ECE 6390: Satellite Communications and Navigation Systems
Solutions to TEST 2 (Fall 2005)

1. **Short Answer Section**

   (a) intensity (luminance), hue, chrominance

   (b) Carson's, modulation

   (c) true

   (d) black-body

2. **Interplanetary Doppler:**

   This looks like a hard problem unless you realize that the planetary motion is orthogonal to the direction of wave propagation. Thus, there is no need to worry about the speed of Jupiter or Earth around the sun. If we view the satellite orbiting Jupiter as a transmitter, then the maximum Doppler contribution will occur when the satellite's circular orbit velocity is aligned towards or away from Earth:

$$|f_{DT}|_{\max} = \frac{V_T}{\lambda} = 1.052 \text{ MHz} \qquad V_T = \sqrt{\frac{GM_J}{R}} = 39,463 \text{ m/s}$$

   One more thing to consider: the earth station receiver will be rotating which contributes a Doppler shift at the receiver (maximized at sunset and sunrise):

$$|f_{DR}|_{\max} = \frac{V_R}{\lambda} = 1.24 \text{ kHz} \qquad V_R = \frac{2\pi R_E}{T_{\text{day}}} = 465 \text{ m/s}$$

   This contribution is significantly less than the transmitter-induced Doppler shift. Based on these numbers, an Earth receiver must be prepared to receive a signal for carrier frequencies in the range of $[7998.95, 8001.05]$ MHz.

3. **Transponder Problem of Death:**

   (a) The received power at the satellite is

$$P_R = \underbrace{P_T + G_T}_{\text{EIRP = 55.0 dBW}} + \overbrace{G_R}^{8.0 \text{ dBi}} - \underbrace{20\log_{10}(r)}_{151.0 \text{ dB}} - \overbrace{20\log_{10}\left(\frac{4\pi}{\lambda}\right)}^{48.3 \text{ dB}} = -136.3 \text{ dBW}$$

   The received noise at the satellite is

$$P_N = 10\log_{10}\left(k \underbrace{T_{\text{sys}}}_{T_{\text{phy}}+T_{\text{LNA}}} B\right) = -137.5 \text{ dBW}$$

   Thus, in the absence of signal processing, there should be an C/N of 1.2 dB. Lousy for video, which is why FM has to be used to relay analog video signals.

(b) The received power plus noise at the output of the satellite must be 3.16 Watts (5 dBW):

$$P_R + P_N = 3.16 \text{ W} \qquad P_R = 10^{\frac{1.2}{10}} P_N$$

Thus, $P_N = 1.4$ W and $P_R = 1.8$ W. If I found you made the right calculation with the wrong numbers from part (a), I gave credit for the answer.

(c) This one is easy:

$$\frac{G}{T} = 10^{\frac{35 \text{ dBi}}{10}} / (13 \text{ K } + 55 \text{ K }) = 46.5 \text{ K}^{-1}$$

(d) The received power at the earth station is

$$P_R = \overbrace{P_T}^{2.6 \text{ dBW}} + \underbrace{G_T}_{5.0 \text{ dBi}} + \overbrace{G_R}^{35.0 \text{ dBi}} - \underbrace{20\log_{10}(r)}_{151.0 \text{ dB}} - \overbrace{20\log_{10}\left(\frac{4\pi}{\lambda}\right)}^{43.8 \text{ dB}} = -152.2 \text{ dBW}$$

The 1.4 Watts of noise is also along for the ride, received as -153.3 dBW (4.6×10^{-16} Watts).

$$\frac{C}{N} = \frac{P_R}{4.6 \times 10^{-16} + kT_{\text{sys}}B} = 0.0988 = -10.0 \text{ dB}$$

Again, plenty of partial credit for this one.

(e) There were a number of acceptable answers here: 1) use higher-gain antennas, 2) lower device noise in the LNAs, 3) lower frequency (less reference path loss), 4) spread the signal with FM, 5) increase transmit power. There were a lot of other student answers that were a little more “creative”, many of which received at least partial credit.

(f) This additional sun noise absolutely clobbers the receiver with a -31.4 dB C/N.

4. **Rain Attenuation:** The distance that a signal must travel through the rain cell is given by

$$L_{\text{eff}} = \frac{h}{\sin\theta_{el}} = \frac{1 \text{ km}}{\sin 35°} = 1.74 \text{ km}$$

For 11 GHz vertical polarization, the propagation constants for rain are

$$k_v = 0.0128 \qquad \alpha_v = 1.232$$

which were computed just by averaging the values for 10 and 12 GHz. Looking at the table for an M-class climate, we see that the rain rate will not exceed 63 mm/hr 99.99% of the time. Thus, the final

$$A_{\text{dB}} = L_{\text{eff}} k_v R^{\alpha_v} = (1.74)(0.0128)(63)^{1.232} = 3.7 \text{ dB}$$