ECE 6390: Satellite Communications and Navigation Systems
Solutions to TEST 2 (Fall 2004)

1. **Short Answer Section (30 points)**

   (a) frequency division

   (b) false

   (c) block (1) convolutional (2) turbo (3)

   (d) matched

   (e) 0 ($-\infty$ dB)

   (f) 50%

   (g) false

   (h) Check the boxes below for scenarios that do *not* lead to Rician fading in a radio link.

   ☐ A satellite mobile phone moves through an environment filled with nearby scatterers.

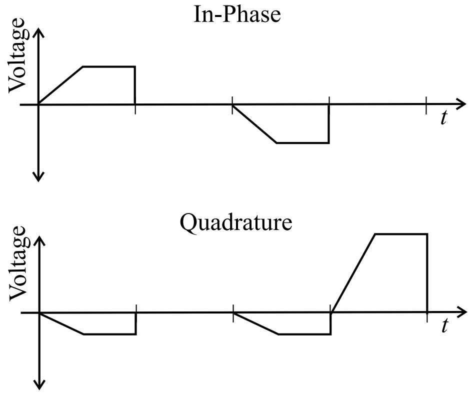
   [X] The output amplifier of a bent-pipe transponder operates in saturation (nonlinear input-output relation).

   [X] Another TDMA packet collides with the data packet that an ES was trying to send.

   ☐ A 30 GHz ES points towards a GEO satellite during a storm.

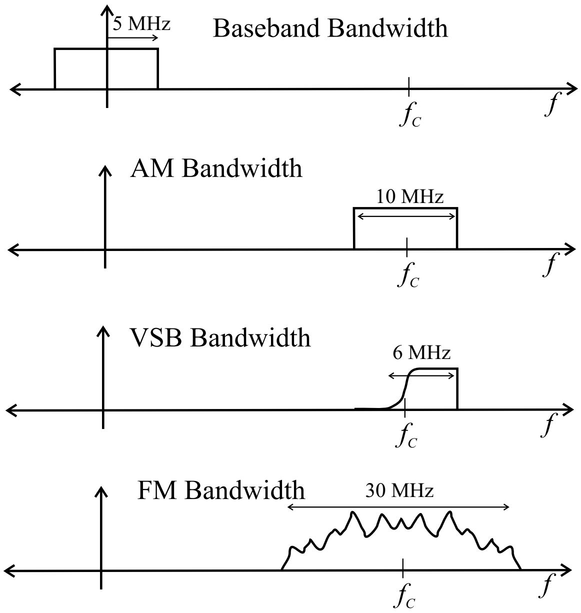
2. **Digital Transmissions:**

   (a) Rough sketch of I and Q channels of the alien modulator:



(b) The pulse has sharp transitions (no gentle roll-off). When modulated onto a carrier, this signal's spectrum will leak a lot of power into adjacent bands.

3. **Video Over Satellite:** Here is a brief summary of the analog bandwidths discussed in this problem: (only positive half of frequency spectrum is shown)



(a) The C/N equations (in dB) for the AM and FM signal, respectively are given by:

$$\left(\frac{C}{N}\right)_{AM} = P_{T,AM} - \text{Link Loss} - 10\log_{10}(kT_{sys}B_{AM})$$

$$\left(\frac{C}{N}\right)_{FM} = P_{T,FM} - \text{Link Loss} + \text{FM Processing Gain} - 10\log_{10}(kT_{sys}B_{FM})$$

Each received C/N should be (at least) 40 dB, so if we set them equal we should be able to solve for the transmit power distance. Simplifying the result produces

$$\begin{aligned} P_{T,FM} - P_{T,AM} &= \text{FM Processing Gain} - 10\log_{10}\left(\frac{B_{AM}}{B_{FM}}\right) \\ &= -20\log_{10}\left(\frac{f_{peak}}{f_{max}}\right) - 1.8 + P \end{aligned}$$

The values for f_{max} and f_{peak} depend on how you define the baseband bandwidth of the analog video signal. The best value is $f_{max} = 5$ MHz, which leads to a $f_{peak} = 10$ MHz by Carson's rule and a difference in transmit power of -14.8 dB. Some students used $f_{max} = 6$ MHz, which was OK since I didn't require anyone to know the exact bandwidth of a baseband TV signal, and resulted in a power difference of -12.3 dB. The key point: with more bandwidth, FM can drop the required transmit power by an order of magnitude and achieve the same analog signal fidelity.

Incidentally, the most common error on this part was to forget about the increased system noise power in the FM receiver due to the larger bandwidth.

(b) Now we look at a digital signal which is a completely different animal. If we use the WGPECG, we should be able to approach the Shannon limit for channel capacity.

$$28.2 \text{ MB/sec } = 43.2 \text{ MHz } \log_2 \left(1 + \frac{C_{dig}}{N_{dig}}\right)$$

This results in a C/N of -2.4 dB. Thus, reliable digital and AM transmission will occur for the respective carrier power levels:

$$C_{dig} = -2.4 \text{ dB } + 10\log_{10}\left(kT_{sys}B_{dig}\right)$$

$$C_{AM} = 40 \text{ dB } + 10\log_{10}\left(kT_{sys}B_{AM}\right)$$

All else being equal (antennas, link loss, etc.), the difference between these values represents the difference in minimum transmit power:

$$C_{dig} - C_{AM} = -42.4 \text{ dB } + 10\log_{10}\left(\frac{B_{dig}}{B_{AM}}\right) = -33.8 \text{ dB}$$

Here lies the potency of digital transmission within a very large bandwidth: it is possible to transmit a high-quality digital image with 3-orders of magnitude less power. An important piece of information for your project...

(c) We use the BER equation for QPSK:

$$\text{BER} = Q\left(\sqrt{2\frac{C}{N}}\right) = 10^{-5}$$

which, from the Q-function graph, implies a C/N of about 9.0 dB. If the WGPECC is employed to get the Shannon Limit, we require only a C/N of -2.4 dB. Thus, the coding gain for WGPECC is 11.4 dB.

(d) The answer follows mechanically from the relationship between pulse bandwidth and bit rate for a raised cosine symbol:

$$\text{Raised Cosine BW} = (1 + r)R_b$$

For the example system, the roll-off factor r is 0.53.

(e) The most important and obvious trade-off is the bandwidth required to transmit each signal. Both the digital and FM transmissions require much less power, but take up much more bandwidth.

Other trade-offs might include receiver cost (digital costs more), applicability for TDMA (digital) vs FDMA (FM or AM) when multiplexing signals, and the desirable clarity of a digital transmission.