**Spring 2010**
**EE 4601: Assignment 7**

- Date Assigned: March 30, 2010.
- Date Due: April 8, 2010.

1. Consider at set of M-ary biorthognal FSK waveforms. You will have to read up a little on what biorthogonal signals are. Derive a union bound on the probability of symbol error and express your result as a function of the received $E_b/N_o$. *use the exact Euclidean distances, $d_{jk}$, in this problem and not the upper bound $d_{jk} \leq d_{\min}$.*

2. Using geometric arguments, prove the following upper and lower bound on the probability of *symbol* error for M-PSK signals, with $M \geq 4$.

$$p \leq P_M \leq 2p$$

where

$$p = Q\left(\sqrt{\frac{E}{2N_o}\sin^2(\pi/M)}\right)$$

and $E$ is the symbol energy-to-noise ratio.

3. Consider a QAM system on an AWGN channel. Let the maximum symbol rate be $1/T = 2000$ baud.

   a) determine the required modulation alphabet size $M$, and the $E_b/N_o$ (in dB) to guarantee a *symbol* error probability of $P_M = 10^{-5}$ with a bit rate of $R_b = 4$ kb/s.

   b) redetermine the above when $R_b = 8$ kb/s and $R_b = 16$ kb/s and draw some conclusions.

4. An FSK system transmits binary data at a rate of 2.5 Mbps During the course of transmission, AWGN with $N_o/2 = 0.2 \times 10^{-13}$ is added to the signal. In the absence of noise, the amplitude of the received sinusoidal waveform for digit 0 or 1 is 1 mV. Determine the average probability of symbol error for the following:

a) Coherent binary FSK

b) Coherent MSK

c) Noncoherent binary FSK

5. A binary ASK system transmits one of the two following waveforms with equal probability

$$\begin{aligned} s_0(t) &= \sqrt{\frac{2E}{T}}\cos(2\pi f_c t), \quad 0 \le t \le T \\ s_1(t) &= 0 \end{aligned}$$

Assuming an AWGN channel find the following:

a) The probability of error with coherent detection.

b) An expression (perhaps involving integrals) for the probability of error with noncoherent detection.