PSK
1. A binary signal is applied to a correlator supplied with a phase reference that deviates from the exact carrier phase by \( \phi \) radians. Determine the average probability of error of the system.

2. The signal component of a coherent PSK system is defined by

\[
s(t) = A_c k \sin(2\pi f_c t) \pm A_c \sqrt{1-k^2} \cos(2\pi f_c t)
\]

where \( 0 \leq t \leq T_b \), and the plus sign corresponds to symbol 1 and the minus sign corresponds to symbol 0. The first term represents a carrier component included for the purpose of synchronizing the receiver to the transmitter.

(a) Draw a constellation diagram for the scheme described here.

(b) Show that, in the presence of additive white Gaussian noise of zero mean and power spectral density \( N_0 / 2 \), the average probability of error is

\[
P_e = \frac{1}{2} \text{erfc} \left( \frac{E_b}{N_0 (1-k^2)} \right)
\]

where

\[
E_b = \frac{1}{2} A_c^2 T_b
\]

(c) Suppose that 10 percent of the transmitted signal power is allocated to the carrier component. Determine the \( E_b / N_0 \) required to realize a probability of error equal to \( 10^{-4} \).

(d) Compare this value of \( E_b / N_0 \) with that required for a conventional PSK system with the same probability of error.

QPSK
3. Let \( P_{d} \) and \( P_{Q} \) denote the probabilities of symbol error for the in-phase and quadrature channels of a digital communication system. Show that the average probability of symbol error for the overall system is given by

\[
P_e = P_{d} + P_{Q} - P_{d} P_{Q}
\]
FSK
4. A coherent binary FSK system transmits binary data at the rate of 2.5x10^6 bits per second. During the course of transmission, white Gaussian noise of zero mean and power spectral density 10^{-20} W/Hz is added to the signal. In the absence of noise, the amplitude of the received sinusoidal wave for digit 1 or 0 is 1mV. Determine the average probability of symbol error.

Given: \( \text{erfc}(x) \approx \frac{e^{-x^2}}{\sqrt{\pi} x} \) for large \( x \)

QAM
5. Determine the transmission bandwidth reduction and average signal energy of 256-QAM, compared to 64-QAM.
6. Two passband data transmission systems are to be compared. One system uses 16-PSK, and the other uses 16-QAM. Both systems are required to produce an average probability of symbol error equal to 10^{-3}. Compare the signal-to-noise ratio requirement of these two systems.

DPSK
7. The binary sequence 1100100010 is applied to the DPSK transmitter.
   a. Sketch the resulting waveform at the transmitter output.
   b. Applying this waveform to the DPSK receiver, show that, in the absence of noise, the original binary sequence is reconstructed at the receiver output.

Comparison of Digital Modulation Schemes
8. Binary data are transmitted over a microwave link at the rate of 10^6 b/s, and the power spectral density of the noise at the receiver input is 10^{-10} V/Hz. Find the average carrier power required to maintain an average probability of error \( P_e \leq 10^{-4} \) for (a) coherent binary PSK and (b) DPSK

9. The values of \( E_b / N_o \) required to realize an average probability of symbol error \( P_e = 10^{-4} \) using coherent binary PSK is 7.2. Using the approximation

\[
\text{erfc}(u) = \frac{1}{\sqrt{\pi u}} \exp(-u^2)
\]

determine the separation in the values of \( E_b / N_o \) for \( P_e = 10^{-4} \), using coherent binary PSK and DPSK
erfc(x)

x