UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 8 Examination in Engineering: July 2022

Module Number: EE8204 **Module Name: Digital Communication**

[Three Hours]

[Answer all questions, each question carries 10 marks]

Notations and symbols have their usual meaning unless otherwise stated

Q1 a) Why is signal orthogonality useful in communication systems?

[1 mark]

b) The following three signals $S_1(t)$, $S_2(t)$ and $S_3(t)$ are to be transmitted over an additive white Gaussian noise (AWGN) channel.

$$S_1(t) = \begin{cases} 1, & 0 \le t \le T \\ 0, & \text{otherwise} \end{cases}$$

$$S_2(t) = -S_3(t) = \begin{cases} 1, & 0 \le t \le T/2 \\ -1, & T/2 < t \le T \\ 0, & \text{otherwise} \end{cases}$$

i) Determine an appropriate orthonormal basis for the signal space.
Hint: You can find the orthonormal basis using the Gram-Schmidt procedure.
ii) What is the dimensionality of the signal space?
iii) Draw the signal constellation of the signals.
iv) Sketch the optimal decision regions corresponding to the three signals.
v) Which one from the three signals is more vulnerable to errors? Explain why.

[9 marks]

Q2 a) If energy content of the m^{th} signal $S_m(t),\ m = 1, 2, \cdots, M$ in a digital modulation scheme is ε_m and the probability of sending signal $S_m(t)$ is p_m, obtain an expression for the average energy per bit.

[2 marks]

b) i) Consider 4-phase and 8-phase signal constellations shown in Figure Q2(a). Determine the radii r_1 and r_2 of the circles, such that the distance between two adjacent points in the two constellations is d.

ii) From the result obtained in part i), determine the additional transmitted energy required in the 8-PSK signal to achieve the same error probability as the 4-phase.

[4 marks]

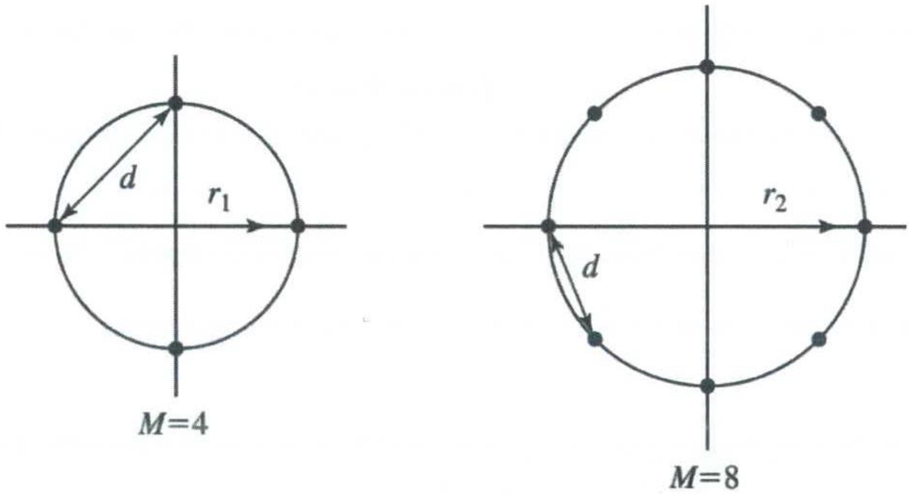

Figure Q2(a)

c) i) What is Gray encoding?

ii) Specify a Gray code for the 8-point QAM signal constellation shown in Figure Q2(b).

iii) Determine the symbol rate of the 8-point QAM signal constellation when the desired bit rate is 90 Mbps.

[4 marks]

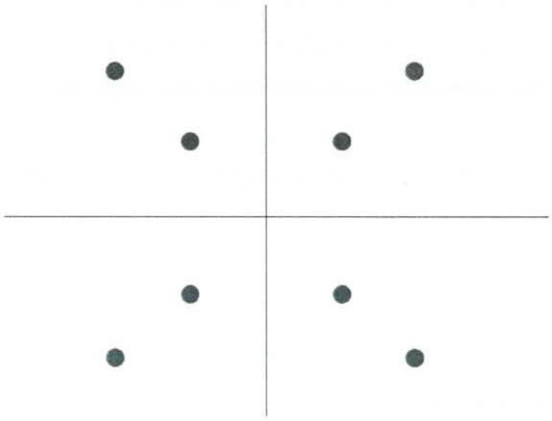

Figure Q2(b)

Q3 a) Mention any four advantages of using digital modulation over analog modulation.

[2 marks]

b) When designing a communication system, the selection of a modulation scheme needs to meet the system requirements. Assume you have the option to select from PSK, FSK and QAM modulations. For each of the following system, which one will you pick? Briefly mention the reason.

i) A system that encounters larger amplitude distortion in the channel with a limited bandwidth

ii) A data communication system, in which a certain bandwidth has been allocated and want to obtain a high data rate.

[3 marks]

c) Consider a digital communication system that transmits information via QAM over a voice-band telephone channel at a rate of 2400 symbols/s. The additive noise is assumed to be white and Gaussian.

i) Determine the SNR value, i.e., ${}^{\varepsilon_b}/_{N_0}$ required to achieve an error probability of 10^{-5} at 4800 bits/s.

ii) Repeat part i) at a rate of 9600 bits/s.

iii) What conclusions do you reach from the results obtained in part i) and part ii)?

<u>**Hint:**</u> The probability of error for an M-ary QAM system is

$$P_e = 1 - \left(1 - 2\left(1 - \frac{1}{\sqrt{M}}\right) Q\left[\sqrt{\frac{3\log_2(M)\varepsilon_b}{(M-1)N_0}}\right]\right)^2$$

and refer Table I in page 6 for Q-function values.

[5 marks]

Q4 a) What is the importance of channel equalization used in wireless communications?

[2 marks]

b) Consider a signal $s(t)$ that is passed through a channel with frequency response $H(f)$. At the receiver front end, white Gaussian noise $n(t)$ is added to the signal. Using the simple linear equalizer, shown in Figure Q4, justify the following statement.

"In the process of removing inter-symbol-interference (ISI), the noise power in the received signal is also enhanced."

[4 marks]

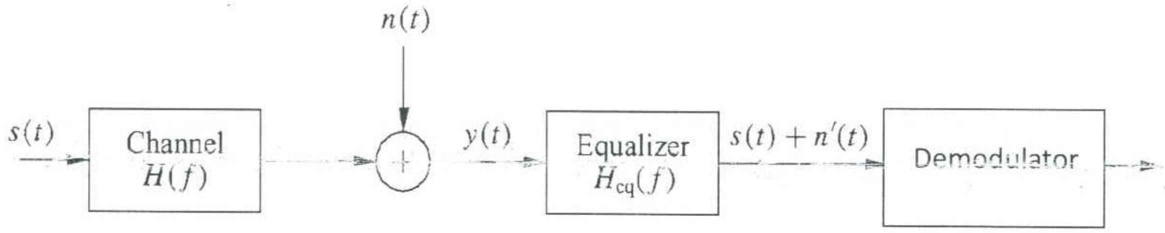

Figure Q4

c) Consider a channel with an impulse response $H(f) = {}^{1}\!/\!\sqrt{|f|}$ for $|f| < B$, where B is the channel bandwidth. Given that the noise power spectral density is $N_0/2$, what is the noise power for channel bandwidth B = 30 kHz **with** and **without** an equalizer that inverts the channel?

[4 marks]

Q5 a) Carrier recovery is required when a signal is detected coherently.

i) Briefly mention what is a Phase lock loop (PLL). Your answer should be limited to maximum 2-3 sentences.

ii) Name two common methods available for achieving BPSK carrier phase recovery. **Hint:** A block diagram of one of the methods is illustrated in Figure Q5(a).

iii) Using the block diagram shown in Figure Q5(a), show that the loop exhibits a π-radian phase ambiguity .

[6 marks]

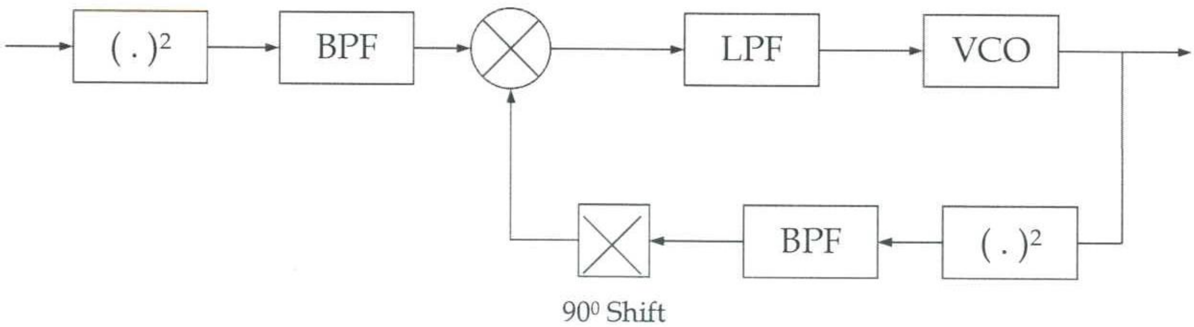

Figure Q5(a)

b) One of the most popular symbol synchronizers is the early/late gate synchronizer which is shown in Figure Q5(b).

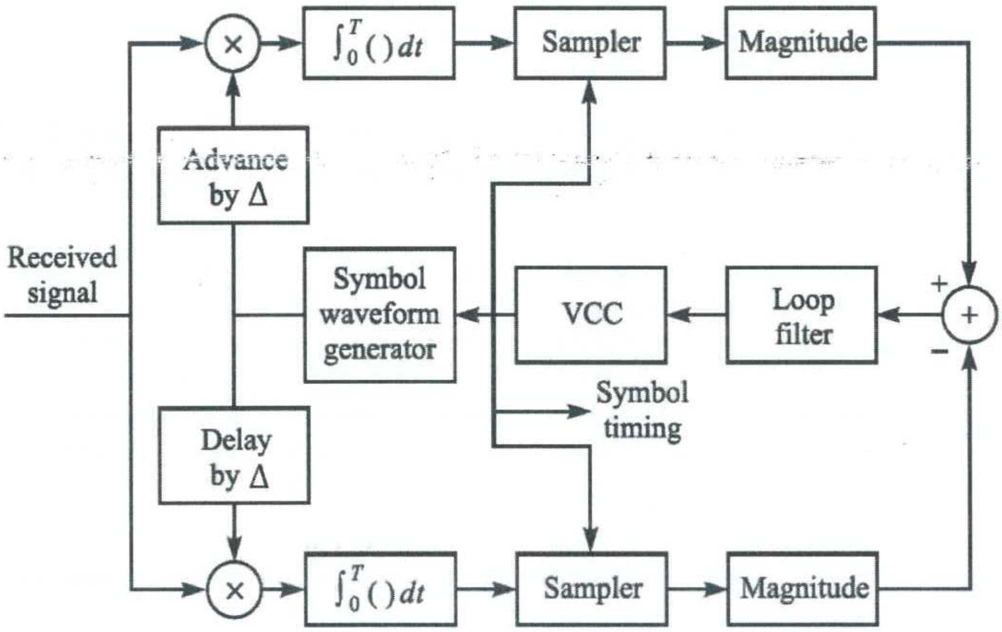

Figure Q5(b)

i) What is meant by symbol synchronization?

ii) Assuming a baseband signal with rectangular pulses, graphically analyze the synchronizer for a perfectly synchronized scenario.

Hint: Consider a received signal similar to the one shown in Figure Q5(c).

[4 marks]

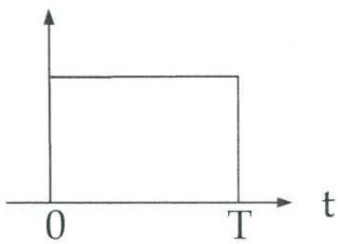

Figure Q5(c)

Table I: Values of $Q(x)$ for $0 \leq x \leq 9$

x	$Q(x)$	x	$Q(x)$	x	$Q(x)$	x	$Q(x)$
0.00	0.5	2.30	0.010724	4.55	2.6823×10^{-6}	6.80	5.231×10^{-12}
0.05	0.48006	2.35	0.0093867	4.60	2.1125×10^{-6}	6.85	3.6925×10^{-12}
0.10	0.46017	2.40	0.0081975	4.65	1.6597×10^{-6}	6.90	2.6001×10^{-12}
0.15	0.44038	2.45	0.0071428	4.70	1.3008×10^{-6}	6.95	1.8264×10^{-12}
0.20	0.42074	2.50	0.0062097	4.75	1.0171×10^{-6}	7.00	1.2798×10^{-12}
0.25	0.40129	2.55	0.0053861	4.80	7.9333×10^{-7}	7.05	8.9459×10^{-13}
0.30	0.38209	2.60	0.0046612	4.85	6.1731×10^{-7}	7.10	6.2378×10^{-13}
0.35	0.36317	2.65	0.0040246	4.90	4.7918×10^{-7}	7.15	4.3389×10^{-13}
0.40	0.34458	2.70	0.003467	4.95	3.7107×10^{-7}	7.20	3.0106×10^{-13}
0.45	0.32636	2.75	0.0029798	5.00	2.8665×10^{-7}	7.25	2.0839×10^{-13}
0.50	0.30854	2.80	0.0025551	5.05	2.2091×10^{-7}	7.30	1.4388×10^{-13}
0.55	0.29116	2.85	0.002186	5.10	1.6983×10^{-7}	7.35	9.9103×10^{-14}
0.60	0.27425	2.90	0.0018658	5.15	1.3024×10^{-7}	7.40	6.8092×10^{-14}
0.65	0.25785	2.95	0.0015889	5.20	9.9644×10^{-8}	7.45	4.667×10^{-14}
0.70	0.24196	3.00	0.0013499	5.25	7.605×10^{-8}	7.50	3.1909×10^{-14}
0.75	0.22663	3.05	0.0011442	5.30	5.7901×10^{-8}	7.55	2.1763×10^{-14}
0.80	0.21186	3.10	0.0009676	5.35	4.3977×10^{-8}	7.60	1.4807×10^{-14}
0.85	0.19766	3.15	0.00081635	5.40	3.332×10^{-8}	7.65	1.0049×10^{-14}
0.90	0.18406	3.20	0.00068714	5.45	2.5185×10^{-8}	7.70	6.8033×10^{-15}
0.95	0.17106	3.25	0.00057703	5.50	1.899×10^{-8}	7.75	4.5946×10^{-15}
1.00	0.15866	3.30	0.00048342	5.55	1.4283×10^{-8}	7.80	3.0954×10^{-15}
1.05	0.14686	3.35	0.00040406	5.60	1.0718×10^{-8}	7.85	2.0802×10^{-15}
1.10	0.13567	3.40	0.00033693	5.65	8.0224×10^{-9}	7.90	1.3945×10^{-15}
1.15	0.12507	3.45	0.00028029	5.70	5.9904×10^{-9}	7.95	9.3256×10^{-16}
1.20	0.11507	3.50	0.00023263	5.75	4.4622×10^{-9}	8.00	6.221×10^{-16}
1.25	0.10565	3.55	0.00019262	5.80	3.3157×10^{-9}	8.05	4.1397×10^{-16}
1.30	0.0968	3.60	0.00015911	5.85	2.4579×10^{-9}	8.10	2.748×10^{-16}
1.35	0.088508	3.65	0.00013112	5.90	1.8175×10^{-9}	8.15	1.8196×10^{-16}
1.40	0.080757	3.70	0.0001078	5.95	1.3407×10^{-9}	8.20	1.2019×10^{-16}
1.45	0.073529	3.75	8.8417×10^{-5}	6.00	9.8659×10^{-10}	8.25	7.9197×10^{-17}
1.50	0.066807	3.80	7.2348×10^{-5}	6.05	7.2423×10^{-10}	8.30	5.2056×10^{-17}
1.55	0.060571	3.85	5.9059×10^{-5}	6.10	5.3034×10^{-10}	8.35	3.4131×10^{-17}
1.60	0.054799	3.90	4.8096×10^{-5}	6.15	3.8741×10^{-10}	8.40	2.2324×10^{-17}
1.65	0.049471	3.95	3.9076×10^{-5}	6.20	2.8232×10^{-10}	8.45	1.4565×10^{-17}
1.70	0.044565	4.00	3.1671×10^{-5}	6.25	2.0523×10^{-10}	8.50	9.4795×10^{-18}
1.75	0.040059	4.05	2.5609×10^{-5}	6.30	1.4882×10^{-10}	8.55	6.1544×10^{-18}
1.80	0.03593	4.10	2.0658×10^{-5}	6.35	1.0766×10^{-10}	8.60	3.9858×10^{-18}
1.85	0.032157	4.15	1.6624×10^{-5}	6.40	7.7688×10^{-11}	8.65	2.575×10^{-18}
1.90	0.028717	4.20	1.3346×10^{-5}	6.45	5.5925×10^{-11}	8.70	1.6594×10^{-18}
1.95	0.025588	4.25	1.0689×10^{-5}	6.50	4.016×10^{-11}	8.75	1.0668×10^{-18}
2.00	0.02275	4.30	8.5399×10^{-6}	6.55	2.8769×10^{-11}	8.80	6.8408×10^{-19}
2.05	0.020182	4.35	6.8069×10^{-6}	6.60	2.0558×10^{-11}	8.85	4.376×10^{-19}
2.10	0.017864	4.40	5.4125×10^{-6}	6.65	1.4655×10^{-11}	8.90	2.7923×10^{-19}
2.15	0.015778	4.45	4.2935×10^{-6}	6.70	1.0421×10^{-11}	8.95	1.7774×10^{-19}
2.20	0.013903	4.50	3.3977×10^{-6}	6.75	7.3923×10^{-12}	9.00	1.1286×10^{-19}
2.25	0.012224						