Midterm Exam 2

Date	:	Wednesday 29$^{\text{th}}$ March, 2023, from 4:30 pm to 6:30 pm
Total Marks	:	50
Notes:	:	All questions are scored (no optionals).
		Do not forget to write your name and student ID below.
		Fully circle your selected option in the MCQ section.

Name: ____________________ **Student ID**: ____________________

Reference:

1 Fill In the Blanks:

Instructions

- There are total 16 questions in this section that carry total of 28 marks.
- There is no negative marking in this section.

Questions

1. (2 points) Name two reasons why a sinusoidal electromagnetic waveform is used as a carrier waveform by the modulator (and frequency upconvertor) to transmit the informative messages.

2. (2 points) What are two advantages of a digital communication system compared to an analog communication system.

3. (2 points) Why is a digital communication system called digital when the transmitted signal (typically a modulated EM wave) is entirely analog in nature?

4. (2 points) How does a digital communication system with a family of modulation and coding schemes provide the scheme of throughput (data rate) adaptation, and why is this beneficial?

5. (2 points) Briefly describe Incremental Redundancy (IR) Type II Hybrid ARQ (H-ARQ):

6. (2 points) Prove that the dot product of $\cos(2\pi f_c t)$ with itself over $t \in [0, T_{sym}]$ equals $T_{sym}/2$ (you may assume $T_{sym} \propto f_c^{-1}$).

7. (2 points) State the complex-envelope (CE) notation of the transmitted modulated signal $s(t)$ as a function of the inphase and the quadrature modulating information components s_i and s_q and the carrier frequency f_c. From this CE notation, derive (show the steps of your derivation) the cartesian coodinate representation (i.e., the inphase/quadrature notation) and the polar coodinate representation (i.e., the magnitude and representation) of $s(t)$.

8. (1 point) State the two requirements for the inphase and the quadrature signal waveforms $g_i(t)$ and $g_q(t)$ so that they can be used at a modulator.

9. (2 points) Suppose a digital communication system sends one bit at a time. The modulator transmits $s_0(t)$ to send bit $X = 0$ and it uses $s_1(t)$ to send bit $X = 1$, where $s_0(t)$ and $s_1(t)$ are the modulated waveforms shown in Fig. 1. Draw appropriate $g_i(t)$ and $g_q(t)$ given these two modulated waveforms. Represent $s_0(t)$ and $s_1(t)$ as vectors in a two-dimensional space whose $\hat{i}$ and $\hat{j}$ vectors are $g_i(t)$ and $g_q(t)$, respectively.

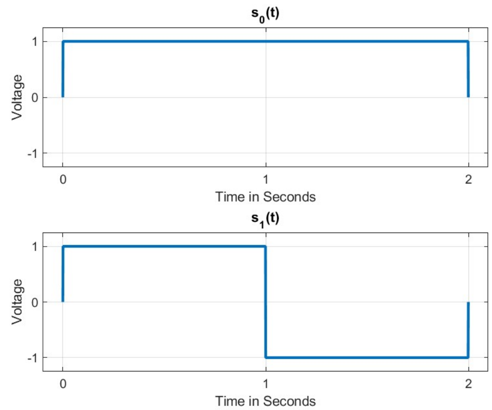

Figure 1: Two signals for Problem 9.

10. (2 points) Given that the transmitter uses two orthogonal waveforms $g_i(t)$ and $g_q(t)$ for transmitting the modulated signal $s(t)$, the noise component at the receiver - regardless of what its exact shape is - can *always* be written as $n(t) = n_i g_i(t) + n_q g_q(t) + u(t)$, where $u(t)$ is the component of the noise $n(t)$ that lies in a vector subspace that is orthogonal to the two-dimensional space formed by $g_i(t)$ and $g_q(t)$, i.e., the dot product of $u(t)$ with either $g_i(t)$ or $g_q(t)$ is zero. Show that $u(t)$ – no matter how powerful or strong it is – has *no* effect on the receiver (demodulator) operation.

11. (1 points) Let $\overline{m_n^2}$ be the power in a normalized version $m_n(t)$ of the message signal $m(t)$ – where the normalization is performed such that the minimum value of $m_n(t) = -1$. Let a_{mod} be the modulation index of the DSB-FC (Conventional) AM. Express the power efficiency η_{AM} of the conventional AM as a function of $\overline{m_n^2}$ and a_{mod}.

12. (2 points) Name four blocks that a digital communication system has which an analog communication system does not have.

13. (2 points) Show that the F.T. of a signal that exhibits time-domain symmetry (i.e., it is an even signal $s_e(t) = s_e(-t)$) is real-valued.

14. (2 points) Prove that if modulo-two sum of two binary error patterns $\mathbf{e}_1$ and $\mathbf{e}_2$ is a valid binary codeword $\mathbf{c}$, each error pattern has the same syndrome.

15. (1 points) Why is DSB-SC AM preferred over DSB-FC AM?

16. (1 points) Why is DSB-FC (Conventional) AM preferred over DSB-SC AM?

2 Multiple Choice Questions:

Instructions

- ▷ This is MCQ Version I of IV.
- ▷ There are total 15 questions in this section that carry a maximum of 22 marks.

→ If the question is answered incorrectly, negative one-fourth of the total marks shown next to each question will be given.

▹ Circle the correct option. No tick marks or partial circling, etc.

→ If more than one option is circled, zero marks will be given for the question.

▹ Note: *Volume* $V(N;t_c)$ of a Hamming Sphere of radius t_c is defined as the number of (binary) codewords of length N bits whose Hamming weight is less than or equal to t_c bits.

Questions

1. (1 points) A digital modulation scheme that transmits $s_m(t) = \cos(2\pi f_c t + (2m+1)\pi/4)$ for $m = 0, 1, 2$ and 3 is called

   (a) analog phase modulation scheme
   (b) digital quaternary phase modulation scheme
   (c) digital quaternary amplitude and phase modulation scheme
   (d) analog quaternary amplitude modulation scheme

2. (1 points) For a perfect channel code, the minimum Hamming distance d_{min}^{H} should be:

   (a) can be either even or odd
   (b) can be either even or odd depending on the specific channel code
   (c) odd
   (d) even

3. (1 points) The syndrome vector computed as $\mathbf{s} = \mathbf{H}\,\mathbf{r}$ using the parity check matrix $\mathbf{H}$ *uniquely* identifies the error pattern $\mathbf{e}$ affecting the received codeword $\mathbf{r} = \mathbf{c} + \mathbf{e}$. This statement is

   (a) true
   (b) false

4. (1 points) The syndrome vector computed as $\mathbf{s} = \mathbf{H}\,\mathbf{r}$ using the parity check matrix $\mathbf{H}$ uniquely identifies the transmitted codeword. This statement is

   (a) true
   (b) false

5. (1 points) A two-bit repetition code (N; $K = 2$) of rate $r = 2/N$ (for N even) is defined as follows. The encoder takes a pair of bits, and repeats it $N/2$ times (as an example, a rate $r = 2/6$ code repeats an input bit-pair $\{0; 1\}$ $N/2 = 3$ times such that encoded bit stream is $\{$ 0; 1; 0; 1; 0; 1 $\}$). Compared to the standard one-bit repetition code ($N' = N/2$; $K = 1$) of rate $r = 1/N' = 2/N$ (that repeats one bit $N' = N/2$ times, where N is even), the probability of codeword detection error for this two-bit repetition code of length N bits operating over the BSC(p) remains

   (a) undetermined
   (b) the same

(c) becomes smaller
(d) becomes larger

6. (2 points) Suppose a modulated transmitted signal is given as $s(t) = 2\cos(2000t + \pi/6)$ for $0 \le t \le T_{sym}$, where the symbol duration $T_{sym} = 8$ seconds. What are s_i and s_q?

(a) $s_i = 0.866, s_q = 0.5$
(b) $s_i = \sqrt{2}, s_q = \sqrt{2}$
(c) $s_i = 3.46, s_q = 2$
(d) $s_i = 1.73, s_q = 1$

7. (2 points) Suppose a CN of degree $d_c = 3$ at an LDPC decoder receives the messages from the two connected VNs (the message from a VN contains the probability that the respective VN equals 1) that are 0.9 and 0.1. What message should the CN send to the third VN connected to it?

(a) 0.5
(b) 0.09
(c) 0.91
(d) 0.82

8. (2 points) Suppose a VN of degree $d_v = 3$ at an LDPC decoder receives the messages from the two connected CNs that are 0.9 and 0.1. What message should the VN send to the third CN?

(a) 0.82
(b) 0.5
(c) 0.91
(d) 0.09

9. (2 points) What is the probability of codeword decoding error for the minimum Hamming distance decoder operating at the output of the BSC(p) when the transmitter sends a rate $r = 1/5$ code that maps bits $X = 0$ to a codeword $\{1, 1, 0, 0, 1\}$ and bit $X = 1$ to another codeword $\{1, 0, 1, 1, 1\}$?

(a) $1 - p^5 - 5p^4(1-p)$
(b) $1 - (1-p)^5 - 5p(1-p)^4$
(c) $\sum_{u=2}^{5} \binom{5}{u} (1-p)^u p^{5-u}$
(d) $\sum_{u=3}^{5} \binom{5}{u} p^u (1-p)^{5-u}$

10. (1 points) A transmitted conventional DSB-FC AM signal is given as $s(t) = 5\cos(2\pi f_c t) + m(t)\cos(2\pi f_c t)$. Suppose $m(t) = 3.5\sin(20\pi t)$ is the message signal. What are the values of modulation indices a_{mod} and the power efficiency η_{AM}?

(a) $a_{\text{mod}} = 0.7$; $\eta_{\text{AM}} = 0.2$
(b) $a_{\text{mod}} = 1.75$; $\eta_{\text{AM}} = 0.6$

(c) $a_{\text{mod}} = 0.35$; $\eta_{\text{AM}} = 0.25$
(d) $a_{\text{mod}} = 0.5$; $\eta_{\text{AM}} = 0.333$

11. (1 points) What is the maximum possible number of unique syndrome vectors that the decoder of a $(N; K)$ binary linear code with rate K/N can encounter?

    (a) 2^N
    (b) 2^{N-K}
    (c) 2^{N-2K}
    (d) 2^K

12. (3 points) The $V(N; t_c)$ is related to the rate $r = K/N$ of the channel code with error correction capability of t_c bits as

    (a) $r \leq \frac{\log_2(V(N; t_c))}{N}$
    (b) $r \leq 1 - \frac{\log_2(V(N; t_c))}{N}$
    (c) $r \geq \frac{\log_2(V(N; t_c))}{N}$
    (d) $r \leq 1 + \frac{\log_2(V(N; t_c))}{N}$

13. (1 points) Linear algebraic representation of the modulation (transmitter) and demodulation (receiver) allows us to think of them as

    (a) demodulator implements synthesis followed by analysis, the modulator performs analysis followed by synthesis
    (b) modulator performs analysis operation, the demodulator performs synthesis operation
    (c) modulator implements synthesis followed by analysis, the demodulator performs analysis followed by synthesis
    (d) modulator performs synthesis operation, the demodulator performs analysis operation

14. (1 points) A message $m(t) = 2\sin(2000\pi t)$ is used in a Conventional AM (DSB-FC) system which has a modulation index $a_{\text{mod}} = 0.71$. What is the power efficiency η_{AM}?

    (a) 1/4
    (b) 1/6
    (c) 1/3
    (d) 1/5

15. (2 points) The Hamming $(N = 7, K = 4, r = 4/7)$ code is a perfect code because

    (a) $2^N = 2^K \times V(N, t_c)$ for this Hamming code
    (b) $2^N \neq 2^K \times V(N, t_c)$ for this Hamming code
    (c) $2^N \neq 2^K / V(N, t_c)$ for this Hamming code
    (d) $2^N = 2^K / V(N, t_c)$ for this Hamming code