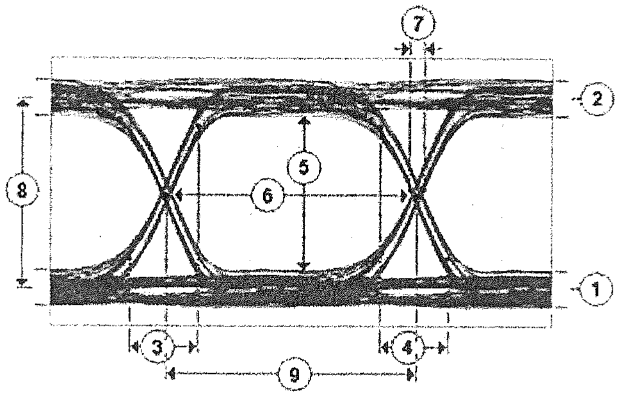
Note: Detailed derivations are required to obtain a full score for each problem.

1. (14%) In baseband communication systems, an eye diagram/pattern is often used to analyze the quality of an on-off keying (OOK) signal. A typical eye diagram is given in the diagram below:



Please answer the following questions. (Note: A short description that justifies your answer is required to get full credit for each problem.)

(a) What are the possible line codes for this diagram? (A) unipolar NRZ, (B) bipolar NRZ, (C) unipolar RZ and (D) bipolar RZ. (3%)

(b) From measurements ① to ⑨ in the diagram, which one can be used to estimate data rate? (3%)

(c) From measurements ① to ⑨ in the diagram, please describe how you can estimate the error probability. (8%)

2. (16%) The power of signal $s(t)$ is defined as

$$P_s = \lim_{T\to\infty} \left\{ \frac{1}{2T} \int_{-T}^{T} |s(t)|^2 dt \right\}.$$

(That is, the signal $s(t)$, in voltage, is applied across a resistor with 1 ohm.)

(a) Suppose that $s(t)$ is an amplitude modulated (AM) signal given by

$$s(t) = A_c(a_0 + m(t))\cos(2\pi f_c t),$$

where $m(t) = A_m \cos(2\pi f_m t)$ is the baseband signal with amplitude A_m and frequency f_m, and A_c and f_c are the carrier's amplitude and frequency, respectively. If there is no over-modulation for all time t, what is the maximum possible value of P_s? (4%)

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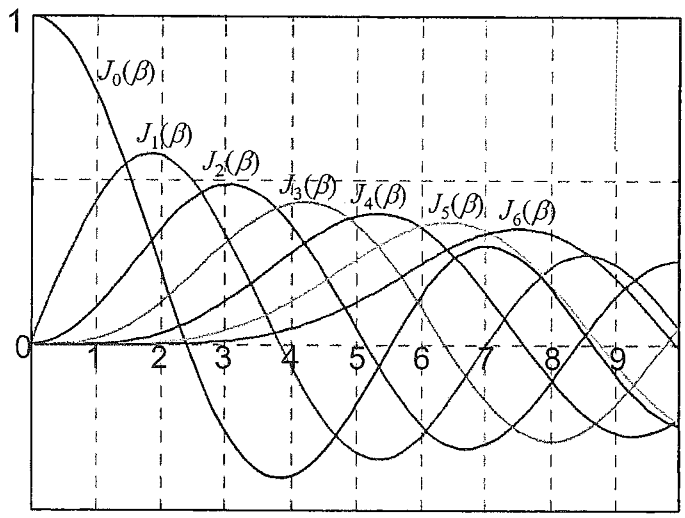
(b) Following (a), assume that the carrier amplitude, A_c, is 2 volts and the message $m(t)$ has a frequency $f_m = 10$ KHz and a power equal to 2 watts. Moreover, assume that the total signal power, P_s, is 22 watts. Is this an over-modulated signal? Why? (4%)

(c) Repeat (a), for a frequency modulated (FM) signal given by

$$s(t) = A_c \cos(2\pi f_c t + 2\pi k_f \int_0^t m(\tau)d\tau) = A_c \sum_{n=-\infty}^{\infty} J_n(\beta)\cos[2\pi(f_c + nf_m)t],$$

where k_f is the frequency sensitivity and β is the phase deviation. An interesting behavior of FM is that, there exists some specific frequency deviation, Δf, such that the carrier component is totally suppressed, i.e., no carrier component. According to the following plot of the nth order Bessel function of the first kind, please use Carson's rule to estimate the smallest bandwidth, in terms of f_m, such that there is no carrier component in the transmitted FM signal $s(t)$. (4%)



(d) At the receiver, we first pass the ideal FM signal $s(t)$, as shown in (c), through an ideal bandpass filter (BPF) with a bandwidth equal to what you obtained in (c). Then, we demodulate this filtered FM signal with an ideal FM demodulator. Can we get an undistorted $m(t)$ at the output of demodulator? Why? (4%)

3. (25%) Let us consider a sinusoidal wave with random phase given by

$$X(t) = A\cos(2\pi f_c t + \Theta),$$

where A and f_c are known constants and Θ is a random variable that is uniformly distributed over the interval $[-\pi, \pi]$.

(a) Please derive the autocorrelation function of $X(t)$. (5%)

(b) Please derive the power spectral density (PSD) of $X(t)$. (5%)

(c) Please derive the PSD of $Y(t) = Z(t)X(t)$, where $Z(t)$ is a stationary process that is independent of Θ. Please express the result in terms of the PSD of $Z(t)$. (5%)

(d) Please derive the PSD of $X(t)$ if f_c is no longer a constant value but a random variable which is independent of Θ. (10%)

4. (10%) In the $(k+1, k)$ single-parity-check (SPC) code, a single parity bit b_1 is appended to a block of k message bits $(m_1, m_2, \cdots, m_k)$. The single parity bit, b_1, is chosen so that the codeword satisfies the even parity rule:

$$m_1 \oplus m_2 \oplus \cdots \oplus m_k \oplus b_1 = 0,$$

where $\oplus$ represents the binary addition.

(a) Please give a k-by-$(k+1)$ generator matrix $\mathbf{G}$ in systematic form for the $(k+1, k)$ SPC code. (5%)

(b) Please give a 1-by-$(k+1)$ matrix $\mathbf{H}$ such that $\mathbf{H}\mathbf{G}^T = 0$. (5%)

5. (20%) Consider M signals

$$s_i(t) = A\cos(2\pi f_i t + \theta_i), \quad 0 \le t < T_s, \quad i = 1, 2, \ldots, M,$$

where θ_i represents the carrier phase at the initial time, $f_i \gg 0$, and M is a power of 2.

(a) Derive the correlation of the two signals $s_i(t)$ and $s_j(t)$ over the interval $(0, T_s)$. (5%)

(b) Determine the minimum spacing Δf between f_i and f_j that maintains the orthogonality between the two signals $s_i(t)$ and $s_j(t)$ when $\theta_i = \theta_j$. (2%)

(c) Determine the minimum spacing Δf between f_i and f_j that maintains the orthogonality between the two signals $s_i(t)$ and $s_j(t)$ for any random phases $\theta_i \neq \theta_j$. (3%)

(d) Assume that a transmitter forwards a data stream to a receiver through an additive white Gaussian noise (AWGN) channel by using the set of M orthogonal signals described above. The transmit power is $P = 0$ dBW, the transmission bandwidth is $B = 4.5$ MHz, the propagation loss of the channel is $L = 40$ dB, and the noise power spectral density is $N_0 = -110$ dBW/Hz. If the required energy per symbol to noise power spectral density ratio at the receiver is $E_s/N_0 \geq 10$ dB, find the maximum achievable transmission rate (in bits per second) for the cases $\theta_i = \theta_j$ and $\theta_i \neq \theta_j$, respectively. (5%)

(e) Following (d), if the propagation loss of the channel is increased to $L = 46$ dB, find the maximum achievable transmission rate for the cases $\theta_i = \theta_j$ and $\theta_i \neq \theta_j$, respectively. (5%) [Hint: $\log_{10} 2 \approx 0.3$]

6. (15%) Consider the design of a differential 8-PSK modulation scheme, which is similar to $\pi/4$-Differential QPSK modulation.

(a) Illustrate the two constellations, including the phases of all signal points, alternately used in two successive symbols. (4%)

(b) Determine the mapping of Gray-encoded input data with respect to the phase change $\Delta\theta$, where "000" has the minimum positive phase change and the signal point "000" is situated between the two points "100" and "001". (4%)

(c) According to (b), if the initial carrier phase is $\theta_0 = 0$, find the transmitted phase θ_k for the following input data sequence "1 1 1 1 0 0 1 0 1 0 1 0 0 1 0 0 0 1". (3%)

(d) If a rectangular pulse shaping waveform is used and the maximum transmitted signal amplitude is $\sqrt{E}$, determine the minimum envelope amplitude of all possible modulation trajectories. (4%) [Hint: Express the answer by using a trigonometric function.]

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