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

1-15

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

1-16

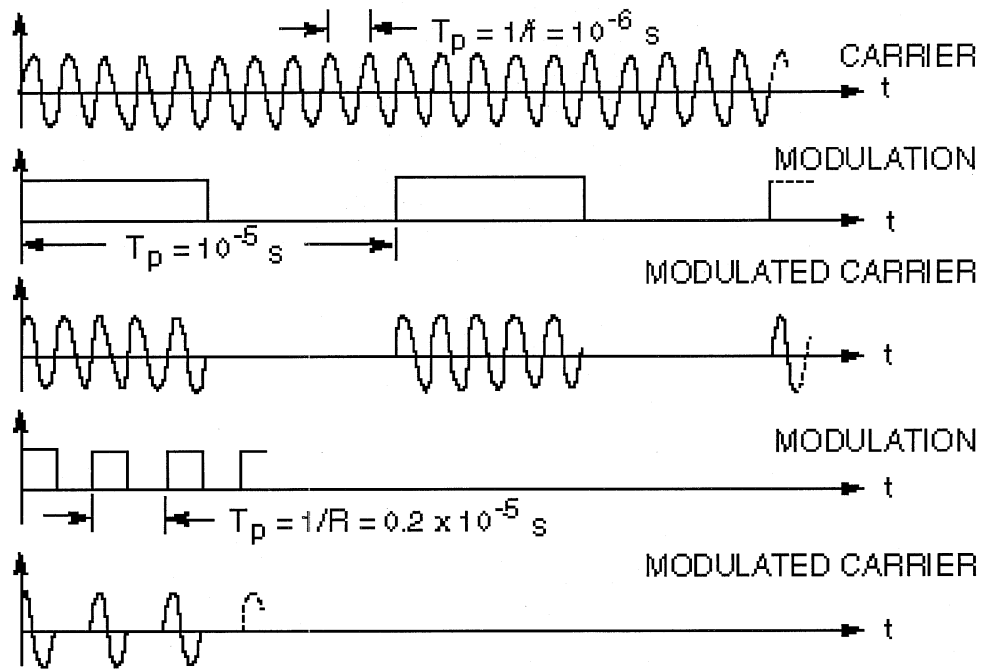
Carrier	Bit Rate (bps)
10 kHz	10^2
1 MHz	10^4
100 MHz	10^6
10 GHz	10^8
1 μm	3×10^{12}

For the $\lambda = 1 \mu\text{m}$ carrier

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

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

1-17



1-18

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

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

$$2.83 \times 10^{12} \text{ Hz} \times 1 \text{ channel}/4000 \text{ Hz} = 7 \times 10^8 \text{ channels}$$

1-19 Open-ended solution.

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

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

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

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 $f \approx 3 \times 10^{14}$ Hz could not be turned on and off this fast.

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

$$W = Nhf = Pt$$

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

(a) At 800 nm

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

(b) At 1550 nm

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

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

1-23 $P_R = -34 \text{ dBm}$

P_T = Transmitted power in dBm

$L = -31 \text{ dB}$, system losses

$$P_R = P_T + L$$

$$-34 = P_T - 31$$

$$P_T = -34 + 31 = -3 \text{ dBm}$$

$$P_T = 0.5 \text{ mW}$$

1-24 T3 rate is $R = 45 \text{ Mbps}$

The number of errors each second is:

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

In one minute, then

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

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

Total capacity of the 144 fibers is

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

Allowing 64,000 bps per voice message, yields

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

1-26 $P_r = -38 \text{ dBm}$, $P_T = 4 \text{ dBm}$

$$L = 4 - (-38) = 42 \text{ dBm}$$

1-27 $P_1 = -60 \text{ dBm} = 10 \log P_1(\text{mW})$

$$P_1 = 10^{-6} \text{ mW} = 10^{-9} \text{ W}$$

$$P_2 = 60 \text{ dBm} = 10 \log P_2(\text{mW})$$

$$P_2 = 10^6 \text{ mW} = 10^3 \text{ W}$$

$$P_2 - P_1 = 1000 \text{ watts (approximately)}$$

1-28 $L = -5 -25 -15 +10 = 35 \text{ dB}$

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:

$$R = 10^{-4} (1.93548 \times 10^{14}) = 1.9354 \times 10^{10} \text{ bps} = 19.4 \text{ Gbps}$$

Use $R_{\text{HDTV}} = 20 \text{ Mbps}$ for each HDTV channel

$$R/R_{\text{HDTV}} = 19.4 \times 10^9 / 20 \times 10^6 = 0.9677 \times 10^3 = 967 \text{ video channels}$$

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

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

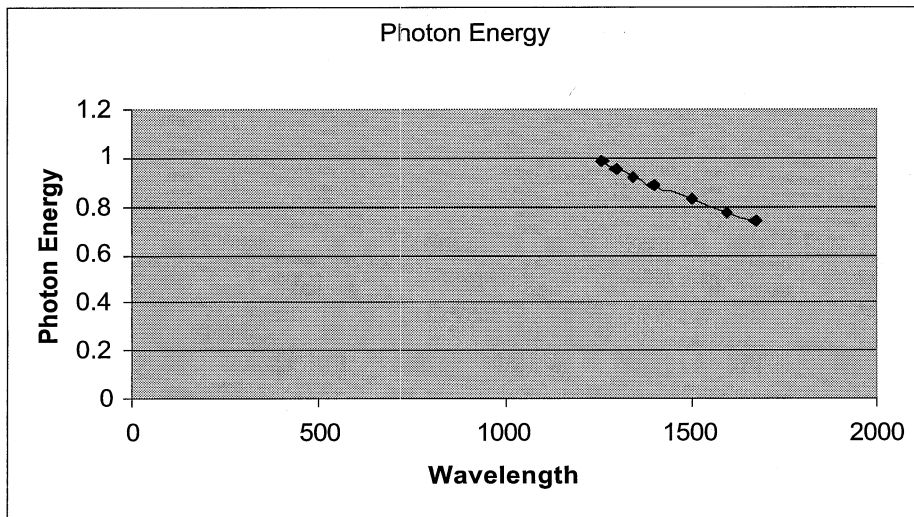
$$W_p = 19.878 \times 10^{-26} / \lambda \text{ Joules}$$

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	

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

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